Watershed Report for Biological Impairment of the Antietam Creek Watershed in Washington County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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Submitted to:

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BOD	Biological Oxygen Demand
BSID	Biological Stressor Identification
Ca++	Calcium
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IDNR	Iowa Department of Natural Resources
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
Mg++	Magneseium
mg/L	Milligrams per liter
MH	Mantel-Haenszel
NH_3	Ammonia
NPDES	National Pollution Discharge Elimination System
OP	Orthophosphate
PCB	Polychlorinated biphenyls
SO4	Sulfate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TDN	Total Dissolved Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

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

The Antietam Creek watershed (basin number 02140502) was assessed by the Maryland Department of the Environment (MDE) resulting in numerous pollutant categories being identified on the State's 2010 Integrated Report. Below is a table identifying the listings associated with this watershed.

Table 1. 2010 Integrated Report Listings for Antietam Creek Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Antietam Creek	02140502	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
				1996	TP	5
				1996	TSS	4a
					BOD (carbonaceous)	2
					BOD (nitrogeneous)	2
			Water Contact Sports	2002	Fecal Coliform	4a
			Fishing	2008	PCB in Fish Tissue	5
					Mercury in Fish Tissue	2
Greenbrier Lake	021405020192	Impoundment	Aquatic Life and Wildlife		TN	2
					TP	2

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Antietam Creek and its tributaries is Use IV-P (Recreational Trout Waters and Public Water Supply) except for Beaver Creek, Marsh Run, and Little Antietam Creek, which are classified as Use III-P (Nontidal Cold Water and Public Water Supply). In addition, COMAR requires these waterbodies to support at a minimum the Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life* (COMAR 2012a,b,c). The Antietam Creek watershed is not attaining its designated use because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact 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 Antietam Creek 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 Antietam Creek is strongly influenced by urban and agricultural land uses and their concomitant effects: altered hydrology and elevated levels of sediments, nutrients, and conductivity (a measure of the presence of dissolved substances). The development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized and agricultural landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID process, and the probable causes and sources of the biological impairments in Antietam Creek, can be summarized as follows:

- The BSID process has determined that the biological communities in Antietam Creek are likely degraded due to sediment and riparian habitat related stressors. Specifically, altered hydrology and runoff from urban and agriculturally developed landscapes have resulted in erosion and subsequent elevated suspended sediment that are, in turn, the probable causes of impacts to biological communities in the watershed. The BSID results confirm the establishment of a USEPA approved sediment TMDL for the Antietam Creek watershed was an appropriate management action to begin addressing the impacts of these stressors on the biological communities in Antietam Creek.

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Antietam Creek watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 20% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus and 19% degraded due to high orthophosphate. Similarly, according to the BSID analysis, 31% of the biologically impacted stream miles in the Antietam 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 Antietam 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 Antietam Creek, and the reduction of nitrogen loads would not be an effective means of ensuring that the Antietam Creek watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Antietam Creek 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 Antietam Creek watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that the biological communities in the Antietam Creek watershed are likely degraded due to inorganic pollutants (i.e., sulfates). Sulfate levels are significantly associated with degraded biological conditions and found in 15% of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Agricultural runoff cause an increase in contaminant loads from nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support a Category 5 listing of sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Antietam Creek watershed.

- The BSID process has also determined that biological communities in the Antietam Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Antietam Creek watershed based on channelization being present in approximately 36% of degraded stream miles.

- The BSID process has also determined that biological communities in the Antietam Creek watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. MDE recommends a Category 4c listing for the Antietam Creek watershed based on inadequate riparian buffer zones in approximately 24% of degraded stream miles.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 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 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. If a TMDL was developed and approved by the USEPA then the pollutant is listed under Category 4a.

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 biological impairment. Identification of stressors responsible for biological impairment is limited to the round two Maryland Department of Natural Resources (MDDNR) Maryland Biological Stream Survey (MBSS) dataset (2000 – 2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be 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 Antietam Creek watershed and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Antietam Creek Watershed Characterization

2.1 Location

The Antietam Creek watershed is located in the Potomac River basin within Washington County, Maryland (see Figure 1). Antietam Creek is a free flowing stream that originates in Pennsylvania and empties into the Potomac River in Maryland. It is approximately 54 miles in length, with 37 miles in Maryland and 17 miles in Pennsylvania. The total watershed area covers 290 square miles, with approximately 185 square miles in Maryland and 106 square miles in Pennsylvania. The largest urban center within the watershed is the City of Hagerstown, with a population of 36,687 (USCB 2000). The watershed area is located in the Highlands region of the three distinct eco-regions identified in the MBSS IBI metrics (Southerland et al. 2005) (see Figure 2).

