Watershed Report for Biological Impairment of the Swan Creek Watershed in Harford County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SSA	Science Services Administration
SSO	Sanitary Sewage Overflow
TP	Total Phosphorous
TSS	Total Suspended Solids
TMDL	Total Maximum Daily Load
µeq/L	Micro equivalent per liter
µS/cm	Micro Siemens per centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

Executive Summary

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

The Swan Creek watershed (basin code 02130706), located in Harford County, MD, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and one estuary portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Swan Creek is the Chesapeake Bay Tidal Fresh (CB1TF). Below is a table identifying the listings associated with this watershed (MDE 2012).

Table E1. 2012 Integrated Report Listings for the Swan Creek Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
Swan Creek	02130706	Non-tidal		Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Northern Chesapeake Bay Tidal Fresh	CB1TF	Tidal		Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TP	4a
						TN	
				Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	-	TSS	2
				Aquatic Life and Wildlife	-	Impacts to Biological Communities	2
				Open-Water Fish and Shellfish	1996	TP	4a
						TN	

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings in the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an

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

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Swan Creek watershed is Use I - *water contact recreation, and protection of nontidal warmwater aquatic life* from its headwaters to the confluences with Carsins Creek and Gasheys Creek tributaries, these tributaries are also Use I. Gasheys Run was declared critical habitat for the federally endangered Maryland darter by the US Fish and Wildlife Service in 1984 (MDDNR 2002). The Swan Creek mainstem is designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013a, b, c). The Swan Creek watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on the degraded sites in the watershed.

The BSID analysis uses data available from the statewide MDDNR MBSS. Once the BSID analysis is completed, a number of stressors (pollutants) may be identified as probable or unlikely causes of poor biological conditions within the Maryland 8-digit watershed study. BSID analysis results can be used as guidance to refine biological impairment listings in the Integrated Report by specifying the probable stressors and sources linked to biological degradation.

This Swan 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 the Swan Creek watershed is due to urban land use and its altered hydrology concomitant effects. Peer-reviewed scientific literature establishes a link between highly agricultural and urbanized landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process identified low dissolved oxygen saturation and high pH as having significant association with degraded biological conditions in the Swan Creek watershed. A Nitrogen and Phosphorus TMDL for the Swan Creek watershed was approved by USEPA in 2001. The tidal portion of the watershed has 1996 and 2012 Category 4a listings for Total Nitrogen and Total Phosphorus; the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the nontidal and tidal regions of the Swan Creek watershed.

- The BSID process has determined that biological communities in Swan Creek watershed are likely degraded due to altered flow/sediment and instream habitat related stressors. Specifically, anthropogenic sources have resulted in altered habitat heterogeneity and possible elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sediment for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the Swan Creek watershed. The BSID results also confirm the establishment of sediment TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediment to the biological communities in the Swan Creek watershed.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2009). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, less than 10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). 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.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to rounds two and three of the Maryland Biological Stream Survey (MBSS) dataset (2000-2004; 2007-2009) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

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

2.0 Swan Creek Watershed Characterization

2.1 Location

The Swan Creek watershed is located entirely within Harford County, Maryland (see Figure 1). It is located approximately four miles south of the mouth of the Susquehanna River; the lower portion of Swan Creek is a small shallow tidal embayment (MDE 2002). It is within the Bush River Basin (Maryland 6-digit 021307), which also includes the Bush River, Lower Winter's Run, Atkisson Reservoir, and Bynum Run subwatersheds. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the total drainage area of the Maryland 8-digit watershed is approximately 15,890 acres not including water/wetlands. The watershed is located in the Coastal Plain and Piedmont regions, two of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

