Watershed Report for Biological Impairment of the Non-Tidal St. Mary's River Watershed, St. Mary's County, Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

MARYLAND

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Submitted to:

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List of Abbreviations

AMD	Acid Mine Drainage
ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
CWP	Center for Watershed Protection
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
HNO3	Nitric Acid
H2SO4	Sulfuric Acid
IBI	Index of Biotic Integrity
ICM	Impervious Cover Model
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NOx	Nitrogen Oxides
SO_2	Sulfur Dioxides
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 St. Mary's River watershed (basin code 02140103), located in St. Mary's County, is associated with two assessment units in the Integrated Report: non-tidal (8-digit basin) St. Mary's River and the Lower Potomac 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 St. Mary's River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
St. Mary's River	0214013	Non-tidal		Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
		Impoundment	St. Mary's Lake	Aquatic Life and Wildlife	-	TP	2
				Fishing	2002	Mercury in Fish Tissue	4a
Lower Potomac River Mesohaline	POTMH	Tidal		Seasonal Migratory fish spawning and nursery Subcategory	1996 & 2012	TP	4a
					2012	TN	4a
				Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5
				Open Water Fish and Shellfish	1996	TP	4a
					1996	TN	4a
				Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	4a
			Locust Grove Cove	Shellfishing	1996	Fecal Coliform	4a
			St. Inigoes Creek		1996	Fecal Coliform	4a
			Carthagena Creek		1996	Fecal Coliform	2
			St. Mary's River	Fishing	-	PCBs in Fish Tissue	2
				Seasonal Deep Water Fish and Shellfish	1996	TN	4a
				Seasonal Deep Channel Refuge Use	1996	TP	4a
						TN	4a

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 the non-tidal St. Mary's River is designated as a Use I - *water contact* *recreation, and protection of nontidal warmwater aquatic life*. The tidal portions of the watershed are designated as Use II - s*upport of estuarine and marine aquatic life and shellfish harvesting (COMAR 2013a,b).* The St. Mary's 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) that were developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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

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

This St. Mary's River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that acidity is the probable cause of biological community degradation in the St. Mary's River watershed. Low pH and low acid neutralizing capacity of streams in the watershed result from anthropogenic sources (atmospheric deposition) and natural conditions (geology and soils).

The results of the BSID process, and the probable causes and sources of the biological impairments in the St. Mary's River watershed can be summarized as follows:

> The BSID process has determined that the biological communities in St. Mary's River watershed are likely degraded due to acidity related stressors. Acidity is indicated directly by the strong association of low pH and low Acid Neutralizing Capacity with biological impairments. The St. Mary's River watershed experiences acidity caused by atmospheric deposition in areas where the geology has little buffering capacity. The BSID results thus support a Category 5 listing of low pH on the Integrated Report as an appropriate management action to begin addressing the

impacts of this stressor on the biological communities in the St. Mary's River watershed.

- The BSID analysis did not identify any sediment, in-stream habitat, or riparian habitat stressors present and/or showing a significant association with degraded biological conditions.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions.

- The BSID analysis has determined that urban sources in the St. Mary's River watershed are impacting biological communities. Since the BSID analysis did not reveal key supporting stressors associated with urban development (e.g., severe erosion, bar formation, elevated chlorides, sulfates, and conductivity); further investigation is recommended.

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 St. Mary's River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 St. Mary's River Watershed Characterization

2.1 Location

The St. Mary's River watershed is located in St. Mary's County, Maryland. The river's headwaters arise in southern St. Mary's County, and flows to the southeast through Great Mills, widening into a tidal estuary near St. Mary's City, and eventually drains into the Lower Potomac River, near the Chesapeake Bay (see Figure 1). The St. Mary's River watershed encompasses approximately 45,000 acres. The watershed is located in the Coastal Plains region of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