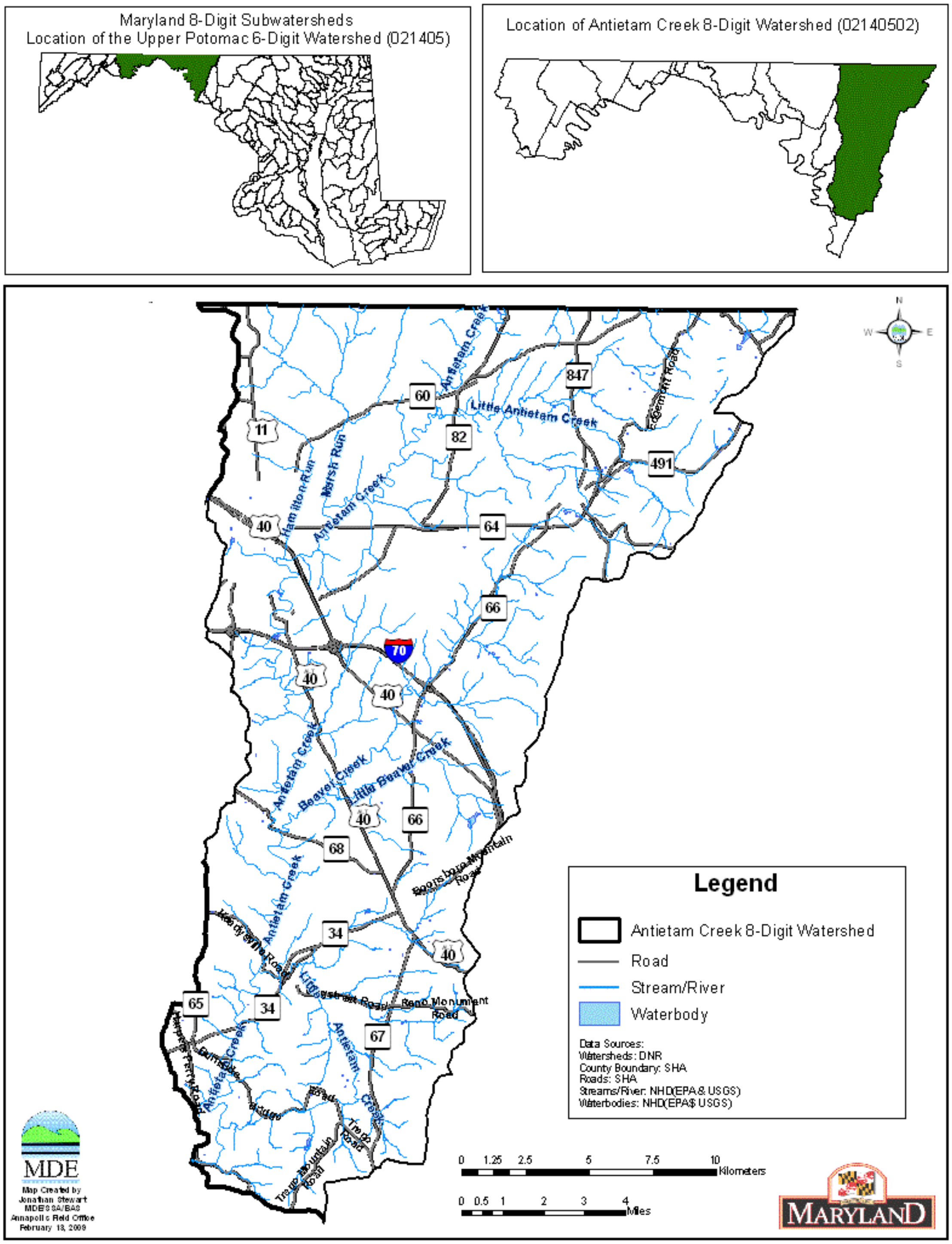

Figure 1. Location Map of the Antietam Creek Watershed

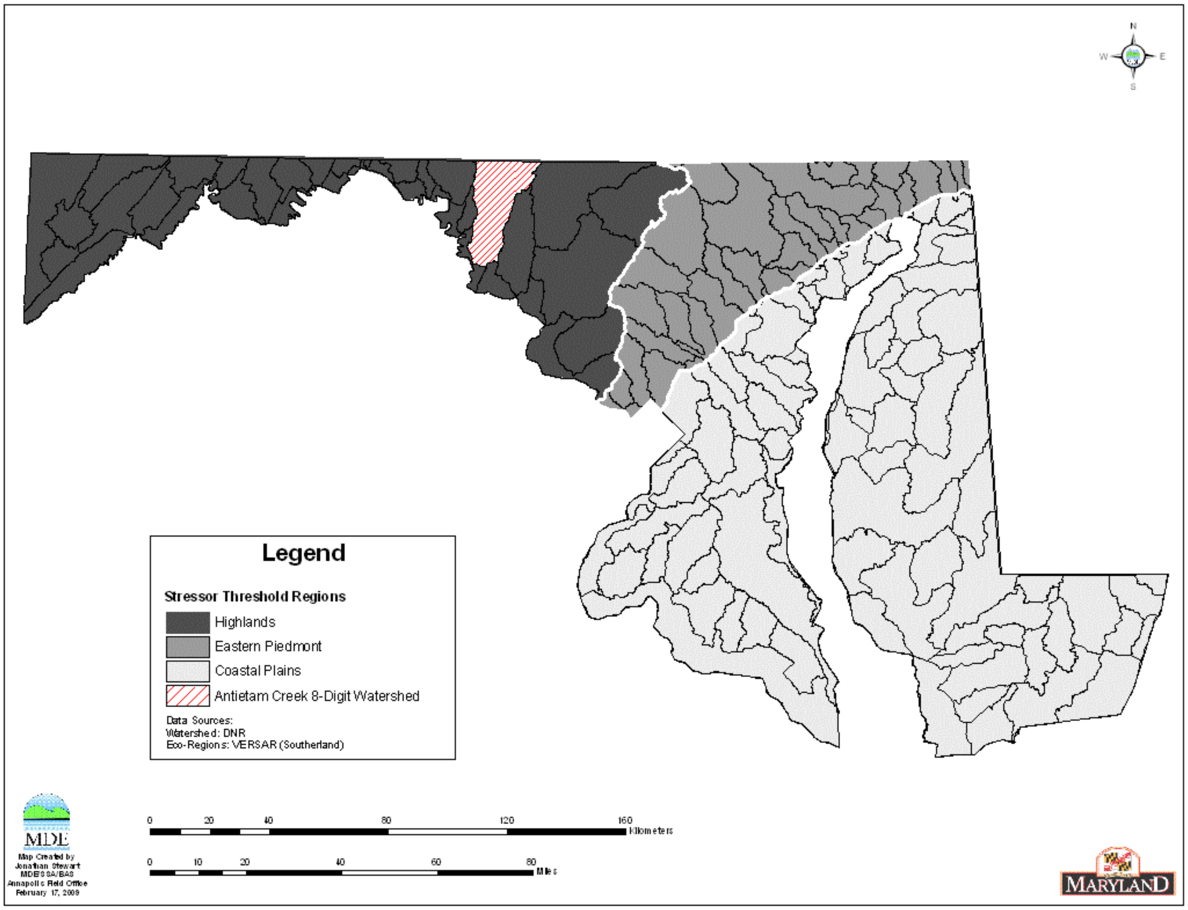

Figure 2. Eco-Region Location Map of the Antietam Creek Watershed

2.2 Land Use

The largest urban center within the Antietam Creek watershed is the City of Hagerstown. Many areas in Hagerstown were built before modern stormwater runoff controls were required by the State. The land use in the Antietam Creek watershed is nearly half agricultural (45%), with forest (30%) and urban (25%) comprising the remaining portions (see Figure 3). The agricultural land use consists mostly of crop production, but also includes some pasture. The land use distribution in the Antietam Creek watershed is shown in Figure 4 (USEPA 2010).

