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

REVISED FINAL

DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

June 2009
Revised: February 2012

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AMD	Acid Mine Drainage
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
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NPDES	National Pollution Discharge Elimination System
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
US EPA	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 (US EPA) 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.

The Wills Creek (basin number 02141003), located in Allegany and Garrett Counties, was identified on the State's Integrated Report as impaired by nutrients (1996 listing), sediments (1996 listing), toxics - cyanide (1996 listing), pH (1998, 2002, 2004, and 2006 listings), bacteria (2002 listing), and impacts to biological communities (2002 listing) (MDE 2008). The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. A WQA for low pH was completed in 2005 to address the 1998 and 2004 listings, and a TMDL for low pH was completed in 2007 to address the 2002 and 2006 listings. Also, a WQA of cyanide was completed in 2006. A bacteria TMDL was completed in 2006, and the 1996 sediment listing, which was refined in the 2008 Integrated Report to a listing for total suspended solids, was addressed via a TMDL completed in 2006 as well.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of the Environment (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 Wills Creek is Use IV-P - r*ecreational Trout Waters and Public Water Supply* for the mainstem only and Use III-P - *Nontidal Coldwater and Public Water Supply* for its tributaries (COMAR 2009a,b). The Wills Creek watershed is not attaining its designated use of supporting aquatic life. 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 (MD DNR) Maryland Biological Stream Survey (MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services

Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact stressors 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 Wills Creek 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 Wills Creek is strongly influenced by urban land use and its concomitant effects: altered hydrology and elevated levels of sulfate, chlorides, and conductivity (a measure of the presence of dissolved substances). The urbanization of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation 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 Wills Creek can be summarized as follows:

- The BSID process has determined that the biological communities in Wills Creek are likely degraded due to inorganic pollutants (chlorides, conductivity, and sulfate). Inorganic pollutants levels are significantly associated with degraded biological conditions and are found to be impacting approximately 59% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. Impacts on water quality due to conductivity, chlorides, and sulfates are dependent on prolonged exposure; future monitoring of these inorganic pollutants will help in determining the spatial and temporal extent of this impairment in the watershed. Urban runoff causes an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) of impairment.

- The BSID process has determined that biological communities in Wills Creek are also likely degraded due to flow/sediment related stressors. Sediment and in-stream habitat stressors are significantly associated with degraded biological conditions and are found to be impacting approximately 31% and 45%, respectively, of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. Specifically, altered hydrology and increased runoff from urban landscapes have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the Integrated Report Category 4a listing for total suspended solids as an impairing substance in Wills Creek, for which a TMDL has been developed, and links this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Wills Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization to be a form of 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 Wills Creek watershed based on channelization being present in approximately 37% of degraded stream miles.

- Although there is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report, the BSID analysis did not identify any nutrient stressors (i.e., total nitrogen, total phosphorus, and dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or 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.

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 of the 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 Wills Creek watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Wills Creek Watershed Characterization

2.1 Location

Wills Creek is located in Allegany and Garrett Counties and flows south from its headwaters in Pennsylvania to its confluence with the North Branch Potomac River at Cumberland, MD (see Figure 1). Jennings Run and Braddock Run are the two main tributaries to Wills Creek, draining western Allegany County and a small portion of northeastern Garrett County. The drainage area of the Maryland portion of the Wills Creek watershed is 38,500 acres. The watershed is located in the highlands region of three distinct eco-regions identified in the MBSS Indices of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

