Watershed Report for Biological Impairment of the Non-Tidal Potomac River Frederick County Watershed, Frederick and Washington Counties Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IDNR	Iowa Department of Natural Resources
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
OP	Orthophosphate
µeq/L	Micro equivalent per liter
µS/cm	Micro Siemens per centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

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 Frederick County, Maryland watershed is associated with one assessment unit, the non-tidal 8-digit basin (basin code 02140301) in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014a).

Table E1. 2014 Integrated Report Listings for the Potomac River Frederick County Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Potomac River Frederick County	02140301	Non-tidal	Aquatic Life and Wildlife	2006	Impacts to Biological Communities	5
				2014	Temperature	
			Fishing		PCB Fish Tissue	
					Mercury in Fish Tissue	

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 in 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 of less than three, and calculating whether this is a significant deviation from reference condition watersheds (i.e., healthy stream, less than 10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Potomac River Frederick County are designated as Use Class I-P *Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*, Use Class III-P *Nontidal Cold Water and Public Water Supply*, and Use Class IV-P *Recreational Trout Waters and Public Water Supply* (COMAR 2016a, b, c, d). 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 Frederick County watershed is not attaining its designated use of protection of aquatic life because of impairments to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has 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 Frederick 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 2014b). Data suggest that the degradation of biological communities in the Potomac River Frederick County watershed is due to urban and agricultural land use and its altered hydrology concomitant effects, and elevated levels of inorganic pollutants. 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 landscapes and degradation, e.g., urban runoff contamination of surface waters, 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 Frederick County watershed, can be summarized as follows:

- The BSID process has determined that the biological communities in Potomac River Frederick County are likely degraded due to sediment and 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 thus support a sediment Category 5 listing of Potomac River Frederick County for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Potomac River Frederick County watershed.

- The BSID process has also determined that biological communities in the Potomac River Frederick County 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 Potomac River Frederick County watershed based on inadequate riparian buffer zones in approximately 25% of degraded stream miles.

- The BSID process has determined that the biological communities in the Potomac River Frederick County watershed are likely degraded due to inorganics (i.e., sulfates and conductivity). Sulfates and conductivity levels are significantly associated with degraded biological conditions and found, respectively, in approximately 47% and 26% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. The BSID results thus support an inorganic sulfate Category 5 listing of Potomac River Frederick County for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Potomac River Frederick 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; 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.

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 2014a). 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, less than 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 the watershed is meeting some of the water quality standards and the level of precision is acceptable; the status of the watershed is listed as Category 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 rounds two and three of the Maryland Biological Stream Survey (MBSS) dataset (2000–2004; 2007-2009) 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 Frederick County watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Potomac River Frederick County Watershed Characterization

2.1 Location

The Potomac River Frederick County watershed is located in Frederick and Washington Counties, MD, and drains to the Middle Potomac River (see Figure 1). The Potomac River Frederick County watershed encompasses approximately 41,500 acres, and includes the towns of Brunswick and Rosemont near Little Catoctin Creek, and Point of Rocks near Washington Run. The Chesapeake and Ohio Canal National Historical Park and Trail, portions of South Mountain and Gathland State Parks west of Israel Creek, and Brownsville Pond Fish Management Area are also located in the watershed. There are four industrial parks located in the watershed: Stanford; Sunnyside; Mullinix Agro, and Eastalco Aluminum Company. The watershed is located in the Highlands region, which is one of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