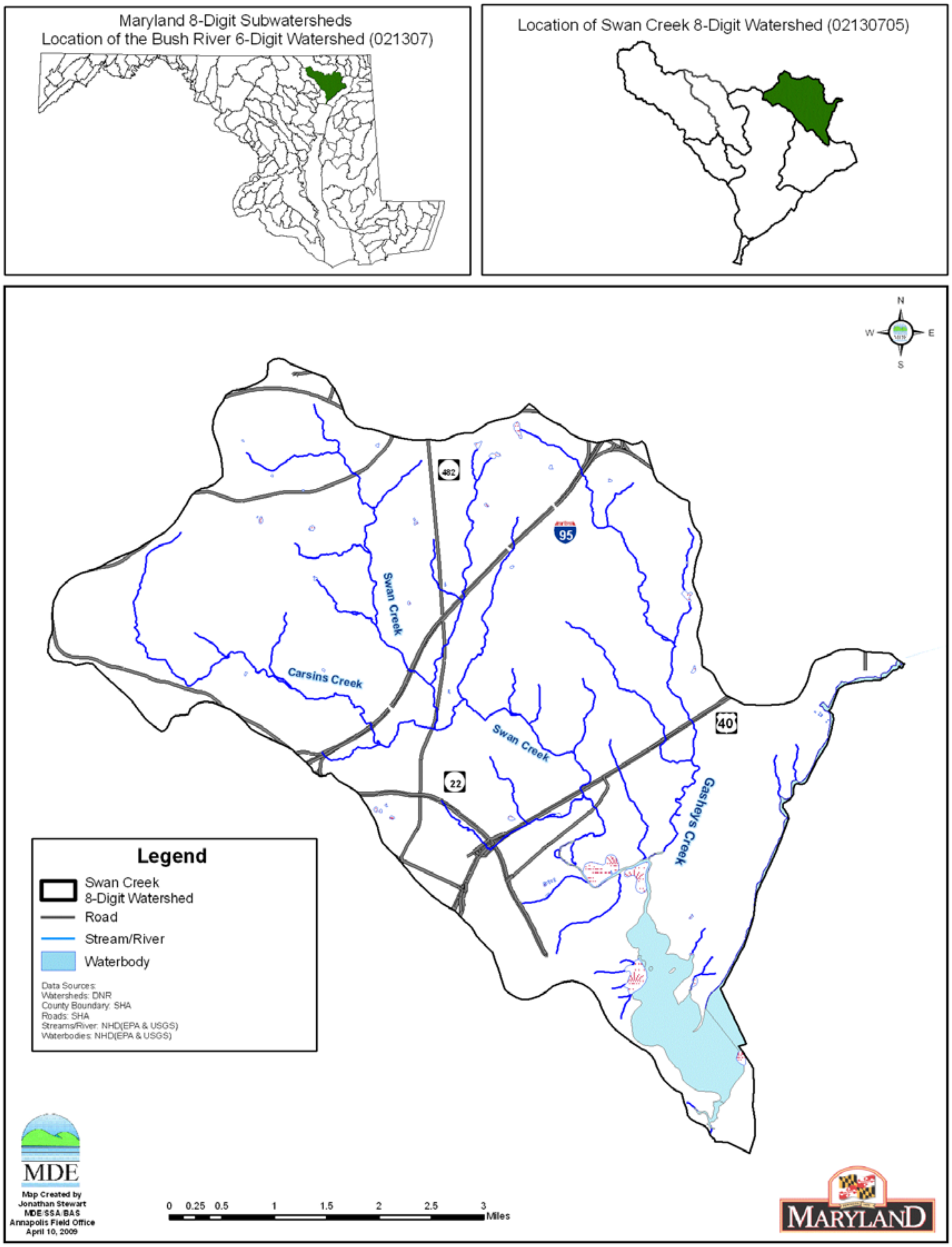

Figure 1. Location Map of the Swan Creek Watershed

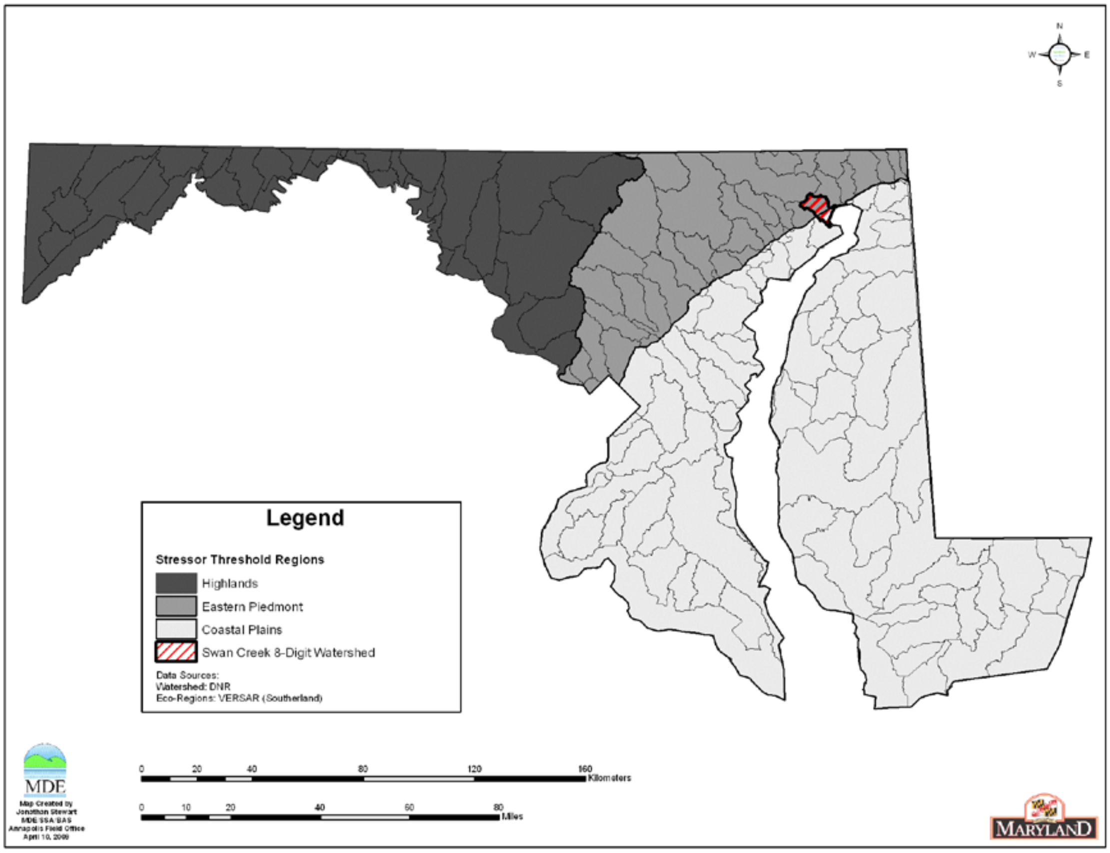

Figure 2. Eco-Region Location Map of the Swan Creek Watershed

2.2 Land Use

The watershed contains primarily forested land use (see Figure 3). The main transportation corridors in the watershed are Maryland Route 40 and Interstate 95, which run through the middle of the watershed. The watershed is located within Harford County's residential and industrial development envelope, which follows the Route 40/I-95 corridor. The placement of development within this geographic area has not been by chance. A "development envelope" was established in 1977 to direct development towards areas served, or planned for service, by public water and sewer. By concentrating the majority of development within the development envelope, outlying areas may be preserved in a rural state to preserve the viability of agriculture in the County, as well as conserve other natural resources (CWP 2003). According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Swan Creek watershed consists of approximately 43% forested, 38% urban, and 19% agricultural (see Figure 4). The Chesapeake Bay Program's Phase 5.2 watershed model does not include water or wetland area for this tidal estuary. Urban impervious surface is 3% of the total land use in the watershed (USEPA 2008).

