Watershed Report for Biological Impairment of the Non-Tidal Rocky Gorge Dam Watershed in Howard, Montgomery, and Prince George's Counties in Maryland Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

Executive Summary

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

The Rocky Gorge Dam watershed is associated with two assessment units, the non-tidal 8-digit basin (basin code 02131107) and the impoundment (basin code 021311070941) in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014a).

Table E1. 2014 Integrated Report Listings for the Rocky Gorge Dam Watershed

Watershed	Basin Code	Non-tidal/ Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Rocky Gorge Dam	02131107	Non-tidal	Aquatic Life and Wildlife	2004	Impacts to Biological Communities	5
Rocky Gorge Reservoir	021311070941	Impoundment		1998	Phosphorus	4a
			Fishing	2010	Mercury in Fish Tissue	5

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings 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 Rocky Gorge Dam are designated as Use Class I-P *Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*, and Use Class IV-P *Recreational Trout Waters and Public Water Supply* (COMAR 2016a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the

designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody. The Rocky Gorge Dam watershed is not attaining its designated use of protection of aquatic life because of impairments to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on 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 Rocky Gorge Dam 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 2014b). Data suggest that the degradation of biological communities in the Rocky Gorge Dam watershed is due to urban land use and the concomitant effects of altered hydrology, and elevated levels of sediment. The development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation, e.g., urban runoff contamination of surface waters, in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process has determined that the biological communities in the Rocky Gorge Dam watershed are likely degraded due to sediment related stressors. Specifically, altered hydrology and runoff from urban developed landscapes have

resulted in erosion and subsequent elevated suspended sediment (i.e., high embeddedness) that are, in turn, the probable causes of impacts to biological communities in the watershed. The BSID results thus support a sediment Category 5 listing of Rocky Gorge Dam watershed for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Rocky Gorge Dam watershed.

- The BSID process identified low dissolved oxygen saturation as having significant association with degraded biological conditions in the Rocky Gorge Reservoir watershed. The BSID analysis uses a case-control, risk-based approach to systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Nutrients in excess do not act directly as pollutants in aquatic systems but, rather, manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since only low dissolved oxygen and low oxygen saturation were identified, but nutrient over enrichment was not identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for the Rocky Gorge Reservoir. There is a phosphorus TMDL (2008) for the impoundment. Reductions in the non-tidal portions for that TMDL should also improve the conditions within the streams. In the absence of a firm causal pathway as described above, concluding that the Rocky Gorge Reservoir is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

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 2014a). 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 still considered impaired but has a TMDL that has been completed or submitted to USEPA 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 rounds two and three of the Maryland Biological Stream Survey (MBSS) dataset (2000–2004; 2007-2009) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results

can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Rocky Gorge Dam watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Rocky Gorge Dam Watershed Characterization

2.1 Location

The Rocky Gorge Dam watershed is located in Howard, Montgomery, and Prince George's counties, and drains to the Patuxent River (see Figure 1). The Rocky Gorge Dam watershed is within the Patuxent Watershed drainage with 46% of the total watershed in the Montgomery County, 53% in Howard County, and less than 1% in Prince George's and Frederick Counties (MCDEP 2012). The Rocky Gorge Dam watershed encompasses approximately 56,000 acres, and includes the towns of Brookesville, Burtonsville, Laytonsville, Olney, and Scaggsville. The Blue Mash Nature Trail, Hawlings River Stream Valley Park, Patuxent River State Park, Patuxent River Watershed Conservation Park. Rachel Carson Conservation Park and Reddy Branch Park are located in the watershed. There are also golf courses, including the Blue Mash Golf Course and Montgomery Golf Course. The watershed is located in the Piedmont region, which is one of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

