Watershed Report for Biological Impairment of the Marsh Run in Washington County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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August 2015

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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
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
n	Number
NADP	National Atmospheric Deposition Program
NH_4^+	Ammonia
NO_3^-	Nitrate
NO_2^-	Nitrite
NPDES	National Pollution Discharge Elimination System
PCB	Polychlorinated Biphenyls
PSU	Primary Sampling Unit
RESAC	Regional Earth Science Applications Center
SSA	Science Services Administration
SSO	Sanitary Sewage Overflow
TN	Total Nitrogen
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 Marsh Run watershed (basin code 02140503), located in Washington County, MD, is associated with one assessment unit, a non-tidal (8-digit basin), in the Integrated Report (IR). Below is a table identifying the listings associated with this watershed (MDE 2012).

Table E1. 2012 Integrated Report Listings for the Marsh Run Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Marsh Run	02140503	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5

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 Marsh Run watershed's tributary Saint James Run (mainstem only) is designated as Use IV-P – *recreational trout waters and public water supply* and Marsh Run and all other tributaries to the same are designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply*. (COMAR 2014a, b, c). The Marsh Run watershed is not attaining its designated use of protection of aquatic life because of impairments to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listing for biological impairments represents 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 Marsh Run 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 2014). Data suggest that the degradation of biological communities in the Marsh Run watershed is due to urban and agricultural land uses and their altered hydrology concomitant effects: altered hydrology and elevated levels of sediments, toxics, and nutrients. The development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation, e.g., urban runoff contamination (nutrients) of surface waters, in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process has determined that biological communities in the Marsh Run watershed are likely degraded due to sediment related stressors. Specifically, altered hydrology and increased runoff from urban and agricultural landscapes have resulted in increased habitat homogeneity and subsequent 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 the Marsh Run watershed as an appropriate management action to begin addressing the impacts of these streams on the biological communities in the Marsh Run watershed.

- The BSID process has determined that the biological communities in the Marsh Run watershed are likely degraded due to water chemistry related stressors.

Specifically, agricultural and urban land use practices have resulted in the potential elevation of nutrient (i.e. nitrogen) inputs in the watershed, which are in turn probable causes of impacts to biological communities. Due to anthropogenic sources, the watershed is vulnerable to nutrient fluxes (e.g., sediment release, fertilizer application, stormwater) that could be detrimental to the biological community, but phosphorus concentrations may be limiting in the watershed. Therefore, MDE scientists recommend a more intense analysis of all available data to assess the TN:TP ratio of the watershed. The establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impact of these stressors to the biological communities in the Marsh Run watershed.

- The BSID process has determined that the biological communities in the Marsh Run watershed are likely degraded due to inorganics (i.e., sulfate). Sulfate levels are significantly associated with degraded biological conditions and found in approximately 92% of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. The BSID results thus support a Category 5 listing of the Marsh Run watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Marsh Run watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

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 the 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 Marsh Run watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Marsh Run Watershed Characterization

2.1 Location

The Marsh Run watershed is located entirely within Washington County, Maryland (see Figure 1). Washington County is bordered by Mason and Dixon's line and Pennsylvania to the north and by the far shore of the Potomac River, Virginia, and West Virginia to the south. It extends eastward to South Mountain and Frederick County and westward to Sideling Hill Creek and Allegany County (NRCS 1996). Hagerstown, the county seat, is a few miles north of the watershed, and is 70 miles from Washington, DC, 72 miles from Baltimore, Maryland, 156 miles from Pittsburgh, Pennsylvania, and 176 miles from Richmond, Virginia. The Hagerstown Valley takes in more than half the county. It ranges in elevation from about 300 feet near the Potomac River to about 700 feet at the Pennsylvania line (NRCS 1996). The total drainage area of the Maryland 8-digit watershed is approximately 13,455 acres, and includes only one major tributary (Saint James Run) to Marsh Run. The watershed is located in the Highland region, one of three distinct eco-regions identified in the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

