Watershed Report for Biological Impairment of the Catoctin Creek Watershed in Frederick County, 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
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
mg/L	Milligrams per liter
NH_3	Ammonia
NPDES	National Pollution Discharge Elimination System
OP	Orthophosphate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
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* (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.

Catoctin Creek (basin code 02140305) was identified on the Maryland's 2010 Integrated Report under Category 5 as impaired by sediments, nutrients (1996 listings), impacts to biological communities (2002), and fecal coliform (2004) (MDE 2010). All impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance, since it is considered to be the limiting nutrient species. Similarly, the 1996 sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. The 2004 fecal coliform listing was moved to Category 3 in the 2008 Integrated Report due to an inappropriate listing methodology being used in its original listing. A TMDL for the sediment listing was approved by the USEPA in 2009.

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Catoctin Creek and its tributaries above alternate U.S. Route 40 is Use III-P - *Nontidal Cold Water and Public Water Supply*, and below alternate U.S. Route 40 only the mainstem is Use IV-P - *Recreational Trout Waters and Public Water Supply* (COMAR 2010a,b,c,d). In addition, COMAR requires all waterbodies in the State to support at a minimum the Use I designation - *Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life*. The Catoctin Creek watershed is not attaining its *Protection of Nontidal Warmwater Aquatic Life* designated use because of impacts to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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

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

This Catoctin Creek watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the degradation of biological communities in Catoctin Creek is strongly associated with agricultural land use within the watershed as well as the sixty meter riparian buffer zone and elevated levels of nitrogen, ammonia, and phosphorus. The development of landscapes creates broad and interrelated forms of degradation (e.g., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly agriculturally developed 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 Catoctin Creek can be summarized as follows:

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Catoctin Creek watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 54% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus and 82% degraded due to high orthophosphate. Similarly, according to the BSID analysis, 78% of the biologically impacted stream miles in the Catoctin Creek 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 Catoctin Creek 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 Catoctin Creek, and the reduction of nitrogen loads would not be an effective means of ensuring that the Catoctin Creek watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Catoctin Creek Nutrient TMDL will apply only to total phosphorus. The BSID results thus confirm the 2008 Category 5 listing for phosphorus as an impairing substance in the Catoctin Creek watershed, and link this pollutant to biological conditions in these waters.

- Although there is presently a Category 4a listing (TMDL submitted and approved by USEPA) for total suspended sediments in the State's 2010 Integrated Report, the BSID analysis did not identify any sediment stressors present showing a significant association with degraded biological conditions.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as Category 4a. If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Catoctin Creek watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Catoctin Creek Watershed Characterization

2.1 Location

The Catoctin Creek watershed is located within the Middle Potomac River Sub-basin in Frederick County, Maryland (see Figure 1). It encompasses the southwestern portion of Frederick County and is framed by Catoctin Mountain on the east and South Mountain on the west. The mainstem flows through the Middletown Valley and eventually empties into the Potomac River approximately three miles upstream from Point of Rocks, Maryland. The Catoctin Creek watershed drains an area of 120 square miles, which includes areas of forested mountain slopes, agricultural valleys, and small towns (MDE 2009b). The watershed area is located in the Highlands region of three distinct eco-regions identified in the MBSS IBI metrics (Southerland et al. 2005) (see Figure 2).

