Watershed Report for Biological Impairment of the Non-Tidal Marshyhope Creek Watershed, Caroline and Dorchester Counties, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DE	Delaware
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MD	Maryland
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NMP	Nutrient Management Practices
NPDES	National Pollution Discharge Elimination System
PDA	Public Drainage Association
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Facility

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*, 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 Marshyhope Creek watershed (basin code 02130306), located in Caroline and Dorchester Counties, has two different assessment units: non-tidal (8-digit basin) and an estuarine portion (Chesapeake Bay segment) in the Integrated Report (IR):. The Chesapeake Bay segment related to the Marshyhope Creek watershed is the Upper Nanticoke River Oligohaline segment. A TMDL was developed for total phosphorus in 2000 and approved by the USEPA in 2001. Below, Table E1 identifies the listings associated with this watershed.

Table E1. 2010 Integrated Report Listings for the Marshyhope Creek Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Marshyhope Creek	02130306	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Upper Nanticoke River Oligohaline	NANOH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			Aquatic Life and Wildlife		Impacts to Estuarine Biological Communities	3
			Open Water Fish and Shellfish	2008	TN	5
				2008	TP	5
			Seasonal Shallow Water Submerged Aquatic Vegetation	1996	TSS	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 on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score less than 3, and calculating whether this is significant from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Marshyhope Creek and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life.* In addition a small section of the lower mainstem of the Marshyhope Creek is Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2011 a, b). The Marshyhope Creek watershed is not attaining its *nontidal warmwater aquatic life* use designation because of impacts 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 listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed biological stressor identification (BSID) analysis that uses a case-controlled, risk-based approach to systematically and objectively determine the predominant cause(s) of reduced biological conditions, which will enable the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on the degraded sites in the watershed.

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

This Marshyhope Creek watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the Marshyhope Creek watershed's biological communities are strongly influenced by agricultural land use, which alters the stream morphology resulting in increased erosion, 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 agricultural landscapes, which often cause increased contaminant loads from runoff.

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

- The BSID process has determined that biological communities in the Marshyhope Creek watershed are likely degraded due to sediment and in-stream habitat-related stressors. Specifically, natural sediment conditions exacerbated by anthropogenic sources in the Coastal Plain physiographic region have resulted in altered habitat heterogeneity and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm that the establishment of total suspended solids (TSS) TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediments to the biological communities in the Marshyhope Creek watershed. The BSID results also confirms the 1996 (tidal) Category 5 listing for TSS as an impairing substance in the Marshyhope Creek watershed, and link this pollutant to biological conditions in these waters, and extend the impairment to the watershed's non-tidal waters. The BSID results thus support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Marshyhope Creek watershed.

- The BSID process indentified low dissolved oxygen <5.0 and <6.0 mg/l, and low dissolved oxygen saturation as significantly associated with degraded biological conditions; elevated nitrogen concentrations were identified but phosphorous was identified as a limiting nutrient in the watershed. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed and seasonal low flow/no flow conditions.

- The BSID process has also determined that biological communities in the Marshyhope Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers a channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards as a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Marshyhope Creek watershed based on channelization being present in approximately 47% of degraded stream miles.

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 (IR) 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 2010). 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, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If the state can demonstrate that a watershed impairment is a result of pollution, but not a pollutant the watershed is listed under Category 4c. If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

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

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

2.0 Marshyhope Creek Watershed Characterization

2.1 Location

Marshyhope Creek is a tributary of the Nanticoke River and is located within Dorchester and Caroline Counties, Maryland with its headwaters in Sussex and Kent Counties, Delaware (DE) (see Figure 1). It drains into the Nanticoke River approximately 2.2 miles southwest of the Town of Sharptown. The Nanticoke River itself drains directly into the Chesapeake Bay. The Creek is approximately 38 miles in length, from its confluence with the Nanticoke River to the upper reaches of the headwaters.

There are several small creeks on the western shore, including Faulkner Branch, Sullivan Branch, Capital Branch, Green Branch, and Horsepen Arm. On the eastern shore the small creeks include Tanyard Branch, Houston Branch, Jones Mill Branch, Double Fork Branch, Quarter Branch, Tomahawk Branch, and Prospect Point Branch.

The watershed is located in Coastal Plains region of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