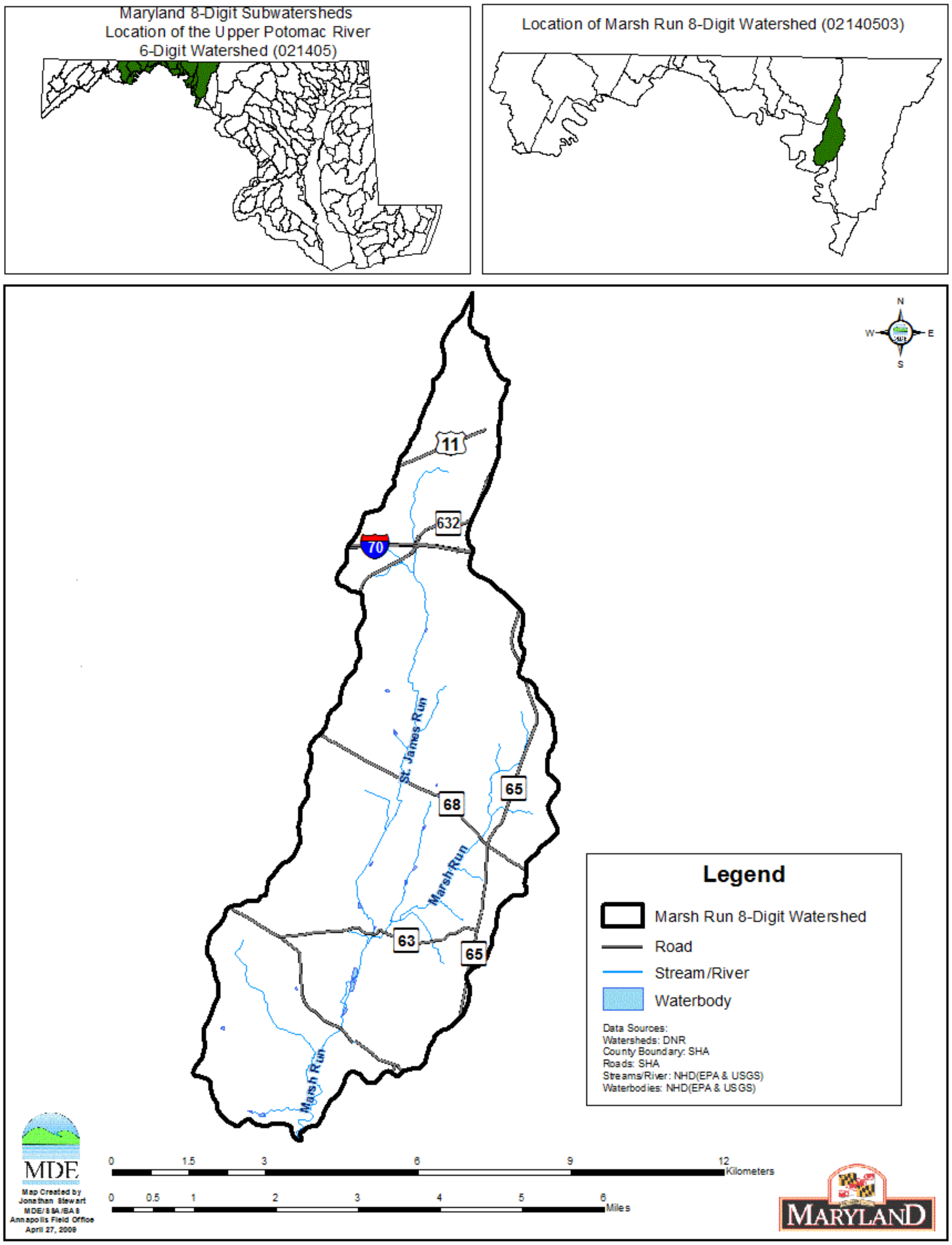

Figure 1. Location Map of the Marsh Run Watershed

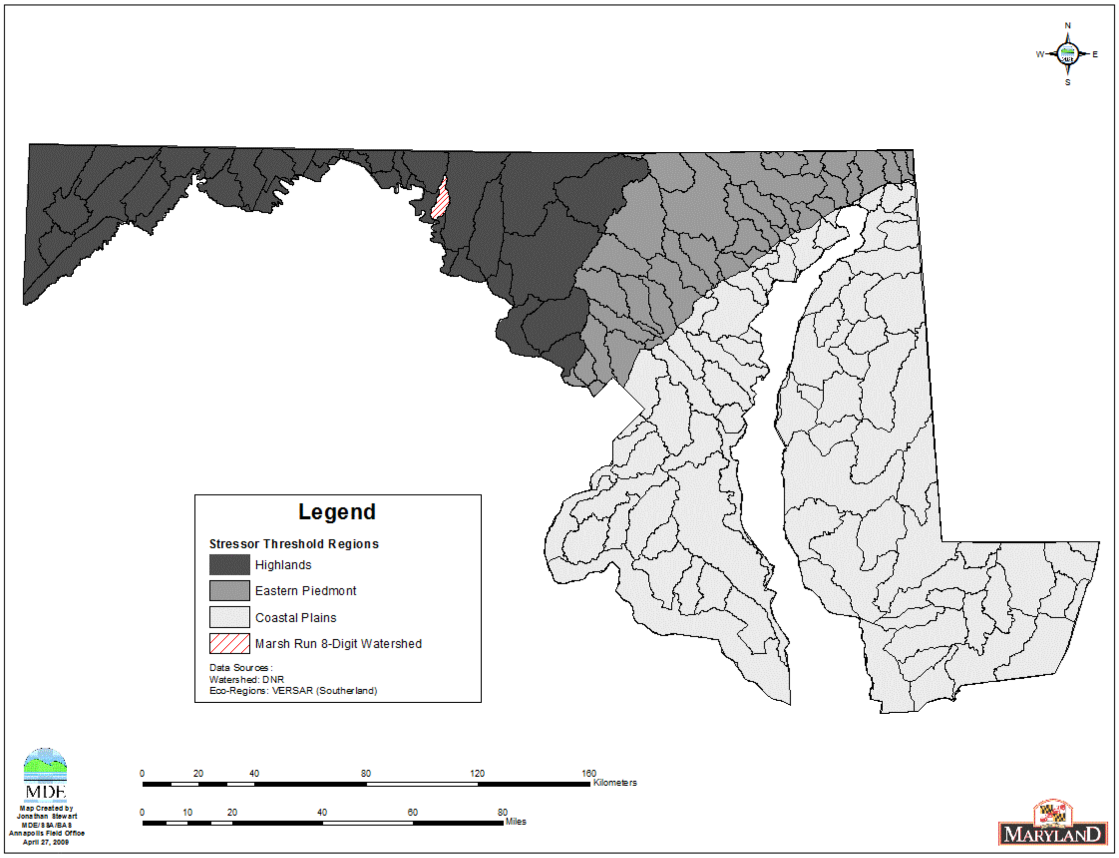

Figure 2. Eco-Region Location Map of the Marsh Run Watershed

2.2 Land Use

The Marsh Run watershed has primarily agricultural land use; urban land use is secondary (see Figure 3). The soils within this province are well suited to intensive agricultural production; they support the dairy industry, grain production, vegetable production, and hay or pasture usage (NRCS 1996). Interstates, such as I-70 and I-81, interconnect some points within the watershed. The land use distribution in the watershed is approximately 53% agriculture, 29% urban, and 18% forest/herbaceous (see Figure 4). Urban impervious surface is 5% of the total land use in the watershed (USEPA 2010).