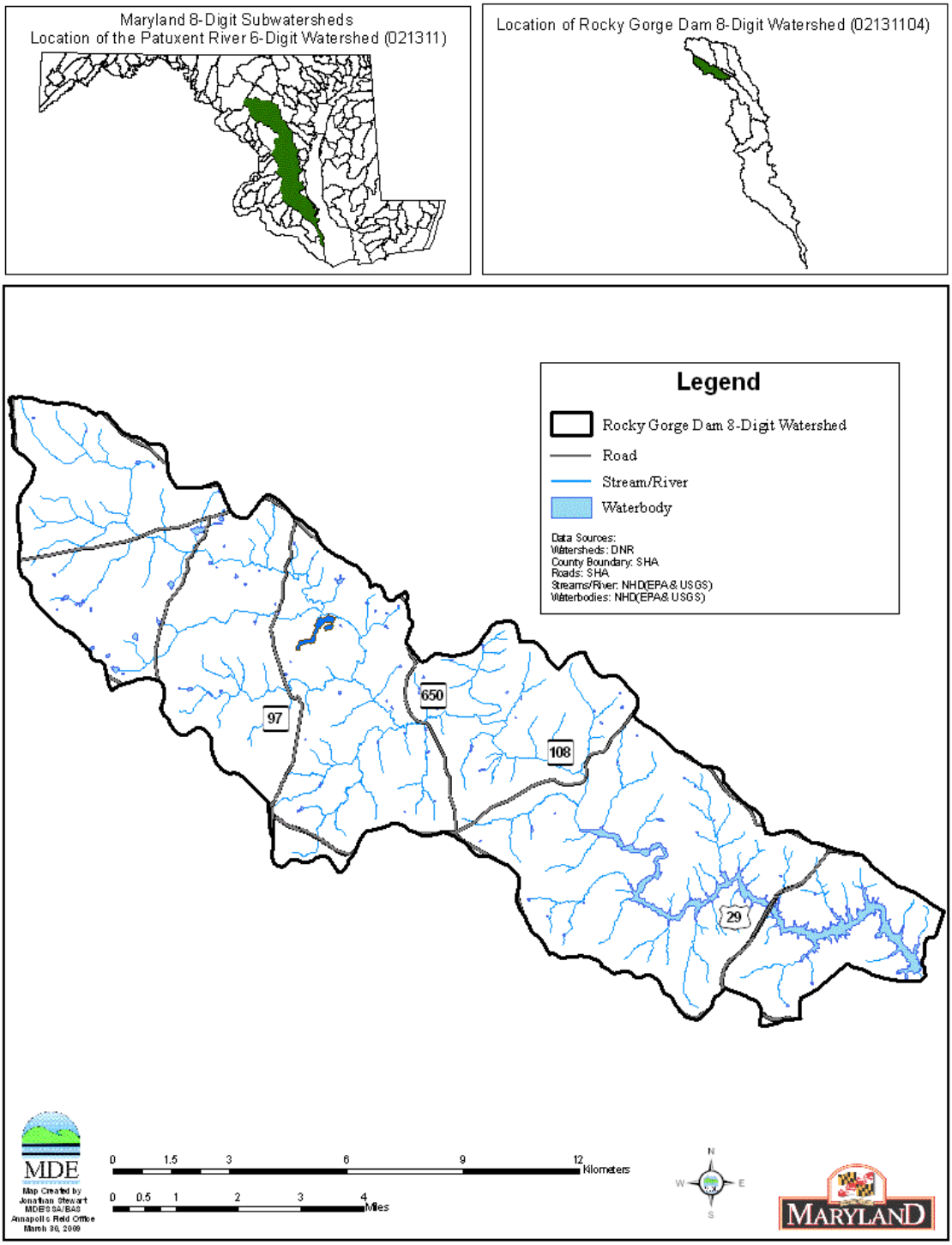

Figure 1. Location Map of the Rocky Gorge Dam Watershed

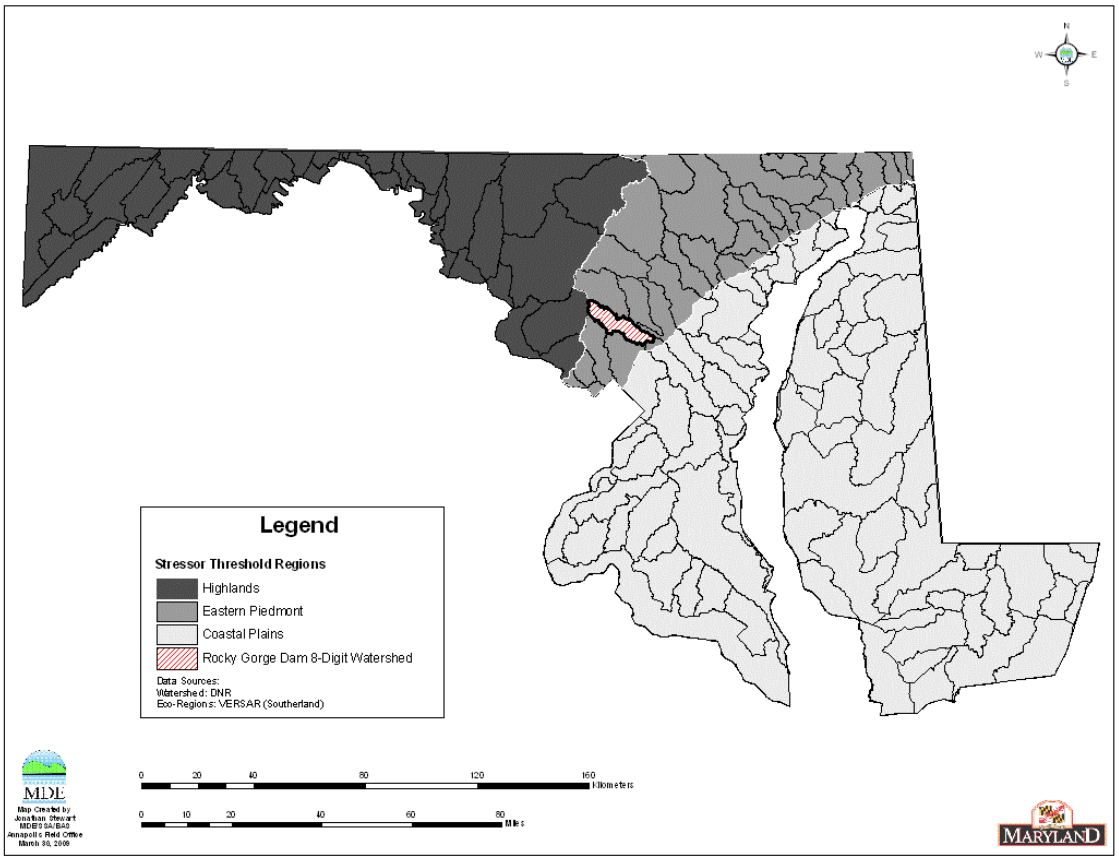

Figure 2. Eco-Region Map of the Rocky Gorge Dam Watershed

2.2 Land Use

The drainage area of the Rocky Gorge Dam watershed is approximately 56,000 acres. The Rocky Gorge Dam watershed contains urban, agricultural, and forested land uses (see Figure 3). The predominant land use in the Maryland 8-digit watershed is forest. The Phase 5.2 Chesapeake Bay Watershed Model reports the land use distribution in the Rocky Gorge Dam watershed as forest (48%), agricultural (11%), urban pervious (31%), and urban impervious (10%) (see Figure 4) (USEPA 2010).