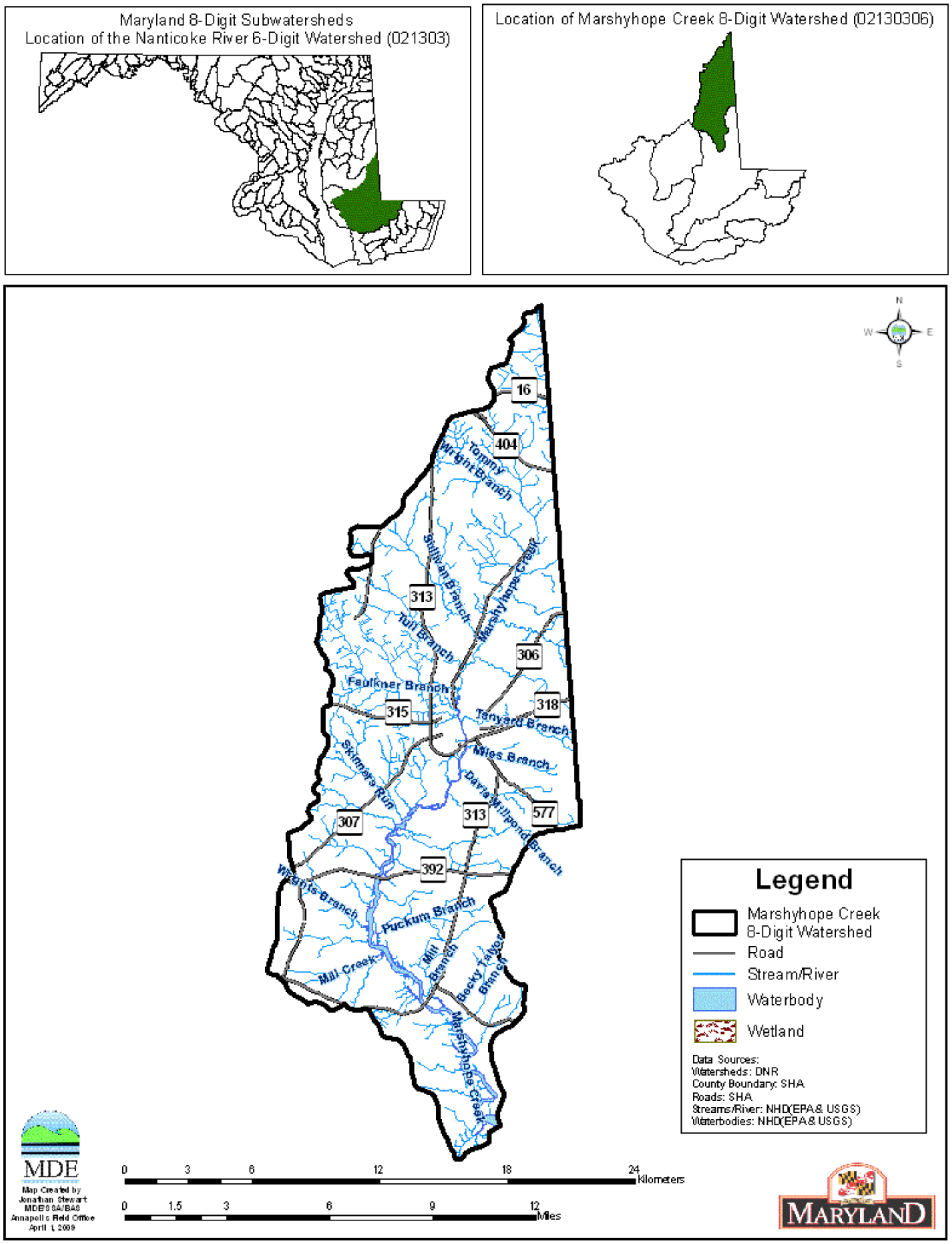

Figure 1. Location Map of the Marshyhope Creek Watershed

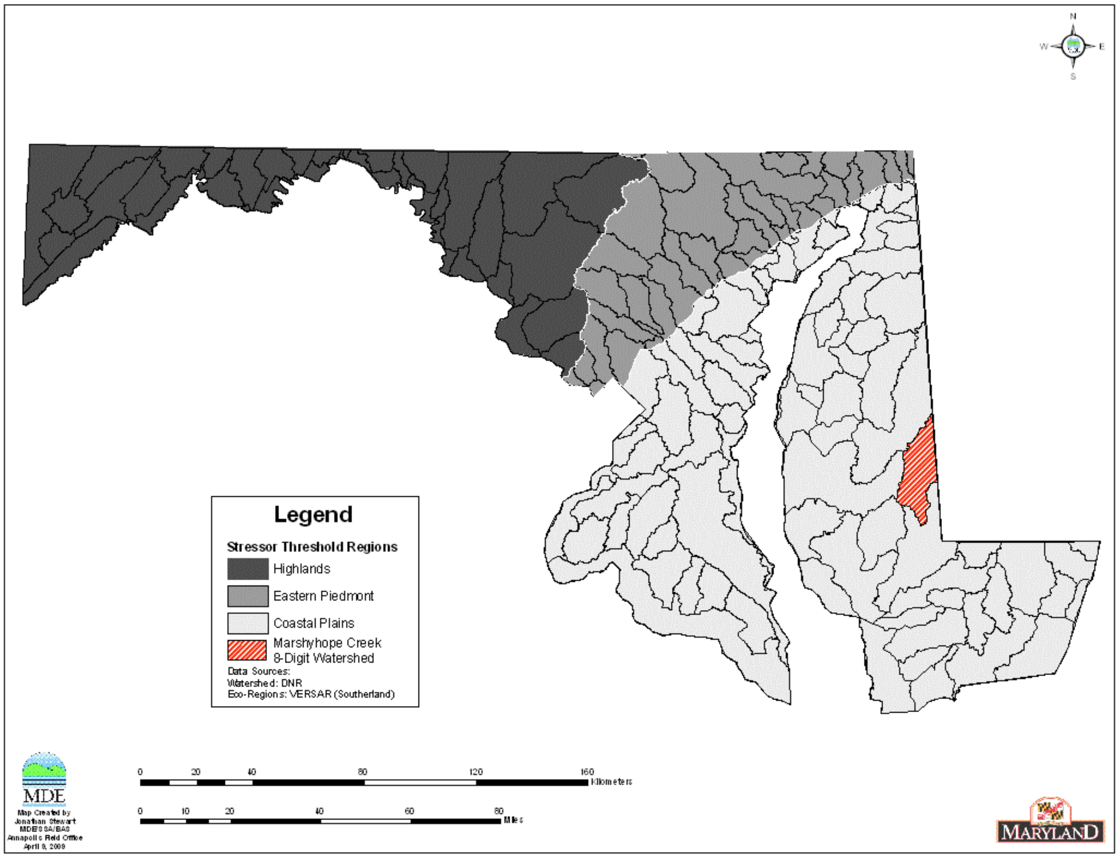

Figure 2. Eco-Region Location Map of the Marshyhope Creek Watershed

2.2 Land Use

Marshyhope Creek watershed comprises approximately 138,485 acres of drainage area in Caroline and Dorchester Counties, Maryland. The upper region of the watershed supports a high density of poultry operations augmented by row crop agriculture. Poultry waste is applied as fertilizer to the crops, which consist mainly of corn and soybeans. In this area, the Army Corps of Engineers has channeled the creek, to drain non-tidal wetlands in order to accommodate agricultural functions. A few miles downstream of the channelized portion of the creek, just beyond the Delaware - Maryland border, starts the Idylwild State Wildlife Management Area. This is an area of approximately 30,000 acres of uninhabited wetlands and forest, which extends from the State's border down to the head of tide. Below this region, beginning at Smithville, the land use becomes predominantly residential until up to the Town of Federalsburg, which is a higher density urban area. Downstream of Federalsburg there is a mix of forest and crop lands with limited poultry growing, except in the region of Walnut Landing, where there are many poultry operations and concentrated feeding operations, mostly swine. According to the Chesapeake Bay Program's Phase 5.2 Model the land use distribution in the watershed is approximately 49% agricultural, 40% forest/herbaceous, and 11% urban (USEPA 2010) (see Figure 3 and Figure 4).

