Watershed Report for Biological Impairment of the Georges Creek Watershed, Garrett and Allegany Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AMD	Acid Mine Drainage
ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MD	Maryland
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
μS/cm	Micro Siemens per Centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

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

The Maryland Department of the Environment (MDE) has identified the waters of the Georges Creek watershed (basin number 02141004) as having multiple listings on the State's Integrated Report (Table E1).

Table E1. 2012 Integrated Report Listings for Georges Creek Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Georges Creek	02141004	Non-Tidal	Aquatic Life and Wildlife	1996	BOD nitrogenous & carbonaceous	4a
				1996	TSS	4a
				-	pH, Low	2
				2002	Impacts to Biological Communities	5
				-	Total Phosphorus	2
				-	Total nitrogen	2
			Water Contact Sports	2002	Escherichia coli	4a
		Mainstem	Aquatic Life and Wildlife	2008	pH, Low	4b
		Non-Tidal segments		2002	pH, Low	4a
		Staub Run		2002	pH, Low	4a
		Mill Run		2008	pH, Low	4a
		Jackson Run		2008	pH, Low	4a
		Matthew Run		2008	pH, Low	4a
		Winebrenner Run		2008	pH, Low	4a
		Multiple Segments		-	pH, Low	2

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Georges Creek and its tributaries are designated as Use III-P - *water contact recreation, and protection of aquatic life and public water supply,* and for the mainstem until the confluence with the North Branch Potomac River is designated as Use IV-P - *recreational trout waters and public water supply.* In addition, COMAR requires all waterbodies to support at a minimum the Use I designation - *water contact recreation, protection of nontidal warmwater aquatic life* (COMAR 2013 a, b). The Georges Creek watershed is not attaining its Use I designation because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, which will enable 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 Georges Creek watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled "Maryland Biological Stressor Identification Process" (MDE 2009). Data suggest that biological communities in Georges Creek are moderately influenced by inorganic urban chemical pollutants, acidity, and insufficient instream habitat. Independently, these three stressor groups appear to influence about the same proportion of degraded stream miles, between 37% and 43%. Collectively however, all chemical pollutants (urban and acidity related) impact 83%. This data suggests that reducing chemical pollutants could restore 83% of the impaired stream miles in the Georges Creek watershed. The combined AR for all stressor groups is 93%, suggesting that stressors revealed in this analysis impact the majority of impairments in the basin.

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

- The BSID process has determined that the biological communities in the Georges Creek watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, urban and transportation land use practices have resulted in the potential elevation of chloride inputs throughout the watershed, which are in turn, the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of chloride for the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Georges Creek watershed. Discharges of inorganic compounds like chloride are 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 this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has determined that the biological communities in the Georges Creek watershed are likely degraded due to acidity related stressors including low pH, low acid neutralizing capacity (ANC), and high sulfate concentrations. The probable source of acidity in the Georges Creek watershed is acid mine drainage (AMD) based on a source assessment that compares values of nitrates, sulfates, ANC and conductivity. Since acid mine drainage is present in the Georges Creek watershed, the elevated sulfate levels identified by the BSID analysis are most probably associated with this land use source. Therefore the most appropriate management actions to address this type of impairment involve improving the acidity levels in the watershed. Thus, the BSID results confirm that the establishment of a pH TMDL in 2008 and revised in 2009 was an appropriate management action to begin addressing these stressors to the biological communities in the Georges Creek watershed.

- The BSID process has also determined that poor instream habitat structure and channelization are associated with biological degradation in Georges Creek. This finding suggests that TMDL efforts to reduce pollutant loadings may not be capable of fully restoring biological communities in all stream miles due to the physically reduced variability of substrates and flow patterns within stream channels. Stream restoration projects could increase habitat diversity and biological community structure locally to help fully realize TMDL improvements.

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 2012). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary. A Category 5 listing can be amended to a Category 4a if a TMDL was established and approved by USEPA or Category 4b if other pollution control requirements (*i.e.*, permits, consent decrees, etc.) are expected to attain water quality standards. If the State can demonstrate that 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 the round two Maryland Biological Stream Survey (MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Georges Creek watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Georges Creek Watershed Characterization

2.1 Location

The Georges Creek Watershed encompasses 47,694 acres (75 square miles) in Allegany and Garrett Counties (see Figure 1). The headwaters of Georges Creek begin in Frostburg, Maryland. The main stem of Georges Creek flows southwest until its confluence with the North Branch Potomac River below the Town of Westernport, Maryland. Several tributaries feed the main stem of Georges Creek including Elklick Run, Mill Run, Winebrenner Run, and Koontz Run. The drainage area for the watershed lies between Dans Mountain and Big Savage Mountain. Towns within the watershed area include: Frostburg, Midlothian, Midland, Lonaconing, Barton, Luke, and Westernport. Dans Mountain State Park and portions of the Savage River State Forest also lie within the Georges Creek Watershed. The watershed is located in the Highland region, one of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

