Watershed Report for Biological Impairment of the Magothy River Watershed in Anne Arundel County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMPs	Best Management Practices
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
MS4	Municipal Separate Storm Sewer System
PCBs	Polychlorinated Biphenyls
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

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

The Magothy River watershed (basin code 02131001), located in Anne Arundel County, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and an estuary portion, the Magothy River Mesohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for the Magothy River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Magothy River	02131001	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Magothy River Mesohaline	MAGMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	2012	TN	4a
				2012	TP	4a
			Aquatic Life and Wildlife	2004	Impacts to Estuarine Biological Communities	5
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	1996	TSS	4a
Magothy River Mesohaline	MAGMH	Tidal	Shellfishing	1996	Fecal Coliform	4a
					Fecal Coliform (Subwatershed Tar Cove)	4a
				2012	Fecal Coliform (Subwatershed Deep Creek)	5
				1996	Fecal Coliform (Subwatershed Forked Creek)	4a
			Fishing	2006	PCBs in Fish Tissue	5
					Mercury in Fish Tissue	2

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of the Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which

maintains consistency with how other listings on the Integrated Report are made, TMDLs are developed, and implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds by measuring the percentage of stream miles that have poor to very poor biological conditions, and calculating whether this is significantly different from a reference condition watershed (i.e., healthy stream, <10% stream miles with poor to very poor biological condition).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Magothy River and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition most of the mainstem of the Magothy River and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). The Magothy River watershed is not attaining its nontidal warmwater aquatic life use designations due to 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 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 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 Magothy River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the biological communities of the Magothy River watershed are strongly influenced by urban land use and its concomitant effects: elevated levels of chlorides, and low dissolved oxygen (DO). The development of landscapes creates broad and interrelated forms of degradation that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between urban landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID analysis, and the probable causes and sources of the biological impairments in the Magothy River watershed can be summarized as follows:

- The BSID process has determined that the biological communities in the Magothy River watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, urban and transportation land use practices have resulted in the potential elevation of chloride inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of chloride for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Magothy River watershed. Discharges of inorganic compounds like chloride are intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process also indentified low dissolved oxygen below <6.0 mg/l and low dissolved oxygen saturation as significantly associated with degraded biological conditions; however, elevated phosphorus and/or nitrogen concentrations were not identified. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and/or low flow velocities due to an abundance of tidal fresh zones.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2012). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as Category 4a. 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 and three Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2009) 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 Magothy River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Magothy River Watershed Characterization

2.1 Location

The Magothy River is situated in the northeastern portion of Anne Arundel County in the State of Maryland. The watershed is located north of the Severn River and south of the Patapsco River. It starts in Severna Park, and flows into Chesapeake Bay next to Gibson Island. The river is relatively small being only 12.1 miles in length and is mostly tidal with a watershed area of 22,800 acres. The Little Magothy River is considered part of the Magothy River watershed, even though the mouth of the Little Magothy River is outside the mouth of the Magothy (Figure 1). Its navigable tidal portion is crossed by one bridge, located on Magothy Bridge Road in Pasadena. Its upper, nontidal portion is called Magothy Branch, and is dammed at MD 648 (Baltimore-Annapolis Boulevard) to form Lake Waterford (there once was an old mill dam at the same site). Some of the creeks on its south shore drain highly developed portions of Severna Park and Arnold, especially North Cypress Creek, which drains much of the Park Plaza and Giant shopping centers along Ritchie Highway north of McKinsey Road.

The watershed is entirely located within the Coastal Plains physiographic region. There are three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

