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

REVISED FINAL

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
ICPRB	Interstate Commission for the Potomac River Basin
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
µeq/L	Micro equivalent per liter
µS/cm	Micro Siemens per centimeter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
NRCS	National Resource Conservation Service
PSU	Primary Sampling Unit
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
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.

The Potomac River Washington County watershed (basin code 02140501) was identified on the Integrated Report under Category 5 as impaired by nutrients and sediments (1996 listings), evidence of biological impacts (2002 listings), methylmercury (impoundment PR Dam #4 2002 listing), and polychlorinated biphenyls (PCBs) in fish tissue (2008 listing) (MDE 2008). The methylmercury listing is for the impoundment created by Potomac River Dam #4 and all other impairments are listed for non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids.

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Potomac River Washington County watershed and all tributaries including the Chesapeake and Ohio Canal, Ditch Run, Downey Branch, and Greenspring Run are designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply*. Camp Spring Run has been designated as Use III-P – *nontidal cold water and public water supply* (COMAR 2009 a, b, c). The Potomac River Washington County Watershed is not attaining its designated use of supporting aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, 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 Potomac River Washington County 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 the Potomac River Washington County watershed is strongly influenced by urban and agricultural land use and its concomitant effects: altered hydrology and elevated levels of sediments, inorganic pollutants, and conductivity (a measure of the presence of dissolved substances). The development of urban 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 agricultural and urbanized 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 the Potomac River Washington County watershed can be summarized as follows:

- The BSID process has determined that biological communities in the Potomac River Washington County watershed are likely degraded due to flow/sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and agricultural landscapes have resulted in channel erosion and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the 1996 Category 5 listing for total suspended solids as an impairing substance in the Potomac River Washington County watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that the biological communities in the Potomac River Washington County watershed are likely degraded due to inorganic pollutants (i.e., chlorides and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in 19% and 12%, respectively of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and 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 chloride and 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 Potomac River Washington County watershed.

- There is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report; BSID analysis identified one water chemistry stressor present (TN) showing a possible association (19% of stream miles) with degraded biological conditions in the Potomac River Washington County watershed. However this is not sufficient evidence of an eutrophication problem, additional monitoring or a more intensive analysis of all available data is recommended to determine if there is a nutrient impairment in the watershed.

1.0 Introduction

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

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

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

The remainder of this report provides a characterization of the Potomac River Washington County watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Potomac River Washington County Watershed Characterization

2.1 Location

The Potomac River Washington County Watershed is bounded to the north by the Pennsylvania State Line and to the west by Allegany County. The watershed includes the Chesapeake & Ohio Canal which follows the Potomac River from the northwest to the southeast (see Figure 1). The major tributaries include Camp Spring Run, Ditch Run, Downey Branch, and Greenspring Run. The drainage area of the Maryland 8-digit watershed Potomac River Washington County is 58,225 acres. The watershed is located the Highland region, one of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