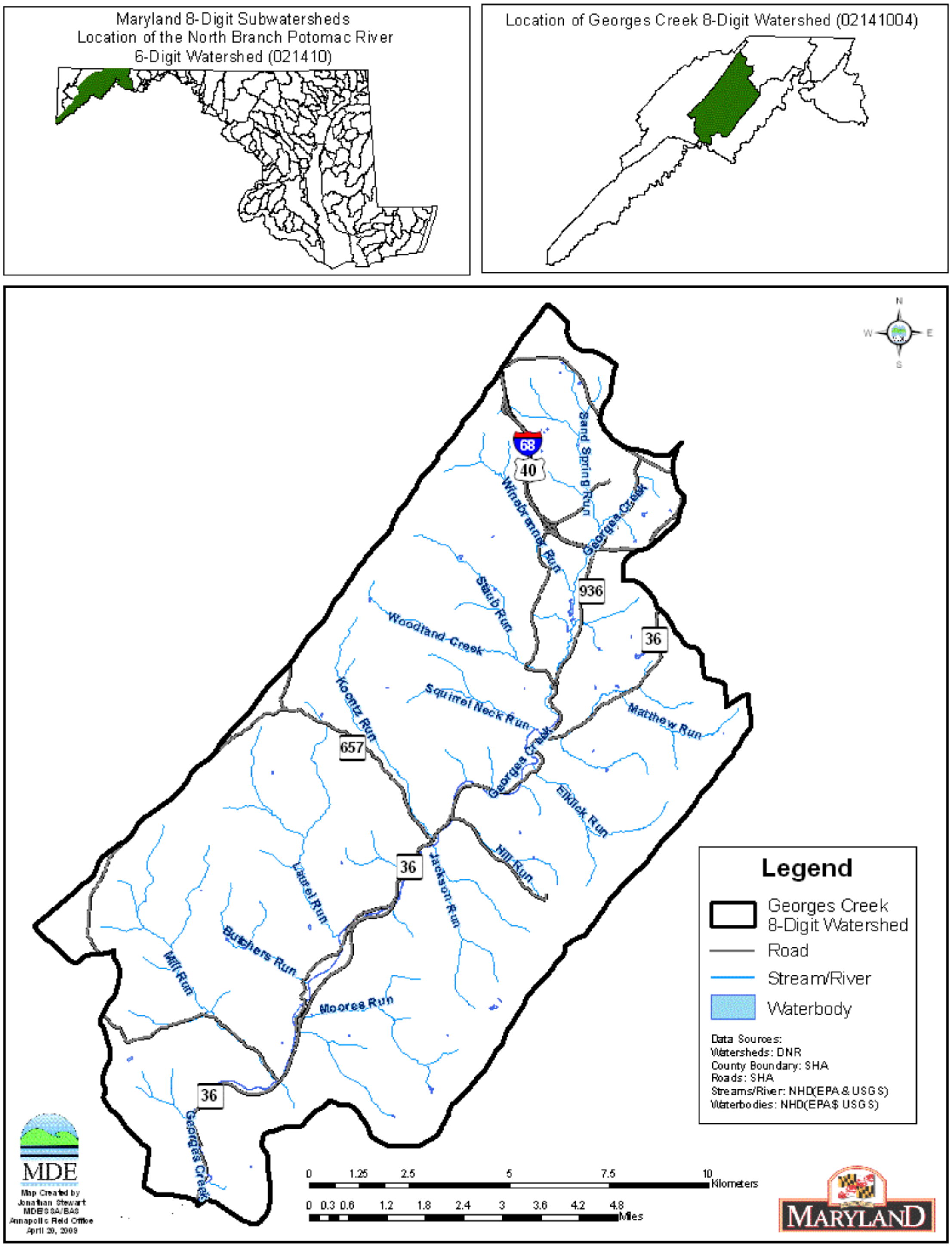

Figure 1. Location Map of the Georges Creek Watershed

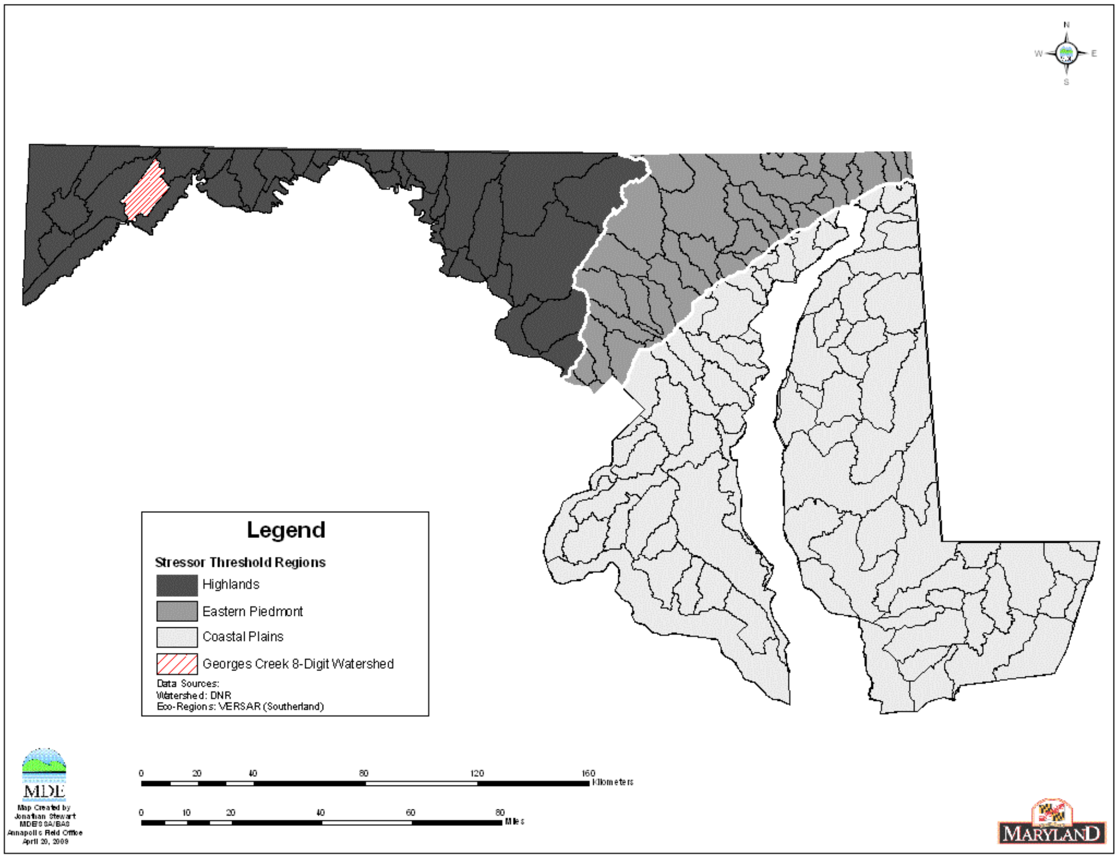

Figure 2. Eco-Region Location Map of the Georges Creek Watershed

2.2 Land Use

Georges Creek and its tributaries flow through several towns including Frostburg, Midlothian, Midland, Lonaconing, Barton, Luke, and Westernport. Many of these areas were built before modern stormwater runoff controls were required by the State. The predominate land use in the watershed is forest; however, there are localized areas containing urban and agriculture (see Figure 3). The land use distribution in the watershed is approximately 79% forest/herbaceous, 12% urban, 6% agricultural, and 2% extractive (see Figure 4) (USEPA 2010).

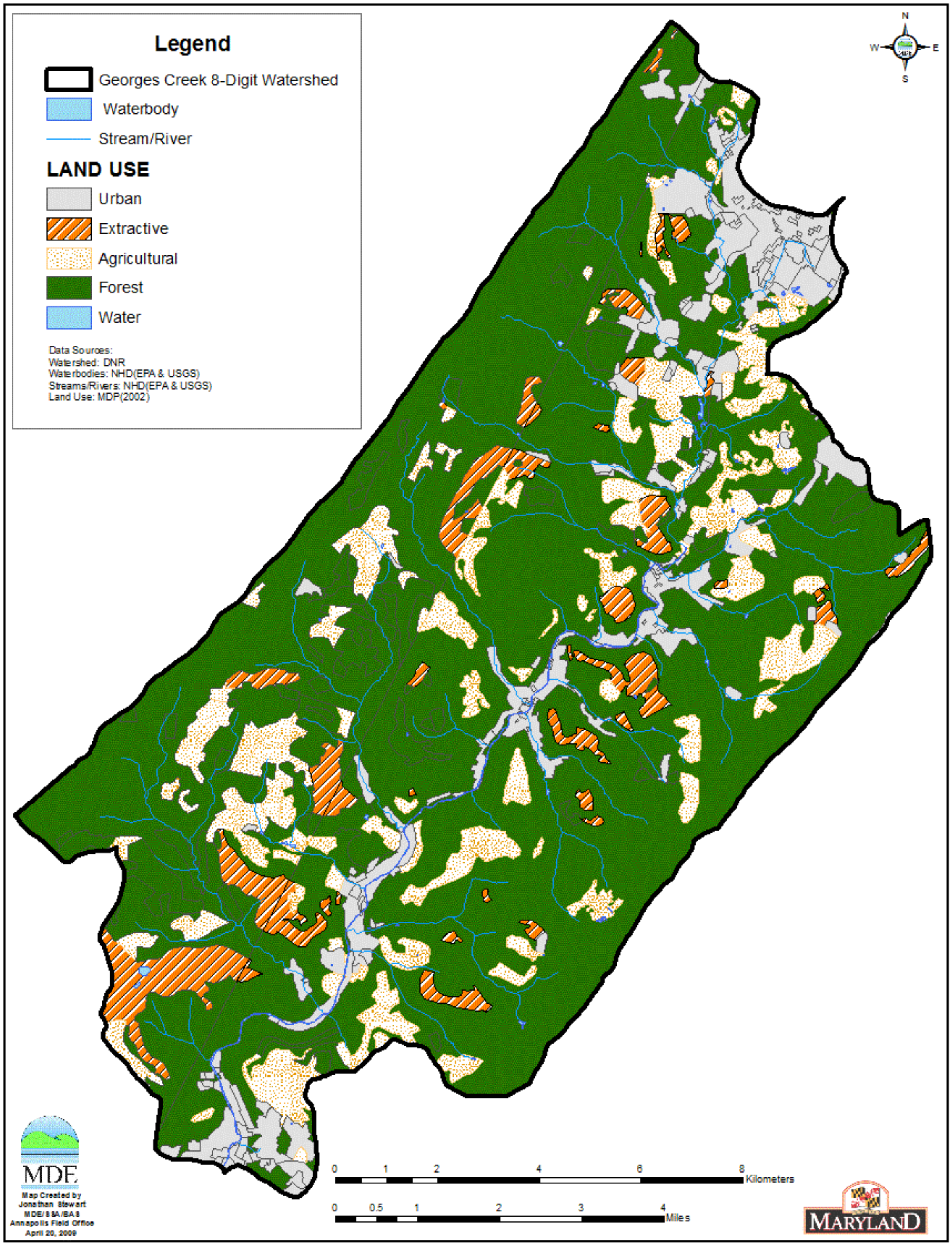

Figure 3. Land Use Map of the Georges Creek Watershed

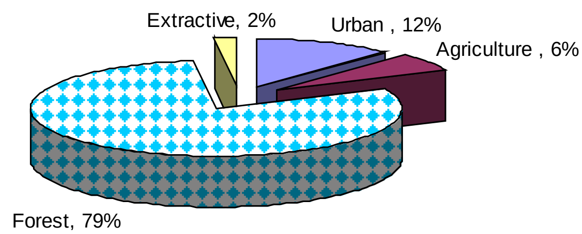

Figure 4. Proportions of Land Use in the Georges Creek Watershed

2.3 Soils/hydrology

The Georges Creek Watershed lies in the Appalachian Plateaus Province of Maryland, and it drains to the North Branch Potomac River. The bedrock of this region consists principally of gently folded shale, siltstone, and sandstone. Folding has produced elongated arches across the region, which exposes Devonian rocks at the surface (MGS 2007). Most of the natural gas fields in Maryland are associated with these anticlinal folds in the Appalachian Plateau. In the intervening synclinal basins, like the Georges Creek basin, coal-bearing strata of the Pennsylvanian and Permian ages are preserved. The topography in the watershed is often steep and deeply carved by winding streams. Georges Creek tributaries carve downward from the 2500 to 2900 feet ridges of Dans Mountain and Backbone Mountain to the North Branch Potomac River in the Town of Westernport at 1000 ft elevation.

