Watershed Report for Biological Impairment of the Non-Tidal Potomac River Upper Tidal Watershed in Charles County and Prince George's County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
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
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
TN	Total Nitrogen
TP	Total Phosphorous
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 Upper Tidal watershed, located in Charles and Prince George's Counties Maryland, is associated with two assessment units, the non-tidal 8-digit basin (basin code 02140201) and Upper Potomac River Tidal Fresh (POTTF) 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 Upper Tidal Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Potomac River Upper Tidal	02140201	Non-tidal	Aquatic Life and Wildlife	2006	Impacts to Biological Communities	5
Upper Potomac River Tidal Fresh (POTTF)		Tidal Fresh	Seasonal Migratory Fish Spawning & Nursery Subcategory	2012	TN	4a
					TP	
			Fishing	2002	PCB in Fish Tissue	
			Open-Water Fish & Shellfish Subcategory	1996	TN	
			Shallow-Water Submerged Aquatic Vegetation Subcategory		TP	
					TSS	3
			Aquatic Life and Wildlife		Benthic IBI	2
					Copper	
			Fishing		Mercury in Fish Tissue	

Note:

- Category 2 indicates the waterbody is meeting water quality standards for the identified substance
- Category 3 indicates insufficient data to make a listing category determination
- Category 4a indicates a TMDL has been completed and approved by EPA
- Category 5 indicates that the waterbody is impaired and a TMDL or water quality analysis (WQA) is needed.

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 based on reference sites determined independent of biological condition).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Potomac River Upper Tidal are designated as Use Class I *Water Contact Recreation and Protection of Nontidal Warmwater Aquatic Life*, and Use Class II *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2017a, 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 uses may differ and are dependent on the specific designated use(s) of a waterbody. The Potomac River Upper Tidal 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 IR listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. MDE 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 improvement of biology if a given stressor were removed.

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 Upper Tidal 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 Upper Tidal watershed is due to urban land use and the concomitant effects of altered hydrology, and elevated levels of sediment. 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 Upper Tidal watershed, can be summarized as follows:

- The BSID process has determined that the biological communities in the Potomac River Upper Tidal watershed are likely degraded due to sediment-related stressors. Specifically, altered hydrology and runoff from urban developed landscapes have resulted in erosion and subsequent elevated suspended sediment (i.e., bar formation) 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 Upper Tidal watershed 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 Upper Tidal watershed.

- The BSID process identified high dissolved oxygen saturation as having significant association with degraded biological conditions in the Potomac River Upper Tidal watershed. The BSID analysis uses a case-control, risk-based approach to systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Excess nutrients do not act directly as pollutants in aquatic systems, but rather manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since only high oxygen saturation was identified, but nutrient over enrichment was not identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for the Potomac River Upper Tidal watershed. There are Category 4a phosphorus TMDLs (1996, 2012) for the tidal fresh assessment unit. Reductions in the non-tidal portions for that TMDL should also improve the conditions within the streams. In the absence of a firm causal pathway as described above, concluding that the Potomac River Upper Tidal is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

- The BSID process has determined that biological communities in the Potomac River Upper Tidal watershed are likely degraded due to human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete and rip rap). Channelization of stream segments in the Potomac River Upper Tidal watershed is significantly associated with degraded biological conditions and found in 45% of the stream miles with poor to very poor biological conditions. Since channelization is not considered to be a pollutant, it will not be listed under Category 5 on the Integrated Report. MDE considers a Category of 4c as a more appropriate management action, with potential for a “technical fix” such as stream restoration.

- The BSID process has also determined that the biological communities in the Potomac River Upper Tidal watershed are likely degraded due to inorganic pollutants (i.e., sulfates, chlorides, conductivity). Sulfate, chloride, and conductivity levels are significantly associated with degraded biological conditions and found in 28%, 55%, and 67% respectively of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal 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 and may influence their impact on aquatic life. Currently, there is a lack of monitoring data for sulfates and chlorides; therefore, additional monitoring of these pollutants is needed to more precisely determine the specific cause(s) and extent of the impairment. The BSID results thus support Category 5 listings of chlorides 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 Upper Tidal 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 dataset 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 based on reference sites determined independent of biological condition) 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 water quality standards, but with insufficient data to completely assess, the watershed is listed under (Category 2). If the level of precision (i.e., insufficient data to determine if any water quality standard is being attained) is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to USEPA it will be listed as (Category 4a). If the state can demonstrate that a watershed impairment is a result of pollution, but not a pollutant the watershed is listed under (Category 4c). If a watershed is classified as impaired for biology (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 a principal dataset, generated after a quality assurance/quality control review and vetting process of the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) round two and round three data, 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 Upper Tidal watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Potomac River Upper Tidal Watershed Characterization

2.1 Location

The Potomac River Upper Tidal watershed is located in Charles and Prince George's Counties (see Figure 1). The river segment extends from the Southeast Washington, D.C. – Maryland boundary downstream to Marshall Hall, MD. The Potomac River Upper Tidal is tidal fresh in the entire river segment. The tidal segment of the Potomac River Upper Tidal differs from a true estuary in that there is little intrusion of salt from the lower Chesapeake Bay for the majority of the year; thus, there is neither longitudinal nor lateral distribution of salinity. This atypical tidal exchange produces unusual salinity distributions within the Potomac River Upper Tidal basin. Low salinity is primarily attributable to the heavy freshwater input from the upstream Potomac River and other tributaries which discharge directly to the Potomac River Upper Tidal basin (MDE 2006).

Potomac River Upper Tidal watershed encompasses approximately 27,620 acres, and includes the towns of Accokeek, Fort Washington, Tantallon, Temple Hills, Oxon Hall, Marshall Hall, Suitland, and Morningside. The watershed is moderately developed, consisting mainly of commercial and residential uses and undeveloped forestland. Agricultural operations are minimal and localized. Urban centers are located at Oxon Hill and Morningside. Henson Creek, a major tributary in the Potomac River Upper Tidal basin has its headwaters near Morningside, and flows southwest to discharge to a Potomac River embayment (MDE 2006). The development of the Indian Head Highway (Rte 210) corridor to Washington D.C. has resulted in an increase in development in the watershed. The National Park Service Piscataway Park, Tantallon Golf Course, Potomac Waterfront Conservation Area, Federal Communications Center, Henson Creek Stream Valley Park, and the northwest region of Andrews Air Force Base are located in the watershed. The watershed is located in the Coastal Plain 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).

