Watershed Report for Biological Impairment of the Non-Tidal Lower Gunpowder Falls Watershed, Baltimore County, Maryland Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

Submitted to:

Water Protection Division
U.S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

January 2012

Table of Contents

List of Figures

List of Tables

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
IES	Institute of Ecosystem Studies
MD	Maryland
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NPDES	National Pollution Discharge Elimination System
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Facility

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*, 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 Lower Gunpowder Falls (basin code 02130802), located in Baltimore County, MD is associated with two assessment units in Maryland's Integrated Report (IR): non-tidal (8-digit basin) and an estuary portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Lower Gunpowder Falls is Gunpowder River Oligohaline. Below is a table identifying the listings associated with this watershed.

Table E1: 2010 Integrated Report Listings for the Lower Gunpowder Falls Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Lower Gunpowder Falls	02130802	Non-tidal	Aquatic Life and Wildlife		Arsenic	2
					Cadmium	2
					Chromium	2
					Lead	2
					Mercury	2
					Nickel	2
					Selenium	2
					Zinc	2
				2002	Impacts to Biological Communities	5
Gunpowder River Oligohaline	GUNOH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			Aquatic Life and Wildlife		Impacts to Estuarine Biological Communities	2
			Open Water Fish and Shellfish	1996	TN	5
				1996	TP	5
			Seasonal Shallow Water Submerged Aquatic Vegetation	2010	TSS	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 on 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 less than 3, and calculating whether this is significant from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of the Lower Gunpowder Falls is Use I – *water contact recreation and nontidal warmwater aquatic life.* Long Green Run [Creek] and Sweathouse Branch, and their respective tributaries are situated within the Lower Gunpowder Falls watershed and are designated as Use III – *nontidal coldwater* (COMAR 2010a,b,c,d). The Lower Gunpowder Falls watershed is not attaining its designated use of protection of aquatic life because of impacts to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

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

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

This Lower Gunpowder Falls watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the degradation of biological communities in the Lower Gunpowder Falls is strongly influenced by urban land use and its concomitant effects: altered hydrology and elevated levels of chlorides, sulfates, and conductivity from impervious surface runoff. The urbanization 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 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 of the Lower Gunpowder Falls can be summarized as follows:

- The BSID process has determined that the biological communities in the Lower Gunpowder Falls 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 approximately 45% and 46% of the stream miles with poor to very poor biological conditions in the watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listings of chloride and sulfates as an appropriate management action to begin addressing these stressor's impacts on the biological communities in the Lower Gunpowder Falls watershed.
- The BSID process has determined that biological communities in Lower Gunpowder Falls are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and impervious surfaces have resulted in channel alteration, channel erosion, scouring, and transport of suspended sediments in the watershed, which are in turn probable causes of impacts to biological communities. The BSID results confirm the tidal 2010 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Lower Gunpowder Falls watershed. In addition, the BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Lower Gunpowder Falls.

- The BSID process has also determined that biological communities in the Lower Gunpowder River watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization 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. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Lower Gunpowder Falls watershed based on channelization being present in approximately 39% of degraded stream miles.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions, except acute ammonia. After analysis of MDE water quality data, it was determined that ammonia toxicity is not a significant stressor in the Lower Gunpowder Falls 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 2008). 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, <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.

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 Lower Gunpowder Falls watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Lower Gunpowder Falls Watershed Characterization

2.1 Location

The Lower Gunpowder Falls Watershed is located in the central eastern portion of Baltimore County, Maryland (see Figure 1). The Loch Raven Dam divides the Loch Raven watershed from the Lower Gunpowder Falls. The watershed begins at the Loch Raven Reservoir dam and flows generally towards the east. Where it meets the tidal portions of Gunpowder River, it becomes the Gunpowder River watershed. Major tributaries in the watershed include Minebank Run, Long Green Creek, Sweathouse Run, Haystack Branch, Jennifer Branch, and Bean Run. The watershed is approximately 29,240 acres. The watershed is located in Eastern Piedmont and Coastal regions of three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

