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**Watershed Report for Biological Impairment of the  
Bush River in Harford County, Maryland  
Biological Stressor Identification Analysis  
Results and Interpretation**

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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
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
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
PCB	Polychlorinated Biphenyls
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SSA	Science Services Administration
SSO	Sanitary Sewage Overflow
TP	Total Phosphorous
TSS	Total Suspended Solids
TMDL	Total Maximum Daily Load
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 Bush River watershed (basin code 02130701), located in Harford County, MD, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and one estuarine or tidal portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Bush River is the Bush River Oligohaline (BSHOH). Below is a table identifying the listings associated with this watershed (MDE 2012).

**Table E1. 2012 Integrated Report Listings for the Bush River Watershed**

Watershed	Basin Code	Non-tidal/Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
Bush River	02130701	Non-tidal		Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Bush River Oligohaline	BSHOH 02130701 02130702	Tidal		Fishing	2002	PCB in Fish Tissue	5
						Mercury in Fish Tissue	2
				Seasonal Migratory Fish Spawning and Nursery Subcategory	-	TP	4a
						TN	
				Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
				Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
Open-Water Fish and Shellfish	1996	TP	4a				
		TN					

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 Bush River watershed’s tributaries including Bush Creek, Church Creek, Cranberry Run, Grays Run, Haha Branch, James Run, and Sod Run are designated as Use I - *water contact recreation, and protection of nontidal warmwater aquatic life*. The Bush River mainstem, Otter Point Creek, and Romney are designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). The Bush River watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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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 Bush River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled “Maryland Biological Stressor Identification Process” (MDE 2009). Data suggest that the degradation of biological communities in the Bush River watershed is due to urban land use and the associated concomitant effects of altered hydrology. Peer-reviewed scientific literature establishes a link between highly agricultural and urbanized landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process has determined that biological communities in Bush River watershed are likely degraded due to altered flow/sediment and instream habitat related stressors. Specifically, anthropogenic sources have resulted in altered habitat heterogeneity and possible elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sediment for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Bush River watershed. The BSID results further confirm that the establishment of a sediment TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediment to the biological communities in the Bush River watershed.
- The BSID process has determined that the biological communities in the Bush River watershed are likely degraded due to inorganics (i.e., chloride and sulfate). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in approximately 95% and 58% respectively of the stream

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miles with poor to very poor biological conditions in the Bush River watershed. The BSID results thus support a Category 5 listing of chloride and sulfate 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 Bush River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has determined that biological communities in the Bush River watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Bush River watershed based on channelization being present in approximately 59% of degraded stream miles.
- The BSID process has also determined that biological communities in the Bush River 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 Bush River watershed based on inadequate riparian buffer zones in approximately 75% of degraded stream miles.
- The BSID process has determined that biological communities in the Bush River watershed are not degraded due to nutrient related stressors. There are tidal 1996 Category 4a listings for Total Nitrogen and Total Phosphorus, the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the tidal regions of the Bush River 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 2009). 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 a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). A Category 5 listing can be amended to Category 4a if a TMDL was established and approved by USEPA. If the state can demonstrate that the watershed impairment is a result of pollution, not a specific pollutant, the watershed is listed under Category 4c.

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

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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 Bush River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

## **2.0 Bush River Watershed Characterization**

### **2.1 Location**

The Bush River watershed is located entirely within Harford County, Maryland (see [Figure 1](#)). It is within the Bush River Basin (Maryland 6-digit 021307), which also includes the Lower Winters Run, Atkisson Reservoir, Bynum Run, and Swan Creek subwatersheds. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the total drainage area of the Maryland 8-digit watershed is approximately 34,985 acres not including water/wetlands. Otter Point Creek in the Bush River watershed is designated as part of the National Estuarine Research Reserve (MDDNR 2002). The major tributaries include Broad Run, Church Creek, Cranberry Run, Grays Run, James Run, Kings Creek, Otter Point Creek, and Romney Creek. The watershed is located in the Coastal Plain and Piedmont regions, two of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see [Figure 2](#)).