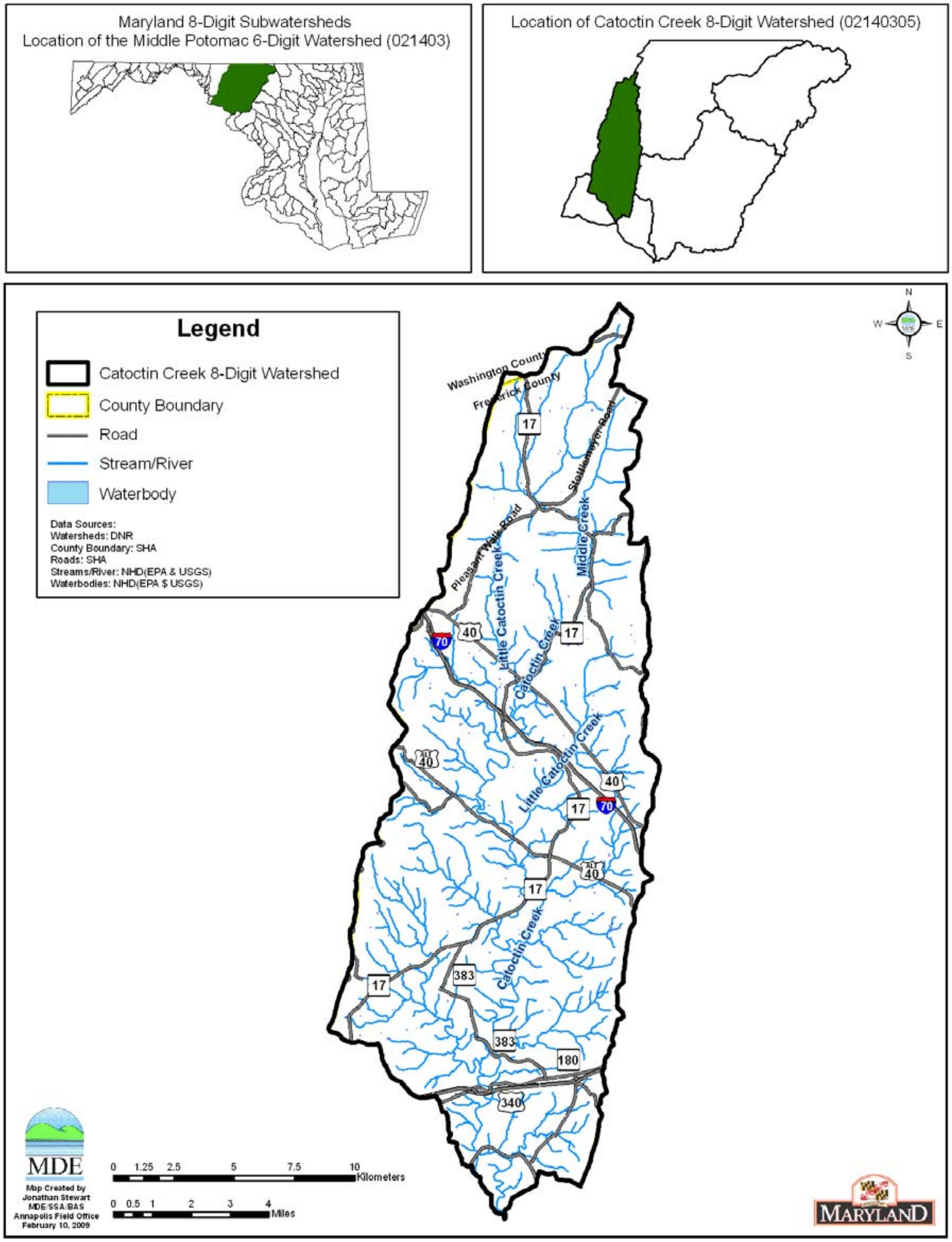

Figure 1. Location Map of the Catoctin Creek Watershed

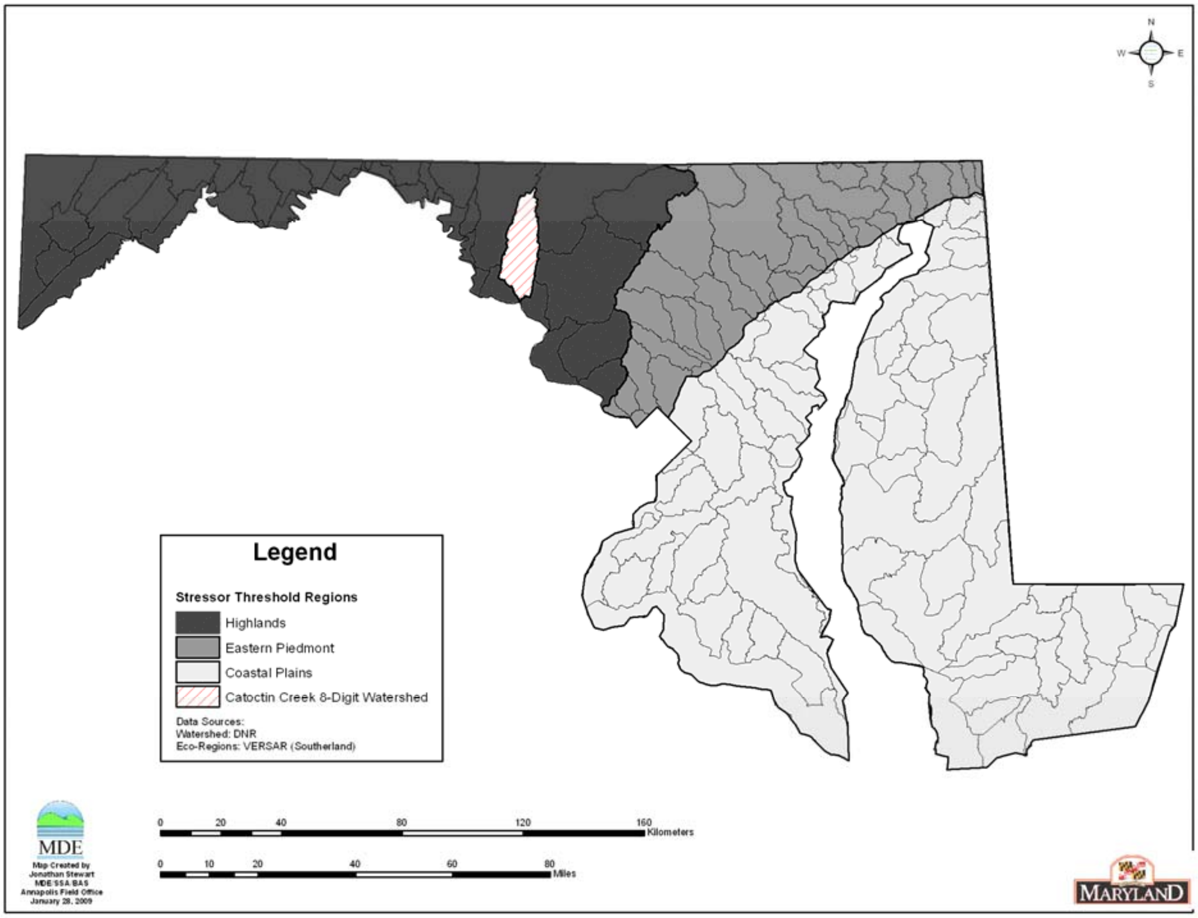

Figure 2. Eco-Region Location Map for the Catoctin Creek Watershed

2.2 Land Use

The Catoctin Creek watershed includes areas of forested mountain slopes, agricultural valleys, and small areas of urban development. There is a significant amount of agriculture within the watershed, which consists mostly of row crop, but also includes pasture. The largest urban centers within the watershed are the towns of Myersville and Middletown (see Figure 3). According to the Chesapeake Bay Program's Phase 5.2 Model, the land use distribution in the watershed is approximately 43% agricultural, 42% forest/herbaceous, and 15% urban (USEPA 2008) (see Figure 4)

