FINAL

Watershed Report for Biological Impairment of the Loch Raven Reservoir in Baltimore, Carroll, and Harford Counties, Maryland and York County, PA Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMPs	Best Management Practices
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
m	Meter
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
NMPs	Nutrient Management Practices
RESAC	Regional Earth Science Applications Center
SSA	Science Services Administration
TP	Total Phosphorous
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

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 Maryland Department of the Environment (MDE) has identified the waters of the Loch Raven Reservoir watershed (basin number 02130805) has having multiple listings on the State's Integrated Report (Table E1) (MDE 2012).

Table E1. 2012 Integrated Report Listings for the Loch Raven Reservoir Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Subwatershed	Designated Use	Year listed	Identified Pollutant	Listing Category
Loch Raven Reservoir	02130805	Non-tidal		Water Contact Sports	2008	Fecal Coliform	4a
				Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
		Non-tidal/ Impoundment		Aquatic Life and Wildlife	1996	TP	4a
						TSS	
					-	Arsenic	2
						Cadmium	
						Total Chromium	
						Copper	
						Lead	
						Nickel	
						Selenium	
				Fishing	2002	Mercury in Fish Tissue	4a
					-	PCB in Fish Tissue	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 Loch Raven Reservoir watershed's tributaries are designated as Use III-P – *non-tidal cold water and public water supply*. The impoundment is designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply* (COMAR 2012 a, b). The Loch Raven Reservoir 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).

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 Loch Raven Reservoir 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 2009a). Data suggest that the Loch Raven Reservoir watershed's biological communities are influenced by anthropogenic development. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to development of natural landscapes, which often cause disturbances in stream habitat and increased contaminant loads from runoff. The results of the BSID process, and the probable causes and sources of the biological impairments in the Loch Raven Reservoir watershed can be summarized as follows:

- The BSID analysis has determined that phosphorus is a probable cause of impacts to biological communities in the Loch Raven Reservoir watershed. Total phosphorus was identified as having significant association with degraded biological conditions. The BSID results thus confirm the development of the 2007 TMDL for nutrients was an appropriate management action to begin addressing the impacts of nutrient stressors on the biological communities in the Loch Raven Reservoir watershed.

- The BSID process has also determined that the biological communities in the Loch Raven Reservoir watershed are likely degraded due to inorganic pollutants (i.e., chlorides and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions, and found in 26% and 23%, respectively, of the stream miles with poor to very poor biological conditions in Loch Raven Reservoir watershed. Runoff from roads, urban, and agricultural land uses causes an increase in contaminant loads from 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 results thus support a Category 5 listing of chloride and sulfates for the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Loch Raven Reservoir watershed.

- The BSID process has also determined that biological communities in the Loch Raven 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 Loch Raven watershed based on inadequate riparian buffer zones in approximately 36% of degraded stream miles.

- In 2007 a TMDL for total suspended sediments in the impoundment was developed and approved by EPA; however, the BSID analysis did not identify any sediment stressors in the non-tidal streams of the Loch Raven Reservoir watershed.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2010). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, 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 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 classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary. A Category 5 listing can be amended to a Category 4a if a TMDL was established and approved by USEPA or Category 4b if other pollution control requirements (i.e., permits, consent decrees, etc.) are expected to attain water quality standards. 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 the round two Maryland Biological Stream Survey (MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Loch Raven Reservoir watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Loch Raven Reservoir Watershed Characterization

2.1 Location

The Loch Raven Reservoir watershed is located both in Maryland and Pennsylvania, the Maryland 8-digit watershed total drainage area is approximately 140,900 acres. The majority of the watershed is in Maryland with a portion in York County, Pennsylvania. The Maryland portion is largely in Baltimore County, with small areas in Carroll and Harford Counties (see Figure 1). Gunpowder Falls, a major tributary of the Loch Raven Reservoir, drains into Chesapeake Bay north of the City of Baltimore. The watershed is located in the Eastern Piedmont 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).