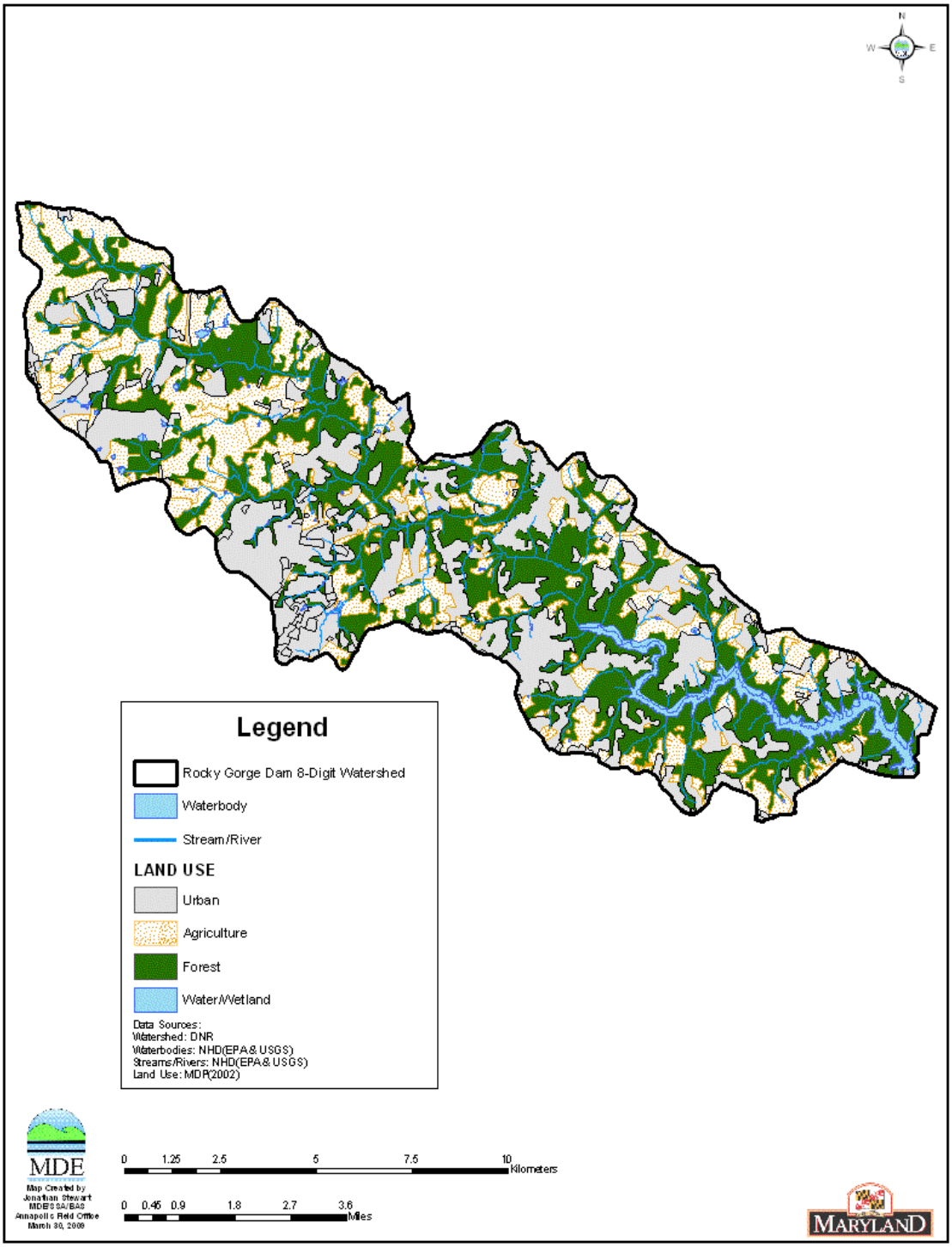

Figure 3. Land Use Map of the Rocky Gorge Dam Watershed

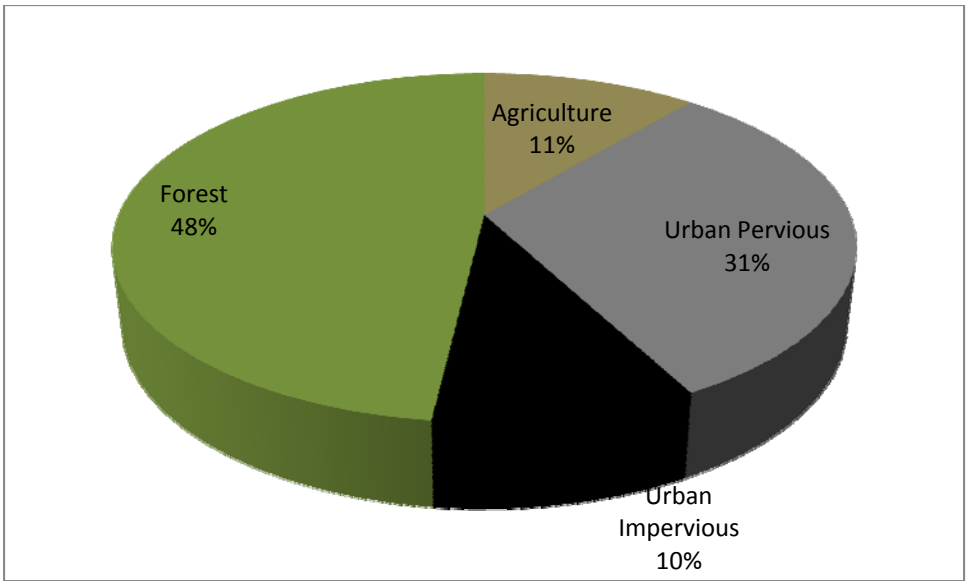

Figure 4. Proportions of Land Use in the Rocky Gorge Dam Watershed

2.3 Soils/hydrology

The Rocky Gorge Dam, a headwater to the Patuxent River, lies in the Piedmont physiographic province. The surficial geology is characterized by metamorphic rock of Late Precambrian age. The headwaters of the Patuxent River lie in the schists and metasedimentary rock of the Marburg Formation. The soils found, Baile, Chester, and Beltsville, are primarily deep and well-drained to excessively drained (Matthews and Hershberger 1968; Brown and Dyer 1995). The dominant soil associations in the Rocky Gorge Reservoir watershed are the Glenelg-Manor-Chester and the Glenelg-Gaila-Occoquan associations.

3.0 Rocky Gorge Dam Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the non-tidal areas of the Rocky Gorge Dam watershed under Category 5 of the State's Integrated Report as impaired for impacts to biological communities (2004 listing). The Rocky Gorge Dam watershed in Maryland is associated with two assessment units, the non-tidal 8-digit basin (basin code 02131107) and the impoundment (basin code 021311070941) in the Integrated Report. Below is a table identifying the listings associated with this watershed (MDE 2014a).

Table 1. 2014 Integrated Report Listings for the Rocky Gorge Dam Watershed

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			Fishing	2010	Mercury in Fish Tissue	5

3.2 Biological Impairment

The Maryland Surface Water Use Designations in the Code of Maryland Regulations (COMAR) for the Rocky Gorge Dam watershed are designated as Use Class I-P *Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*, and Use Class IV-P *Recreational Trout Waters and Public Water Supply* (COMAR 2016a, b, c). Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Rocky Gorge Dam watershed is listed under Category 5 of the 2014 Integrated Report as impaired for impacts to biological communities. Approximately 28% of the Rocky Gorge Dam watershed is 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), round two (2000-2004), and round three (2007-2009) data, which include eighteen stations. Five of the eighteen 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 rounds two and three (2000-2004, 2007-2009), contains thirteen sites with five of the thirteen having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Rocky Gorge Dam watershed.