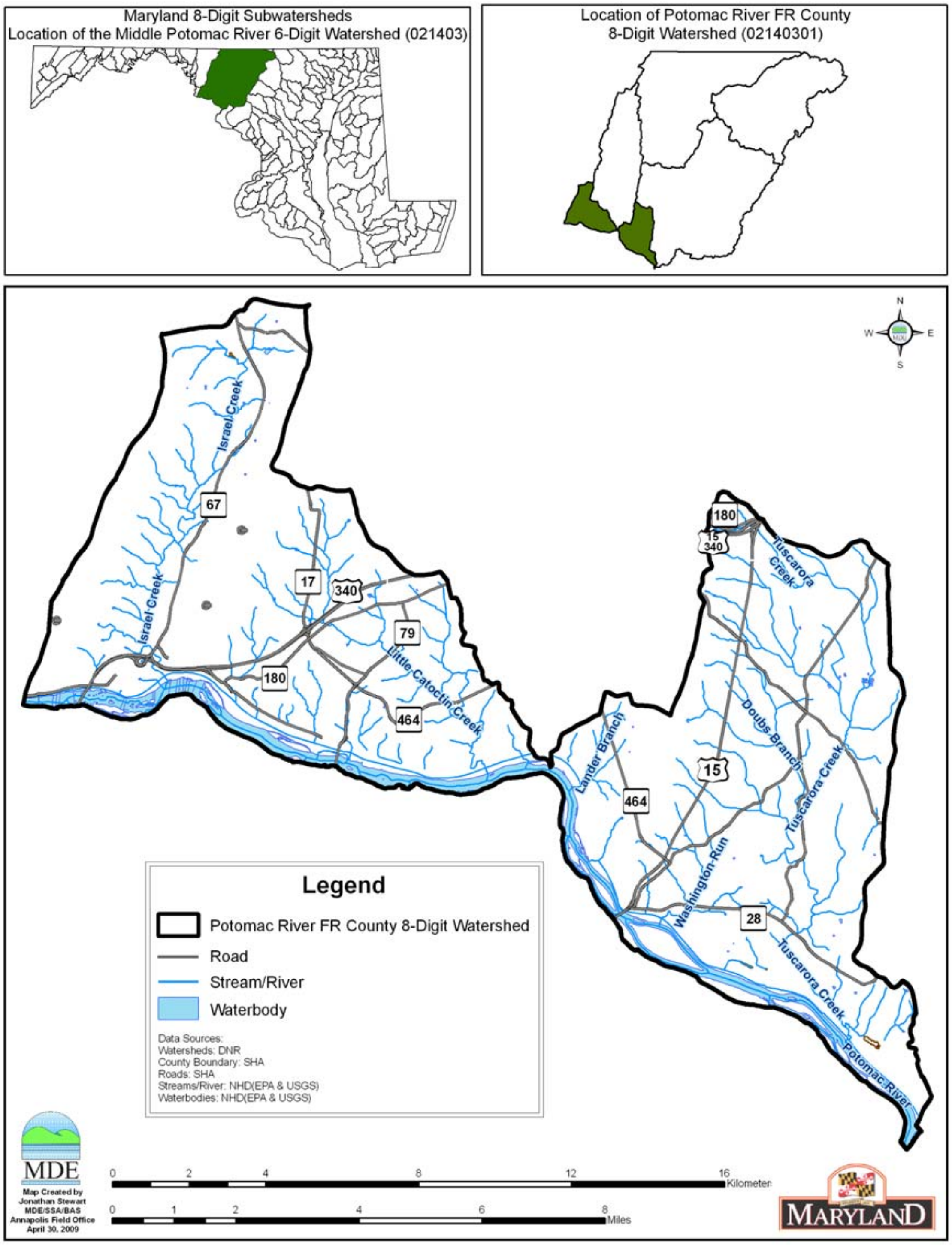

Figure 1. Location Map of the Potomac River Frederick County Watershed

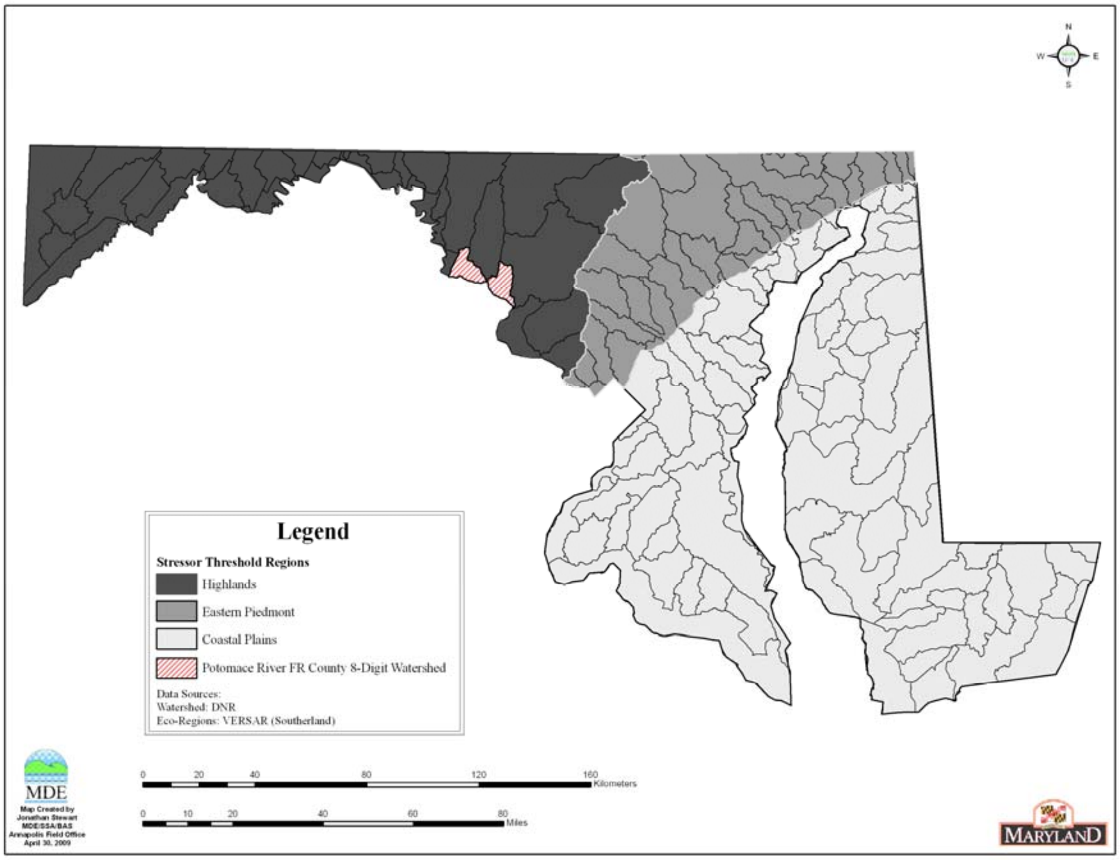

Figure 2. Eco-Region Map of the Potomac River Frederick County Watershed

2.2 Land Use

The drainage area of the Potomac River Frederick County watershed is approximately 41,500 acres. The Potomac River Frederick County watershed contains urban, agricultural, and forested land uses (see Figure 3). The predominant land use in the Maryland 8-digit watershed is forest. The Phase 5.2 Chesapeake Bay Watershed Model reports the land use distribution in the Potomac River Frederick County watershed as forest (41%), agricultural (39%), urban pervious (18%), and urban impervious (2%) (see Figure 4) (USEPA 2010).