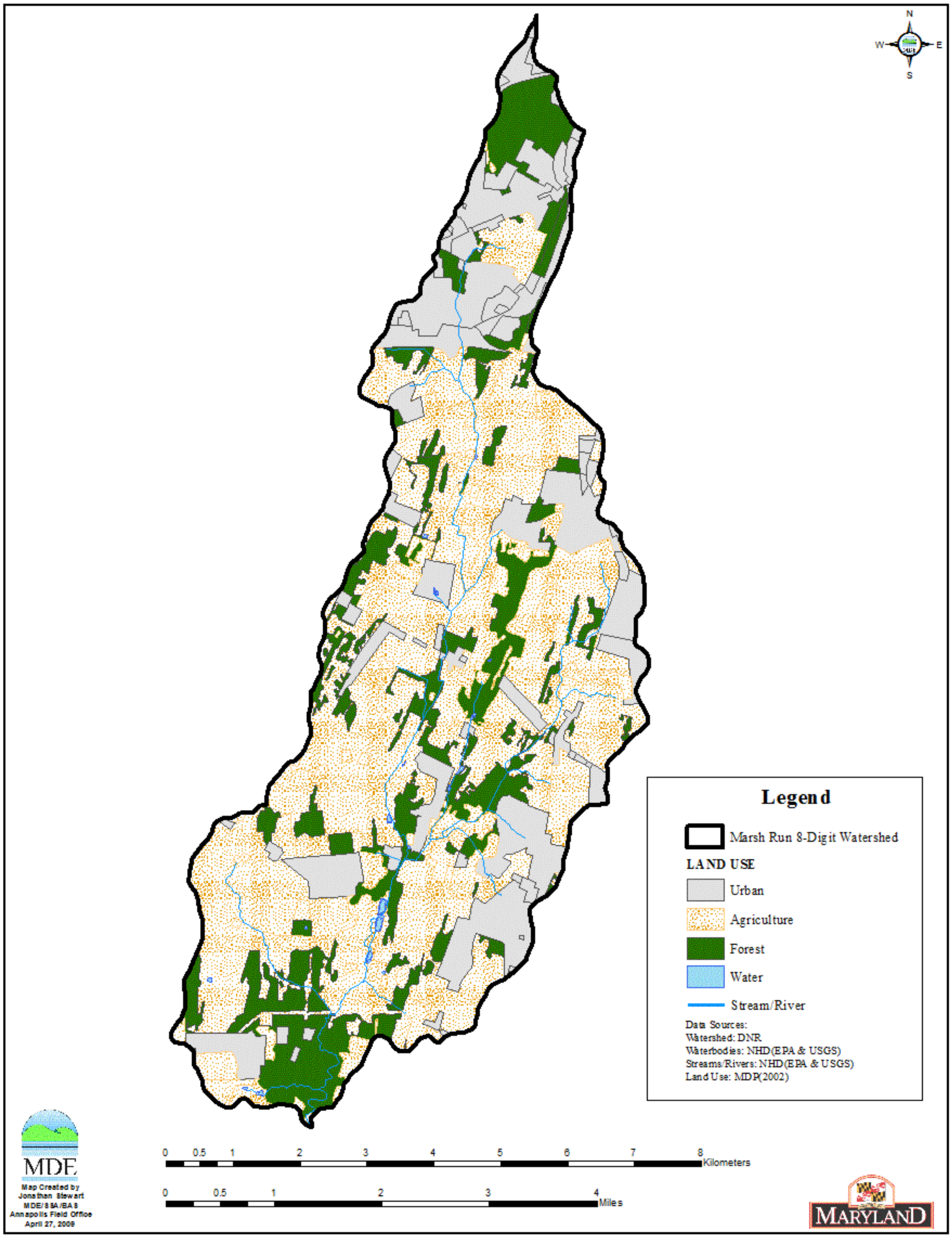

Figure 3. Land Use Map of the Marsh Run Watershed

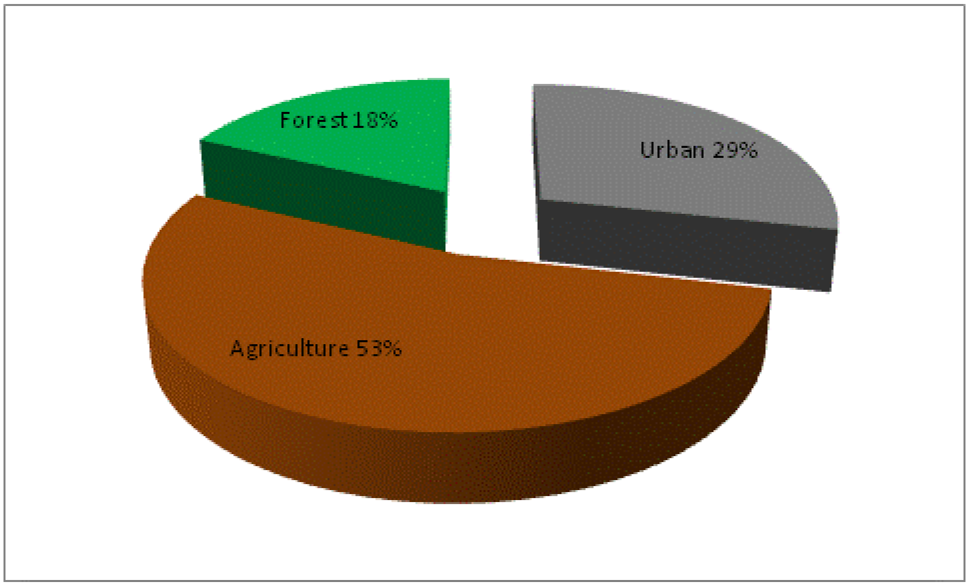

Figure 4. Proportions of Land Use in the Marsh Run Watershed

2.3 Soils/hydrology

The Marsh Run watershed lies within the Highland physiographic region. There are two soil series in the watershed, Lindside and Waynesboro, with Lindside being dominant. The Lindside series lies at the southeast portion of the watershed. The Lindside series consists of very deep, moderately well drained soils. Permeability is moderate in upland regions. The Lindside series is nearly level to gently sloping, well drained to poorly drained, very deep soils that formed in marl, limestone, sandstone, shale, greenstone, quartzite, and phyllite. They are on active flood plains within the central limestone valley of Washington County. Slopes range from 0 to 3 percent. The Waynesboro series consists of very deep, well drained, moderately permeable soils that formed in old alluvium or unconsolidated material of sandstone, shale, and limestone origin. Slopes range from 2 to 30 percent. Soil erosion from both water and wind is a common concern. As hedgerows and wood lots are removed, buffers against wind and water have been greatly reduced (NRCS 1996).

3.0 Marsh Run Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the Marsh Run watershed under Category 5 of the State's Integrated Report as impaired for impacts to biological communities (2004 listing). The Marsh Run watershed (basin code 02140503), located in Washington County, MD, is associated with one assessment unit, a non-tidal 8-digit basin, in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2012).

Table 1. 2012 Integrated Report Listings for the Marsh Run Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Marsh Run	02140503	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Marsh Run watershed's tributary Saint James Run (mainstem only) is designated as Use class IV-P – *recreational trout waters and public water supply,* Marsh Run and all other tributaries are designated as Use Class I-P – *water contact recreation, protection of aquatic life, and public water supply*. (COMAR 2014a, 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 Marsh Run watershed is listed under Category 5 of the 2012 IR as impaired for impacts to biological communities. Approximately 83% of the Marsh Run 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 six stations. Five of the six stations have degraded benthic and/or fish indices of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS rounds two and three (2000-2009), contains four sites; all four have BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Marsh Run watershed.