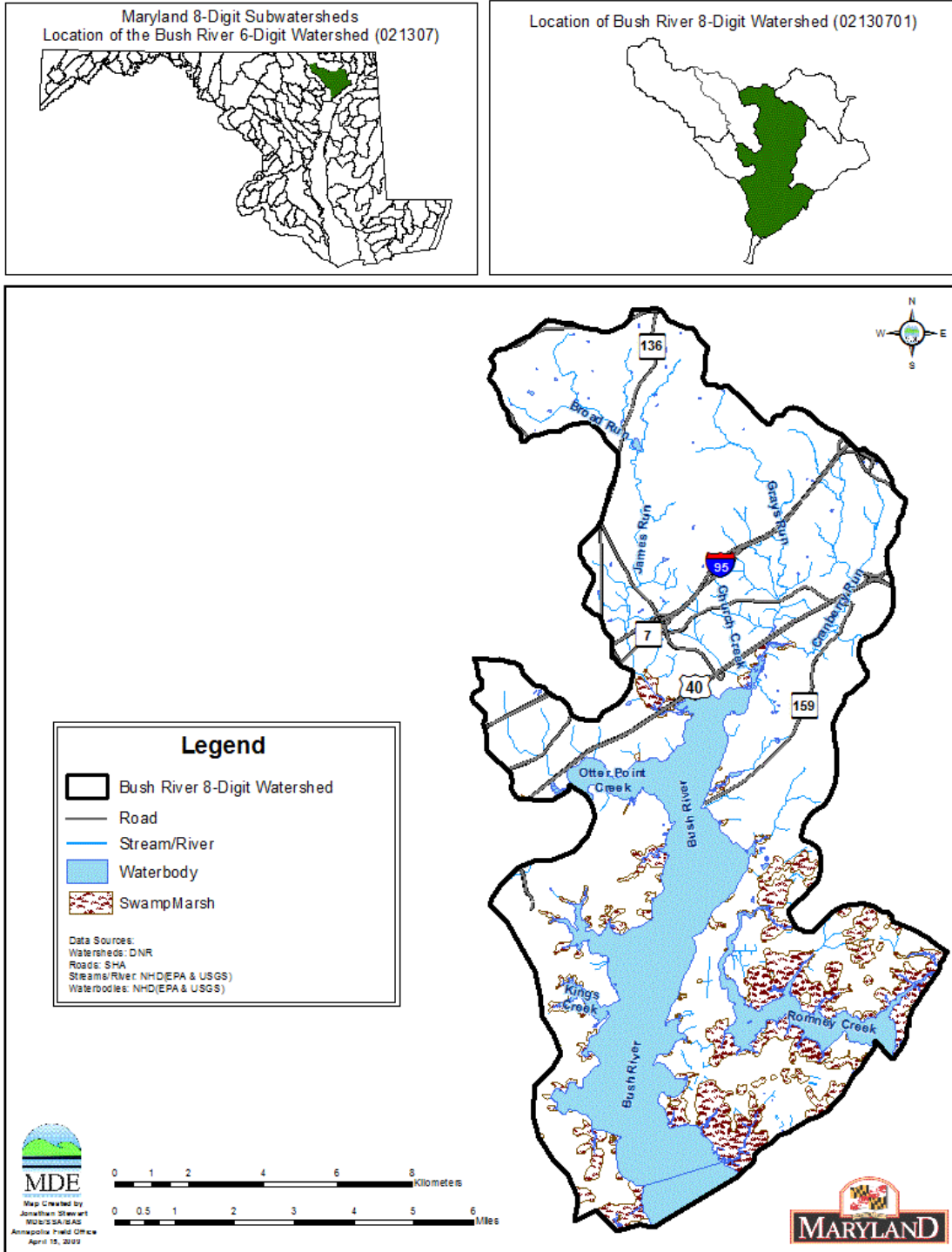
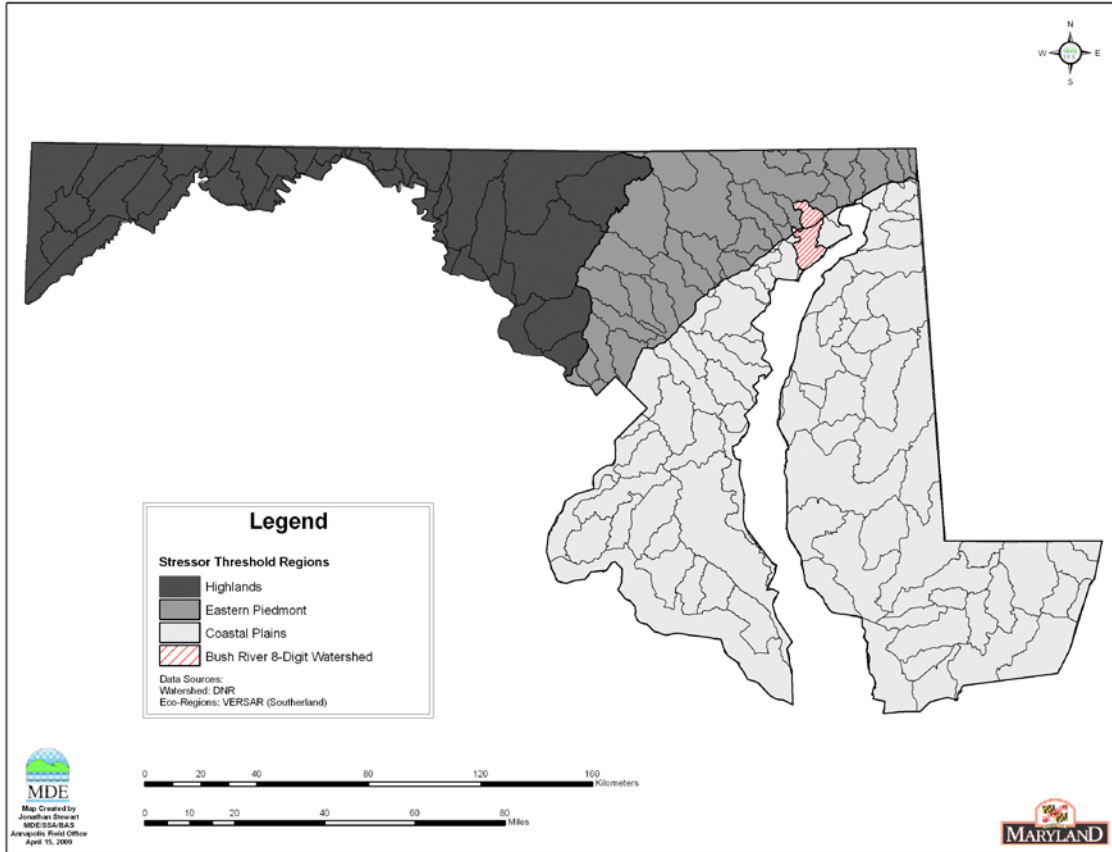