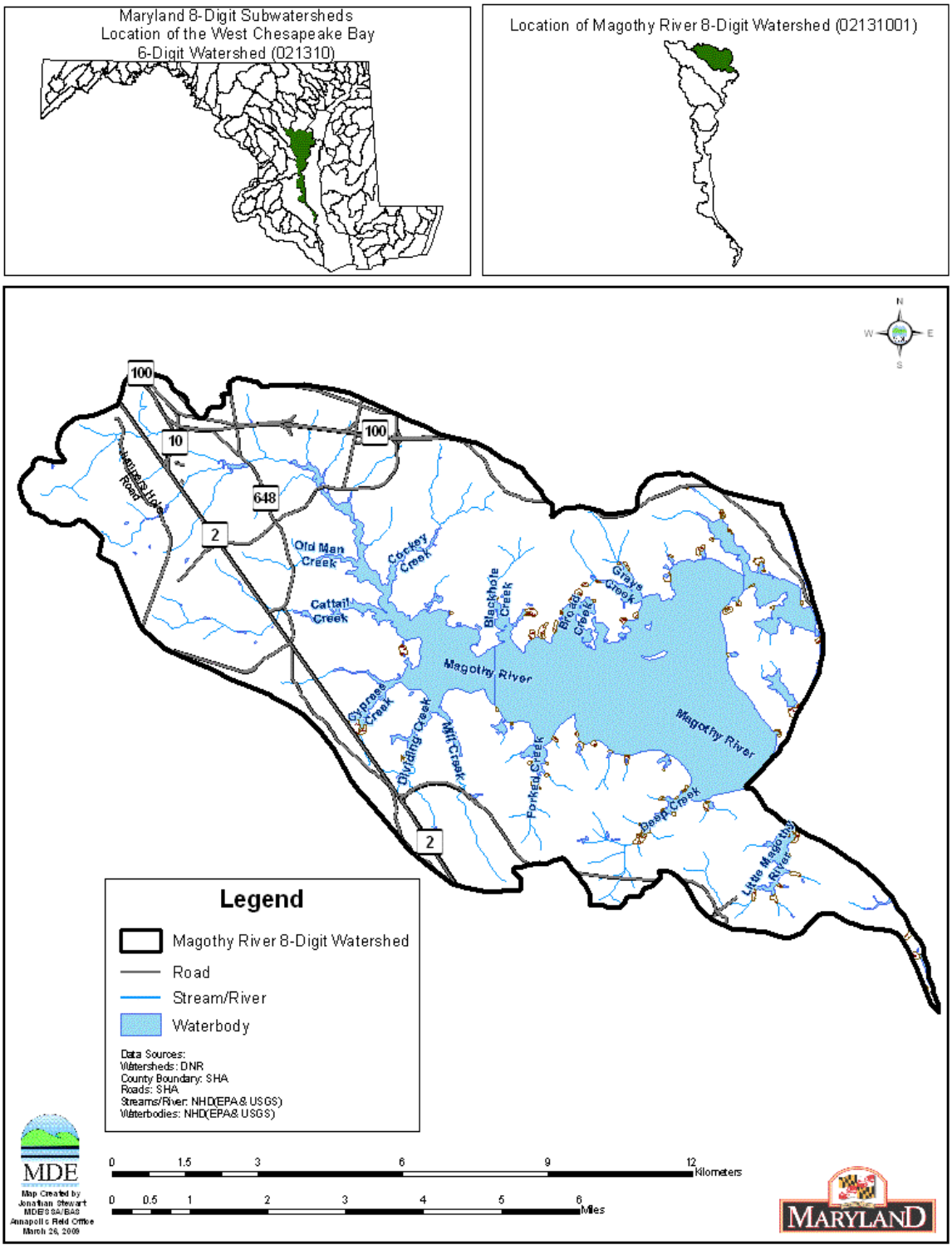

Figure 1. Location Map of the Magothy River Watershed

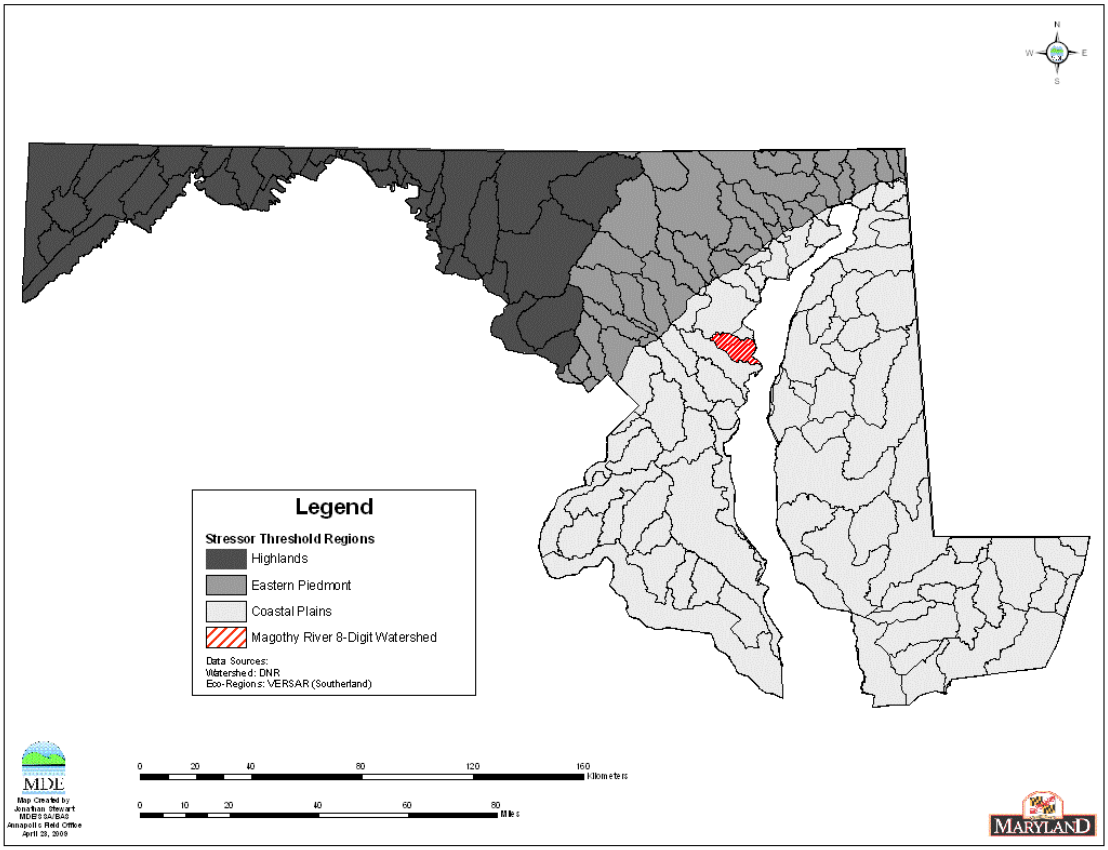

Figure 2. Eco-Region Location Map of the Magothy River Watershed

2.2 Land Use

The Magothy River watershed is predominantly urban with the areas of Magothy River, Tar Cove, Forked Creek, and Deep Creek having over 50% residential and non-residential for each. Residential urban land use includes low-density residential, medium density residential, and high-density residential. Non-residential urban land use includes commercial, industrial, institutional, extractive, and open urban land. The two major urban centers in the watershed are Severna Park and Pasadena. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Magothy River watershed consists of primarily urban development. The watershed's land use is approximately 82% urban (with 9% impervious surfaces), 17% forest/herbaceous, and 1% agricultural (USEPA 2010) (see Figure 3 and Figure 4).