The Georges Creek Watershed lies predominantly in the Dekalb soil series. A small portion of the watershed in the southeastern region lies in the Hazleton soil series. The Dekalb soil series consists of moderately deep, well-drained, loamy soils that developed in material weathered in place from sandstone and some conglomerate and shale bedrock. These nearly level to very steep soils are normally found in stony, mountainous regions. Dekalb soils have rapid permeability and internal drainage. The Hazleton soil series consists of deep, well-drained, loamy soils. These soils developed in materials weathered in place from sandstone and shale bedrock. These nearly level to moderately steep soils occur on the top and upper and middle side slopes of hills and mountains. Hazleton soils have moderately rapid permeability and rapid internal drainage (USDA - SCS, 1974 and USDA – NRCS, 1977).

3.0 Georges Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

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					Total nitrogen	2
			Water Contact Sports	2002	Escherichia coli	4a
		Mainstem	Aquatic Life and Wildlife	2008	pH, Low	4b
		Non-Tidal segments		2002	pH, Low	4a
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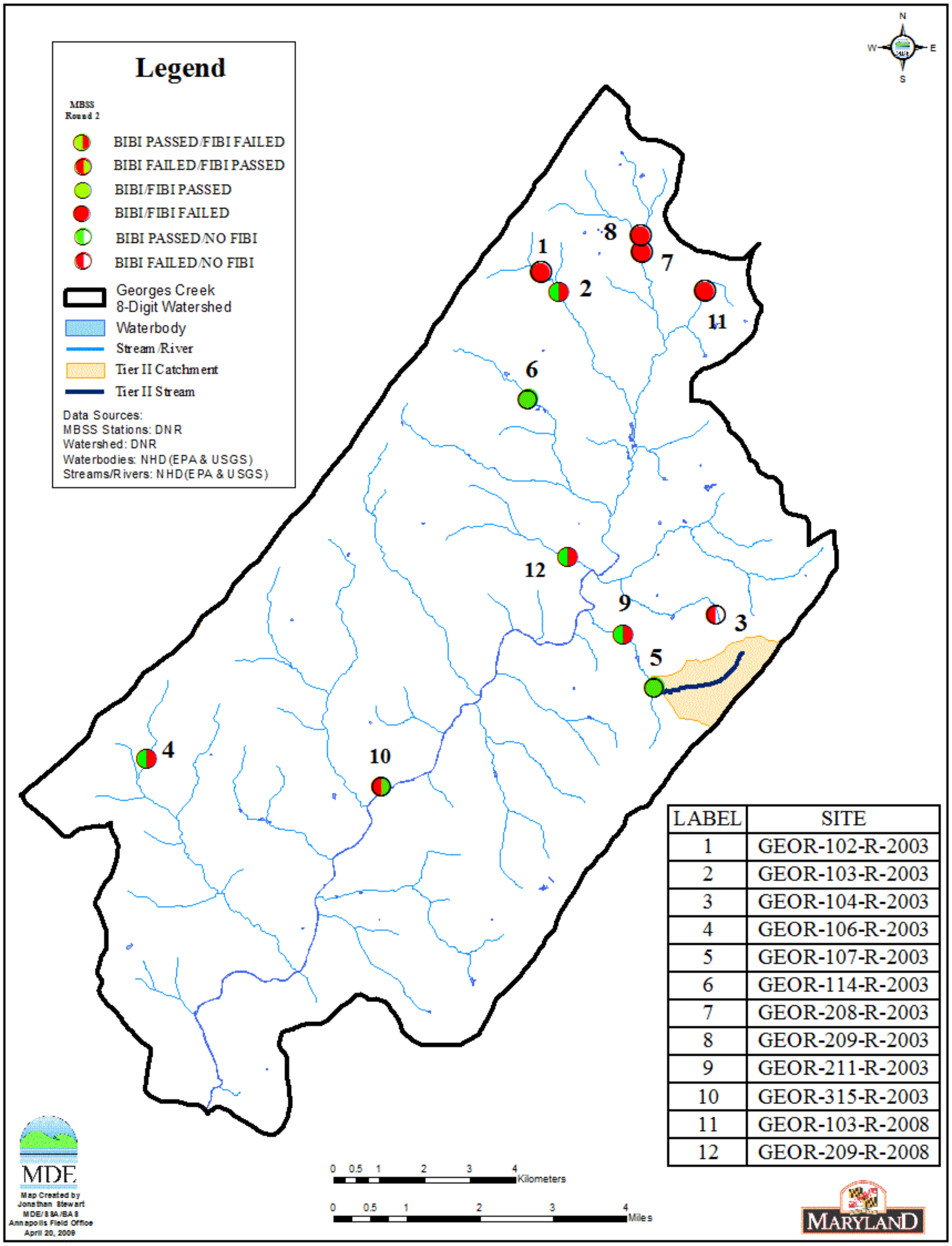
		Matthew Run		2008	pH, Low	4a
		Winebrenner Run		2008	pH, Low	4a
		Multiple Segments			pH, Low	2

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Georges Creek and its tributaries are designated as Use III-P - *water contact recreation, and protection of aquatic life and public water supply*, and for the mainstem until the confluence with the North Branch Potomac River is designated as Use IV-P - *recreational trout waters and public water supply*. In addition, COMAR requires all waterbodies to support at a minimum the Use I designation - *water contact recreation, protection of nontidal warmwater aquatic life* (COMAR 2013 a, b). The Georges Creek watershed is not attaining its use designations because of biological impairments. 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.