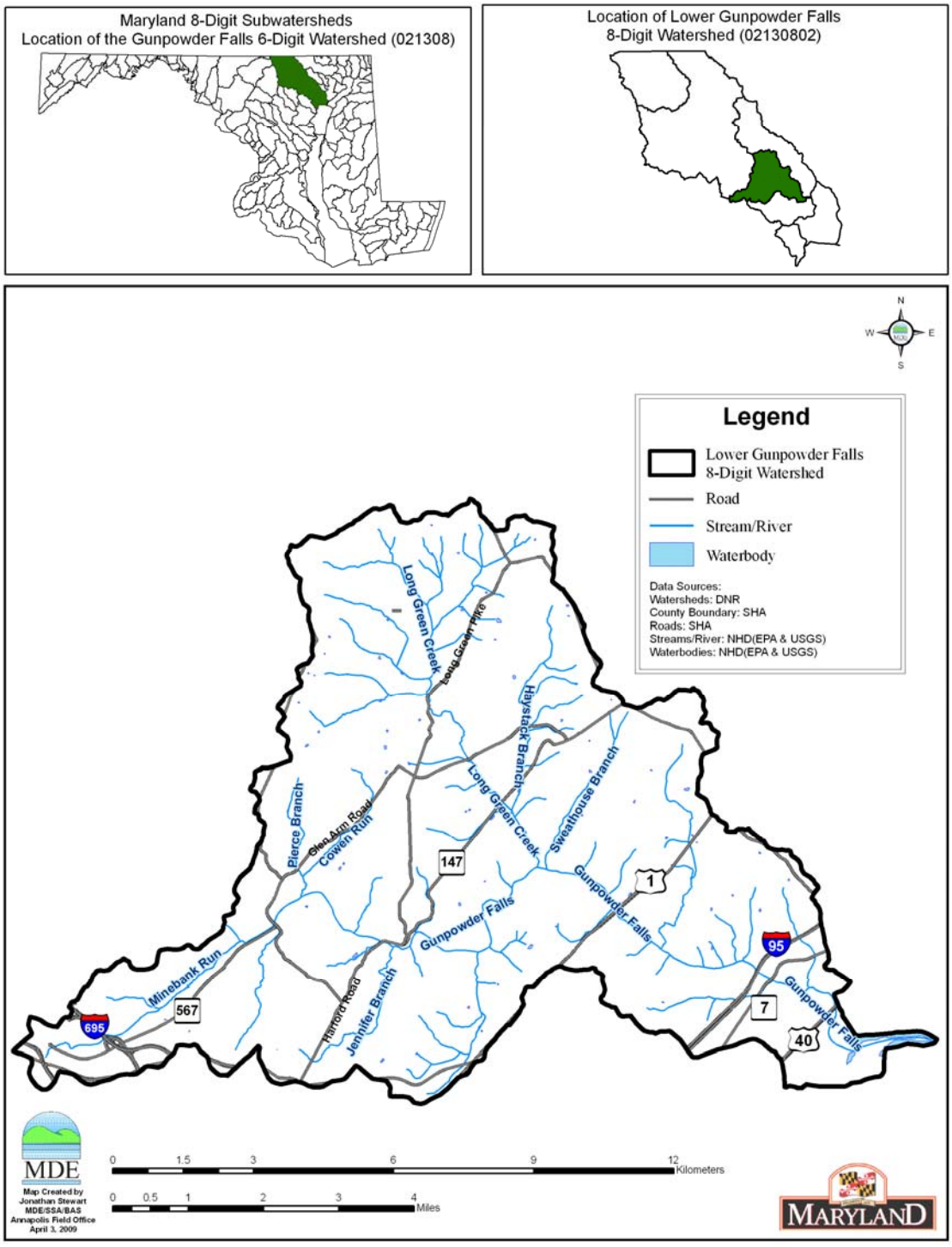

Figure 1. Location Map of the Lower Gunpowder Falls Watershed

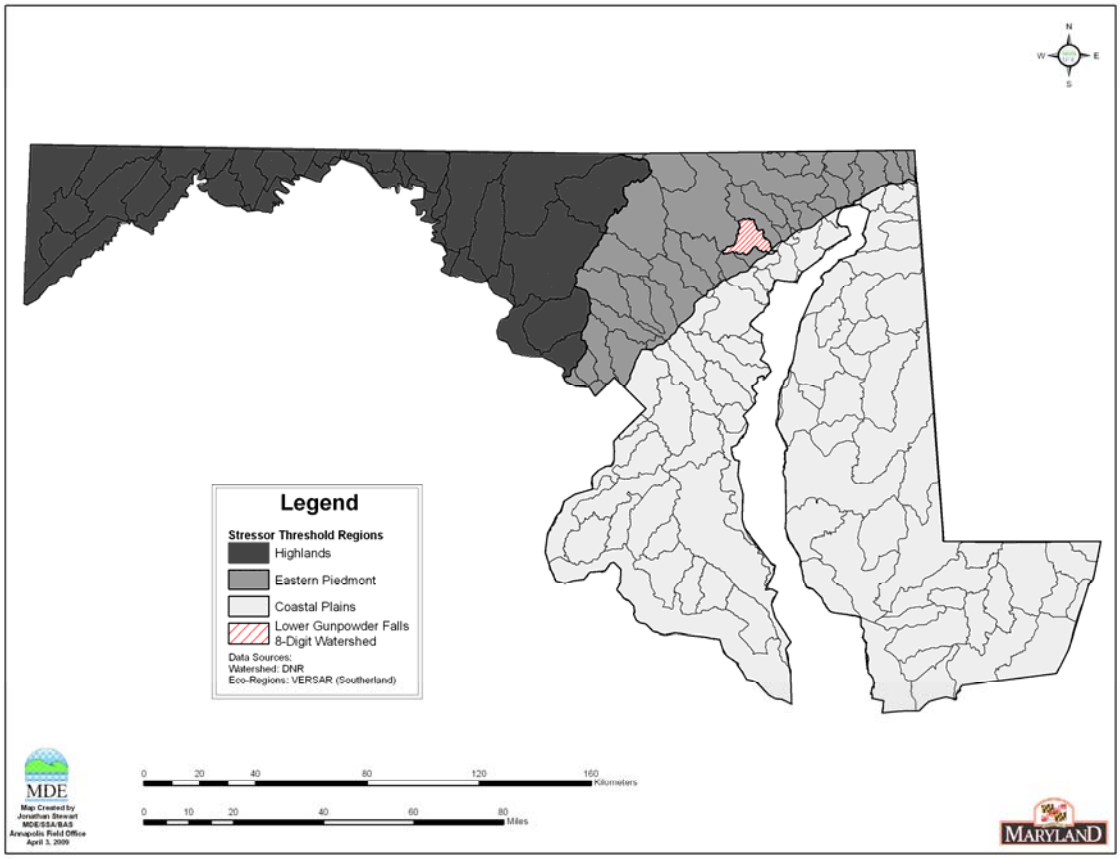

Figure 2. Eco-Region Location Map of the Lower Gunpowder Falls

2.2 Land Use

The Lower Gunpowder Falls watershed comprises 29,217 acres of drainage area in Baltimore County, Maryland. The Lower Gunpowder Falls watershed has a unique geographic divide with very rural countryside to the north and a very urbanized area on the southern side. The land to the north is primarily agricultural in nature and includes the communities of Long Green, Hydes, Glen Arm, Fork, Kingsville, and Upper Falls. Land south of the river consists of older developed areas such as Towson, Carney, and Parkville, the commercial corridor along Joppa Road, and newer, rapidly developing areas such as Perry Hall. The valley forming the Lower Gunpowder Falls main stem consists of heavily forested lands that are part of the Gunpowder Falls State Park (DEPRM 2009). There are five minor and no major point source discharges within the watershed. According to the Chesapeake Bay Program's Phase 5.2 Model the land use distribution in the watershed is approximately 15 % agricultural, 36% urban pervious, 6%

impervious surfaces, and 43% forest/herbaceous (USEPA 2008) (see Figure 3 and Figure 4).