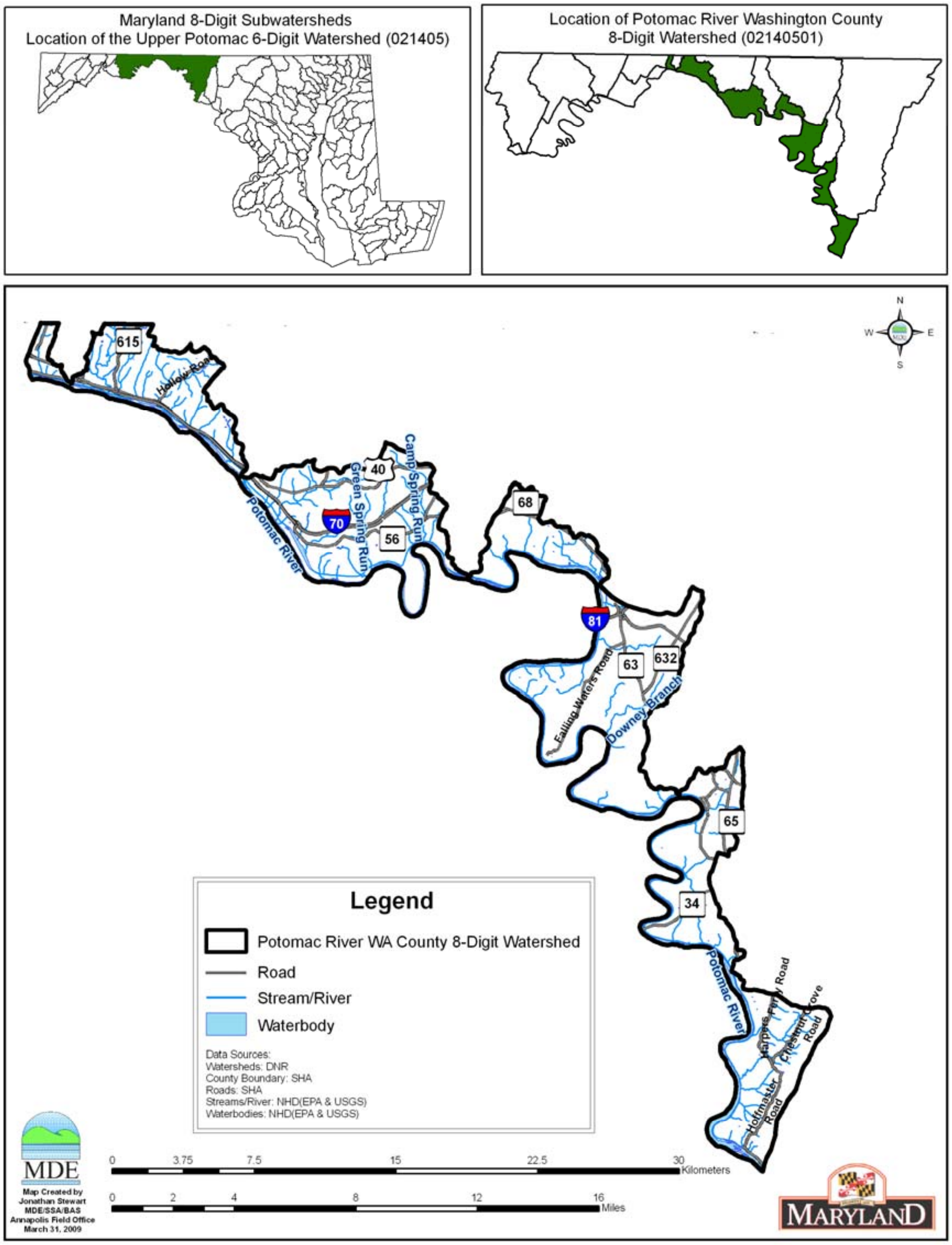

Figure 1. Location Map of the Potomac River Washington County Watershed

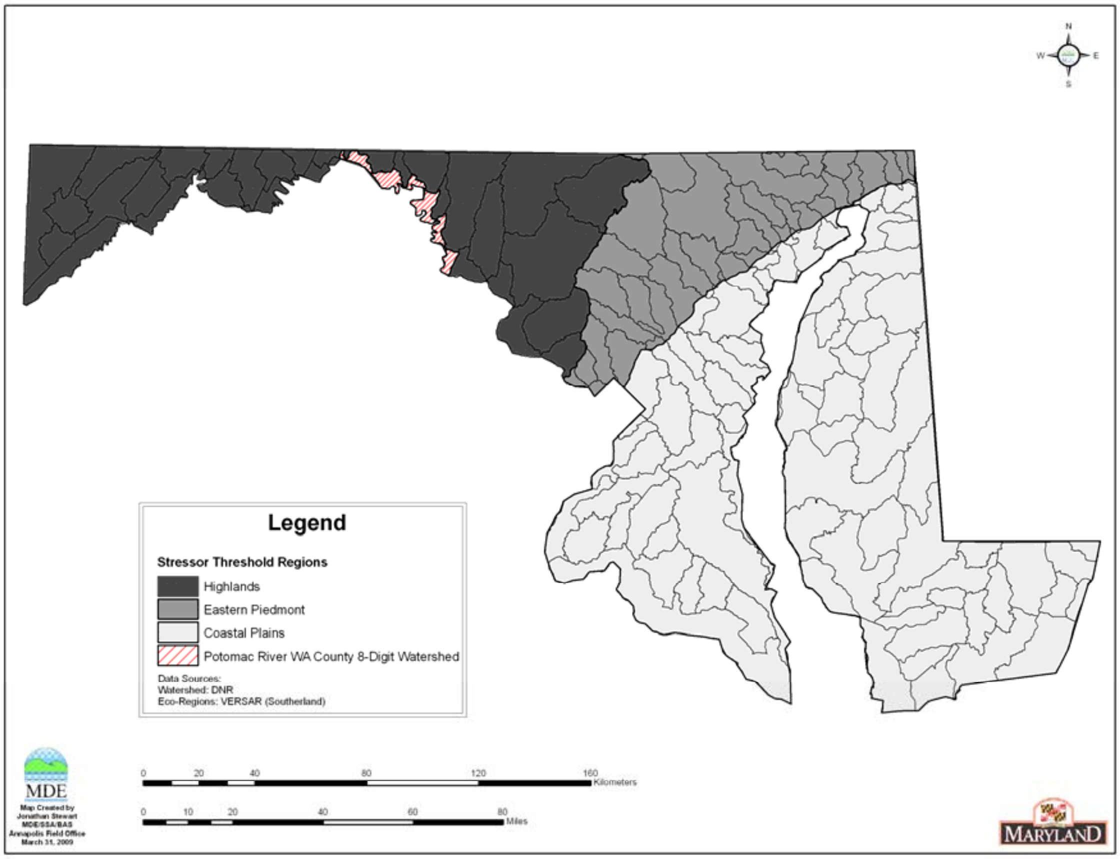

Figure 2. Eco-Region Location Map of the Potomac River Washington County Watershed

2.2 Land Use

The Potomac River Washington County watershed contains primarily forest land use, agricultural land use is secondary, specifically livestock/feeding and cropland operations (see Figure 3). The soils within this province are well suited to intensive agricultural production; they support the dairy industry, grain production, vegetable production, and hay or pasture usage (NRCS 1996). Urban land use is also present in the watershed; the towns of Hancock and Williamsport lie within the watershed, and Hagerstown and Sharpsburg are nearby. Interstates, such as I-70 and I-81, and State and county paved roads interconnect points within the region. State and federal forest preserves are abundant throughout the province, including the Chesapeake and Ohio Canal National Historical Park, Antietam National Battlefield, Harper's Ferry National Historic Park, and Fort Frederick State Park. The land use distribution in the watershed is approximately 46% forest/herbaceous, 34% agriculture/pasture, 13% urban, and 7% water (see Figure 4) (MDP 2002).