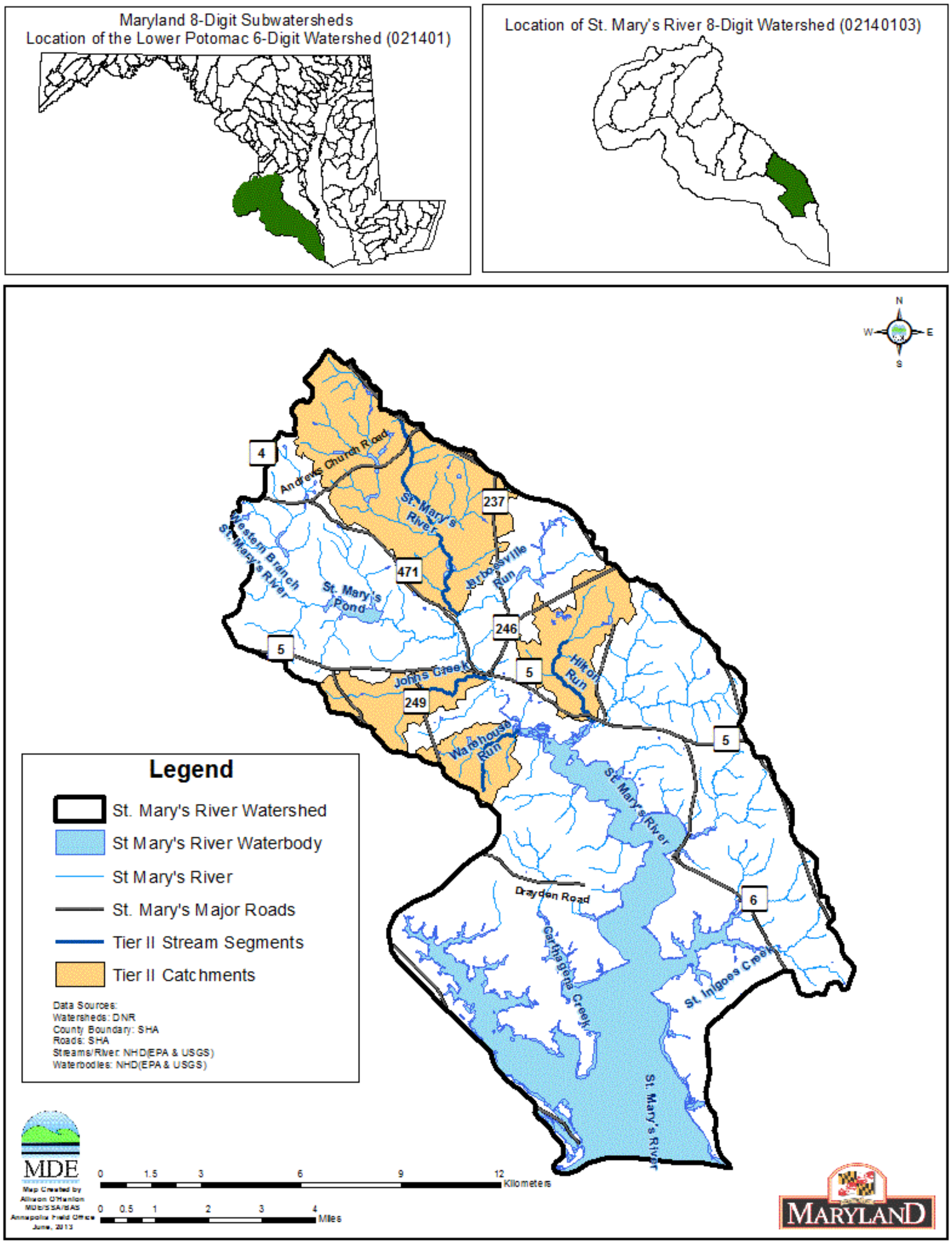

Figure 1. Location Map of the St. Mary's River Watershed

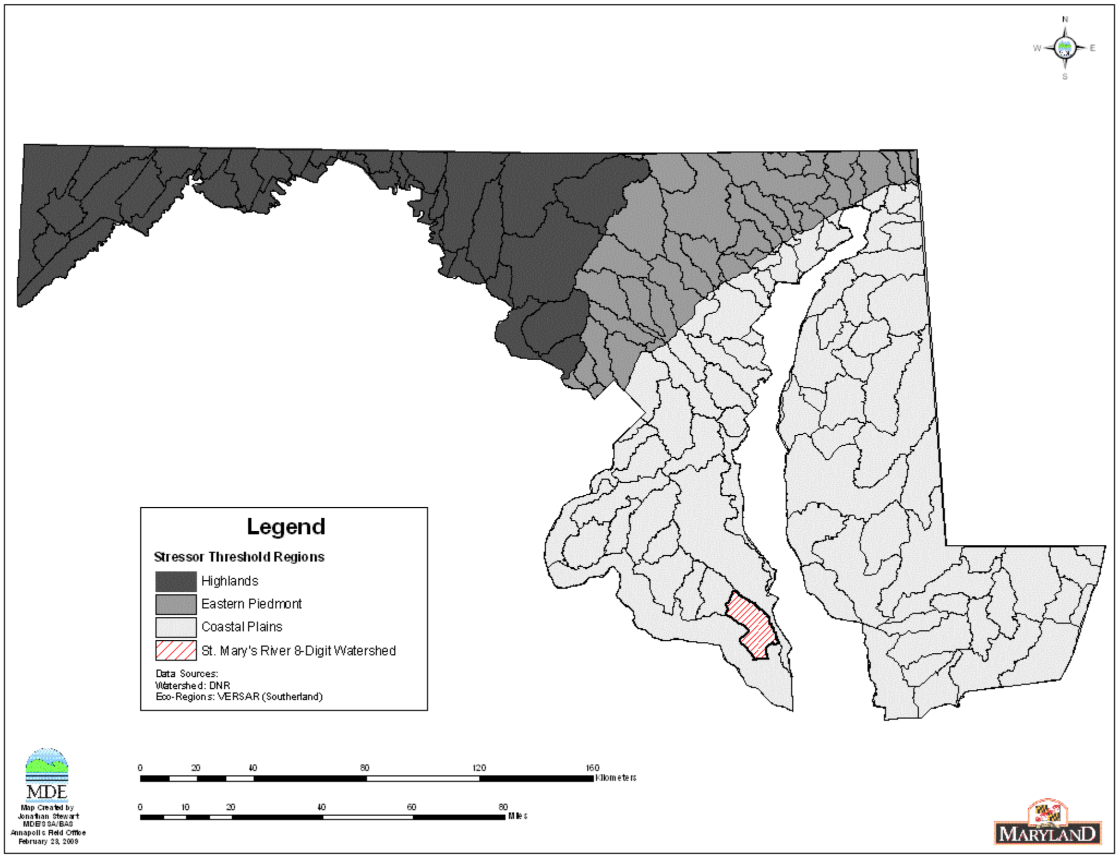

Figure 2. Eco-Region Map of the St. Mary's River Watershed

2.2 Land Use

The drainage area of the St. Mary's River watershed is approximately 45,000 acres. The St. Mary's River watershed contains urban, agricultural, and forested land uses. The predominant land use in the Maryland 8-digit watershed is forest; however, the watershed has become increasingly urbanized particularly in the areas of Leonardtown and Lexington Park. Impervious surface development due to urbanization is above 12% in some subwatersheds of the St. Mary's River and expected to climb to 20-25% in Lexington Park (Brown 2001 and Paul 2008a). According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the St. Mary's River watershed consists of 63% forest, 24% urban pervious (with 3% impervious surfaces), and 14% agricultural (USEPA 2010) (see Figure 3 and Figure 4).