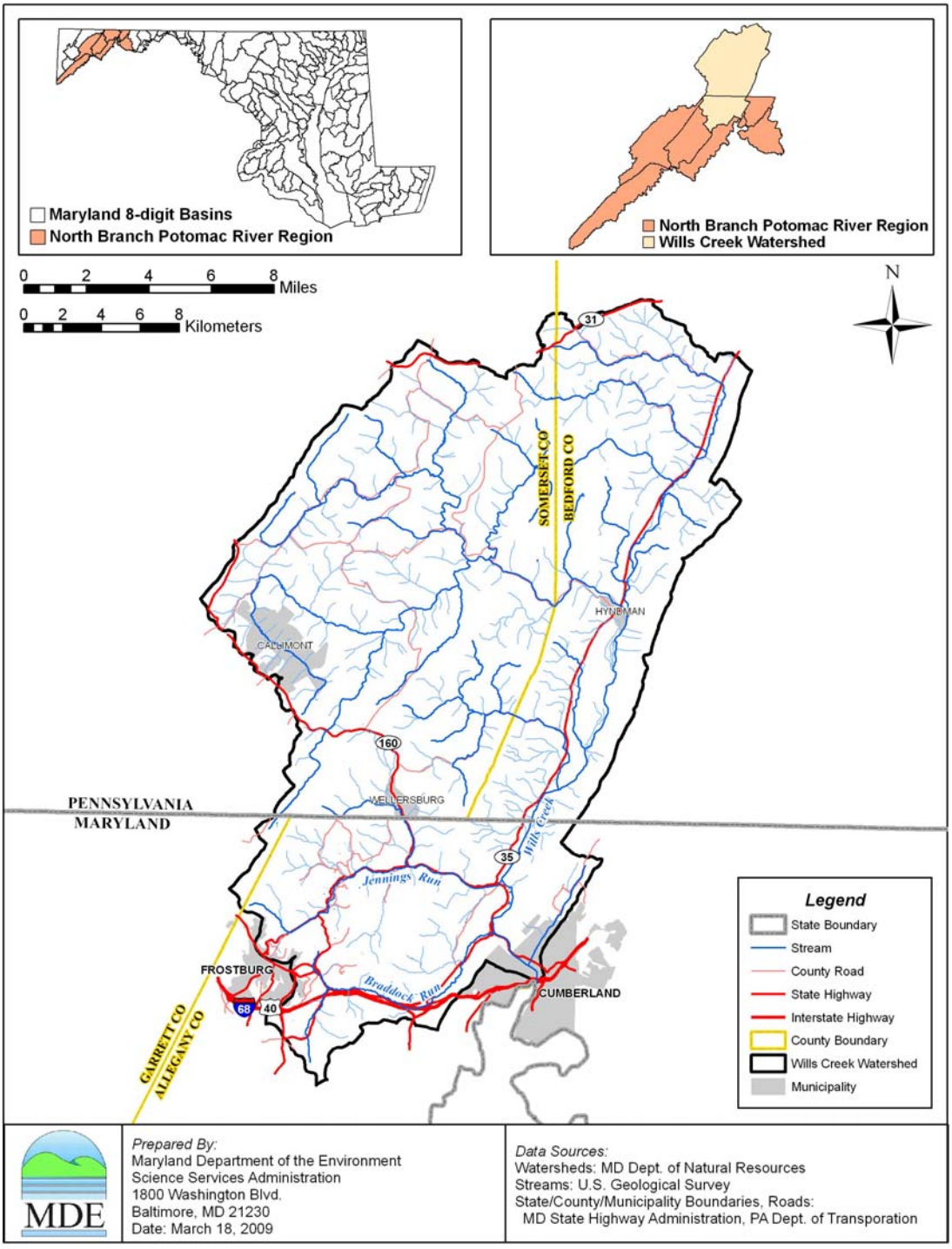

Figure 1. Location Map of Wills Creek Watershed

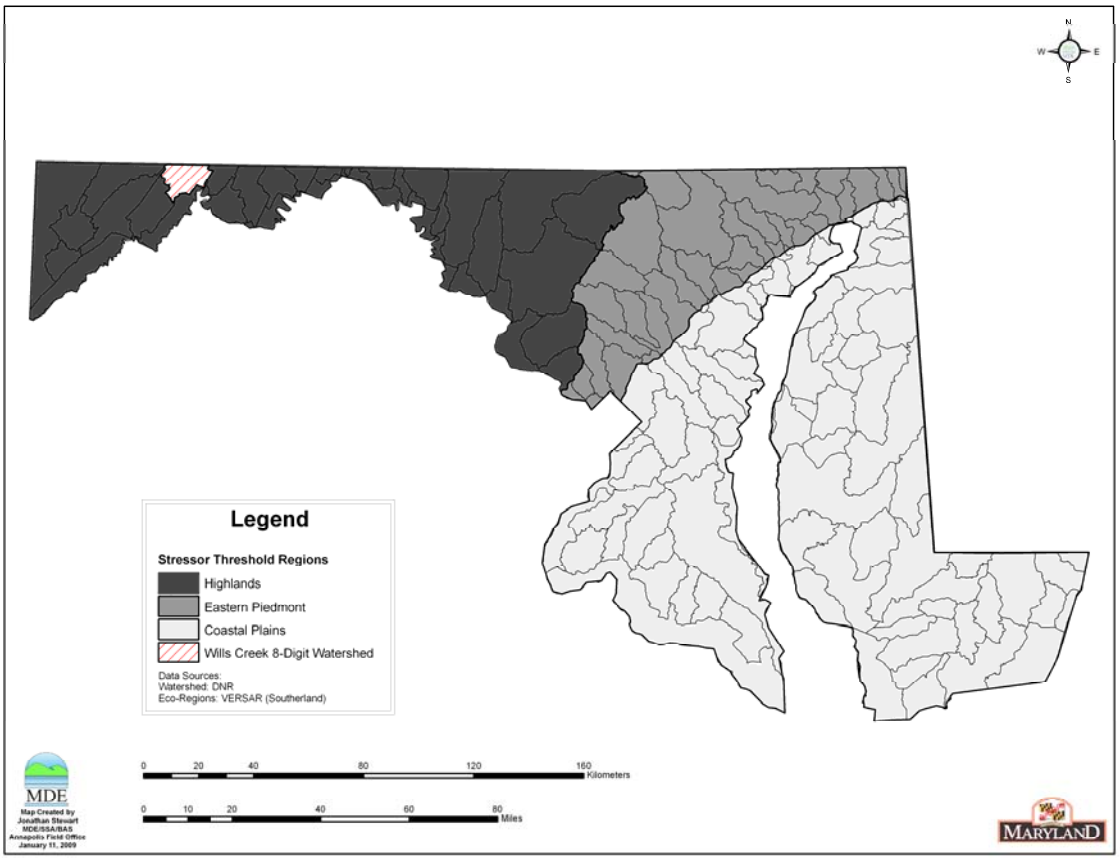

Figure 2. Eco-Region Location Map for Wills Creek Watershed

2.2 Land Use

The primary land use in the Wills Creek watershed is forest/herbaceous. Urban areas are mainly concentrated around the City of Cumberland in the southeast corner of the watershed and the City of Frostburg in the southwest corner of the watershed. The land use distribution in the watershed is 75% forest (28,875 acres), 17% urban (6,545 acres), and 8% mixed agriculture (3,080 acres) (see Figure 3 and Figure 4) (MDP 2002).