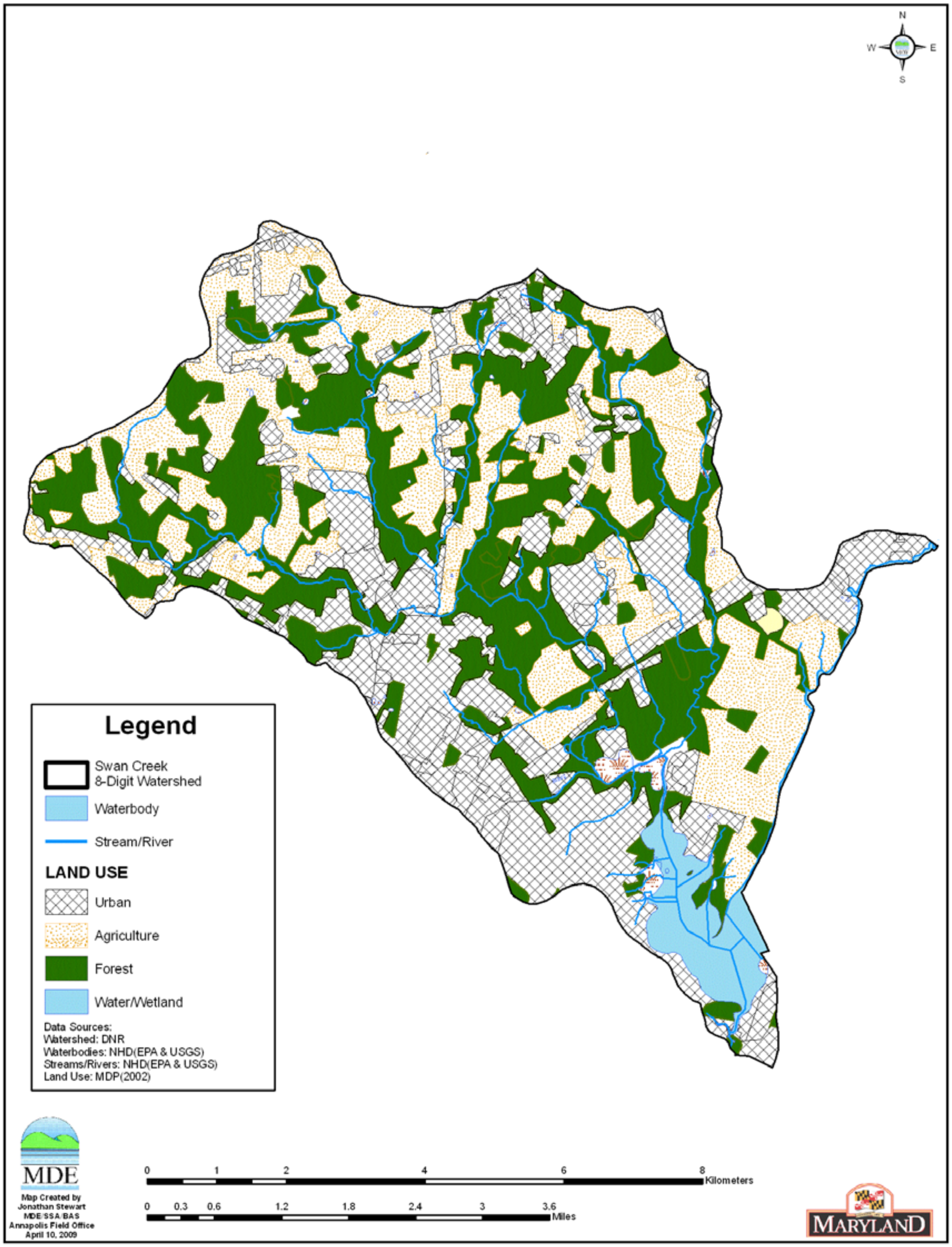

Figure 3. Land Use Map of the Swan Creek Watershed

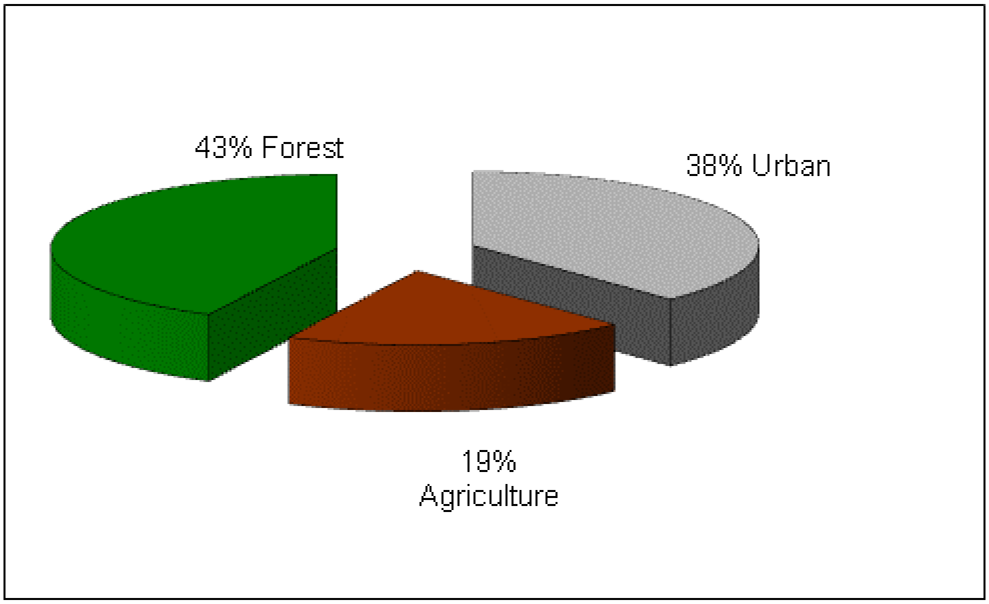

Figure 4. Proportions of Land Use in the Swan Creek Watershed

2.3 Soils/hydrology

The Swan Creek watershed is in the Coastal Plain and Piedmont Physiographic Provinces, in Harford County. The piedmont province is characterized by gentle to steep rolling topography, low hills and ridges. Broad upland areas with low slopes and gentle drainage characterize the coastal province. There are three soil series in the watershed, Beltsville, Lehigh and Othello; Othello is dominant. These soils consist of unconsolidated deposits of gravel, sand, silt, and clay. The drainage capacity of the soils range from poor to moderate, and are strongly to extremely acidic. The soils have a low to moderate erosion potential; the hazard of erosion is severe if soil is regularly tilled (NRCS 1975). The average soil erodibility of lands within 1000 feet of steams is 0.30 value /acre, which suggests that control of soil erosion is particularly important in this watershed (MDDNR 2002).

3.0 Swan Creek Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Swan Creek watershed on the State's Integrated Report under Category 5 as impaired by evidence of biological impacts (2002 listing). The Swan Creek watershed (basin code 02130706), located in Harford County, MD, is associated with two assessment units in the Integrated Report: non-tidal (8-digit basin) and one estuary portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Swan Creek is the Chesapeake

Bay Tidal Fresh (CB1TF). Below is a table identifying the listings associated with this watershed (MDE 2012).

