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

Executive Summary

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

The South River watershed (basin code 02131003), located in Anne Arundel County, MD, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and one estuarine or tidal portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the South River is the South River Mesohaline (SOUMH). Below is a table identifying the listings associated with this watershed (MDE 2012).

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

Watershed	Basin Code	Non-tidal/ Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
South River	02131003	Non-tidal		Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
			Broad Creek		-	Zinc	2
						pH, low	
						Copper	
						Lead	
South River Mesohaline	SOUMH	Tidal		Open-Water Fish and Shellfish Subcategory	1996	TP	4a
						TN	
				Seasonal Shallow Water Submerged Aquatic Vegetation Subcategory	1996	TSS	4a
				Aquatic Life and Wildlife	2008	Impacts to Biological Communities	5
				Fishing	2002	Polychlorinated biphenyls in fish tissue	5
					-	Mercury	2
				Seasonal Migratory Fish Spawning and Nursery Subcategory	2012	TP	4a
						TN	
			South River, Duvall Creek, Selby Bay, Ramsey Lake	Tidal Shellfish Area	1996	Fecal Coliform	
			Annapolis Landing	Water Contact Sports	-	Enterococus	2

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings in the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score of less than three, and calculating whether this is a significant deviation from reference condition watersheds (i.e., healthy stream, less than 10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the South River watershed's uppermost tributaries (Bacon Ridge Branch, Bell Branch, Broad Creek, Flat Creek, North River) are designated as Use I - *water contact recreation, and protection of nontidal warmwater aquatic life.* All other tributaries (Beards Creek, Glebe Creek) and the South River mainstem are Use II -

support of estuarine and marine aquatic life and shellfish harvesting (COMAR 2013a, b, c). The South River watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) (Southerland et al. 2005a).

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

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

This South 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 degradation of biological communities in the South River watershed is due to anthropogenic impacts (i.e., altered hydrology, elevated levels of sediments, and inorganic pollutants) exacerbating naturally occurring conditions. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

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

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

management action to begin mitigating the impacts of sediment to the biological communities in the South River watershed.

- The BSID process has determined that biological communities in the South River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones 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 is a result of pollution. MDE recommends a Category 4c listing for the South River watershed based on inadequate riparian buffer zones in approximately 60% of degraded stream miles.

- The BSID process has determined that the biological communities in the South River watershed are likely degraded due to inorganics (i.e., chloride). Chloride levels are significantly associated with degraded biological conditions and found in approximately 42% of the stream miles with poor to very poor biological conditions in the South River watershed. 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 these stressors on the biological communities in the South River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has determined that biological communities in the South River watershed are not degraded due to nutrient related stressors. There are tidal 1996 Category 4a listings for Total Nitrogen and Total Phosphorus, which establish nutrient reductions through the 2010 Chesapeake Bay TMDL.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2009). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, less than 10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary. A Category 5 listing can be amended to Category 4a if a TMDL was established and approved by USEPA. If the state can demonstrate that the watershed impairment is a result of pollution, not a specific pollutant, the watershed is listed under Category 4c.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to rounds two and three of the Maryland Biological Stream Survey (MBSS) dataset (2000-2004; 2007-2009) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review

for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

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

2.0 South River Watershed Characterization

2.1 Location

The South River watershed is located entirely within Anne Arundel County, Maryland (see Figure 1). It is located on Maryland's Western Shore in the transportation corridor of two major urban centers, Baltimore and Washington, D.C. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the total drainage area of the Maryland 8-digit watershed is approximately 36,433 acres not including water/wetlands. The watershed is located in the Coastal Plain region, one of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