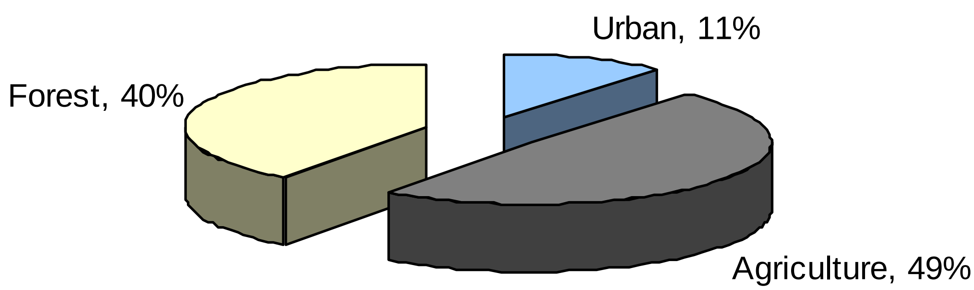

Figure 3. Proportions of Land Use in the Marshyhope Creek Watershed

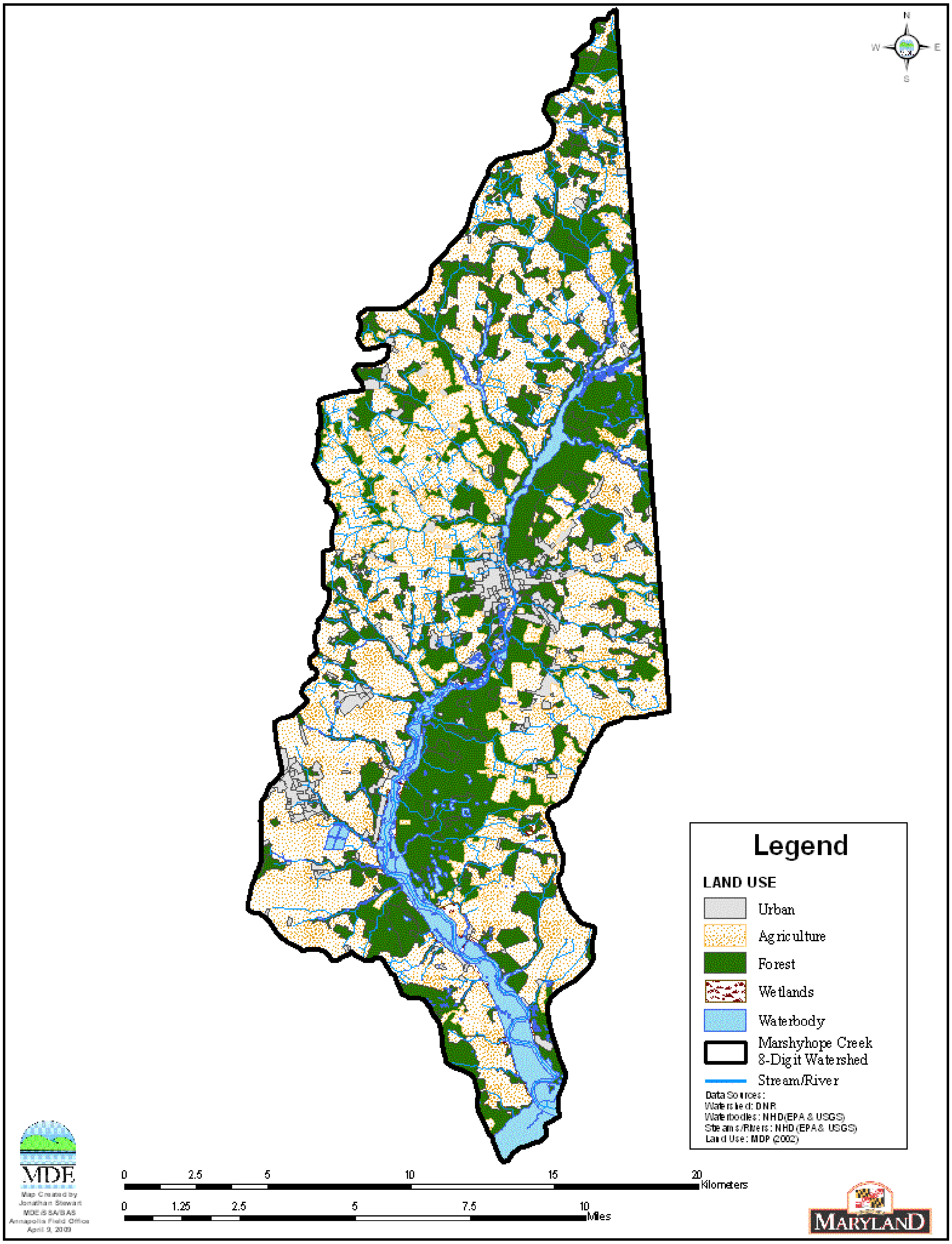

Figure 4. Land Use Map of the Marshyhope Creek Watershed

2.3 Soils/hydrology

The Marshyhope Creek watershed lies within the Coastal Plain physiographic region, which is a wedge-shaped mass of primarily unconsolidated sediments of the Lower Cretaceous, Upper Cretaceous and Pleistocene Ages covered by sandy soils. The Coastal Plain region is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2011).

Soils typically found in the Marshyhope Creek watershed are the Sassafras, Fallsington, Galestown, and Matapeake series. The Sassafras series consist of very deep, well drained soils on sandy marine and old alluvial sediments. The Fallsington series consist of very deep poorly drained on coastal plain flatlands. Saturated hydraulic conductivity is high in the subsoil and high to very high in the substratum. The Galestown series consist of very deep, somewhat excessively drained soils formed in sandy marine sediments and glacial outwash on glacial terminal moraine. The Matapeake series consist of very deep, well drained soils in silty eolian sediments underlain by coarser fluvial or marine sediments (USDA NRCS 1977).

3.0 Marshyhope Creek Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Marshyhope Creek watershed (basin code 02130306), located in Caroline and Dorchester Counties, has two different assessment units: non-tidal (8-digit basin) and an estuarine portion (Chesapeake Bay segment) in the Integrated Report (IR):. The Chesapeake Bay segment related to the Marshyhope Creek watershed is the Upper Nanticoke River Oligohaline segment. A TMDL was developed for total phosphorus in 2000 and approved by the USEPA in 2001. Below is a table identifying the listings associated with this watershed.

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			Open Water Fish and Shellfish	2008	TN	5
				2008	TP	5
			Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	5

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Marshyhope Creek and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition a small section of the lower mainstem of the Marshyhope Creek is Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2011 a, b). 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 Marshyhope Creek watershed is listed under Category 5 of the 2010 Integrated Report as impaired for impacts to biological communities. Approximately 55% of stream miles in the Marshyhope Creek basin are estimated as having fish and 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 eleven sites. Six of the eleven sites have 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 round 2 contains seven MBSS sites with five having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Marshyhope Creek watershed.