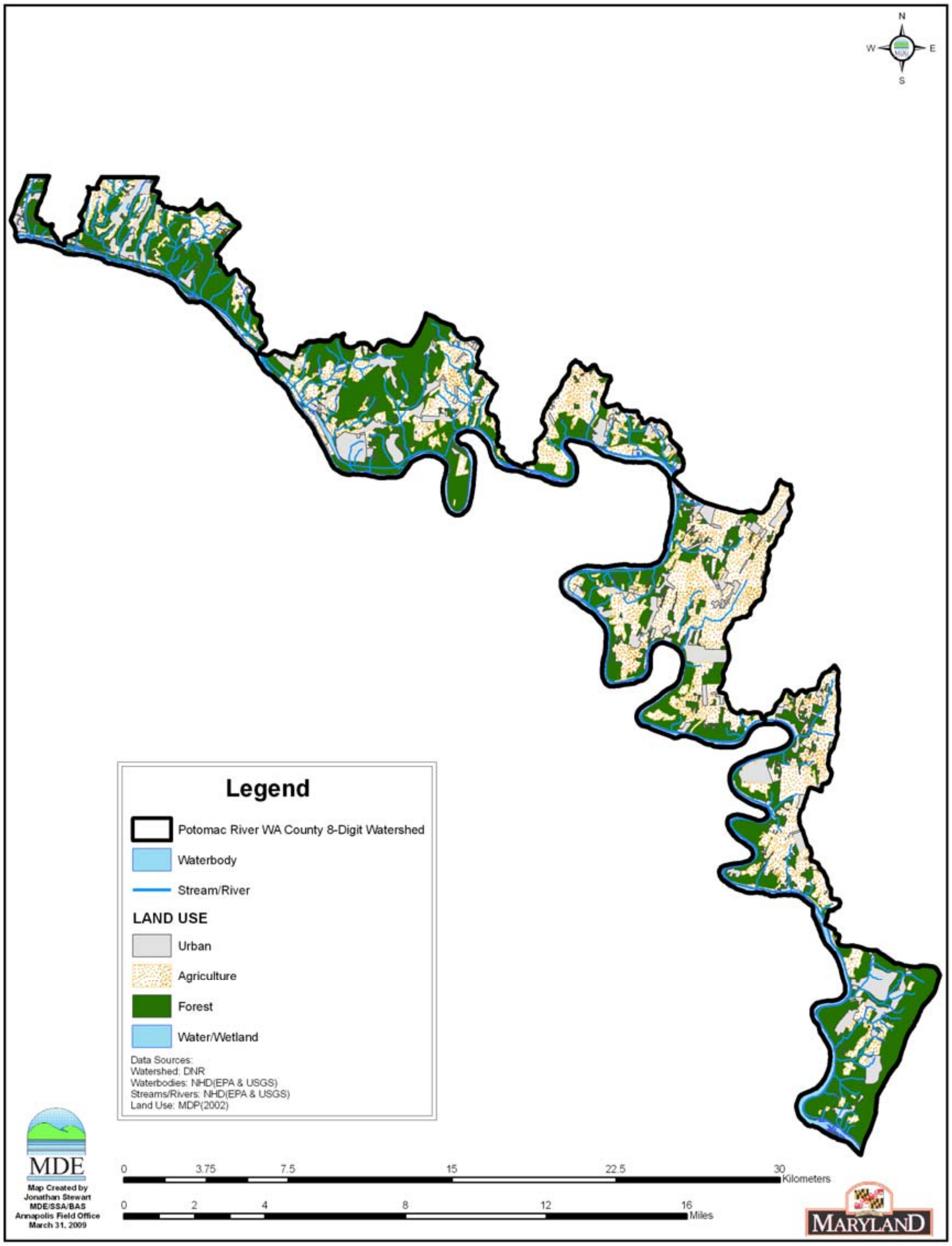

Figure 3. Land Use Map of the Potomac River Washington County Watershed

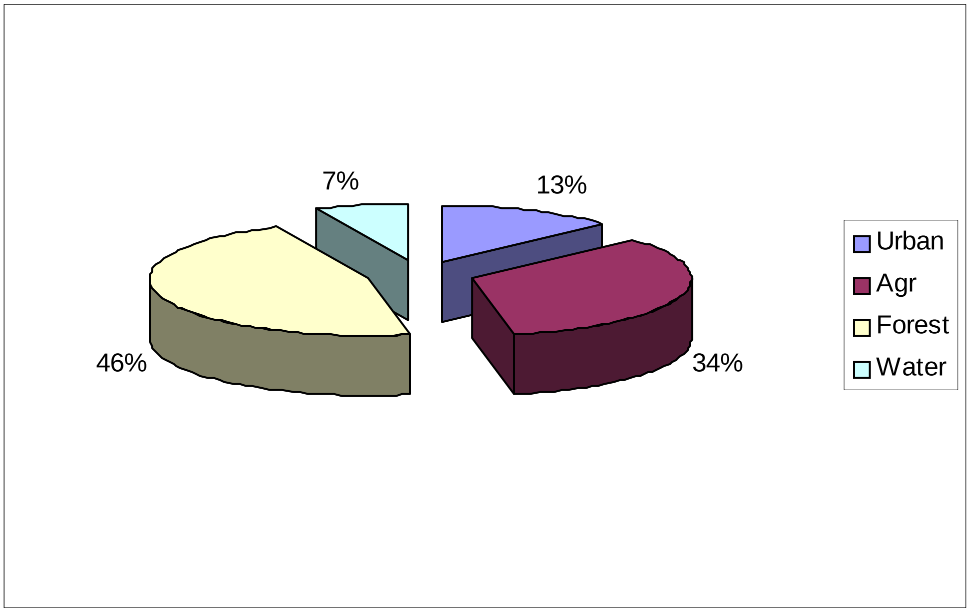

Figure 4. Proportions of Land Use in the Potomac River Washington County Watershed

2.3 Soils/hydrology

The Potomac River Washington County watershed is in the Eastern Valley and Ridge Physiographic Province, numerous ridges and valleys run generally northeast to southwest lie within this province (Schmidt 1993). There are many different soils in the watershed including Berks, Hagerstown, and Lindside; they are very deep, and moderately deep to shallow soils. The soils exhibit varying drainage characteristics, from well drained to somewhat poorly drained soils, moderately drained soils, and poorly drained soils (NRCS 1996). Limestones and shales, neither of which is very resistant to erosion, underlie most of the province. This susceptibility to dissolution from ground water creates numerous formations of underground caverns and surface sinkholes, sinkholes pose a great threat to water quality and underground streams are common (NRCS 1996).

In this physiographic region, the tributary rivers of the Potomac River only flow in the linear valleys, not across the mountains, and only join the Potomac River in pairs, one from the north and one from the south, as the river cuts west to east through each valley. The main sources of recharge are about 39 inches of annual precipitation and spring discharge, especially in the limestone regions. Surface reservoirs, wells, springs, and the Potomac River supply potable water for various cities and towns and individual landowners (NRCS 1996).

3.0 Potomac River Washington County Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Potomac River Washington County watershed (basin code 02140501) was identified on the Integrated Report under Category 5 as impaired by nutrients and sediments (1996 listings), evidence of biological impacts (2002 listings), methylmercury (impoundment PR Dam #4 2002 listing), and polychlorinated biphenyls (PCBs) in fish tissue (2008 listing) (MDE 2008). The methylmercury listing is for the impoundment created by Potomac River Dam #4 and all other impairments are listed for non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Potomac River Washington County watershed and all tributaries including the Chesapeake and Ohio Canal, Ditch Run, Greenspring Run and Downey Branch have been designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply*. Camp Spring Run has been designated as Use III-P – *nontidal cold water and public water supply* (COMAR 2009 a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Potomac River Washington County watershed is listed under Category 5 of the 2008 Integrated Report as impaired for impacts to biological communities. Approximately 73% of stream miles in the Potomac River Washington County 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 twenty-nine stations. Twenty-one of the twenty-nine have degraded 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 twenty-four sites; with nineteen having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Potomac River Washington County watershed.