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3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Swan Creek watershed is Use I - *water contact recreation, and protection of nontidal warmwater aquatic life* from its headwaters to the confluences with Carsins Creek and Gasheys Creek tributaries, these tributaries are also Use I. Gasheys Run was declared critical habitat for the Federally endangered Maryland darter by the US Fish and Wildlife Service in 1984 (MDDNR 2002). The Swan Creek mainstem is designated as Use II - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Swan Creek watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 46% of the Swan Creek watershed is estimated as having fish and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include seven stations. Five of the seven stations have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor).

For the Swan Creek watershed, MDE chose to include all the MBSS data rounds (1995-1997; 2000-2004; 2007-2009) in the BSID analysis, which contains eleven MBSS sites with six having BIBI and/or FIBI scores lower than 3.0. Rounds one and two are usually used, the reason for this management decision was the results of the BSID analysis of MBSS round two and three data did not yield an acceptable attributable risk (AR) value for all identified stressors (70% AR). By including the three MBSS round one sites in the BSID analysis the AR value for all stressors identified was increased to a more acceptable value (78% AR), which MDE considers would sufficiently account for the biological degradation in the watershed. The BSID analysis and AR calculations will be explained in the next section. Figure 5 illustrates principal dataset (round one, two, and three) site locations for the Swan Creek watershed.