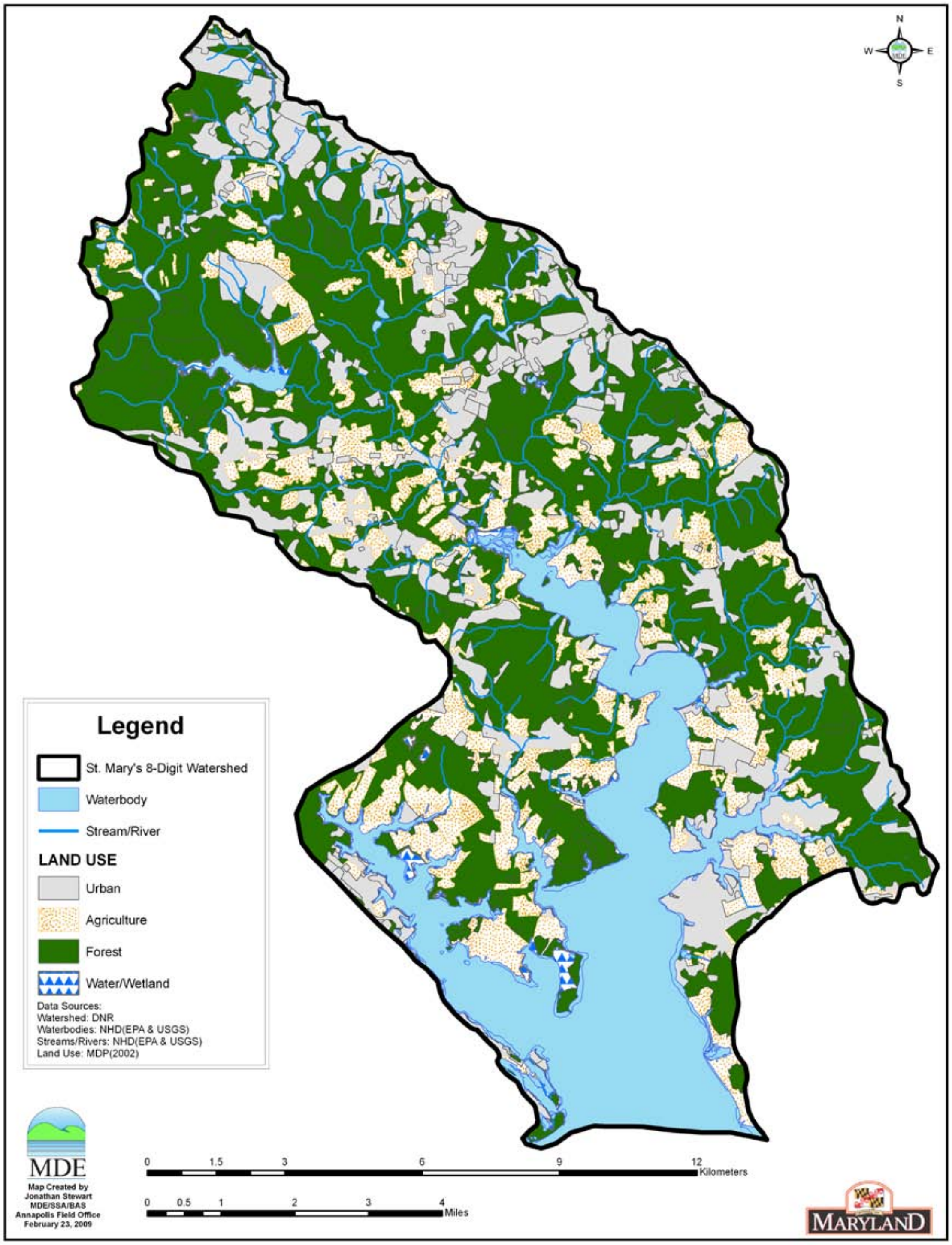

Figure 3. Land Use Map of the St. Mary's River Watershed

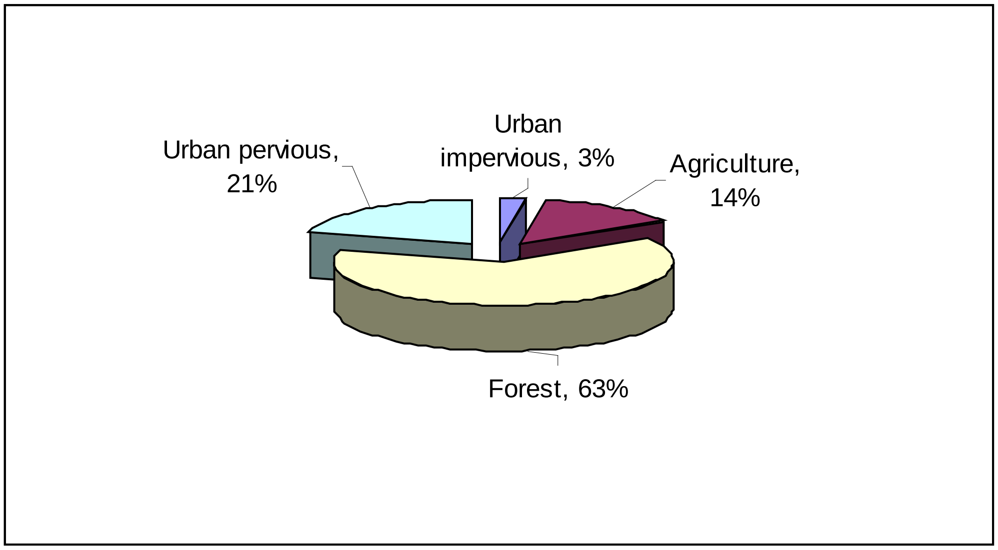

Figure 4. Proportions of Land Use in the St. Mary's River Watershed

2.3 Soils/hydrology

The St. Mary's River lies in the Coastal Plain physiographic province. The Coastal Plain region is characterized by flat or gently rolling topography and elevations rising from sea level to about 100 feet (MDDNR 2013). The highest elevation within the St. Mary's River watershed is approximately 165 feet in the northwest corner of the watershed. Many of the small tributaries in this region of the St. Mary's River watershed follow deeply incised channels that have been cut into the soft Coastal Plain substrate. The southern portion of the watershed, near the mouth of the tidal river, has low elevation gradients and stream channels are not so deeply incised.