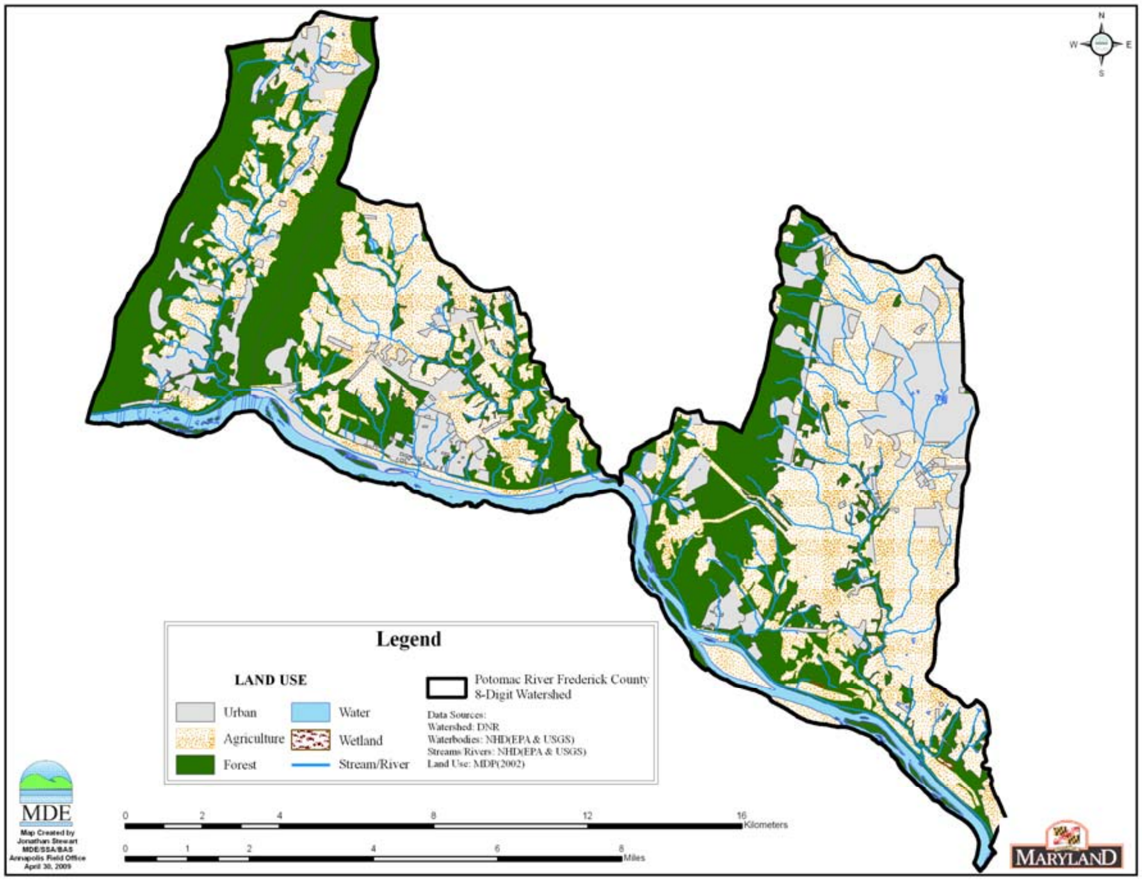

Figure 3. Land Use Map of the Potomac River Frederick County Watershed

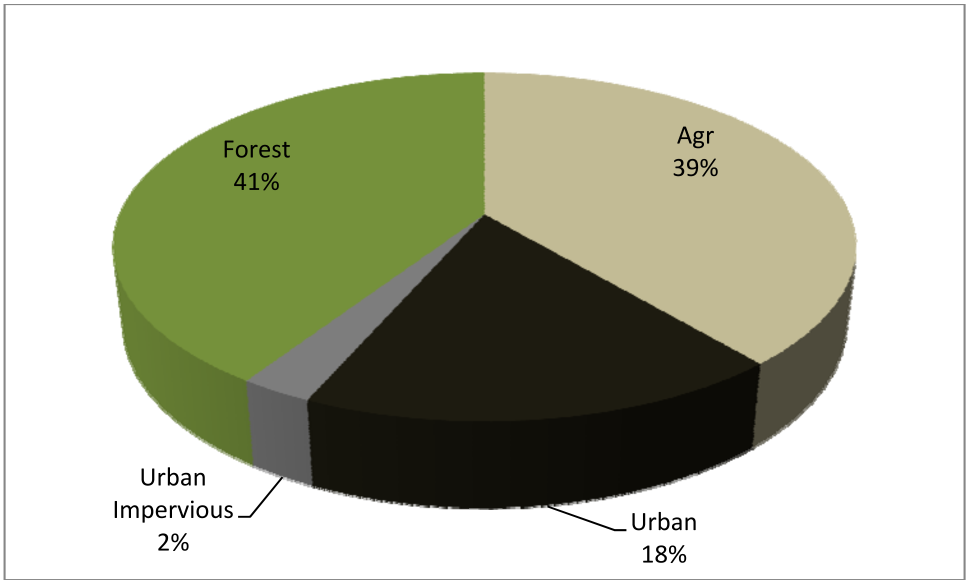

Figure 4. Proportions of Land Use in the Potomac River Frederick County Watershed

2.3 Soils/hydrology

The Potomac River Frederick County lies in the Highlands, specifically the Blue Ridge physiographic province. The Blue Ridge province is mountainous, and is underlain mainly by folded and faulted sedimentary rocks (MGS 2007). There are several soil types within the watershed Codorus, Hazelton, Athol, Catoctin, Penn, Waynesboro, Hayesville, Airmont, Hagerstown and Baile. The province has nearly level and gently sloping, poorly to well drained, and highly erodible soils with a shallow aquifer system (NRCS 2002).

3.0 Potomac River Frederick County Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Potomac River Frederick County watershed under Category 5 of the State's Integrated Report as impaired for impacts to biological communities (2006 listing). The Potomac River Frederick County watershed in Maryland is associated with one assessment unit, the non-tidal 8-digit basin (basin code 02140301) in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014a).