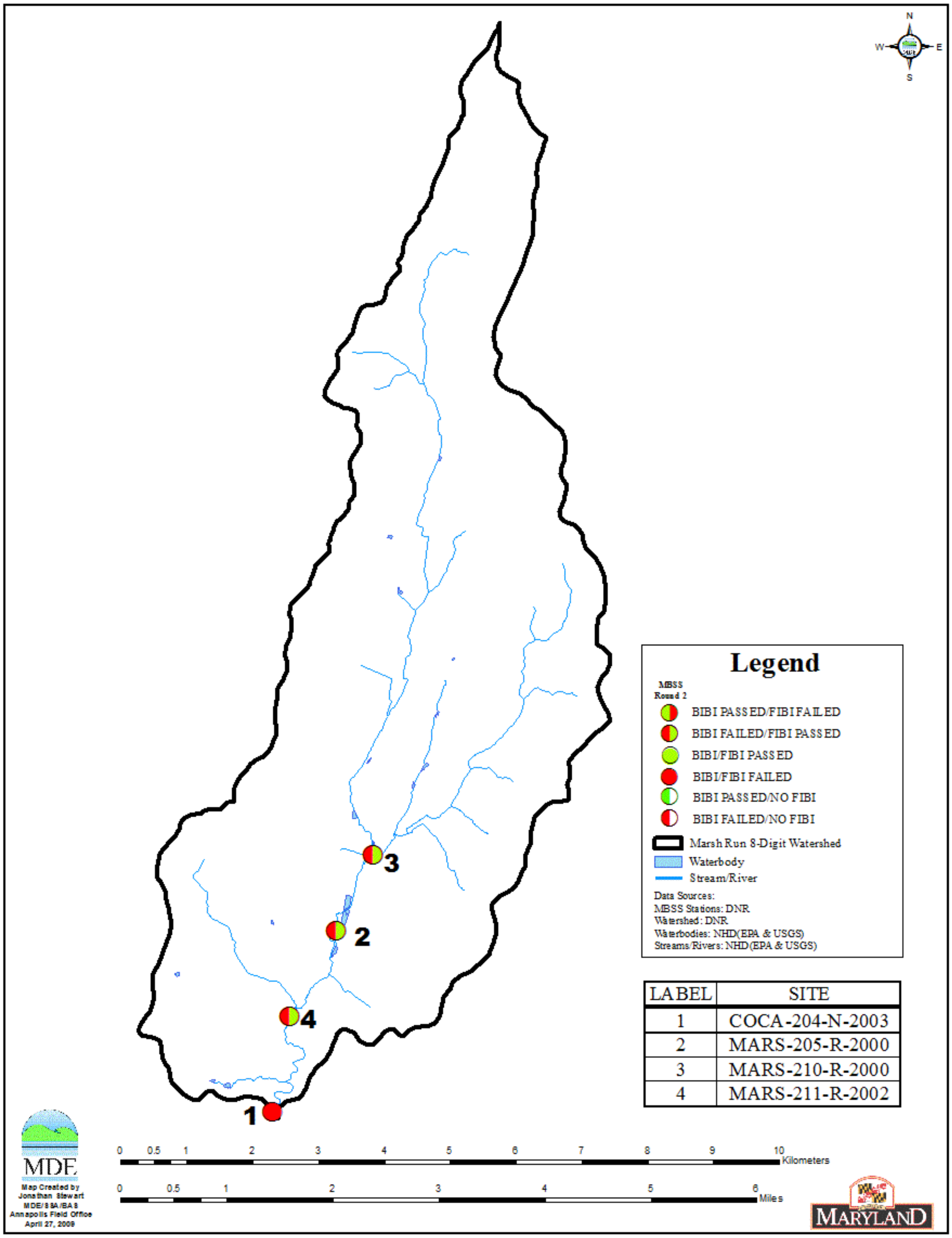

Figure 5. Principal Dataset Sites for the Marsh Run Watershed

4.0 Stressor Identification Results for the Marsh Run 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).

Through the BSID data analysis, MDE identified sediment, water chemistry, and potential sources significantly associated with degraded fish and/or benthic macroinvertebrate biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various urban land use types. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 4 and Table 6, parameters from the sediment and water chemistry groups are identified as possible biological stressors in the Marsh Run watershed. A summary of combined AR values for each stressor group is shown in Table 6.

Table 2. Stressor Source Identification Analysis Results for the Marsh Run 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	4	4	168	0%	1%	1	No	_
	AMD acid source present	4	4	168	0%	5%	1	No	_
	Organic acid source present	4	4	168	0%	0%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	4	4	171	100%	11%	0	Yes	89%
	High % of agriculture in 60m buffer	4	4	171	100%	6%	0	Yes	94%
Sources - Anthropogenic	Low % of forest in watershed	4	4	171	100%	5%	0	Yes	95%
	Low % of wetland in watershed	4	4	171	0%	0%	1	No	_
	Low % of forest in 60m buffer	4	4	171	75%	2%	0	Yes	73%
	Low % of wetland in 60m buffer	4	4	171	0%	0%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	4	4	171	100%	5%	0	Yes	95%
	High % of impervious surface in 60m buffer	4	4	171	75%	12%	0.007	Yes	63%
	High % of roads in watershed	4	4	171	25%	8%	0.304	No	_
	High % of roads in 60m buffer	4	4	171	0%	8%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	4	4	171	75%	2%	0	Yes	73%
	High % of low-intensity developed in watershed	4	4	171	0%	3%	1	No	_
	High % of medium-intensity developed in watershed	4	4	171	100%	4%	0	Yes	96%
	High % of residential developed in watershed	4	4	171	25%	2%	0.11	No	_
	High % of rural developed in watershed	4	4	171	25%	3%	0.131	No	_
	High % of high-intensity developed in 60m buffer	4	4	171	25%	1%	0.067	Yes	24%

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	4	4	171	0%	5%	1	No	_
	High % of medium-intensity developed in 60m buffer	4	4	171	25%	1%	0.067	Yes	24%
	High % of residential developed in 60m buffer	4	4	171	100%	5%	0	Yes	95%
	High % of rural developed in 60m buffer	4	4	171	50%	7%	0.033	Yes	43%

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Marsh Run Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	94%
Sources - Anthropogenic	97%
Sources - Impervious	95%
Sources - Urban	98%
All Sources	***98%***

4.1 Sources Identified by BSID Analysis

The sources identified by the BSID analysis (Table 2) are the result of agricultural and urban development in the watershed, which has significant association with degraded biological conditions in the Marsh Run watershed. The watershed is comprised of 53% agricultural land use, and 29% urban land use with 5% of the total watershed being impervious surface. The BSID analysis identified several stressor sources including high agriculture in the watershed and 60m buffer zone, impervious surface in the watershed and 60-meter buffer zone, and urban development (low to high intensity, residential and rural) in the watershed and 60-meter buffer zone.