There are seventy-seven soil types contained within the St. Mary's River watershed. All the soil types are typical of the Coastal Plain Province, which are all derived from thick unconsolidated beds of sand, silt, clay, and gravel laid down as marine deposits. (Gibson 1978; SMRWA 2009). Most of the soils in St. Mary's County are acidic and have naturally low fertility (NRCS 1978). The primary soils group in the St. Mary's watershed is the Beltsville series which consists of moderately well drained silt and loam soils. In general, low stream alkalinities reflect the marine origin; sand, silt, clay and gravel composition; and the low pH of St. Mary's County soils (Gibson 1978 and SMRWA 2009).

3.0 St. Mary's River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The St. Mary's River watershed (basin code 02140103), located in St. Mary's County, is associated with two assessment units in the Integrated Report: non-tidal (8-digit basin) St. Mary's River and the Lower Potomac River Mesohaline Chesapeake Bay segment (MDE 2012). Below is a table identifying the listings associated with this watershed.

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				Seasonal Deep Water Fish and Shellfish	1996	TN	4a
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						TN	4a

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the non-tidal St. Mary's River are designated as a Use I - *water contact recreation, and protection of nontidal warmwater aquatic life*. The tidal portions of the watershed are designated as Use II - s*upport of estuarine and marine aquatic life and shellfish harvesting (COMAR 2013a,b).* Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

A portion of the St. Mary's River watershed is designated as a Tier II (i.e., Maryland's antidegradation policy) waterbody; this Tier II designation protects surface water that is better than the minimum requirements specified by water quality standards. The St. Mary's River watershed's Tier II catchments are the headwaters of St. Mary's River, John's Creek, Warehouse Run, and Hilton Run. (COMAR 2013c).

The St. Mary's River watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 29% of stream miles in the St. Mary's River basin are estimated as having fish and and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include twenty-three sites. Seven of the twenty-three 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, i.e. MBSS round two and three (2000-2009), contains twenty-one MBSS sites with six having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the St. Mary's River watershed.

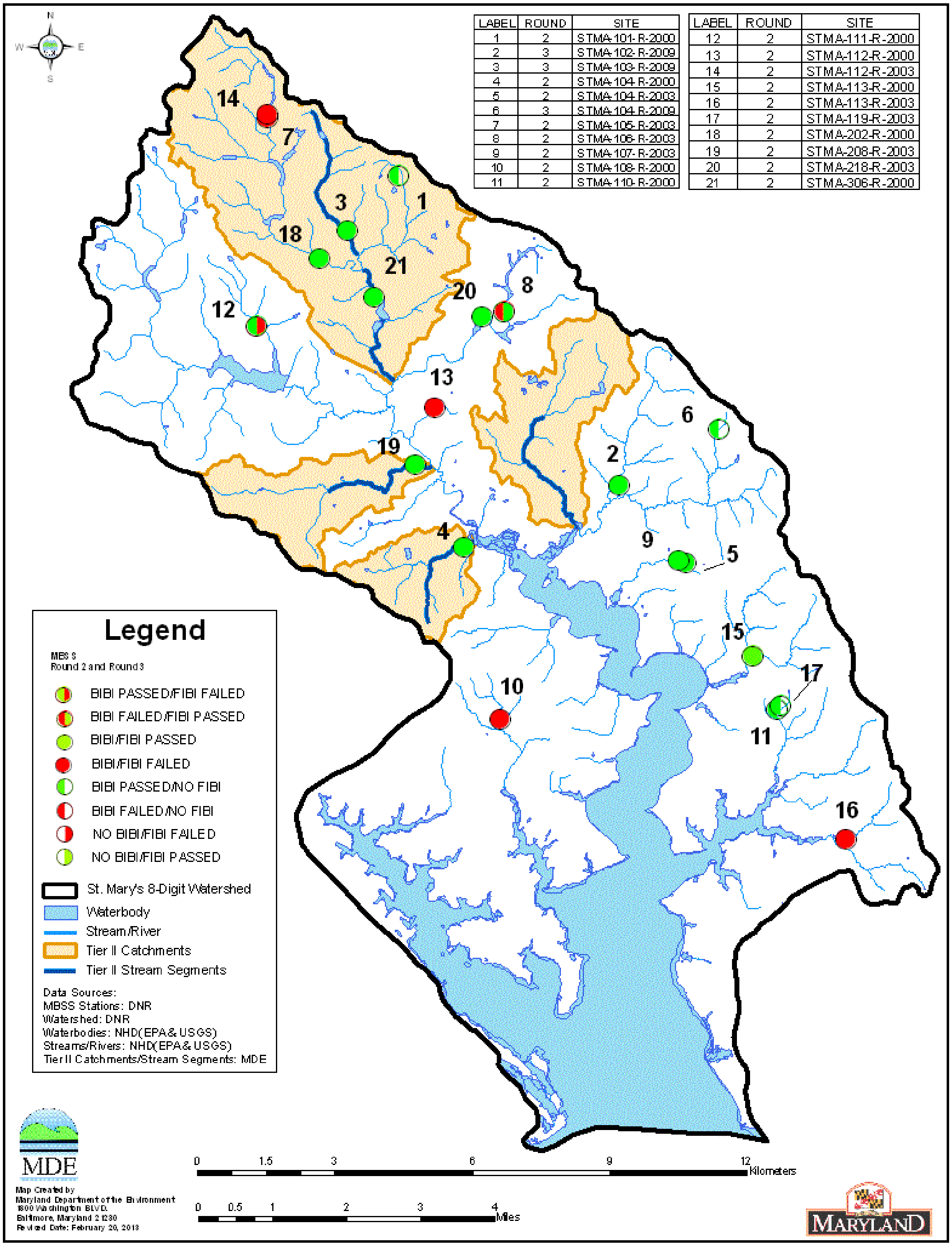

Figure 5. Principle Dataset Sites for the St. Mary's River Watershed

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 (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 analysis, MDE identified water chemistry parameters, urban land uses, and atmospheric deposition as having a significant association with poor to very poor benthic and/or fish biological conditions in the St. Mary's River watershed. 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 St. Mary's 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 St. Mary's River watershed.