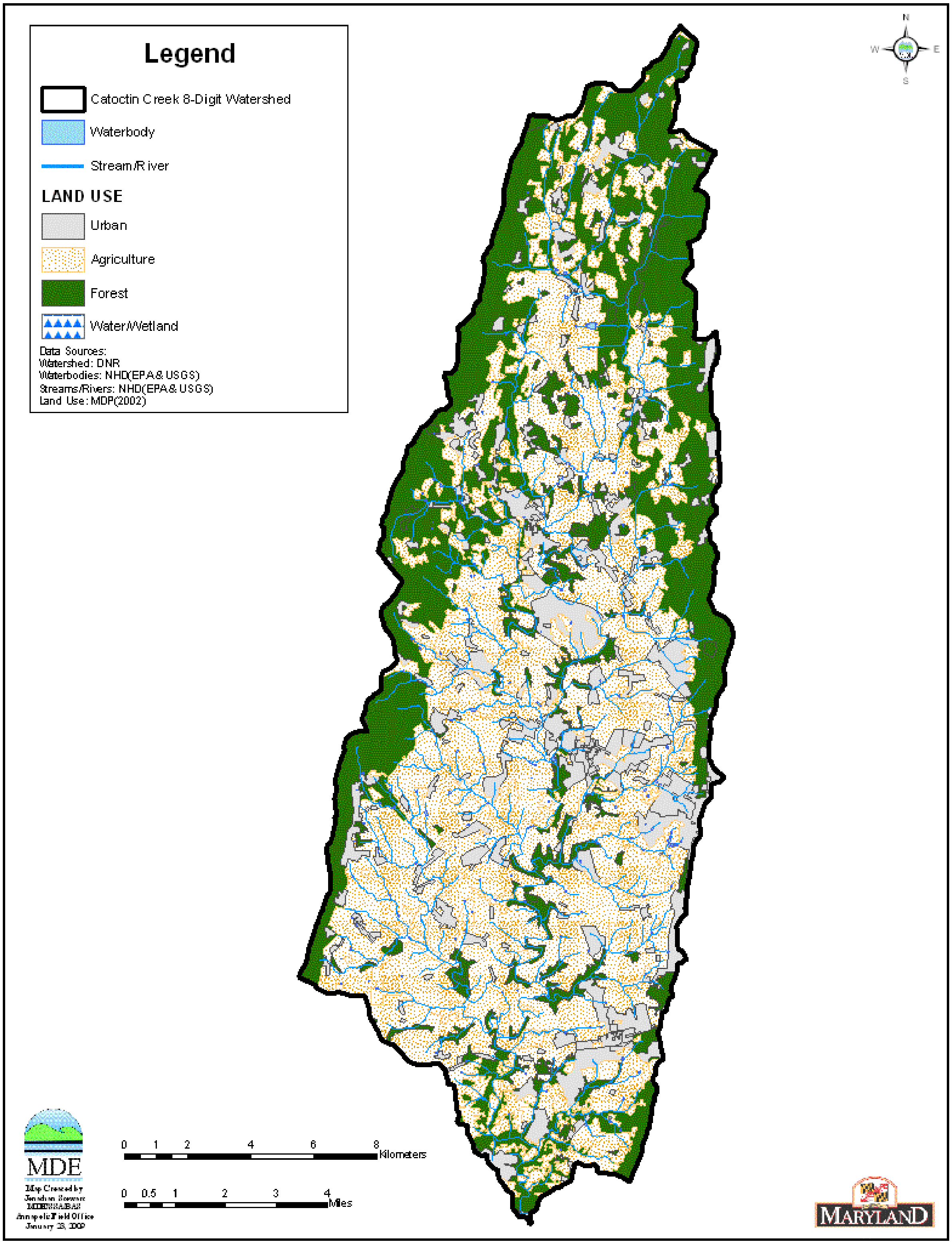

Figure 3. Land Use Map of the Catoctin Creek Watershed

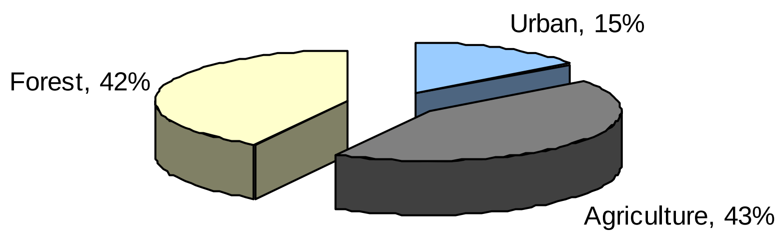

Figure 4. Proportions of Land Use in the Catoctin Creek Watershed

2.3 Soils/hydrology

The Catoctin Creek watershed lies within the Blue Ridge Province physiographic region of Maryland. The Blue Ridge Province is on the eastern edge of the Appalachian Mountains. In Frederick County, the province consists of the Middletown Valley and three separate ridges: Catoctin Mountain, South Mountain, and Elk Ridge. The Blue Ridge Province physiographic region of Maryland has mountainous soils composed of sandy or stony loams. Metamorphosed basalt is the predominant rock type in the mountains, although the ridges and crests are formed by erosion resistant quartzite of the Cambrian age (505 to 570 million years old). The Middletown Valley, a rolling upland between the mountain ridges in southwestern Frederick County, is underlain by granodiorite and granitic gneiss of the Precambrian age (greater than 570 million years old). The climate of the Blue Ridge province is similar to that in the Piedmont Province, but somewhat cooler and more moist (DNR 2007; MGS 2007; MDE 2000).

3.0 Catoctin Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

Catoctin Creek (basin code 02140305) was identified on the Maryland's 2010 Integrated Report under Category 5 as impaired by sediments, nutrients (1996 listings), impacts to biological communities (2002), and fecal coliform (2004) (MDE 2010). All impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance, since it is considered to be the limiting nutrient species. Similarly, the 1996 sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. The 2004 fecal coliform listing was moved to Category 3 in the 2008 Integrated Report due to an inappropriate listing methodology being used in its original listing. A TMDL for the sediment listing was approved by the USEPA in 2009.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Catoctin Creek and its tributaries above alternate U.S. Route 40 is Use III-P - *Nontidal Cold Water and Public Water Supply*, and below alternate U.S. Route 40 only the mainstem is Use IV-P - *Recreational Trout Waters and Public Water Supply* (COMAR 2010a,b,c,d). In addition, COMAR requires all waterbodies in the State to support at a minimum the Use I designation - *Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life*. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Catoctin Creek watershed is listed under Category 5 of the 2010 Integrated Report as impaired for evidence of biological impacts. Approximately 47% of stream miles in the Catoctin Creek watershed are estimated as having fish and and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include seventeen sites. Ten of the seventeen sites have 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 thirteen MBSS sites with seven having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site location for the Catoctin Creek watershed.