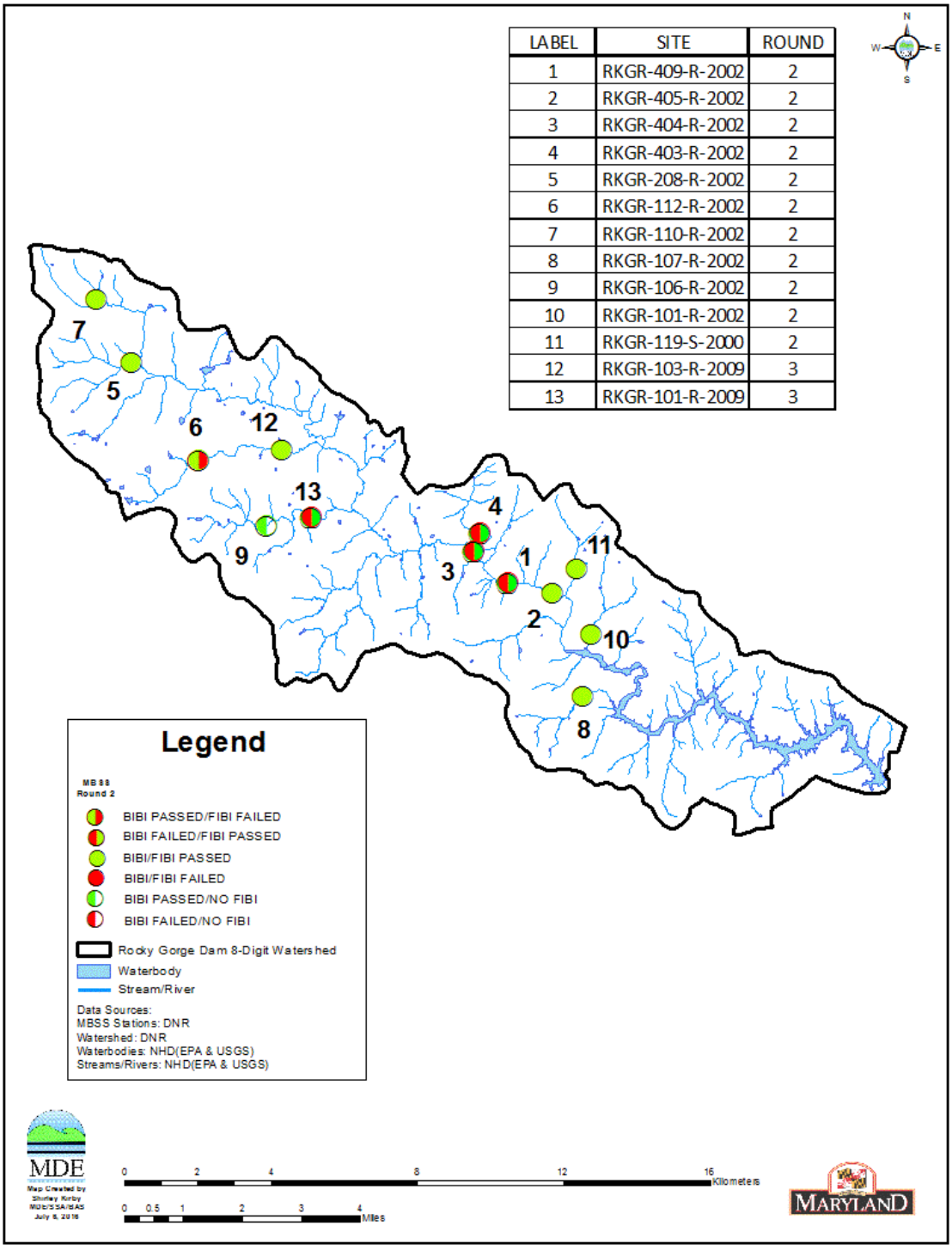

Figure 5. Principal Dataset Sites for the Rocky Gorge Dam Watershed

4.0 Stressor Identification Results

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

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

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

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

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

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

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2014b).

Through the BSID data analysis, MDE identified sediment, 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 an urban land use source. A summary of combined AR values for each source group is shown in Table 3. As shown in Table 4 and Table 6, parameters from the sediment and water chemistry groups are identified as possible biological stressors in the Rocky Gorge Dam 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 Rocky Gorge Dam 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	13	5	206	0%	2%	1	No	_
	AMD acid source present	13	5	206	0%	0%	1	No	_
	Organic acid source present	13	5	206	0%	0%	1	No	_
Sources - Agricultural	High % of agriculture in watershed	13	5	207	0%	6%	1	No	_
	High % of agriculture in 60m buffer	13	5	207	0%	3%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	13	5	207	0%	3%	1	No	_
	Low % of wetland in watershed	13	5	207	0%	19%	1	No	_
	Low % of forest in 60m buffer	13	5	207	0%	5%	1	No	_
	Low % of wetland in 60m buffer	13	5	207	0%	0%	1	No	_
Sources - Impervious	High % of impervious surface in watershed	13	5	207	20%	7%	0.327	No	_
	High % of impervious surface in 60m buffer	13	5	207	0%	7%	1	No	_
	High % of roads in watershed	13	5	207	0%	4%	1	No	_
	High % of roads in 60m buffer	13	5	207	0%	1%	1	No	_
Sources - Urban	High % of high-intensity developed in watershed	13	5	207	0%	1%	1	No	_
	High % of low-intensity developed in watershed	13	5	207	40%	8%	0.065	Yes	32%
	High % of medium-intensity developed in watershed	13	5	207	0%	3%	1	No	_
	High % of residential developed in watershed	13	5	207	0%	7%	1	No	_
	High % of rural developed in watershed	13	5	207	0%	3%	1	No	_
	High % of high-intensity developed in 60m buffer	13	5	207	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	13	5	207	0%	2%	1	No	_
	High % of medium-intensity developed in 60m buffer	13	5	207	0%	0%	1	No	_
	High % of residential developed in 60m buffer	13	5	207	0%	6%	1	No	_
	High % of rural developed in 60m buffer	13	5	207	0%	6%	1	No	_

Table 3. Summary of Combined Attributable Risk Values for Source Groups in the Rocky Gorge Dam Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Urban	32%
All Sources	***32%***

4.1 Sources Identified by BSID Analysis

The sources identified by the BSID analysis (Table 2) are the result of urban development in the watershed, which has significant association with degraded biological conditions in the Rocky Gorge Dam watershed. The watershed is comprised of urban pervious (31%) and urban impervious (10%) land use. The BSID analysis identified a high percentage of low-intensity urban development (32%) in the watershed. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer, Paul, and Taulbee 2005) has consistently identified negative impacts to biological conditions as a result of increased urbanization. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed “urban stream syndrome” (Meyer, Paul, and Taulbee 2005). Symptoms of urban stream syndrome include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors. Impervious cover reduces base flow by limiting the amount of ground water recharge in the watershed. Flow volumes and velocities in streams generally increase during storm events due to the higher quantity of water that runs off impervious surfaces and into the stream channels. This creates a very unstable system that goes from destructive floods to total de-watering in very short time intervals resulting in biological communities under constant stress and adjustment (CAWPD 2000).