Table 2. Stressor Source Identification Analysis Results for the St. Mary's 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	20	7	272	86%	37%	0.014	Yes	49%
	Agricultural acid source present	20	7	272	0%	7%	1	No	_
	AMD acid source present	20	7	272	0%	0%	1	No	_
	Organic acid source present	20	7	273	0%	7%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	21	7	277	0%	3%	1	No	_
	High % of agriculture in 60m buffer	21	7	277	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	21	7	277	0%	6%	1	No	_
	Low % of wetland in watershed	21	7	277	14%	11%	0.559	No	_
	Low % of forest in 60m buffer	21	7	277	0%	8%	1	No	_
	Low % of wetland in 60m buffer	21	7	277	14%	10%	0.546	No	_
Sources - Impervious	High % of impervious surface in watershed	21	7	277	43%	4%	0.003	Yes	39%
	High % of impervious surface in 60m buffer	21	7	277	57%	5%	0	Yes	52%
	High % of roads in watershed	21	7	277	0%	0%	1	No	_
	High % of roads in 60m buffer	21	7	277	14%	4%	0.282	No	_
Sources - Urban	High % of high-intensity developed in watershed	21	7	277	57%	7%	0.001	Yes	50%
	High % of low-intensity developed in watershed	21	7	277	43%	6%	0.009	Yes	37%
	High % of medium-intensity developed in watershed	21	7	277	0%	2%	1	No	_
	High % of early-stage residential in watershed	21	7	277	14%	5%	0.301	No	_
	High % of residential developed in watershed	21	7	277	43%	6%	0.009	Yes	37%

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 rural developed in watershed	21	7	277	29%	5%	0.053	Yes	24%
	High % of high-intensity developed in 60m buffer	21	7	277	43%	6%	0.009	Yes	37%
	High % of low-intensity developed in 60m buffer	21	7	277	43%	4%	0.004	Yes	39%
	High % of medium-intensity developed in 60m buffer	21	7	277	43%	3%	0.001	Yes	40%
	High % of early-stage residential in 60m buffer	21	7	277	0%	7%	1	No	_
	High % of residential developed in 60m buffer	21	7	277	43%	4%	0.004	Yes	39%
	High % of rural developed in 60m buffer	21	7	277	29%	5%	0.047	Yes	24%

Table 3. Summary AR Values for Source Groups for the St. Mary's River Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Acidity	49%
Sources - Impervious	53%
Sources - Urban	82%
All Sources	***92%***

4.1 Sources Identified by BSID Analysis

Various types of urban land uses including impervious surfaces were identified as significantly associated with degraded biological conditions in the St Mary's River and found to impact approximately 82% of the stream miles with poor to very poor biological conditions (Table 2 and Table 3). Although urban land uses and impervious surfaces were identified as sources in the watershed, none of the stressors typically associated with anthropogenic disturbances were identified in the BSID analysis. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the St. Mary's River watershed contains 3% of impervious surfaces; however, some subwatersheds contain significantly higher amounts (Brown 2001 and Paul 2008a). In recent years impervious cover has emerged as a key indicator to explain and sometimes predict how severely streams change in response to different levels of watershed development (CWP 2003). The Center for Watershed Protection (CWP) has integrated these research findings into a general watershed planning model, known as the impervious cover model (ICM). The ICM predicts that most stream quality indicators decline when watershed impervious cover exceeds 10%, with severe degradation expected beyond 25% impervious cover. The model classifies subwatersheds into one of three categories: sensitive (0-10%), impacted (11-25%), and non-supporting (over 25%).

Atmospheric deposition present was identified as significantly associated with degraded biological conditions in the St Mary's River and found to impact approximately 49% of the stream miles with very poor to poor biological conditions (Table 2 and Table 3). The acidity related stressor parameters (*low pH* and *acid neutralizing capacity*), identified in Table 6 of this report are representative of impacts from atmospheric deposition and a geology with a poor buffering capacity.

Large amounts of nitrogen oxides and sulfur dioxides (NOxs and SO_2) have been emitted into the atmosphere for the past century from burning fossil fuels such as gas, oil, and coal. These emissions of NOxs and SO_2 return to the earth's surface through atmospheric deposition. Atmospheric deposition refers to substances that are deposited on land or water surfaces from the air. These substances can be carried in precipitation, also called wet deposition, or they can reach the earth's surface via dry deposition, which includes both the settling out of particles and the adsorption by soil, trees, and/or water. An important consequence of atmospheric deposition is acidity. In precipitation, most acidity is contributed by sulfuric acid (H_2SO_4) and nitric acid (HNO_3). The effects of acid rain are most problematic in regions where the soils and water bodies acid neutralizing capacity (ANC). A reduction in pH (more acidic) in surface waters may allow the release of toxic metals that would otherwise be absorbed to sediment and essentially removed from the water system. Once mobilized, these metals are available for uptake by organisms. Metal uptake can cause extreme physiological damage to aquatic life. Acidification of aquatic systems also inhibits microbial activity in the benthos, reducing decomposition and nutrient cycling. This may lead to a reduction of the invertebrates and plankton that are a vital part of the food chain. Eventually, a shift in community structure may occur (Smith 1990).