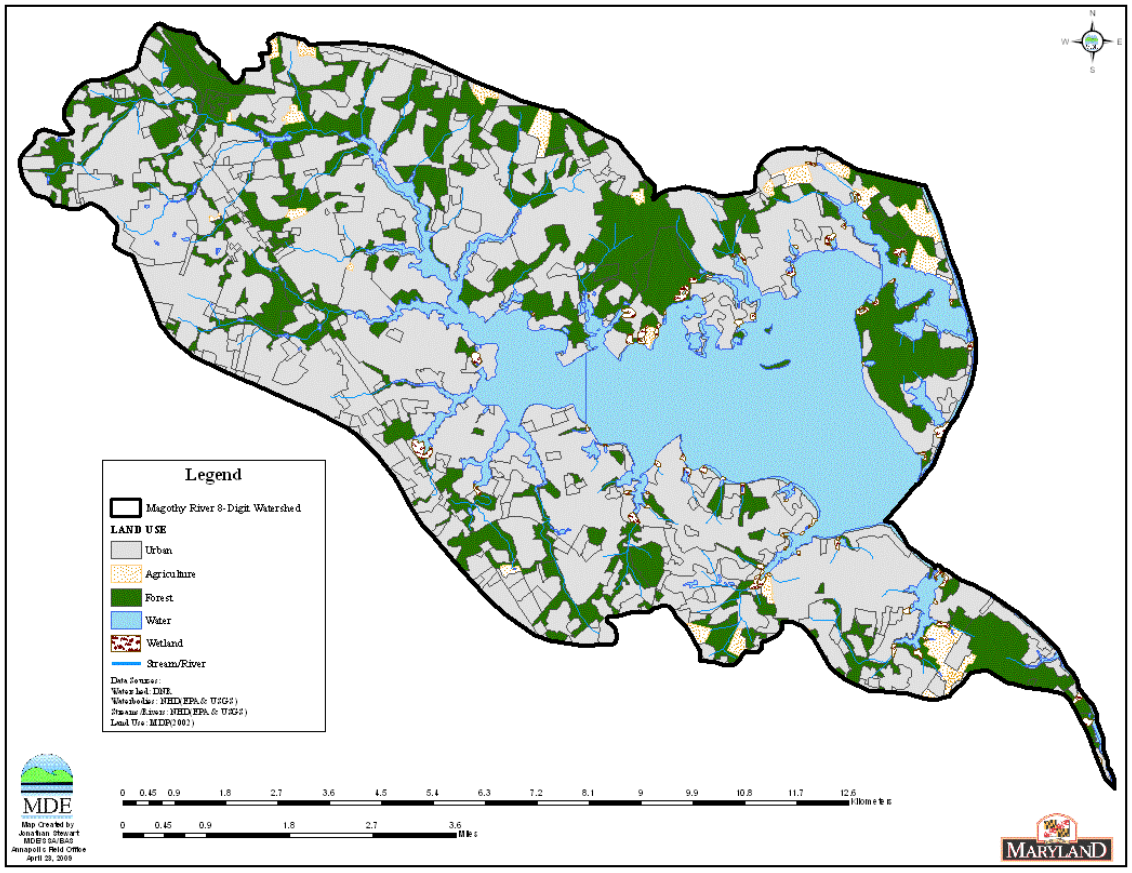

Figure 3. Land Use Map of the Magothy River Watershed

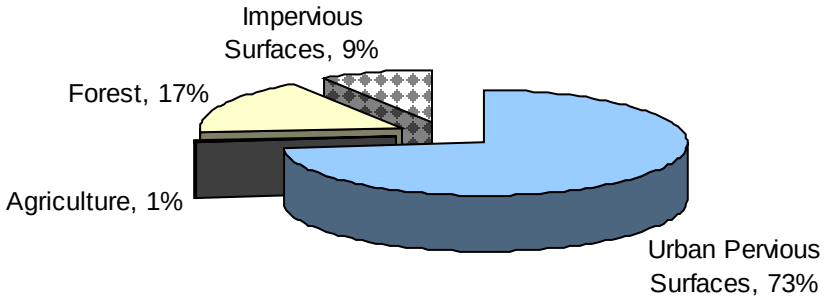

Figure 4. Proportions of Land Use in the Magothy River Watershed

2.3 Soils/hydrology

The Magothy River 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 2007). The majority of slopes within the watershed are less than 14%. The western and southern upstream portions of the Magothy River watershed are highest in elevation. The southeastern tip of the watershed is an area of low elevation and little topographic variation (AACDPW 2010).

Soils within the Magothy River watershed are varied in their hydrologic properties and expected erodibility. All four hydrologic soil groups are present, with the majority of soils (62%) classified as hydrologic soil group B. These soils have moderately low runoff potential when thoroughly wet and water transmission through the soil is unimpeded. Hydrologic soil group A accounts for 20% of the soils in the watershed. These soils have low runoff potential when thoroughly wet and water is transmitted freely through the soil. Soils categorized in hydrologic soil groups C and D, which are the soils with the highest runoff potential, are less prominent in the watershed, at 13% and 5% respectively (AACDPW 2010). The soils in the watershed mainly consist of sand (67%), clay (13%), and silt (20%) (USDA 1995).

3.0 Magothy River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

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Table 1. 2012 Integrated Report Listings for the Magothy River Watershed (cont)

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				2012	Fecal Coliform (Subwatershed Deep Creek)	5
				1996	Fecal Coliform (Subwatershed Forked Creek)	4a
			Fishing	2006	PCBs in Fish Tissue	5
					Mercury in Fish Tissue	2

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Magothy River and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, most of the mainstem of the Magothy River and some tributaries are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, b, c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. 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 Magothy River watershed is listed under Category 5 of the 2012 Integrated Report for impacts to biological communities. Approximately 67% of stream miles in the Magothy River watershed are estimated as having benthic and/or fish indices of biological integrity 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. Four of the six stations have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e.,

poor to very poor). The principal dataset, MBSS round two and round three (2000-2009) contains six MBSS sites; with four having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Magothy River watershed.