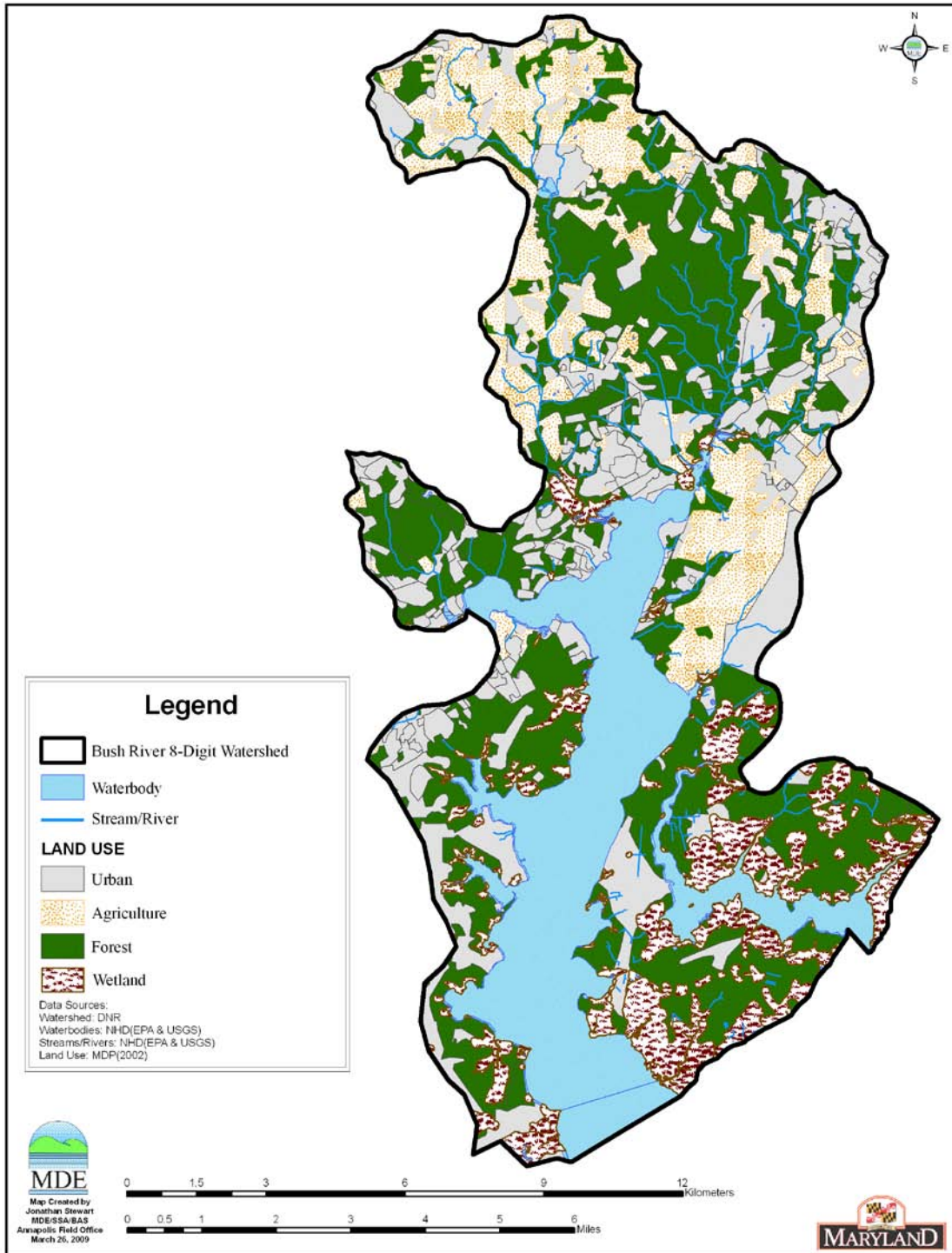
Figure 1. Location Map of the Bush River Watershed



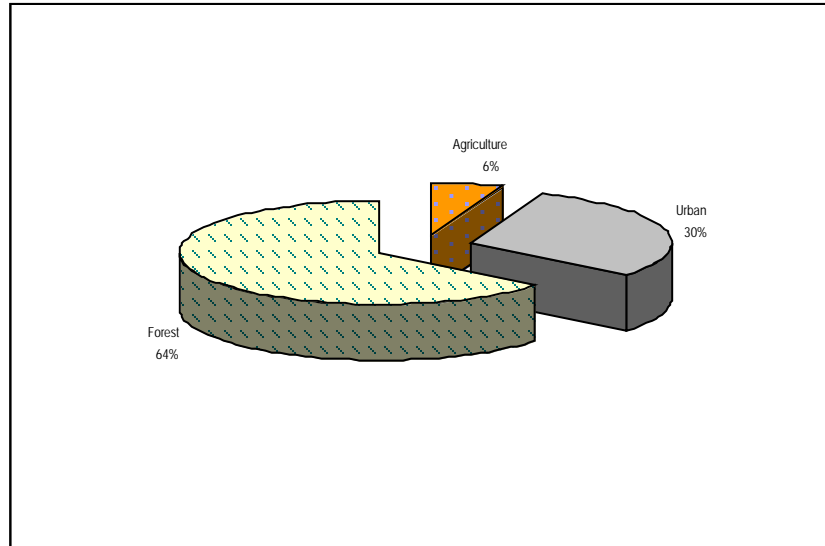
**Figure 2. Eco-Region Location Map of the Bush River Watershed**

## 2.2 Land Use

The watershed contains primarily forest land use (see [Figure 3](#)). The main transportation corridors in the watershed are Maryland Route 40 and Interstate 95; both are located in the mid to northern portion of the watershed. The watershed is located within Harford County’s residential and industrial development envelope, which follows the Route 40/I-95 corridor. The placement of development within this geographic area has not been by chance. A “development envelope” was established in 1977 to direct development towards areas served, or planned for service, by public water and sewer. By concentrating the majority of development within the development envelope, outlying areas may be preserved in a rural state to preserve the viability of agriculture in the County, as well as to conserve other natural resources (CWP 2003). According to the Chesapeake Bay Program’s Phase 5.2 watershed model land use, the Bush River watershed consists of approximately 64% forested, 30% urban, and 6% agricultural (see [Figure 4](#)). The Chesapeake Bay Program’s Phase 5.2 watershed model does not include water or wetland area for this tidal estuary. Urban impervious surface is 5% of the total land use in the watershed (USEPA 2008).