Table 4. Sediment Biological Stressor Identification Analysis Results for the St. Mary's 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	20	7	161	29%	21%	0.643	No	_
	Moderate bar formation present	20	7	160	43%	49%	1	No	_
	Bar formation present	20	7	160	100%	78%	0.348	No	_
	Channel alteration moderate to poor	18	7	131	43%	59%	0.454	No	_
	Channel alteration poor	18	7	131	29%	26%	1	No	_
	High embeddedness	20	7	160	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	20	7	160	43%	46%	1	No	_
	Epifaunal substrate poor	20	7	160	14%	13%	1	No	_
	Moderate to severe erosion present	20	7	160	57%	43%	0.466	No	_
	Severe erosion present	20	7	160	14%	13%	1	No	_
	Silt clay present	20	7	160	100%	99%	1	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the St. Mary's 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)
In-stream Habitat	Channelization present	21	7	172	0%	13%	0.597	No	_
	Concrete/gabion present	18	7	148	0%	1%	1	No	_
	Beaver pond present	19	7	159	0%	7%	1	No	_
	Instream habitat structure marginal to poor	20	7	160	29%	39%	0.707	No	_
	Instream habitat structure poor	20	7	160	0%	6%	1	No	_
	Pool/glide/eddy quality marginal to poor	20	7	160	29%	46%	0.457	No	_
	Pool/glide/eddy quality poor	20	7	160	0%	3%	1	No	_
	Riffle/run quality marginal to poor	20	7	160	57%	53%	1	No	_
	Riffle/run quality poor	20	7	160	29%	21%	0.638	No	_
	Velocity/depth diversity marginal to poor	20	7	160	29%	61%	0.122	No	_
	Velocity/depth diversity poor	20	7	160	29%	16%	0.316	No	_
Riparian Habitat	No riparian buffer	18	7	140	29%	15%	0.301	No	_
	Low shading	20	7	160	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the St. Mary's 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	21	7	277	0%	8%	1	No	_
	High conductivity	21	7	277	0%	6%	1	No	_
	High sulfates	21	7	277	0%	8%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	20	7	261	29%	17%	0.355	No	_
	Dissolved oxygen < 6mg/l	20	7	261	29%	25%	1	No	_
	Low dissolved oxygen saturation	20	7	261	29%	6%	0.073	Yes	22%
	High dissolved oxygen saturation	20	7	261	29%	3%	0.019	Yes	26%
	Ammonia acute with salmonid present	21	7	277	0%	0%	1	No	_
	Ammonia acute with salmonid absent	21	7	277	0%	0%	1	No	_
	Ammonia chronic with early life stages present	21	7	277	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	21	7	277	0%	0%	1	No	_
	High total nitrogen	21	7	277	0%	6%	1	No	_
	High total phosphorus	21	7	277	0%	9%	1	No	_
	High orthophosphate	21	7	277	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	21	7	277	43%	9%	0.025	Yes	33%
	Acid neutralizing capacity below episodic level	21	7	277	86%	45%	0.052	Yes	40%
	Low field pH	20	7	262	86%	40%	0.022	Yes	45%
	High field pH	20	7	262	0%	1%	1	No	_
	Low lab pH	21	7	277	86%	38%	0.016	Yes	48%
	High lab pH	21	7	277	0%	0%	1	No	_

Table 7. Summary AR Values for Stressor Groups for the St. Mary's River Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	----
Habitat	----
Chemistry - Nutrients	53%
Chemistry - pH	64%
All Chemistry	89%
All Stressors	***89%***

4.2 Stressors Identified by BSID Analysis

Below is an analysis of the six stressor parameters identified by the BSID analysis (Table 4 through 6), as being significantly associated with biological degradation in the St. Mary's River watershed. Any form of anthropogenic change to natural conditions can create broad and interrelated forms of degradation that can affect stream ecology and biological composition.

Sediment Conditions

BSID analysis results for the St. Mary's River watershed did not identify any sediment parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community).

In-stream Habitat Conditions

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

Riparian Habitat Conditions

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

Water Chemistry

BSID analysis results for the St. Mary's River watershed identified six 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). These parameters are *low dissolved oxygen (DO) saturation*, *high DO saturation, low lab & field pH, acid neutralizing capacity below chronic level,* and *acid neutralizing capacity below episodic level* (Table 6).

Low DO saturation was identified as significantly associated with degraded biological conditions and found in 22% of the stream miles with poor to very poor biological conditions in the St. Mary's River watershed. Natural diurnal fluctuations can become exaggerated in streams with elevated nutrient concentrations, resulting in excessive primary production. High and low DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Low DO saturation is considered to demonstrate high respiration associated with excessive decomposition of organic material.

High DO saturation was identified as significantly associated with degraded biological conditions and found in 26% of the stream miles with poor to very poor biological conditions in the St. Mary's 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.

There were two MBSS sites with degraded biology and low dissolved oxygen saturation. Both stream segments flowed through a marsh and were located within close proximity to each other. Typically streams located within marshes are shallow with very little flow and are often predisposed to low dissolved oxygen levels due to high respiration associated with excessive decomposition of organic material.