There is a small sub-watershed in the Georges Creek watershed that is designated as a Tier II (i.e., Maryland's antidegradation policy) waterbody; this Tier II designation protects surface water that is better than the minimum requirements specified by water quality standards. Georges Creek watershed's Tier II catchment is Elklick Creek (COMAR 2014d).

The Georges Creek watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 79% of stream miles in the Georges Creek basin are estimated as having fish and and/or benthic indices of biological impairment in the very poor to 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 seventeen sites. Fifteen of the seventeen have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, MBSS round two and round three (2000-2009) contains twelve MBSS sites; with ten having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Georges Creek watershed.



LABEL	SITE
1	GEOR-102-R-2003
2	GEOR-103-R-2003
3	GEOR-104-R-2003
4	GEOR-106-R-2003
5	GEOR-107-R-2003
6	GEOR-114-R-2003
7	GEOR-208-R-2003
8	GEOR-209-R-2003
9	GEOR-211-R-2003
10	GEOR-315-R-2003
11	GEOR-103-R-2008
12	GEOR-209-R-2008

Figure 5. Principle Dataset Sites for the Georges Creek Watershed

4.0 Georges Creek Watershed Stressor Identification Results

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

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (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 2009).

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID analysis, MDE identified parameters from sources, habitat, and water chemistry groups as having significant association with degraded fish and/or benthic biological conditions. Parameters identified as representing sources are listed in Table 2. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 4 through Table 6, parameters from two stressor groups were identified as possible biological stressors in the Georges Creek 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 Georges Creek 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	12	10	168	0%	1%	1	No	_
	AMD acid source present	12	10	168	30%	5%	0.017	Yes	25%
	Organic acid source present	12	10	168	0%	0%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	12	10	171	0%	11%	0.603	No	_
	High % of agriculture in 60m buffer	12	10	171	0%	6%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	12	10	171	10%	5%	0.442	No	_
	Low % of wetland in watershed	12	10	171	0%	0%	1	No	_
	Low % of forest in 60m buffer	12	10	171	0%	2%	1	No	_
	Low % of wetland in 60m buffer	12	10	171	0%	0%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	12	10	171	10%	5%	0.408	No	_
	High % of impervious surface in 60m buffer	12	10	171	40%	12%	0.029	Yes	28%
	High % of roads in watershed	12	10	171	30%	8%	0.055	Yes	22%
	High % of roads in 60m buffer	12	10	171	10%	8%	0.589	No	_
Sources - Urban	High % of high-intensity developed in watershed	12	10	171	10%	2%	0.25	No	_
	High % of low-intensity developed in watershed	12	10	171	10%	3%	0.292	No	_
	High % of medium-intensity developed in watershed	12	10	171	10%	4%	0.333	No	_
	High % of early-stage residential in watershed	12	10	171	40%	6%	0.005	Yes	34%
	High % of residential developed in watershed	12	10	171	10%	3%	0.292	No	_
	High % of rural developed in watershed	12	10	171	0%	3%	1	No	_
	High % of high-intensity developed in 60m buffer	12	10	171	40%	1%	0	Yes	39%

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	12	10	171	30%	5%	0.021	Yes	25%
	High % of medium-intensity developed in 60m buffer	12	10	171	20%	1%	0.016	Yes	19%
	High % of early-stage residential in 60m buffer	12	10	171	40%	4%	0.001	Yes	36%
	High % of residential developed in 60m buffer	12	10	171	30%	5%	0.021	Yes	25%
	High % of rural developed in 60m buffer	12	10	171	0%	7%	1	No	_

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

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Acidity	25%
Sources - Impervious	31%
Sources - Urban	39%
All Sources	***48%***

4.1 Sources Identified by BSID Analysis

All nine source parameters identified in the BSID analysis for the Georges Creek watershed are representative of impacts from urban and/or anthropogenic landscapes. The watershed contains numerous small urban centers that intermittently crowd the narrow Georges Creek valley for most of its length. The largest urban areas are the City of Frostburg and Town of Westernport. Most of these areas were established between the 1800s and early 1900s coincident with coal mining activities and before modern stormwater runoff controls were required by the State. Coal is central to Georges Creek's past, present, and future. Production of coal from deep mining peaked in 1910 (Allegany County 2011). There are a number of extractive surface mining activities still active today, but coal mining legacy impacts have much greater overall influence on biological conditions within the basin.

The BSID source analysis (Table 2) identifies various types of urban land uses, the majority of which reflect the close proximity of urban infrastructure to waterways in the basin (within 60 meters). The results suggest that urban land use is associated with approximately 39% of degraded streams miles in the Georges Creek watershed. Impervious surface sources, although similar to urban, are grouped separately in the analysis and are associated with 31% of degraded stream miles. Acidity from acid mine drainage (AMD) impacts approximately 25% of the degraded stream miles. The combined AR for all source groups is approximately 48%, suggesting these sources impact a moderate proportion of the degraded stream miles in Georges Creek (Table 3).