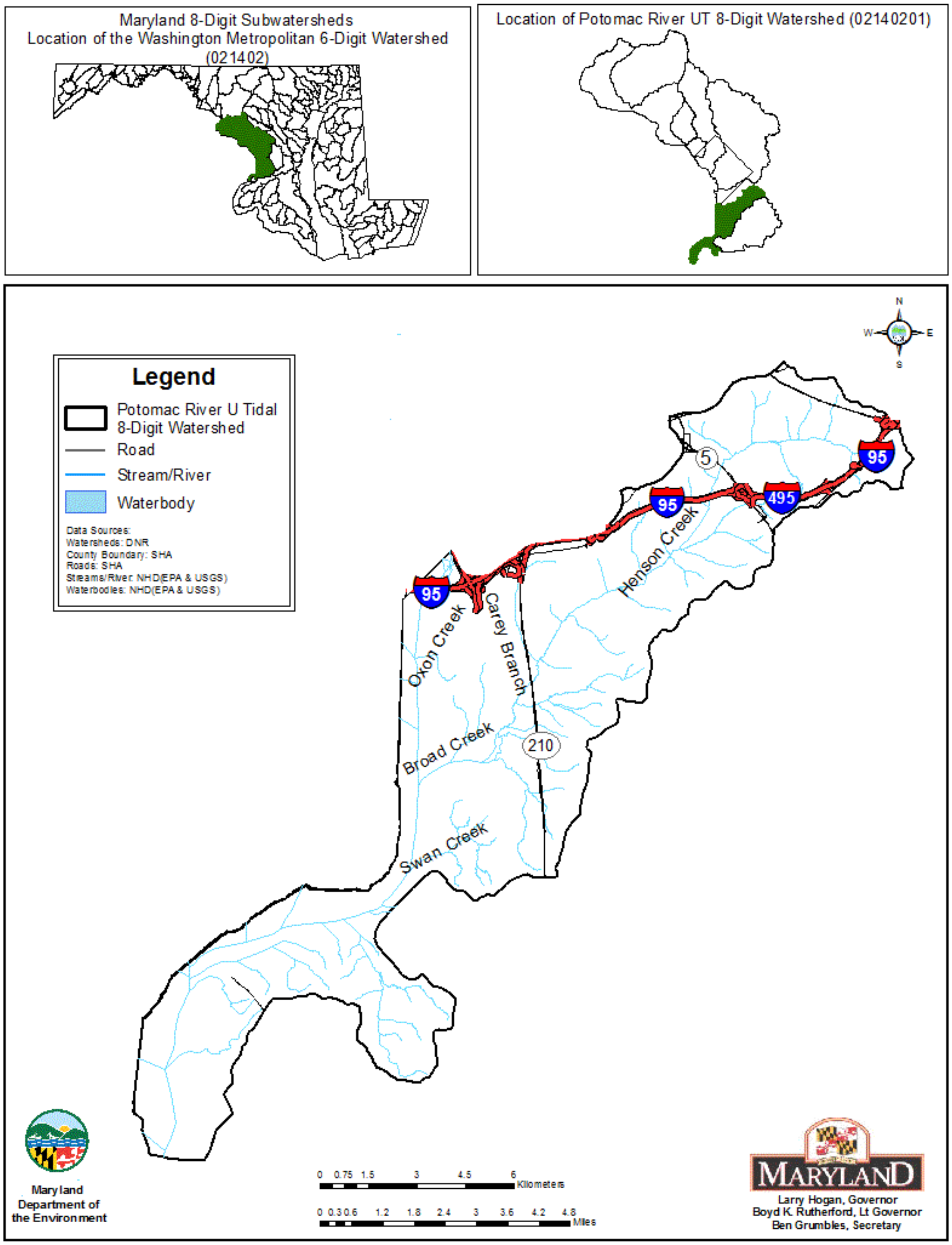


Figure 1. Location Map of the Potomac River Upper Tidal Watershed

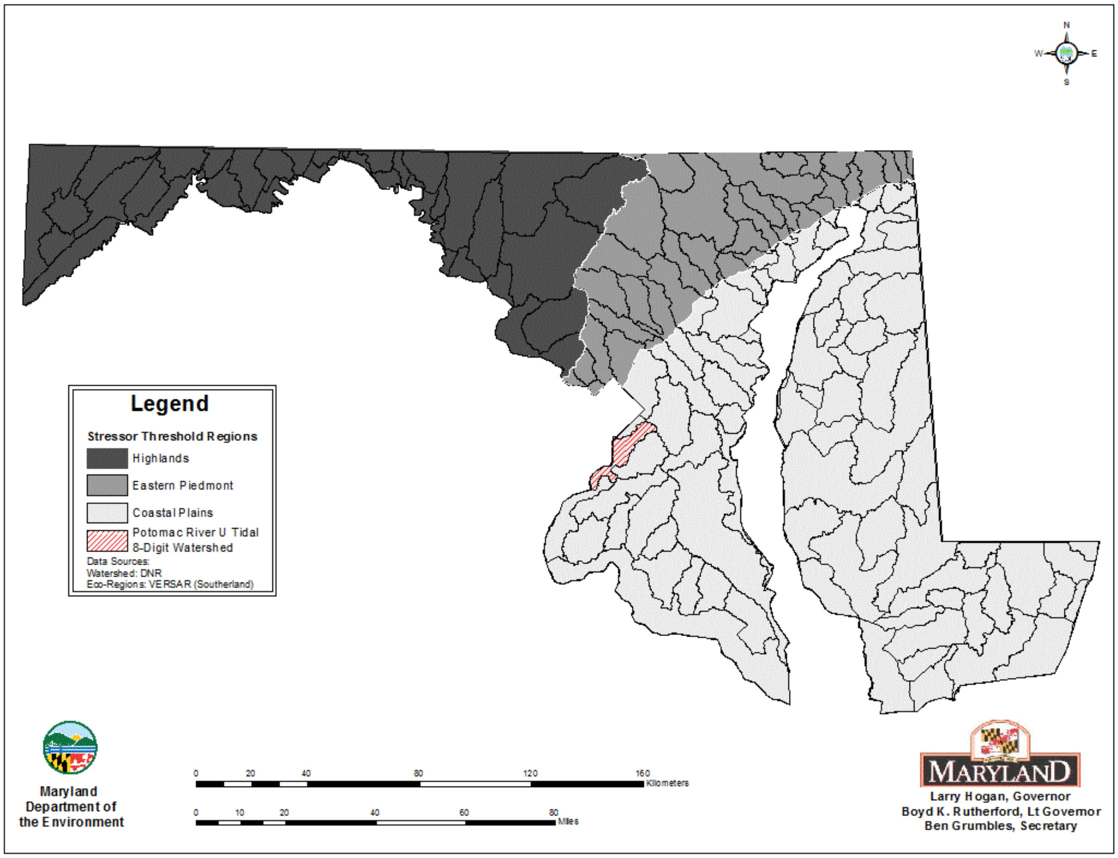


Figure 2. Eco-Region Map of the Potomac River Upper Tidal Watershed

2.2 Land Use

The drainage area of the Potomac River Upper Tidal watershed is approximately 27,620 acres. The Potomac River Upper Tidal watershed contains urban, agricultural, and forested land uses (see Figure 3). The predominant land use in the Maryland 8-digit watershed is urban. The Phase 5.2 Chesapeake Bay Watershed Model reports the land use distribution in the Potomac River Upper Tidal watershed as urban pervious (54%), urban impervious (15%), forest (28%), and agriculture (3%), (see Figure 4) (USEPA 2010).