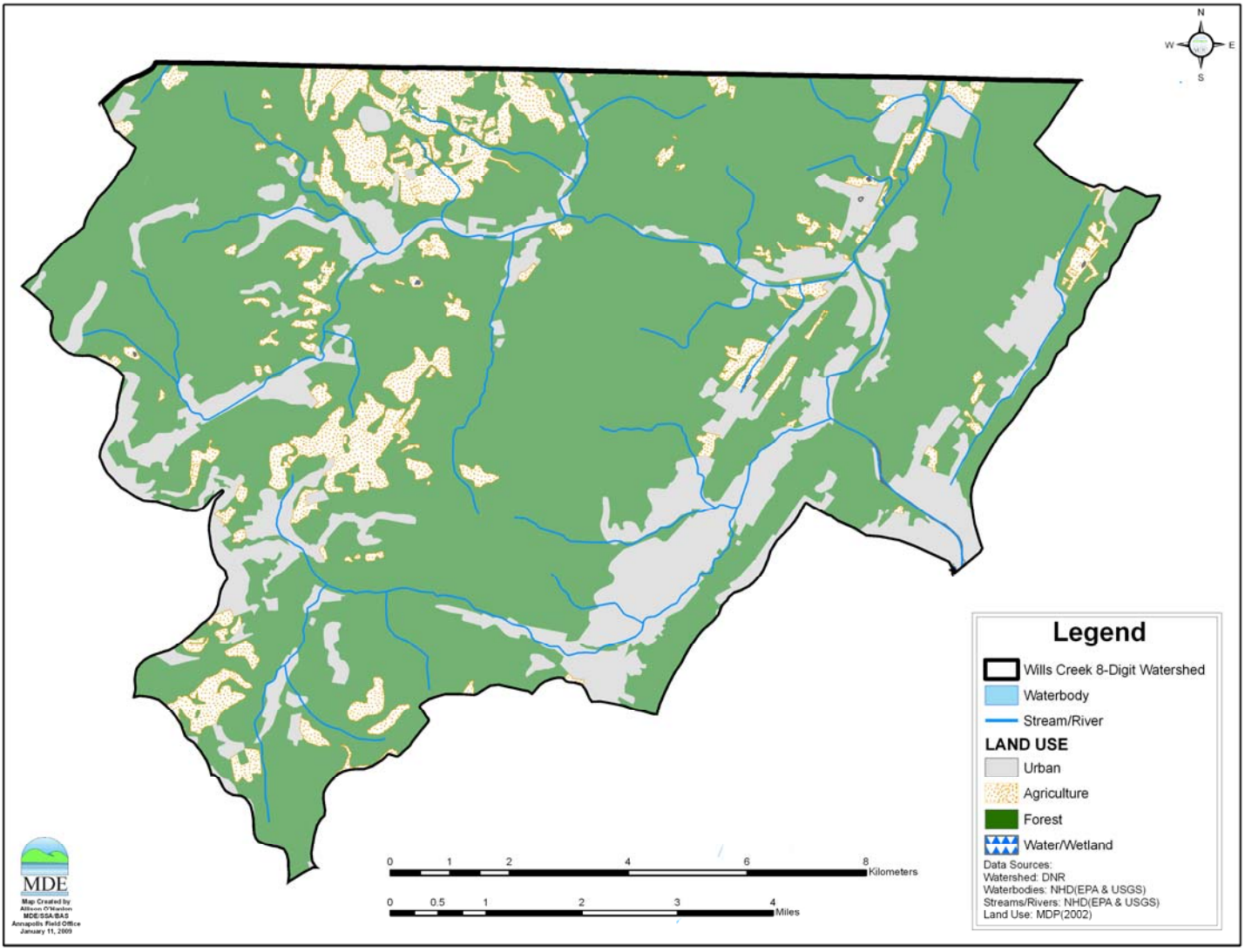

Figure 3. Land Use Map of Wills Creek Watershed

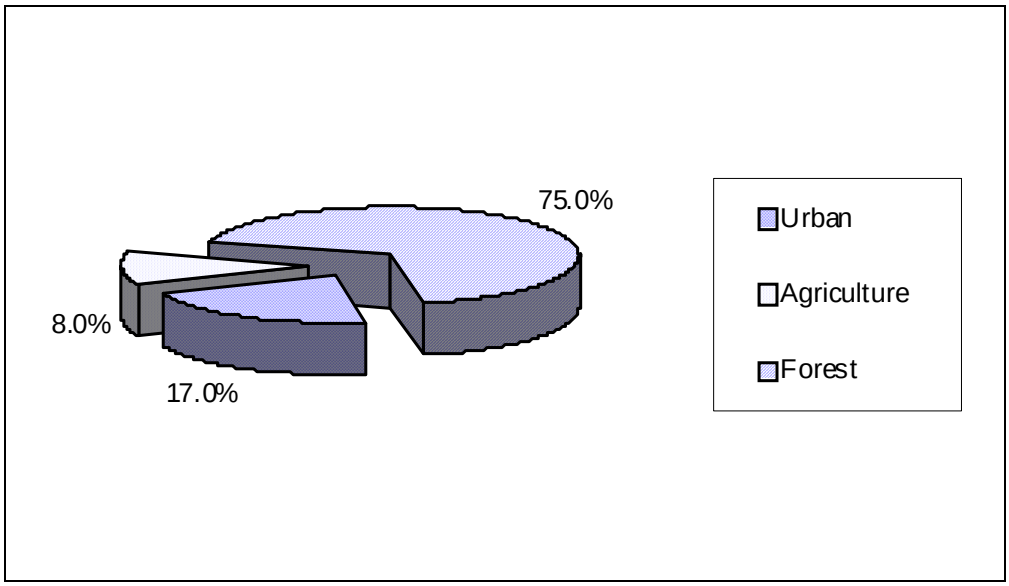

Figure 4. Proportions of Land Use in the Wills Creek Watershed

2.3 Soils/hydrology

The Wills Creek watershed is situated within the Appalachian Plateau and the Ridge and Valley Provinces in western Maryland. The surficial geology of the western portion of the Ridge and Valley Provinces is characterized by strongly folded and faulted sedimentary rock, producing a rugged surface terrain. The surficial geology of the Appalachian Plateau Province is characterized by gently folded shale, siltstone, and sandstone. Folding has produced elongated arches across the region, which exposes Devonian rock at the surface (MGS 2009). Coal-bearing strata are preserved in the intervening synclinal basins of these folds. Consequently, this region in western Allegany County has been a productive source for coal mining. The topography in the watershed is often steep and deeply carved by winding streams, with elevations ranging up to 3,360 feet.