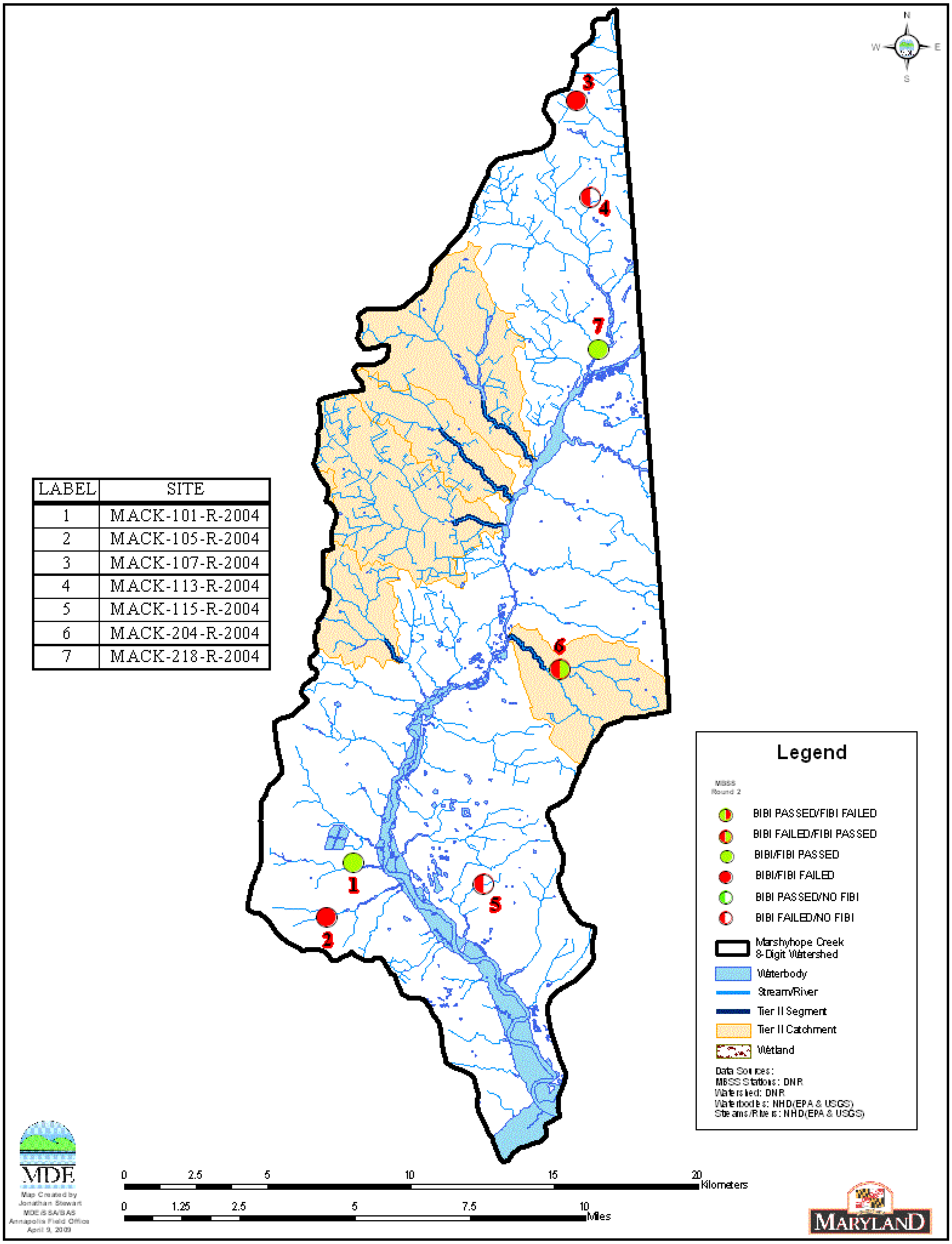

Figure 5. Principal Dataset Sites for the Marshyhope Creek Watershed

4.0 Stressor Identification Results

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

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores significantly lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 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-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are very poor to poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and very poor to poor biological conditions, and is used to identify potential stressors.

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

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

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

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Marshyhope Creek watershed, MDE identified sources, sediment, in-stream habitat, and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various agricultural land uses within the watershed as well as in sixty meter riparian buffer. Table 3 shows the summary of combined AR values for the source groups in the Marshyhope Creek watershed. As shown in Table 4 through Table 6, numerous parameters from the sediment, in-stream habitat, and water chemistry groups were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Marshyhope Creek watershed.

Table 2. Stressor Source Identification Analysis Results for the Marshyhope Creek Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	7	5	214	0%	5%	No	----
	high % of high intensity urban in watershed	7	5	214	0%	9%	No	----
	high % of low intensity urban in watershed	7	5	214	0%	4%	No	----
	high % of transportation in watershed	7	5	214	0%	7%	No	----
	high % of high intensity urban in 60m buffer	7	5	212	20%	7%	No	----
	high % of low intensity urban in 60m buffer	7	5	212	0%	5%	No	----
	high % of transportation in 60m buffer	7	5	212	80%	9%	Yes	71%
Sources Agriculture	high % of agriculture in watershed	7	5	214	80%	18%	Yes	62%
	high % of cropland in watershed	7	5	214	100%	27%	Yes	73%
	high % of pasture/hay in watershed	7	5	214	0%	6%	No	----
	high % of agriculture in 60m buffer	7	5	212	60%	8%	Yes	52%
	high % of cropland in 60m buffer	7	5	212	80%	18%	Yes	62%
	high % of pasture/hay in 60m buffer	7	5	212	60%	8%	Yes	52%
Sources Barren	high % of barren land in watershed	7	5	214	0%	23%	No	----
	high % of barren land in 60m buffer	7	5	212	0%	6%	No	----

Table 2. Stressor Source Identification Analysis Results for the Marshyhope Creek Watershed (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Anthropogenic	low % of forest in watershed	7	5	214	20%	5%	No	----
	low % of forest in 60m buffer	7	5	212	60%	5%	Yes	55%
Sources Acidity	atmospheric deposition present	7	5	208	0%	40%	No	----
	AMD acid source present	7	5	208	0%	0%	No	----
	organic acid source present	7	5	208	0%	6%	No	----
	agricultural acid source present	7	5	208	40%	7%	Yes	33%

Table 3. Summary AR Values for Source Groups for Marshyhope Creek Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	71%	94%
Agriculture	90%	
Barren Land	----	
Anthropogenic	55%	
Acidity	33%	

4.1 Sources Identified by BSID Analysis

The land use sources identified by the BSID analysis (Table 2), are the result of agricultural development within the Marshyhope Creek watershed. A significant amount of the watershed is comprised of agricultural land uses (49%). The upper region of the watershed supports a high density of poultry operations augmented by row crop agriculture. Poultry waste is applied as fertilizer to the crops, which consist mainly of corn and soybeans. In this area, the Army Corps of Engineers has channeled the creek, to drain non-tidal wetlands in order to accommodate agricultural functions. In the lower region of the watershed there is a mix of forest and crop lands with limited poultry growing, except in the region of Walnut Landing, where there are many poultry operations and concentrated feeding operations, mostly swine.