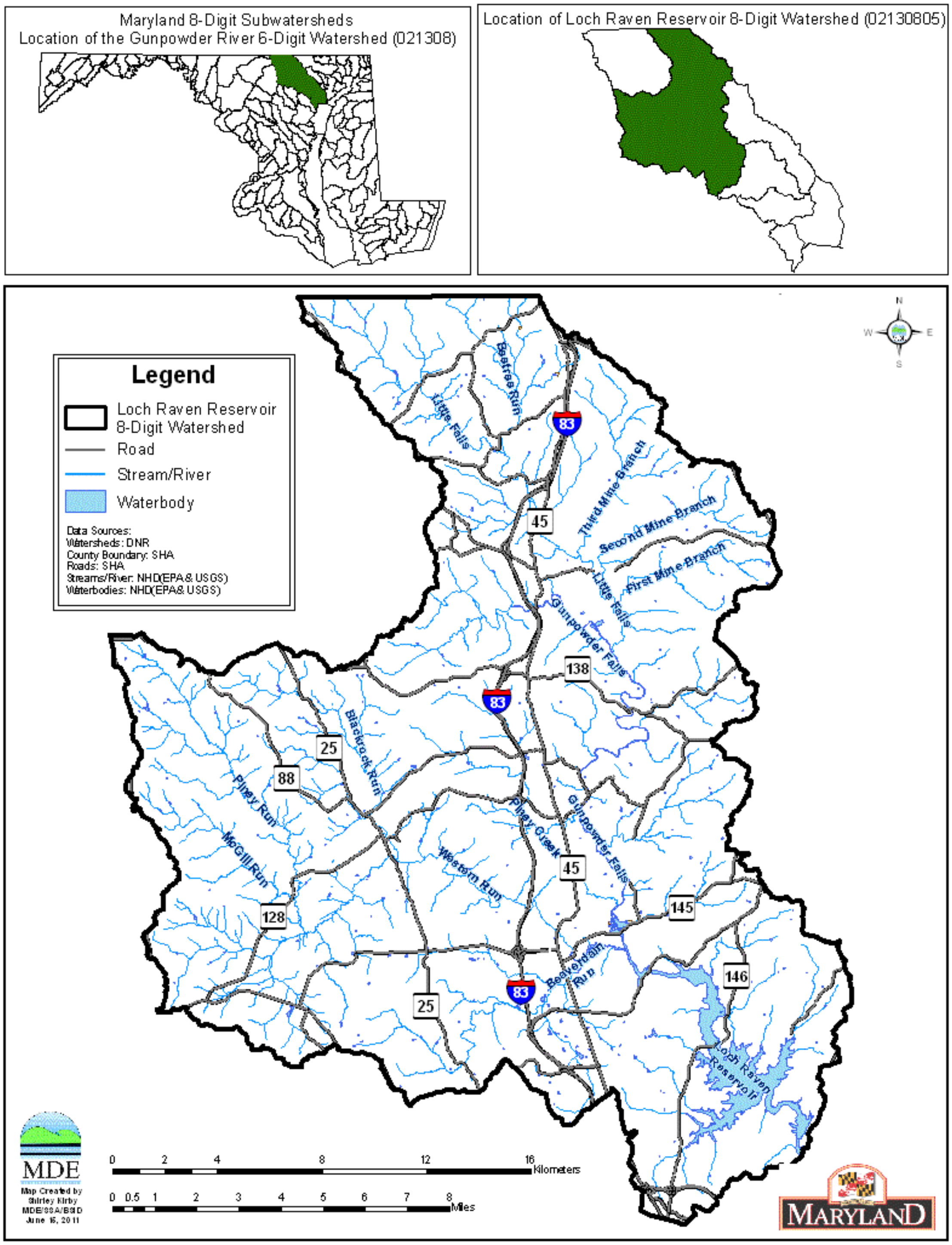

Figure 1. Location Map of the Loch Raven Reservoir Watershed

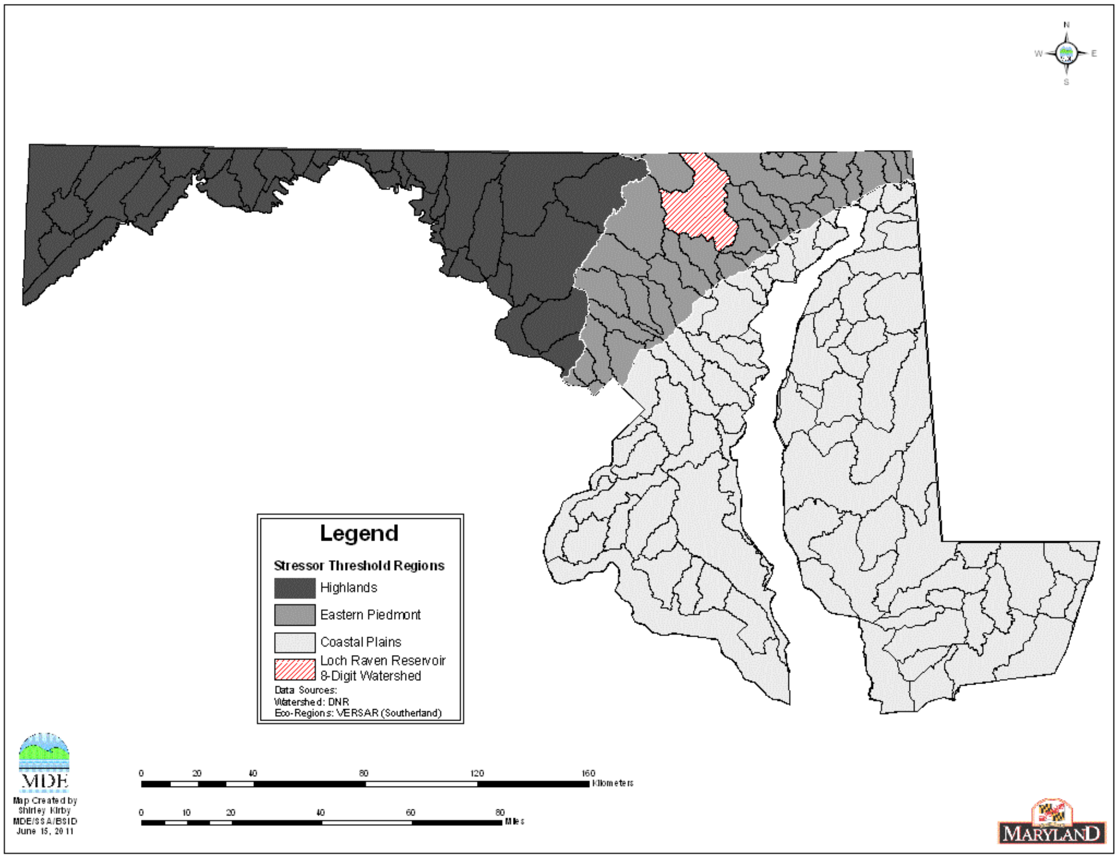

Figure 2. Eco-Region Location Map of the Loch Raven Reservoir Watershed

2.2 Land Use

Land use in the Loch Raven Reservoir watershed is primarily agricultural/pasture but also consists of forested and urban areas (see Figure 3). The forested areas are mainly along Gunpowder Falls and surrounding the reservoir. The urban areas are mostly in the southern part of the watershed. Regional Earth Science Application Center (RESAC) land use/land cover was used to estimate the land use for the Pennsylvania portion of the watershed. RESAC shows that the Pennsylvania portion is largely pasture and agricultural (MDE 2009b). The watershed includes the towns of Lutherville, Timonium, Cockeysville, Phoenix, Parkton, and Hampstead. State and county paved roads, such as Interstate 83, Routes 25, 45, 88, 128, 138, 145, and 146 and several minor roads interconnect points within the watershed. The tributaries to the reservoir include Beetree Run, Little Falls, Third Mine Branch, Second Mine Branch, First Mine Branch, Gunpowder Falls, Blackrock Run, Piney Run, McGill Run, Western Run and Beaverdam Run. Gunpowder Falls begins at the outlet of the Prettyboy Reservoir. A major tributary to Gunpowder Falls is Little Falls, which begins near the Pennsylvania border. Waters of the Loch Raven Reservoir watershed are designated as Tier II and they include Beetree