**Figure 3. Land Use Map of the Bush River Watershed**



**Figure 4. Proportions of Land Use in the Bush River Watershed**

### 2.3 Soils/hydrology

The Bush River watershed is in the Coastal Plain and Piedmont Physiographic Provinces, in Harford County. The piedmont province is characterized by gentle to steep rolling topography, low hills and ridges. Broad upland areas with low slopes and gentle drainage characterize the coastal province. There are three soil series in the watershed: Beltsville, Lehigh and Othello; Othello is dominant. These soils consist of unconsolidated deposits of gravel, sand, silt, and clay. The drainage capacity of the soils range from poor to moderate, and are strongly to extremely acidic. The soils have a low to moderate erosion potential; the hazard of erosion is severe if soil is regularly tilled (NRCS 1975). The average soil erodibility of lands within 1000 feet of streams is 0.18 value/acre, which suggests that control of soil erosion is particularly important in this watershed (MDDNR 2002).

## 3.0 Bush River Watershed Water Quality Characterization

### 3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Bush River watershed on the State's Integrated Report under Category 5 as impaired for evidence of biological impacts (2002 listings). The Bush River watershed (basin code 02130701), located in Harford County, MD, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and one estuarine or tidal portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Bush River is the Bush River Oligohaline. Below is a table identifying the listings associated with this watershed (MDE 2012).

**Table 1. 2012 Integrated Report Listings for the Bush River Watershed**

Watershed	Basin Code	Non-tidal/Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
Bush River	02130701	Non-tidal		Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Bush River Oligohaline	BSHOH 02130701 02130702	Tidal		Fishing	2002	PCB in Fish Tissue	5
						Mercury in Fish Tissue	2
				Seasonal Migratory Fish Spawning and Nursery Subcategory	-	TP	4a
						TN	
				Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
				Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
Open-Water Fish and Shellfish	1996	TP	4a				
		TN					

### 3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Bush River watershed’s tributaries including Bush Creek, Church Creek, Cranberry Run, Grays Run, Haha Branch, James Run, and Sod Run are designated as Use I - *water contact recreation, and protection of nontidal warmwater aquatic life*. The Bush River mainstem, Otter Point Creek, and Romney are designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Bush River watershed is listed under Category 5 of the 2012 IR as impaired for impacts to biological communities. Approximately 100% of the Bush River 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) and round two (2000-2004) data, which include four stations. All four stations have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, MBSS round two and round three (2000-2009) contains three MBSS sites; with all three having BIBI and/or FIBI scores lower than 3.0. [Figure 5](#) illustrates principal dataset site locations for the Bush River watershed.