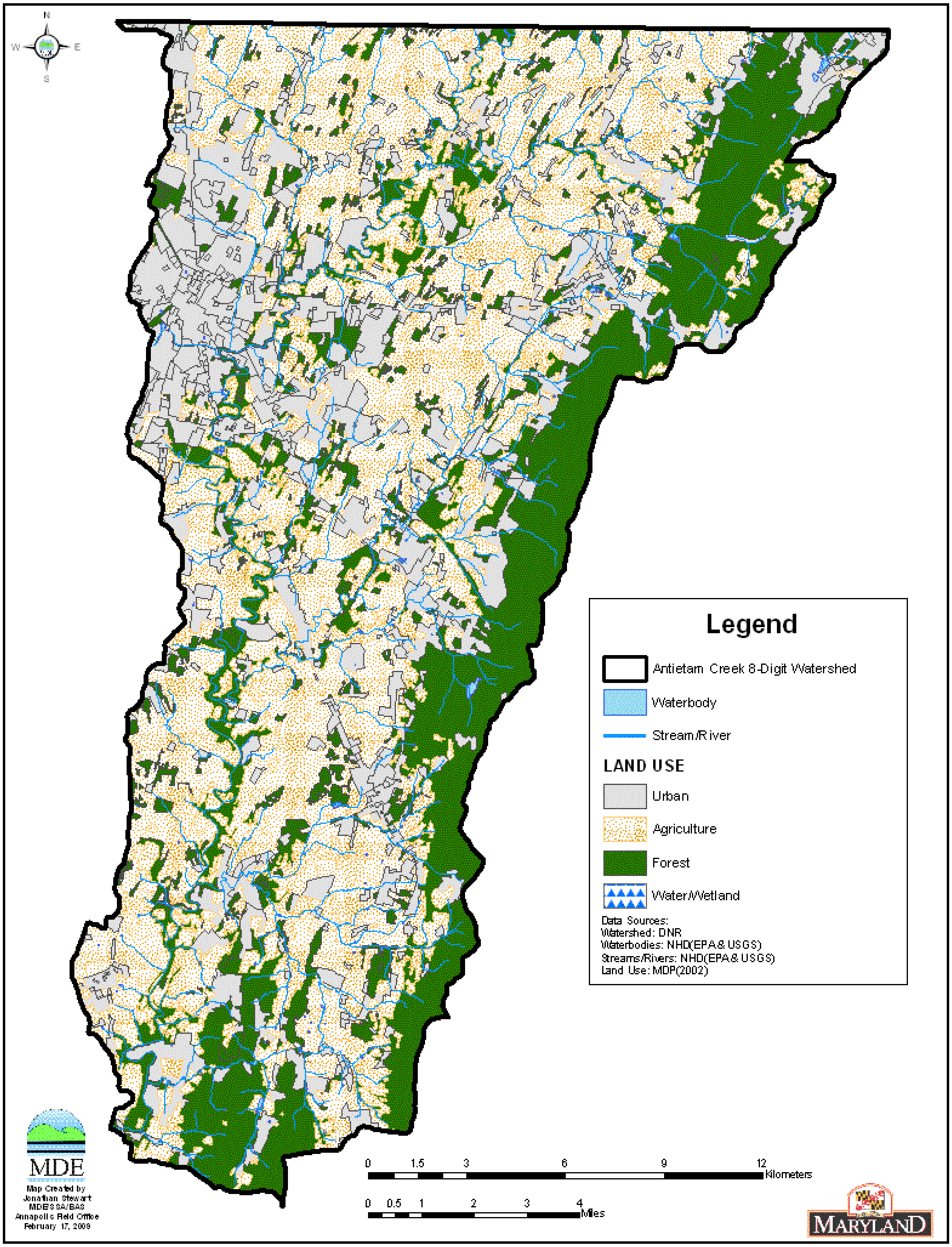

Figure 3. Land Use Map of the Antietam Creek Watershed

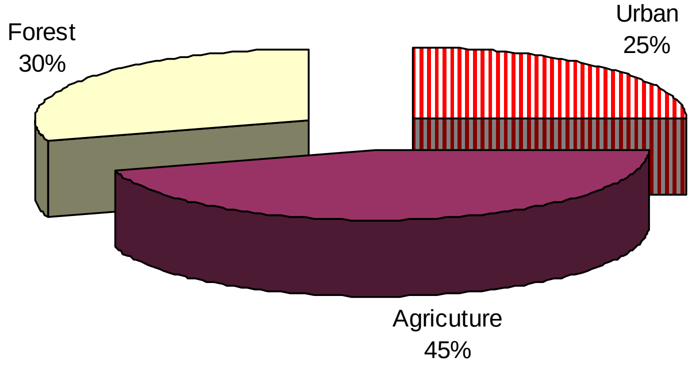

Figure 4. Proportions of Land Use in the Antietam Creek Watershed

2.3 Soils/hydrology

The Antietam watershed lies entirely within the Great Valley Section (Hagerstown Valley) of the Ridge and Valley Province (MGS 2007). The Great Valley is a wide, flat, and open valley formed on Cambrian and Ordovician limestone, dolomite, and alluvial fan deposits alongside the bordering mountains. The surface geology is characterized by folded and faulted sedimentary rocks, layered limestone and shale, and mountainous soils composed of clay, clay loams, and sandy and stony loams (MGS 2007; MDE 2000).

The soils in the watershed are in the Elliber-Dekalb-Opequon Association. The Elliber soils are very deep on both the tops and sides of the ridges where they cover a cherty limestone. They also contain large quantities of chert fragments. The Dekalb soils are moderately deep, very stony, and cover sandstone. The Opequon soils are generally found on the sides of the limestone ridges. (USDA SCS 1962).

3.0 Antietam Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Antietam Creek watershed (basin number 02140502) was assessed by the Maryland Department of the Environment (MDE) resulting in numerous pollutant categories being identified on the State's 2010 Integrated Report. Below is a table identifying the listings associated with this watershed.

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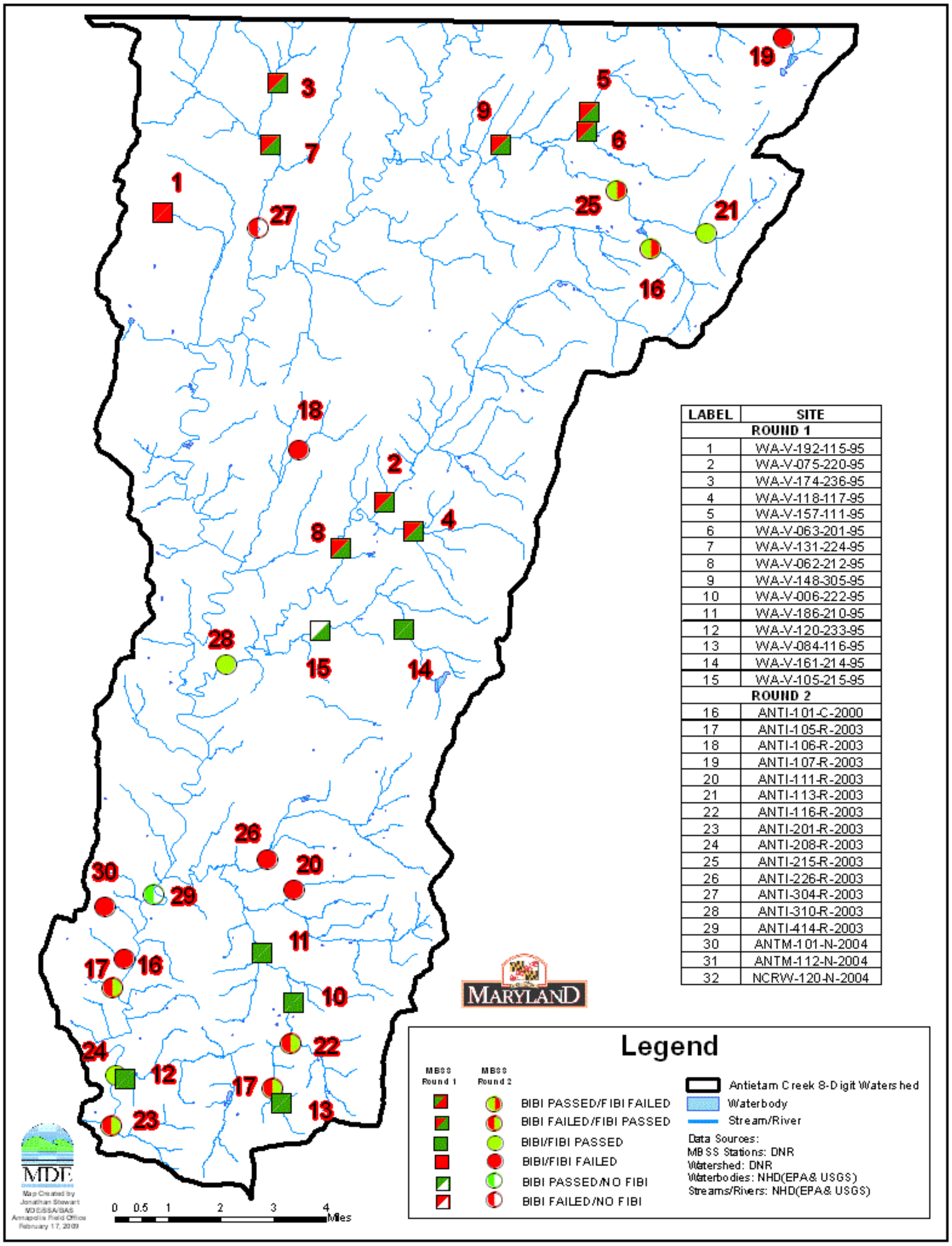
					Mercury in Fish Tissue	2
Greenbrier Lake	021405020192	Impoundment	Aquatic Life and Wildlife		TN	2
					TP	2