The Wills Creek watershed is comprised of several different soil series including the Dekalb, Ernest and Hazleton 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. The Ernest soil series consists of deep, moderately well-drained,

loamy soils. These nearly level to moderately steep soils formed in materials that accumulated at the base of the steeper slopes. Ernest soils have moderately slow permeability and a moderate available moisture capacity (USDA 1977, 1974).

3.0 Wills Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Wills Creek (basin number 02141003), located in Allegany and Garrett Counties, was identified on the State's Integrated Report as impaired by nutrients (1996 listing), sediments (1996 listing), toxics - cyanide (1996 listing), pH (1998, 2002, 2004, and 2006 listings), bacteria (2002 listing), and impacts to biological communities (2002 listing) (MDE 2008). The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. A WQA for low pH was completed in 2005 to address the 1998 and 2004 listings, and a TMDL for low pH was completed in 2007 to address the 2002 and 2006 listings. Also, a WQA of cyanide was completed in 2006. A bacteria TMDL was completed in 2006, and the 1996 sediment listing, which was refined in the 2008 Integrated Report to a listing for total suspended solids, was addressed via a TMDL completed in 2006 as well.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Wills Creek is Use IV-P - r*ecreational Trout Waters and Public Water Supply* for the mainstem only and Use III-P - *Nontidal Coldwater and Public water Supply* for its tributaries (COMAR 2009a,b). 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. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. 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 Wills Creek watershed is listed under Category 5 of the 2008 Integrated Report as impaired for impacts to biological communities. Approximately 63% of stream miles in the Wills Creek watershed 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 Maryland Department of Natural Resources (MD DNR) MBSS round one (1995-1997) and round two (2000-2004) data, which include sixteen stations. Ten of the sixteen 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 (i.e., MBSS Round 2) contains ten MBSS sites with eight having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Wills Creek watershed.