Table 1. 2014 Integrated Report Listings for the Potomac River Frederick County Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Potomac River Frederick County	02140301	Non-tidal	Aquatic Life and Wildlife	2006	Impacts to Biological Communities	5
				2014	Temperature	
			Fishing		PCB Fish Tissue	
					Mercury in Fish Tissue	

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Potomac River Frederick County are designated as Use Class I-P *Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*, Use Class III-P *Nontidal Cold Water and Public Water Supply*, and Use Class IV-P *Recreational Trout Waters and Public Water Supply* (COMAR 2016a, b, c, d). 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 Frederick County watershed is listed under Category 5 of the 2014 Integrated Report as impaired for impacts to biological communities. Approximately 76% of the Potomac River Frederick County watershed is 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), round two (2000-2004), and round three (2007-2009) data, which include twenty-one stations. Seventeen of the twenty-one stations have degraded benthic and/or fish indices of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS rounds two and three (2000-2004, 2007-2009), contains thirteen sites with nine of the thirteen having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Potomac River Frederick County watershed.

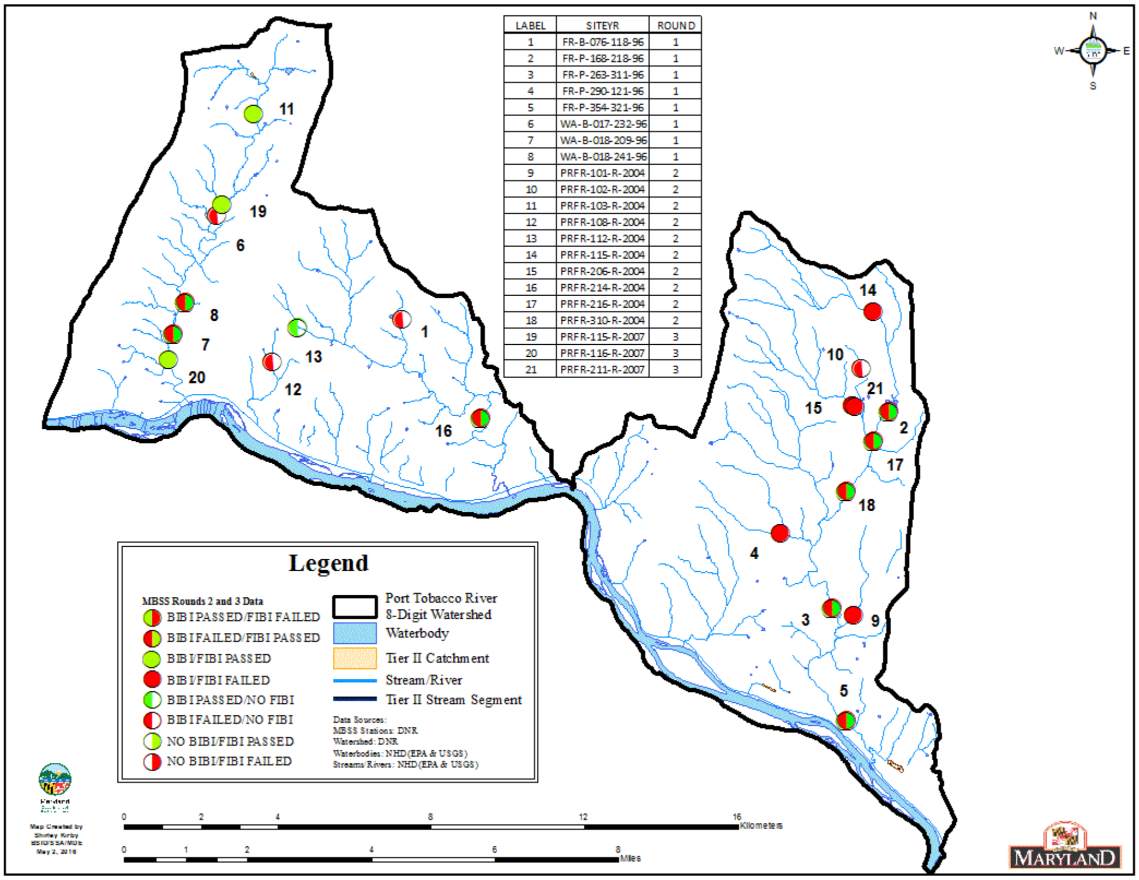

Figure 5. Principal Dataset Sites for the Potomac River Frederick County Watershed

4.0 Stressor Identification Results

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

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4^{th} order), that have 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 (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 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 2014b).

Through the BSID data analysis, MDE identified sediment, instream and riparian habitat, water chemistry, and potential sources significantly associated with degraded fish and/or benthic macroinvertebrate biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various agriculture and urban land use types. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 4, Table 5, and Table 6, parameters from the sediment, instream habitat, riparian habitat, and water chemistry groups are identified as possible biological stressors in the Potomac River Frederick County watershed. A summary of combined AR values for each stressor group is shown in Table 7.

Table 2. Stressor Source Identification Analysis Results for the Potomac River Frederick 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sources - Acidity	Agricultural acid source present	13	9	168	0%	1%	1	No	_
	AMD acid source present	13	9	168	0%	5%	1	No	_
	Organic acid source present	13	9	168	0%	0%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	13	9	171	89%	11%	0	Yes	78%
	High % of agriculture in 60m buffer	13	9	171	78%	6%	0	Yes	72%
Sources - Anthropogenic	Low % of forest in watershed	13	9	171	67%	5%	0	Yes	61%
	Low % of wetland in watershed	13	9	171	0%	0%	1	No	_
	Low % of forest in 60m buffer	13	9	171	33%	2%	0.003	Yes	31%
	Low % of wetland in 60m buffer	13	9	171	0%	0%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	13	9	171	67%	5%	0	Yes	62%
	High % of impervious surface in 60m buffer	13	9	171	89%	12%	0	Yes	77%
	High % of roads in watershed	13	9	171	22%	8%	0.185	No	_
	High % of roads in 60m buffer	13	9	171	11%	8%	0.552	No	_
Sources - Urban	High % of high-intensity developed in watershed	13	9	171	33%	2%	0.003	Yes	31%
	High % of low-intensity developed in watershed	13	9	171	11%	3%	0.268	No	_
	High % of medium-intensity developed in watershed	13	9	171	22%	4%	0.053	Yes	19%
	High % of residential developed in watershed	13	9	171	0%	2%	1	No	_
	High % of rural developed in watershed	13	9	171	11%	3%	0.268	No	_
	High % of high-intensity developed in 60m buffer	13	9	171	33%	1%	0.001	Yes	32%