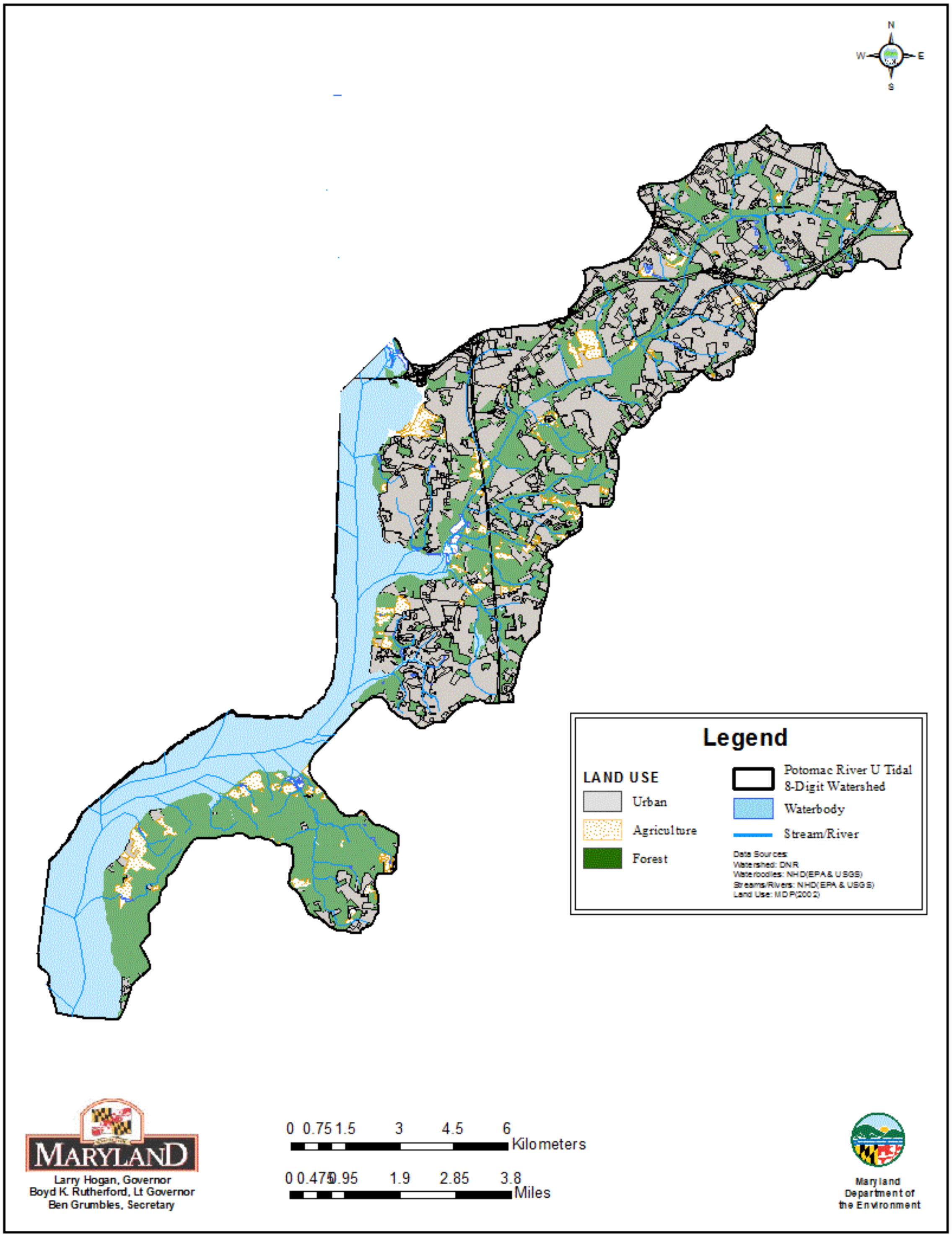


Figure 3. Land Use Map of the Potomac River Upper Tidal Watershed

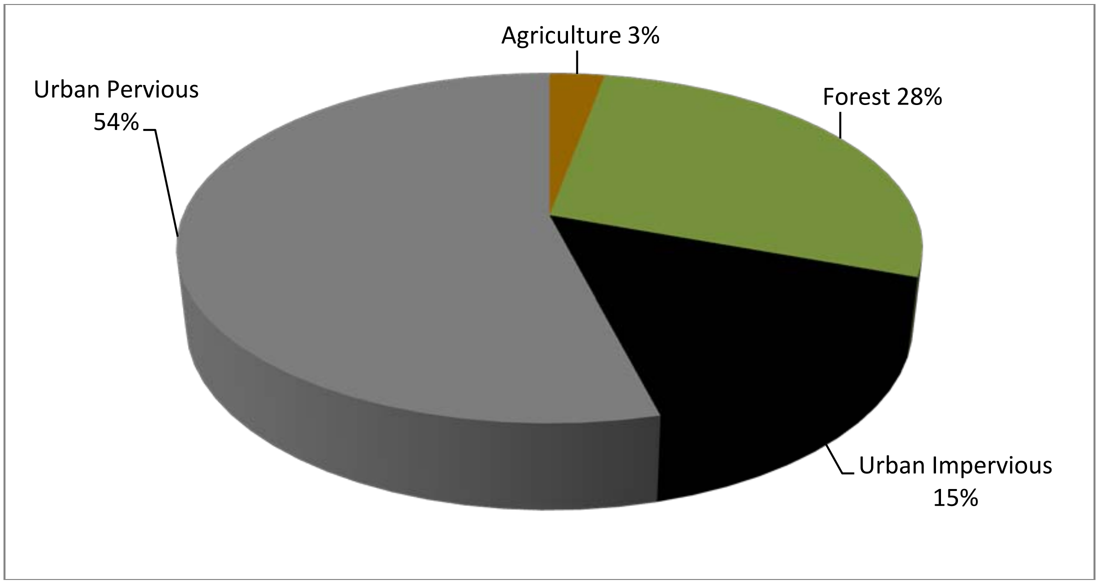


Figure 4. Proportions of Land Use in the Potomac River Upper Tidal Watershed

2.3 Soils/hydrology

The Potomac River Upper Tidal lies in the Coastal Plains physiographic province. It is west of the Chesapeake Bay and is nearly flat with areas not much above sea level compared to areas of higher relief west of the Chesapeake Bay (Schmidt 1997). The sediments of the Coastal Plain Province are formed from previous sea level stands, are on flat terrain, and have been reworked by the meandering streams from the west. The nature of the soils also varies roughly from west to east approaching the ocean as the depth to the water table generally decreases (Braun et al. 2001, USDA 1994a,b). The soils in the watershed are Beltsville, Bibb, and Othello, are primarily deep and well-drained to excessively drained (NRCS 2017a; NRCS 2017b).

3.0 Potomac River Upper Tidal 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 Upper Tidal watershed under Category 5 of the State's Integrated Report as impaired for impacts to biological communities (2006 listing). The Potomac River Upper Tidal watershed in Maryland is associated with two assessment units, the non-tidal 8-digit basin (basin code 02140201) and Upper Potomac River Tidal Fresh (POTTF) 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 Upper Tidal Watershed