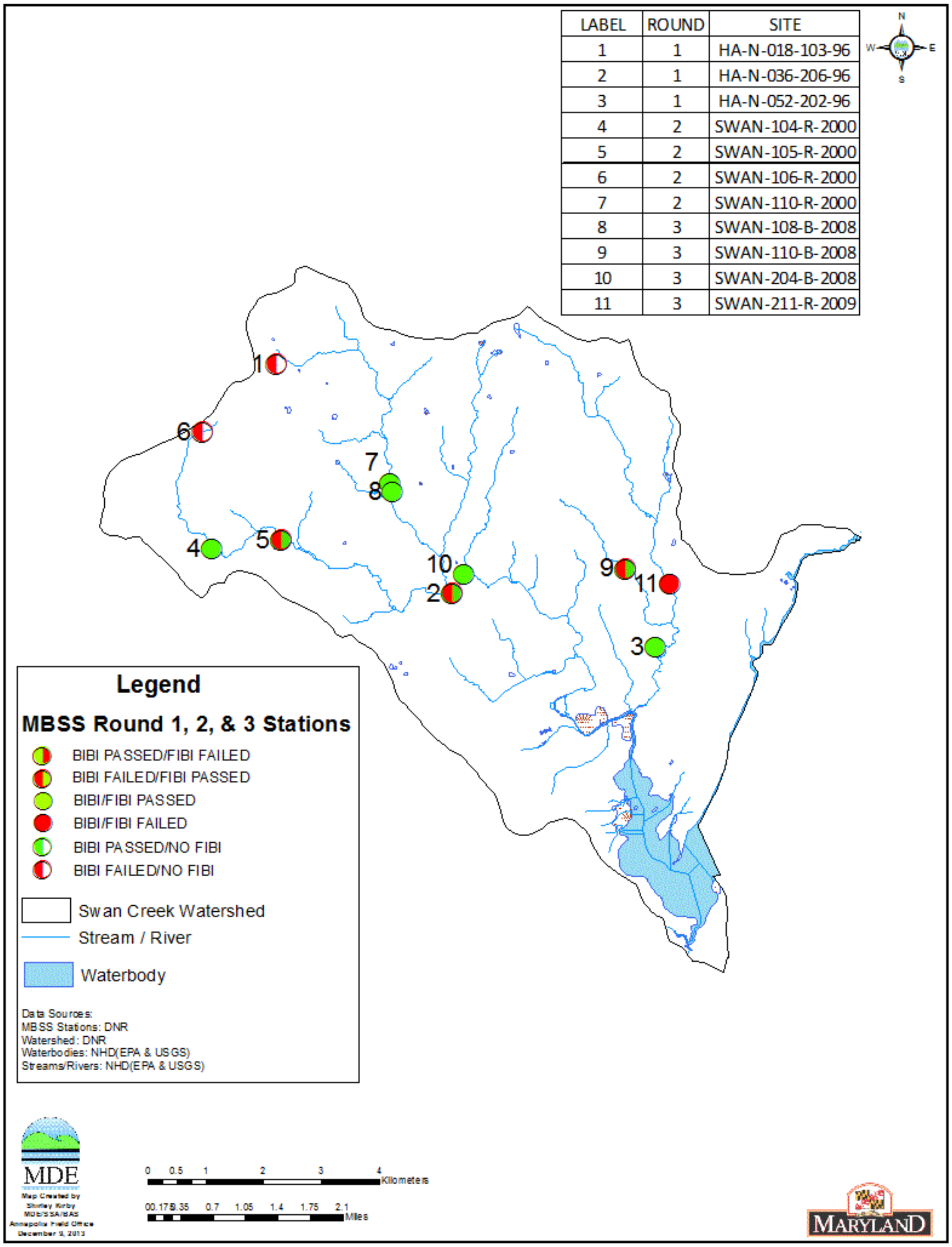

Figure 5. Principal Dataset Sites for the Swan Creek Watershed

4.0 Stressor Identification Results for the Swan Creek Watershed

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

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenszel (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

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

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, instream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Swan Creek watershed, MDE identified sediment, habitat, water chemistry stressors, and one source as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters representing possible sources in the watershed are listed in Table 2 and Table 3 shows the summary of combined AR values for the source groups in the Swan Creek watershed. As shown in Table 4 through Table 6, a number of parameters from the sediment, habitat, and water chemistry group were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Swan Creek watershed.

Table 2. Stressor Source Identification Analysis Results for the Swan 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	11	6	371	0%	3%	1	No	_
	AMD acid source present	11	6	371	0%	0%	1	No	_
	Organic acid source present	11	6	371	0%	1%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	11	6	373	0%	6%	1	No	_
	High % of agriculture in 60m buffer	11	6	373	0%	3%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	11	6	373	0%	4%	1	No	_
	Low % of wetland in watershed	11	6	373	17%	13%	0.575	No	_
	Low % of forest in 60m buffer	11	6	373	0%	5%	1	No	_
	Low % of wetland in 60m buffer	11	6	373	17%	2%	0.081	Yes	15%
Sources - Impervious	High % of impervious surface in watershed	11	6	373	0%	9%	1	No	_
	High % of impervious surface in 60m buffer	11	6	373	33%	19%	0.33	No	_
	High % of roads in watershed	11	6	373	0%	4%	1	No	_
	High % of roads in 60m buffer	11	6	373	0%	3%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	11	6	373	0%	3%	1	No	_
	High % of low-intensity developed in watershed	11	6	373	0%	7%	1	No	_
	High % of medium-intensity developed in watershed	11	6	373	0%	3%	1	No	_
	High % of residential developed in watershed	11	6	373	17%	9%	0.431	No	_
	High % of rural developed in watershed	11	6	373	0%	3%	1	No	_
	High % of high-intensity developed in 60m buffer	11	6	373	0%	2%	1	No	_

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	11	6	373	17%	3%	0.178	No	_
	High % of medium-intensity developed in 60m buffer	11	6	373	0%	2%	1	No	_
	High % of residential developed in 60m buffer	11	6	373	17%	7%	0.341	No	_
	High % of rural developed in 60m buffer	11	6	373	0%	4%	1	No	_

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Swan Creek Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Anthropogenic	15%
All Sources	***15%***

4.1 Sources Identified by BSID Analysis

The BSID source analysis (Table 2) only identified loss of wetlands within the sixty meter riparian buffer zone as a potential source of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 15% suggesting land use sources are not the most probable cause of biological impairments in the Swan Creek watershed (Table 3). Other land use sources may not be significantly associated with poor to very poor biological conditions, but the presence of urban development in the watershed probably exacerbates naturally occurring conditions (e.g., soil properties, oxygen saturation) and possibly contributes to degradative effects in the watershed.

The Swan Creek watershed has lost approximately 5% of its nontidal wetlands. This is considered a permanent loss (MDDNR 2002). In most of Maryland's watersheds, extensive wetland areas have been converted to other land uses by draining and filling.

This conversion unavoidably reduces or eliminates the natural functions that wetlands provide.