Increases in impervious surface cover that accompany urbanization alter stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, decreasing the time it takes water to reach streams and causing them to be more “flashy” (Walsh et al. 2005). 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).

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 32%, suggesting that these stressors are a probable cause of the biological impairments in the Rocky Gorge Dam watershed (Table 3).

Table 4. Sediment Biological Stressor Identification Analysis Results for the Rocky Gorge Dam 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	13	5	101	0%	11%	1	No	_
	Moderate bar formation present	13	5	101	60%	44%	0.39	No	_
	Channel alteration moderate to poor	11	4	75	50%	43%	0.576	No	_
	Channel alteration poor	11	4	75	0%	11%	1	No	_
	High embeddedness	13	5	101	40%	5%	0.029	Yes	35%
	Epifaunal substrate marginal to poor	13	5	101	0%	10%	1	No	_
	Epifaunal substrate poor	13	5	101	0%	1%	1	No	_
	Moderate to severe erosion present	13	5	101	100%	58%	0.069	Yes	42%
	Severe erosion present	13	5	101	40%	13%	0.148	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Rocky Gorge Dam 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	13	5	101	0%	11%	1	No	_
	Concrete/gabion present	11	4	87	0%	3%	1	No	_
	Beaver pond present	13	5	101	0%	2%	1	No	_
	Instream habitat structure marginal to poor	13	5	101	0%	8%	1	No	_
	Instream habitat structure poor	13	5	101	0%	0%	1	No	_
	Pool/glide/eddy quality marginal to poor	13	5	101	0%	29%	1	No	_
	Pool/glide/eddy quality poor	13	5	101	0%	0%	1	No	_
	Riffle/run quality marginal to poor	13	5	101	20%	15%	0.566	No	_
	Riffle/run quality poor	13	5	101	20%	2%	0.137	No	_
	Velocity/depth diversity marginal to poor	13	5	101	20%	32%	0.863	No	_
	Velocity/depth diversity poor	13	5	101	0%	0%	1	No	_
Riparian Habitat	No riparian buffer	13	5	101	20%	8%	0.34	No	_
	Low shading	13	5	101	20%	4%	0.197	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Rocky Gorge Dam 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	13	5	207	20%	5%	0.255	No	_
	High conductivity	13	5	207	20%	5%	0.255	No	_
	High sulfates	13	5	207	0%	9%	1	No	_
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	13	5	206	0%	1%	1	No	_
	Dissolved oxygen < 6mg/l	13	5	206	40%	2%	0.009	Yes	38%
	Low dissolved oxygen saturation	13	5	206	80%	11%	0.001	Yes	69%
	High dissolved oxygen saturation	13	5	206	0%	0%	1	No	_
	Ammonia acute with salmonid present	13	5	207	0%	0%	1	No	_
	Ammonia acute with salmonid absent	13	5	207	0%	0%	1	No	_
	Ammonia chronic with early life stages present	13	5	207	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	13	5	207	0%	0%	1	No	_
	High nitrites	13	5	207	0%	4%	1	No	_
	High nitrates	13	5	207	0%	2%	1	No	_
	High total nitrogen	13	5	207	0%	5%	1	No	_
	High total phosphorus	13	5	207	0%	7%	1	No	_
	High orthophosphate	13	5	207	0%	4%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	13	5	207	0%	0%	1	No	_
	Low field pH	13	5	206	0%	8%	1	No	_
	High field pH	13	5	206	0%	1%	1	No	_
	Low lab pH	13	5	207	0%	2%	1	No	_
	High lab pH	13	5	207	0%	2%	1	No	_

Table 7. Summary AR Values for Stressor Groups for the Rocky Gorge Dam Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	63%
Chemistry - Nutrients	74%
All Chemistry	74%
All Stressors	***84%***

4.2 Stressors Identified by BSID Analysis

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

Sediment Conditions

BSID analysis results for the Rocky Gorge Dam watershed identified two sediment parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high embeddedness, and moderate to severe erosion present.*

High embeddedness was identified as significantly associated with degraded biological conditions and found to impact approximately 35% of the stream miles with poor to very poor biological conditions in the Rocky Gorge Dam watershed. Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition (Mercurio, Chaillou, and Roth 1999). High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams; Roth et al. 2005), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Moderate to severe erosion present was identified as significantly associated with degraded biological conditions and found to impact approximately 42% of the stream miles with poor to very poor biological conditions in the Rocky Gorge Dam watershed.

Erosion severity represents a visual observation that the stream discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy, resulting in channel instability, which in turn affects bank stability. Where such conditions are observed, flow energy is considered to have increased in frequency or intensity, accelerating channel and bank erosion (Allan and Castillo 2007). Increased flow energy suggested by this measure is also expected to negatively influence stream biology.