Run, First Mine Branch, Little Falls, Blackrock Run, Delaware Run, Indian Run, and Western Run (see Figure 5). The reservoir is part of the water supply system for Baltimore City and surrounding jurisdictions. Water supply intakes in Loch Raven Reservoir feed Baltimore City's Montebello Water Treatment Plant. The land use distribution in the watershed is approximately 37% agricultural/pasture, 37% forest/herbaceous, and 24% urban (see Figure 4) (MDP 2002). Urban impervious surface is 3% of the total land use in the watershed (USEPA 2010).

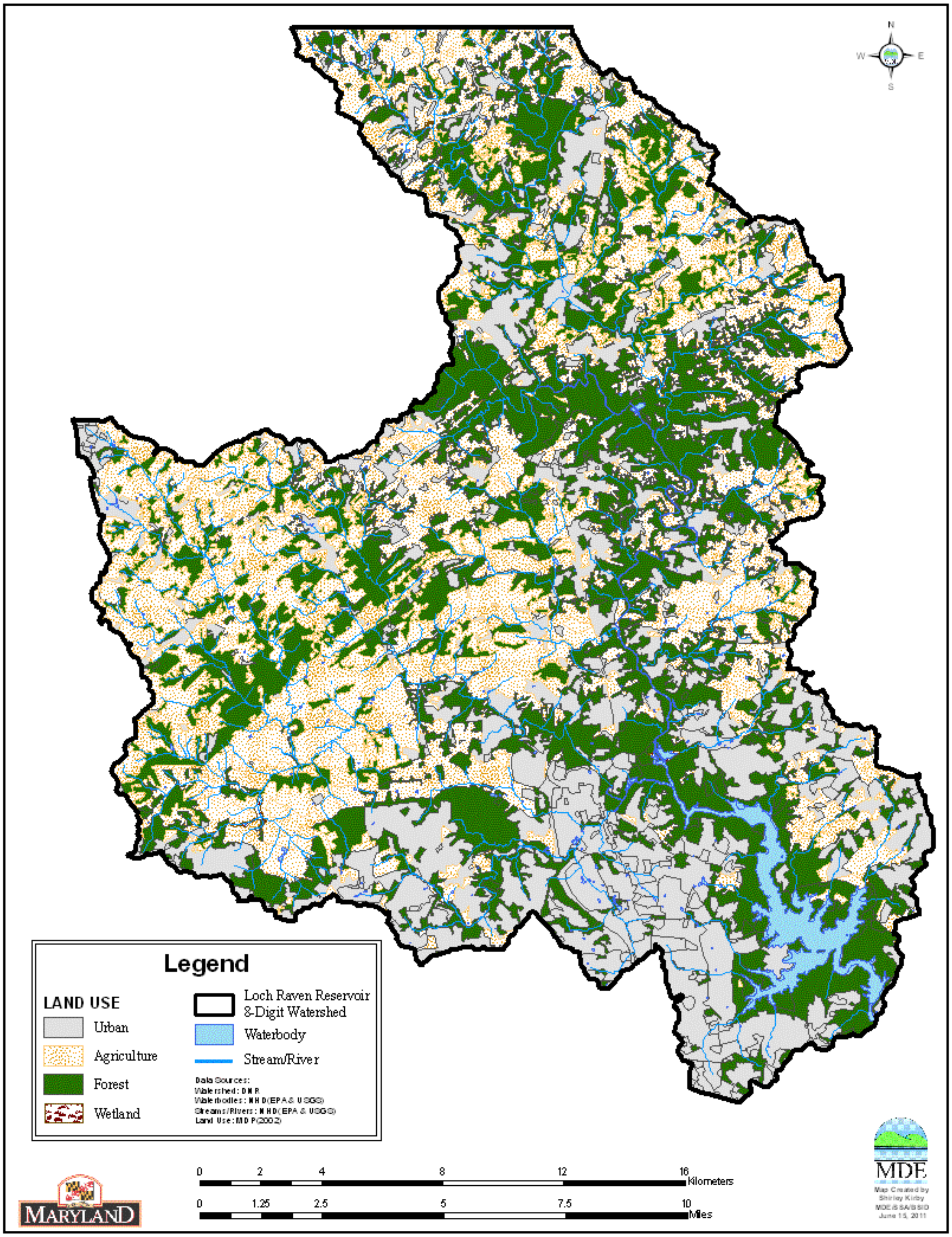

Figure 3. Land Use Map of the Loch Raven Reservoir Watershed

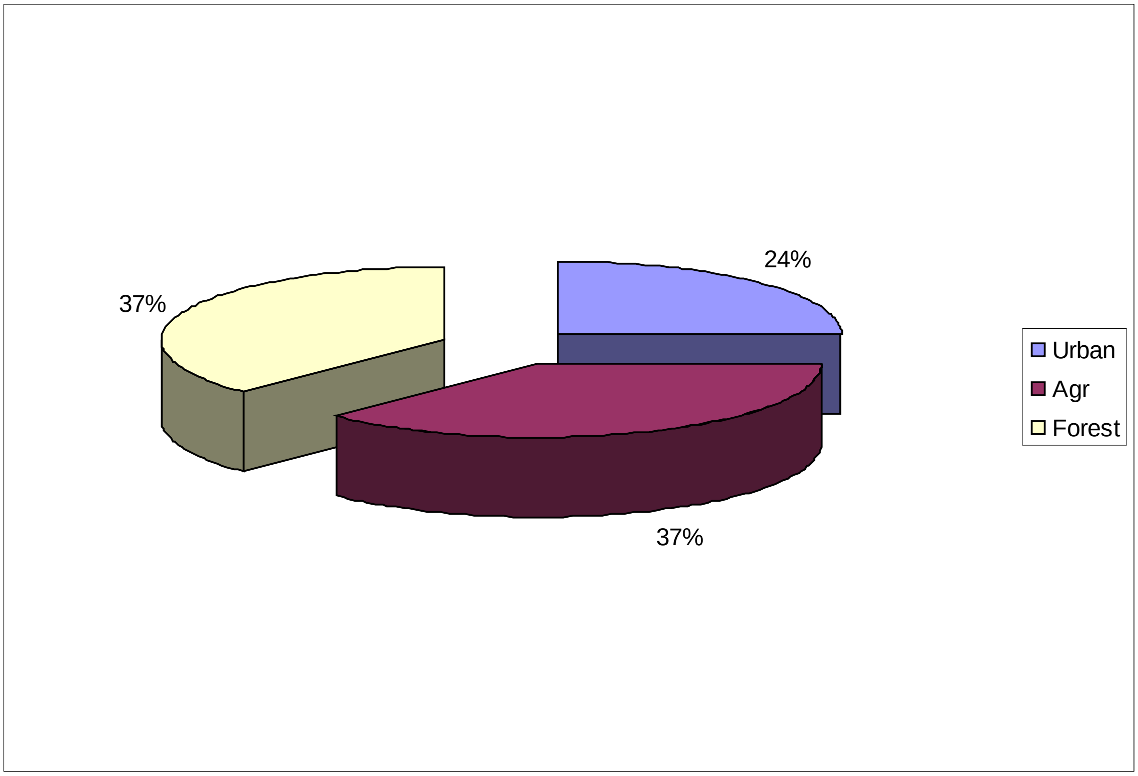

Figure 4. Proportions of Land Use in the Loch Raven Reservoir Watershed

2.3 Soils/hydrology

The Loch Raven Reservoir watershed is in the Piedmont Physiographic Province, which lies between the Blue Ridge and Coastal Plain physiographic provinces. Physiographic, or geomorphic, regions are broad-scale subdivisions based on terrain texture, rock type, and geologic structure and history (USGS 2013). The Piedmont surficial geology is characterized by metamorphic rock of Precambrian and Cambrian age (MDE 2004). The underlying metamorphic rock complex of the Loch Raven watershed downstream of Prettyboy Reservoir consists mainly of crystalline schists and gneiss with smaller areas of marble. The underlying marble formations, Cockeysville Marble and the Patuxent Formation, are less resistant to weathering than the schists and gneiss and consequently occur mainly in valleys. The primary soil associations in the watershed are the Manor-Glenelg, Chester-Glenelg, Baltimore-Conestoga-Hagerstown, Beltsville-Chillum-Sassafras, Glenelg-Chester-Manor, and Mt. Airy-Linganore associations. These soils are mainly deep and well drained to moderately well-drained. Within the stream floodplains, alluvial, Codorus and Hatboro soil series predominate (Reybold and Matthews 1976; Matthews 1969).

3.0 Loch Raven Reservoir Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment (MDE) has identified the waters of the Loch Raven Reservoir watershed (basin number 02130805) has having multiple listings on the State's Integrated Report (Table 1) (MDE 2012).