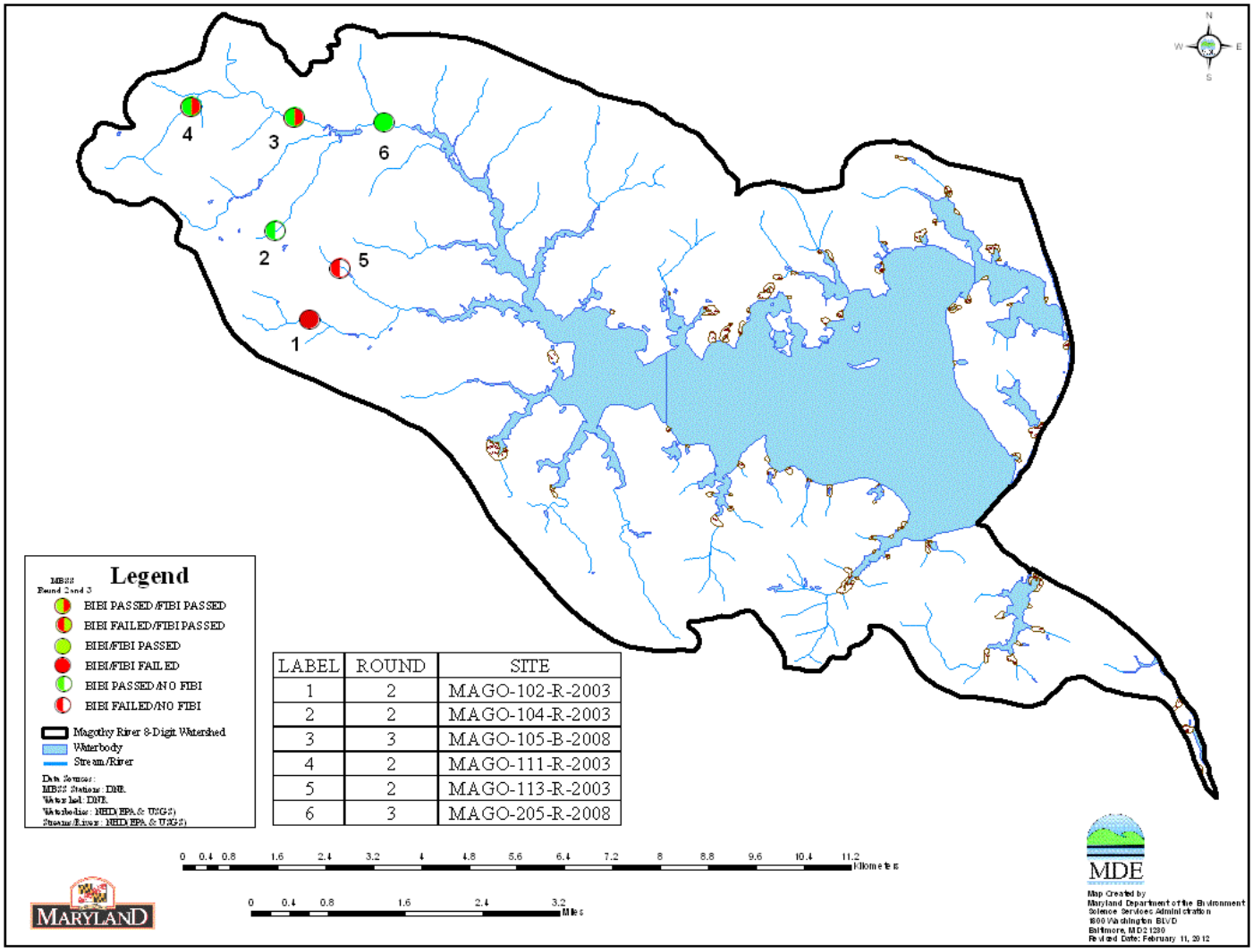

Figure 5. Principal Dataset Sites for the Magothy River Watershed

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 lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4^{th} order), that have fair to good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (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 poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

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

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a

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

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

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Magothy River watershed, MDE identified sources, 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 in the watershed are listed in Table 2 and include various urban land uses and impervious surfaces. Table 3 shows the summary of combined AR values for the source groups in the Magothy River watershed. As shown in Table 4 through Table 6, a number of parameters from the water chemistry group were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Magothy River watershed.

Table 2. Stressor Source Identification Analysis Results for the Magothy River 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	Atmospheric deposition present	6	4	272	25%	37%	1	No	_
	Agricultural acid source present	6	4	272	0%	7%	1	No	_
	AMD acid source present	6	4	272	0%	0%	1	No	_
	Organic acid source present	6	4	272	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	6	4	277	0%	3%	1	No	_
	High % of agriculture in 60m buffer	6	4	277	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	6	4	277	0%	6%	1	No	_
	Low % of wetland in watershed	6	4	277	0%	11%	1	No	_
	Low % of forest in 60m buffer	6	4	277	25%	8%	0.302	No	_
	Low % of wetland in 60m buffer	6	4	277	0%	10%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	6	4	277	25%	4%	0.161	No	_
	High % of impervious surface in 60m buffer	6	4	277	50%	5%	0.017	Yes	45%
	High % of roads in watershed	6	4	277	0%	0%	1	No	_
	High % of roads in 60m buffer	6	4	277	50%	4%	0.013	Yes	46%
Sources - Urban	High % of high-intensity developed in watershed	6	4	277	25%	7%	0.268	No	_
	High % of low-intensity developed in watershed	6	4	277	50%	6%	0.024	Yes	44%
	High % of medium-intensity developed in watershed	6	4	277	0%	2%	1	No	_
	High % of early-stage residential in watershed	6	4	277	0%	5%	1	No	_

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
	High % of residential developed in watershed	6	4	277	50%	6%	0.024	Yes	44%
	High % of rural developed in watershed	6	4	277	25%	5%	0.198	No	_
	High % of high-intensity developed in 60m buffer	6	4	277	25%	6%	0.234	No	_
	High % of low-intensity developed in 60m buffer	6	4	277	25%	4%	0.173	No	_
	High % of medium-intensity developed in 60m buffer	6	4	277	25%	3%	0.123	No	_
	High % of early-stage residential in 60m buffer	6	4	277	50%	7%	0.032	Yes	43%
	High % of residential developed in 60m buffer	6	4	277	25%	4%	0.173	No	_
	High % of rural developed in 60m buffer	6	4	277	50%	5%	0.015	Yes	45%