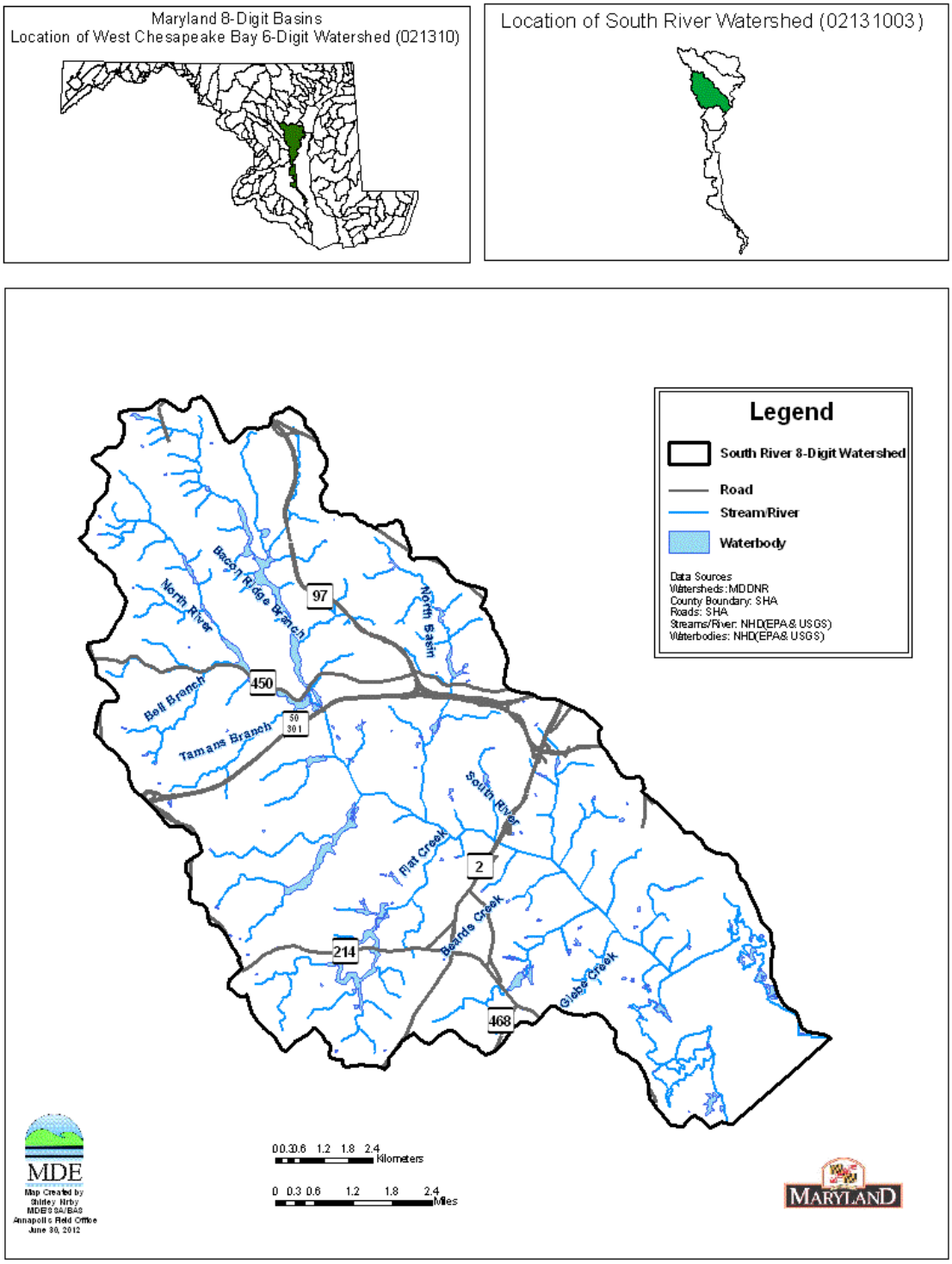

Figure 1. Location Map of the South River Watershed

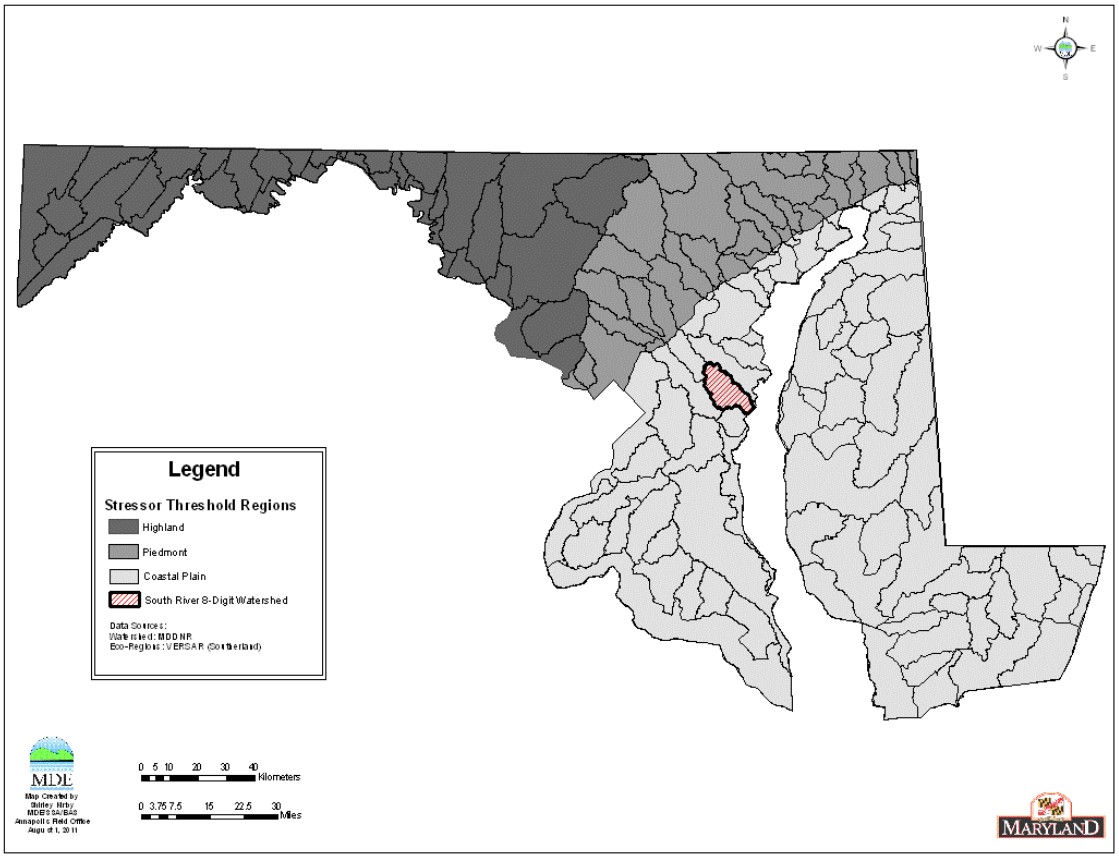

Figure 2. Eco-Region Location Map of the South River Watershed

2.2 Land Use

The watershed contains primarily forested and urban land use (see Figure 3). The main transportation corridors in the watershed are Maryland Routes 97, 450, and 50/301 in the northern region, and 32, 214, and 468 in the southern region. Urban, specifically residential, land use is also present in the watershed; this includes the cities of Annapolis, Bowie, Crofton, Laurel and several others. The Jug Bay Wetlands Sanctuary is located in the southwest region of the watershed. Also, Fort George G. Meade is located in the watershed; it is a Department of Defense installation of military and civilian employees. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the South River watershed consists of approximately 45% forest, 46% urban, and 9% agriculture (see Figure 4). The Chesapeake Bay Program's Phase 5.2 watershed model does not include water or wetland area for this tidal estuary. Urban impervious surface is 7% of the total land use in the watershed (USEPA 2008).