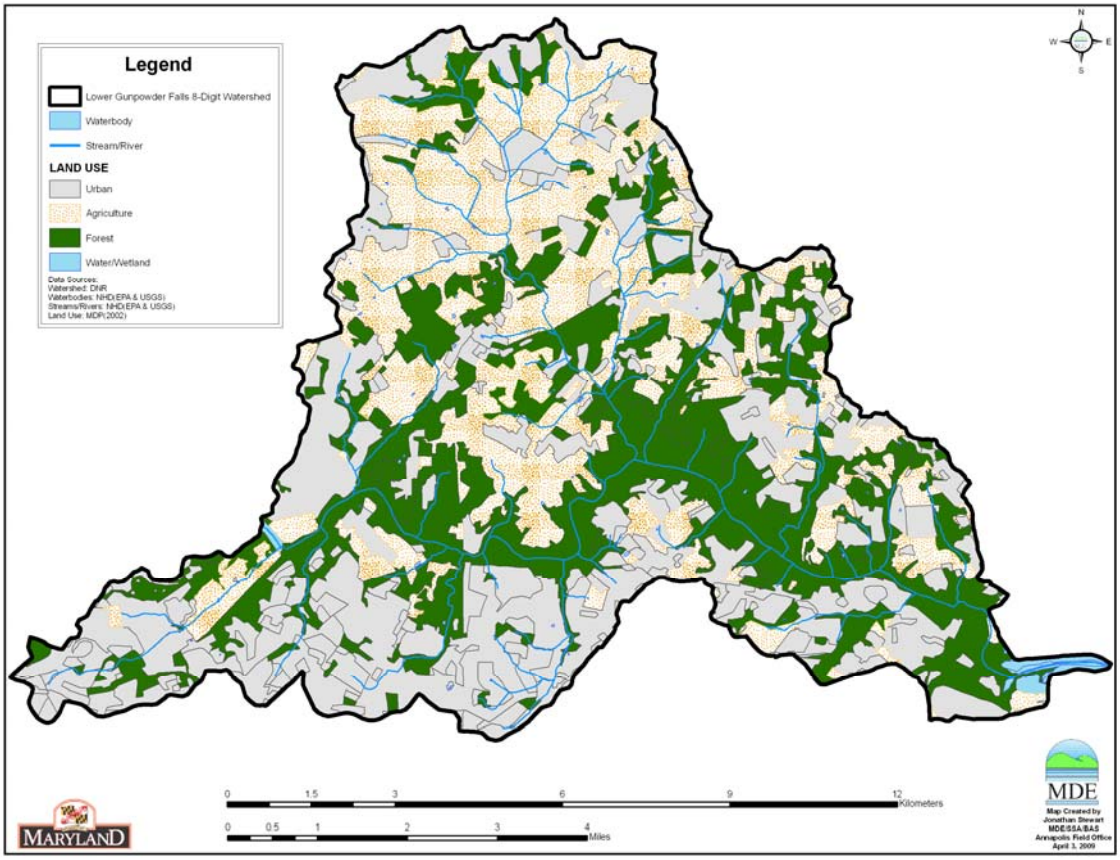

Figure 3. Land Use Map of the Lower Gunpowder Falls Watershed

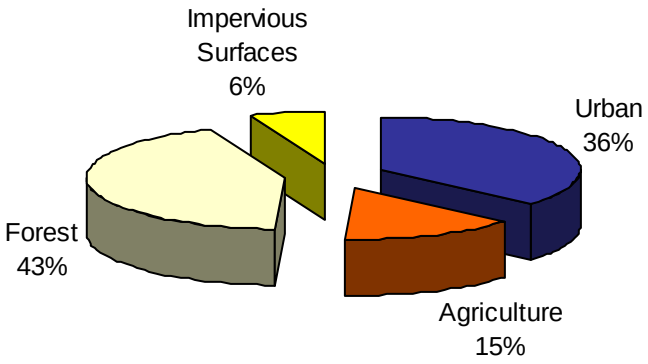

Figure 4. Proportions of Land Use in the Lower Gunpowder Falls Watershed

2.3 Soils/hydrology

The Lower Gunpowder Falls watershed lies within the Piedmont and Coastal Plain provinces of Central Maryland. The Piedmont province is characterized by gentle to steep rolling topography, low hills and ridges. Crystalline rocks of volcanic origin consisting primarily of schist and gneiss characterize the surficial geology. These formations are resistant to short-term erosion and often determine the limits of stream bank and streambed. These crystalline formations decrease in elevation from northwest to southeast and eventually extend beneath the younger sediments of the Coastal Plain. The fall line represents the transition between the Atlantic Coastal Plain province and the Piedmont province. Thick, unconsolidated marine sediments deposited over the crystalline rock of the Piedmont province characterize the Atlantic Coastal Plain surficial geology. The deposits include clays, silts, sands and gravels (CES, 1995).

The Lower Gunpowder Falls watershed drains from northwest to southeast, following the dip of the underlying crystalline bedrock in the Piedmont province. The surface elevations range from approximately 625 feet to sea level at the Chesapeake Bay shorelines. Stream channels of the sub-watersheds are well incised in the Eastern Piedmont, and exhibit relatively straight reaches and sharp bends, reflecting their tendency to following zones of fractured or weathered rock. The stream channels broaden abruptly as they flow down across the fall line and into the soft, flat Coastal Plain sediments (CES, 1995).