BSID results identified agricultural, cropland, and pasture/hay land uses within the watershed, as well as the sixty meter riparian buffer zone as having significant association with degraded biological conditions. The high percentage of cropland and pasture/hay within the riparian buffer zone is indicative of crops that are cultivated all the way to the stream banks and agricultural practices that allow cattle to have direct access to ditches and streams. Although nutrient and best management practices (NMPs and BMPs) are in place to control sediment and nutrient runoff in the watershed, the BSID analyses revealed that agricultural practices especially in the riparian buffer zone continue to create conditions in the watershed that are impacting biological resources. Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995).

Typical anthropogenic alterations to a stream caused by agricultural development include channelization, substrate disturbance (dredging), nutrient eutrophication, hydrological changes, and riparian removal (Hynes 1970; Allan 1995). Some of the alterations have direct in-stream effects on structure, water chemistry (e.g., nutrient additions due to lack of riparian buffer), and some have geomorphological repercussions (e.g., channelization).

The BSID analysis also identified agricultural sources of acidity as having significant association with degraded biological conditions. Fertilizers used in agricultural practices often contain high levels of nitrogen, or other acidifying compounds, which are sources of acidification in surface waters. Agricultural activities in watersheds effect stream chemistry by lowering the acid neutralizing capacity (ANC), from soil liming practices, and strong acid anions from nitrogen fertilizers.

Transportation land use within sixty meter buffer was also identified as significantly associated with degraded biological conditions. Almost all of the transportation corridors in the watershed are small rural two lane roads. The majority of impacts to streams in the watershed from these types of roads would be associated with habitat conditions. In all likelihood the detrimental impacts of transportation corridors is secondary to that of agricultural development.

The BSID source analysis (Table 2) identifies a variety of agricultural land uses within the watershed, and sixty meter buffer as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 94% suggesting these sources potentially impacts a substantial portion of the degraded stream miles in the Marshyhope Creek watershed (Table 3).

All the stressors identified in the BSID analysis for the Marshyhope Creek watershed can be linked to the typical consequences of agricultural development. The remainder of this section will discuss identified stressors and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for Marshyhope 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	7	5	120	0%	22%	No	----
	moderate bar formation present	7	5	120	40%	55%	No	----
	bar formation present	7	5	120	80%	81%	No	----
	channel alteration marginal to poor	7	5	117	80%	61%	No	----
	channel alteration poor	7	5	117	0%	26%	No	----
	high embeddedness	7	5	120	0%	0%	No	----
	epifaunal substrate marginal to poor	7	5	120	80%	42%	No	----
	epifaunal substrate poor	7	5	120	40%	9%	Yes	32%
	moderate to severe erosion present	7	5	120	0%	45%	No	----
	severe erosion present	7	5	120	0%	13%	No	----
	poor bank stability index	7	5	120	0%	23%	No	----
	silt clay present	7	5	120	100%	99%	No	----

Table 5. Habitat Biological Stressor Identification Analysis Results for the Marshyhope 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	7	5	122	60%	13%	Yes	47%
	instream habitat structure marginal to poor	7	5	120	80%	37%	Yes	44%
	instream habitat structure poor	7	5	120	60%	4%	Yes	56%
	pool/glide/eddy quality marginal to poor	7	5	120	80%	41%	Yes	42%
	pool/glide/eddy quality poor	7	5	120	20%	3%	No	----
	riffle/run quality marginal to poor	7	5	120	80%	44%	No	----
	riffle/run quality poor	7	5	120	60%	19%	Yes	41%
	velocity/depth diversity marginal to poor	7	5	120	100%	55%	Yes	46%
	velocity/depth diversity poor	7	5	120	80%	12%	Yes	69%
	concrete/gabion present	7	5	126	0%	2%	No	----
	beaver pond present	7	5	119	0%	7%	No	----
Riparian Habitat	no riparian buffer	7	5	122	20%	13%	No	----
	low shading	7	5	120	0%	9%	No	----

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Marshyhope 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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	7	5	208	80%	25%	Yes	55%
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	7	5	208	20%	39%	No	----
	ammonia acute with salmonid absent	7	5	208	20%	26%	No	----
	ammonia chronic with salmonid present	7	5	208	40%	67%	No	----
	ammonia chronic with salmonid absent	7	5	208	40%	57%	No	----
	low lab pH	7	5	208	80%	38%	Yes	42%
	high lab pH	7	5	208	0%	0%	No	----
	low field pH	7	5	207	80%	39%	No	----
	high field pH	7	5	207	0%	0%	No	----
	high total phosphorus	7	5	208	0%	3%	No	----
	high orthophosphate	7	5	208	20%	13%	No	----
	dissolved oxygen < 5mg/l	7	5	206	80%	14%	Yes	66%
	dissolved oxygen < 6mg/l	7	5	206	80%	22%	Yes	58%
	low dissolved oxygen saturation	5	3	184	67%	18%	Yes	48%
	high dissolved oxygen saturation	5	3	184	0%	0%	No	----
	acid neutralizing capacity below chronic level	7	5	208	0%	9%	No	----
	acid neutralizing capacity below episodic level	7	5	208	40%	48%	No	----
	high chlorides	7	5	208	0%	6%	No	----
	high conductivity	7	5	208	20%	5%	No	----
	high sulfates	7	5	208	0%	4%	No	----

Table 7. Summary AR Values for Stressor Groups for Marshyhope Creek Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	32%	91%
In-Stream Habitat	91%	
Riparian Habitat	----	
Water Chemistry	84%	

4.2 Stressors Identified by BSID Analysis

All thirteen stressor parameters identified by the BSID analysis (Table 3, 4, and 5), as being significantly associated with biological degradation in the Marshyhope Creek watershed are characteristic of agriculturally developed landscapes.