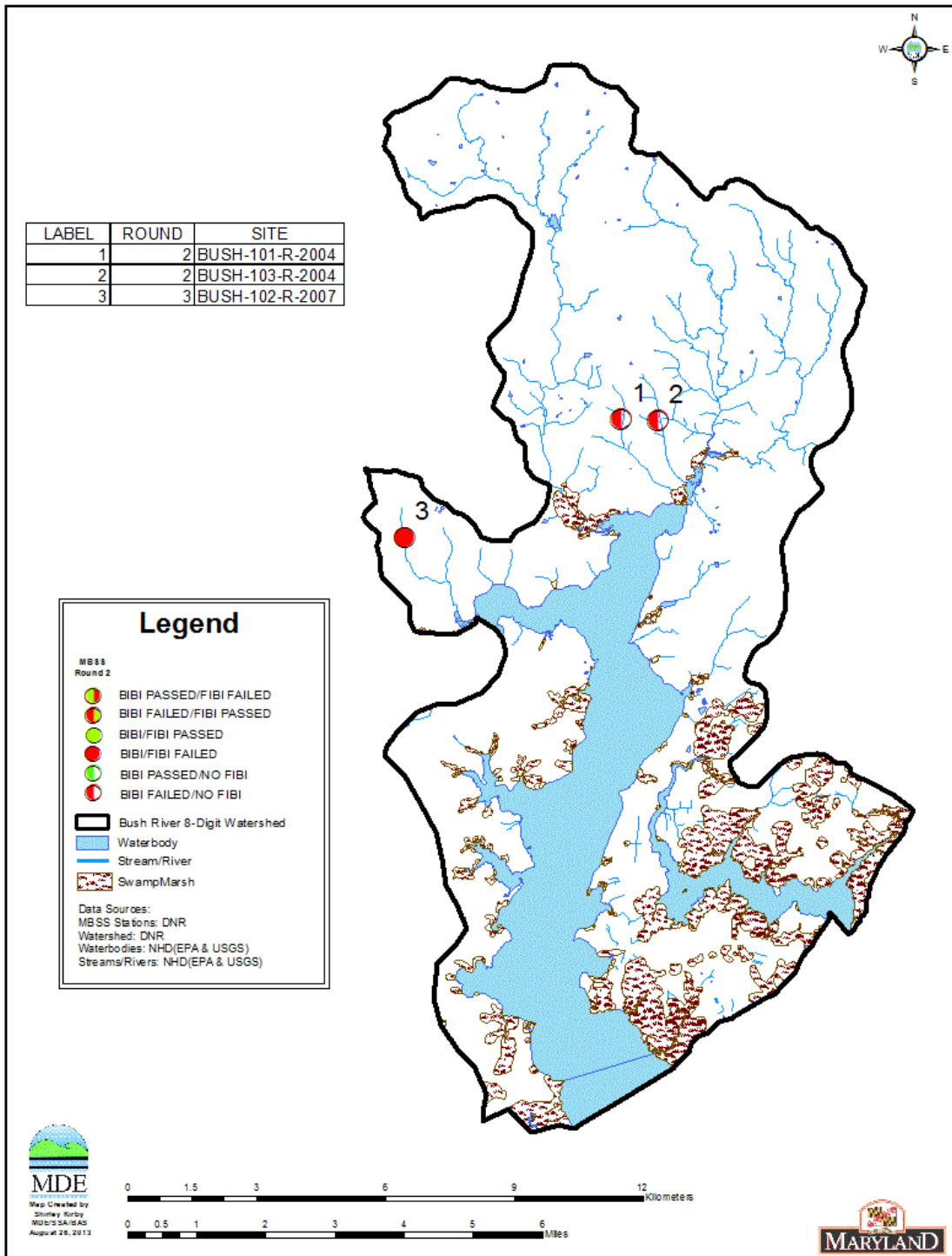


Figure 5. Principal Dataset Sites for the Bush River Watershed



#### 4.0 Stressor Identification Results for the Bush River Watershed

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

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

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risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

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

Through the BSID data analysis, MDE identified sediment, instream habitat, 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 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 Bush River 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 Bush River 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	Atmospheric deposition present	3	3	206	0%	4%	1	No	–
	Agricultural acid source present	3	3	206	0%	2%	1	No	–
	AMD acid source present	3	3	206	0%	0%	1	No	–
	Organic acid source present	3	3	206	0%	0%	1	No	–
Sources - Agricultural	High % of agriculture in watershed	3	3	207	0%	6%	1	No	–
	High % of agriculture in 60m buffer	3	3	207	0%	3%	1	No	–
Sources - Anthropogenic	Low % of forest in watershed	3	3	207	0%	3%	1	No	–
	Low % of wetland in watershed	3	3	207	33%	19%	0.471	No	–
	Low % of forest in 60m buffer	3	3	207	0%	5%	1	No	–
	Low % of wetland in 60m buffer	3	3	207	0%	0%	1	No	–
Sources - Impervious	High % of impervious surface in watershed	3	3	207	67%	7%	0.018	Yes	59%
	High % of impervious surface in 60m buffer	3	3	207	67%	7%	0.018	Yes	59%
	High % of roads in watershed	3	3	207	100%	4%	0	Yes	96%
	High % of roads in 60m buffer	3	3	207	67%	1%	0.001	Yes	65%
Sources - Urban	High % of high-intensity developed in watershed	3	3	207	0%	1%	1	No	–
	High % of low-intensity developed in watershed	3	3	207	33%	8%	0.237	No	–
	High % of medium-intensity developed in watershed	3	3	207	33%	3%	0.097	Yes	30%
	High % of early-stage residential in watershed	3	3	207	0%	5%	1	No	–
	High % of residential developed in watershed	3	3	207	33%	8%	0.237	No	–

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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 rural developed in watershed	3	3	207	33%	3%	0.11	No	–
	High % of high-intensity developed in 60m buffer	3	3	207	0%	0%	1	No	–
	High % of low-intensity developed in 60m buffer	3	3	207	0%	2%	1	No	–
	High % of medium-intensity developed in 60m buffer	3	3	207	0%	0%	1	No	–
	High % of early-stage residential in 60m buffer	3	3	207	0%	6%	1	No	–
	High % of residential developed in 60m buffer	3	3	207	33%	4%	0.137	No	–
	High % of rural developed in 60m buffer	3	3	207	33%	6%	0.175	No	–

**Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Bush River Watershed**

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Impervious	98%
Sources - Urban	30%
<b>All Sources</b>	<b>98%</b>

#### 4.1 Sources Identified by BSID Analysis

All of the sources identified by the BSID analysis ([Table 2](#)) are the result of urban development in the watershed. The BSID analysis identifies impervious surface and urban sources as the source groups with significant combined attributable risk values for the watershed. All identified stressor parameters that are significantly associated with biological degradation in the Bush River watershed BSID analysis are representative of impacts from urban developed landscapes. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer, Paul, and Taulbee 2005) has consistently identified negative impacts to biological conditions as a result of increased urbanization. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed “urban stream syndrome” (Meyer, Paul, and Taulbee 2005). Symptoms of urban stream syndrome include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors.

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. 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 urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 98% suggesting that these sources are the probable cause of biological degradation in the Bush River watershed. ([Table 3](#)).

**Table 4. Sediment Biological Stressor Identification Analysis Results for the Bush River 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	3	3	114	33%	11%	0.32	No	–
	Moderate bar formation present	3	3	114	67%	43%	0.579	No	–
	Bar formation present	3	3	114	100%	92%	1	No	–
	Channel alteration moderate to poor	2	2	95	100%	40%	0.168	No	–
	Channel alteration poor	2	2	95	50%	12%	0.233	No	–
	High embeddedness	3	3	114	33%	3%	0.1	Yes	31%
	Epifaunal substrate marginal to poor	3	3	114	33%	16%	0.415	No	–
	Epifaunal substrate poor	3	3	114	33%	3%	0.1	Yes	31%
	Moderate to severe erosion present	3	3	116	67%	59%	1	No	–
	Severe erosion present	3	3	114	0%	11%	1	No	–
	Silt clay present	3	3	114	100%	100%	1	No	–

**Table 5. Habitat Biological Stressor Identification Analysis Results for the Bush River 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	3	3	116	67%	8%	0.022	Yes	59%
	Concrete/gabion present	2	2	107	0%	1%	1	No	–
	Beaver pond present	3	3	114	0%	4%	1	No	–
	Instream habitat structure marginal to poor	3	3	114	100%	16%	0.005	Yes	84%
	Instream habitat structure poor	3	3	114	33%	1%	0.051	Yes	32%
	Pool/glide/eddy quality marginal to poor	3	3	114	100%	54%	0.253	No	–
	Pool/glide/eddy quality poor	3	3	114	0%	1%	1	No	–
	Riffle/run quality marginal to poor	3	3	114	100%	24%	0.016	Yes	76%
	Riffle/run quality poor	3	3	114	33%	1%	0.051	Yes	32%
	Velocity/depth diversity marginal to poor	3	3	114	100%	55%	0.256	No	–
	Velocity/depth diversity poor	3	3	114	33%	0%	0.026	Yes	33%
Riparian Habitat	No riparian buffer	2	2	96	100%	25%	0.068	Yes	75%
	Low shading	3	3	114	0%	4%	1	No	–

**Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Bush River 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	3	3	207	100%	5%	0	Yes	95%
	High conductivity	3	3	207	100%	5%	0	Yes	95%
	High sulfates	3	3	207	67%	9%	0.024	Yes	58%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	3	3	206	33%	9%	0.262	No	–
	Dissolved oxygen < 6mg/l	3	3	206	33%	9%	0.262	No	–
	Low dissolved oxygen saturation	3	3	206	33%	11%	0.296	No	–
	High dissolved oxygen saturation	3	3	206	0%	0%	1	No	–
	Ammonia acute with salmonid present	3	3	207	0%	0%	1	No	–
	Ammonia acute with salmonid absent	3	3	207	0%	0%	1	No	–
	Ammonia chronic with early life stages present	3	3	207	0%	0%	1	No	–
	Ammonia chronic with early life stages absent	3	3	207	0%	0%	1	No	–
	High nitrites	3	3	207	0%	4%	1	No	–
	High nitrates	3	3	207	0%	2%	1	No	–
	High total nitrogen	3	3	207	0%	5%	1	No	–
	High total phosphorus	3	3	207	0%	7%	1	No	–
	High orthophosphate	3	3	207	0%	4%	1	No	–
Chemistry - pH	Acid neutralizing capacity below chronic level	3	3	207	33%	10%	0.284	No	–
	Acid neutralizing capacity below episodic level	3	3	207	33%	10%	0.284	No	–
	Low field pH	3	3	206	33%	10%	0.285	No	–
	High field pH	3	3	206	0%	10%	1	No	–
	Low lab pH	3	3	207	33%	2%	0.084	Yes	31%
	High lab pH	3	3	207	0%	2%	1	No	–



**Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Bush River Watershed**

<b>Stressor Group</b>	<b>% of degraded sites associated with specific stressor group (attributable risk)</b>
Sediment	31%
Instream Habitat	92%
Riparian Habitat	75%
Chemistry - Inorganic	95%
Chemistry - pH	31%
All Chemistry	96%
<b>All Stressors</b>	<b>97%</b>

#### **4.2 Stressors Identified by BSID Analysis**

All thirteen stressor parameters identified by the BSID analysis (Tables 4 and 5) are significantly associated with biological degradation in the Bush River watershed and are representative of impacts from urban developed landscapes.

##### Sediment Conditions

BSID analysis results for the Bush River watershed identified two sediment 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): *high embeddedness* and *epifaunal substrate (poor)*. (Table 4).

*High embeddedness* was identified as significantly associated with degraded biological conditions and found to impact approximately 31% of the stream miles with poor to very poor biological conditions in the Bush River watershed. This stressor measures the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. High embeddedness is a result of excessive sediment deposition. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow and/or stream channel erosion.

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*Epifaunal substrate (poor)* was identified as significantly associated with degraded biological conditions and found to impact approximately 31% of the stream miles with poor to very poor biological conditions in the Bush River watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrates can be impacted by hydrological changes with resultant streambed scouring.

As development and urbanization increased in the Bush River watershed, so did morphological changes that affected the stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams causing urban streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are 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 these processes result in an unstable stream ecosystem that impacts habitat and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 31% suggesting that this stressor group impacts a moderate proportion of the degraded stream miles in the Bush River ([Table 7](#)).

### Instream Habitat Conditions

BSID analysis results for the Bush River watershed identified six habitat parameters that have a statistically significant association with poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *channelization present*, *instream habitat structure (marginal to poor)*, *instream habitat structure (poor)*, *riffle/run quality (marginal to poor)*, *riffle/run quality (poor)*, and *velocity/depth diversity (poor)*. ([Table 5](#)).

*Channelization present* was identified as significantly associated with degraded biological conditions and found to impact approximately 59% of the stream miles with poor to very poor biological conditions in the Bush River 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,

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(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.

*Instream habitat structure* was identified as significantly associated with degraded biological conditions and found to impact approximately 84% (*marginal to poor* rating) and 32% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Bush River watershed. Instream habitat structure is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High instream habitat scores are evidence of the lack of sediment deposition. Low instream habitat values can be caused by high flows that collapse undercut banks, sediment inputs that fill pools and other fish habitats. A poor rating of this measure indicates excessive erosion and/or sedimentation.

*Riffle/run quality* was identified as significantly associated with degraded biological conditions in the Bush River watershed, and found to impact approximately 76% (*marginal to poor* rating) and 32% (*poor* rating) of the stream miles with poor to very poor biological conditions. Riffle/run quality is a visual observation including quantitative measurements based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

*Velocity/depth diversity* was identified as significantly associated with degraded biological conditions and found to impact approximately 33% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Bush River watershed. Velocity/depth diversity is a visual observation including quantitative measurements based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The 'poor' diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.).

All the stressors identified for the instream habitat parameter group are intricately linked with habitat heterogeneity. The lower the ratings for these habitat parameters the lower the diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The flashiness and channelization of the Bush

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River watershed have resulted in significant channel and streambed alteration within the watershed. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and decreasing habitat heterogeneity. Channelization has been used extensively in urban landscapes for flood control. The purpose is to increase channel capacity and flow velocities so water moves more efficiently downstream. However, channelization is detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in channelized streams. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats (Bolton and Shellberg 2001). The refuge cavities removed by channelization not only provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates.