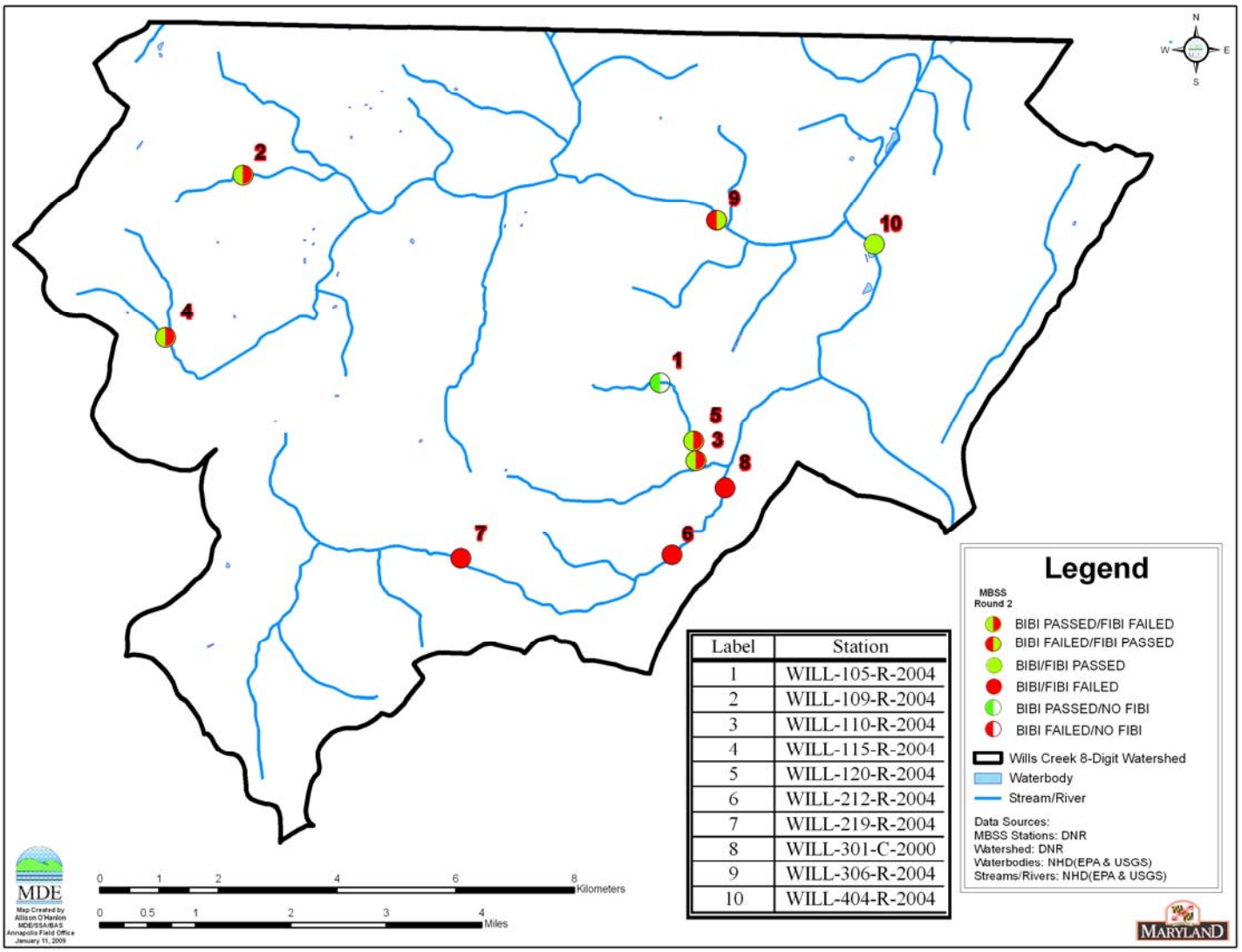

Figure 5. Principal Dataset for Wills Creek Watershed

4.0 Stressor Identification Results

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

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are very poor to 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 very poor to 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 very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to 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).

Through the BSID analysis, MDE identified sediment/in-stream habitat parameters, water chemistry parameters, and potential sources significantly associated with poor to very poor benthic and/or fish biological conditions. As shown in Table 1 through Table 3, parameters from the sediment, in-stream habitat, and water chemistry groups are identified as possible biological stressors in Wills Creek. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. Table 5 shows the summary of combined AR values for the stressor groups in the Wills Creek watershed. Table 6 shows the summary of combined AR values for the source groups in the Wills Creek watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for Wills Creek

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	10	8	80	13%	10%	No	----
	moderate bar formation present	10	8	77	25%	46%	No	----
	bar formation present	10	8	80	75%	89%	No	----
	channel alteration marginal to poor	10	8	77	25%	44%	No	----
	channel alteration poor	10	8	77	13%	10%	No	----
	high embeddedness	10	8	76	13%	3%	No	----
	epifaunal substrate marginal to poor	10	8	77	50%	19%	Yes	31%
	epifaunal substrate poor	10	8	77	13%	3%	No	----
	moderate to severe erosion present	10	8	77	50%	25%	No	----
	severe erosion present	10	8	77	0%	3%	No	----
	poor bank stability index	10	8	77	13%	5%	No	----
	silt clay present	10	8	77	100%	99%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for Wills Creek

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	10	8	80	50%	11%	Yes	39%
	instream habitat structure marginal to poor	10	8	77	13%	21%	No	----
	instream habitat structure poor	10	8	77	0%	2%	No	----
	pool/glide/eddy quality marginal to poor	10	8	77	38%	44%	No	----
	pool/glide/eddy quality poor	10	8	77	13%	6%	No	----
	riffle/run quality marginal to poor	10	8	77	13%	31%	No	----
	riffle/run quality poor	10	8	77	0%	7%	No	----
	velocity/depth diversity marginal to poor	10	8	77	38%	48%	No	----
	velocity/depth diversity poor	10	8	77	0%	7%	No	----
	concrete/gabion present	10	8	80	38%	4%	Yes	34%
	beaver pond present	10	8	77	0%	2%	No	----
Riparian Habitat	no riparian buffer	10	8	80	25%	23%	No	----
	low shading	10	8	77	0%	12%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for Wills Creek

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	10	8	159	0%	8%	No	----
	high total dissolved nitrogen	1	1	50	0%	6%	No	----
	ammonia acute with salmonid present	10	8	159	0%	2%	No	----
	ammonia acute with salmonid absent	10	8	159	0%	1%	No	----
	ammonia chronic with salmonid present	10	8	159	0%	4%	No	----
	ammonia chronic with salmonid absent	10	8	159	0%	2%	No	----
	low lab pH	10	8	159	0%	5%	No	----
	high lab pH	10	8	159	0%	1%	No	----
	low field pH	10	8	154	13%	14%	No	----
	high field pH	10	8	154	0%	0%	No	----
	high total phosphorus	10	8	159	0%	3%	No	----
	high orthophosphate	10	8	159	0%	4%	No	----
	dissolved oxygen < 5mg/l	10	8	154	0%	3%	No	----
	dissolved oxygen < 6mg/l	10	8	154	0%	7%	No	----
	low dissolved oxygen saturation	8	7	138	0%	4%	No	----
	high dissolved oxygen saturation	8	7	138	0%	1%	No	----
	acid neutralizing capacity below chronic level	10	8	159	0%	6%	No	----
	acid neutralizing capacity below episodic level	10	8	159	13%	43%	No	----
	high chlorides	10	8	159	38%	7%	Yes	31%
	high conductivity	10	8	159	38%	4%	Yes	34%
	high sulfates	10	8	159	63%	4%	Yes	59%

Table 4. Stressor Source Identification Analysis Results for Wills Creek

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources	high impervious surface in watershed	10	8	156	0%	1%	No	----
	high % of high intensity urban in watershed	10	8	159	25%	4%	Yes	21%
	high % of low intensity urban in watershed	10	8	159	38%	8%	Yes	30%
	high % of transportation in watershed	10	8	159	38%	9%	Yes	29%
	high % of high intensity urban in 60m buffer	10	8	159	75%	6%	Yes	69%
	high % of low intensity urban in 60m buffer	10	8	159	50%	7%	Yes	43%
	high % of transportation in 60m buffer	10	8	159	75%	9%	Yes	66%
	high % of agriculture in watershed	10	8	159	0%	6%	No	----
	high % of cropland in watershed	10	8	159	0%	6%	No	----
	high % of pasture/hay in watershed	10	8	159	0%	8%	No	----
	high % of agriculture in 60m buffer	10	8	159	0%	6%	No	----
	high % of cropland in 60m buffer	10	8	159	0%	4%	No	----
	high % of pasture/hay in 60m buffer	10	8	159	0%	8%	No	----
	high % of barren land in watershed	10	8	159	0%	7%	No	----
	high % of barren land in 60m buffer	10	8	159	0%	6%	No	----
	low % of forest in watershed	10	8	159	0%	5%	No	----