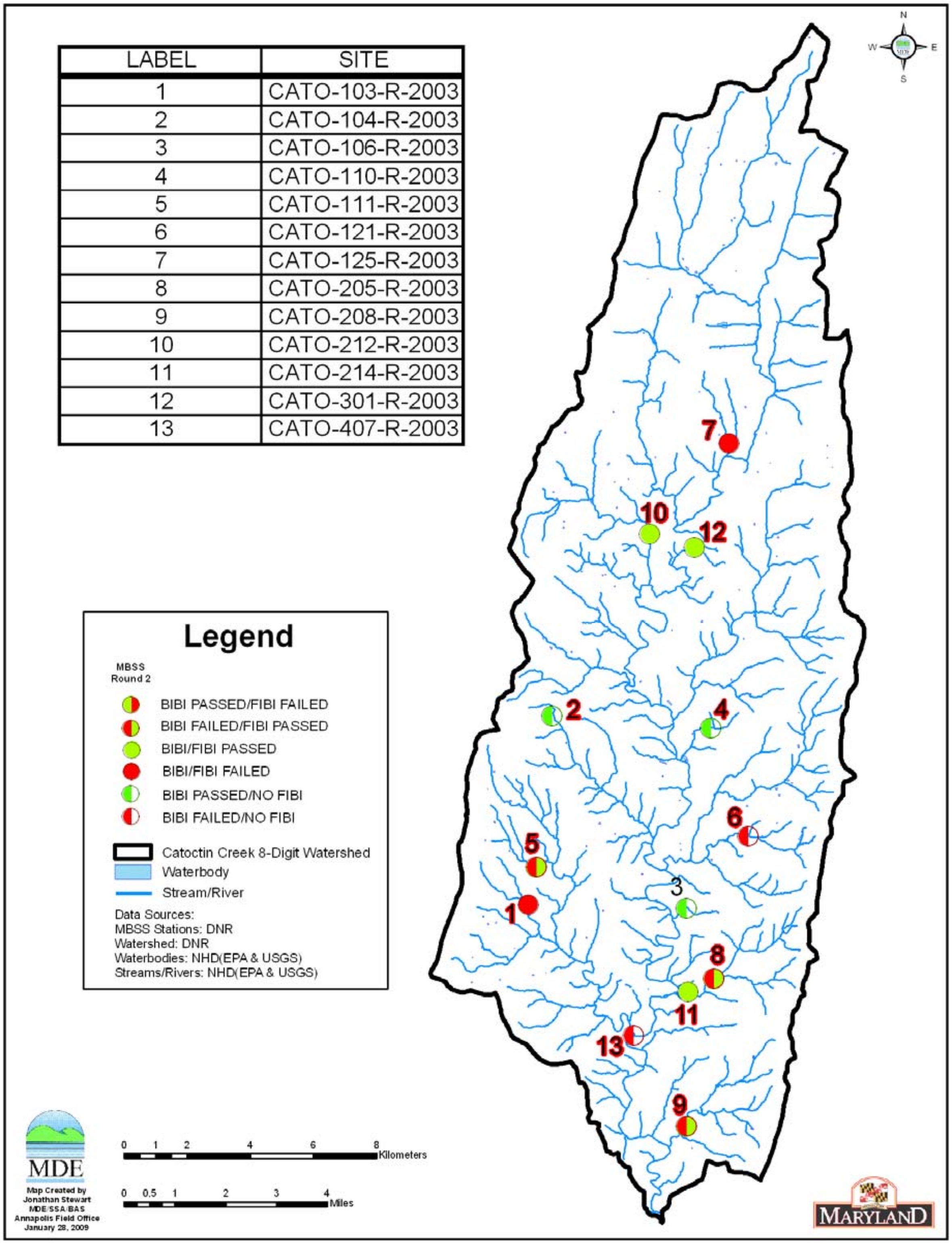

Figure 5. Principal Dataset Sites for the Catoctin Creek Watershed

4.0 Stressor Identification Results

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

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

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

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are a 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 habitat parameters, water chemistry parameters, and potential sources significantly associated with degraded fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 1 and include various agricultural land uses in the watershed as well as in sixty meter riparian buffer, and low percentage of forested land use in watershed. Table2 shows the summary of combined AR values for the source groups in the Catoctin Creek watershed. As shown in Table 3 through Table 5, numerous parameters from the riparian habitat, and water chemistry groups were identified as possible biological stressors. Table 6 shows the summary of combined AR values for the stressor groups in the Catoctin Creek watershed.

Table 1. Stressor Source Identification Analysis Results for Catoctin Creek

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	13	7	156	0%	1%	No	----
	high % of high intensity urban in watershed	13	7	159	14%	3%	No	----
	high % of low intensity urban in watershed	13	7	159	29%	8%	No	----
	high % of transportation in watershed	13	7	159	14%	9%	No	----
	high % of high intensity urban in 60m buffer	13	7	159	0%	6%	No	----
	high % of low intensity urban in 60m buffer	13	7	159	14%	7%	No	----
	high % of transportation in 60m buffer	13	7	159	0%	9%	No	----
Sources Agriculture	high % of agriculture in watershed	13	7	159	71%	6%	Yes	66%
	high % of cropland in watershed	13	7	159	57%	6%	Yes	51%
	high % of pasture/hay in watershed	13	7	159	29%	8%	No	----
	high % of agriculture in 60m buffer	13	7	159	100%	6%	Yes	94%
	high % of cropland in 60m buffer	13	7	159	43%	4%	Yes	38%
	high % of pasture/hay in 60m buffer	13	7	159	100%	8%	Yes	92%
Sources Barren	high % of barren land in watershed	13	7	159	0%	7%	No	----
	high % of barren land in 60m buffer	13	7	159	0%	6%	No	----

Table 1. Stressor Source Identification Analysis Results for Catoctin Creek (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Anthropogenic	low % of forest in watershed	13	7	159	57%	5%	Yes	52%
	low % of forest in 60m buffer	13	7	159	86%	6%	Yes	80%
Sources Acidity	atmospheric deposition present	13	7	159	0%	39%	No	----
	AMD acid source present	13	7	159	0%	4%	No	----
	organic acid source present	13	7	159	0%	3%	No	----
	agricultural acid source present	13	7	159	0%	1%	No	----

Table 2. Summary of Combined AR Values for Source Groups for the Catoctin Creek Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Urban		95%
Agriculture	95%	
Barren Land		
Lack of Forest	95%	
Acidity		

Sources Identified by BSID Analysis

The seven land use sources identified by the BSID analysis (Table 2), are the result of agricultural development within the Catoctin Creek watershed. According to the Chesapeake Bay Program's Phase 5.2 Model, a significant amount of the watershed is comprised of agricultural land uses (43%) (USEPA 2008). The watershed and riparian buffer zones of Catoctin Creek contains a significant amount of agricultural land uses, which consist mostly of cropland and pasture/hay. Numerous studies have 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). Researchers commonly report that streams draining agricultural lands support fewer species of sensitive insect and fish taxa than streams draining forested catchments (Wang et al. 1997). Large-scale and long-term agricultural disturbances in a watershed can limit the recovery of stream diversity for many decades (Harding et al. 1998). Macroinvertebrate community richness usually does not vary by more than three families in streams affected by intensive agriculture (Delong and Brusven 1998).