The watershed is comprised primarily of B and C type soils. Soil type is categorized by four hydrologic soil groups developed by the Soil Conservation Service (SCS).

The definitions of the groups are as follows (SCS, 1976):

Group A: Soils with high infiltration rates, typically deep well-drained to excessively drained sands or gravels.

Group B: Soils with moderate infiltration rates, generally moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils with slow infiltration rates, mainly soils with a layer that impedes downward water movement or soils with moderately fine to fine texture.

Group D: Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted.

3.0 Lower Gunpowder Falls Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Lower Gunpowder Falls (basin code 02130802), located in Baltimore County, MD is associated with two assessment units in Maryland's Integrated Report (IR): non-tidal (8-digit basin) and an estuary portion (Chesapeake Bay segment). The Chesapeake Bay segment related to the Lower Gunpowder Falls is Gunpowder River Oligohaline. Below is a table identifying the listings associated with this watershed.

Table 1: 2010 Integrated Report Listings for the Lower Gunpowder Falls Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Lower Gunpowder Falls	02130802	Non-tidal	Aquatic Life and Wildlife		Arsenic	2
					Cadmium	2
					Chromium	2
					Lead	2
					Mercury	2
					Nickel	2
					Selenium	2
					Zinc	2
				2002	Impacts to Biological Communities	5
Gunpowder River Oligohaline	GUNOH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			Aquatic Life and Wildlife		Impacts to Estuarine Biological Communities	2
			Open Water Fish and Shellfish	1996	TN	5
				1996	TP	5
			Seasonal Shallow Water Submerged Aquatic Vegetation	2010	TSS	5

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of the Lower Gunpowder Falls is Use I – *water contact recreation, and non-tidal warmwater aquatic life.* Long Green Run [Creek]and Sweathouse Branch, and their respective tributaries are situated within the Lower Gunpowder Falls watershed and are designated as Use III – *nontidal coldwater* (COMAR 2010a,b,c,d). 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 Lower Gunpowder Falls watershed is listed under Category 5 of the 2008 Integrated Report as impaired for impacts to biological communities. Approximately 54% of stream miles in the Lower Gunpowder Falls basin are estimated as having fish and and/or

benthic indices of biological impairment in the very poor to 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 thirteen sites. Nine of the thirteen sites have 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 2 contains ten MBSS sites with eight having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Lower Gunpowder Falls watershed.