Non-tidal wetlands, although similar in function to tidal wetlands differ greatly in their range of habitats, and species composition. Non-tidal wetlands are often referred to as inland or upland wetlands and include freshwater swamps, bogs and bottomland hardwood forests. As in the case of tidal wetlands, they provide habitat for plants, fish, and wildlife, maintain water quality, act as ground water recharge areas, and control flooding and erosion.

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 the Swan 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	8	4	111	0%	12%	1	No	_
	Moderate bar formation present	8	4	111	25%	44%	0.635	No	_
	Channel alteration moderate to poor	7	5	145	40%	42%	1	No	_
	Channel alteration poor	7	5	145	0%	11%	1	No	_
	High embeddedness	11	6	173	33%	6%	0.05	Yes	28%
	Epifaunal substrate marginal to poor	11	6	173	33%	19%	0.313	No	_
	Epifaunal substrate poor	11	6	173	17%	4%	0.227	No	_
	Moderate to severe erosion present	8	4	112	50%	55%	1	No	_
	Severe erosion present	8	4	111	0%	9%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Swan 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	11	6	177	33%	10%	0.115	No	_
	Concrete/gabion present	10	5	158	0%	2%	1	No	_
	Beaver pond present	11	6	173	0%	2%	1	No	_
	Instream habitat structure marginal to poor	11	6	173	50%	14%	0.038	Yes	36%
	Instream habitat structure poor	11	6	173	17%	1%	0.1	Yes	15%
	Pool/glide/eddy quality marginal to poor	11	6	173	50%	33%	0.646	No	_
	Pool/glide/eddy quality poor	11	6	173	0%	1%	1	No	_
	Riffle/run quality marginal to poor	11	6	173	67%	24%	0.033	Yes	42%
	Riffle/run quality poor	11	6	173	33%	5%	0.025	Yes	29%
	Velocity/depth diversity marginal to poor	11	6	173	67%	43%	0.391	No	_
	Velocity/depth diversity poor	11	6	173	33%	2%	0.006	Yes	32%
Riparian Habitat	No riparian buffer	7	5	146	0%	24%	0.592	No	_
	Low shading	11	6	173	17%	4%	0.216	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Swan 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	8	4	225	25%	6%	0.223	No	_
	High conductivity	11	6	374	17%	4%	0.21	No	_
	High sulfates	11	6	373	0%	7%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	11	6	365	17%	3%	0.176	No	_
	Dissolved oxygen < 6mg/l	11	6	365	17%	5%	0.282	No	_
	Low dissolved oxygen saturation	11	6	365	33%	6%	0.058	Yes	27%
	High dissolved oxygen saturation	11	6	365	0%	4%	1	No	_
	Ammonia acute with salmonid present	8	4	225	0%	0%	1	No	_
	Ammonia acute with salmonid absent	8	4	225	0%	0%	1	No	_
	Ammonia chronic with early life stages present	8	4	225	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	8	4	225	0%	0%	1	No	_
	High nitrites	8	4	225	0%	4%	1	No	_
	High nitrates	11	6	373	0%	4%	1	No	_
	High total nitrogen	8	4	225	0%	5%	1	No	_
	High total phosphorus	8	4	225	0%	8%	1	No	_
	High orthophosphate	8	4	225	0%	4%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	11	6	373	0%	2%	1	No	_
	Low field pH	11	6	365	0%	11%	1	No	_
	High field pH	11	6	365	0%	1%	1	No	_
	Low lab pH	11	6	371	0%	8%	1	No	_
	High lab pH	11	6	371	17%	1%	0.095	Yes	15%

Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Swan Creek Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	28%
Instream Habitat	61%
Chemistry - Nutrients	27%
Chemistry - pH	15%
All Chemistry	47%
All Stressors	***78%***

4.2 Stressors Identified by BSID Analysis

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

Sediment Conditions

BSID analysis results for the Swan Creek watershed identified one sediment parameter that have statistically significant associations with poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *high embeddedness* (Table 4).

High embeddedness was identified as significantly associated with degraded biological conditions and found to impact approximately 28% of the stream miles with poor to very poor biological conditions in the Swan Creek watershed. This stressor measures the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. High embeddedness is a result of excessive sediment deposition. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow and/or stream channel erosion.

As development and urbanization increased in the Swan Creek watershed so did morphological changes that affected the stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams causing urban streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are streambed scouring. The scouring associated with these increased flows leads to accelerated channel and bank erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Some of the impacts associated with sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman, Rattner, and Burton 2003). All of these processes result in an unstable stream ecosystem that impacts habitat and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 28%, suggesting that these stressors are probable cause of the biological impairments in the Swan Creek watershed (Table 7).

Instream Habitat Conditions

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

Instream habitat structure was identified as significantly associated with degraded biological conditions and found to impact approximately 36% (*marginal to poor* rating) and 15% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Swan Creek watershed. Instream habitat structure is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High instream habitat scores are evidence of the lack of sediment deposition. Low instream habitat values can be caused by high flows that collapse undercut banks, sediment inputs that fill pools and other fish habitats. A poor rating of this measure indicates excessive erosion and/or sedimentation.

Riffle/run quality was identified as significantly associated with degraded biological conditions in the Swan Creek watershed, and found to impact approximately 42% (*marginal to poor* rating) and 29% (*poor* rating) of the stream miles with poor to very poor biological conditions. Riffle/run quality is a visual observation including quantitative measurements based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Velocity/depth diversity was identified as significantly associated with degraded biological conditions and found to impact approximately 32% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Swan Creek watershed. Velocity/depth diversity is a visual observation including quantitative measurements based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The 'poor' diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.).