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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
	High % of low-intensity developed in 60m buffer	13	9	171	11%	5%	0.409	No	_
	High % of medium-intensity developed in 60m buffer	13	9	171	22%	1%	0.013	Yes	21%
	High % of residential developed in 60m buffer	13	9	171	0%	5%	1	No	_
	High % of rural developed in 60m buffer	13	9	171	0%	7%	1	No	_

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Potomac River Frederick County Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	93%
Sources - Anthropogenic	63%
Sources - Impervious	83%
Sources - Urban	43%
All Sources	***97%***

4.1 Sources Identified by BSID Analysis

The sources identified by the BSID analysis (Table 2) are the result of agricultural and urban development in the watershed, which has significant association with degraded biological conditions in the Potomac River Frederick County watershed. The watershed is comprised of 39% agriculture, 18% urban and 2% urban impervious land use. The BSID analysis identified several stressor sources in the 60-meter buffer zone including agriculture (72%), low forest (31%), high urban impervious surface (77%), and urban sources (32%) also impacting the watershed. 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). Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indices and bank stability, as well as greater deposition of sediments on and within the streambed (Roth, Allan, and Erickson 1996; Wang et al. 1997). Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995).

The 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. Impervious cover reduces base flow by limiting the amount of ground water recharge in the watershed.

Flow volumes and velocities in streams generally increase during storm events due to the higher quantity of water that runs off impervious surfaces and into the stream channels. This creates a very unstable system that goes from destructive floods to total de-watering in very short time intervals resulting in biological communities under constant stress and adjustment (CAWPD 2000).

Increases in impervious surface cover that accompany urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, decreasing the time it takes water to reach streams and causing them to be more “flashy” (Walsh et al. 2005). Land development can also cause an increase in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, and inorganic pollutants to surface waters. In virtually all studies, as the amount of impervious area in a watershed increases, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The BSID source analysis (Table 2) identifies various types of agricultural and urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 97%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Frederick County watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Potomac River Frederick 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sediment	Extensive bar formation present	12	9	82	11%	8%	0.56	No	_
	Moderate bar formation present	12	9	82	78%	42%	0.039	Yes	35%
	Channel alteration moderate to poor	9	8	67	75%	41%	0.067	Yes	33%
	Channel alteration poor	9	8	67	13%	7%	0.457	No	_
	High embeddedness	12	9	81	22%	2%	0.027	Yes	20%
	Epifaunal substrate marginal to poor	12	9	82	78%	15%	0	Yes	62%
	Epifaunal substrate poor	12	9	82	11%	1%	0.135	No	_
	Moderate to severe erosion present	12	9	82	44%	26%	0.21	No	_
	Severe erosion present	12	9	82	0%	3%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Potomac River Frederick 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Instream Habitat	Channelization present	13	9	85	0%	10%	1	No	_
	Concrete/gabion present	10	8	75	0%	3%	1	No	_
	Beaver pond present	12	9	82	0%	1%	1	No	_
	Instream habitat structure marginal to poor	12	9	82	33%	16%	0.167	No	_
	Instream habitat structure poor	12	9	82	11%	0%	0.047	Yes	11%
	Pool/glide/eddy quality marginal to poor	12	9	82	56%	40%	0.253	No	_
	Pool/glide/eddy quality poor	12	9	82	0%	4%	1	No	_
	Riffle/run quality marginal to poor	12	9	82	44%	25%	0.178	No	_
	Riffle/run quality poor	12	9	82	11%	5%	0.378	No	_
	Velocity/depth diversity marginal to poor	12	9	82	44%	46%	0.678	No	_
	Velocity/depth diversity poor	12	9	82	11%	4%	0.367	No	_
Riparian Habitat	No riparian buffer	13	9	85	33%	9%	0.047	Yes	25%
	Low shading	12	9	82	11%	5%	0.429	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Potomac River Frederick 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Chemistry - Inorganic	High chlorides	13	9	171	11%	6%	0.47	No	_
	High conductivity	13	9	171	56%	8%	0.001	Yes	47%
	High sulfates	13	9	171	33%	8%	0.035	Yes	26%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	13	9	165	11%	2%	0.236	No	_
	Dissolved oxygen < 6mg/l	13	9	165	11%	5%	0.421	No	_
	Low dissolved oxygen saturation	13	9	165	11%	7%	0.483	No	_
	High dissolved oxygen saturation	13	9	165	0%	4%	1	No	_
	Ammonia acute with salmonid present	13	9	171	0%	0%	1	No	_
	Ammonia acute with salmonid absent	13	9	171	0%	0%	1	No	_
	Ammonia chronic with early life stages present	13	9	171	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	13	9	171	0%	0%	1	No	_
	High nitrites	13	9	171	67%	6%	0	Yes	61%
	High nitrates	13	9	171	78%	6%	0	Yes	72%
	High total nitrogen	13	9	171	89%	6%	0	Yes	83%
	High total phosphorus	13	9	171	67%	8%	0	Yes	58%
	High orthophosphate	13	9	171	56%	8%	0.001	Yes	48%
Chemistry - pH	Acid neutralizing capacity below chronic level	13	9	171	0%	5%	1	No	_
	Low field pH	13	9	165	0%	11%	1	No	_
	High field pH	13	9	165	0%	1%	1	No	_
	Low lab pH	13	9	171	0%	5%	1	No	_
	High lab pH	13	9	171	0%	2%	1	No	_