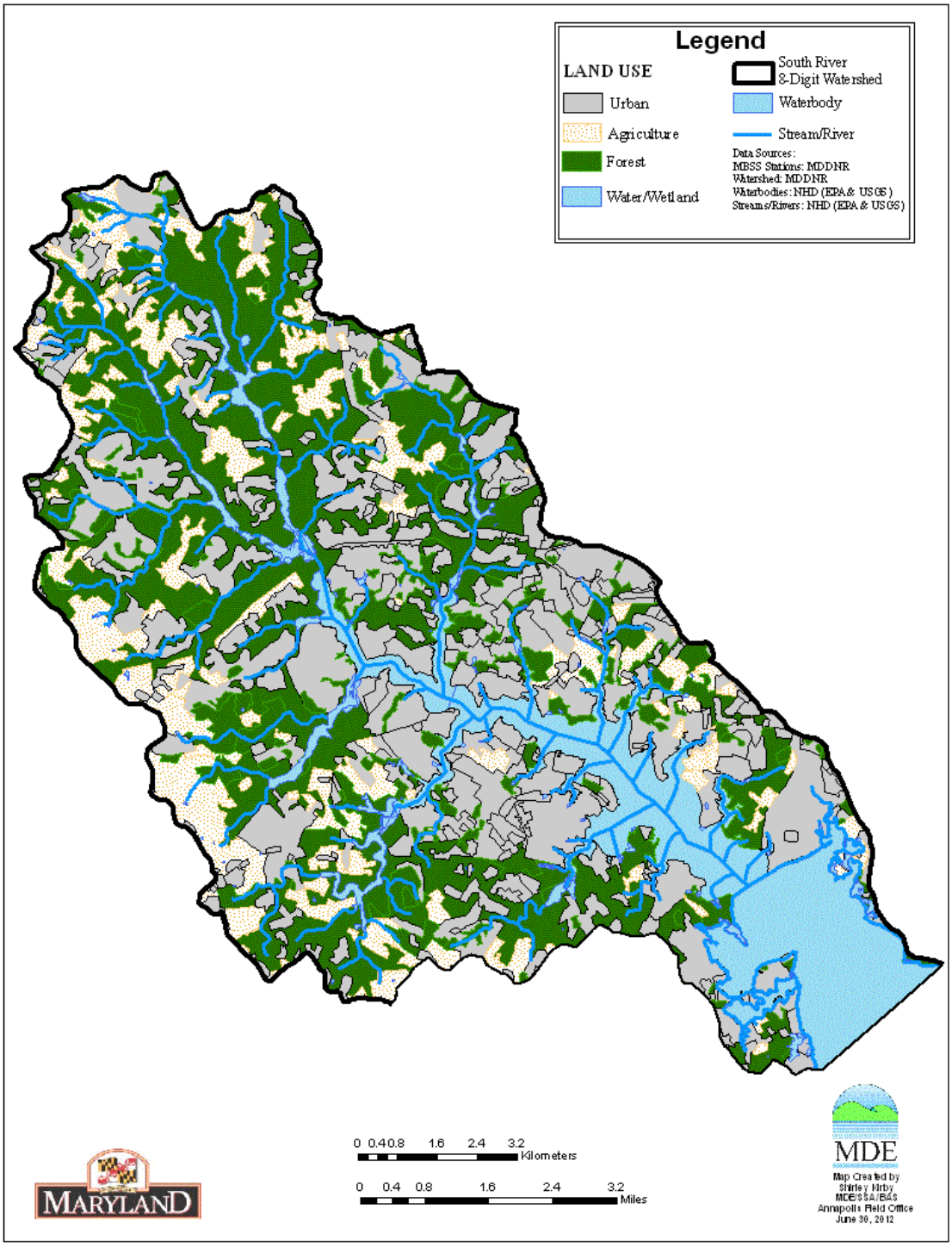

Figure 3. Land Use Map of the South River Watershed

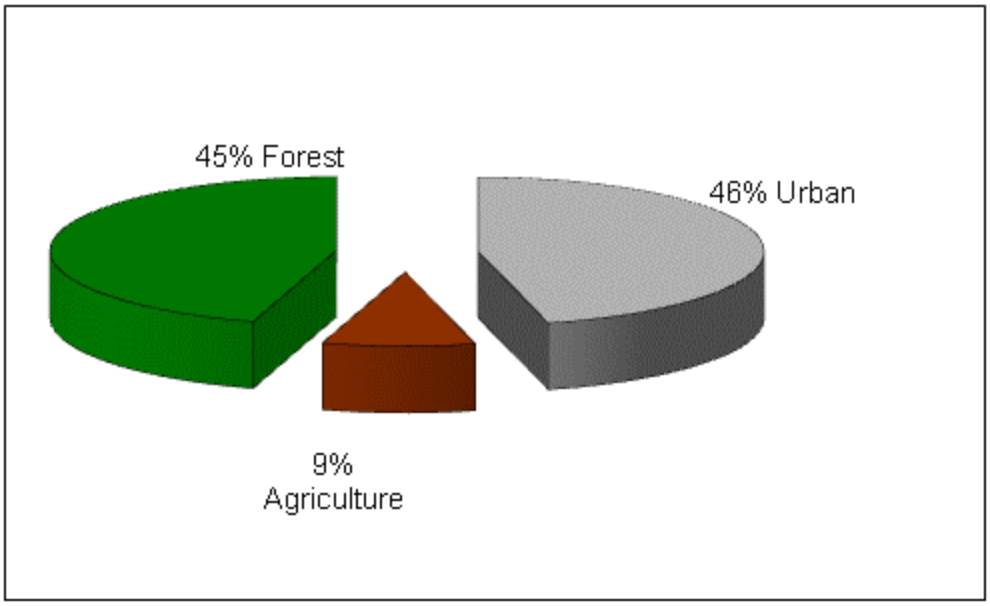

Figure 4. Proportions of Land Use in the South River Watershed

2.3 Soils/hydrology

The South River watershed is in the Coastal Plain Physiographic Province in Anne Arundel County. Broad upland areas with low slopes and gentle drainage characterize the coastal province. There are two soil series in the watershed, they are Collington and Westphalia. These soils consist of unconsolidated deposits of gravel, sand, silt, and clay. Sand is the dominant soil type in the watershed. Greensand and iron ore are also present (MDDNR 2003). The moisture capacity of the soils range from moderately low to high, strongly to extremely acidic, and have a high silt concentration and erosion potential (NRCS 1973). The topography ranges from nearly level to very steep; erosion can easily remove any high spots that develop in these soft, uncemented materials (NRCS 1973; Schmidt 1993).

3.0 South River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the South River watershed on the State's Integrated Report under Category 5 as impaired by evidence of biological impacts (2002 listings). The South River watershed (basin code 02131003), located in Anne Arundel County, MD, is associated with two assessment units in the Integrated Report (IR): non-tidal (8-digit basin) and one estuarine or tidal portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the South River is the South River Mesohaline (SOUMH). Below is a table identifying the listings associated with this watershed (MDE 2012).

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				Fishing	2002	Polychlorinated biphenyls in fish tissue	5
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3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the South River watershed's uppermost tributaries (Bacon Ridge Branch, Bell Branch, Broad Creek, Flat Creek, North River) are designated as Use I - *water contact recreation, and protection of nontidal warmwater aquatic life.* All other tributaries (Beards Creek, Glebe Creek) and the South River mainstem are Use II - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The South River watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 75% of the South River watershed are estimated as having fish and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include twelve stations. Ten of the twelve stations have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS round two and round three (2000-2004; 2007-2009) contains eight sites; six of the eight have BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the South River watershed.