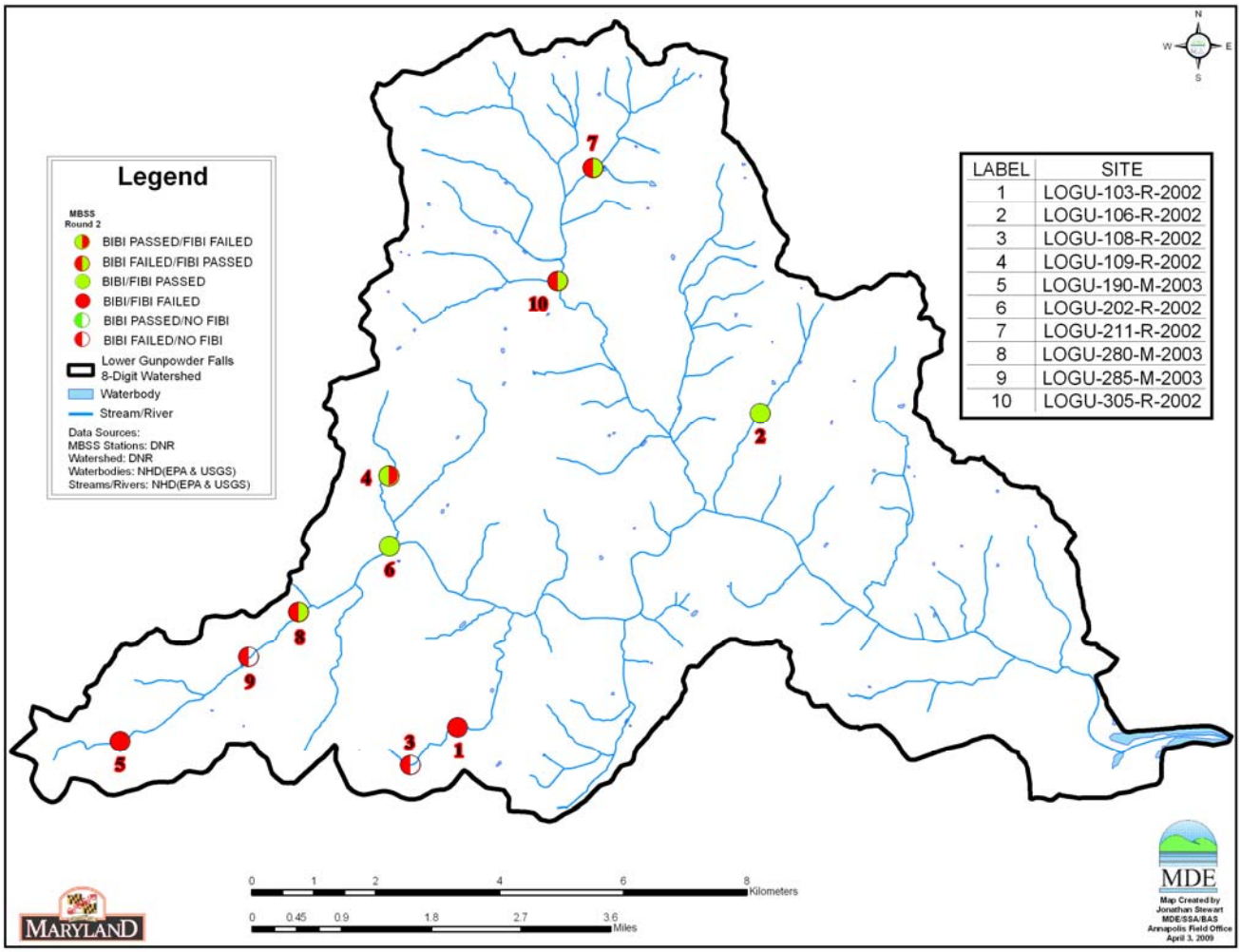

Figure 5. Principal Dataset Sites for the Lower Gunpowder Falls Watershed

4.0 Stressor Identification Results

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

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores significantly 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 – 1st and 2nd-4th 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-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are very poor to 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 very poor to 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 very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

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

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

Through the BSID analysis, MDE identified sediment, in-stream habitat, water chemistry parameters, and potential sources significantly associated with poor to very poor benthic and/or fish biological conditions. As shown in Table 2 through Table 4, parameters from the sediment, habitat, and water chemistry groups are identified as possible biological stressors in the Lower Gunpowder Falls. Parameters identified as representing possible sources are listed in Table 5 and include various urban land use types. Table 6 shows the summary of combined AR values for each stressor group in the Lower Gunpowder River watershed. Table 7 shows the summary of combined AR values for each source group.

Table 2. Sediment Biological Stressor Identification Analysis Results for Lower Gunpowder Falls

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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	9	7	84	43%	13%	Yes	29%
	moderate bar formation present	9	7	84	57%	42%	No	----
	bar formation present	9	7	84	86%	91%	No	----
	channel alteration marginal to poor	9	7	84	57%	42%	No	----
	channel alteration poor	9	7	84	43%	12%	Yes	31%
	high embeddedness	9	7	84	29%	9%	No	----
	epifaunal substrate marginal to poor	9	7	84	43%	12%	Yes	32%
	epifaunal substrate poor	9	7	84	14%	2%	No	----
	moderate to severe erosion present	9	7	84	71%	61%	No	----
	severe erosion present	9	7	84	0%	13%	No	----
	poor bank stability index	9	7	84	0%	5%	No	----
	silt clay present	9	7	84	100%	100%	No	----

Table 3. Habitat Biological Stressor Identification Analysis Results for the Lower Gunpowder Falls

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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	10	8	83	50%	10%	Yes	39%
	instream habitat structure marginal to poor	9	7	84	43%	11%	Yes	33%
	instream habitat structure poor	9	7	84	0%	1%	No	----
	pool/glide/eddy quality marginal to poor	9	7	84	14%	43%	No	----
	pool/glide/eddy quality poor	9	7	84	0%	1%	No	----
	riffle/run quality marginal to poor	9	7	84	71%	16%	Yes	57%
	riffle/run quality poor	9	7	84	29%	1%	Yes	27%
	velocity/depth diversity marginal to poor	9	7	84	43%	44%	No	----
	velocity/depth diversity poor	9	7	84	0%	0%	No	----
	concrete/gabion present	10	8	83	38%	2%	Yes	35%
	beaver pond present	9	7	84	14%	3%	No	----
Riparian Habitat	no riparian buffer	10	8	83	38%	22%	No	----
	low shading	9	7	84	14%	8%	No	----