Table 1. 2012 Integrated Report Listings for the Loch Raven Reservoir Watershed

<table>
<tr><th>Watershed</th><th>Basin Code</th><th>Non-tidal/ Tidal</th><th>Subwatershed</th><th>Designated Use</th><th>Year listed</th><th>Identified Pollutant</th><th>Listing Category</th></tr>
<tr><td rowspan="13">Loch Raven Reservoir</td><td rowspan="13">02130805</td><td rowspan="2">Non-tidal</td><td></td><td>Water Contact Sports</td><td>2008</td><td>Fecal Coliform</td><td>4a</td></tr>
<tr><td></td><td>Aquatic Life and Wildlife</td><td>2002</td><td>Impacts to Biological Communities</td><td>5</td></tr>
<tr><td rowspan="11">Non-tidal/ Impoundment</td><td rowspan="9"></td><td rowspan="9">Aquatic Life and Wildlife</td><td rowspan="2">1996</td><td>TP</td><td rowspan="2">4a</td></tr>
<tr><td>Sedimentation</td></tr>
<tr><td rowspan="7">-</td><td>Arsenic</td><td rowspan="7">2</td></tr>
<tr><td>Cadmium</td></tr>
<tr><td>Total Chromium</td></tr>
<tr><td>Copper</td></tr>
<tr><td>Lead</td></tr>
<tr><td>Nickel</td></tr>
<tr><td>Selenium</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Fishing</td><td>2002</td><td>Mercury in Fish Tissue</td><td>4a</td></tr>
<tr><td>-</td><td>PCB in Fish Tissue</td><td>2</td></tr>
</table>

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Loch Raven Reservoir watershed's tributaries are designated as Use III-P – *non-tidal cold water and public water supply*. The impoundment is designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply* (COMAR 2012 a, b). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Loch Raven Reservoir watershed is listed under Category 5 of the 2012 Integrated Report as impaired for impacts to biological communities. Approximately 27% of stream miles in the Loch Raven Reservoir 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 forty-five stations. Twelve of the forty-five stations have degraded benthic and/or fish indices of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS round two, contains twenty sites; ten of the twenty sites have BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site and Tier II catchment locations for the Loch Raven Reservoir watershed.