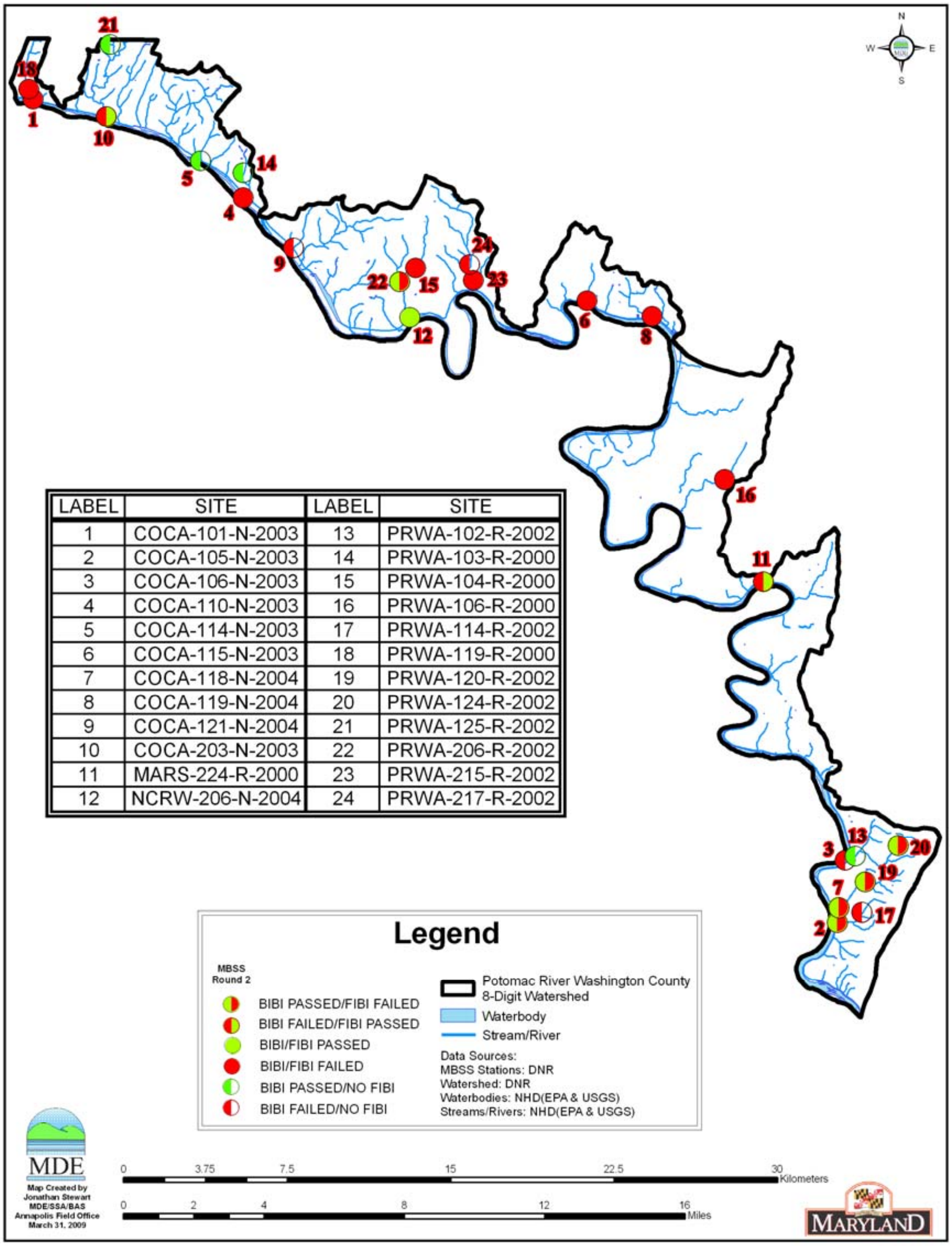

Figure 5. Principal Dataset Sites for the Potomac River Washington County Watershed

4.0 Stressor Identification Results

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

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are 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 result of the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

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

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

Through the BSID data analysis, MDE identified sediment, instream habitat, and water chemistry parameters, and potential sources significantly associated with degraded fish and/or benthic biological conditions. As shown in Table 1 through Table 3, parameters from the sediment, instream habitat, and water chemistry groups are identified as possible biological stressors in the Potomac River Washington County watershed. Parameters identified as representing possible sources are listed in Table 4 and include various agricultural and urban land use types. A summary of combined AR values for each stressor group is shown in Table 5. A summary of combined AR values for each source group is shown in Table 6.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Potomac River Washington County Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	20	16	78	19%	9%	No	----
	moderate bar formation present	20	16	78	38%	43%	No	----
	bar formation present	20	16	78	88%	88%	No	----
	channel alteration moderate to poor	20	16	78	44%	41%	No	----
	channel alteration poor	20	16	78	19%	9%	No	----
	high embeddedness	20	16	78	31%	4%	Yes	27%
	epifaunal substrate marginal to poor	20	16	78	50%	21%	Yes	29%
	epifaunal substrate poor	20	16	78	19%	4%	Yes	15%
	moderate to severe erosion present	20	16	78	63%	25%	Yes	38%
	severe erosion present	20	16	78	13%	1%	Yes	11%
	poor bank stability index	20	16	78	19%	4%	Yes	15%
	silt clay present	20	16	78	100%	99%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Potomac River Washington County Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	24	19	82	32%	9%	Yes	22%
	instream habitat structure marginal to poor	20	16	78	50%	26%	Yes	25%
	instream habitat structure poor	20	16	78	19%	3%	Yes	16%
	pool/glide/eddy quality marginal to poor	20	16	78	63%	55%	No	----
	pool/glide/eddy quality poor	20	16	78	13%	8%	No	----
	riffle/run quality marginal to poor	20	16	78	56%	39%	No	----
	riffle/run quality poor	20	16	78	13%	8%	No	----
	velocity/depth diversity marginal to poor	20	16	78	69%	59%	No	----
	velocity/depth diversity poor	20	16	78	25%	10%	Yes	15%
	concrete/gabion present	24	19	82	16%	3%	Yes	13%
	beaver pond present	20	16	78	0%	2%	No	----
Riparian Habitat	no riparian buffer	24	19	82	37%	24%	No	----
	low shading	20	16	78	13%	7%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Potomac River Washington County Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	24	19	159	26%	8%	Yes	19%
	ammonia acute with salmonid present	24	19	159	5%	2%	No	----
	ammonia acute with salmonid absent	24	19	159	5%	1%	No	----
	ammonia chronic with salmonid present	24	19	159	5%	4%	No	----
	ammonia chronic with salmonid absent	24	19	159	5%	2%	No	----
	low lab pH	24	19	159	0%	5%	No	----
	high lab pH	24	19	159	0%	1%	No	----
	low field pH	20	16	154	0%	14%	No	----
	high field pH	20	16	154	0%	0%	No	----
	high total phosphorus	24	19	159	11%	3%	No	----
	high orthophosphate	24	19	159	0%	4%	No	----
	dissolved oxygen < 5mg/l	20	16	154	6%	3%	No	----
	dissolved oxygen < 6mg/l	20	16	154	6%	7%	No	----
	low dissolved oxygen saturation	19	15	138	0%	4%	No	----
	high dissolved oxygen saturation	19	15	138	0%	1%	No	----
	acid neutralizing capacity below chronic level	24	19	159	0%	6%	No	----
	acid neutralizing capacity below episodic level	24	19	159	5%	43%	No	----
	high chlorides	24	19	159	26%	7%	Yes	19%
	high conductivity	24	19	159	21%	4%	Yes	17%
	high sulfates	24	19	159	16%	4%	Yes	12%