Sediment Conditions

BSID analysis results for the Marshyhope Creek identified one sediment parameter that has a statistically significant association with poor to very poor stream biological condition: *epifaunal substrate (poor)* (Table 4).

Epifaunal substrate (poor) was identified as significantly associated with degraded biological conditions in 32% of the stream miles with poor to very poor biological conditions in the Marshyhope Creek watershed. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

The BSID analysis applies a threshold of 100% for embeddedness in the Coastal Plains since the eco-region is naturally embedded. Consequently, embeddedness was not identified as significantly associated with degraded biological conditions in the Marshyhope Creek watershed in this analysis. The data review did, however, identify all of the MDDNR MBSS round two sites used in this analysis were 100% embedded. Embeddedness describes the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. High embeddedness is a result of excessive sediment deposition that may interfere with feeding or reproductive processes.

Agricultural development especially in the riparian buffer zones typically results in increased sediment deposition throughout the streambed primarily through settling of sediment in the stream substrate, as demonstrated by the lack of adequate epifaunal substrate. This effect is compounded by the low topographic relief throughout the watershed that does not allow for sediment transport to downstream reaches. Sediment deposited on the streambed can suffocate benthic organisms, especially in the embryonic and larval stages (NRCS 1997). The sediment deposition in the watershed has led to a loss of suitable habitat to support the full colonization of a healthy fish and benthic macroinvertebrate community.

The watershed consists of approximately 49% agricultural land uses (USEPA 2010). Ditching on agricultural lands in the Marshyhope Creek watershed is an extensive practice that has been used to drain wetlands for agriculture (Bell and Favero 2000; Gellis et al. 2009). The majority of agricultural uses in the watershed are comprised of cropland, pasture, and poultry operations. Agricultural practices, such as row crop cultivation and cattle grazing typically extend directly to the stream and ditch banks, lacking adequate forested or vegetated buffer zones. Ditching and straightening (channelization) of streams within the watershed, and continual dredging have created conditions favorable for channel-corridor erosion (Gellis et al. 2009).

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 sediment stressor group is approximately 32%, suggesting these stressors impact a moderate proportion of the degraded stream miles in the Marshyhope Creek watershed (See Table 7).

In-stream Habitat Conditions

BSID analysis results for the Marshyhope Creek watershed identified seven in-stream habitat parameters that have statistically significant association with poor to very poor stream biological condition: *channelization present, in-stream habitat structure (marginal to poor & poor), pool/glide/eddy quality (marginal to poor,) riffle/run quality (poor), velocity/depth diversity (marginal to poor & poor)* (Table 5).

Channelization present was identified as significantly associated with degraded biological conditions in the Marshyhope Creek watershed, and found to impact approximately 47% of the stream miles with poor to very poor biological conditions. This stressor measures the presence/absence of channelization in stream banks. It describes both the straightening of channels and their fortification with concrete or other hard materials. Natural channels have diverse habitats with varying water velocities as the morphology changes between riffles and pools. The diverse nature of natural channels provides slow water refugia during high flow and many resting areas. With less structural diversity, channelized systems have minimal resting areas and organisms are easily swept away during high flows. In low flow periods, natural channels have sufficient water depth to support fish and aquatic species during the dry season; where as, channelized streams often have insufficient depth to sustain diverse aquatic life (Bolton and Shellberg 2001).

In-stream habitat structure (marginal to poor & poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 44% (marginal to poor) and 56% (poor) of the stream miles with poor to very poor biological conditions in the Marshyhope Creek watershed. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High in-stream habitat scores are evidence of the lack of sediment deposition. In-stream habitat structure is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Pool/glide/eddy quality (marginal to poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 42% of the degraded stream miles in the Marshyhope Creek watershed. Pool/glide/eddy quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment referred to as pool/glide/eddy. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the pool/glide/eddy habitat decreases valuable habitat for fish species. Pool/glide/eddy quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels 1) poor, defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely; and 2) marginal, defined as <10% heterogeneous habitat with shallow areas (<0.2 meters) prevalent and slow moving water areas with little cover.

Riffle/run quality (poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 41% of the degraded stream miles in the Marshyhope Creek watershed. Riffle/run quality is a visual observation and quantitative measurement based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase in the 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. Riffle/run quality conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal to poor, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity.

Velocity/depth diversity (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in the Marshyhope Creek watershed, and found to impact approximately 46% (*marginal to poor* rating) and 69% (*poor* rating) of the stream miles with poor to very poor biological conditions. Velocity/depth diversity is a visual observation and quantitative measurement 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 velocity/depth/diversity category 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.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime. Velocity is one of the critical variables that controls the presence and number of species (Gore 1978). Many invertebrates depend on certain velocity ranges for either feeding or breathing (Brookes 1988).

All the in-stream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity; the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Substrate is an essential component of in-stream habitat to macroinvertebrates for two reasons. First, many organisms are adapted to living on or obtaining food from specific types of substrate, such as cobble or sand. The group of organisms known as scrapers, for instance, cannot easily live in a stream with no large substrate because there is nothing from which to scrape algae and biofilm. Hence substrate diversity is strongly correlated with macroinvertebrate assemblage composition (Cole, Russel, and Mabee 2003). Second, obstructions in the stream such as cobble or boulders slow the movement of coarse particulate organic matter, allowing it to break down and feed numerous insects in its vicinity (Hoover, Richardson, and Yonesmitsu 2006).

The presence of a well-developed riffle/pool/glide/eddy system is indicative of different types of habitat, and is typically assumed to have a higher biodiversity of organisms (Richards, Host, and Arthur 1993). Often sedimentation and increased flooding can disrupt riffle/pool/glide/eddy sequences (Richards, Host, and Arthur 1993). The geomorphological characteristics described above are often strongly influenced by land use characteristics, e.g., agricultural development within the riparian buffer zone allowing for increased sedimentation and flow which alters natural in-stream habitat.