Table 4. Stressor Source Identification Analysis Results for Wills Creek (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources	low % of forest in 60m buffer	10	8	159	0%	6%	No	----
	atmospheric deposition present	10	8	159	0%	39%	No	----
	AMD acid source present	10	8	159	13%	4%	No	----
	organic acid source present	10	8	159	0%	3%	No	----
	agricultural acid source present	10	8	159	0%	1%	No	----

Table 5. Summary of Combined Attributable Risk Values for the Stressor Groups in the Wills Creek Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	31%	85%
In-Stream Habitat	45%	
Riparian Habitat	----	
Water Chemistry	59%	

Table 6. Summary of Combined Attributable Risk Values for the Source Groups in the Wills Creek Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	70%	70%
Agriculture	----	
Barren Land	----	
Anthropogenic	----	
Acidity	----	

Sediment Conditions

BSID analysis results for Wills Creek identified one sediment parameter that has a statistically significant association with poor to very poor stream biological condition: *epifaunal substrate (marginal to poor).*

Epifaunal substrate (marginal to poor) was identified as significantly associated with degraded biological conditions and found in 31% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. This stressor is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon. Epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates.

Wills Creek and its tributaries pass through the low to high-density urban areas of Eckhart, Mt. Savage, Lavale, and Corriganville. As development and urbanization increased in the Wills Creek watershed so did the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in 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 stream channel widening and streambed scouring. Some of the effects of scouring in streams that experience "flashy" conditions are streambeds that lack woody debris, aquatic vegetation, and other stable substrate. All of these effects are characteristic of marginal to poor epifaunal substrate quality.

Increased flows can also lead 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 et al. 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). An unstable stream ecosystem is often characterized by a continuous displacement of biological communities that require frequent re-colonization, particularly in channelized streams where refuge areas such as rocks and large woody debris are lacking (Winterbourn and Townsend 1991). Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the stressor group indicates that approximately 31% of the biologically degraded stream miles in the Wills Creek watershed are impacted by sediment stressors (Table 5).

In-Stream Habitat Conditions

BSID analysis results for Wills Creek identified two habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *channelization present* and *concrete/gabion.*

Channelization present was identified as significantly associated with degraded biological conditions and found in 39% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. This stressor measures the presence/absence of channelization in stream banks. It describes both the straightening of channels and their fortification with concrete or other hard materials. Channelization inhibits the natural flow regime of a stream resulting in increased flows during storm events that can lead to scouring and, consequently, displacement of biological communities. The resulting bank/channel erosion creates unstable channels and excess sediment deposits downstream.

Concrete/gabion present was identified as significantly associated with degraded biological conditions and found in 34% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. The presence or absence of concrete is determined by a visual observation within the stream segment, resulting from the field description of the types of channelization. Like 'channelization present', concrete inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities.

Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

The stressors identified for in-stream habitat conditions are intricately linked to an altered hydrology, resulting in the loss of habitat heterogeneity in the Wills Creek watershed. Urban development in the Wills Creek watershed is concentrated along streams due to the steep nature of the drainage area. Channelization has been used extensively in urban landscapes like Wills Creek 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 et al. 1998; Haapala & Muotka 1998).

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 stressor group indicates that approximately 45% of the biologically degraded stream miles in the Wills Creek watershed are impacted by in-stream habitat stressors (Table 5).

Riparian Habitat Conditions

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

Water Chemistry

BSID analysis results for Wills Creek identified three water chemistry parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high conductivity*, *high chlorides*, and *high sulfates.*

Conductivity levels were identified as significantly associated with degraded biological conditions and found in approximately 34% of the stream miles with very poor to poor biological conditions in the Wills 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. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2009). Conductivity, chlorides, and

sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity.

High chloride levels were identified as significantly associated with degraded biological conditions and found in approximately 31% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. High concentrations of chlorides can be naturally occurring or result from industrial discharges, metals contamination, and application of road salts in urban landscapes. There are eight National Pollutant Discharge Elimination System (NPDES) permitted point source discharges in the watershed. Three NPDES industrial facilities contain chlorine on their list of permitted discharges; however, there have been no permit violations in the past five years for chlorine.

There are no current Integrated Report listings for metals impairments in Wills Creek. Application of road salts in the watershed is considered a likely source of the chlorides and high conductivity levels. Smith et al. (1997) reported that most of the chloride that enters the environment is associated with the storage and application of road salt. The three MBSS sites that have degraded biological conditions and exceed the target value for chlorides are located in close proximity to Interstate 68, which is a major transportation route through western Maryland. According to Church and Friesz (1993), road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz 1993).

High sulfates concentrations were identified as significantly associated with degraded biological conditions and found in 59% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. There are eight NPDES permitted municipal and industrial discharges in Wills Creek that are regulated for various parameters including metals, temperature, and pH. Since NPDES permitting enforcement does not require sulfate testing at any of these facilities, data was not available to verify/identify sulfate as a specific pollutant in this watershed. Acid Mine Drainage (AMD) waters can contain significant concentrations of sulfate, but sources were not found to be significantly different than the controls. Coal mining is very prevalent in the Appalachian Plateau region.