The remainder of this section will discuss the eight stressors identified by the BSID analysis (Table 4, 5, and 6) and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for Georges Creek Watershed

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sediment	Extensive bar formation present	12	10	82	0%	8%	1	No	_
	Moderate bar formation present	12	10	85	20%	40%	0.312	No	_
	Channel alteration moderate to poor	10	8	67	25%	41%	0.465	No	_
	Channel alteration poor	10	8	67	0%	7%	1	No	_
	High embeddedness	12	10	82	10%	2%	0.26	No	_
	Epifaunal substrate marginal to poor	12	10	82	30%	16%	0.374	No	_
	Epifaunal substrate poor	12	10	82	10%	1%	0.164	No	_
	Moderate to severe erosion present	12	10	83	0%	26%	0.123	No	_
	Severe erosion present	12	10	83	0%	2%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Georges Creek 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	12	10	86	30%	10%	0.085	Yes	20%
	Concrete/gabion present	12	10	75	0%	3%	1	No	_
	Beaver pond present	12	10	82	0%	1%	1	No	_
	Instream habitat structure marginal to poor	12	10	82	30%	17%	0.373	No	_
	Instream habitat structure poor	12	10	82	10%	0%	0.057	Yes	10%
	Pool/glide/eddy quality marginal to poor	12	10	82	50%	42%	0.726	No	_
	Pool/glide/eddy quality poor	12	10	82	10%	4%	0.387	No	_
	Riffle/run quality marginal to poor	12	10	82	20%	27%	1	No	_
	Riffle/run quality poor	12	10	82	0%	5%	1	No	_
	Velocity/depth diversity marginal to poor	12	10	82	50%	48%	1	No	_
	Velocity/depth diversity poor	12	10	82	0%	5%	1	No	_
Riparian Habitat	No riparian buffer	10	8	69	25%	19%	0.645	No	_
	Low shading	12	10	82	10%	5%	0.425	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Georges Creek 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	12	10	171	30%	6%	0.032	Yes	24%
	High conductivity	12	10	171	40%	8%	0.01	Yes	32%
	High sulfates	12	10	171	30%	8%	0.047	Yes	22%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	12	10	165	0%	2%	1	No	_
	Dissolved oxygen < 6mg/l	12	10	165	0%	5%	1	No	_
	Low dissolved oxygen saturation	12	10	165	0%	7%	1	No	_
	High dissolved oxygen saturation	12	10	165	10%	4%	0.343	No	_
	Ammonia acute with salmonid present	12	10	171	0%	0%	1	No	_
	Ammonia acute with salmonid absent	12	10	171	0%	0%	1	No	_
	Ammonia chronic with early life stages present	12	10	171	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	12	10	171	0%	0%	1	No	_
	High nitrites	12	10	171	0%	6%	1	No	_
	High nitrates	12	10	171	0%	6%	1	No	_
	High total nitrogen	12	10	171	0%	6%	1	No	_
	High total phosphorus	12	10	171	10%	8%	0.589	No	_
	High orthophosphate	12	10	171	0%	8%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	12	10	171	30%	5%	0.021	Yes	25%
	Low field pH	12	10	165	40%	11%	0.024	Yes	29%
	High field pH	12	10	165	0%	1%	1	No	_
	Low lab pH	12	10	171	30%	5%	0.021	Yes	25%
	High lab pH	12	10	171	0%	2%	1	No	_

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

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Instream Habitat	37%
Chemistry - Inorganic	43%
Chemistry - pH	34%
All Chemistry	83%
All Stressors	***93%***

4.2 Stressors Identified by BSID Analysis

Sediment Conditions

BSID analysis results for the Georges Creek watershed did not identify any sediment related stressor parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 4).

In-stream Habitat Conditions

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

Channelization present was identified as significantly associated with degraded biological conditions and found in 20% of the degraded stream miles in Georges Creek. This stressor measures the presence/absence of channelization in stream banks and its presence is a metric for the channel alteration rating. It describes both the straightening of channels and their fortification with concrete or other hard materials. Channelization inhibits the natural flow regime of a stream resulting in increased flows during storm events that can lead to scouring and, consequently, displacement of biological communities. The resulting bank/channel erosion creates unstable channels and excess sediment deposits downstream.

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

Channelization has been used in the Georges Creek watershed 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 Schellberg 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). Consequently, streams with extensive channelization often have impaired biological community with poor IBI scores is observed.

Some of the typical consequences of channelization may also be exaggerated in the Georges Creek watershed. Discharge extremes (higher high flows and lower low flows) are increased as water is transported through a basin more rapidly through channelized corridors. Low flows in the upper 1/3 of the watershed are potentially more extreme due to groundwater removal accomplished by the Hoffman Drainage Tunnel. The Hoffman Drainage tunnel is a two- mile long, ~8ft diameter drain constructed in the early 1900s to allow access to submerged coal seams in the Georges Creek basin. The tunnel extends from Shaft (above Woodland Creek) through Dans Mountain to the Braddock Run basin. The tunnel is registered as a historic site AL-V-A-053 (Maryland Historical Trust 1977).

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

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 37% suggesting this stressor impacts a moderate proportion of the degraded stream miles in the Georges Creek (See Table 7).

Riparian Habitat Conditions

BSID analysis results for the Georges Creek watershed did not identify any riparian habitat related stressor parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 5).

Water Chemistry

BSID analysis results for the Georges Creek identified six water chemistry parameters that have 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, acid neutralizing capacity below chronic level (ANC), low field pH, and low lab pH.*

High chlorides concentration was identified as significantly associated with degraded biological conditions and found in approximately 24% (*high* rating) of the stream miles with poor to very poor biological conditions in the Georges Creek watershed. Chloride can play a critical role in the elevation of conductivity. Chloride in surface waters can result from both natural and anthropogenic sources, such as run-off containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, and irrigation drainage.