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Antietam Creek and its tributaries is Use IV-P (Recreational Trout Waters and Public Water Supply) except for Beaver Creek, Marsh Run, and Little Antietam Creek, which are classified as Use III-P (Nontidal Cold Water and Public Water Supply). In addition, COMAR requires these waterbodies to support at a minimum the Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life* (COMAR 2012a,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 Antietam Creek watershed is listed under Category 5 of the 2010 Integrated Report as impaired for evidence of biological impacts. Approximately 59% of the stream miles in the Antietam watershed are estimated as having fish 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 thirty-two sites. Twenty-two of the thirty-two sites have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS Round 2 contains seventeen MBSS sites with thirteen having degraded BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Antietam Creek watershed.



LABEL	SITE
ROUND 1	
1	WA-V-192-115-95
2	WA-V-075-220-95
3	WA-V-174-236-95
4	WA-V-118-117-95
5	WA-V-157-111-95
6	WA-V-063-201-95
7	WA-V-131-224-95
8	WA-V-062-212-95
9	WA-V-148-305-95
10	WA-V-006-222-95
11	WA-V-186-210-95
12	WA-V-120-233-95
13	WA-V-084-116-95
14	WA-V-161-214-95
15	WA-V-105-215-95
ROUND 2	
16	ANTI-101-C-2000
17	ANTI-105-R-2003
18	ANTI-106-R-2003
19	ANTI-107-R-2003
20	ANTI-111-R-2003
21	ANTI-113-R-2003
22	ANTI-116-R-2003
23	ANTI-201-R-2003
24	ANTI-208-R-2003
25	ANTI-215-R-2003
26	ANTI-226-R-2003
27	ANTI-304-R-2003
28	ANTI-310-R-2003
29	ANTI-414-R-2003
30	ANTM-101-N-2004
31	ANTM-112-N-2004
32	NCRW-120-N-2004

Figure 5. Principal Dataset Sites for the Antietam Creek Watershed

4.0 Stressor Identification Results

The BSID process uses results from the BSID analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID 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; 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 – 1^{st} and 2^{nd}-4^{th} order), that have good biological conditions.

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

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

The BSID analysis and the identification of stressors responsible for biological impairment is usually limited to the round two 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. In the case of the Antietam Creek watershed, the combined AR for all stressors identified was 65%. MDE does not consider AR values under 75% for all stressors identified as sufficient enough to fully address the biological impairment in the watershed. MDE utilized both round one and round two data for the BSID analysis of Antietam Creek thus resulting in a combined stressor AR value of 83%. Only parameters contained in both round one and round two datasets were used for the BSID results. Many sediment and water chemistry parameters were not collected during the round one sampling.

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 sediment, habitat, and water chemistry parameters, as well as potential sources significantly associated with degraded fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various urban and agricultural land uses in the watershed as well as in sixty meter riparian buffer, and low percentage of forested land use in the watershed. Table 3 shows the summary of combined AR values for the source groups in the Antietam Creek watershed. As shown in Table 4 through Table 5, numerous parameters from the sediment, in-stream habitat, riparian habitat, and water chemistry groups were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Antietam Creek watershed.

Table 2. Stressor Source Identification Analysis Results for Antietam 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 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	17	13	156	8%	1%	No	----
	high % of high intensity urban in watershed	32	22	295	23%	2%	Yes	20%
	high % of low intensity urban in watershed	32	22	295	18%	4%	Yes	14%
	high % of transportation in watershed	32	22	295	18%	5%	Yes	13%
	high % of high intensity urban in 60m buffer	31	21	295	24%	3%	Yes	20%
	high % of low intensity urban in 60m buffer	31	21	295	19%	4%	Yes	15%
	high % of transportation in 60m buffer	31	21	295	19%	5%	Yes	14%
Sources Agriculture	high % of agriculture in watershed	32	22	295	27%	11%	Yes	17%
	high % of cropland in watershed	32	22	295	14%	3%	Yes	10%
	high % of pasture/hay in watershed	32	22	295	32%	16%	Yes	16%
	high % of agriculture in 60m buffer	31	21	295	48%	10%	Yes	38%
	high % of cropland in 60m buffer	31	21	295	14%	2%	Yes	12%
	high % of pasture/hay in 60m buffer	31	21	295	43%	16%	Yes	27%
Sources Barren	high % of barren land in watershed	32	22	295	5%	4%	No	----
	high % of barren land in 60m buffer	31	21	295	0%	3%	No	----
Sources Anthropogenic	low % of forest in watershed	32	22	295	36%	7%	Yes	29%
	low % of forest in 60m buffer	31	21	295	38%	8%	Yes	30%

Table 2. Stressor Source Identification Analysis Results for Antietam 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 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Acidity	atmospheric deposition present	32	22	295	5%	44%	No	----
	AMD acid source present	32	22	295	0%	6%	No	----
	organic acid source present	32	22	295	0%	2%	No	----
	agricultural acid source present	32	22	295	0%	2%	No	----

Table 3. Summary of Combined AR Values for Source Groups for the Antietam Creek Watershed

	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)
Source Groups	81%

4.1 Sources Identified by BSID Analysis

All fourteen stressor parameters, identified in Tables 4-6, that are significantly associated with biological degradation in the Antietam Creek watershed BSID analysis are representative of impacts from both urban and agricultural landscapes. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer, Paul, and Taulbee 2005) has consistently identified negative impacts to biological conditions as a result of increased urbanization. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed "urban stream syndrome" (Meyer, Paul, and Taulbee 2005). Symptoms of urban stream syndrome include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors. Numerous studies have also documented declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments (Roth, Allan, Erickson 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). Agricultural land use degrades streams by increasing nonpoint inputs of nutrients and sedimentation, which impacts riparian and stream channel habitat.