Table 7. Summary AR Values for Stressor Groups for the Potomac River Frederick County Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	75%
Instream Habitat	11%
Riparian Habitat	25%
Chemistry - Inorganic	48%
Chemistry - Nutrients	83%
All Chemistry	83%
All Stressors	***95%***

4.2 Stressors Identified by BSID Analysis

All thirteen stressor parameters identified by the BSID analysis (Tables 5 and 6) are significantly associated with biological degradation in the Potomac River Frederick County watershed and are representative of impacts from agricultural and urban developed landscapes.

Sediment Conditions

BSID analysis results for the Potomac River Frederick County watershed identified four sediment parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *moderate bar formation present, channel alteration (moderate to poor), high embeddedness, epifaunal substrate (marginal to poor).*

Moderate bar formation present was identified as significantly associated with degraded biological conditions and found to impact approximately 35% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Bar formation represents deposition of sand, gravel, and small stones in an area of the stream with a gentle slope and an elevation very close to the stream's water level. Bar formation typically reflects the overall sediment transport capacity of the stream with observed categories of moderate to extensive or extensive bar formation present. Moderate to extensive bar formation indicates channel instability related to frequent and intense high stream velocities that quickly dissipate and rapidly lose the capacity to transport excessive sediment loads downstream (Allan and Castillo 2007).

Channel alteration (moderate to poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 33% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Channel alteration is a rating of large-scale changes in the shape of a stream channel. This rating addresses deliberate stream manipulations within a 75-meter sample station (e.g., concrete channels, artificial embankments, obvious straightening of the natural channel, rip-rap, or other structures), as well as stream alterations resulting from large changes in hydrologic energy (e.g., recent bar development; Mercurio, Chaillou, and Roth 1999). Deliberate alterations typically result in higher velocities by smoothing channel surfaces, straightening channels, or raising/steepening banks. Thus, the presence of alterations assessed in this rating is considered to demonstrate increased probability that the stream is prone to frequent high velocities. The corresponding occurrence of more frequent low discharges is also expected, due to reduced base flow resulting from rapid exit of water from a watershed. Many channel alterations may also directly reduce habitat heterogeneity (Allan and Castillo 2007).

High embeddedness was identified as significantly associated with degraded biological conditions and found to impact approximately 20% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. 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 (Mercurio, Chaillou, and Roth 1999). 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; Roth et al. 2005), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Epifaunal substrate (marginal to poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 62% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County 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. Varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates (Mercurio, Chaillou, and Roth 1999). 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 (Covich, Palmer, and Crowl 1999).

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 (Mercurio, Chaillou, and Roth 1999).

As agricultural development and urbanization increased in the Potomac River Frederick County watershed so did the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime causing 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 highly unstable stream channels with widening, downcutting, and streambed scouring. The scouring associated with these increased flows leads to accelerated channel and bank erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Some of the impacts associated with sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman, Rattner, and Burton 2003). All of the stressors identified for the sediment group (e.g., high embeddedness and poor epifauanal substrate), indicate channel instability related to frequent and intense high flows that scour streambeds then quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 75%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Frederick County watershed (Table 7).

Instream Habitat Conditions

BSID analysis results for the Potomac River Frederick County watershed identified one instream habitat parameter that has a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community).

Instream habitat structure (poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 11% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Instream 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 instream habitat scores are evidence of the lack of sediment deposition. Like embeddedness, instream habitat is confounded by natural variability (i.e., some streams will naturally have more or less instream habitat). Low instream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats (Allan and Castillo 2007). *Marginal* and/or *poor* ratings of this measure indicate excessive erosion and/or sedimentation.

The MDDNR MBSS noted concreted and unstable substrates at two sites in the BSID analysis dataset. The instream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity; the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Substrate is an essential component of instream habitat to macroinvertebrates for several reasons. First, many organisms are adapted to living on or obtaining food from specific types of substrate, such as cobble or sand. The group of organisms known as scrapers, for instance, cannot easily live in a stream with no large substrate because there is nothing from which to scrape algae and biofilm. Hence, substrate diversity is strongly correlated with macroinvertebrate assemblage composition (Cole, Russel, and Mabee 2003).

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the instream habitat stressor group is approximately 11% suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Frederick County watershed (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Potomac River Frederick County watershed identified one riparian habitat parameter that has a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). This parameter is *no riparian buffer*.

No riparian buffer was identified as significantly associated with degraded biological conditions and found to impact approximately 25% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Riparian buffer width represents the minimum width of vegetated buffer in meters, considering both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer (Mercurio, Chaillou, and Roth 1999). 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 and urban 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 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 Potomac River Frederick County 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 very poor to poor biological conditions. The combined AR for the riparian habitat stressor group is approximately 25% suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Frederick County watershed (Table 7).

Water Chemistry

BSID analysis results for the Potomac River Frederick County watershed identified seven water chemistry parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high conductivity, high sulfates, high nitrites, high nitrates, high total nitrogen, high total phosphorous, and high orthophosphate.*

High conductivity was identified as significantly associated with degraded biological conditions and found in 47% of the stream miles with very poor to poor biological conditions in the Potomac River Frederick County watershed. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2009). Urban runoff, road salts, fertilizers, and leaking wastewater infrastructure are typical sources of inorganic compounds. Conductivity levels typically increase in watersheds where urban land uses are predominant. Conductivity, chlorides and sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity.