All the stressors identified for the instream habitat parameter group are intricately linked with habitat heterogeneity. The lower the ratings for these habitat parameters the lower the diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The flashiness (intermittent high flows) of the Swan Creek watershed has resulted in significant channel and streambed alteration within the watershed. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and decreasing habitat heterogeneity. The combination of the altered flow regime and subsequent increased sediment deposition the Swan Creek watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the instream habitat stressor group is approximately 61% suggesting that these stressors are probable cause of the biological impairments in the Swan Creek watershed (Table 7).

Riparian Habitat Conditions

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

Water Chemistry

BSID analysis results for the Swan Creek watershed identified two water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *low dissolved saturation and high lab pH* (Table 5).

Low dissolved oxygen (DO) saturation was identified as significantly associated with degraded biological conditions and found in 27% of the stream miles with poor to very poor biological conditions in the Swan Creek watershed. Natural diurnal fluctuations can become exaggerated in streams with elevated nutrient concentrations, resulting in excessive primary production. High and low DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Low DO saturation is considered to demonstrate high respiration associated with excessive decomposition of organic material.

High lab pH concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 15% of the stream miles with poor to very poor biological conditions in the Swan Creek watershed. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. Most stream organisms prefer a pH range of 6.5 to 8.5. Low stream pH results from agricultural land use, acid mine drainage, atmospheric deposition and organic sources. Intermittent high pH (greater than 8.5) is often associated with eutrophication related to increased algal blooms. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

Natural and anthropogenic changes to an aquatic environment can affect the availability of DO. The normal diurnal fluctuations of a system can be altered resulting in large fluctuations in DO levels which can occur throughout the day. The low DO concentration may be associated with the impacts of elevated nutrient loadings, low precipitation, low gradient streams, and the decomposition of leaf litter.

There are two National Pollutant Discharge Elimination System (NPDES) permitted discharge facilities (e.g., surface water, municipal, industrial) in the Swan Creek watershed, including the City of Aberdeen Wastewater Treatment Plant which is located about 3.1 river miles from the mouth of the creek and the Swan Creek Harbour Dell Wastewater Treatment Plant, located 4.7 river miles from the mouth of the creek. Water quality is strongly influenced by land use, water quality impairments are likely due to urban runoff, municipal and industrial discharges, failing septic systems, and erosion and upstream sources (MDE 2002). Examples of contaminant loads from point and nonpoint sources include sediments and nutrients.

Although low DO and high pH concentrations are usually associated with surface waters experiencing eutrophication as the result of excessive nutrient loading, the BSID analysis has not identified nutrients in the watershed. The two failing stations (SWAN-105-R-2000; SWAN-106-R-2000) with low dissolved oxygen saturation are first order streams, many first order streams on the Maryland upper western shore tend to have very little or no flow during long stretches of the year. Low DO values are not uncommon in small low gradient streams with low or stagnant flows. The BSID analysis results of rounds two and three did not indicate pH as an issue in the watershed, however, with the addition of round one, high lab pH was identified. Round one has one station (HA-N-036-206-96) with a lab pH of 9.04. This result is an outlier when compared with the lab pH of the other stations, and may be attributable to fluctuations caused by urban runoff.

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 47% suggesting that these stressors are probable cause of the biological impairments in the Swan Creek watershed (Table 7).

4.3 Discussion of BSID Results

The BSID results did not identify any urban land use sources as significant in the Swan Creek watershed but urban land use is 38% of the watershed. A "development envelope" was established in 1977 to direct development towards areas served, or planned for service, by public water and sewer (CWP 2003). Urban land development can cause an increase in contaminant loads from point and non-point sources by adding sediments and pollutants to surface waters. In watersheds already experiencing anthropogenic stress, hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events (Southerland et al. 2005b). Urbanization exacerbates overland flows during storm events carrying pollutants when flows recede, and when water velocity slows it stagnates and there are resulting fluctuations in oxygen and pH concentrations.

During the spring and summer index sampling periods, the MDDNR MBSS reported anthropogenic impacts to four failing stations in the BSID primary dataset. There were impacts noted due to the Bulle Rock Golf Course, which surrounds Gasheys Creek. There are also headwater or first order streams included in this analysis. Headwater streams do not typically support biologically diverse and/or sustainable communities (Vannote 1980), making their biological communities more vulnerable to natural and anthropogenic land use alterations, and their associated stressors (e.g., nutrient runoff from golf courses). One of the headwater streams on Carsins Creek is located in a cropland area, and another had recent disturbance to the riparian area.

The BSID analysis identified low dissolved oxygen saturation and high lab pH as significantly associated with biologically degraded condition in the watershed. There were no additional nutrient stressors identified to indicate eutrophication. However, water quality assessments conducted over many years by MDE (MDE 2002) have demonstrated that nutrient over enrichment had been occurring in the watershed. All the MDDNR MBSS sampling in the Swan Creek watershed was conducted in the years 2000, 2008, and 2009. Due to the naturally low gradients and lack of aeration in streams of the Coastal Plains region, they tend to become more over enriched than elsewhere in the State; therefore, ensuring minimal nutrient loads is crucial to support diverse aquatic life. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, decomposition of organic matter, and elevated nutrient loading. A TMDL for Nitrogen and Phosphorus for the Swan Creek watershed was approved by USEPA in 2002 (MDE 2002). With continued efforts in implementing and enforcing nutrient TMDLs by State and local agencies downward trends in nutrient loadings will continue in the Swan Creek watershed, as well as reduced occurrences of low DO levels. Also, with continued efforts in implementing and enforcing the 2010 Chesapeake Bay TMDL by State and local agencies, nutrient loads in the Swan Creek watershed will decrease and the streams' habitats will improve.