High conductivity levels were 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 Georges Creek 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. Conductivity can serve as an indicator that a pollution discharge or some other source of inorganic contaminant has entered a stream. Increased levels of inorganic pollutants can be toxic to aquatic organisms and lead to exceedences in species tolerances. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions, such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban and agricultural runoffs (i.e., fertilizers), septic drainage, as well as leaking wastewater infrastructure are typical sources of inorganic compounds. There are more than 300 private septic systems located within the Georges Creek Region (Allegany County 2011). Georges Creek, falling in the Highland region, is a limestone influenced stream in which higher conductivity levels above 300 µS/cm are not uncommon. In the Highland region, where limestone influenced streams are prevalent, the conductivity threshold has been set at 500 µS/cm.

High sulfates concentration was identified as significantly associated with degraded biological conditions and found in 22% of the stream miles with poor to very poor biological conditions in the Georges Creek watershed. Sulfates can play a critical role in the elevation of conductivity. Other detrimental impacts of elevated sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. Typically sulfates derived from agricultural landscapes are associated with fertilizers which often contain various types and concentrations of sulfate anions. Due to the historical and present day coal mining activities in the watershed, AMD is the likely source of elevated sulfates.

Heavily traveled road routes in the Georges Creek watershed include Interstate 68, Route 40, and Route 36. Route 36 follows Georges Creek between Frostburg and Westernport, including several bridge crossings. Application of road salts in the watershed is a likely source of the chlorides. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith, Alexander, and Wolman 1987). For surface waters associated with roadways or storage facilities, episodes of salinity have been reported during the winter and spring in some urban watercourses in the range associated with acute toxicity in laboratory experiments (EC 2001). These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 meters on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. On-site septic systems, sanitary sewage overflows, and stormwater discharges are quite frequent in the watershed and are also likely sources of elevated concentrations of chloride, sulfates, and conductivity. Surface flows due to the high imperviousness of the watershed are also a factor.

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

Low field & lab pH levels below 6.5 was identified as significantly associated with degraded biological conditions in the Georges Creek watershed, and found to impact approximately 29% (field) and 25% (lab) of the stream miles with poor to very poor biological conditions. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations in COMAR (2013c). Many biological processes, such as reproduction, cannot function in acidic waters. Acidic conditions also aggravate toxic contamination problems because sediments release toxicants (such as copper, zinc, nitrite and aluminum) in acidic waters. Some types of plants and animals are able to tolerate acidic waters. Others, however, are acid-sensitive and will be lost as the pH declines. Generally, the young of most species are more sensitive to environmental conditions than adults. At pH 5, most fish eggs cannot hatch. At lower pH levels, some adult fish die (USEPA 2008). Common sources of acidity include mine drainage, atmospheric deposition, runoff from mine tailings, agricultural fertilizers, and natural organic sources.

Low ANC below chronic level was identified as significantly associated with degraded biological conditions in the Georges Creek watershed and found in approximately 25% of the stream miles with poor to very poor biological conditions. Acid neutralizing capacity (ANC) is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids. ANC can be used as an index of the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. Repeated additions of acidic materials, like those found in AMD, generally cause a decrease in ANC. ANC values less than 50µeq/l are considered to demonstrate chronic (highly sensitive to acidification) exposures for aquatic organisms, and values less than 200 are considered to demonstrate episodic (sensitive to acidification) exposures (Kazyak et al 2005, Southerland et al 2007).

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 83% suggesting these stressors are the probable causes of biological impairments in the Georges Creek (Table 7).

4.3 Discussion of Stressors Identified by BSID Analysis

The historical as well as present day coal mining activities in the Georges Creek watershed have had significant impacts on water quality and stream habitats; however, environmental impacts from coal mining are complex and not easily remediated. The percentages of impacts to biological communities from the three distinct stressor pathways (acidity, inorganics, and habitat degradation) are all similar. Therefore, it may be good to reflect with broad perspective to visualize the best achievable pathway to healthier streams in the basin. Coal mining activity is the prominent reason why most groundwater and surface water in Georges Creek is acidic. It is also the reason why residential development is concentrated in a narrow river valley, resulting in stream bank fortification and channelization. To accommodate coal mining in the area, transportation corridors were built and high traffic flow through the Georges Creek watershed continues today. Coal is linked directly or indirectly to all of the variables that are empirically associated with degraded stream biology in this analysis. The challenge is to decipher multiple degradation pathways to enable precise and effective relief to the aquatic life in Georges Creek.

Due to the history of mining activities in the Georges Creek watershed it was not unexpected that acidity plays a role in observed biological impairments (AR 34%). In fact, what may be more surprising is that according to BSID results acidity could be less responsible for impairments than other inorganic pollutants originating from urban land use (AR 43%). Even the physical condition of in-stream habitat could have more influence than acidity (AR 37%). Although acidity is slightly less responsible for biological impairments, the role of acidity in biological remediation is perhaps more important because we fully understand the sources, mechanisms, and controls. Technology is getting more efficient and advanced consequently acid remediation projects have been highly successful as compared to addressing urban runoff or stream habitat restorations. The pH TMDL approved in 2008 and revised in 2009 will guide these efforts.

In contrast to acidity, other inorganic pollutants originating from transportation corridors, urban stormwater, and septic systems have very complex associations with stream biology. Elevated chloride concentrations have been identified as a probable biological stressor, and the BSID process supports continued efforts to understand the chloride degradation pathway. The State of Maryland is in the process of developing management actions to begin addressing chloride impairments and provide future opportunities for remediation and protection from this pollutant.