There were also two MBSS sites with degraded biology and high dissolved oxygen saturation. MBSS site STMA-108-R-2000 has sub-optimal to optimal habitat scores, and did not have elevated nutrient concentrations. This stream segment, however, did have low pH (4.9) and ANC (-7.6 ueq/L), which have been identified through the BSID analysis as having significant association with biological degradation. Currently, the only DO data available for Carthagena Creek is this individual MBSS site with a value of 9.4 mg/L. The other MBSS site with high DO saturation is STMA-112-R-2000 located on an unnamed tributary to St. Mary's River. This site has sub-optimal to optimal scores for every habitat category except riffle/run, this was rated marginal. Water quality data at this site indicates no acidity, sufficient ANC, and none of the nutrient concentrations exceeded BSID thresholds. Analysis of additional water quality data in these two tributaries would be needed to determine if excessive primary production is resulting in exaggerated natural diurnal fluctuations. A water quality synoptic survey conducted in the St. Mary's River watershed did conclude that nutrients were generally low and below levels of concern at almost all non-tidal monitoring sites (Paul 2008b). Also in 2009 and 2011, MDE collected sixty-six water quality samples at ten stations in the non-tidal portion of the St. Mary's watershed. None of the samples had DO values below 5.0 mg/L. COMAR (2013d) establishes a criteria for designated Use I Waters— *water contact recreation, and protection of nontidal warmwater aquatic life*, that DO concentrations may not be less than 5 mg/L at any time. Dissolved oxygen concentrations at MBSS sites STMA-108-R-2000 and STMA-112-R-2000 were not below 5.0 mg/L.

Low ANC below chronic and episodic level was identified as significantly associated with degraded biological conditions and found in approximately 33% (chronic level) and 40% (episodic level) of the stream miles with poor to very poor biological conditions in the St. Mary's River watershed. ANC is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids. ANC can be used as an index of the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. Repeated additions of acidic materials, like those found in atmospheric deposition, may cause a decrease in ANC. ANC values less than 50µeq/l are considered to demonstrate chronic (highly sensitive to acidification) exposures for aquatic organisms, and values less than 200 are considered to demonstrate episodic (sensitive to acidification) exposures (Kazyak et al 2005, Southerland et al 2007). Since many stream segments in the St. Mary's River watershed have very low ANC, these segments become acidic when the supply of acids from atmospheric deposition exceeds the capacity of watershed soils and drainage waters to neutralize them.

Low lab & field pH levels below 6.5 were identified as significantly associated with degraded biological conditions and found to impact approximately 48% (lab pH) and 45% (field pH) of the stream miles with poor to very poor biological conditions in the St. Mary's 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 once during the summer, which are measured in situ (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Low pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2013d). Some types of plants and animals are able to tolerate acidic waters. Others, however, are acid-sensitive and will be lost as the pH declines. Generally, the young of most species are more sensitive to environmental conditions than adults. At pH 5, most fish eggs cannot hatch. At lower pH levels, some adult fish die (USEPA 2008). Low pH values are a common occurance in surface waters affected by atmospheric deposition.

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 St. Mary's River watershed (Table 7).

4.3 Discussion

The BSID results identified *pH* and *ANC* as the most probable stressors associated with biological impairment in the St. Mary's River watershed. These acidity related stressors indicate that approximately 64% of biological impairments would be improved if the stressors were removed.

The BSID results also identified various urban land uses and impervious surfaces, as well as atmospheric deposition as likely sources associated with biological impairment in the St. Mary's River watershed. These BSID results indicate that approximately 85% of biological impairments would be improved if these sources were removed.

The St. Mary's River watershed has undergone significant development since the 1960s, and this trend is expected to continue (SMRWA 2009). While the pH and ANC stressors can be attributed to the geology/soils in the watershed and atmospheric deposition, it is unlikely that the urban development in the watershed directly contributes to the acidity related stressors. Since the BSID did not identify key stressors associated with the urban sources in the watershed, analysis of additional water quality data may be needed to determine the extent of development impacts to the biological resources in the watershed.

Due to the atmospheric deposition and the geology/soils in the St. Mary's River watershed, acidity levels may exceed species tolerances resulting in a decreased diversity of aquatic organisms needed to sustain full colonization of a healthy community structure. Regulations have been enacted in both the federal and state level to reduce emissions of SO_2 and NOx from sources such as industrial facilities. Some of these regulations like the Clean Air Act Amendments of 1990 have been in effect for more than two decades and have reduced U.S. emissions of SO_2 by about forty percent (Spiro and Stigliani 2003). Studies have shown reduction in atmospheric deposition of sulfates because of a decrease in SO_2 emissions. Figure 6 illustrates the decreases in levels of sulfate, nitrate, and pH in precipitation across the United States since 1989. Strict enforcement of federal regulations such as the Clean Air Act Amendments of 1990 and other state regulations should be sufficient to reduce atmospheric deposition's effect in areas where the soils and water bodies have limited acid neutralizing capacity (ANC).