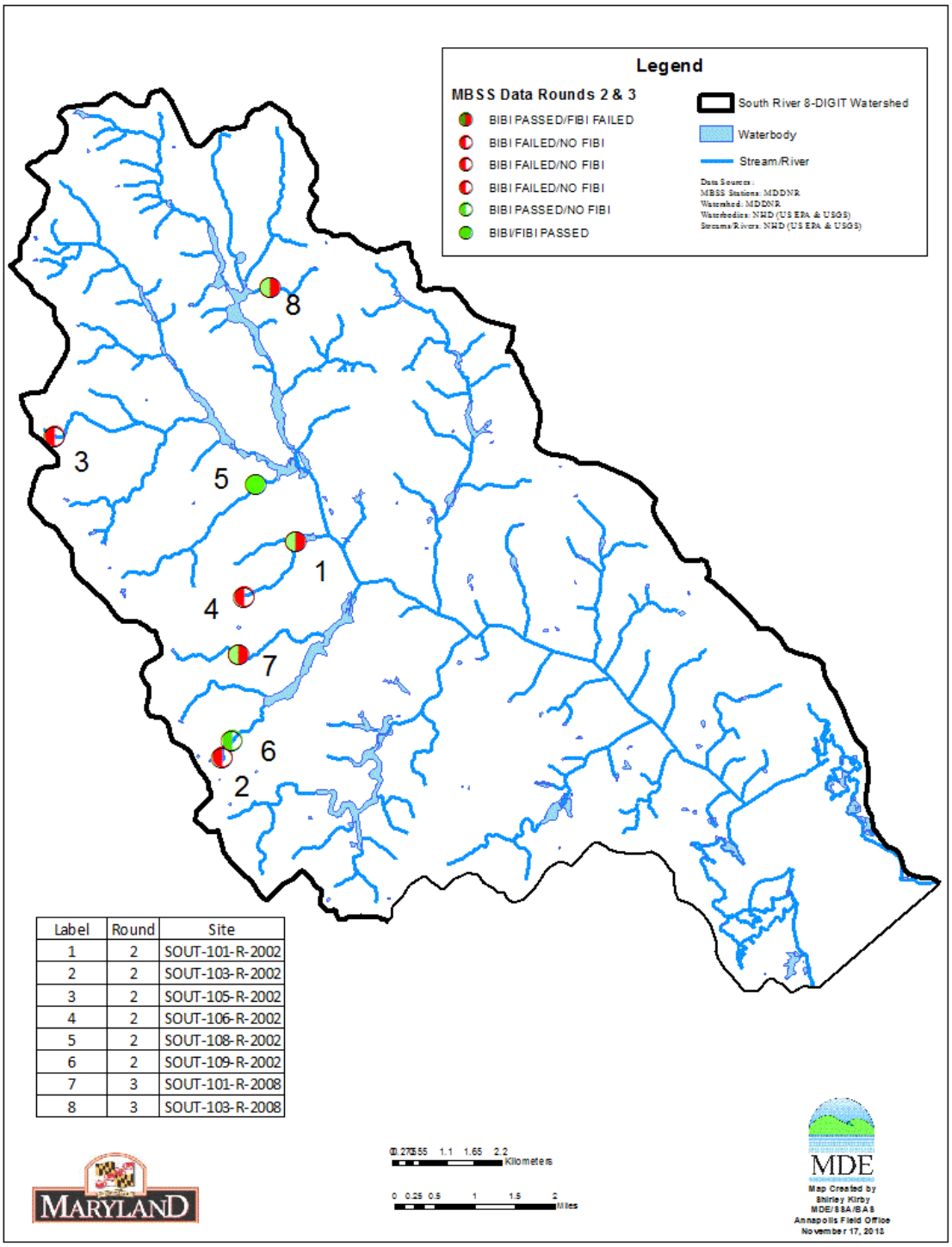

Figure 5. Principal Dataset Sites for the South River Watershed

4.0 Stressor Identification Results for the South River Watershed

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

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

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

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

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

risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

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

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

Table 2. Stressor Source Identification Analysis Results for the South 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	Agricultural acid source present	8	6	274	0%	7%	1	No	_
	AMD acid source present	8	6	274	0%	0%	1	No	_
	Organic acid source present	8	6	275	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	8	6	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	8	6	279	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	8	6	279	0%	6%	1	No	_
	Low % of wetland in watershed	8	6	279	50%	11%	0.022	Yes	39%
	Low % of forest in 60m buffer	8	6	279	0%	8%	1	No	_
	Low % of wetland in 60m buffer	8	6	279	33%	10%	0.13	No	_
Sources - Impervious	High % of impervious surface in watershed	8	6	279	0%	4%	1	No	_
	High % of impervious surface in 60m buffer	8	6	279	0%	5%	1	No	_
	High % of roads in watershed	8	6	279	0%	0%	1	No	_
	High % of roads in 60m buffer	8	6	279	33%	5%	0.034	Yes	29%
Sources - Urban	High % of high-intensity developed in watershed	8	6	279	0%	8%	1	No	_
	High % of low-intensity developed in watershed	8	6	279	0%	6%	1	No	_
	High % of medium-intensity developed in watershed	8	6	279	0%	2%	1	No	_
	High % of residential developed in watershed	8	6	279	0%	8%	1	No	_
	High % of rural developed in watershed	8	6	279	50%	5%	0.003	Yes	45%
	High % of high-intensity developed in 60m buffer	8	6	279	0%	6%	1	No	_

Parameter group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
	High % of low-intensity developed in 60m buffer	8	6	279	0%	5%	1	No	_
	High % of medium-intensity developed in 60m buffer	8	6	279	0%	3%	1	No	_
	High % of residential developed in 60m buffer	8	6	279	0%	8%	1	No	_
	High % of rural developed in 60m buffer	8	6	279	33%	5%	0.034	Yes	29%

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the South River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Anthropogenic	39%
Sources - Impervious	29%
Sources - Urban	45%
All Sources	***78%***

4.1 Sources Identified by BSID Analysis

All of the sources identified by the BSID analysis (Table 2), are the result of development in the South River watershed. The BSID analysis identifies anthropogenic, impervious surface (roads), and rural sources as the source groups with significant combined attributable risk values for the watershed. However, due to the location of the watershed, within the transportation and residential corridor for Baltimore and Washington, D.C., the stressor parameters identified in the South River watershed BSID analysis are also probably representative of impacts from the residential development in the watershed, even though residential was not identified by the BSID analysis. Residential development is similar to urban development in that it removes forest and wetland areas, which allows for increased sedimentation and alters instream habitat. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer, Paul, and Taulbee 2005) has consistently identified negative impacts to biological conditions as a result of increased development. Symptoms residential development are similar to the effects of

"urban stream syndrome", which include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors (Meyer, Paul, and Taulbee 2005).