The BSID source analysis (Table 2) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 98% suggesting that these stressors impact a substantial proportion of the degraded stream miles in the Marsh Run watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Marsh Run 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	4	4	82	0%	11%	1	No	_
	Moderate bar formation present	4	4	85	0%	48%	0.121	No	_
	Channel alteration moderate to poor	4	4	62	0%	50%	0.116	No	_
	Channel alteration poor	4	4	62	0%	8%	1	No	_
	High embeddedness	4	4	81	100%	1%	0	Yes	99%
	Epifaunal substrate marginal to poor	4	4	82	100%	12%	0	Yes	88%
	Epifaunal substrate poor	4	4	82	75%	0%	0	Yes	75%
	Moderate to severe erosion present	4	4	83	25%	27%	1	No	_
	Severe erosion present	4	4	83	0%	4%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Marsh Run 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	4	4	83	25%	11%	0.392	No	_
	Concrete/gabion present	4	4	71	25%	4%	0.201	No	_
	Beaver pond present	4	4	82	0%	2%	1	No	_
	Instream habitat structure marginal to poor	4	4	82	0%	7%	1	No	_
	Instream habitat structure poor	4	4	82	0%	0%	1	No	_
	Pool/glide/eddy quality marginal to poor	4	4	82	25%	22%	1	No	_
	Pool/glide/eddy quality poor	4	4	82	0%	1%	1	No	_
	Riffle/run quality marginal to poor	4	4	82	0%	13%	1	No	_
	Riffle/run quality poor	4	4	82	0%	4%	1	No	_
	Velocity/depth diversity marginal to poor	4	4	82	0%	27%	0.568	No	_
	Velocity/depth diversity poor	4	4	82	0%	1%	1	No	_
Riparian Habitat	No riparian buffer	4	4	62	0%	13%	1	No	_
	Low shading	4	4	82	25%	10%	0.363	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Marsh Run 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	4	4	171	0%	6%	1	No	_
	High conductivity	4	4	171	100%	8%	0	Yes	92%
	High sulfates	4	4	171	100%	8%	0	Yes	92%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	4	4	165	0%	2%	1	No	_
	Dissolved oxygen < 6mg/l	4	4	165	0%	5%	1	No	_
	Low dissolved oxygen saturation	4	4	165	0%	7%	1	No	_
	High dissolved oxygen saturation	4	4	165	0%	4%	1	No	_
	Ammonia acute with salmonid present	4	4	171	0%	0%	1	No	_
	Ammonia acute with salmonid absent	4	4	171	0%	0%	1	No	_
	Ammonia chronic with early life stages present	4	4	171	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	4	4	171	0%	0%	1	No	_
	High nitrites	4	4	171	50%	6%	0.024	Yes	44%
	High nitrates	4	4	171	75%	6%	0.001	Yes	69%
	High total nitrogen	4	4	171	100%	6%	0	Yes	94%
	High total phosphorus	4	4	171	0%	8%	1	No	_
	High orthophosphate	4	4	171	0%	8%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	4	4	171	0%	5%	1	No	_
	Low field pH	4	4	165	0%	11%	1	No	_
	High field pH	4	4	165	0%	1%	1	No	_
	Low lab pH	4	4	171	0%	5%	1	No	_
	High lab pH	4	4	171	0%	2%	1	No	_

Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Marsh Run Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	100%
Chemistry - Inorganic	92%
Chemistry - Nutrients	94%
All Chemistry	94%
All Stressors	***100%***

4.2 Stressors Identified by BSID Analysis

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

Sediment Conditions

BSID analysis results for the Marsh Run watershed identified three sediment parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *high embeddedness, epifaunal substrate marginal to poor*, *and epifaunal substrate poor.* (Table 4).

High embeddedness was identified as significantly associated with degraded biological conditions and found to impact approximately 99% of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition. This stressor 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 or stream channel erosion.

Epifaunal substrate was identified as significantly associated with degraded biological conditions and found to impact approximately 88% (*marginal to poor*) and 75% (*poor*) of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. The epifaunal substrate category is rated based on the amount and variety of hard, stable substrates usable by benthic macroinvertebrates. High epifaunal substrate scores are evidence of the lack of sediment deposition. However, epifaunal substrate is confounded by natural variability, i.e., some streams will naturally have different kinds of epifaunal substrate (Southerland et al. 2005b).

As development and u-rbanization increases in the watershed, so do morphological changes affecting a 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 accompany urbanization alter stream hydrology, forcing runoff to occur more readily and quickly during rainfall events. This decreases 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. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Significant channel alteration of stream habitats is typical in urban streams affected by altered hydrology.

There is a significant amount of agriculture (53%) within the Marsh Run watershed. The MDDNR MBSS noted heavy deposits of fine material above a manmade dam within a sampling segment, 15m of another segment were in a culvert, and although there had not been rain in over a week one of the sampling sites was still turbid. Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indices (Richards et al. 1997; Roth, Allan, and Erickson 1996; Wang et al. 1997), as well as greater deposition of sediments on and within the streambed.

Marginal to poor and poor ratings for epifaunal substrate, and the presence of high embeddedness are indicators that stable substrates are lacking and stream bottoms are covered with fine layers of sediment. Some of the impacts associated with sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from the embedding of stream bottoms (Hoffman, Rattner, and Burton 2003). All of these processes result in an unstable stream ecosystem that impacts habitat heterogeneity and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

The combined AR, used to measure the extent of stressor impact of the sediment stressor group, is approximately 100%, suggesting that these stressors are probable cause of the biological impairments in the Marsh Run watershed (Table 7).

Instream Habitat Conditions

BSID analysis results for the Marsh Run watershed did not identify instream 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).

Riparian Habitat Conditions

BSID analysis results for the Marsh Run watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition (Table 5).

Water Chemistry

BSID analysis results for the Marsh Run watershed identified five water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *high conductivity, high sulfates, high nitrites, high nitrates, and high total nitrogen* (Table 6).

High conductivity levels were identified as significantly associated with degraded biological conditions and found to impact approximately 92% of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Conductivity can serve as an indicator that a pollution discharge or some other source of inorganic contaminant has entered a stream. Increased levels of inorganic pollutants can be toxic to aquatic organisms and lead to exceedences in species' tolerances. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions, such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban and agricultural runoffs (i.e., fertilizers), septic drainage, as well as leaking wastewater infrastructure are typical sources of inorganic compounds.

High sulfates concentration was identified as significantly associated with degraded biological conditions and found in 92% of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. Sulfates can play a critical role in the elevation of conductivity. Other detrimental impacts of elevated sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, or of water passing through rock or soil containing gypsum and other common minerals. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. Typically sulfates derived from agricultural landscapes are associated with fertilizers, which often contain various types and concentrations of sulfate anions.

A high nitrite concentration was identified as significantly associated with degraded biological conditions in Marsh Run and was found to impact approximately 44% of the stream miles with poor to very poor biological conditions. Nitrite (NO_2^-) is a measure of the amount of NO_2^- in the water column. NO_2^- is an inorganic ion formed as an intermediate from ammonium (NH_4^+) to nitrate (NO_3^-) by bacteria in soil, sewage, and water. It can lead to eutrophication, can bioaccumulate in organisms, and causes biological harm to benthics and fish mainly through anoxia. Human sources that increase NO_2^- concentrations include agriculture, sewage, and some industrial processes (Lewis and Morris 1986; Doull, Klaassen, and Amdur 1980).