Table 4. Stressor Source Identification Analysis Results for the Potomac River Washington County Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources – Urban	high impervious surface in watershed	24	19	156	5%	1%	No	----
	high % of high intensity urban in watershed	24	19	159	11%	4%	No	----
	high % of low intensity urban in watershed	24	19	159	21%	8%	Yes	14%
	high % of transportation in watershed	24	19	159	37%	9%	Yes	28%
	high % of high intensity urban in 60m buffer	24	19	159	37%	6%	Yes	31%
	high % of low intensity urban in 60m buffer	24	19	159	21%	7%	Yes	14%
	high % of transportation in 60m buffer	24	19	159	53%	9%	Yes	44%
Sources – Agriculture	high % of agriculture in watershed	24	19	159	11%	6%	No	----
	high % of cropland in watershed	24	19	159	32%	6%	Yes	26%
	high % of pasture/hay in watershed	24	19	159	0%	8%	No	----
	high % of agriculture in 60m buffer	24	19	159	16%	6%	No	----
	high % of cropland in 60m buffer	24	19	159	26%	4%	Yes	22%
	high % of pasture/hay in 60m buffer	24	19	159	0%	8%	No	----
Sources – Barren	high % of barren land in watershed	24	19	159	5%	7%	No	----
	high % of barren land in 60m buffer	24	19	159	0%	6%	No	----
Sources - Anthropogenic	low % of forest in watershed	24	19	159	5%	5%	No	----
	low % of forest in 60m buffer	24	19	159	16%	6%	No	----
Sources – Acidity	atmospheric deposition present	24	19	159	0%	39%	No	----
	AMD acid source present	24	19	159	0%	4%	No	----
	organic acid source present	24	19	159	5%	3%	No	----
	agricultural acid source present	24	19	159	0%	1%	No	----

Table 5. Summary of Combined Attributable Risk Values of the Stressor Group in the Potomac River Washington County Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	73%	84%
In-Stream Habitat	56%	
Riparian Habitat	----	
Water Chemistry	43%	

Table 6. Summary of Combined Attributable Risk Values of the Source Group in the Potomac River Washington County Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	52%	68%
Agriculture	27%	
Barren Land	----	
Anthropogenic	----	
Acidity	----	

Sediment Conditions

BSID analysis results for the Potomac River Washington County watershed identified six sediment parameters that have a 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 embeddedness, epifaunal substrate (marginal to poor and poor), erosion present (moderate to severe and severe), and bank stability index (poor).*

High embeddedness was identified as significantly associated with degraded biological conditions and found in 27% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor measures the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Epifaunal substrate was identified as significantly associated with degraded biological conditions and found in 29% (*marginal to poor* rating) and 15% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates.

Erosion severity was identified as significantly associated with degraded biological conditions and found in 38% (*moderate to severe* rating) and 11% (*severe* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed County watershed. This stressor is a visual observation indicating that the stream discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy, resulting in channel instability, which in turn affects bank stability. Where such conditions are observed, flow energy is considered to have increased in frequency or intensity, accelerating channel and bank erosion. Increased flow energy suggested by this measure is also expected to negatively influence stream biology. A level of *moderate* indicates that a marginal amount of stream banks show erosion and the stream segment shows elevated levels of instability due to erosion. A level of *severe* indicates that a substantial amount of stream banks show severe erosion and the stream segment display high levels of instability due to erosion.

Bank stability index was identified as significantly associated with degraded biological conditions and found in 15% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor measures the degree of channel erosion in a stream, it is a composite score based on the presence or absence of stabilizing bank materials with quantitative measures of erosion extent and erosion severity. Lower scores on this index are considered to demonstrate that discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy. The index may further identify conditions in which stream banks are vulnerable regardless of flood severity or frequency, thus demonstrating increased probability of high sediment loadings.

The sediment stressors identified by the BSID analysis are characteristic of regions that have been developed for agricultural and urban land use. As agricultural and urban development increased in the Potomac River Washington County watershed so did morphological changes that affected the watershed's stream habitat. The most critical of these environmental changes are those that altered the watershed's hydrologic regime; increased sedimentation is a consequence of altered stream hydrology.

The watershed contains urban development (13%); low- to high-intensity urbanized areas include Hancock and Williamsport. Hagerstown and Sharpsburg, while not in the Potomac River Washington County watershed, are in close proximity and may affect the receiving drainage of streams south of the Antietam River watershed. Many portions of these areas were built before modern stormwater runoff controls were required by the State. The realization that human activities can seriously harm and degrade our waterways led to the authorization of sediment control regulations in the early 1960s, but a statewide sediment and erosion control program did not exist until 1970. About ten years later, in 1982, the Maryland General Assembly passed the State Stormwater Management Act, designed to address stormwater runoff generated during the land development process. In 1987 Congress wrote Section 402(p) of the Clean Water Act, bringing stormwater control into the National Pollutant Discharge (NPDES) program, and in 1990 the U.S. Environmental Protection Agency (USEPA) issued the Phase I Stormwater Rules. These rules require NPDES permits for operators of municipal separate storm sewer systems (MS4s) serving populations over 100,000 and for runoff associated with industry, including construction sites five acres and larger. In 1999 USEPA issued the Phase II Stormwater Rules to expand the requirements to small MS4s and construction sites between one and five acres in size (NRC 2008).

Stormwater management helps to settle and filter many pollutants before runoff is discharged into a receiving body of water, but the system is consistently challenged due to pollution increase and old infrastructure, and research indicates that most conventional stormwater management controls can still harm streams and rivers. There are also problems with the stormwater program as it is currently implemented; one key issue is the limited information on the effectiveness of stormwater control measures (NRC 2008). In a study by the MDDNR (2002a), street-level storm drains that flush debris into the river during heavy rains was found to be one of the biggest sources of pollution and "floatable" trash in the Potomac River Montgomery County watershed. When stormwater flows through stream channels faster, more often, and with more force, the results are stream channel alteration, bank erosion, and streambed scouring. The scouring associated with these increased flows leads to accelerated channel and bank erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Increased inputs of sediments impact riparian and stream channel habitat, and alter flows (Cooper 1993). Altered flow regimes are a result of developed landscapes; greater flooding creates a less stable stream channel, leading to excessive bank erosion, loss of pool habitat and instream cover, and excessive streambed scour and sediment deposition (Wang et al. 2001).