Increases in impervious surface cover, specifically in the case of the South River watershed a high percentage of roads in the 60m buffer (29%), that accompany urbanization alter stream hydrology forcing runoff to occur more readily and quickly during rainfall events, and decreasing the time it takes water to reach streams and causing them to be more "flashy" (Walsh et al. 2005). As noted previously the watershed is in a residential and transportation corridor of two major urban areas, land development can also cause an increase in contaminant loads (e.g., runoff) from point and nonpoint sources. In virtually all studies, as the amount of impervious area in a watershed increases, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The BSID source analysis (Table 2) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 78% suggesting that these sources are the probable cause of biological degradation in the South River watershed. (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the South 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	8	6	161	17%	21%	1	No	_
	Moderate bar formation present	8	6	160	67%	49%	0.682	No	_
	Channel alteration moderate to poor	6	4	131	50%	60%	1	No	_
	Channel alteration poor	6	4	131	25%	26%	1	No	_
	High embeddedness	8	6	160	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	8	6	160	83%	46%	0.103	No	_
	Epifaunal substrate poor	8	6	160	67%	13%	0.004	Yes	54%
	Moderate to severe erosion present	8	6	160	33%	43%	1	No	_
	Severe erosion present	8	6	160	0%	13%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the South 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	Channelization present	8	6	172	17%	13%	0.586	No	_
	Concrete/gabion present	8	6	148	0%	1%	1	No	_
	Beaver pond present	8	6	159	0%	7%	1	No	_
	Instream habitat structure marginal to poor	8	6	160	100%	40%	0.005	Yes	60%
	Instream habitat structure poor	8	6	160	50%	6%	0.007	Yes	44%
	Pool/glide/eddy quality marginal to poor	8	6	160	67%	46%	0.421	No	_
	Pool/glide/eddy quality poor	8	6	160	17%	3%	0.201	No	_
	Riffle/run quality marginal to poor	8	6	160	33%	53%	0.43	No	_
	Riffle/run quality poor	8	6	160	0%	21%	0.6	No	_
	Velocity/depth diversity marginal to poor	8	6	160	67%	61%	1	No	_
	Velocity/depth diversity poor	8	6	160	17%	16%	1	No	_
Riparian Habitat	No riparian buffer	6	4	140	75%	15%	0.015	Yes	60%
	Low shading	8	6	160	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the South 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	8	6	279	50%	8%	0.011	Yes	42%
	High conductivity	8	6	279	17%	6%	0.326	No	_
	High sulfates	8	6	279	17%	8%	0.413	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	8	6	261	17%	17%	1	No	_
	Dissolved oxygen < 6mg/l	8	6	261	17%	25%	1	No	_
	Low dissolved oxygen saturation	8	6	261	17%	6%	0.329	No	_
	High dissolved oxygen saturation	8	6	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	8	6	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	8	6	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	8	6	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	8	6	279	0%	0%	1	No	_
	High nitrites	8	6	279	0%	3%	1	No	_
	High nitrates	8	6	279	0%	7%	1	No	_
	High total nitrogen	8	6	279	0%	6%	1	No	_
	High total phosphorus	8	6	279	33%	9%	0.109	No	_
	High orthophosphate	8	6	279	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	8	6	279	33%	9%	0.109	No	_
	Low field pH	8	6	262	50%	40%	0.69	No	_
	High field pH	8	6	262	0%	1%	1	No	_
	Low lab pH	8	6	279	83%	38%	0.033	Yes	46%
	High lab pH	8	6	279	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the South River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	54%
Instream Habitat	77%
Riparian Habitat	60%
Chemistry - Inorganic	42%
Chemistry - pH	46%
All Chemistry	65%
All Stressors	***87%***

4.2 Stressors Identified by BSID Analysis

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

Sediment Conditions

BSID analysis results for the South River watershed identified one sediment parameter that has a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *epifaunal substrate (poor)* (Table 4).

Epifaunal substrate (poor) was identified as significantly associated with degraded biological conditions and found to impact approximately 54% of the stream miles with poor to very poor biological conditions in the South River watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. The epifaunal substrate category is rated based on the amount and variety of hard, stable substrates usable by benthic macroinvertebrates. High epifaunal substrate scores are evidence of the lack of sediment deposition. However, epifaunal substrate is confounded by natural variability, i.e., some streams will naturally have different kinds of epifaunal substrate (Southerland et al. 2005b).

Coastal Plain regions do not have the required characteristics to exhibit optimal scores for the epifaunal substrate category because they naturally have a higher percentage of sediment loading than other physiographic regions. The South River watershed is located in Anne Arundel County in the mid-Atlantic Coastal Plain; the soils (i.e., Collington and Westphalia) have a silt loam and sand consistency, and are highly erodible. All of the major streams in this region are normally sluggish, and many have large accumulations of silt (NRCS 1973). Increased sediment pollution in the South River watershed has resulted in the exceedance of species tolerances and subsequent trophic alteration (e.g., shift to more silt-tolerant species). Anthropogenic (land development) impacts have exacerbated the naturally occurring conditions of the South River watershed. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 54% suggesting that these stressors are probable cause of the biological impairments in the South River watershed (Table 7).

Instream Habitat Conditions

BSID analysis results for the South River watershed identified two instream habitat parameters that have a statistically significant association with poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *instream habitat structure (marginal to poor)* and *instream habitat structure (poor)* (Table 5).

Instream habitat structure was identified as significantly associated with degraded biological conditions and found to impact approximately 60% *(marginal to poor)* and 44% *(poor)* respectively in the stream miles with poor to very poor biological conditions in the South River watershed. Instream 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 instream habitat scores are evidence of the lack of sediment deposition. Instream habitat is confounded by natural variability (i.e., some streams will naturally have more or less instream habitat). Low instream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats.

The instream habitat stressor identified is intricately linked with habitat heterogeneity. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in altered streams. 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. A lack of varying velocities and depth may reflect a combination of natural conditions, anthropogenic conditions, or excessive erosional conditions.

The combination of the altered flow regime and increased sediment in the South River watershed has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous sediment deposition that smothers instream biological communities. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the instream habitat stressor group is approximately 77% suggesting that these stressors are probable cause of the biological impairments in the South River watershed (Table 7).

Riparian Habitat Conditions

BSID analysis results for the South River watershed identified one riparian habitat parameter that has a statistically significant association with poor to very poor stream biological condition, i.e., removal of stressors would result in improved biological community: *no riparian buffer* (Table 5).

No riparian buffer was identified as significantly associated with degraded biological conditions and found to impact approximately 60% of the stream miles with poor to very poor biological conditions in the South River watershed. Riparian Buffer Width represents the minimum width of vegetated buffer in meters, looking at both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer. Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee, Smyth, and Boutin 2004).

Anthropogenic land development has led to significant impacts in the watershed; sources include a low percentage of wetland in the watershed (39%), high percent of low and high intensity rural development in the 60-meter buffer (45% and 29%), and a high percentage of roads in the 60-meter buffer (29%). Stream channel shading is reduced or eliminated as forests, wetlands, and other riparian vegetation are replaced with development (Allan 2004; Kline, Hilderbrand, and Hairston-Strang 2005; Southerland et al. 2005b). Local riparian vegetation is a secondary predictor of stream integrity; the extent of riparian vegetation may affect the volume of pollutants in runoff (Kline, Hilderbrand, and Hairston-Strang 2005; Roth, Allan, and Erickson 1996).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the instream habitat stressor group is approximately 60% suggesting that this stressor is a probable cause of the biological impairments in the South River watershed (Table 7).