A high total nitrate concentration was identified as significantly associated with degraded biological conditions in Marsh Run and was found to impact approximately 69% of the stream miles with poor to very poor biological conditions. Nitrate (NO_3^-) is a measure of the amount of NO_3^- in the water column. Nitrifying bacteria oxidize ammonium (NH_4^+) to nitrite (NO_2^-) to nitrate (NO_3^-), three inorganic forms of nitrogen. NO_3^- is highly soluble and tends to exist in greater concentrations than other inorganic forms do, even in the presence of relatively low dissolved oxygen. In addition to agriculture, sewage, and industrial sources, atmospheric deposition can be a source of NO_3^-. Like NO_2^-, it causes biological harm via anoxia. Unlike NH_4^+ and NO_2^-, however, biological uptake of NO_3^- is limited, making it less toxic (Carmago, Alonso, and Salamanca 2005; Doull, Klaassen, and Amdur 1980).

A high total nitrogen concentration was identified as significantly associated with degraded biological conditions in Marsh Run and was found to impact approximately 94% of the stream miles with poor to very poor biological conditions. The total nitrogen (TN) parameter is the measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedences of dissolved oxygen and pH levels. Runoff and leaching from agricultural land and wastewater dischargers can generate high in-stream levels of nitrogen.

The watershed primarily consists of agricultural land use, but there is urban development in the watershed. The watershed is serviced by septic systems; there are no wastewater treatment plants in the watershed. In urban areas, excessive fertilization of lawns can be significant contributors of nutrients (Weibel 1969). The three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. The MDDNR MBSS notes that at two of the sampling sites there are pastures and/or hayfields, and BSID personnel observed a horse farm at one of the sampling stations.

Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the "limiting nutrient." The amount of the abundant nutrient does not matter because both nutrients are needed for algae growth. In general, a Nitrogen:Phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the TN:TP ratio is less than 5:1, nitrogen tends to be limiting (Chiandani and Vighi 1974).

Although TP was not identified by the BSID analysis as significantly associated with degraded biological conditions in Marsh Run a TN:TP analysis of MDE data was done. The results show that 100% of the samples collected by MDE in the Marsh Creek watershed during 2008 have TN:TP ratios above 10. The median ratio was 338. The BSID results demonstrate that phosphorus concentrations are less of an impact on stream miles with very poor to poor biological conditions in the Marsh Run watershed, therefore phosphorus may be a limiting nutrient in the watershed (Allan 1995). But due to anthropogenic sources, the watershed is vulnerable to nutrient fluxes (e.g., stormwater) that could be detrimental to the biological community. Additional analysis of available data (i.e., TN:TP ratio) is necessary to confirm if phosphorus concentrations are limiting in the watershed.

Due to the expansion of suburban development in the Marsh Run watershed, soils are often disturbed by construction activities. When these soils are excavated too deeply, they can give rise to severe active acid sulfate soil problems if the underlying un-oxidized zone of the soil-geologic column that still contains sulfide minerals is exposed (MAPSS 2006). Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. The National Atmospheric Deposition Program (NADP) monitors sulfate deposition in the United States; there is a decreasing trend in sulfate deposition in the continental United States (NADP 2010). Although sulfate deposition is generally decreasing, sulfates are still present in the sediment and can be released by natural and anthropogenic conditions.

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity 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) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 94% suggesting that these stressors are probable cause of the biological impairments in the Marsh Run watershed (Table 7).

4.3 Discussion of BSID Results

Agriculturally, Washington County is one of the most developed counties in the state of Maryland (NRCS 1996). The region has transitioned from primarily wheat and corn to general (wheat, corn, and hay) farming, dairy, and live stock. However, there has been suburban development within the Hagerstown region; the Marsh Run watershed lies southeast of Hagerstown. The Marsh Run watershed's primary land use is agricultural (53%), and it lies within active flood plains. Urban land use is also present within the watershed, but to a lesser (29%) degree. According Wang et al. 2001, even under the best-case urban development scenarios, stream fish communities will decline substantially in quality even while a watershed remains largely rural in character. Agricultural land use results in increased sediment deposition within a watershed; sediment "pollution" is the number one impairment of streams nationwide and sediments can depress populations of invertebrates and fishes, increasing the dominance of silt-tolerant species (Southerland et al. 2005b). The MDDNR MBSS noted evidence of sediment deposition within two of the Marsh Run sampling sites. The effects of increasing transportation in the watershed may also be related to degraded stream miles, and altered stream hydrology, in the watershed. State and county paved roads, such as Interstates I-70 and I-81, interconnect points within the region and are heavily traveled. Roads tend to capture and export more stormwater pollutants than other land covers; as rainfall amounts become larger, previously pervious areas in most residential landscapes become more significant sources of runoff, including sediment (NRC 2008). 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).