The effects of transportation in both the watershed and the riparian areas are also related to degraded stream miles (and altered stream hydrology) in the Potomac River Washington County watershed. Interstates, such as I-70 and I-81, and State and county paved roads interconnect points within the region. Roads tend to capture and export more stormwater pollutants than other land covers; as rainfall amounts become larger, previously pervious areas in most residential landscapes become more significant sources of runoff, including sediment (NRC 2008).

The watershed contains a relatively narrow area land bordering the Maryland shore of the Potomac River, the Chesapeake and Ohio Canal (C & O Canal) is located in this area. Lands immediately adjacent to the Potomac River mainstem occupy a well-defined floodplain. There are numerous MDDNR MBSS stations on tributaries draining into the mainstem, which have small drainage areas and are heavily influenced by seasonal water table fluctuations due to their location on the Potomac River floodplain. The lower reaches of these tributaries are subject to Potomac River floodwaters that back water up into the tributaries and cause bank erosion and sediment deposition. These tributary's "confluence areas" tend to be both highly susceptible to erosion during flood events and become depositional areas as the floodwaters subside. These areas tend to have cut stream banks and silted bottoms, therefore, making the habitat unstable as compared to either the Potomac River mainstem or the "out-of-influence" upstream tributaries. The unstable habitat in these "confluence areas" is caused by natural events, although often exacerbated by anthropogenic land-use issues, but it is atypical and shouldn't be compared to reference conditions. Field observations in the MDDNR MBSS dataset include several comments including "site begins at confluence", "site begins at upstream end of culvert under C & O Canal", "C & O Canal above. Site 10 meters from Potomac River confluence", "first 12 meters were under C & O Canal in culvert (arch)", "Potomac River confluence is approximately 100 meters downstream", and "bottom 5 meters of site is influenced by Potomac River". Documentation and field observations (ICPRB 2009; USGS 1997) indicate flooding exacerbated by the aqueducts and culverts associated with the canal, i.e., the constriction of the Potomac River mainstem's floodplain.

The Potomac River Washington County watershed also contains 34% of agricultural land use (i.e., dairy, livestock/feeding, cropland, and pasture/hay operations) within the watershed. Agricultural (i.e., row crop) land use was identified by BSID analysis as impacting a proportion of the degraded stream miles in the watershed and riparian buffer. Agricultural land use is an important source of pollution when rainfall carries sediment, fertilizers, and manure into streams. Agricultural land use results in increased sediment deposition within a watershed; sediment "pollution" is the number one impairment of streams nationwide (Southerland et al. 2005b). In a study of the effects of the livestock industry, George et al. 2004 reports that livestock trampling in the riparian zone is a key mode of sediment transport into stream channels. The MDDNR MBSS documented (i.e., photographs, comments) several examples of livestock access to streams as part of the site habitat assessment in the Potomac River Washington County watershed, "cow damaged banks", "bank erosion/cow pasture", and "stream flows through cow pasture, banks are in poor condition"; livestock trampling of stream banks increases erosion and sedimentation. Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indexes and bank stability, as well as greater deposition of sediments on and within the streambed (Roth et al. 1996; Wang et al. 1997).

Urban and agricultural land use were identified as significantly associated with degraded stream miles in the Potomac River Washington County watershed; both of these source groups result in significant sedimentation. Some of the impacts associated with sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman et al. 2003). The altered flow regime and increased sediment deposition in the Potomac River Washington County watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 73% suggesting that this stressor group impacts a considerable proportion of the degraded stream miles in the Potomac River Washington County watershed (Table 5).

Instream Habitat Conditions

BSID analysis results for the Potomac River Washington County watershed identified five habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *channelization present, concrete/gabion present, instream habitat structure (marginal to poor, and poor), and velocity/depth diversity (poor).*

Channelization present was identified as significantly associated with degraded biological conditions and found in 22% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor measures the presence/absence of channelization in stream banks and its presence is a metric for the channel alteration rating. It describes both the straightening of channels and their fortification with concrete or other hard materials. Channelization inhibits the natural flow regime of a stream resulting in increased flows during storm events that can lead to scouring and, consequently, displacement of biological communities. The resulting bank/channel erosion creates unstable channels and excess sediment deposits downstream.

Concrete/gabion present was identified as significantly associated with degraded biological conditions and found in 13% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. The presence or absence of concrete is determined by a visual observation within the stream segment, resulting from the field description of the types of channelization. Like 'channelization present', concrete inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

In-stream habitat structure was identified as significantly associated with degraded biological conditions and found in 25% (*marginal to poor* rating) and 16% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. Instream habitat structure 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. Low in-stream habitat values can be caused by high flows that collapse undercut banks and sediment inputs that fill pools and other fish habitats. A poor rating of this measure indicates excessive erosion and/or sedimentation.

Velocity/depth diversity was identified as significantly associated with degraded biological conditions and found in 15% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. Velocity/depth diversity is a visual observation including quantitative measurements based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). The increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The 'poor' diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., embeddedness, entrenchment, etc.).

All of the stressors identified (*channelization present, concrete/gabion present, instream habitat structure (marginal to poor, and poor), and velocity/depth diversity (poor)*) by the BSID analysis are intricately linked with habitat heterogeneity. 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 scouring associated with increased flows, due to channelization, leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and decreasing habitat heterogeneity. Channelization has been used extensively in developed landscapes for flood control. Thirteen percent of the degraded stream miles in the Potomac River Washington County watershed have concrete or gabion reinforced channels. The purpose is to increase channel capacity and flow velocities so water moves more efficiently downstream. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats (Bolton and Shellberg, 2001). The refuge cavities removed by channelization not only provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates.

The combination of the altered flow regime, increased sediment, and artificial channelization in the Potomac River Washington County watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 56% suggesting that this stressor group impacts a considerable proportion of the degraded stream miles in the Potomac River Washington County (Table 5).

Riparian Habitat Conditions

BSID analysis results for the Potomac River Washington County watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition.

Water Chemistry

BSID analysis results for the Potomac River Washington County watershed identified four 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 chlorides, high conductivity, and high sulfates.*

High total nitrogen (TN) concentrations were identified as significantly associated with degraded biological conditions and found in 19% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor 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 exceedences of dissolved oxygen and pH levels. Runoff and leaching from agricultural land can generate high in-stream levels of nitrogen.

One of the three major nutrients in fertilizers and manure is nitrogen. Livestock waste is one of the primary agricultural sources of TN; it is a greater contributor than commercial fertilizer (USEPA 2000). The MDDNR MBSS documented (i.e., photographs) two examples of livestock access as part of the site habitat assessment in the Potomac River

Washington County watershed. The MDDNR MBSS included comments such as "stream flows through forested area that is pasture; cows have access to streams, many fresh cow patties".