High sulfates was identified as significantly associated with degraded biological conditions and found in 26% of the stream miles with very poor to poor biological conditions in the Potomac River Frederick County watershed. 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 nitrites was identified as significantly associated with degraded biological conditions and found to impact approximately 61% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Nitrite

(NO_2^-) is a measure of the amount of NO_2^- in the water column. NO_2^- is an inorganic ion formed as an intermediate from ammonium (NH_4^+) to nitrate (NO_3^-) by bacteria in soil, sewage, and water. It can lead to eutrophication, can bioaccumulate in organisms, and causes biological harm to benthics and fish mainly through anoxia. Human sources that increase NO_2^- concentrations include agriculture, sewage, and some industrial processes (Lewis and Morris 1986; Doull, Klaassen, and Amdur 1980).

High nitrates was identified as significantly associated with degraded biological conditions and found to impact approximately 72% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Nitrate (NO_3^-) is a measure of the amount of NO_3^- in the water column. Nitrifying bacteria oxidize ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-), three inorganic forms of nitrogen. NO_3^- is highly soluble and tends to exist in greater concentrations than other inorganic forms do, even in the presence of relatively low dissolved oxygen. In addition to agriculture, sewage, and industrial sources, atmospheric deposition can be a source of NO_3^-. Like NO_2^-, it causes biological harm via anoxia. Unlike NH_4^+ and NO_2^-, however, biological uptake of NO_3^- is limited, making it less toxic (Carmago, Alonso, and Salamanca 2005, Doull et al. 1980).

High total nitrogen was identified as significantly associated with degraded biological conditions and found to impact approximately 83% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Total nitrogen (TN) is a measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. Runoff and leaching from agricultural land can generate high instream levels of nitrogen (Johnes 1996).

High total phosphorus was identified as significantly associated with degraded biological conditions and found to impact approximately 58% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. Total phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. About three-quarters of the TP (in all of its chemical forms) used in the United States goes into fertilizers. Other important uses are as builders for detergents and nutrient supplements for animal feeds. Phosphorus plays a crucial role in primary production. Elevated levels of phosphorus can lead to excessive growth of filamentous algae and aquatic plants. Excessive phosphorus input can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. TP input to surface waters typically increases in watersheds where urban and agricultural developments are predominant (Johnes 1996).

High orthophosphate was identified as significantly associated with degraded biological conditions and found to impact approximately 48% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. 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. Excessive OP input can also lead to increased primary production (accelerating eutrophication), which potentially results in species tolerance exceedences of dissolved oxygen and pH levels. OP loads to surface waters typically increases in watersheds where urban and agricultural developments are predominant.

Excess phosphorus and nitrogen, e.g., from fertilizer applications, may lead to eutrophication in the watershed, as evidenced by the high total nitrogen, high total phosphorus, and orthophosphate stressors identified as significantly associated with degraded biological conditions in the watershed. Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the "limiting nutrient." The amount of the abundant nutrient does not matter because both nutrients are needed for algae growth. In general, a Nitrogen: Phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the TN:TP ratio is less than 5:1, nitrogen tends to be limiting (Chiandani and Vighi 1974).

The BSID results demonstrate that total phosphorus (58%) and orthophosphate (48%) concentrations are less of an impact on stream miles with poor to very poor biological conditions in the watershed, as compared to nitrogen concentrations (83%); therefore, phosphorus may be a limiting nutrient in the watershed (Allan and Castillo 2007). Due to anthropogenic sources, the watershed is vulnerable to nutrient fluxes (e.g., rain events and stormwater) that could be detrimental to the biological community, additional analysis of available data (i.e., TN:TP ratio) is necessary to confirm if phosphorus concentrations are limiting in the watershed.

To make an accurate determination of whether phosphorus or nitrogen concentrations are limiting in the watershed, MDE reviewed additional data. During 2009, MDE collected ninety water quality samples from the Potomac River Frederick County watershed. Samples were collected at four stations throughout the watershed, with most stations being sampled monthly. According to samples collected by MDE in the Potomac River Frederick County watershed, 100% of the samples have TN:TP ratios above 10. The observed data strongly implies that the streams in the Potomac River Frederick County watershed are phosphorus limited.

In the Potomac River Frederick County watershed there are several heavily traveled road routes, such as Route 340, connecting the urban areas of the watershed. Application of road salts in the watershed is a likely source of the high conductivity levels. Although salts can originate from natural sources, most of the salts that enter the environment are associated with the storage and application of road salt (Smith, Alexander, and Wolman 1987). 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). These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). 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 meters on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. On-site septic systems, sanitary sewage overflows, and stormwater discharges are quite frequent in the watershed and are also likely sources of elevated concentrations of sulfates and conductivity. Surface flows due to the high imperviousness of the watershed are also a factor.

Currently in Maryland there are no specific numeric criteria that quantify the impact of sulfates or 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.

Point source discharges are a potential source of nutrient, inorganics, and suspended solids to surface waters. Based on MDE's point source permitting information, there are several active municipal National Pollutant Discharge Elimination System (NPDES) permitted point source facilities (e.g., Point of Rocks Wastewater Treatment Plant) in the Potomac River Frederick County Watershed. The types of permits identified include individual municipal, general industrial stormwater, and general municipal separate storm sewer systems (MS4s). Another potential nonpoint source of nutrients and inorganic compounds into a watershed is on-site disposal (septic) systems. Nutrient and suspended solid loads from any wastewater treatment facility, MS4 discharge, or septic system is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the chemistry stressors is approximately 83% suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Frederick County watershed (Table 7).