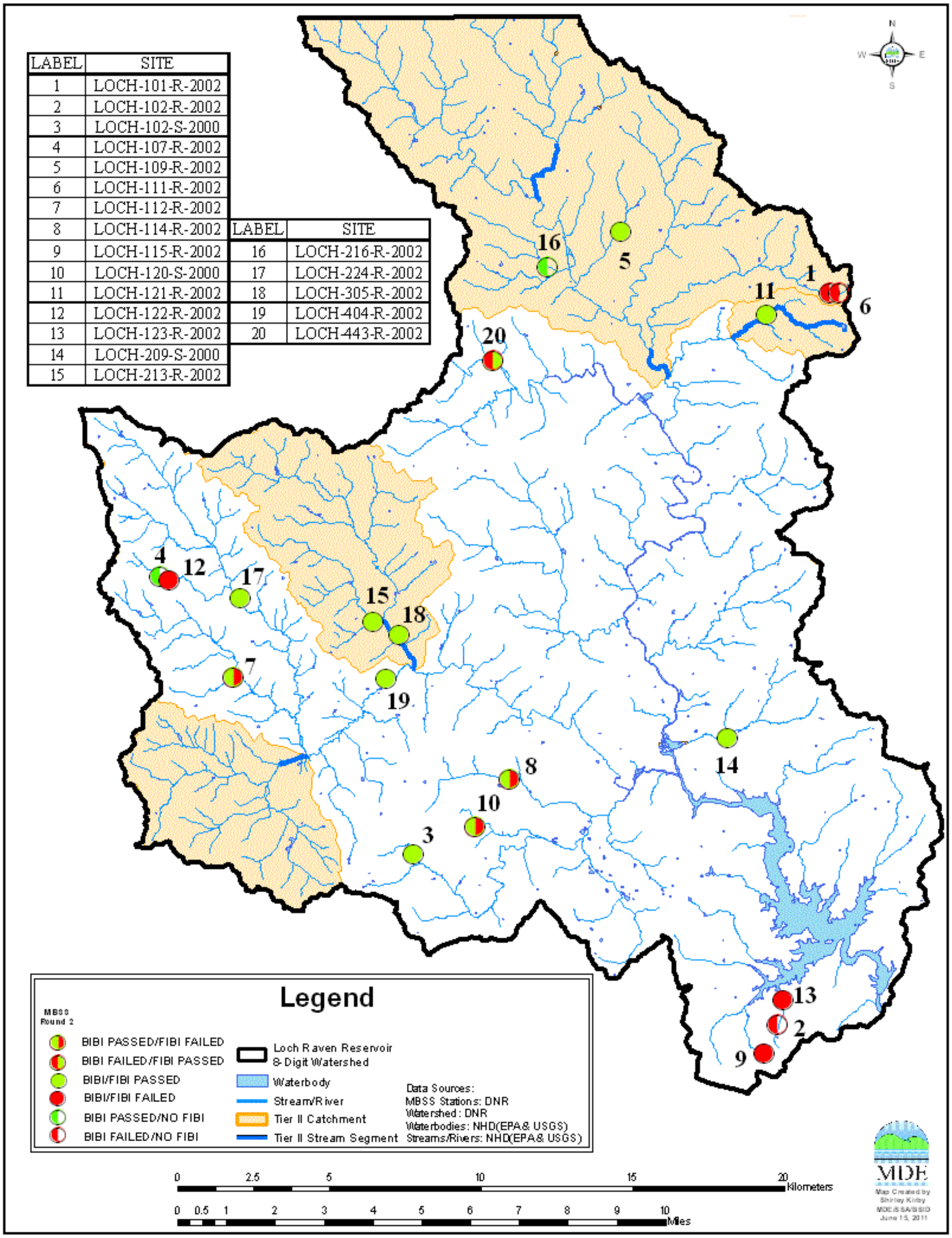

Figure 5. Principal Dataset Sites for the Loch Raven Reservoir Watershed

4.0 Stressor Identification Results for the Loch Raven Reservoir Watershed

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 calculated over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute prevalence at each control site is estimated based on the stressor present at the site that has the lowest absolute prevalence 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 excess prevalence of all potential stressors in cases, sites in the watershed with poor to very poor biological conditions, beyond the prevalence in controls. The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis, MDE identified instream and riparian habitat, water chemistry, and potential sources significantly associated with degraded fish and/or benthic macroinvertebrate biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various agricultural and urban land use types. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 5 and Table 6, parameters from the instream and riparian habitat and water chemistry groups are identified as possible biological stressors in the Loch Raven Reservoir watershed. A summary of combined AR values for each stressor group is shown in Table 7.

Table 2. Stressor Source Identification Analysis Results for the Loch Raven Reservoir 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	20	10	164	0%	2%	1	No	_
	AMD acid source present	20	10	164	0%	0%	1	No	_
	Organic acid source present	20	10	164	0%	0%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	20	10	164	30%	7%	0.043	Yes	23%
	High % of agriculture in 60m buffer	20	10	164	20%	4%	0.086	Yes	16%
Sources - Anthropogenic	Low % of forest in watershed	20	10	164	20%	4%	0.086	Yes	16%
	Low % of wetland in watershed	20	10	164	60%	23%	0.016	Yes	37%
	Low % of forest in 60m buffer	20	10	164	20%	6%	0.144	No	_
	Low % of wetland in 60m buffer	20	10	164	0%	0%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	20	10	164	20%	7%	0.186	No	_
	High % of impervious surface in 60m buffer	20	10	164	30%	8%	0.052	Yes	22%
	High % of roads in watershed	20	10	164	20%	4%	0.086	Yes	16%
	High % of roads in 60m buffer	20	10	164	10%	1%	0.164	No	_
Sources - Urban	High % of high-intensity developed in watershed	20	10	164	0%	1%	1	No	_
	High % of low-intensity developed in watershed	20	10	164	30%	9%	0.061	Yes	21%
	High % of medium-intensity developed in watershed	20	10	164	10%	2%	0.259	No	_
	High % of residential developed in watershed	20	10	164	20%	8%	0.208	No	_
	High % of rural developed in watershed	20	10	164	10%	4%	0.344	No	_
	High % of high-intensity developed in 60m buffer	20	10	164	0%	0%	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	20	10	164	10%	2%	0.212	No	_
	High % of medium-intensity developed in 60m buffer	20	10	164	0%	0%	1	No	_
	High % of residential developed in 60m buffer	20	10	164	20%	5%	0.105	No	_
	High % of rural developed in 60m buffer	20	10	164	30%	6%	0.029	Yes	24%