Erosion severity is described categorically as minimal, moderate, or severe. Conditions indicating biological degradation are set at moderate and severe. A level of severe indicates that a substantial amount of stream banks show severe erosion, and the stream segment exhibits high levels of instability due to erosion. A level of moderate indicates that a marginal amount of stream banks show erosion and the stream segment shows elevated levels of instability due to erosion.

As urbanization increased in the Rocky Gorge Dam watershed so did the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime causing streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are highly unstable stream channels with widening, downcutting, and streambed scouring. The scouring associated with these increased flows leads to accelerated channel and bank erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate and thereby increasing embeddedness. Some of the impacts associated with sedimentation are smothering of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman, Rattner, and Burton 2003). All of the stressors identified for the sediment group (e.g., channel alteration and erosion), indicate channel instability related to frequent and intense high flows that scour streambeds then quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 63%, suggesting that these stressors are a probable cause of the biological impairments in the Rocky Gorge Dam watershed (Table 7).

Instream Habitat Conditions

BSID analysis results for the Rocky Gorge Dam watershed did not identify instream habitat parameters that have statistically significant associations with poor to very poor stream biological condition, i.e., removal of stressors would result in improved biological community (Table 5).

Riparian Habitat Conditions

BSID analysis results for the Rocky Gorge Dam watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition, i.e., removal of stressors would result in improved biological community (Table 5).

Water Chemistry

BSID analysis results for the Rocky Gorge Dam watershed identified two water chemistry parameters that have a statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *dissolved oxygen <6mg/l and low dissolved oxygen saturation.*

Dissolved oxygen <6mg/l was identified as significantly associated with degraded biological conditions and found in 38% of the stream miles with poor to very poor biological conditions in the Rocky Gorge Dam watershed. Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in the water as a function of variables such as water temperature, atmospheric pressure, physical aeration, and chemical/biological oxygen demand. DO is generally reported as a concentration (mg/L). The Maryland Department of Natural Resources Maryland Biological Stream Survey measures DO in situ once during the summer (rounds 1, 2, and 3). Low DO concentrations may indicate organic pollution due to heterotrophic oxygen consumption and may stress aquatic organisms. Low DO concentrations are considered to demonstrate excessive oxygen demand, primarily from decomposition of organic material (Allan and Castillo 2007). Sources are agricultural, forested, and urban land uses.

The COMAR criterion for Use I waters is that the DO concentration may not be less than 5.0 mg/L at any time. The criterion for Use IV-P waters (Nontidal Cold Water) is that the DO concentration may not be less than 5.0 mg/L at any time, with a minimum daily average of not less than 6.0 mg/L (COMAR 2014d).

Low dissolved oxygen (DO) saturation was identified as significantly associated with degraded biological conditions and found in 69% of the stream miles with poor to very poor biological conditions in the Rocky Gorge Dam 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.

There are nonpoint and point sources in the watershed (MDE 2008). Point source discharges are a potential source of nutrient, inorganics, and suspended solids to surface

waters. Based on MDE's point source permitting information, there are active municipal National Pollutant Discharge Elimination System (NPDES) permitted point source facilities (e.g., Federal Emergency Management Agency Region 2 Wastewater Treatment Plant) in the Rocky Gorge Dam Watershed. The types of permits identified include individual municipal, and general municipal separate storm sewer systems (MS4s). Another potential nonpoint source of nutrients and inorganic compounds into a watershed is on-site disposal (septic) systems. Nutrient and suspended solid loads from any wastewater treatment facility, MS4 discharge, or septic system is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

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 chemistry stressors is approximately 74%, suggesting that these stressors are a probable cause of the biological impairments in the Rocky Gorge Dam watershed (Table 7).

4.3 Discussion of BSID Results

The BSID analysis results suggest that degraded biological communities in the Rocky Gorge Dam watershed are a result of increased urban land uses, which cause alterations to hydrology (e.g. high stream flows) and riparian habitat. The high proportions of these land uses also typically result in increased contaminant loads to surface waters. Altered flow regimes create a less stable stream channel, leading to excessive bank erosion and sedimentation (embeddedness), loss of pool habitat and instream cover, and excessive streambed scour (Wang et al. 2001). During the spring and summer index sampling periods, the MDDNR MBSS reported evidence of turbidity despite a lack of rain. In addition to the impact of flow extremes on erosion and habitat, high flows can also eliminate taxa if such events occur during sensitive life stages. Macroinvertebrates that are able to withstand dislodgement, have short and fast life cycles, and good colonizing ability tend to be the dominant species in highly urbanized streams (Richards et al. 1997). Rivers and streams with frequent high flows or no-flow periods have relatively simple trophic structure, low taxonomic diversity, and high dominance by a few taxa (Power and Stewart 1987, Death and Winterbourn 1995).