<table>
<tr><th>Watershed</th><th>Basin Code</th><th>Non-tidal/ Tidal</th><th>Designated Use</th><th>Year listed</th><th>Identified Pollutant</th><th>Listing Category</th></tr>
<tr><td>Potomac River Upper Tidal</td><td>02140201</td><td>Non-tidal</td><td>Aquatic Life and Wildlife</td><td>2006</td><td>Impacts to Biological Communities</td><td>5</td></tr>
<tr><td rowspan="9">Upper Potomac River Tidal Fresh (POTTF)</td><td rowspan="9"></td><td rowspan="9">Tidal Fresh</td><td rowspan="2">Seasonal Migratory Fish Spawning & Nursery Subcategory</td><td rowspan="2">2012</td><td>TN</td><td rowspan="5">4a</td></tr>
<tr><td>TP</td></tr>
<tr><td>Fishing</td><td>2002</td><td>PCB in Fish Tissue</td></tr>
<tr><td>Open-Water Fish & Shellfish Subcategory</td><td rowspan="3">1996</td><td>TN</td></tr>
<tr><td rowspan="2">Shallow-Water Submerged Aquatic Vegetation Subcategory</td><td>TP</td></tr>
<tr><td>TSS</td><td>3</td></tr>
<tr><td rowspan="2">Aquatic Life and Wildlife</td><td rowspan="3"></td><td>Benthic IBI</td><td rowspan="3">2</td></tr>
<tr><td>Copper</td></tr>
<tr><td>Fishing</td><td>Mercury in Fish Tissue</td></tr>
</table>