Urban land use is also a potential source for nitrogen loading. Non-point source discharges (e.g., surface runoff) are a potential source of pollutants to surface waters; they do not have one discharge point but occur over the entire length of a stream or waterbody. This transport is dictated by rainfall, soil type, land use, and topography of the watershed. Surface runoff include sources from roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, and storm drains; they are designed to collect or convey stormwater and deliver it to a waterbody. Non-point source contributions also arise from failing septic systems and their associated drain fields or from leaking infrastructure (i.e., sewer systems) (MDE 2008b). A number of areas in Washington County are served by septic systems, some of which could develop critical health issues and require sewer service (WCDWQ 2006). Fertilizer use and the extent of lawn in residential areas are also a source of non-point source pollution. The atmosphere can contribute various forms of nitrogen arising from the burning of fossil fuels and from automobile exhaust (MDDNR 2002b).

Identification of high TN by the BSID analysis is possibly indicative of degradation to water quality but in conditions of excessive nutrient loading (i.e., eutrophication) there is usually also pH, high ammonia, high phosphates, and/or low oxygen values. BSID results only identify TN as statistically significant in the watershed; this result does not support a case of excessive nutrient loading in the Potomac River Washington County watershed.

High conductivity concentrations were identified as significantly associated with degraded biological conditions and found in 17% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. This stressor is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban and agricultural runoffs as well as leaking wastewater infrastructure are typical sources of inorganic compounds.

High sulfates concentration was identified as significantly associated with degraded biological conditions and found in 12% of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. 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.

High chlorides concentration was identified as significantly associated with degraded biological conditions and found in approximately 19% (*high* rating) of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. High concentrations of chlorides can result from industrial discharges, metals contamination, and application of road salts in urban landscapes.

There are three National Pollutant Discharge Elimination System (NPDES) permitted municipal discharge facilities in the Potomac River Washington County watershed. There are two industrial facilities, which are regulated for various parameters including flow, total suspended solids, grease and oil, various chloride parameters, and pH. NPDES permitting enforcement does not require sulfate testing at any of these facilities, therefore data was not available to verify/identify sulfate as a specific pollutant in this watershed. Neither of the two industrial facilities has exceeded limits for permitted dischargers, and there is not a metals impairment listed for the watershed, therefore application of road salts in the watershed is a likely source of the chlorides, sulfates, and high conductivity levels. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith et al., 1987). The potential effects of road salt accumulation in a watershed include increased mobility of metals and reduced acid neutralizing capacity from ion exchange (Flora et al. 2009). Road salts remain in solution and are not subject to any significant natural removal mechanisms; their accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). As a result of Environment Canada’s five year study (EC 2001), it was reported that road salts may affect wildlife habitat, with reduction in plant cover or shifts in communities that could affect wildlife dependent on these plants for food or shelter.

In the Potomac River Washington County watershed there are several heavily traveled road routes, such as Interstates 70 and 81, connecting the urban areas of the watershed. According to a study of Liberty Reservoir watershed (MDDNR 2002b), analysis suggests a relationship between increasing chloride concentration and increasing miles of roadway and area of commercial land use where salt is used to limit seasonal icy conditions. Water bodies most subject to the impacts of road salts are small ponds and watercourses draining large urbanized areas, as well as streams, wetlands or lakes draining major roadways (EC 2001). For surface waters associated with roadways or storage facilities, episodes of salinity have been reported during the winter and spring in some urban watercourses in the range associated with acute toxicity in laboratory experiments (EC 2001). Lawn fertilizers (e.g., potassium nitrate) are also a source of salts in urban environments. Fertilizer salts are soluble; they readily dissolve in water and leach with rainfall, in excess quantities salts can increase instream conductivity. Extended dry periods and low flow conditions also contribute to higher conductivity results.

Currently in Maryland there are no specific numeric criteria that quantify the impact of chlorides, sulfates, and conductivity on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of the specific pollutant(s) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

Agricultural and urban land use were identified as significantly associated with degraded stream miles in the Potomac River Washington County watershed, both of these source groups result in increased loads of chemical pollutants. Chemical pollution in the Potomac River Washington County watershed has resulted in the exceedence of species tolerances and subsequent trophic alteration (e.g., shift to more salinity-tolerant species). Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 43% suggesting this stressor impacts a moderate proportion of the degraded stream miles in the Potomac River Washington County watershed (Table 5).

Sources

All seven stressor parameters, identified in Tables 1-4, are significantly associated with biological degradation in the Potomac River Washington County Watershed County watershed and are representative of impacts from urban and agriculturally developed landscapes.

Although agricultural land use (34%) comprises a higher percentage than urban land use (13%) of the Potomac River Washington County Watershed, the BSID identified urban development as more significantly associated (52%) with poor to very poor biological conditions in the watershed. As urban development increases in a watershed, so do morphological changes that affect a stream's habitat. Urban land use was identified as significant not only in the watershed but also in the riparian buffer zone. The watershed contains two urban centers, the cities of Hancock and Williamsport. Hagerstown and Sharpsburg, while not in the Potomac River Washington County watershed, are in close proximity in the Antietam Creek Watershed and may affect receiving waters of downstream watersheds. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed "urban stream syndrome" (Meyer et al. 2005). In watersheds already experiencing anthropogenic stress, hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events (Southerland et al. 2005b).

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. Urbanization alters the hydrological regime of streams by increasing the magnitude and frequency of high flows and reducing water infiltration into soil, leading to bank erosion and channel widening, and reduced baseflows (Poff et al. 1997). Increases in impervious surface cover that accompany urbanization alter stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, decreasing the time it takes water to reach streams and causing them to be more "flashy" (Walsh et al. 2005). According to Wang et al. 2001, even under the best-case urban development scenarios, stream fish communities will decline substantially in quality even while a watershed remains largely rural in character.

The effects of transportation in both the watershed and the riparian areas are also related to degraded stream miles in the Potomac River Washington County watershed. Interstates, such as I-70 and I-81, and State and county paved roads interconnect points within the region. According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 m (average of 300 m) on each side of four-lane roads. Roads have negative effects on the biotic integrity of both terrestrial and aquatic organisms; modifications of habitat alter reproductive success (Trombulak and Frissell 2000).

As noted, agricultural land use was also identified as a potential source of stressors in the Potomac River Washington County watershed. There is a moderate percentage (26%) of cropland in the watershed and the watershed's riparian buffer zone (22%), but the impacts can be considerable. Developed landscapes, particularly the proportion of agriculture in the catchments and the riparian zone, often results in increased inputs of nitrogen and suspended sediments to surface waters. One of the three major nutrients in fertilizers and manure is nitrogen. Livestock waste is one of the primary agricultural sources of TN; it is a greater contributor than commercial fertilizer (USEPA 2000). Livestock trampling affects riparian zones and cattle are a key mode of sediment transport into stream channels (George et al. 2004). Eroded soils contain nutrients and other pollutants that are beneficial on agricultural fields, but can impair water quality when transported. Physical habitats, when exposed to detrimental and chronic water chemistry effects, cease functioning efficiently and degrade.