In summary, water chemistry can be another major determinant of the integrity of surface waters that is strongly influenced by land-use. Land development causes an increase in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, petroleum products, and inorganic pollutants to surface waters. Increased levels of many pollutants like chlorides and sulfates can be toxic to aquatic organisms and lead to exceedences in species tolerances.

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity, chlorides, and 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) from the array of potential inorganic pollutants inferred from the BSID analysis.

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 stressor group indicates that approximately 59% of the biologically degraded stream miles in the Wills Creek watershed are impacted by water chemistry stressors (Table 5).

Sources

All six stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation are representative of impacts from urban/developed landscapes. The scientific community (Booth 1991; Konrad and Booth 2002; Meyer et al. 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 et al. 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.

Channelization of streams in the Wills Creek watershed has altered the 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 has also likely caused an increase in contaminant loads from point and nonpoint sources to surface waters. In virtually all studies, as the amount of urbanized landscapes 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 4) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source groups indicates that approximately 70% of the biologically degraded stream miles in the Wills Creek watershed are impacted by the entirety of the stressor sources (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Wills Creek watershed are a result of increased urban land use causing an alteration to hydrology and leading to loss of optimal habitat. The increased urbanization also results in an increase in contaminant loads from point and nonpoint sources. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade Wills Creek, leading to a loss of diversity in the biological community.

In summary, the altered hydrology has caused frequent high flow events and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat. Due to the increased proportion of urban land use, the Wills Creek watershed has experienced an increase in contaminant loads from point and nonpoint sources, resulting in levels of inorganic pollutants

that can potentially be extremely toxic to aquatic organisms. The combined AR for sediment, in-stream habitat, and water chemistry stressor is approximately 85%, suggesting that altered hydrology/sediment, in-stream habitat, and water chemistry stressors adequately account for the biological impairment in Wills Creek (Table 5).

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 scenarios (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.

Final Causal Model for Wills Creek

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; US EPA 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 causal model for Wills Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

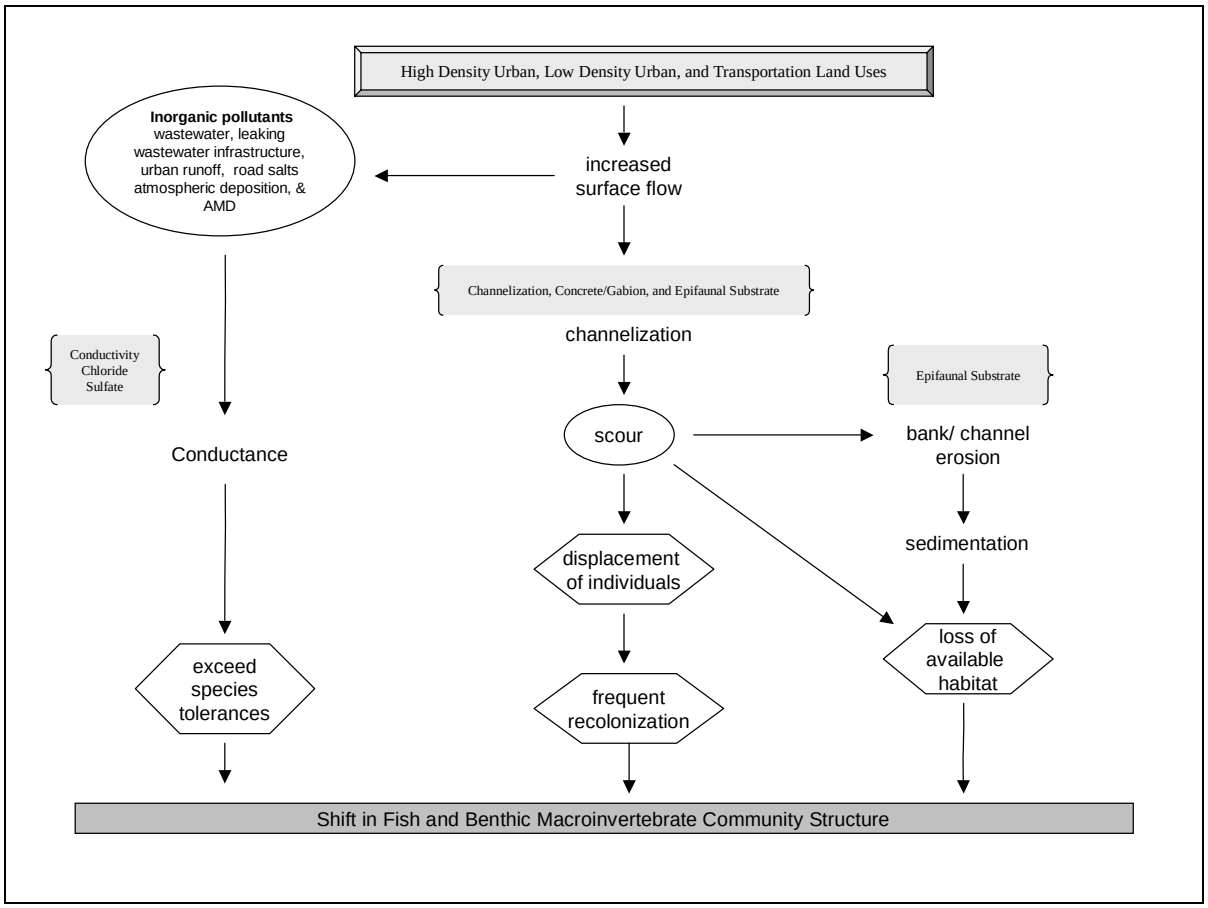

Figure 6. Final Causal Model for the Wills Creek Watershed

5.0 Conclusion

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

- The BSID process has determined that the biological communities in Wills Creek are likely degraded due to inorganic pollutants (chlorides, conductivity, and sulfate). Inorganic pollutants levels are significantly associated with degraded biological conditions and are found to be impacting approximately 59% of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. Impacts on water quality due to conductivity, chlorides, and sulfates are dependent on prolonged exposure; future monitoring of these inorganic pollutants will help in determining the spatial and temporal extent of this impairment in the watershed. Urban runoff causes an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) of impairment.