Agricultural land use is an important source of pollution when rainfall carries fertilizers, manure, and pesticides into streams. The three major nutrients in fertilizers are nitrogen, phosphorus, and potassium. High concentrations of nitrogen in agricultural streams were correlated with nitrogen inputs from fertilizers and manure used for crops and from livestock wastes (USGS, 1999). The BSID analysis identified pasture/hay land use as significant in the riparian buffer zone (92%). Pasture/hay land use within the riparian buffer often results in increased incidences of livestock being allowed direct access to streams, and one of the primary sources of ammonia to surface waters is livestock waste. The agricultural land uses in the Catoctin Creek watershed are potential sources for the elevated levels of TN, TP, OP, and ammonia.

The BSID source analysis (Table 4) identifies various types of agricultural land uses as potential sources of stressors that may cause negative biological impacts. The *low % of forest land use* is likely a result of the increased landscape development in the watershed. The combined AR for this source group is approximately 95% suggesting that agricultural land uses potentially impacts a substantial proportion of the degraded stream miles in Catoctin Creek (Table 6).

All the stressors identified in the BSID analysis for the Catoctin Creek watershed 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 3. Sediment Biological Stressor Identification Analysis Results for Catoctin Creek

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	11	5	77	0%	10%	No	----
	moderate bar formation present	11	5	77	40%	45%	No	----
	bar formation present	11	5	77	60%	89%	No	----
	channel alteration moderate to poor	11	5	77	40%	42%	No	----
	channel alteration poor	11	5	77	0%	9%	No	----
	high embeddedness	11	5	77	0%	4%	No	----
	epifaunal substrate marginal to poor	11	5	77	20%	20%	No	----
	epifaunal substrate poor	11	5	77	0%	4%	No	----
	moderate to severe erosion present	11	5	77	20%	25%	No	----
	severe erosion present	11	5	77	0%	2%	No	----
	poor bank stability index	11	5	77	0%	4%	No	----
	silt clay present	11	5	77	100%	99%	No	----

Table 4. Habitat Biological Stressor Identification Analysis Results for Catoctin Creek

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	13	7	80	29%	10%	No	----
	instream habitat structure marginal to poor	11	5	77	40%	23%	No	----
	instream habitat structure poor	11	5	77	0%	2%	No	----
	pool/glide/eddy quality marginal to poor	11	5	77	40%	48%	No	----
	pool/glide/eddy quality poor	11	5	77	0%	7%	No	----
	riffle/run quality marginal to poor	11	5	77	0%	34%	No	----
	riffle/run quality poor	11	5	77	0%	7%	No	----
	velocity/depth diversity marginal to poor	11	5	77	40%	53%	No	----
	velocity/depth diversity poor	11	5	77	0%	8%	No	----
	concrete/gabion present	13	7	80	0%	3%	No	----
	beaver pond present	11	5	77	0%	2%	No	----
Riparian Habitat	no riparian buffer	13	7	80	57%	23%	Yes	34%
	low shading	11	5	77	0%	10%	No	----

Table 5. Water Chemistry Biological Stressor Identification Analysis Results for Catoctin Creek

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	13	7	159	86%	8%	Yes	78%
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	13	7	159	29%	2%	Yes	27%*
	ammonia acute with salmonid absent	13	7	159	29%	1%	Yes	27%*
	ammonia chronic with salmonid present	13	7	159	29%	4%	Yes	25%*
	ammonia chronic with salmonid absent	13	7	159	29%	2%	Yes	27%*
	low lab pH	13	7	159	0%	5%	No	----
	high lab pH	13	7	159	0%	1%	No	----
	low field pH	11	5	154	0%	14%	No	----
	high field pH	11	5	154	0%	0%	No	----
	high total phosphorus	13	7	159	57%	3%	Yes	54%
	high orthophosphate	13	7	159	86%	4%	Yes	82%
	dissolved oxygen < 5mg/l	11	5	154	0%	3%	No	----
	dissolved oxygen < 6mg/l	11	5	154	20%	7%	No	----
	low dissolved oxygen saturation	9	4	138	0%	4%	No	----
	high dissolved oxygen saturation	9	4	138	0%	1%	No	----
	acid neutralizing capacity below chronic level	13	7	159	0%	6%	No	----
	acid neutralizing capacity below episodic level	13	7	159	0%	43%	No	----
	high chlorides	13	7	159	0%	7%	No	----
	high conductivity	13	7	159	0%	4%	No	----
	high sulfates	13	7	159	0%	4%	No	----

*** Due to minimal sampling for ammonia in MBSS data set, 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 25)**

Table 6. Summary Combined AR Values for Stressor Groups for Catoctin Creek Watershed

<table>
<tr><th>Stressor Group</th><th colspan="2">Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)</th></tr>
<tr><td>Sediment</td><td>----</td><td rowspan="4">83%</td></tr>
<tr><td>In-Stream Habitat</td><td>----</td></tr>
<tr><td>Riparian Habitat</td><td>34%</td></tr>
<tr><td>Water Chemistry</td><td>83%</td></tr>
</table>

Stressors Identified by BSID Analysis

All eight stressor parameters identified by the BSID analysis (Tables 3, 4, and 5), as being significantly associated with biological degradation in the Catoctin Creek watershed, are emblematic of agriculturally developed landscapes.