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Loch Raven Reservoir Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Agricultural	25%
Sources - Anthropogenic	57%
Sources - Impervious	35%
Sources - Urban	53%
All Sources	***81%***

4.1 Sources Identified by BSID Analysis

All the sources identified by the BSID analysis (Table 2), are the result of anthropogenic development within the Loch Raven Reservoir watershed. The watershed is comprised of 24% urban and 37% agricultural land uses; BSID results show that agricultural, urban and transportation development in the watershed and within the sixty meter riparian buffer zone has a significant association with degraded biological conditions. Due to the anthropogenic development there is a low percentage of forest and wetland in the watershed and the sixty meter riparian buffer zone. The land sources identified (a *high* *percentage of agriculture in watershed and riparian buffer, low percentage of forest, low percentage of wetlands, high impervious surfaces in riparian buffer, high percentage of roads in riparian buffer, high percentage of low intensity development in the watershed, and high percentage of rural development in the riparian buffer*) are indicative of anthropogenic activities that result in altered natural landscapes, and increased inputs of nutrients and contaminants to streams.

Anthropogenic land development can also cause an increase in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, and inorganic pollutants to surface waters. 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).

Numerous studies have documented declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments (Roth, Allan, and Erickson 1996; Wang et al. 1997; and Bis, Zdanowicz, and Zalewski 2000). Researchers commonly report that streams draining agricultural lands support fewer species of sensitive benthic and fish taxa than streams draining forested catchments (Wang et al. 1997). Agricultural land use degrades streams by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitat, and altering flows.

Agricultural land uses comprise 37% of the Loch Raven Reservoir watershed. Agricultural land use within the watershed, as well as within the sixty meter riparian zone, were found to be significantly associated with poor to very poor biological conditions in the watershed. The high percentage of agricultural land use within the 60 meter (m) buffer zone is indicative of the agricultural crops that are cultivated to the stream banks. Although nutrient management practices (NMPs) and best management practices (BMPs) are in place to control nutrient runoff in the watershed, the BSID analyses revealed that agricultural practices continue to create conditions in the watershed that are impacting biological resources. The excess nitrogen and phosphorus from fertilizer applications is leading to eutrophication in the watershed, as evidenced by the low dissolved oxygen stressors identified as significantly associated with degraded biological conditions in the watershed.

Streams in highly agricultural landscapes also tend to have poor habitat quality, reflected in declines in habitat indices and bank stability, as well as greater deposition of sediments on and within the streambed (Roth, Allan, and Erickson 1996; Wang et al. 1997). Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995).

The BSID source analysis (Table 2) identifies various types of agricultural and urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 81%, suggesting these land use sources are the most prevalent sources of biological impairments in the Loch Raven Reservoir watershed (Table 3).

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

Table 4. Sediment Biological Stressor Identification Analysis Results for the Loch Raven Reservoir 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	19	9	92	11%	13%	1	No	_
	Moderate bar formation present	19	9	92	56%	41%	0.496	No	_
	Channel alteration moderate to poor	19	9	92	56%	40%	0.491	No	_
	Channel alteration poor	19	9	92	11%	11%	1	No	_
	High embeddedness	19	9	92	11%	3%	0.311	No	_
	Epifaunal substrate marginal to poor	19	9	92	33%	14%	0.135	No	_
	Epifaunal substrate poor	19	9	92	11%	3%	0.28	No	_
	Moderate to severe erosion present	19	9	94	67%	60%	1	No	_
	Severe erosion present	19	9	92	22%	12%	0.337	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Loch Raven Reservoir 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	20	10	94	10%	9%	1	No	_
	Concrete/gabion present	20	10	93	10%	1%	0.201	No	_
	Beaver pond present	19	9	92	0%	4%	1	No	_
	Instream habitat structure marginal to poor	19	9	92	33%	14%	0.128	No	_
	Instream habitat structure poor	19	9	92	11%	1%	0.15	No	_
	Pool/glide/eddy quality marginal to poor	19	9	92	44%	55%	0.719	No	_
	Pool/glide/eddy quality poor	19	9	92	11%	1%	0.15	No	_
	Riffle/run quality marginal to poor	19	9	92	67%	20%	0.004	Yes	47%
	Riffle/run quality poor	19	9	92	0%	1%	1	No	_
	Velocity/depth diversity marginal to poor	19	9	92	44%	55%	0.72	No	_
	Velocity/depth diversity poor	19	9	92	0%	0%	1	No	_
Riparian Habitat	No riparian buffer	20	10	93	60%	25%	0.023	Yes	36%
	Low shading	19	9	92	11%	4%	0.367	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Loch Raven Reservoir 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	20	10	164	30%	4%	0.013	Yes	26%
	High conductivity	20	10	164	50%	4%	0	Yes	46%
	High sulfates	20	10	164	30%	7%	0.043	Yes	23%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	19	9	163	11%	1%	0.15	No	_
	Dissolved oxygen < 6mg/l	19	9	163	22%	3%	0.045	Yes	19%
	Low dissolved oxygen saturation	19	9	163	44%	12%	0.023	Yes	32%
	High dissolved oxygen saturation	19	9	163	0%	1%	1	No	_
	Ammonia acute with salmonid present	20	10	164	0%	0%	1	No	_
	Ammonia acute with salmonid absent	20	10	164	0%	0%	1	No	_
	Ammonia chronic with early life stages present	20	10	164	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	20	10	164	0%	0%	1	No	_
	High nitrites	20	10	164	20%	5%	0.105	No	_
	High nitrates	20	10	164	0%	3%	1	No	_
	High total nitrogen	20	10	164	0%	7%	1	No	_
	High total phosphorus	20	10	164	30%	8%	0.052	Yes	22%
	High orthophosphate	20	10	164	10%	5%	0.421	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	20	10	164	0%	1%	1	No	_
	Low field pH	19	9	163	11%	4%	0.318	No	_
	High field pH	19	9	163	0%	2%	1	No	_
	Low lab pH	20	10	164	10%	3%	0.303	No	_
	High lab pH	20	10	164	0%	2%	1	No	_