The Swan Creek watershed is in the Piedmont and Coastal Plain physiographic region, the Coastal Plain region is naturally impacted by sediment deposition due to the region's soil and hydrology. Under normal conditions, the watershed receives low freshwater input and experiences very little flushing except from stormwater. Therefore, there are usually episodic pulses of nutrients and sediments. Due to these factors, the fish and benthic macroinvertebrate communities experience drastic changes in water quality, and a reduction in the quantity and quality of available physical habitat. Altered flow regimes as a result of urbanization allow for greater flooding, which creates a less stable stream channel, leading to excessive bank erosion, loss of pool habitat and instream cover, and excessive streambed scour and sediment deposition (Wang et al. 2001). All of these impacts have resulted in the shift in fish and benthic macroinvertebrate community structure in the Swan Creek watershed. The combined AR for all the stressors is approximately 78%, suggesting that altered hydrology/sediment, instream habitat, and water chemistry stressors adequately account for the biological impairment in the Swan Creek watershed.

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

4.4 Final Causal Model

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

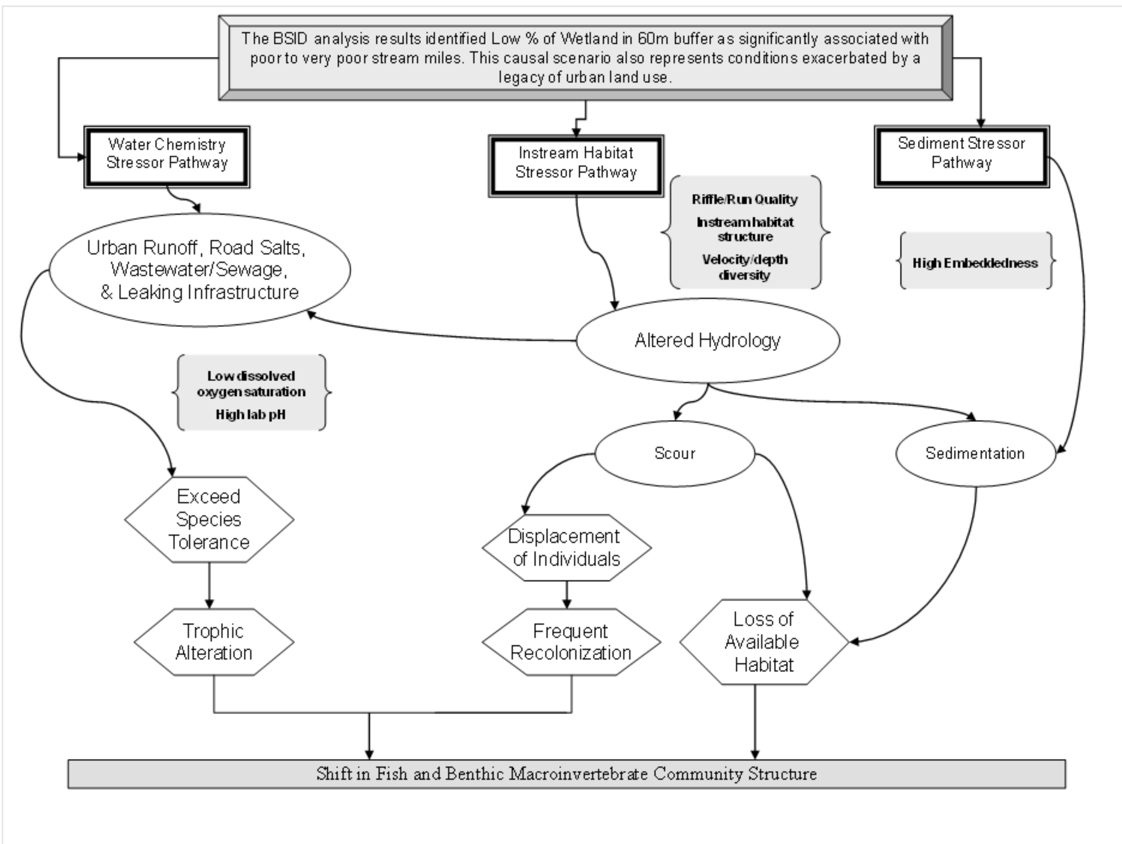

Figure 6. Final Causal Model for the Swan Creek Watershed

5.0 Conclusions

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

- The BSID process identified low dissolved oxygen saturation and high pH as having significant association with degraded biological conditions in the Swan Creek watershed. A Nitrogen and Phosphorus TMDL for the Swan Creek watershed was approved by USEPA in 2001. The tidal portion of the watershed has 1996 and 2012 Category 4a listings for Total Nitrogen and Total Phosphorus; the establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the nontidal and tidal regions of the Swan Creek watershed.

- The BSID process has determined that biological communities in Swan Creek watershed are likely degraded due to altered flow/sediment and instream habitat related stressors. Specifically, anthropogenic sources have resulted in altered habitat heterogeneity and possible elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of sediment for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors to the biological communities in the Swan Creek watershed. The BSID results also confirm the establishment of sediment TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediment to the biological communities in the Swan Creek watershed.

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