Sediment Conditions

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

In-stream Habitat Conditions

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

Riparian Habitat Conditions

BSID analysis results for Catoctin Creek 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 Catoctin Creek, and found to impact approximately 34% 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). Decreased riparian buffer 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 habitat and cover for aquatic organisms. As agricultural development increases in a watershed so do morphological changes that affect a stream's habitat. Landscape alteration and the removal of riparian vegetation potentially can affect the species diversity and assemblage composition of fish communities through a number of adverse changes to the stream system (Roth et al 1996). Agricultural land use degrades streams by increasing inputs of nutrients and impacting riparian habitat (Cooper 1993). Riparian buffers have been shown to moderate terrestrial inputs of nutrients from agricultural sources thus reducing their influence on surface stream waters (Lowrance et al. 1984, Lee et al 2004, Anbumozhi et al 2005).

The BSID results identified several land uses within the 60 meter (M) buffer zone that indicate agricultural practices are negatively impacting the biological resources in this watershed. The high percentage of agricultural land use in the watershed is indicative of the agricultural crops that are cultivated to the stream banks. The high percentage of pasture/hay land use in the 60 M buffer is indicative of agricultural practices that allow cattle to have direct access to ditches and streams. Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995).

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the riparian habitat stressor group is approximately 34 % suggesting this stressor impacts a moderate proportion of the degraded stream miles in Catoctin Creek (Table 6).

Water Chemistry

BSID analysis results for Catoctin Creek identified seven water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high total phosphorous, high orthophosphate, high total nitrogen, ammonia acute with salmonid present & absent*, and *ammonia chronic with salmonid present & absent*.

High total phosphorous concentration was identified as significantly associated with degraded biological conditions in Catoctin Creek and found in approximately 54% of the stream miles with poor to very poor biological conditions. Total Phosphorous (TP) is a measure of the amount of TP in the water column. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Elevated levels of phosphorus can lead to excessive growth of filamentous algae and aquatic plants. Excessive phosphorus input can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen (DO) and pH levels. Phosphorus is added to the soil from crop residue, manure, synthetic fertilizer, and phosphorus-bearing minerals. If land use includes livestock pastures, the addition of phosphorus from manures can be significant. The primary transport of phosphorus from terrestrial to aquatic environments is runoff and erosion. TP input to surface waters typically increases in watersheds where agricultural developments are predominant.

High orthophosphate concentrations levels was identified as significantly associated with degraded biological conditions in Catoctin Creek and found in approximately 82% of the stream miles with poor to very poor biological conditions. Orthophosphate (OP) is a measure of the amount of OP in the water column and is the most readily available form of phosphorus for uptake by aquatic organisms (see '*high total phosphorous'* above). OP input to surface waters typically increases in watersheds where agricultural developments are predominant.

High total nitrogen concentrations levels was identified as significantly associated with degraded biological conditions in Catoctin Creek and found in approximately 78% of the stream miles with poor to very poor biological conditions. 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. 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.

Ammonia acute concentrations were identified as significantly associated with degraded biological conditions in Catoctin Creek, and found to impact approximately 27% (*with salmonid present*) and 27% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. Acute ammonia toxicity refers to potential exceedances 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 2010). 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. 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 concentrations are significantly associated with degraded biological conditions in Catoctin Creek, and found in approximately 25% (*with salmonid present)* and 27% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. Chronic ammonia toxicity refers to potential exceedances of species tolerance caused by repeated exposure over a long period of time. Ammonia chronic with salmonid present and absent is a USEPA water quality criteria for ammonia concentrations causing chronic toxicity in surface waters where salmonid species of fish are absent (USEPA 2010).

Identification of ammonia toxicity by the BSID analysis is also indicative of degradation to water quality due to nutrient loading in the Catoctin Creek 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). The presence of pasture/hay land uses in the riparian buffer often results in incidences of livestock having direct access to the stream. One of the primary agricultural sources of ammonia to surface waters is livestock waste (Oemke & Borrello 2008).

There are thirteen MBSS stations in the Catoctin Creek watershed and minimal sampling for ammonia was conducted (one-time sample) at each station. Acute ammonia toxicity refers to potential exceedances of species tolerance caused by a one-time, sudden, high exposure of ammonia. However, chronic ammonia toxicity refers to potential exceedances 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, and 2009, MDE collected five hundred and ninety-three water quality samples from the Catoctin Creek watershed. Samples were collected at sixteen stations through out the watershed, with most stations being sampled monthly for approximately a year. None of the samples showed exceedances of any of the four USEPA and MDE criteria for ammonia: acute criterion when salmonid fish are present, acute criterion when salmonid fish are absent, chronic criterion when early life stages are present or chronic criterion when early life stages are absent (USEPA 2006). Due to these results from the MDE water quality data analysis, it was determined that ammonia toxicity is not a widespread problem in the Catoctin Creek watershed.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. 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 (Allan 2004 and Quinn 2000). 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). The elevated nutrient levels within the Catoctin

Creek watershed are not resulting in species tolerance exceedances of dissolved oxygen and pH levels.