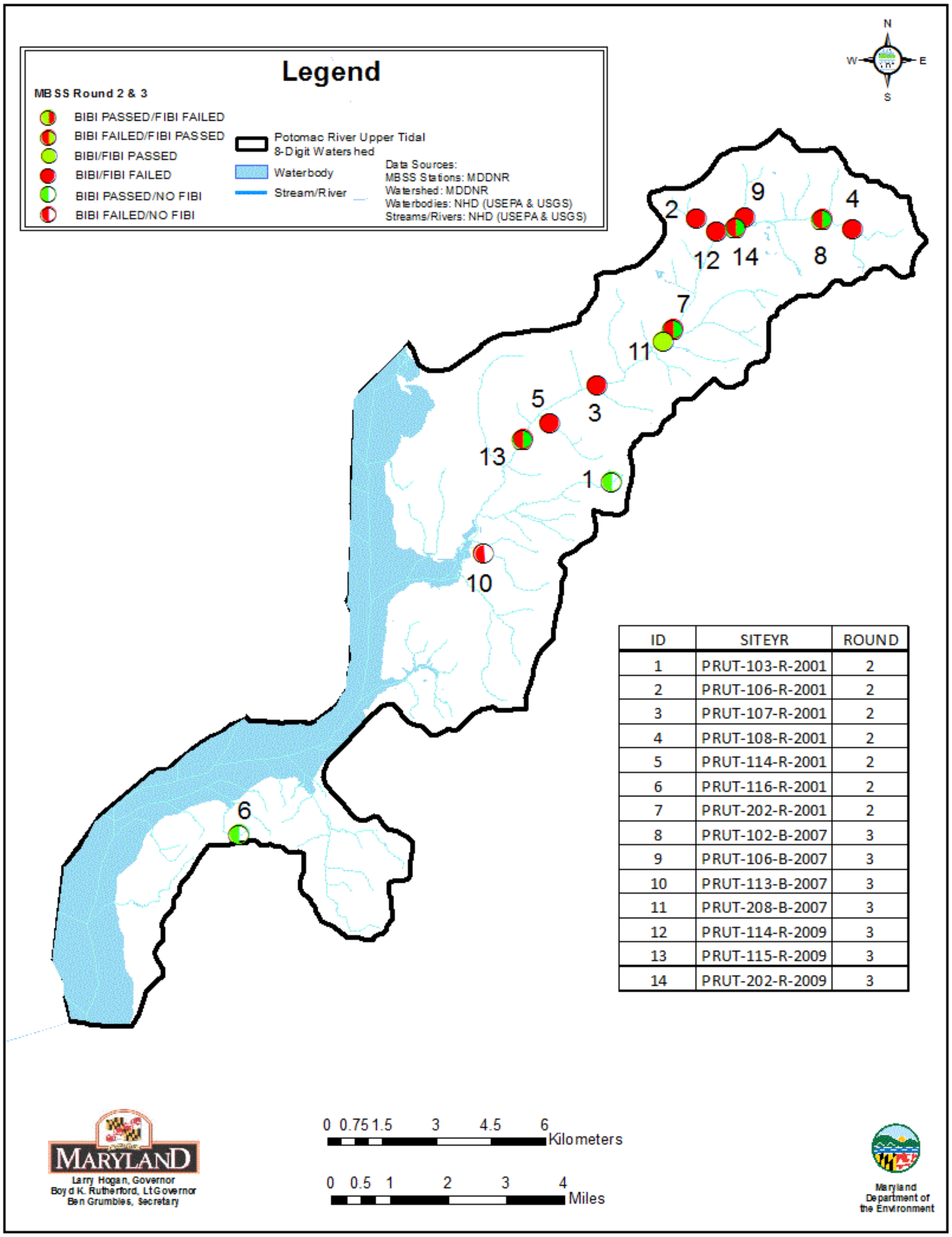
Note:

- Category 2 indicates the waterbody is meeting water quality standards for the identified substance
- Category 3 indicates insufficient data to make a listing category determination
- Category 4a indicates a TMDL has been completed and approved by EPA
- Category 5 indicates that the waterbody is impaired and a TMDL or water quality analysis (WQA) is needed.

3.2 Biological Impairment

The Maryland Surface Water Use Designations in the Code of Maryland Regulations (COMAR) for the Potomac River Upper Tidal watershed are designated as Use Class I *Water Contact Recreation and Protection of Nontidal Warmwater Aquatic Life*, and Use Class II *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2017a, 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 Upper Tidal watershed is listed under Category 5 of the 2014 Integrated Report as impaired for impacts to biological communities. Approximately 78% of the Potomac River Upper Tidal 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 eighteen stations. Eleven of the eighteen 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 fourteen sites with eleven of the fourteen having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Potomac River Upper Tidal watershed.



ID	SITEYR	ROUND
1	PRUT-103-R-2001	2
2	PRUT-106-R-2001	2
3	PRUT-107-R-2001	2
4	PRUT-108-R-2001	2
5	PRUT-114-R-2001	2
6	PRUT-116-R-2001	2
7	PRUT-202-R-2001	2
8	PRUT-102-B-2007	3
9	PRUT-106-B-2007	3
10	PRUT-113-B-2007	3
11	PRUT-208-B-2007	3
12	PRUT-114-R-2009	3
13	PRUT-115-R-2009	3
14	PRUT-202-R-2009	3

Figure 5. Principal Dataset Sites for the Potomac River Upper Tidal 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 – 1st and 2nd-4th order), that have good biological conditions (IBI>3.0).

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 habitat, water chemistry, and potential sources as significantly associated with degraded fish and/or benthic macroinvertebrate biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include an urban land use source. 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, and water chemistry groups are identified as possible biological stressors in the Potomac River Upper Tidal 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 Upper Tidal 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	14	11	274	0%	7%	1	No	_
	AMD acid source present	14	11	274	0%	0%	1	No	_
	Organic acid source present	14	11	274	0%	7%	1	No	_
Sources – Agricultural	High % of agriculture in watershed	14	11	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	14	11	279	0%	4%	1	No	_
Sources – Anthropogenic	Low % of forest in watershed	14	11	279	0%	6%	1	No	_
	Low % of wetland in watershed	14	11	279	45%	11%	0.005	Yes	35%
	Low % of forest in 60m buffer	14	11	279	0%	8%	1	No	_
	Low % of wetland in 60m buffer	14	11	279	36%	10%	0.026	Yes	26%
Sources – Impervious	High % of impervious surface in watershed	14	11	279	82%	4%	0	Yes	78%
	High % of impervious surface in 60m buffer	14	11	279	73%	5%	0	Yes	67%
	High % of roads in watershed	14	11	279	0%	0%	1	No	_
	High % of roads in 60m buffer	14	11	279	64%	5%	0	Yes	59%
Sources – Urban	High % of high-intensity developed in watershed	14	11	279	73%	8%	0	Yes	65%
	High % of low-intensity developed in watershed	14	11	279	64%	6%	0	Yes	57%
	High % of medium-intensity developed in watershed	14	11	279	73%	2%	0	Yes	71%
	High % of residential developed in watershed	14	11	279	9%	8%	0.62	No	_
	High % of rural developed in watershed	14	11	279	0%	5%	1	No	_
	High % of high-intensity developed in 60m buffer	14	11	279	64%	6%	0	Yes	57%