Water Chemistry

BSID analysis results for the South River watershed identified two water chemistry 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): *low lab pH* and *high chlorides* (Table 6).

Low lab pH was identified as significantly associated with degraded biological conditions and found to impact approximately 46% of the stream miles with poor to very poor biological conditions in the South River watershed. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. 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. Values of less than 6.5 for pH are considered to demonstrate acidity, which can be damaging to aquatic life. Intermittent high pH (greater than 8.5) is often associated with eutrophication related to increased algal blooms. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

Iron ore is present in the soils of the watershed (MDDNR 2003). The MDDNR MBSS field crew observed iron flocculation at four sites in the primary dataset. Iron flocculation is the result of oxidizing bacteria, which grow in a pH range of 5.0 to 7.5; the process of iron oxidation lowers the pH of the surrounding medium (Bull Run Conservancy 2013). In an analysis of round two data (2000-2004) the MDDNR found that 50% of Lower Western Shore streams were affected by acidic deposition (Southerland 2005b). Anthropogenic impacts exacerbate the natural condition (acidic soils and water) of the South River watershed.

High chlorides 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 South River watershed. Chloride is a measure of the amount of dissolved chloride in the water column. Chlorides can play a critical role in the elevation of conductivity (an indicator of the presence of dissolved substances). Most fish and benthic communities cannot survive in waters with high levels of chlorides. Excessive chloride concentrations indicate a potentially damaging chemical content to stream biology.

High concentrations of chlorides can be due to several types of pollution, including industrial discharges, leaking wastewater infrastructure, metals contamination, and application of road salts in urban landscapes. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt. Road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating

through soils and into groundwater aquifers (Church and Friesz 1993). A high percentage of road development in the 60m buffer is identified by the BSID analysis as significantly associated (29%) with biological degradation in the watershed; these roads allow for direct runoff of roads salts into the South River watershed. Increased levels of many pollutants like chlorides can be toxic to aquatic organisms and lead to exceedences in species tolerances.

Currently in Maryland there are no specific numeric criteria that quantify the impact of chlorides 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 65% suggesting that these stressors are probable cause of the biological impairments in the South River watershed (Table 7).

4.3 Discussion of BSID Results

Anthropogenic land development can cause an increase in contaminant loads from point and non-point sources by adding sediments and pollutants to surface waters. In watersheds experiencing anthropogenic stress, hydrologic variability is causing higher overland flows to streams, especially during storm events (Southerland et al. 2005b). During storm events overland flows carry increased pollutant loads to surface waters. When flows recede, and when water velocity slows it stagnates and there are resulting fluctuations in water chemistry. The South River Federation's technical report states that there has been a decrease in the macroinvertebrate index from 1997 to the present day, low species diversity was found throughout the watershed and is the product of a combination of a variety of factors including channelization, lack of habitat variety and abundance, and a lack of recruitment from neighboring sites (SRF 2013).

During the spring and summer index sampling periods, the MDDNR MBSS field crew reported anthropogenic impacts to the failing stations in the BSID primary dataset. The MDDNR MBSS field crew noted high stream turbidity, severe bank erosion, sediment and sand deposition, water logger dry, and that one of the sites is located in a sheep pasture. Iron flocculation or "iron floc", visible as orange slimy material, was also noted at four of the eight stations in the primary dataset. Iron floc is the result of oxidizing bacteria, they grow in a pH range of 5.0 to 7.5; the process of iron oxidation lowers the pH of the surrounding medium. Iron floc occurs where there is a significant amount of soluble iron in the soil and enough standing water to encourage bacterial growth. The bacteria need oxygen to survive, but not too much. They can usually be found in sediment or under a few centimeters of water. Iron floc is indicative of low-flow or standing water, and can be active constantly (Bull Run Conservancy 2013). The BISD

analysis identified low lab pH as significantly associated with biologically degraded condition in the watershed. But there were no additional nutrient stressors identified to indicate eutrophication. In a report identifying watersheds in need of restoration and protection the MDDNR noted that degradation (i.e., poor physical habitat and acidity) appears to be relatively widespread in the South River watershed (MDDNR 2003). The low acidity may be attributable to naturally occurring conditions exacerbated by anthropogenic factors. Due to the relatively recent expansion of suburban development in the South River watershed, a corridor between Baltimore and Washington, D.C., soils are often disturbed by construction activities. When these soils are excavated too deeply, they can give rise to severe active acid soil problems.

Natural hydrological variability may also play a significant role in the degradation of biological communities in the South River watershed. All the physiographic regions of Maryland were affected by the drought of 2001-2002; the western shore Coastal Plain region had a dramatic response with very low flows and standing pools (Prochaska 2005). During this time, the fish and benthic macroinvertebrate communities experienced drastic changes in water quality, and a reduction in the quantity and quality of available physical habitat. The South River watershed primary dataset contains eight sites, six of these sites were sampled in 2002; during the spring sampling index period the MDDNR MBSS noted that two of the streams would probably be dry and there were no fish collected in the summer.