4.3 Discussion of BSID Results

The BSID analysis results suggest that degraded biological communities in the Potomac River Frederick County watershed are a result of increased urban and agricultural land uses, which cause alterations to hydrology (e.g. high stream flows) and riparian habitat. The high proportions of these land uses also typically result in increased contaminant loads to surface waters. Agricultural land uses within the watershed as well as within the sixty meter riparian zone were found to be significantly associated with poor to very poor biological conditions in the watershed. Decreased riparian buffer areas are potentially contributing to increased stream temperatures, and reduced amounts of large wood debris and allochthonous material in the stream.

Altered flow regimes create a less stable stream channel, leading to excessive bank erosion and sedimentation, loss of pool habitat and instream cover, and excessive streambed scour (Wang et al. 2001). In addition to the impact of flow extremes on erosion and habitat, high flows can also eliminate taxa if such events occur during sensitive life stages. Macroinvertebrates that are able to withstand dislodgement, have short and fast life cycles, and good colonizing ability tend to be the dominant species in highly urbanized streams (Richards et al. 1997). Rivers and streams with frequent high flows or no-flow periods have relatively simple trophic structure, low taxonomic diversity, and high dominance by a few taxa (Power and Stewart 1987, Death and Winterbourn 1995).

Water chemistry is a major determinant of the integrity of surface waters that is strongly influenced by land-use. Agricultural land uses comprise 39% of the Potomac River Frederick County watershed. Developed landscapes, particularly the proportion of agriculture and urban land use in the catchments and the riparian zone, often results in increased inputs of nitrogen, phosphorus, and suspended sediments to surface waters. Elevated concentrations of sulfate and conductivity identified by the BSID analysis can also be indicative of urban and agricultural developed landscapes. Anthropogenic activities associated with such land uses degrade water quality by causing an increase in contaminant loads from various point and nonpoint sources especially during storm events. These sources can add inorganic pollutants to surface waters at levels potentially toxic to aquatic organisms. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade the Potomac River Frederick County watershed, leading to a loss of diversity in the biological community.

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

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 2015). 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 Frederick County watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

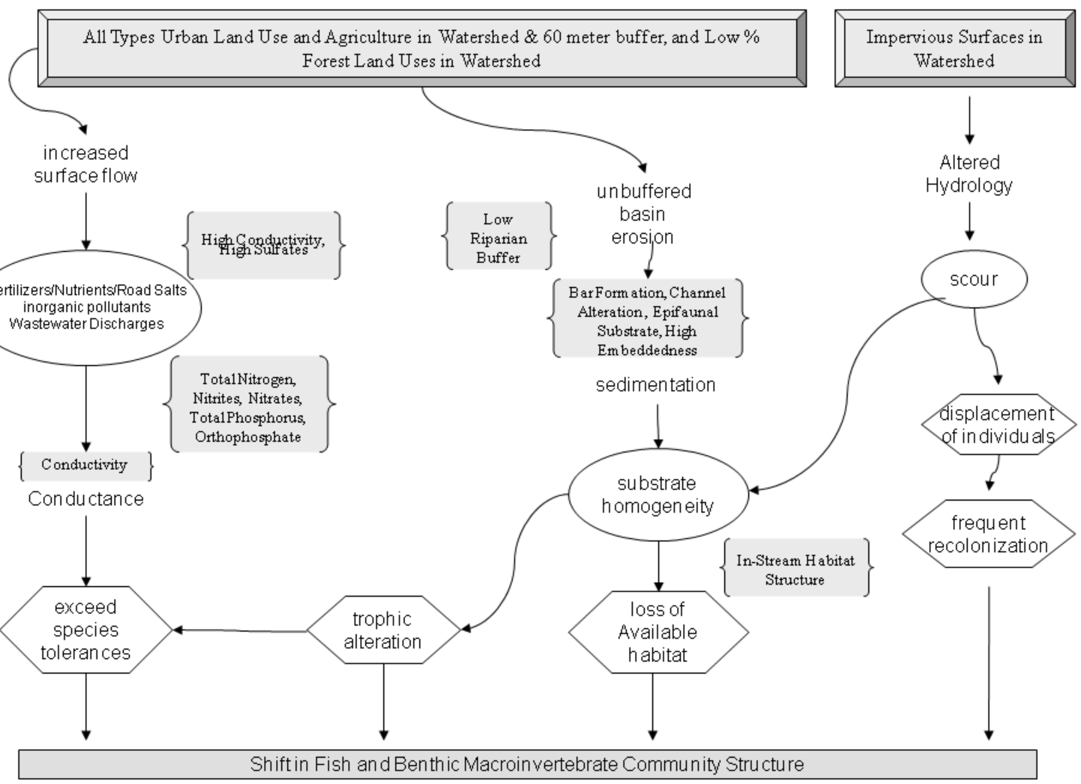

Figure 6. Final Causal Model for the Potomac River Frederick County Watershed

5.0 Conclusion

Data suggest that the Potomac River Frederick County watershed's biological communities are strongly influenced by urban and agricultural land use, which alters the hydrologic regime resulting in increased pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes, which often cause 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 Frederick County watershed are summarized as follows:

- The BSID process has determined that the biological communities in Potomac River Frederick County are likely degraded due to sediment and 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 thus support a sediment Category 5 listing of Potomac River Frederick County for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Potomac River Frederick County watershed.

- The BSID process has also determined that biological communities in the Potomac River Frederick County 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 Potomac River Frederick County watershed based on inadequate riparian buffer zones in approximately 25% of degraded stream miles.

- The BSID process has determined that the biological communities in the Potomac River Frederick County watershed are likely degraded due to inorganics (i.e., sulfates, and conductivity). Sulfates and conductivity levels are significantly associated with degraded biological conditions and found, respectively, in approximately 47% and 26% of the stream miles with poor to very poor biological conditions in the Potomac River Frederick County watershed. The BSID results thus support an inorganic sulfate Category 5 listing of Potomac River Frederick County for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Potomac River Frederick 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.

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