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	14	11	279	73%	5%	0	Yes	68%
	High % of medium-intensity developed in 60m buffer	14	11	279	73%	3%	0	Yes	70%
	High % of residential developed in 60m buffer	14	11	279	0%	8%	1	No	_
	High % of rural developed in 60m buffer	14	11	279	0%	5%	1	No	_

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

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Anthropogenic	35%
Sources - Impervious	78%
Sources - Urban	80%
All Sources	***80%***

4.1 Sources Identified by BSID Analysis

The sources identified by the BSID analysis (Table 2) are the result of urban development in the watershed, which has significant association with degraded biological conditions in the Potomac River Upper Tidal watershed. The watershed is contains significant amounts of urban pervious (54%) and urban impervious (15%) land use. The BSID analysis identified a high percentage of urban development sources in the watershed and 60-meter riparian buffer. 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 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). 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 anthropogenic and urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 80%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Upper Tidal watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Potomac River Upper Tidal 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	13	10	142	50%	20%	0.035	Yes	30%
	Moderate bar formation present	13	10	142	80%	49%	0.048	Yes	32%
	Channel alteration moderate to poor	7	5	119	80%	59%	0.319	No	_
	Channel alteration poor	7	5	119	60%	24%	0.089	Yes	37%
	High embeddedness	13	10	142	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	13	10	142	50%	42%	0.37	No	_
	Epifaunal substrate poor	13	10	142	10%	10%	0.65	No	_
	Moderate to severe erosion present	13	10	142	40%	42%	0.667	No	_
	Severe erosion present	13	10	142	10%	11%	0.67	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Potomac River Upper Tidal 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	14	11	154	45%	13%	0.014	Yes	32%
	Concrete/gabion present	7	5	136	0%	1%	1	No	_
	Beaver pond present	13	10	140	0%	7%	1	No	_
	Instream habitat structure marginal to poor	13	10	142	50%	35%	0.221	No	_
	Instream habitat structure poor	13	10	142	0%	5%	1	No	_
	Pool/glide/eddy quality marginal to poor	13	10	142	60%	39%	0.101	No	_
	Pool/glide/eddy quality poor	13	10	142	0%	3%	1	No	_
	Riffle/run quality marginal to poor	13	10	142	50%	49%	0.574	No	_
	Riffle/run quality poor	13	10	142	10%	21%	0.902	No	_
	Velocity/depth diversity marginal to poor	13	10	142	60%	56%	0.476	No	_
	Velocity/depth diversity poor	13	10	142	10%	13%	0.727	No	_
Riparian Habitat	No riparian buffer	14	11	154	9%	5%	0.407	No	_
	Low shading	13	10	142	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Potomac River Upper Tidal 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	14	11	279	64%	8%	0	Yes	55%
	High conductivity	14	11	279	73%	6%	0	Yes	67%
	High sulfates	14	11	279	36%	8%	0.013	Yes	28%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	13	10	261	0%	17%	1	No	_
	Dissolved oxygen < 6mg/l	13	10	261	0%	25%	1	No	_
	Low dissolved oxygen saturation	13	10	261	0%	6%	1	No	_
	High dissolved oxygen saturation	13	10	261	20%	3%	0.038	Yes	17%
	Ammonia acute with salmonid present	14	11	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	14	11	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	14	11	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	14	11	279	0%	0%	1	No	_
	High nitrites	14	11	279	0%	3%	1	No	_
	High nitrates	14	11	279	0%	7%	1	No	_
	High total nitrogen	14	11	279	0%	6%	1	No	_
	High total phosphorus	14	11	279	0%	9%	1	No	_
	High orthophosphate	14	11	279	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	14	11	279	0%	9%	1	No	_
	Low field pH	13	10	262	10%	40%	0.994	No	_
	High field pH	13	10	262	0%	1%	1	No	_
	Low lab pH	14	11	279	0%	38%	1	No	_
	High lab pH	14	11	279	0%	0%	1	No	_

Table 7. Summary AR Values for Stressor Groups for the Potomac River Upper Tidal Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	52%
Instream Habitat	32%
Chemistry - Inorganic	76%
Chemistry - Nutrients	17%
All Chemistry	77%
All Stressors	***85%***

4.2 Stressors Identified by BSID Analysis

All eight stressor parameters identified by the BSID analysis (Tables 4, 5 and 6) are significantly associated with biological degradation in the Potomac River Upper Tidal watershed and are representative of impacts from urban developed landscapes.

<u>Sediment Conditions</u>

BSID analysis results for the Potomac River Upper Tidal watershed identified three 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 *extensive and moderate bar formation present, and channel alteration poor.*

Extensive and moderate bar formation present were identified as significantly associated with degraded biological conditions and found to impact approximately 30% and 32% respectively of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal 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).

Sediment loads may originate from terrestrial (surface) erosion or from instream channel/bank erosion. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions (Allan 2004). Distinguishing between terrestrial or aquatic sources of sediment is not possible from this measure. Since many pollutants readily attach to sediment particles, it is possible that this parameter may also represent the presence of pollutants other than sediment. For example, sediment loads from terrestrial erosion may also introduce phosphorus into the stream segment.

Channel alteration poor was identified as significantly associated with degraded biological conditions and found to impact approximately 37% of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal 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 2004).

Channel alteration is described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels. The first level, poor channel alteration, is defined as heavy deposits of fine material and/or extensive bar development, or recent channelization, or evidence of dredging, or greater than 80% of the banks artificially armored. The second level, marginal channel alteration, is defined as recent but moderate deposition of gravel and sand on bars and/or embankments; and/or 40% to 80% of banks artificially armored or channel lined in concrete (Mercurio, Chaillou and Roth 1999).