Point source discharges are a potential source of nutrients to surface waters. There are eight municipal discharges in the Catoctin Creek 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 water chemistry stressors identified by the BSID are indicative of agricultural activities that degrade water quality by causing an increase in contaminant loads from fertilizer/manure application. Although nutrient management practices (NMPs) and best management practices (BMPs) are in place to control nutrient runoff in the watershed, the BSID analyses revealed that agricultural practices continue to create conditions in the watershed that are negatively impacting biological resources.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 83 % suggesting these stressors impacts a substantial proportion of the degraded stream miles in Catoctin Creek (Table 6).

Discussion

The BSID analysis results suggest that degraded biological communities in the Catoctin Creek watershed are a result of increased agricultural land use causing an increase in contaminant loads from nonpoint sources by adding nutrients to surface waters. Alterations to the riparian habitat and water chemistry have all combined to degrade Catoctin Creek, leading to a loss of diversity in the biological community.

In summary, the lack of a riparian buffer has resulted in a stream ecosystem that eliminates large woody debris and allochthonous input in streams, which results in loss of optimal habitat. Loss of riparian buffers also allows increased terrestrial inputs of nutrients from agricultural sources. Due to the increased proportions of agricultural land use in Catoctin Creek, the watershed has experienced an increase of nutrients that can potentially be extremely toxic to aquatic organisms. The combined AR for riparian habitat stressors and water chemistry stressors is approximately 83%, suggesting that altered riparian habitat and water chemistry stressors adequately account for the biological impairment in Catoctin Creek (Table 6).

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

Final Causal Model for Catoctin Creek

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 2010). 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 Catoctin Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

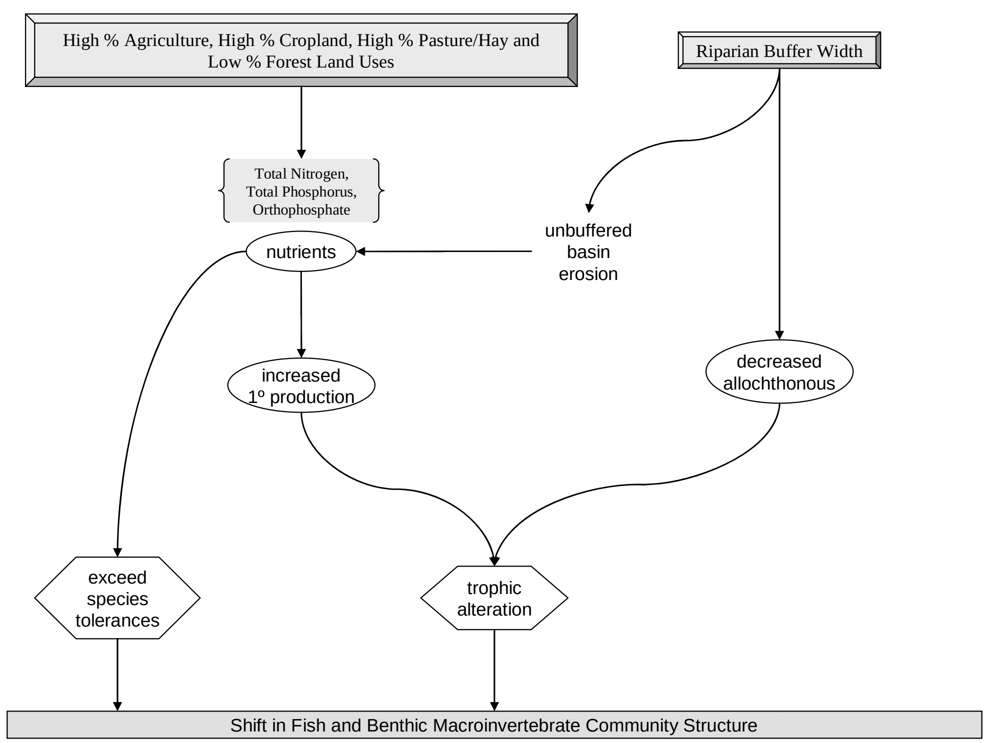

Figure 6. Final Causal Model for the Catoctin Creek Watershed

5.0 Conclusions

Data suggest that the Catoctin Creek watershed's biological communities are strongly influenced by agricultural land use resulting in increased 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, particularly those landscapes without a suitable riparian buffer, which often increases contaminant loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of Catoctin Creek are summarized as follows:

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Catoctin Creek watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 54% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus and 82% degraded due to high orthophosphate. Similarly, according to the BSID analysis, 78% of the biologically impacted stream miles in the Catoctin Creek 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 Catoctin Creek 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 Catoctin Creek, and the reduction of nitrogen loads would not be an effective means of ensuring that the Catoctin Creek watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Catoctin Creek Nutrient TMDL will apply only to total phosphorus (MDE 2011). The BSID results thus confirm the 2008 Category 5 listing for phosphorus as an impairing substance in the Catoctin Creek watershed, and link this pollutant to biological conditions in these waters.

- Although there is presently a Category 4a listing (TMDL submitted and approved by USEPA) for total suspended sediments in the State's 2010 Integrated Report, the BSID analysis did not identify any sediment stressors present showing a significant association with degraded biological conditions.

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