Table 3. Summary of Combined Attributable Risk Values of the Source Group in the Magothy River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Impervious	46%
Sources - Urban	95%
All Sources	***95%***

4.1 Sources Identified by BSID Analysis

The BSID source analysis (Table 2) identifies various urban land uses within the watershed and sixty meter buffer, as well as impervious surfaces in the riparian buffer zone as potential sources of stressors that may cause negative biological impacts. According to the Chesapeake Bay Program's Phase 5.2 Model, eighty-two percent of the watershed is comprised of urban land uses with nine percent consisting of impervious surfaces (USEPA 2010). The combined AR for the source group is approximately 95% suggesting these sources are the probable causes of biological impairments in the Magothy River watershed (Table 3).

The Magothy River watershed contains large areas of urban and impervious surfaces, which alter the hydrologic cycle, leading to increased runoff and decreased infiltration. Many areas within the Magothy River watershed were developed before regulatory requirements were in place to treat the runoff to remove some of the pollutants or to reduce the flows and volumes running off the hard surfaces into nearby streams.

Center for Watershed Protection (CWP) suggested that streams with greater than 25% tributary impervious cover are typically considered impaired or non-supporting; streams with 10 to 25% impervious cover are typically considered stressed or impacted, and streams with less than 10% imperviousness can support sensitive habitat and are typically relatively unimpaired (Schueler 1992). Anne Arundel County government conducted biological monitoring in the Magothy River watershed in 2007, and they utilized an impervious cover GIS layer based on 2007 land use data to calculate the impervious percent cover within the drainage area of all assessed perennial reaches. The study determined impervious surface coverage was relatively high throughout the study area with an average imperviousness of 19.5 %. Only three drainage areas had imperviousness below 10 %, while eight sites had impervious drainages of 25 % or greater (AAC-DPW 2007). Based on the guidance discussed above from CWP, each perennial reach was assigned a rating of "Sensitive," "Impacted," or "Non-supporting" related to its percent impervious cover. Approximately 36% of the stream reaches in the Magothy River watershed were rated "Non-supporting" (AAC-DPW 2010).

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

Table 4. Sediment Biological Stressor Identification Analysis Results for the Magothy River 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	5	3	160	0%	21%	1	No	_
	Moderate bar formation present	5	3	160	33%	49%	1	No	_
	Bar formation present	5	3	160	100%	78%	1	No	_
	Channel alteration moderate to poor	3	2	131	50%	59%	1	No	_
	Channel alteration poor	3	2	131	0%	26%	1	No	_
	High embeddedness	5	3	160	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	5	3	160	67%	46%	0.595	No	_
	Epifaunal substrate poor	5	3	160	0%	13%	1	No	_
	Moderate to severe erosion present	6	4	160	0%	43%	0.142	No	_
	Severe erosion present	6	4	160	0%	13%	1	No	_
	Silt clay present	5	3	160	100%	99%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Magothy River 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	Beaver pond present	5	3	159	0%	7%	1	No	_
	Channelization present	6	4	172	25%	13%	0.447	No	_
	Concrete/gabion present	6	4	148	0%	1%	1	No	_
	Instream habitat structure marginal to poor	5	3	160	67%	39%	0.564	No	_
	Instream habitat structure poor	5	3	160	0%	6%	1	No	_
	Pool/glide/eddy quality marginal to poor	5	3	160	67%	46%	0.599	No	_
	Pool/glide/eddy quality poor	5	3	160	0%	3%	1	No	_
	Riffle/run quality marginal to poor	5	3	160	33%	53%	0.607	No	_
	Riffle/run quality poor	5	3	160	0%	21%	1	No	_
	Velocity/depth diversity marginal to poor	5	3	160	67%	61%	1	No	_
	Velocity/depth diversity poor	5	3	160	33%	16%	0.408	No	_
Riparian Habitat	No riparian buffer	4	3	140	0%	15%	1	No	_
	Low shading	5	3	160	0%	8%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Magothy River 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	6	4	277	50%	8%	0.038	Yes	42%
	High conductivity	6	4	277	50%	6%	0.024	Yes	44%
	High sulfates	6	4	277	25%	8%	0.302	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	6	4	261	50%	17%	0.146	No	_
	Dissolved oxygen < 6mg/l	6	4	261	75%	25%	0.055	Yes	50%
	Low dissolved oxygen saturation	6	4	261	50%	6%	0.024	Yes	44%
	High dissolved oxygen saturation	6	4	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	6	4	277	0%	0%	1	No	_
	Ammonia acute with salmonid absent	6	4	277	0%	0%	1	No	_
	Ammonia chronic with salmonid present	6	4	277	0%	0%	1	No	_
	Ammonia chronic with salmonid absent	6	4	277	0%	0%	1	No	_
	High total nitrogen	6	4	277	0%	6%	1	No	_
	High total phosphorus	6	4	277	0%	9%	1	No	_
	High orthophosphate	6	4	277	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	6	4	277	0%	9%	1	No	_
	Acid neutralizing capacity below episodic level	6	4	277	25%	45%	0.629	No	_
	Low field pH	6	4	262	75%	40%	0.308	No	_
	High field pH	6	4	262	0%	1%	1	No	_
	Low lab pH	6	4	277	50%	38%	0.637	No	_
	High lab pH	6	4	277	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values of the Stressor Group in the Magothy River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Chemistry - Inorganic	44%
Chemistry - Nutrients	64%
All Chemistry	89%
All Stressors	***89%***