Subsequently, channelized streams retained less leaf litter and supported lower densities of detritivore invertebrates than natural streams. The overall densities and biomasses of macroinvertebrates in channelized streams are very low by comparison with intact natural streams (Laasonen, Muotka, and Kivijaervi 1998; Haapala and Muotka 1998). The combination of the altered flow regime, increased sediment, and artificial channelization in the Bush River watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the instream habitat stressor group is approximately 92% suggesting that this stressor group impacts a substantial proportion of the degraded stream miles in the Bush River ([Table 7](#)).

### Riparian Habitat Conditions

BSID analysis results for the Bush River watershed identified one riparian habitat parameter that has statistically significant associations with poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *no riparian buffer* ([Table 5](#)).

*No riparian buffer* was identified as significantly associated with degraded biological conditions and found to impact approximately 75% of the stream miles with poor to very poor biological conditions in the Bush River watershed. Riparian Buffer Width represents the minimum width of vegetated buffer in meters, looking at both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer. Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic

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matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee, Smyth, and Boutin 2004).

The BSID analysis identified sources from urban land use as significantly (98%) associated with degraded biological conditions in the Bush River watershed. These urban land use sources include anthropogenic factors, a high percent of impervious surface (59%) and transportation in the 60-meter buffer (65%), which directly affect the riparian buffer. Stream channel shading is reduced or eliminated as forests and other riparian vegetation are replaced with urban development (Allan 2004; Kline, Hilderbrand, and Hairston-Strang 2005; Southerland et al. 2005b). Local riparian vegetation is a secondary predictor of stream integrity; the extent of riparian vegetation may affect the volume of pollutants in runoff (Kline, Hilderbrand, and Hairston-Strang 2005; Roth, Allan, and Erickson 1996).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 75% suggesting that this stressor group impacts a considerable proportion of the degraded stream miles in the Bush River watershed ([Table 7](#)).

### Water Chemistry

BSID analysis results for the Bush River watershed identified four water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *high chlorides*, *high conductivity*, *high sulfates*, and *low lab pH* ([Table 6](#)).

*High conductivity* levels are significantly associated with degraded biological conditions and found to impact approximately 95% (*high* rating) of the stream miles with poor to very poor biological conditions in the Bush River 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 chlorides, sulfates, carbonate, sodium, and phosphate (IDNR 2008). Conductivity, chlorides, and sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity.

*High chlorides* levels are significantly associated with degraded biological conditions and found to impact approximately 95% (*high* rating) of the stream miles with poor to very poor biological conditions in the Bush River watershed. High concentrations of chlorides can result from industrial discharges, metals contamination, and application of road salts in urban landscapes.

*High sulfates* concentration 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 Bush River watershed. Sulfates can play a critical role in the elevation of conductivity. Other detrimental impacts of elevated

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sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities.

*Low lab pH* concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 31% of the stream miles with poor to very poor biological conditions in the Bush River watershed. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. Most stream organisms prefer a pH range of 6.5 to 8.5. Low stream pH results from agricultural land use, acid mine drainage, atmospheric deposition and organic sources. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

There are several National Pollutant Discharge Elimination System (NPDES) permitted discharge facilities (e.g., surface water, municipal, industrial) in the Bush River watershed, including Sod Run Wastewater Treatment Plant (NPDES MD0056545) which discharges directly to the Bush River. Water quality is strongly influenced by land use, water quality impairments are likely due to urban runoff, municipal and industrial discharges, failing septic systems, and erosion and upstream sources (MDDNR 1996). Examples of contaminant loads from point and nonpoint sources include sediments, nutrients, road salts, toxics, petroleum products, and inorganic pollutants to surface waters. The BSID did identify high conductivity, high chlorides, high sulfates and low lab pH as associated with poor biological conditions in the watershed. As previously noted, streams with elevated levels of chlorides and sulfates typically display high conductivity. Increased levels of many pollutants like chlorides and sulfates can be toxic to aquatic organisms and lead to exceedances in species tolerances.

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 water chemistry stressor group is approximately 96% suggesting this stressor impacts a substantial proportion of the degraded stream miles in the Bush River watershed ([Table 7](#)).

### 4.3 Discussion of BSID Results

Urban land use in the Bush River watershed is 30% of the watershed, a “development envelope” was established in 1977 to direct development towards areas served, or planned for service, by public water and sewer (CWP 2003). All three of the sites included in the BSID analysis primary dataset are located near major roads and/or located in culverts. The BSID results identified urban land use sources, i.e., impervious surface and a high percentage of medium urban intensity development, as significant (98%) in the Bush River watershed.

Urban land development can cause an increase in contaminant loads from point and non-point sources by adding sediments and inorganic pollutants to surface waters. In watersheds already experiencing anthropogenic stress, hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events (Southerland et al. 2005b). Urbanization, specifically channelization (identified as a stressor in the Bush River watershed) exacerbates the overland flows during storm events carrying pollutants (i.e., chlorides, sulfates); when flows recede and water velocity slows it stagnates and there are resulting fluctuations in conductivity and pH. During the spring and summer index sampling periods, the MDDNR MBSS reported channelization and sediment deposition, altered flow for the three sites included in the BSID analysis; BUSH-101-R-2004 (44m of site in a culvert), BUSH-103-R-2004 (high turbidity caused by beavers in stormwater holding pond directly above site, and BUSH-102-R-2007 (site under Rte 95 in culvert, ATV use through culvert is obvious). These streams are headwater (i.e., first-order) streams; they do not typically support biologically diverse and/or sustainable communities (Vannote 1980), making their biological communities more vulnerable to natural and anthropogenic land use alterations, and their associated stressors. Urban land use exacerbates the slow flushing characteristics of the Bush River watershed, which tends to accentuate water quality problems there (MDDNR 2002).