All of the stations in the BSID primary dataset are headwater (i.e., first-order) streams. Headwater streams do not typically support biologically diverse and/or sustainable communities (Vannote 1980), making their biological communities more vulnerable to natural and anthropogenic land use alterations, and their associated stressors. The South River watershed is located in the Coastal Plain physiographic region, the Coastal Plain region is naturally impacted by sediment deposition due to the region's soil and hydrology. Under normal conditions, the watershed receives low freshwater input and experiences very little flushing except from storm events, therefore there are usually episodic pulses of sand and sediments. Due to these factors, the fish and benthic macroinvertebrate communities experience drastic changes in water quality, and a reduction in the quantity and quality of available physical habitat resulting in the shift in fish and benthic macroinvertebrate community structure in the South River watershed. The combined AR for all the stressors is approximately 87%, suggesting that altered hydrology/sediment, instream habitat, and water chemistry stressors adequately account for the biological impairment in the South River watershed.

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

4.4 Final Causal Model

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2013). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the South River watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

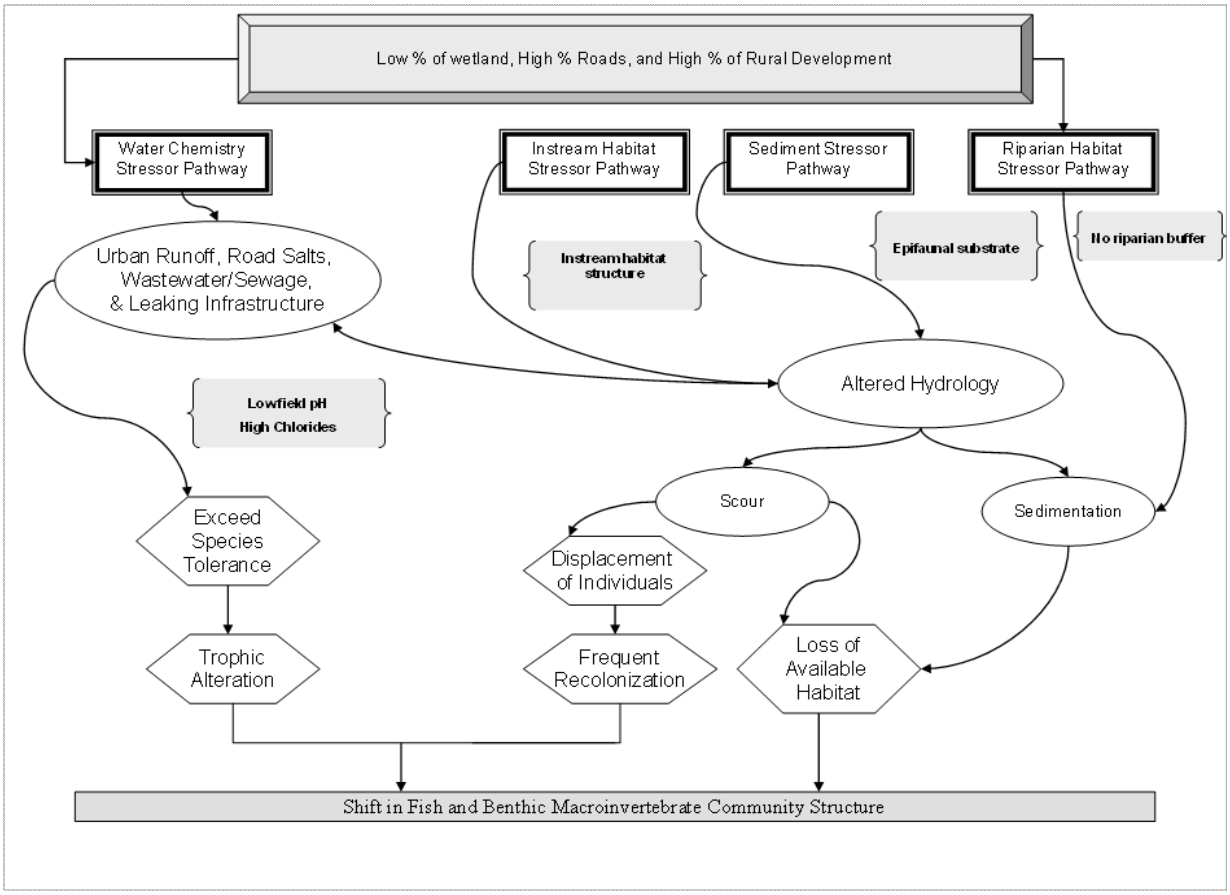

Figure 6. Final Causal Model for the South River Watershed

5.0 Conclusions

Data suggest that the South River watershed's biological communities are influenced by the anthropogenic impacts of land development. Naturally occurring conditions (e.g., high acidity, sediment, headwater streams) are exacerbated by anthropogenic impacts, and the hydrologic regime of the watershed has been altered, resulting in increased habitat homogeneity in the South River watershed. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the South River watershed are summarized as follows:

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

- The BSID process has determined that biological communities in the South River watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones 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 is a result of pollution. MDE recommends a Category 4c listing for the South River watershed based on inadequate riparian buffer zones in approximately 60% of degraded stream miles.

- The BSID process has determined that the biological communities in the South River watershed are likely degraded due to inorganics (i.e., chloride). Chloride levels are significantly associated with degraded biological conditions and found in approximately 42% of the stream miles with poor to very poor biological conditions in the South River watershed. 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 these stressors on the biological communities in the South River watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will

help in determining the spatial and temporal extent of these impairments in the watershed.

- The BSID process has determined that biological communities in the South River watershed are not degraded due to nutrient related stressors. There are tidal 1996 Category 4a listings for Total Nitrogen and Total Phosphorus, which establish nutrient reductions through the 2010 Chesapeake Bay TMDL.

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