The BSID analysis results suggest that degraded biological communities in the Marsh Run watershed are a result of increased urban and agricultural land uses causing alteration to hydrology, increased sedimentation, loss of available habitat, and increased nutrients resulting in an unstable stream ecosystem with degraded biological communities. High proportions of these land uses also typically result in increased contaminant loads from point and nonpoint sources by adding sediments and nutrients to surface waters, resulting in levels of nutrients that can potentially be toxic to aquatic organisms. Alterations to the hydrologic regime, physical habitat, and water chemistry have all combined to degrade the Marsh Run watershed, leading to a loss of diversity in the biological community. Hopefully with continued efforts in implementing and enforcing the 2010 Chesapeake Bay TMDL by State and local agencies, sediment loads in the Marsh Run watershed will decrease, and even though not identified in the BSID analysis has having significant association with degraded biological conditions in the watershed, stream riparian habitat will improve. The combined AR for all the stressors is approximately 100%, suggesting that altered hydrology/sediment, habitat, and water chemistry stressors adequately account for the biological impairment in the Marsh Run 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 2014). 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 Marsh Run watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

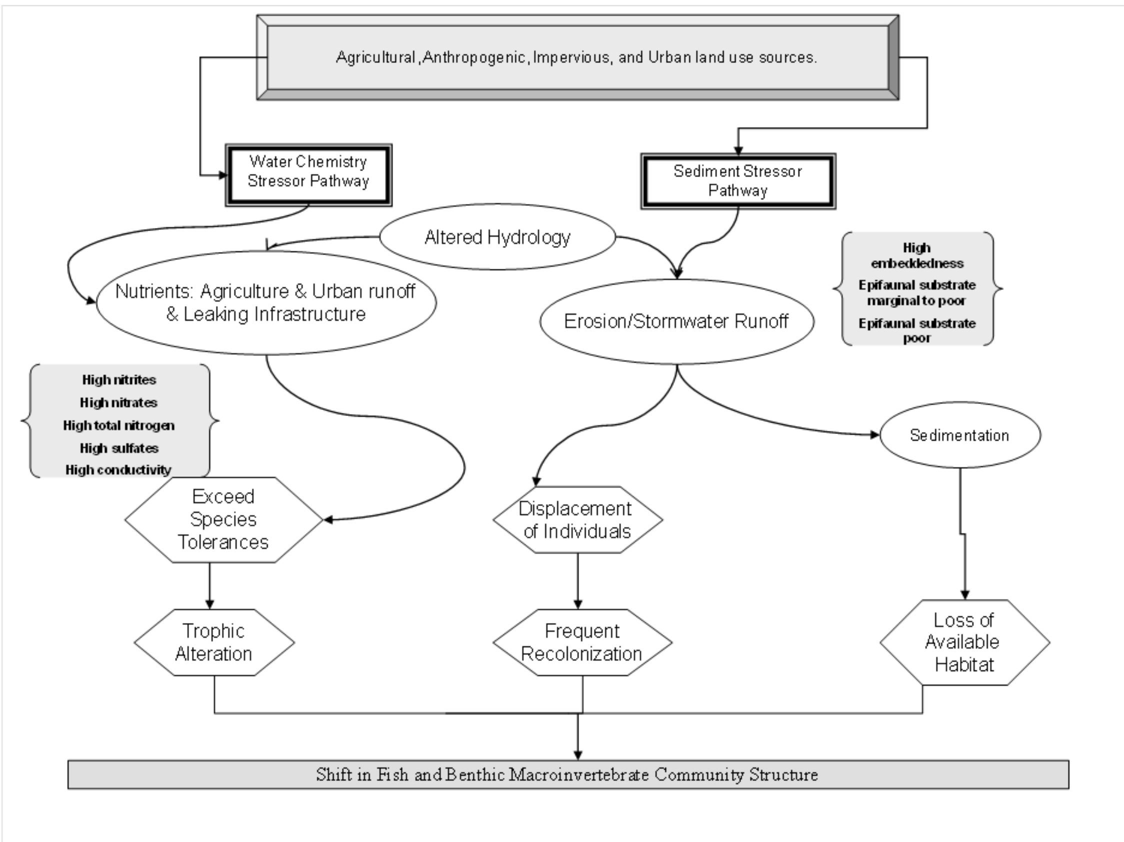

Figure 6. Final Causal Model for the Marsh Run Watershed

5.0 Conclusions

Data suggest that the Marsh Run watershed's biological communities are strongly influenced by urban and agricultural land use, which alters the hydrologic regime resulting in increased sediment and nutrient pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to urban and agricultural 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 Marsh Run watershed are summarized as follows:

- The BSID process has determined that biological communities in the Marsh Run watershed are likely degraded due to sediment related stressors. Specifically, altered hydrology and increased runoff from urban and agricultural landscapes have resulted in increased habitat homogeneity and subsequent 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 the Marsh Run watershed as an appropriate management action to begin addressing the impacts of these streams on the biological communities in the Marsh Run watershed.

- The BSID process has determined that the biological communities in the Marsh Run watershed are likely degraded due to water chemistry related stressors. Specifically, agricultural and urban land use practices have resulted in the potential elevation of nutrient (i.e. nitrogen) inputs in the watershed, which are in turn probable causes of impacts to biological communities. Due to anthropogenic sources, the watershed is vulnerable to nutrient fluxes (e.g., sediment release, fertilizer application, stormwater) that could be detrimental to the biological community, but phosphorus concentrations may be limiting in the watershed. Therefore, MDE scientists recommend a more intense analysis of all available data to assess the TN:TP ratio of the watershed. The establishment of nutrient reductions through the 2010 Chesapeake Bay TMDL was an appropriate management action to begin addressing the impact of these stressors to the biological communities in the Marsh Run watershed.

- The BSID process has determined that the biological communities in the Marsh Run watershed are likely degraded due to inorganics (i.e., sulfate). Sulfate levels are significantly associated with degraded biological conditions and found in approximately 92% of the stream miles with poor to very poor biological conditions in the Marsh Run watershed. The BSID results thus support a Category 5 listing of the Marsh Run watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Marsh Run watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

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