The Bush River watershed is in the Piedmont and Coastal Plain physiographic region, the Coastal Plain region is naturally impacted by sediment deposition due to the region’s soil and hydrology. Under normal conditions, the watershed receives low freshwater input and experiences very little flushing except from stormwater, therefore there are usually episodic pulses of nutrients and sediments. Due to these factors, the fish and benthic macroinvertebrate communities experience drastic changes in water quality, and a reduction in the quantity and quality of available physical habitat. Altered flow regimes as a result of urbanization allow for greater flooding, which creates a less stable stream channel, leading to excessive bank erosion, loss of pool habitat and instream cover, and excessive streambed scour and sediment deposition (Wang et al. 2001). All of these impacts have resulted in the shift in the fish and benthic macroinvertebrate community structure in the Bush River watershed. The combined AR for all the stressors is approximately 97%, suggesting that altered hydrology/sediment, instream and riparian habitat, and water chemistry stressors adequately account for the biological impairment in the Bush River watershed.

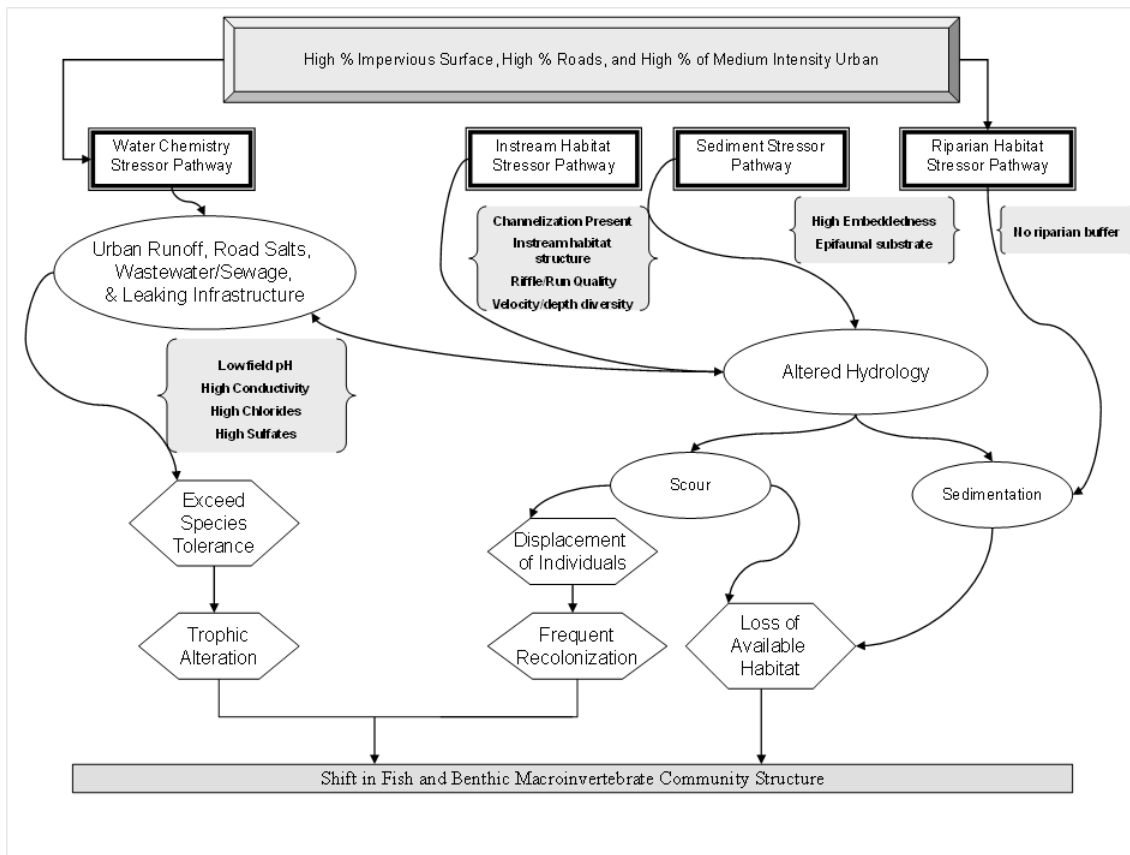
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The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of 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 2009). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the Bush River 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 Bush River Watershed**

### 5.0 Conclusions

Data suggest that the Bush River watershed’s biological communities are influenced by urban land use. This land use alters the hydrologic regime of a watershed resulting in increased habitat homogeneity. 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 contaminant loads from

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runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Bush River watershed are summarized as follows:

- The BSID process has determined that biological communities in Bush River watershed are likely degraded due to altered flow/sediment and instream habitat related stressors. Specifically, anthropogenic sources have resulted in altered habitat heterogeneity and possible elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sediment for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Bush River watershed. The BSID results further confirm that the establishment of a sediment TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediment to the biological communities in the Bush River watershed.
- The BSID process has determined that the biological communities in the Bush River watershed are likely degraded due to inorganics (i.e., chloride and sulfate). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in approximately 95% and 58% respectively of the stream miles with poor to very poor biological conditions in the Bush River watershed. The BSID results thus support a Category 5 listing of chloride and sulfate 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 Bush River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.
- The BSID process has determined that biological communities in the Bush River watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Bush River watershed based on channelization being present in approximately 59% of degraded stream miles.
- The BSID process has also determined that biological communities in the Bush River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a

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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 Bush River watershed based on inadequate riparian buffer zones in approximately 75% of degraded stream miles.

- The BSID process has determined that biological communities in the Bush River watershed are not degraded due to nutrient related stressors. There are tidal 1996 Category 4a listings for Total Nitrogen and Total Phosphorus, the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the tidal regions of the Bush River watershed.

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