Forty-seven percent of degraded stream miles in the watershed are artificially straightened or channelized in some way. Historically many streams in the coastal plain were channelized to improve drainage of croplands. The water table in the basin before ditching was close to the surface and interfered with agricultural practices; subsequent ditching lowered the groundwater table (Maguire, Needelman, and Vadas 2009). During channelization, trees in the riparian buffer zone are often cut and woody debris is removed from the stream channel to allow for efficient movement of water away from agricultural fields. Channelization has changed many streams into straight shallow ditches with severely depressed biodiversity. Effects of channelization include loss of stream habitat, loss of aquatic productivity, increased streambed and bank erosion, and a reduction of ground water levels. The Delmarva Peninsula contains over 808 miles of Public Drainage Association (PDA) or tax ditches that drain over 143,311 acres of land (Bell and Favero 2000). Caroline County, which is part of the Marshyhope Creek watershed, holds the greatest number of tax ditches in the Maryland Eastern Shore, draining over 69,190 acres of cropland (MDDNR 2002).

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 in-stream habitat stressor group is approximately 91% suggesting these stressors impacts almost all of the degraded stream miles in the Marshyhope Creek (See Table 7).

Riparian Habitat Conditions

BSID analysis results for the Marshyhope Creek watershed did not identify any riparian habitat 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) (Table 5).

Water Chemistry

BSID analysis results for the Marshyhope Creek 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). These parameters are *high total nitrogen, low lab pH, low dissolved oxygen < 5.0 mg/l & <6.0 mg/l, and low dissolved oxygen saturation* (Table 6).

High total nitrogen concentration was identified as significantly associated with degraded biological conditions in Marshyhope Creek and found in approximately 55% of the stream miles with poor to very poor biological conditions. Total nitrogen (TN) is a 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 can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. Runoff and leaching from fertilizers applied to agricultural lands, groundwater infiltration, and wastewater effluent can generate elevated levels of nitrogen in surface waters.

Fertilizer and poultry waste applications on agricultural lands are one potential source of high nitrogen loads in the watershed. Poultry operations are located throughout the Marshyhope Creek watershed. The poultry manure generated by these operations is commonly spread on fields as fertilizers (often near streams or ditches that drain to nearby streams). The Water Quality Improvement Act of 1998 mandated that farmers use nutrient management practices (NMPs) to reduce nitrogen and phosphorus inputs. The NMPs do not require use of storage sheds for poultry litter, and it is sometimes stored outdoors. If manure is stored uncovered and in close proximity to surface waters for more than a few days or on top of the ground with no barrier, there are serious risks of groundwater and surface water contamination (MAG 2008).

Groundwater transports a large amount of nitrogen to streams in the Chesapeake Bay watershed. Nitrogen reaches the land surface in rainfall or through fertilizer application associated with agricultural land uses. Once on the land surface, some of the nitrogen infiltrates into the underlying soil and groundwater. Once in the groundwater, nitrogen generally is converted to nitrate and moves through the aquifer. Much of the nitrate is discharged into streams and contributes to the total nitrogen load in a stream (USGS 2009). Of the major nitrogen sources (atmospheric, urban, and agricultural) in a watershed, multiple studies (Ator and Ferrari, 1997; Lindsey, Loper, and Hainly 1997, Shedlock et al. 1999) have shown that agricultural land use has the greatest impact on nitrogen concentrations in groundwater. Many streams in the Marshyhope Creek watershed were ditched to improve drainage of croplands. The water table in the basin is fairly close to the surface and interfered with agricultural practices; subsequent ditching lowered the groundwater table, increasing transport of groundwater to the surface waters.

Increased leaching of groundwater into surface waters of the Marshyhope Creek watershed is another potential source of elevated TN.

There are five wastewater treatment plant (WWTP) discharges within the Marshyhope Creek watershed. These five point sources are: Hurlock WWTP, Federalsburg WWTP, Col. Richardson High School WWTP, W.O. Whyteley and Sons Company, and the Solo Cup Company. Information was reviewed from discharge monitoring reports stored in MDE's point source database. Of the five current discharges, the W. O. Whiteley and the Solo Cup Company were considered to be insignificant point sources of nutrients and suspended solids to the watershed. Nutrient and suspended solid loads from any wastewater treatment facility is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

MDE considers phosphorus to be the limiting nutrient species in an ecosystem. Phosphorus is generally much less soluble than nitrogen; it is leached from the soil at a much slower rate than nitrogen. Consequently, phosphorus is much more important as a limiting nutrient in aquatic systems (Smith, Tilman, and Nekola 1999). An analysis of MDE data (1998, 2000, 2003, 2004, 2005, 2010**)** of the TN:TP ratio was completed for the Marshyhope Creek watershed confirming that phosphorus is a limiting factor.

Low lab pH was significantly associated with degraded biological conditions and found in 42% of the stream miles with poor to very poor biological conditions in the Marshyhope Creek watershed. pH is a measure of acidity that uses a logarithmic scale ranging from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. *Low pH* values (less than 6.5) can be damaging to aquatic life. The pH threshold values, below 6.5 and above 8.5, which may indicate biological degradation, are established from state regulations (COMAR 2011c). Many biological processes, such as reproduction, cannot function in acidic waters. Common sources of acidity include mine drainage, atmospheric deposition, runoff from mine tailings, agricultural fertilizers, and natural organic sources. The BSID analysis identified agricultural sources as having significant association with degraded biological conditions. Fertilizers used in agricultural practices include the use of nitrogen fertilizers, which often contain high levels of strong acid anions, and other acidifying compounds, which are sources of acidification in surface waters.

Low (< 5mg/L and *< 6mg/L) dissolved oxygen* (DO) concentrations were identified as significantly associated with degraded biological conditions and found in 66% and 58%, respectively, of the stream miles with poor to very poor biological conditions in the Marshyhope Creek watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms or lead to exceedences in species tolerances. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR (2011c).

Low dissolved oxygen saturation was significantly associated with degraded biological conditions and found in 48% of the stream miles with poor to very poor biological conditions in the Marshyhope Creek watershed. DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Percent saturation is relative to the amount of oxygen that water can hold, as determined by temperature and atmospheric pressure. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production. DO saturation less than 60% (like DO concentrations <5mg/L) is considered to demonstrate high respiration associated with excessive decomposition of organic material. Additionally, DO saturation greater than 125% is considered to demonstrate oxygen production associated with high levels of photosynthesis. Sources are agricultural, forested and urban land uses.

Usually low DO concentrations in the a watershed are associated with surface waters experiencing eutrophication. Because of the low topographic relief of the Marshyhope Creek watershed and the Coastal Plains physiographic ecoregion in general, streams tend to have very gentle slopes with few riffles to aerate the water. Many first order streams on the Maryland eastern 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. Three of the four MBSS stations with low DO levels had recorded "field crew comments" referencing little flow, standing pools, and dry segments.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the water chemistry stressor group is approximately 84% suggesting that these stressors impact a substantial proportion of degraded stream miles in the Marshyhope Creek (Table 7).