- The BSID process has determined that biological communities in Wills Creek are also likely degraded due to flow/sediment related stressors. Sediment and in-stream habitat stressors are significantly associated with degraded biological conditions and are found to be impacting approximately 31% and 45%, respectively, of the stream miles with very poor to poor biological conditions in the Wills Creek watershed. Specifically, altered hydrology and increased runoff from urban landscapes have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the Integrated Report Category 4a listing for total suspended solids as an impairing substance in Wills Creek, for which a TMDL has been developed, and links this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Wills Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization to be a form of 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 Wills Creek watershed based on channelization being present in approximately 39% of degraded stream miles.

- Although there is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report, the BSID analysis did not identify any nutrient stressors (i.e., total nitrogen, total phosphorus, and dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

References

Allan, J. D. 2004. LANDSCAPES AND RIVERSCAPES: The Influence of Land Use on Stream Ecosystems. *Annual Review Ecology, Evolution, & Systematics* 35: 257–84.

Bolton, S., and J. Shellberg. 2001. *Ecological Issues in Floodplains and Riparian Corridors*. Olympia, Washington: University of Washington, Center for Streamside Studies.

Booth, D. 1991. Urbanization and the natural drainage system – impacts, solutions and prognoses. *Northwest Environmental Journal* 7: 93-118.

Church, P., and P. Friesz. 1993. *Effectiveness of Highway Drainage Systems in preventing Road-Salt Contamination of Groundwater: Preliminary Findings*. Transportation Research Board. Transportation Research Record 1420.

COMAR (Code of Maryland Regulations). 2009a. *26.08.02.08* http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed June, 2009).

_____. 2009b. 26.08.02.02. http://www.dsd.state.md.us/comar/26/26.08.02.02.htm (Accessed June, 2009).

Haapala, A., and T. Muotka. 1998. Seasonal dynamics of detritus and associated macroinvertebrates in a channelized boreal stream. *Archiv. Fuer. Hydrobiologie* 142 (2): 171-189.

Hill, A. B. 1965. The Environment and Disease: Association or Causation? *Proceedings of the Royal Society of Medicine* 58: 295-300.

Hoffman D. J., B. A. Rattner, and G. A. Burton. 2003. *Handbook of Ecotoxicology: Edition 2*. United Kingdom: CRC Press.

IDNR (Iowa Department of Natural Resources). 2009. *Iowa's Water Quality Standard Review –Total Dissolved Solids (TDS).* http://www.iowadnr.gov/water/standards/files/tdsissue.pdf (Accessed March, 2009).

Karr, J. R. 1991. Biological integrity - A long-neglected aspect of water resource management. *Ecological Applications* 1: 66-84.

Konrad, C. P., and D. B. Booth. 2002. Hydrologic trends associated with urban development for selected streams in the Puget Sound Basin. *Western Washington. Water-Resources Investigations Report 02-4040*. Denver, Colorado: US Geological Survey.

Laasonen, P., T. Muotka, and I. Kivijaervi. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 101-113.

Mantel, N., and W. Haenzel. 1959. Statistical aspects of the analysis of data from retrospective studies of disease. *Journal of the National Cancer Institute* 22: 719-748.

MDE (Maryland Department of the Environment). 2008. *2008 Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2008_303d_pubnotice.asp.

_____. 2009. *Maryland Biological Stressor Identification Process*. Baltimore, MD: Maryland Department of the Environment.

MDP (Maryland Department of Planning). 2002. 2002 *Land Use/Land Cover*. Baltimore, MD: Maryland Department of Planning.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society* 24: 602–612.

MGS (Maryland Geological Survey). 2009. *A Brief Description of the Geology of Maryland*. http://www.mgs.md.gov/esic/brochures/mdgeology.html (Accessed March, 2009).

Smith, R. A., R. B. Alexander, and M. G. Wolman. 1987. Water Quality Trends in the Nation's Rivers. *Science* 235: 1607-1615.

Southerland, M. T., G. M. Rogers, R. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda, and S. A. Stranko. 2005. *New biological indicators to better assess the condition of Maryland Streams*. Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. Also Available at http://www.dnr.state.md.us/streams/pubs/ea-05-13_new_ibi.pdf.

USDA (U.S. Department of Agriculture). 1977. Soil Survey of Allegany County Maryland. Washington, D.C: United States Department of Agriculture, Natural Resources Conservation Service.

_____. 1974. Soil Survey of Garrett County Maryland. Washington, D.C: United States Department of Agriculture, Soil Conservation Service.

US EPA (U.S. Environmental Protection Agency). 2009. *The Causal Analysis/Diagnosis Decision Information System*. hhtp://www.epa.gov/caddis (Accessed March 2009).

Van Sickle, J., and S. G. Paulsen. 2008. Assessing the attributable risks, relative risks, and regional extents of aquatic stressors. *Journal of the North American Benthological Society* 27 (4): 920-931.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society* 24 (3):706–723.

Winterbourn, M., and C. Townsend C. 1991. Streams and rivers: One- way flow systems. In *Fundamentals of Aquatic Ecology*, edited by R. Barnes and K. Mann. Oxford, United Kingdom: Blackwell Scientific Publications.