The BSID analysis identified agriculture, cropland, and hay/pasture land uses as significant not only in the Antietam Creek watershed but also in the riparian buffer zone. Numerous studies have identified row crop agriculture as being the most significantly detrimental type of agriculture within a watershed regardless of whether the entire watershed, catchment, riparian zone, or different riparian widths are considered (McCollum 2004). The proportion of row crop agriculture is more significantly important than the proportion of all agriculture in regards to the effects of habitat quality, water quality, and biotic integrity (Richards et al. 1997, Johnson et al. 1997).

The BSID source analysis (Table 2) identifies various types of urban and agricultural land uses as potential sources of stressors that may cause negative biological impacts. The *low percentage of forestland use* not only in the watershed but also within the 60m buffer is likely a result of the increased landscape development in the watershed. 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 sources group is approximately 81% suggesting these sources impacts a substantial proportion of the degraded stream miles in Antietam Creek (see Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for Antietam 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 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of 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	15	12	78	8%	9%	No	----
	moderate bar formation present	15	12	78	42%	43%	No	----
	bar formation present	15	12	78	83%	88%	No	----
	channel alteration moderate to poor	30	21	140	57%	37%	No	----
	channel alteration poor	30	21	140	38%	9%	Yes	29%
	high embeddedness	30	21	140	33%	6%	Yes	27%
	epifaunal substrate marginal to poor	30	21	140	48%	28%	Yes	20%
	epifaunal substrate poor	30	21	140	48%	14%	Yes	34%
	moderate to severe erosion present	15	12	78	33%	25%	No	----
	severe erosion present	15	12	78	0%	1%	No	----
	poor bank stability index	15	12	78	0%	4%	No	----
	silt clay present	15	12	78	100%	99%	No	----

Table 5. Habitat Biological Stressor Identification Analysis Results for Antietam 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 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of 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	32	22	145	45%	10%	Yes	36%
	instream habitat structure marginal to poor	30	21	140	38%	24%	No	----
	instream habitat structure poor	30	21	140	14%	3%	Yes	11%
	pool/glide/eddy quality marginal to poor	30	21	140	43%	41%	No	----
	pool/glide/eddy quality poor	30	21	140	10%	8%	No	----
	riffle/run quality marginal to poor	30	21	140	19%	36%	No	----
	riffle/run quality poor	30	21	140	14%	8%	No	----
	velocity/depth diversity marginal to poor	30	21	140	48%	53%	No	----
	velocity/depth diversity poor	30	21	140	5%	7%	No	----
	concrete/gabion present	32	22	145	5%	4%	No	----
	beaver pond present	30	21	139	0%	1%	No	----
Riparian Habitat	no riparian buffer	32	22	145	50%	26%	Yes	24%
	low shading	30	21	140	14%	12%	No	----

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for Antietam 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 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of 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	17	13	159	38%	8%	Yes	31%
	high total dissolved nitrogen	1	1	50	0%	6%	No	----
	ammonia acute with salmonid present	17	13	159	0%	2%	No	----
	ammonia acute with salmonid absent	17	13	159	0%	1%	No	----
	ammonia chronic with salmonid present	17	13	159	0%	4%	No	----
	ammonia chronic with salmonid absent	17	13	159	0%	2%	No	----
	low lab pH	32	22	295	0%	5%	No	----
	high lab pH	32	22	295	14%	0%	Yes	13%
	low field pH	30	21	289	0%	11%	No	----
	high field pH	30	21	289	10%	0%	Yes	10%
	high total phosphorus	17	13	159	23%	3%	Yes	20%
	high orthophosphate	17	13	159	23%	4%	Yes	19%
	dissolved oxygen < 5mg/l	30	21	290	0%	3%	No	----
	dissolved oxygen < 6mg/l	30	21	290	0%	6%	No	----
	low dissolved oxygen saturation	24	17	205	0%	3%	No	----
	high dissolved oxygen saturation	24	17	205	6%	0%	No	----
	acid neutralizing capacity below chronic level	32	22	295	5%	5%	No	----
	acid neutralizing capacity below episodic level	32	22	295	5%	48%	No	----
	high chlorides	17	13	159	15%	7%	No	----
	high conductivity	32	22	295	32%	2%	Yes	29%
	high sulfates	32	22	295	18%	3%	Yes	15%

Table 7. Summary of Combined AR Values for Stressor Groups for the Antietam Creek Watershed

Parameter Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Sediment	45%	83%
In-Stream Habitat	40%	
Riparian Habitat	24%	
Water Chemistry	58%	

4.2 Stressors Identified by BSID Analysis

Sediment Stressors

BSID analysis results for Antietam Creek identified four sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *channel alteration poor, high embeddedness and epifaunal substrate (marginal to poor & poor).*

Channel alteration poor was identified as significantly associated with degraded biological conditions and found in 29% of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Channel alteration measures large-scale modifications in the shape of the stream channel due to the presence of artificial structures (channelization) and/or bar formations. Poor ratings are expected in unstable stream channels that experience frequent high flows.

High embeddedness was identified as significantly associated with degraded biological conditions in Antietam Creek, and found to impact approximately 27% of the stream miles with poor to very poor biological conditions. Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Epifaunal Substrate (marginal to poor & poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 20% (marginal to poor) and 34% (poor) of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Like embeddedness, epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

The largest urban center within the Antietam Creek watershed is the City of Hagerstown. As development and urbanization increased around Hagerstown and other areas in the watershed so did morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams causing urban streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are stream channel widening and streambed scouring. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Significant channel alteration of stream habitats is typical in urban streams affected by altered hydrology.

There is a significant amount of agriculture within the Antietam Creek watershed, which consists mostly of crop production, but also includes some pasture. Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indices (Richards et al. 1997, Roth, Allan, and Erickson 1996, Wang et al. 1997), as well as greater deposition of sediments on and within the streambed.

A poor rating for epifaunal substrate and the presence of high embeddedness is an indicator that stable substrate is lacking and stream bottom is covered with fine layer of sediment. Some of the impacts associated with sedimentation are smoothing of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of stream bottom (Hoffman, Rattner, and Burton 2003). All of these processes result in an unstable stream ecosystem that impacts habitat heterogeneity and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 45%, suggesting these stressors impact a moderate proportion of the degraded stream miles in the in Antietam Creek (see Table 4).

In-Stream Habitat Stressors

BSID analysis results for the Antietam Creek identified two in-stream habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *channelization present* and *in-stream habitat structure (poor).*

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 36% of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Channelized describes a condition determined by visual observation of the presence or absence of the channelization of the stream segment and the extent of the channelization. Channelization is the human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete, rip rap, and ditching). Natural channels have diverse habitats with varying water velocities as the morphology changes between riffles and pools. The diverse nature of natural channels provides slow water refugia during high flow and many resting areas. With less structural diversity, channelized systems have minimal resting areas and organisms are easily swept away during high flows. In low flow periods, natural channels have sufficient water depth to support fish and aquatic species during the dry season; where as, channelized streams often have insufficient depth to sustain diverse aquatic life (Bolton and Shellberg 2001). Channelization likely inhibits heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities.