Habitat is the third side of the stressor triangle along with acidity and inorganics as identified by this BSID, affecting 37% of Georges Creek's biological impairments. Impacts from urban development in the watershed especially along the stream banks and stream channel have lead to the degradation of steam habitat. Stream restorations along with removal of chemical stressors could allow biological improvements in a substantial portion of the watershed. Stream restorations could also help alleviate sediment impairments that materialize in downstream areas. This BSID did not identify any sediment stressors likely because sediment is quickly and efficiently delivered downstream due to naturally high currents which are accelerated by channelized streams. Reconnection of flood plains to the stream would slow storm flows, create sediment traps along the stream corridor, and increase habitat diversity.

Another potential stress on stream habitat in the Georges Creek watershed, in addition to channelized streams, is water table modification. By lowering the water table in the upper third of the basin, the Hoffman Drainage Tunnel likely reduces natural groundwater contributions to stream flow into Georges Creek and its tributaries above and including Woodland Creek. Any groundwater recharge areas along these streams may even result in additional loss of flow. The predisposition of streams for low or no flow conditions may episodically concentrate chemical pollutants as well as reduce available habitat, thus potentially influencing the overall success of remediation efforts.

Independently, these three stressor groups appear to influence about the same proportion of degraded stream miles, between 34%, and 43%. Collectively however, the combined AR for all stressor groups is 93%, suggesting that stressors revealed in this analysis impact the majority of impairments in the basin (Table 7). Management actions required to restore biological community diversity in Georges Creek watershed would have to focus on both habitat restoration and reduction of chemical pollutants.

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

4.4 Final Causal Model for the Georges Creek Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991, and USEPA-CADDIS 2013). 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 causal model for the Georges Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

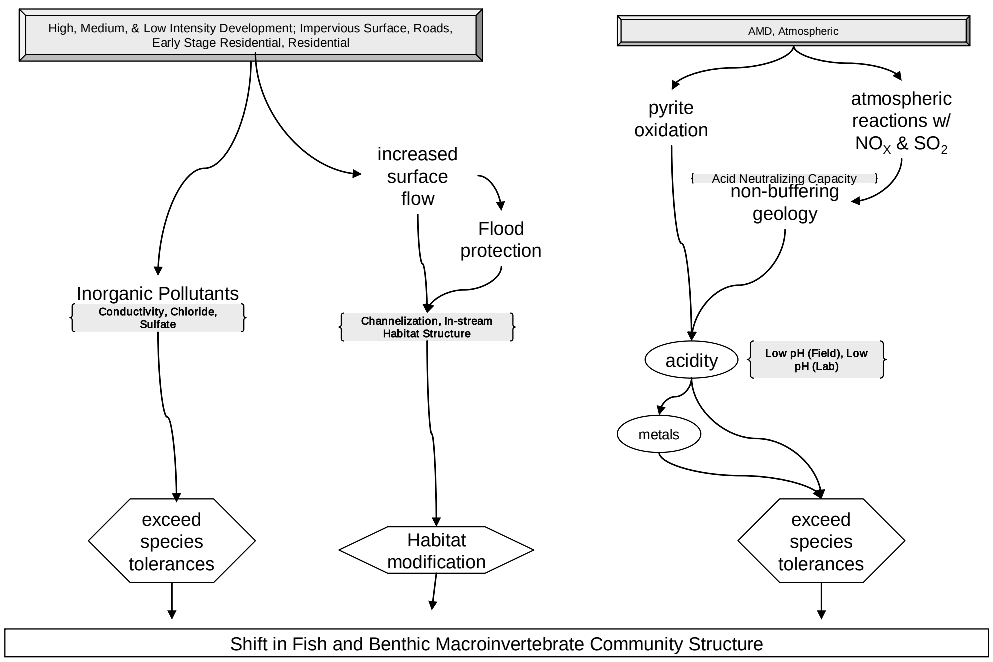


Figure 6. Final Causal Model for the Georges Creek Watershed

5.0 Conclusion

Data suggest that acidity, inorganic pollutants, channelization, and low in-stream habitat diversity are the probable cause of biological community degradation in the Georges Creek watershed. The historical as well as present day coal mining activities in the Georges Creek watershed have had significant impacts on water quality and stream habitats.

Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Georges Creek are summarized as follows:

- The BSID process has determined that the biological communities in the Georges Creek watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, urban and transportation land use practices have resulted in the potential elevation of chloride inputs throughout the watershed, which are in turn, the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of chloride for the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Georges Creek watershed. Discharges of inorganic compounds like chloride are 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 this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has determined that the biological communities in the Georges Creek watershed are likely degraded due to acidity related stressors including low pH, low acid neutralizing capacity (ANC), and high sulfate concentrations. The probable source of acidity in the Georges Creek watershed is acid mine drainage (AMD) based on a source assessment that compares values of nitrates, sulfates, ANC, and conductivity. Since acid mine drainage is present in the Georges Creek watershed, the elevated sulfate levels identified by the BSID analysis are most probably associated with this land use source. Therefore the most appropriate management actions to address this type of impairment involve improving the acidity levels in the watershed. Thus, the BSID results confirm that the establishment of a pH TMDL in 2008 and revised in 2009 was a appropriate management action to begin addressing these stressors to the biological communities in the Georges Creek watershed.

- The BSID process has also determined that poor instream habitat structure and channelization are associated with biological degradation in Georges Creek. This finding suggests that TMDL efforts to reduce pollutant loadings may not be capable of fully restoring biological communities in all stream miles due to the physically reduced variability of substrates and flow patterns within stream channels. Stream restoration projects could increase habitat diversity and biological community structure locally to help fully realize TMDL improvements.

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