The BSID source analysis (Table 4) identifies various types of urban and agricultural land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 68% suggesting that these stressors impact a considerable proportion of the degraded stream miles in Potomac River Washington County Watershed (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Potomac River Washington County watershed are a result of increased agricultural and urban land uses causing alteration to hydrology and increased sediment deposition, resulting in an unstable stream ecosystem that eliminates habitat heterogeneity. High proportions of these land uses also typically results in increased contaminant loads from point and nonpoint sources by adding sediments and chemical pollutants to surface waters, resulting in concentrations that are potentially toxic to aquatic organisms. Alterations to hydrologic regime and water chemistry have resulted in the degradation of the Potomac River Washington County Watershed, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 84%, suggesting that altered hydrology/sediment, instream habitat and water chemistry stressors adequately account for the biological impairment in the Potomac River Washington County watershed.

Both agricultural and urban land uses are anthropogenic source groups that contribute to detrimental changes in the Potomac River Washington County Watershed. Flow regime is of central importance in sustaining the ecological integrity of flowing water systems (Karr 1991; Poff et al. 1997; Vannote 1980). Land development alters hydrology resulting in increases of contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, petroleum products, and inorganic pollutants to surface water and ground waters. An unstable stream ecosystem is created, often resulting in a loss of available habitat from sedimentation, continuous displacement of biological communities that require frequent re-colonization and the loss of sensitive taxa. Increased levels of many pollutants like chlorides, sulfates, and conductivity can be toxic to aquatic organisms and lead to exceedences in species tolerances. All of these impacts have resulted in the shift of fish and benthic macroinvertebrate community structure in the Potomac River Washington County Watershed.

The results of this analysis are not intended or implied to be absolute and unchanging. However, the results do configure the most probable pathway for biological impairment using the highest quality data currently available. BSID analysis evaluates numerous key stressors that could act independently or act as part of complex causal scenarios (e.g., eutrophication, urbanization, habitat modification). In this process, absence of a key stressor(s) can be as important as the presence of stressors to ultimately determine impairment causation. Uncertainty resulting from basic limitations of the principal dataset (e.g., temporal and spatial variability, sample size) is reduced, but not eliminated in BSID.

<u>Final Causal Model for the Potomac River Washington County Watershed</u>

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2009). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the Potomac River Washington County watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

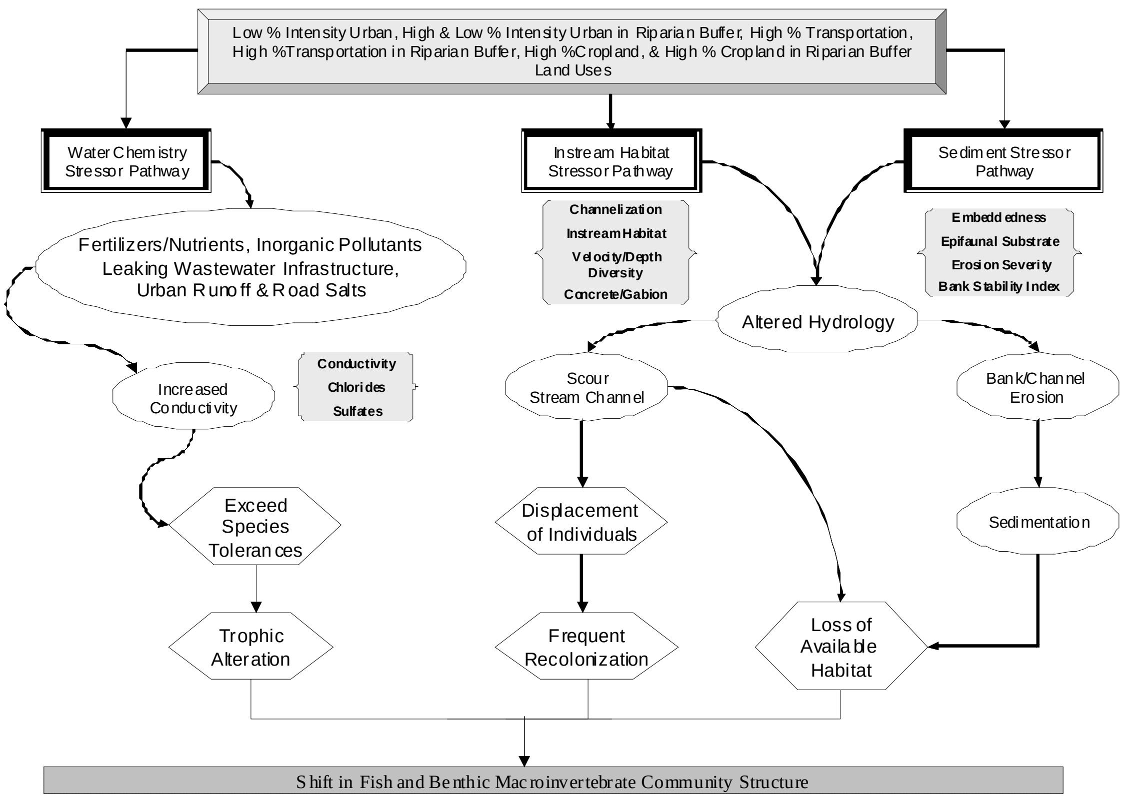

Figure 6. Final Causal Model for the Potomac River Washington County Watershed

5.0 Conclusions

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

- The BSID process has determined that biological communities in Potomac River Washington County watershed are likely degraded due to flow/sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and agricultural landscapes have resulted in channel erosion and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the 1996 Category 5 listing for total suspended solids as an impairing substance in the Potomac River Washington County Watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that the biological communities in the Potomac River Washington County watershed are likely degraded due to inorganic pollutants (i.e., chlorides and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in 19% and 12%, respectively of the stream miles with poor to very poor biological conditions in the Potomac River Washington County watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and 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 chloride and 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 Potomac River Washington County watershed.

- There is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report; BSID analysis identified one water chemistry stressor present (TN) showing a possible association (19% of stream miles) with degraded biological conditions in the Potomac River Washington County watershed. However this is not sufficient evidence of an eutrophication problem, additional monitoring or a more intensive analysis of all available data is recommended to determine if there is a nutrient impairment in the watershed.

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