In-stream habitat structure was identified as significantly associated with degraded biological conditions in the Antietam Creek watershed, and found to impact approximately 11% of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High in-stream habitat scores are evidence of the lack of sediment deposition. In-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habit where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

The in-stream habitat parameters identified as significantly associated with degraded conditions in the Antietam Creek watershed are primarily linked to the watershed's high percentage of agricultural and urban land use development. Historically many streams flowing through agricultural fields were channelized to improve drainage of croplands. During channelization, trees in the riparian buffer zone are often cut and woody debris is removed from the stream channel to allow for efficient movement of water away from agricultural fields. Channelization has changed many streams into straight shallow ditches with severely depressed biodiversity. Effects of channelization include loss of stream habitat, loss of aquatic productivity, increased streambed and bank erosion, and a reduction of ground water levels.

Channelization has also been used in urban landscapes for flood control, and has resulted in significant channel and streambed alteration. These alterations significantly impact the other habitat parameters identified as significantly associated with degraded conditions in the watershed. Channelization is detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows, e.g. flashiness. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in channelized streams. The overall densities and biomasses of macroinvertebrates in channelized streams are very low by comparison with intact natural streams (Laasonen, Muotka, and Kivikaervi 1998; Haapala and Muotka 1998).

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 in-stream habitat stressor group is approximately 40% suggesting these stressors impacts a moderate proportion of the degraded stream miles in the Antietam Creek (See Table 5).

Riparian Habitat Stressors

BSID analysis results for Antietam 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 Antietam Creek, and found to impact approximately 24% 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 60 m, with 0 m having no buffer and 60 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, Smyth, and Boutin 2004). Natural forested headwater streams generally rely on allochthonous input of leaf litter as the major energy source, but agricultural land use typically reduces or eliminates the trees in the riparian area that would contribute detritus.

This reduction can have strong impacts on stream communities, exclusion of leaf litter decreased invertebrate biomass and/or abundance by 93 to 97% in of more than half of the invertebrate shredder, collector and predator taxa (Wallace et al. 1997). A decreased riparian buffer also leads to reduced amounts of large wood debris in the stream. Stable wood substrate in streams performs multiple functions, influencing channel features, flow, habitat, and providing cover for fish. The lack of adequate riparian buffer zones along some streams in the Antietam Creek watershed exacerbates erosion and sedimentation caused by altered hydrology and agricultural land uses.

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 24%, suggesting this stressor impacts a minimal proportion of the degraded stream miles in Antietam Creek (see Table 5).

Water Chemistry Stressors

BSID analysis results for Antietam 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 nitrogen, high total phosphorus, high orthophosphate, high lab pH, high filed pH, high conductivity,* and *high sulfates.*

A high total nitrogen concentration was identified as significantly associated with degraded biological conditions in Antietam Creek and was found to impact approximately 31% of the stream miles with poor to very poor biological conditions. The total nitrogen (TN) parameter is the measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedences of dissolved oxygen and pH levels. Runoff and leaching from agricultural land and wastewater dischargers can generate high in-stream levels of nitrogen.

A high total phosphorus concentration was identified as significantly associated with degraded biological conditions in Antietam Creek and found to impact approximately 20% of the stream miles with poor to very poor biological conditions. The total phosphorus (TP) parameter is the 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 are the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. Eutrophication can potentially result in low dissolved oxygen and high pH levels, which can exceed tolerance levels of many biological organisms. Typically, TP input to surface waters increases in watersheds where urban and agricultural developments are predominant.

A high orthophosphate concentration was identified as significantly associated with degraded biological conditions in Antietam Creek and found to impact approximately 19% of the stream miles with poor to very poor biological conditions. The orthophosphate (OP) parameter is the measure of the amount of OP in the water column. OP is the most readily available form of phosphorus for uptake by aquatic organisms (see *high total phosphorus* above). Typically, OP input to surface waters increases in watersheds where urban and agricultural developments are predominant.

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).

More than 94% of the samples collected in the Antietam Creek watershed since 1998 by various State agencies have TN:TP ratios above 10 and less than 1% had TN:TP ratios below 5. All samples with ratios below 10 come from the mainstem Antietam Creek. The median ratio was 38. The observed data strongly implies that the streams in the Antietam Creek watershed are phosphorus limited (MDE 2012).

A high lab & field pH (above 8.5) was identified as significantly associated with degraded biological conditions in Antietam Creek, and found to impact approximately 13% (*lab*) and 10% (*field*) of the stream miles with poor to very poor biological conditions. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Exceedences of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2012d). Intermittent high pH (greater than 8.5) is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms.

A high conductivity was identified as significantly associated with degraded biological conditions in Antietam Creek and found to impact approximately 29% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. The presence of limestone in the local geology leads to higher electrical conductivity because of the dissolution of carbonate minerals in the water.

Antietam Creek, falling in the Highland region, is a limestone influenced stream in which higher conductivity levels above 300 µS/cm are not uncommon. In the Highland region, where limestone influenced streams are prevalent, the conductivity threshold has been set at 500 µS/cm. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2009). Urban and agricultural runoffs (i.e., fertilizers and wastewater discharges) as well as leaking wastewater infrastructure are typical sources of inorganic compounds.

High sulfates were identified as significantly associated with degraded biological conditions and found in 15% of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Sulfate is the amount of dissolved sulfate (SO_4^{2-}) in the water column. MDDNR MBSS measures sulfate once in the spring and reports it as mg/L. Sulfates can play a critical role in the elevation of conductivity. Other detrimental impacts of elevated sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. Typically sulfates derived from agricultural landscapes are associated with fertilizers which often contain various types and concentrations of sulfate anions.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. The prevalence of agricultural land use in the Antietam Creek watershed is an important source of pollution when rainfall carries sediment, fertilizers, manure, and pesticides into streams. The three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. Elevated nutrient concentrations are reported to result in greater algal production and changes in autotrophic assemblage composition (Delong & Brusven 1998, Quinn 2000). However, the hypoxic conditions that high nutrient loading causes in lentic and coastal waters are uncommon in streams located in the eastern piedmont region and are likely to occur only in localized areas of slow-moving water (Carpenter et al. 1998). Although low dissolved oxygen was not found to have significant association with degraded biology in Antietam Creek, the BSID analysis did identify high lab pH values. Intermittent high pH is often associated with elevated nutrient concentrations and eutrophication related to increased algal blooms.

Antietam Creek flows through limestone substrate, which contributes calcium (CA++) and magnesium (Mg++) to surface water. Both CA++ and Mg++ contribute to elevated pH and conductivity levels. Anions, such as sulfates from fertilizers, also contribute to elevated conductivity levels.