As urbanization increased in the Potomac River Upper Tidal 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 and thereby increasing embeddedness. 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., moderate to extensive bar formation and channel alteration), 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 52%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Upper Tidal watershed (Table 7).

<u>Instream Habitat Conditions</u>

BSID analysis results for the Potomac River Upper Tidal 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). This parameter is *channelization present.*

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 32% of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal watershed. Channelization describes a condition determined by visual observation of the presence or absence of the channelization of the stream segment and the extent of the channelization. Channelization is the human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete, rip rap, and ditching). Streams are channelized to increase the efficiency of the downstream flow of water. Channelization likely inhibits heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities (Petersen et al. 1987).

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 32%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Upper Tidal watershed (Table 7).

<u>Riparian Habitat Conditions</u>

BSID analysis results for the Potomac River Upper Tidal watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition, i.e., removal of stressors would result in improved biological community (Table 5).

<u>Water Chemistry</u>

BSID analysis results for the Potomac River Upper Tidal watershed identified four 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 chlorides, high conductivity, high sulfates, and high dissolved oxygen saturation.*

High chlorides were identified as significantly associated with degraded biological conditions and found in 55% of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal watershed. Chloride is a measure of the amount of dissolved chloride (Cl^-) in the water column. MDDNR MBSS measures chlorides during the spring index period and reports it as mg/L. Chlorides can play a critical role in the elevation of conductivity (an indicator of the presence of dissolved substances). Most fish and benthic communities cannot survive in waters with high levels of chlorides. Excessive chloride concentrations indicate potential damage to stream biology.

High concentrations of chlorides can be due to several types of pollution, including industrial discharges, leaking wastewater infrastructure, metals contamination, and application of road salts in urban landscapes. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt (Sherwood 1989). Road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz 1993).

High conductivity was identified as significantly associated with degraded biological conditions and found in 67% of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal 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. MDDNR MBSS collects conductivity samples once during the spring, which is analyzed in the laboratory *(conductivity lab)*.

Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate. Natural stream conductivity is determined primarily by the geology of the area through which the stream flows. Streams supporting fish assemblages usually have a range between 150 and 500 µS/cm; conductivity outside this range may indicate that the water is unsuitable for certain species of fish and/or macroinvertebrates resulting a shift to more salinity-tolerant species (USEPA 2012).

High sulfates were identified as significantly associated with degraded biological conditions and found in 28% of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal watershed. Sulfate is the amount of dissolved sulfate (SO_4^{2-}) in the water column. Sulfur is an essential plant nutrient. 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.

High dissolved oxygen (DO) saturation was 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 Upper Tidal watershed. Natural diurnal fluctuations can become exaggerated in streams with elevated nutrient concentrations, resulting in excessive primary production. DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Percent saturation is relative to the amount of oxygen that water can hold, as determined by temperature and atmospheric pressure. High DO saturation is considered to demonstrate oxygen production associated with high levels of photosynthesis. Sources are agricultural, forested and urban land uses. MDDNR MBSS only measures DO concentrations expressed in mg/L; therefore, MDE calculated DO saturation percentages. Percent saturation is the ratio of observed DO to DO saturation value, expressed as a percent (Chapra 1997).

Excluding two of the sampling sites, the majority of the sampling sites are located in the headwaters of the streams. Two of the sampling sites (PRUT-114-R-2001 and PRUT-202-R-2009) on Henson Creek, sampled in July 2001 and August in 2009 within close proximity to one another exhibited high DO saturation results. This could be indicative of excessive primary production due to excess sunlight (i.e., lack of riparian buffer); however, no nutrient stressors were identified as having significant association with degraded biological conditions. There is a racetrack and golf course upstream of the sites. In round one, there are sampling sites (PG-N-2057-303-97, PG-N-257-306-97, and PG-N-257-324-97) nearby that also have high dissolved oxygen saturation concentrations. MDE 2009 data was reviewed from June to September dissolved oxygen values ranged from 6.8 to 9.9 mg/L therefore the watershed is meeting COMAR limits.

Point source discharges are a potential source of inorganics to surface waters. Based on MDE’s point source permitting information, there are active municipal National Pollutant Discharge Elimination System (NPDES) permitted point source facilities in the Potomac River Upper Tidal Watershed. The types of permits identified include individual municipal, and general municipal separate storm sewer systems (MS4s), e.g. Morningside Phase II municipality. A potential nonpoint source of inorganic compounds into a watershed are on-site disposal (septic) systems, there are numerous septic systems within the watershed. 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.

In the Potomac River Upper Tidal watershed, there are several heavily traveled road routes, such as Route 5, connecting the urban areas of the watershed. According to a study of the Liberty Reservoir watershed (MDDNR 2002), 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.

Iron flocculate was noted by the MDDNR at four sampling sites in the watershed. Iron flocculate is indicative of iron-oxidizing bacteria activity, which occurs in streams experiencing high acidity levels and sufficient dissolved oxygen. The Chesapeake Bay region has acidic soils, but in addition to that natural condition; there is a legacy of acidic deposition (McFee 1980). The BSID results for the Potomac River Upper Tidal watershed reflect high acidic contamination, i.e., sulfates. Acid neutralizing capacity (ANC) is a measure of capacity of dissolved constituents in water to react with and neutralize acids; the higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH (Southerland 2005b). Although not identified as significantly associated with degraded biological conditions; the four sampling sites noted for evidence of iron flocculate have the lowest ANC results of the watershed. The ANC results are less than the other results in the watershed. Anthropogenic impacts exacerbate the natural condition (acidic soils and water) of the watershed.

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.

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 77%, suggesting that these stressors are a probable cause of the biological impairments in the Potomac River Upper Tidal watershed (Table 7).

4.3 Discussion of BSID Results

The BSID analysis results (land use sources 80%, stressors 85%) suggest that degraded biological communities in the Potomac River Upper Tidal watershed are a result of a significant increase in urban land uses (i.e., urban pervious 54%, urban impervious 15%), which cause alterations to hydrology (e.g. high stream flows). Flow regime is of central importance in sustaining the ecological integrity of flowing water systems (Karr 1991; Poff et al. 1997; Vannote et al. 1980). The high proportions of these land uses also typically result in increased contaminant loads to surface waters 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. 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).