4.3 Discussion of BSID Results

The Marshyhope Creek watershed has a highly agricultural landscape consisting of row crops, pasture/hay, and poultry operations. Agricultural practices include row crops that are commonly cultivated to the stream banks, disturbed buffer zones maintained for ditch maintenance, and poultry manure application to fields. Despite the NMPs and best management practices (BMPs) applied in the watershed, agricultural practices continue to impact the water quality.

The BSID sediment and instream habitat analysis results suggest that degraded biological communities in the Marshyhope Creek watershed are a result of agricultural land use practices that have altered the stream morphology (primarily through channelization and ditching). These practices have led to increased sediment settling in the stream substrate and a homogeneous habitat unsuitable for full colonization of a healthy fish and macroinvertebrate community structure.

The BSID water chemistry analysis results also suggest that degraded biological communities in the Marshyhope Creek watershed are a result of agricultural land use practices that have led to increased nitrogen loads from fertilizer applications. MDE considers phosphorus to be the limiting nutrient species in an ecosystem, and since phosphorus was not identified as a potential stressor, reduction of nitrogen loads would not be an effective means of ensuring that the watershed is free from impacts on aquatic life from eutrophication. A TN:TP ratio analysis of six years of MDE was completed for the watershed confirming that phosphorus is a limiting factor. Due to the low topographic relief of the Marshyhope Creek watershed, streams tend to have very gentle slopes, seasonal low flow conditions, and few riffles to aerate the water most probably resulting in naturally low DO.

Due to significant anthropogenic changes of natural stream channels within the watershed, health and diversity of biological communities are severely impacted. The stressors c*hannelization present* was identified as significantly associated with degraded biological conditions, and found to impact approximately 47% of the stream miles with poor to very poor biological conditions in the Marshyhope 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 for the Marshyhope Creek Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent 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 1991and USEPA 2011). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final causal model for the Marshyhope Creek watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

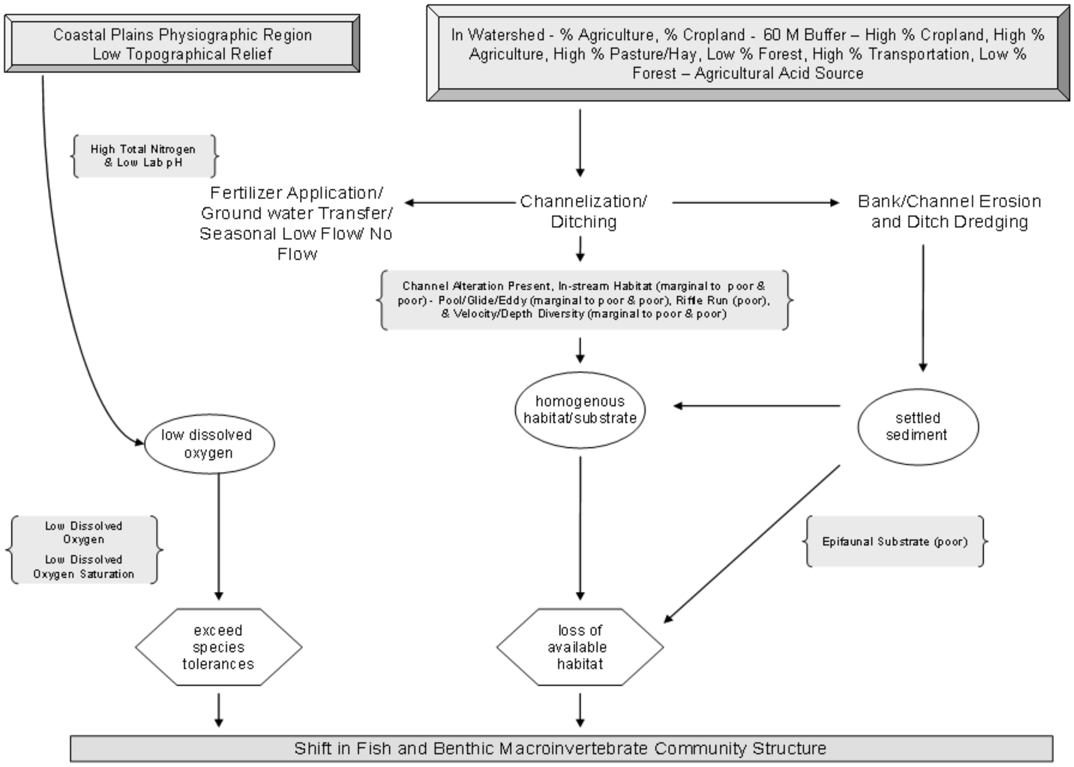

Figure 6. Final Causal Model for the Marshyhope Creek Watershed

5.0 Conclusion

Data suggest that the Marshyhope Creek watershed's biological communities are strongly influenced by agricultural land use, which alters the stream morphology resulting in increased erosion, 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 agricultural landscapes, which often cause increased contaminant loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Marshyhope Creek watershed are summarized as follows:

- The BSID process has determined that biological communities in the Marshyhope Creek watershed are likely degraded due to sediment and in-stream habitat-related stressors. Specifically, natural sediment conditions exacerbated by anthropogenic sources in the Coastal Plain physiographic region have resulted in altered habitat heterogeneity and subsequent elevated suspended sediment in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm that the establishment of total suspended solids (TSS) TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediments to the biological communities in the Marshyhope Creek watershed. The BSID results also confirms the 1996 (tidal) Category 5 listing for TSS as an impairing substance in the Marshyhope Creek watershed, and link this pollutant to biological conditions in these waters, and extend the impairment to the watershed's non-tidal waters. The BSID results thus support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Marshyhope Creek watershed.

- The BSID process indentified low dissolved oxygen <5.0 and <6.0 mg/l, and low dissolved oxygen saturation as significantly associated with degraded biological conditions; elevated nitrogen concentrations were identified but phosphorous was identified as a limiting nutrient in the watershed. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed and seasonal low flow/no flow conditions.

- The BSID process has also determined that biological communities in the Marshyhope Creek watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers a channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards as a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the

Marshyhope Creek watershed based on channelization being present in approximately 47% of degraded stream miles.

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