Point source discharges are a potential source of nutrient and suspended solids to surface waters. There are ten municipal and nine industrial discharges in the Antietam Creek watershed. Nutrient, sulfates, conductivity, and suspended solid loads from any wastewater treatment facility is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

The agricultural and urban land uses in the Antietam Creek watershed are potential sources for the elevated levels of TN, TP, OP, SO_4, conductivity and high pH. 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 58% suggesting this stressor impacts a considerable proportion of the degraded stream miles in Antietam Creek (see Table 6).

4.3 Discussion of Stressors Identified by BSID Analysis

The BSID analysis results suggest that degraded biological communities in the Antietam Creek watershed are a result of increased agricultural and urban land uses causing alterations to hydrology and increased sedimentation, resulting in an unstable stream ecosystem that eliminates optimal habitat. High proportions of these land uses also typically result in increased contaminant loads from point and nonpoint sources by adding sediments, nutrients, and sulfates to surface waters, resulting in levels of nutrients that can potentially cause eutrophication in the watershed. Decreased riparian buffer areas are potentially contributing to increased erosion, sedimentation, and reduced amounts of large wood debris in the stream. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade Antietam Creek, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 83%, suggesting that altered hydrology/sediment and water chemistry stressors adequately account for the biological impairment in Antietam Creek (see Table 7).

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.

4.4 Final Causal Model for the Antietam Creek Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991 and USEPA 2012). The five factors guide the selection 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 Antietam Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

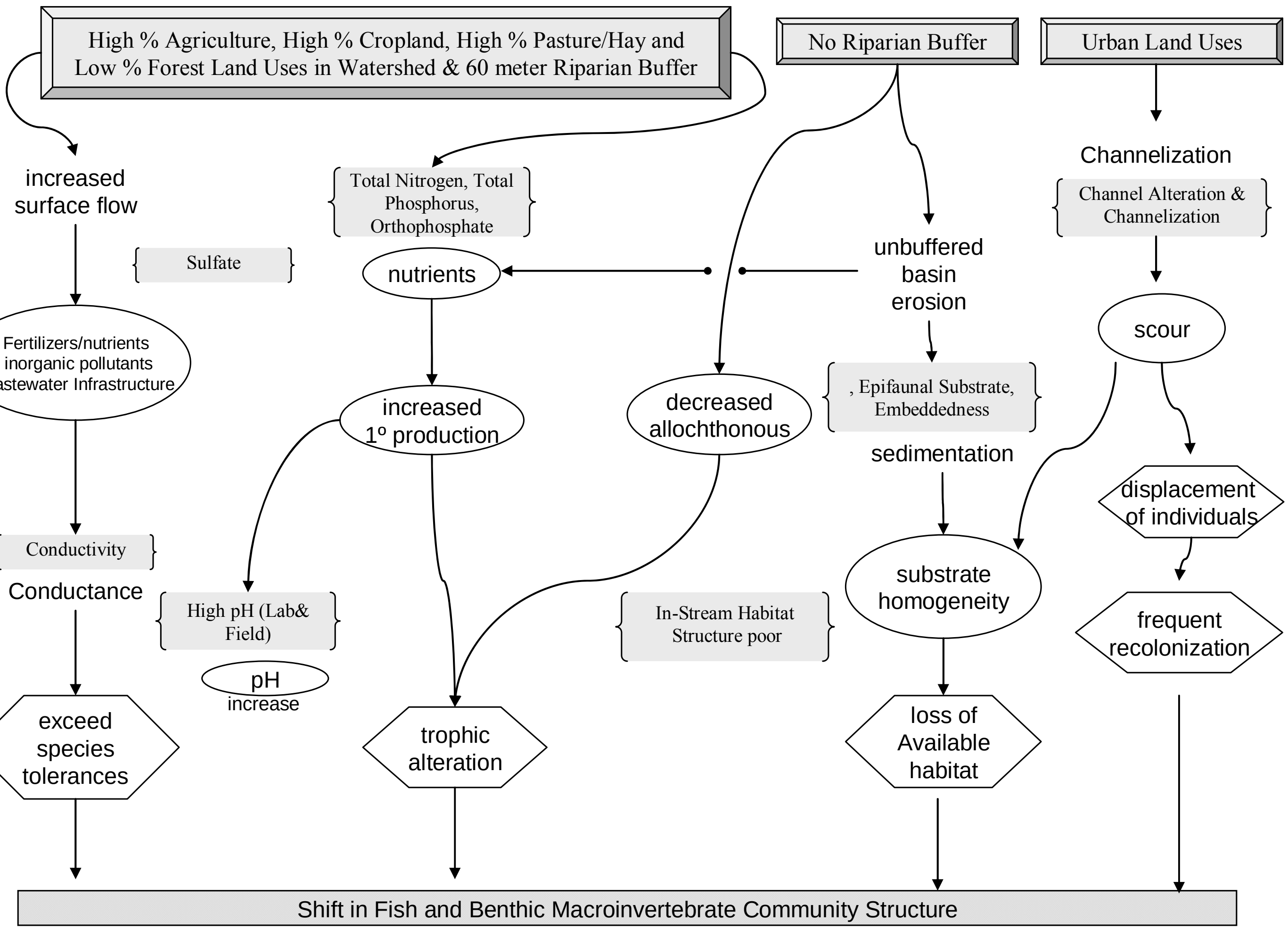


Figure 6. Final Causal Model for the Antietam Creek Watershed

5.0 Conclusion

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

- The BSID process has determined that the biological communities in Antietam Creek are likely degraded due to sediment and riparian habitat related stressors. Specifically, altered hydrology and runoff from urban and agriculturally developed landscapes have resulted in erosion and subsequent elevated suspended sediment that are, in turn, the probable causes of impacts to biological communities in the watershed. The BSID results confirm the establishment of a USEPA approved sediment TMDL for the Antietam Creek watershed was an appropriate management action to begin addressing the impacts of these stressors on the biological communities in Antietam Creek.

- The BSID analysis has determined that both phosphorus and nitrogen are probable causes of impacts to biological communities in the Antietam Creek watershed. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions; as much as 20% of the biologically impacted stream miles in the watershed may be degraded due to high total phosphorus and 19% degraded due to high orthophosphate. Similarly, according to the BSID analysis, 31% of the biologically impacted stream miles in the Antietam 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 Antietam 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 Antietam Creek, and the reduction of nitrogen loads would not be an effective means of ensuring that the Antietam Creek watershed is free from impacts on aquatic life from eutrophication. Therefore, load allocations for the Antietam Creek 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 Antietam Creek watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that the biological communities in the Antietam Creek watershed are likely degraded due to inorganic pollutants (i.e., sulfates). Sulfate levels are significantly associated with degraded biological conditions and found in 15% of the stream miles with poor to very poor biological conditions in the Antietam Creek watershed. Agricultural runoff cause an increase in contaminant loads from nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support a Category 5 listing of sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Antietam Creek watershed.

- The BSID process has also determined that biological communities in the Antietam Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Antietam Creek watershed based on channelization being present in approximately 36% of degraded stream miles.