During the spring and summer index sampling periods, the MDDNR MBSS reported evidence of acidic contamination (i.e., sulfates), channelization, silt and muddy substrates, erosion and deposition, and fish blockages (i.e., four feet high culverts). In addition, 66 meters of a 75 meter sampling site was located in a culvert under the Suitland Parkway. 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). 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 Upper Tidal Watershed.

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report (MDE 2014b). It is important to recognize that stressors can act independently or as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). In addition, uncertainties in the analysis can 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 2017). 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 Upper Tidal watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

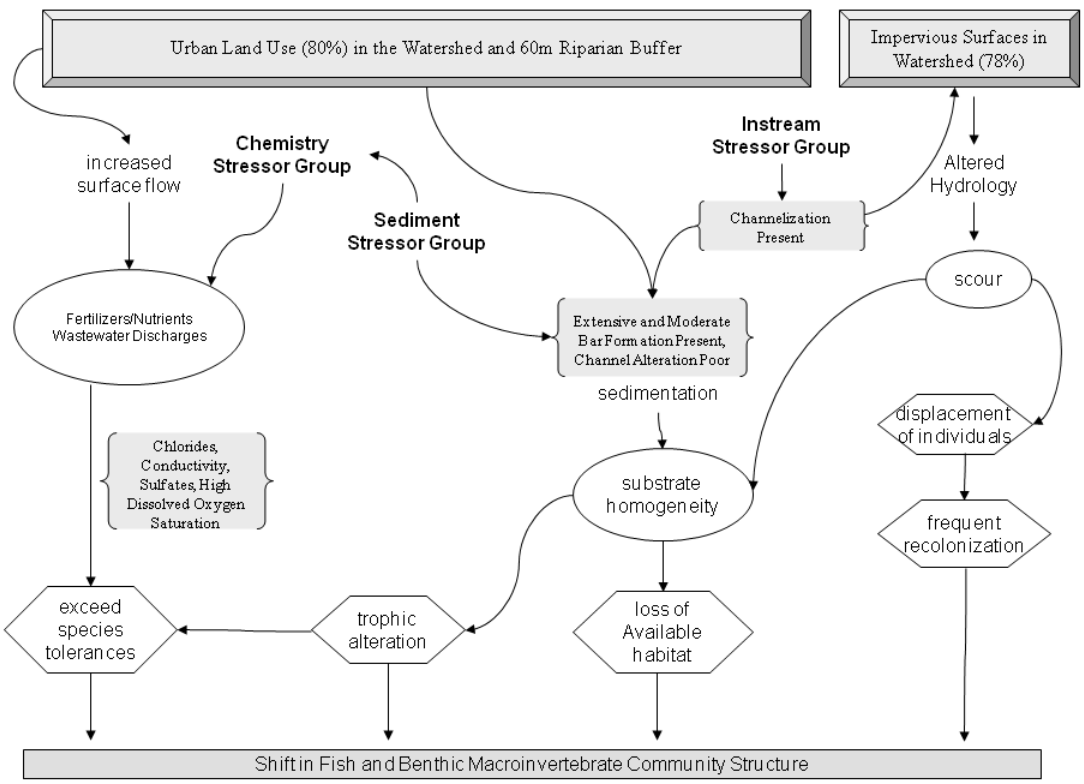


Figure 6. Final Causal Model for the Potomac River Upper Tidal Watershed

5.0 Conclusion

Data suggest that the Potomac River Upper Tidal watershed's biological communities are strongly influenced by urban 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 urban landscapes, which often cause flashy hydrology in streams and increased sediment loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Potomac River Upper Tidal watershed are summarized as follows:

- The BSID process has determined that the biological communities in the Potomac River Upper Tidal watershed are likely degraded due to sediment-related stressors. Specifically, altered hydrology and runoff from urban developed landscapes have resulted in erosion and subsequent elevated suspended sediment (i.e., bar formation) 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 Upper Tidal watershed 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 Upper Tidal watershed.

- The BSID process identified high dissolved oxygen saturation as having significant association with degraded biological conditions in the Potomac River Upper Tidal watershed. The BSID analysis uses a case-control, risk-based approach to systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Excess nutrients do not act directly as pollutants in aquatic systems, but rather manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since only high oxygen saturation was identified, but nutrient over enrichment was not identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for the Potomac River Upper Tidal watershed. There are Category 4a phosphorus TMDLs (1996, 2012) for the tidal fresh assessment unit. Reductions in the non-tidal portions for that TMDL should also improve the conditions within the streams. In the absence of a firm causal pathway as described above, concluding that the Potomac River Upper Tidal is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

- The BSID process has determined that biological communities in the Potomac River Upper Tidal watershed are likely degraded due to human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete and rip rap). Channelization of stream segments in the Potomac River Upper Tidal watershed is significantly associated with degraded biological conditions and found in 45% of the stream miles with poor to very poor biological conditions. Since channelization is not considered to be a pollutant, it will not be listed under Category 5 on the Integrated Report. MDE considers a Category of 4c as a more appropriate management action, with potential for a “technical fix” such as stream restoration.

- The BSID process has also determined that the biological communities in the Potomac River Upper Tidal watershed are likely degraded due to inorganic pollutants (i.e., sulfates, chlorides, conductivity). Sulfate, chloride, and conductivity levels are significantly associated with degraded biological conditions and found in 28%, 55%, and 67% respectively of the stream miles with poor to very poor biological conditions in the Potomac River Upper Tidal 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 and influence their impact on aquatic life. Currently, there is a lack of monitoring data for sulfates and chlorides; therefore, additional monitoring of these pollutants is needed to more precisely determine the specific cause(s) and extent of the impairment. The BSID results thus support Category 5 listing of chlorides 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 Upper Tidal watershed.

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