4.2 Stressors Identified by BSID Analysis

Sediment Conditions

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

In-stream Habitat Conditions

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

Riparian Habitat Conditions

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

Water Chemistry Conditions

BSID analysis results for Magothy River identified only four 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 chlorides, high conductivity, low dissolved oxygen < 6mg/l,* and *low dissolved oxygen saturation* (Table 6).

High chloride concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 42% of the stream miles with poor to very poor biological conditions in the Magothy River watershed. High concentrations of chloride can result from industrial discharges, metals contamination, discharges from water softeners, and application of road salts in urban landscapes.

High conductivity concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 44% of the stream miles with poor to very poor biological conditions in the Magothy River watershed. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Conductivity and chloride are closely related. Streams with elevated levels of chlorides typically display high conductivity.

Low dissolved oxygen < 6mg/L (DO) concentration was identified as significantly associated with degraded biological conditions and found in 50% of the stream miles with poor to very poor biological conditions in the Magothy River watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR 2013d.

Low (< 60%) DO saturation was identified as significantly associated with degraded biological conditions and found in 44% of the stream miles with poor to very poor biological conditions in the Magothy River watershed. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production. High and low DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. High DO saturation is considered to demonstrate oxygen production associated with high levels of photosynthesis. Low DO saturation is considered to demonstrate high respiration associated with excessive decomposition of organic material.

Natural and anthropogenic changes to an aquatic environment can affect the availability of DO. The normal diurnal fluctuations of a system can be altered resulting in large fluctuations in DO levels which can occur throughout the day. The low DO concentration results may be associated with the impacts of sewage, low precipitation, and the decomposition of leaf litter, grass clippings. The Magothy River watershed was sampled in 2003 and 2008 by MDDNR MBSS; two of six sampling sites had DO concentrations less than 5.0 mg/L, which is the threshold identified by COMAR (COMAR 2013d). These two sites are located in the Cattail Creek subwatershed, which is characterized by relatively small drainage areas with minimal flow, low topographical relief, and low pH values associated with leaf litter and organic matter decomposition. Anne Arundel County government conducted biological monitoring in the Magothy River watershed in 2007. They describe the Cattail Creek as a stream that flows through a large wetland and had a very mucky, organic substrate. Some beaver activity was observed around the stream (AAC-DPW 2007). No nutrient stressors were identified as having significant association with degraded biological conditions in the watershed. Low dissolved oxygen levels in the watershed are likely attributed to an abundance of leaf and organic matter decomposing in the wetlands draining into the stream, and the low topographic relief of the watershed.

Application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith, Alexander, and Wolman 1987). For surface waters associated with roadways or storage facilities, episodes of salinity have been reported during the winter and spring in some urban watercourses in the range associated with acute toxicity in laboratory experiments (EC 2001). These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). The BSID analysis identified transportation corridors as a significant land use within the riparian buffer zones. According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 m (average of 300 m) on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. The presence of salts also limits the DO concentration in water. There are no industrial or municipal National Pollutant Discharge Elimination System facilities in the watershed; however, the watershed does contain Municipal Separate Storm Sewer System (MS4) permits which would also contribute to increased loads of chloride.

Currently in Maryland there are no specific numeric criteria that quantify the impact of chlorides or conductivity 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 89% suggesting these stressors are the probable causes of biological impairments in the Magothy River watershed (Table 7).

4.3 Discussion

The BSID analysis results suggest that urban stressors appear to be the primary cause of biological impairment observed throughout the watershed. There is a significant presence of residential, impervious, urban, and transportation land uses within the Magothy River's riparian buffer zones, and high chloride and conductivity are indications that a potential array of pollutants are being exported to surface waters from urban developed run-off.