- The BSID process has also determined that biological communities in the Antietam Creek watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. MDE recommends a Category 4c listing for the Antietam Creek watershed based on inadequate riparian buffer zones in approximately 24% of degraded stream miles.

References

Allan, J.D. 2004. *LANDSCAPES AND RIVERSCAPES: The Influence of Land Use on Stream Ecosystems*. Annual Review Ecology, Evolution, & Systematics. 35:257–84 doi: 10.1146/annurev.ecolsys.35.120202.110122.

Bolton, S and Shellberg, J. 2001. *Ecological Issues in Floodplains and Riparian Corridors.* University of Washington, Center for Streamside Studies, Olympia, Washington.

Booth, D. 1991. *Urbanization and the natural drainage system – impacts, solutions and prognoses.* Northwest Environmental Journal 7: 93-118.

Carpenter SR, Caraco NF, Howarth RW, Sharpley AN, Smith VH. 1998. *Nonpoint pollution of surface waters with phosphorus and nitrogen*. Ecology Appl. 8:559–68.

Chiandani, G. and M. Vighi. 1974. The N:P Ratio and Tests with *Selanastrum* to Predict Eutrophication in Lakes. *Water Research*, Vol. 8, pp. 1063-1069.

COMAR (Code of Maryland Regulations). 2012a. *26.08.02.02*. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed February, 2012).

___________. 2012b. *26.08.02.08 Q(6)(g)*. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed February, 2012).

___________. 2012c. *26.08.02.08 Q(4)*. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed February, 2012).

___________. 2012d. 26.08.02.03-3 http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed February, 2012).

Delong MD, Brusven MA. 1998. *Macroinvertebrate community structure along the longitudinal gradient of an agriculturally impacted stream.* Environmental Management. 22:445–57

Haapala A., and T. Muotka 1998. Seasonal dynamics of detritus and associated macroinvertebrates in a channelized boreal stream. *Archiv. Fuer. Hydrobiologie* 142(2):171-189.

Hill, A. B. 1965. *The Environment and Disease: Association or Causation?* Proceedings of the Royal Society of Medicine, 58: 295-300.

Hoffman D. J., Rattner B. A. , Burton G. A.. 2003. *Handbook of ecotoxicology* Edition: 2, Published by CRC Press: 598-600.

IDNR (Iowa Department of Natural Resources). 2009. *Iowa's Water Quality Standard Review –Total Dissolved Solids (TDS).* http://www.iowadnr.gov/portals/idnr/uploads/water/standards/ws_review.pdf?amp;tabid=1302 (Accessed April, 2012).

Johnson, L. B., C. Richards, G. E. Host, and J. W. Arthur. 1997. *Landscape influences on water chemistry in Midwestern stream ecosystems*. Freshwater Biology 37:193-208.

Karr, J. R. 1991. *Biological integrity - A long-neglected aspect of water resource management*. Ecological Applications. 1: 66-84.

Konrad, C. P., and D. B. Booth. 2002. *Hydrologic trends associated with urban development for selected streams in the Puget Sound Basin*. Western Washington. Water-Resources Investigations Report 02-4040. US Geological Survey, Denver, Colorado.

Laasonen, P., T. Muotka, and I. Kivijaervi. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. *Aquatic Conservation of Marine Freshwater Ecosystems*. 8:101-113.

Lee, P., C. Smyth and S. Boutin. 2004. *Quantative review of riparian buffer guidelines from Canada and the United States*. Journal of Environmental Management. 70:165-180.

Mantel, N., and W. Haenszel. 1959. Statistical aspects of the analysis of data from retrospective studies of disease. Journal of the National Cancer Institute, 22, 719-748.

McCollum, Donna S. 2004. *Landscapes and local influences on the biotic integrity of fish communities in Ohio headwater streams.* Miami, FL: Miami University – Department of Zoology.

MDE (Maryland Department of the Environment). 2000. *An Overview of Wetlands and Water Resources of Maryland*. Baltimore, MD: Maryland Department of the Environment.

_________.2009. *2009 Maryland Biological Stressor Identification Process*. Baltimore, MD: Maryland Department of the Environment. Also available at: http://staging.mde.state.md.us/programs/Water/TMDL/Documents/www.mde.state.md.us/assets/document/BSID_Methodology_Final.pdf

________2010. Final *2010 Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at: http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Pages/Final_approved_2010_ir.aspx (Accessed March, 2012).

________2012. Draft. *Total Maximum Daily Load of Phosphorus in the Antietam Creek Watershed, Washington County, Maryland*. Baltimore, MD: Maryland Department of the Environment.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. *Stream ecosystem function in urbanizing landscapes.* Journal of the North American Benthological Society. 24:602–612.

MGS (Maryland Geological Survey). 2007. *A Brief Description of the Geology of Maryland*. http://www.mgs.md.gov/esic/brochures/mdgeology.html (Accessed March, 2012).

Quinn JM. 2000. *Effects of pastoral development*. In New Zealand Stream Invertebrates:Ecology and Implications for Management, ed. KJ Collier,MJWinterbourn, pp. 208–29. Christchurch, NZ: Caxton

Richards C, Haro RJ, Johnson LB, Host GE. 1997. *Catchment- and reach-scale properties as indicators of macroinvertebrate species traits*. Freshwater Biology 37:219–30.

Roth NE, Allan JD, Erickson DL. 1996. *Landscape influences on stream biotic integrity assessed at multiple spatial scales*. Landsape Ecology 11:141–56.

Southerland, M. T., G. M. Rogers, R. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda and S. A. Stranko. 2005. *New biological indicators to better assess the condition of Maryland Streams.* Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. CBWP-MANTA-EA-05-13.

USCB (U.S. Census Bureau) 2000. U.S.Census http://www.census.gov/census2000/states/us.html (Accessed February 25, 2011).

USDA SCS (U.S. Department of Agriculture Soil Conservation Service). 1962. *Soil Survey of Washington County, Maryland*. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service.

USEPA (U.S. Environmental Protection Agency). 2010. Chesapeake Bay Phase 5 Community Watershed Model. Annapolis MD:Chesapeake Bay Program Office. In Preparation EPA XXX-X-XX-008 February 2010.

http://www.chesapeakebay.net/about/programs/modeling/53/ (Accessed March, 2012)

USEPA – CADDIS (U.S. Environmental Protection Agency). 2012. The Causal Analysis/Diagnosis Decision Information System. http://www.epa.gov/caddis/

Van Sickle, J., and Paulson, S.G. 2008. *Assessing the attributable risks, relative risks, and regional extents of aqautic stressors*. Journal of the North American Benthological Society 27: 920-931.

Wallace, J. B., S. L. Eggert, J. L. Meyer, and J. R. Webster. 1997. *Multiple trophic levels of a forest stream linked to terrestrial litter inputs*. Science **277**:102-104.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan. 2005. *The urban stream syndrome: current knowledge and the search for a cure*. Journal of the North American Benthological Society 24(3):706–723.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. *Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams*. Fisheries 22(6): 6-12.