Table 7. Summary of Combined Attributable Risk Values for Stressor Groups in the Loch Raven Reservoir Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Instream Habitat	47%
Riparian Habitat	36%
Chemistry - Inorganic	46%
Chemistry - Nutrients	45%
All Chemistry	66%
All Stressors	***83%***

4.2 Stressors Identified by BSID Analysis

All eight stressor parameters identified by the BSID analysis (Tables 4 and 5), are significantly associated with biological degradation in the Loch Raven Reservoir watershed and are representative of impacts from anthropogenic development of natural landscapes.

Sediment Conditions

BSID analysis results for the Loch Raven Reservoir watershed did not identify any sediment 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 (Table 4).

Instream Habitat Conditions

BSID analysis results for the Loch Raven Reservoir watershed identified one instream habitat parameter 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: *riffle/run quality (marginal to poor)* (Table 5).

Riffle/run quality was identified as significantly associated with degraded biological conditions and found to impact approximately 47% *(marginal to poor)* of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. Riffle/run quality is a visual observation including quantitative measurements based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

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 in-stream habitat stressor group is approximately 47% suggesting that this stressor group impacts a moderate proportion of the degraded stream miles in the Loch Raven Reservoir (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Loch Raven Reservoir 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 36% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir 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).

Riparian buffers are beneficial because they slow water runoff, trap sediment, and enhance infiltration. Often, the natural transition zone is altered through various land uses, and the protective nature of the riparian zone becomes ineffective or even detrimental to the health of the water body. Some typical quality problems for watersheds with anthropogenic disturbances in riparian buffer zones involve an influx of chemicals and excessive sediment from both agricultural and urban sources (Delong and Brusven 1994). Agricultural, rural, and impervious development within the riparian buffer zones was identified in the BSID analysis as significant sources.

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 in-stream habitat stressor group is approximately 36% suggesting these stressors are associated with biological impairments in the Loch Raven Reservoir (Table 7).

<u>Water Chemistry</u>

BSID analysis results for the Loch Raven Reservoir watershed identified six water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community): *high chloride, high conductivity, high sulfates, dissolved oxygen <6 mg/L, low dissolved oxygen saturation, high total phosphorus* (Table 6).

High chlorides concentration was identified as significantly associated with degraded biological conditions and found in approximately 26% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. Chloride can play a critical role in the elevation of conductivity. Chloride in surface waters can result from both natural and anthropogenic sources, such as run-off containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage, and seawater intrusion in coastal areas. Smith, Alexander, and Wolman (1987), have identified that, although chloride can originate from natural sources, in urban watersheds road salts (i.e., sodium chloride) can be a likely source of high chloride and conductivity levels.

High sulfates concentration was identified as significantly associated with degraded biological conditions and found in 23% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. Sulfates can also play a critical role in the elevation of conductivity. Other detrimental impacts of elevated sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, or of water passing through rock or soil containing gypsum and other common minerals. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, and diesel; discharge from industrial sources, and discharge from municipal wastewater treatment facilities. Typically sulfates derived from agricultural landscapes are associated with fertilizers, which often contain various types and concentrations of sulfate anions.

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

Dissolved oxygen (DO) <6 mg/L concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 19% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR (2012c).

Low (<60%) *DO saturation* concentration was identified as significantly associated with degraded biological conditions and found to impact approximately 32% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production. DO saturation levels less than 60% saturation are considered to demonstrate high respiration associated with excessive decomposition of organic material. Fluctuations of saturation concentration can be due to agricultural, forested, and urban land uses.

High total phosphorus (TP) concentrations were identified as significantly associated with degraded biological conditions and found to impact approximately 22% of the stream miles with poor to very poor biological conditions in the Loch Raven Reservoir watershed. This stressor is a measure of the amount of TP in the water column. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. Eutrophication can potentially result in low dissolved oxygen and high pH levels, which can exceed tolerance levels of many biological organisms. TP input to surface waters typically increases in watersheds where agricultural and urban development are predominant.

Water chemistry is a major determinant of the integrity of surface waters that is strongly influenced by land use. Agricultural land uses comprise 37% of the Loch Raven reservoir watershed. Agricultural land uses within the watershed as well as within the sixty meter riparian zone were found to be significantly associated with poor to very poor biological conditions in the watershed. Developed landscapes, particularly the proportion of agriculture in the catchments and the riparian zone, often result in increased inputs of nitrogen, phosphorus, sulfates, and suspended sediments to surface waters. Although NMPs and BMPs are in place to control nutrient runoff in the watershed, the BSID analysis revealed that agricultural practices continue to create conditions that are negatively impacting biological resources. The excess phosphorus from fertilizer applications is leading to eutrophication in the watershed, as evidenced by the *high total phosphorus* and *low dissolved oxygen* stressors identified as significantly associated with degraded biological conditions in the watershed. Also, sulfate loadings from fertilizers can potentially reach levels that are toxic to aquatic organisms.

Elevated concentrations of chloride, sulfate, and conductivity identified by the BSID analysis can also be indicative of urban developed landscapes. Anthropogenic activities associated with urban land uses degrade water quality by causing an increase in contaminant loads from various point and nonpoint sources especially during storm events. These sources can add inorganic pollutants to surface waters at levels potentially toxic to aquatic organisms.