Biological communities in localized areas may also be affected by low dissolved oxygen levels. Nitrogen and phosphorus were not identified as being significant stressors in the watershed nor in the localized areas with low DO. The low dissolved oxygen levels observed in these localized areas are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and decomposition of organic matter.

The combined AR for all the stressors is approximately 89%, suggesting that the water chemistry stressors identified in the BSID analysis would account for almost all of the degraded stream miles within the Magothy River watershed (Table 7).

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 Patuxent River Middle 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 1991; USEPA 2013). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final causal model for the Magothy River watershed, with pathways to show the watershed's probable stressors as indicated by the BSID analysis.

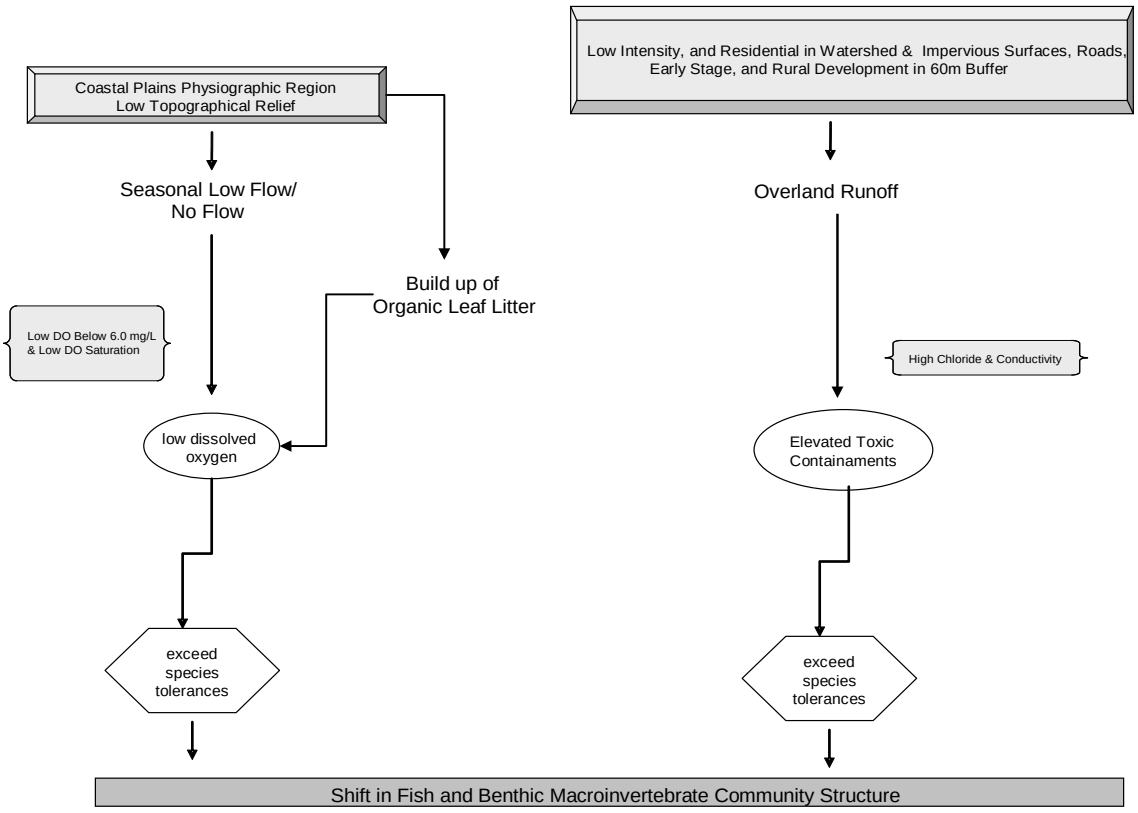

Figure 6. Final Causal Model for the Magothy River Watershed

5.0 Conclusions

Data suggest that the biological communities of the Magothy River watershed are strongly influenced by urban land use and its concomitant effects: elevated levels of chlorides, and low dissolved oxygen (DO). The development of landscapes creates broad and interrelated forms of degradation that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between urban landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID analysis, and the probable causes and sources of the biological impairments in the Magothy River watershed can be summarized as follows:

- The BSID process has determined that the biological communities in the Magothy River watershed are likely degraded due to inorganic water chemistry related stressors. Specifically, urban and transportation land use practices have resulted in the potential elevation of chloride inputs throughout the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus support a Category 5 listing of chloride for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the Magothy River watershed. Discharges of inorganic compounds like chloride are intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of this parameter will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process also indentified low dissolved oxygen below <6.0 mg/l and low dissolved oxygen saturation as significantly associated with degraded biological conditions; however, elevated phosphorus and/or nitrogen concentrations were not identified. Low dissolved oxygen levels in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and/or low flow velocities due to an abundance of tidal fresh zones.

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