Although low DO concentrations are usually associated with surface waters experiencing eutrophication as the result of excessive nutrient loading, this might not be the only cause in the Rocky Gorge watershed and the BSID analysis has not identified nutrients as impairing the watershed. Water chemistry is a major determinant of the integrity of surface waters that is strongly influenced by land-use. Urban land uses comprise 41% of the Rocky Gorge Dam watershed. Developed landscapes, particularly the proportion of urban land use in the catchments and the riparian zone, often results in increased inputs of suspended sediments to surface waters. Several of the streams sampled in the watershed are first order streams, low DO values are not uncommon in small low gradient streams with low or stagnant flows. Also 2002 was a drought year; one of the stations (RKGR-106-R-2002) was vetted (FIBI only) due to low flow. Reduced concentrations of oxygen identified by the BSID analysis can also be indicative of urban developed landscapes. One of the failing stations (RKGR-112-R-2002) is located downstream of a golf course. Anthropogenic activities associated with such land uses degrade water quality by causing an increase in contaminant loads from various point and nonpoint sources especially during storm events. Alterations to the hydrologic regime and water chemistry have all combined to degrade the Rocky Gorge Dam watershed, leading to a loss of diversity in the biological community.

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 2015). 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 Rocky Gorge Dam watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

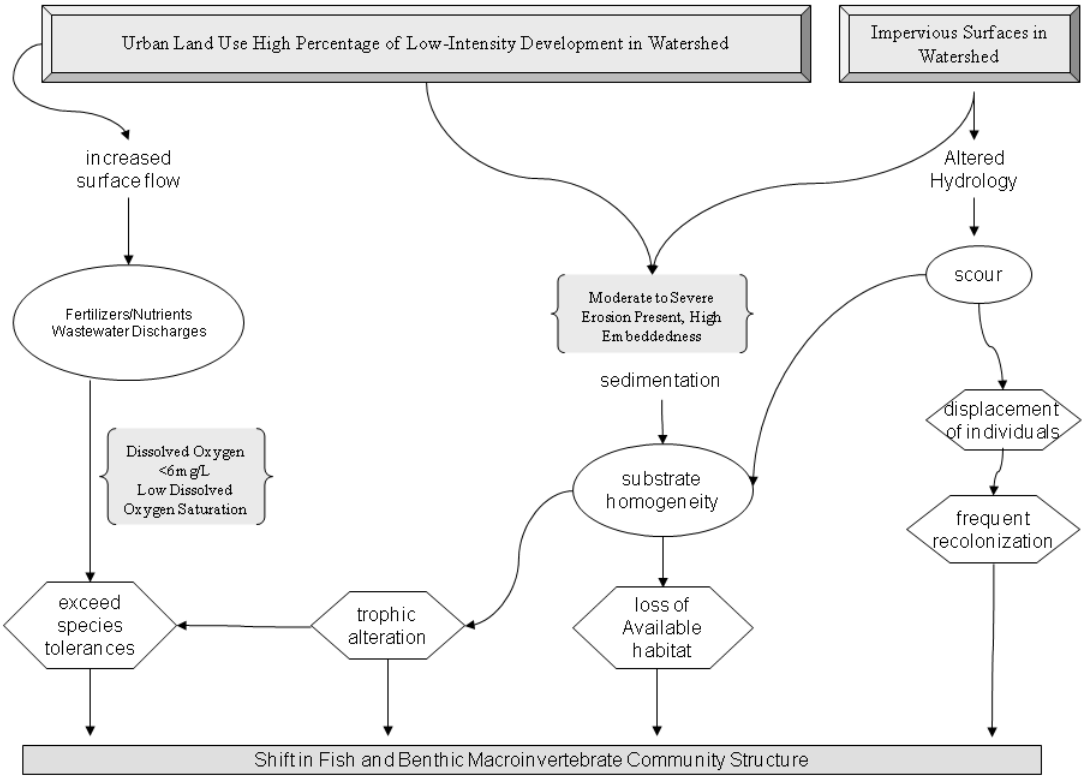

Figure 6. Final Causal Model for the Rocky Gorge Dam Watershed

5.0 Conclusion

Data suggest that the Rocky Gorge Dam watershed's biological communities are strongly influenced by urban land use, which alters the hydrologic regime resulting in increased pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to urban landscapes, which often cause flashy hydrology in streams and increased sediment loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Rocky Gorge Dam watershed are summarized as follows:

- The BSID process has determined that the biological communities in Rocky Gorge Dam are likely degraded due to sediment related stressors. Specifically, altered hydrology and runoff from urban developed landscapes have resulted in erosion and subsequent elevated suspended sediment (i.e., high embeddedness) that are, in turn, the probable causes of impacts to biological communities in the watershed. The BSID results thus support a sediment Category 5 listing of Rocky Gorge Dam watershed for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Rocky Gorge Dam watershed.

- The BSID process identified low dissolved oxygen saturation as having significant association with degraded biological conditions in the Rocky Gorge Reservoir watershed. The BSID analysis uses a case-control, risk-based approach to systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Nutrients in excess do not act directly as pollutants in aquatic systems but, rather, manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since only low dissolved oxygen and low oxygen saturation were identified, but nutrient over enrichment was not identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for the Rocky Gorge Reservoir. There is a phosphorus TMDL (2008) for the impoundment. Reductions in the non-tidal portions for that TMDL should also improve the conditions within the streams. In the absence of a firm causal pathway as described above, concluding that the Rocky Gorge Reservoir is impaired by nutrients could result in unnecessary

planning and pollution control implementation costs. In the absence of a firm causal pathway as described above, concluding that the Rocky Gorge Reservoir is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

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