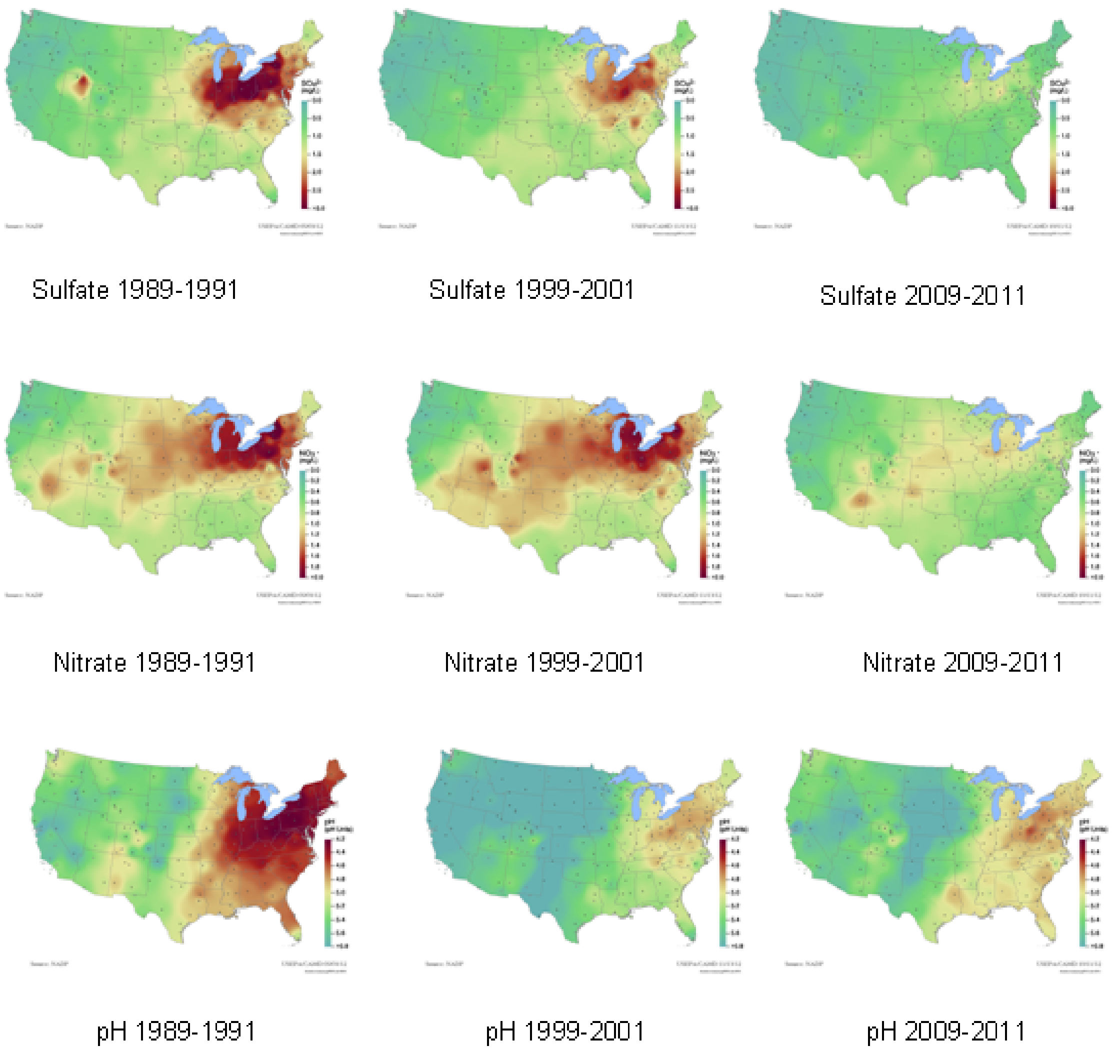

Figure 6. Trends in Atmospheric Deposition (NADP 2013)

4.4 Final Causal Model for the St. Mary's River 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 and 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 7 illustrates the final causal model for the St. Mary's River watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

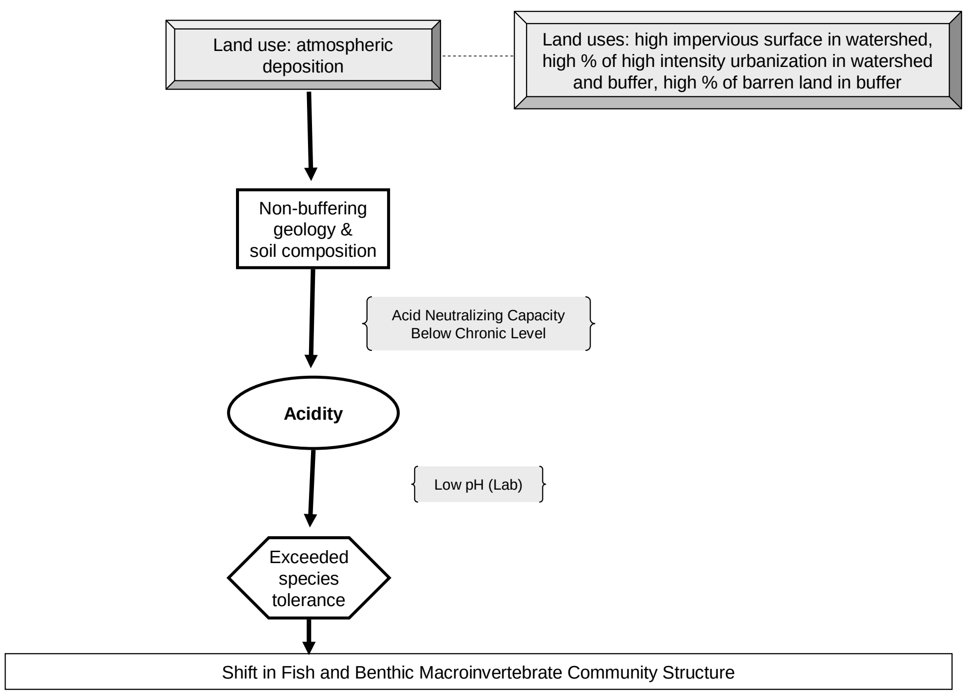

Figure 7. Final Causal Model for the St. Mary's River Watershed

5.0 Conclusion

Data suggest that the St. Mary's River watershed's biological communities are strongly influenced by acidity and development/urbanization. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the St. Mary's River are summarized as follows:

- The BSID process has determined that the biological communities in St. Mary's River watershed are likely degraded due to acidity related stressors. Acidity is indicated directly by the strong association of low pH and low Acid Neutralizing Capacity with biological impairments. St. Mary's River watershed experiences acidity caused by atmospheric deposition in areas where the geology has little buffering capacity. The BSID results thus support a Category 5 listing of low pH on the Integrated Report as an appropriate management action to begin addressing the impacts of this stressor on the biological communities in the St. Mary's River watershed.

- The BSID analysis did not identify any sediment, in-stream habitat, or riparian habitat stressors present and/or showing a significant association with degraded biological conditions.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions.

- The BSID analysis has determined that urban sources in the St. Mary's River watershed are impacting biological communities. Since the BSID analysis did not reveal key supporting stressors associated with urban development (e.g., severe erosion, bar formation, elevated chlorides, sulfates, and conductivity); further investigation is recommended.

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