In the Loch Raven Reservoir watershed there are several heavily traveled road routes, such as Routes 83, 45, 25 among others, connecting the urban areas of the watershed. Application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith, Alexander, and Wolman 1987). For surface waters associated with roadways or storage facilities, episodes of salinity have been reported during the winter and spring in some urban watercourses in the range associated with acute toxicity in laboratory experiments (EC 2001). These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001). According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 meters on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. On-site septic systems, sanitary sewage overflows, and stormwater discharges are quite frequent in the watershed and are also likely sources of elevated concentrations of chloride, sulfates, and conductivity.

Currently in Maryland there are no specific numeric criteria that quantify the impact of chlorides, sulfates, or conductivity on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of the specific pollutant(s) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 66% suggesting these stressors are associated with biological impairments in the Loch Raven Reservoir watershed (Table 7).

4.3 Discussion of BSID Results

The BSID analysis results suggest that degraded biological communities in the Loch Raven Reservoir watershed are a result of increased urban and agricultural land uses causing alteration to stream habitat that eliminates habitat heterogeneity. High proportions of these types of land uses also typically results in increased contaminant loads from point and nonpoint sources by adding nutrients and inorganic pollutants to surface waters, resulting in concentrations that can potentially be toxic to aquatic organisms. Alterations to the physical habitat and water chemistry have all combined to degrade the Loch Raven Reservoir watershed, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 83%, suggesting the stressors identified by the BSID analysis would adequately account for the biological impairment in the Loch Raven Reservoir watershed (Table 7).

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

4.4 Final Causal Model

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 Loch Raven Reservoir watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

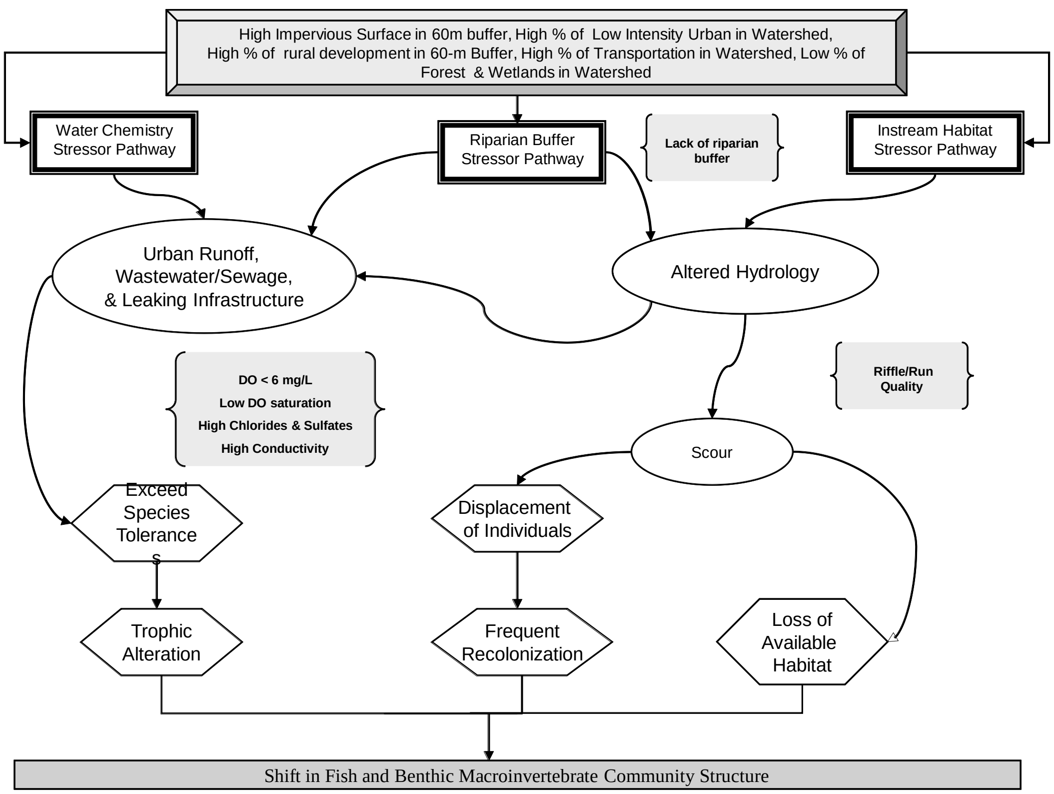

Figure 6. Final Causal Model for the Loch Raven Reservoir Watershed

5.0 Conclusion

Data suggest that the Loch Raven Reservoir watershed's biological communities are influenced by anthropogenic development. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to development of natural landscapes, which often causes disturbances in stream habitat and increased contaminant loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Loch Raven Reservoir watershed are summarized as follows:

- The BSID analysis has determined that phosphorus is a probable cause of impacts to biological communities in the Loch Raven Reservoir watershed. Total phosphorus was identified as having significant association with degraded biological conditions. The BSID results thus confirm the development of the 2007 TMDL for nutrients was an appropriate management action to begin addressing the impacts of nutrient stressors on the biological communities in the Loch Raven Reservoir watershed.

- The BSID process has also determined that the biological communities in the Loch Raven Reservoir watershed are likely degraded due to inorganic pollutants (i.e., chlorides and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions, and found in 26% and 23% respectively of the stream miles with poor to very poor biological conditions in Loch Raven Reservoir watershed. Runoff from roads, urban, and agricultural land uses causes an increase in contaminant loads from 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 results thus support a Category 5 listing of chloride and sulfates for the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Loch Raven Reservoir watershed.

- The BSID process has also determined that biological communities in the Loch Raven 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 Loch Raven watershed based on inadequate riparian buffer zones in approximately 36% of degraded stream miles.

- In 2007 a TMDL for total suspended sediments in the impoundment was developed and approved by EPA; however, the BSID analysis did not identify any sediment stressors in the non-tidal streams of the Loch Raven Reservoir watershed.

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