Table 4. Water Chemistry Biological Stressor Identification Analysis Results for the Lower Gunpowder Falls

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 Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	10	8	165	25%	47%	No	----
	high total disolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	10	8	165	25%	5%	Yes	20%
	ammonia acute with salmonid absent	10	8	165	0%	3%	No	----
	ammonia chronic with salmonid present	10	8	165	25%	15%	No	----
	ammonia chronic with salmonid absent	10	8	165	0%	4%	No	----
	low lab pH	10	8	165	0%	2%	No	----
	high lab pH	10	8	165	0%	2%	No	----
	low field pH	9	7	164	0%	4%	No	----
	high field pH	9	7	164	0%	2%	No	----
	high total phosphorus	10	8	165	0%	6%	No	----
	high orthophosphate	10	8	165	0%	8%	No	----
	dissolved oxygen < 5mg/l	9	7	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	9	7	164	14%	2%	No	----
	low dissolved oxygen saturation	9	7	152	14%	1%	Yes	14%
	high dissolved oxygen saturation	9	7	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	10	8	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	10	8	165	0%	7%	No	----
	high chlorides	10	8	165	50%	5%	Yes	45%
	high conductivity	10	8	165	88%	6%	Yes	81%
	high sulfates	10	8	165	50%	4%	Yes	46%

Table 5. Stressor Source Identification Analysis Results for the Lower Gunpowder Falls

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	9	8	164	63%	3%	Yes	59%
	high % of high intensity urban in watershed	10	8	165	63%	21%	Yes	41%
	high % of low intensity urban in watershed	10	8	165	50%	5%	Yes	45%
	high % of transportation in watershed	10	8	165	63%	9%	Yes	53%
	high % of high intensity urban in 60m buffer	10	8	164	63%	4%	Yes	58%
	high % of low intensity urban in 60m buffer	10	8	164	63%	6%	Yes	56%
	high % of transportation in 60m buffer	10	8	164	13%	6%	No	----
Sources Agriculture	high % of agriculture in watershed	10	8	165	13%	22%	No	----
	high % of cropland in watershed	10	8	165	0%	3%	No	----
	high % of pasture/hay in watershed	10	8	165	13%	29%	No	----
	high % of agriculture in 60m buffer	10	8	164	13%	13%	No	----
	high % of cropland in 60m buffer	10	8	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	10	8	164	25%	23%	No	----
Sources Barren	high % of barren land in watershed	10	8	165	0%	10%	No	----
	high % of barren land in 60m buffer	10	8	164	0%	10%	No	----

Table 5. Stressor Source Identification Analysis Results for the Lower Gunpowder River (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Anthropogenic	low % of forest in watershed	10	8	165	38%	8%	Yes	30%
	low % of forest in 60m buffer	10	8	164	88%	9%	Yes	79%
Sources Acidity	atmospheric deposition present	10	8	165	0%	5%	No	----
	AMD acid source present	10	8	165	0%	0%	No	----
	organic acid source present	10	8	165	0%	0%	No	----
	agricultural acid source present	10	8	165	0%	2%	No	----

Table 6. Summary AR Values for Stressor Groups for Lower Gunpowder Falls

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	61%	85%
In-Stream Habitat	70%	
Riparian Habitat	----	
Water Chemistry	84%	

Table 7. Summary AR Values for Source Groups for Lower Gunpowder Falls

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	72%	95%
Agriculture	----	
Barren Land	----	
Anthropogenic	79%	
Acidity	----	

Sediment Conditions

BSID analysis results for the Lower Gunpowder Falls identified three sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *extensive bar formation present, channel alteration (poor), and epifaunal substrate (marginal to poor).*

Extensive bar formation present was identified as significantly associated with degraded biological conditions and found to impact approximately 29% of the stream miles with very poor to poor biological conditions in the Lower Gunpowder Falls. This stressor measures the movement of sediment in a stream system, and typically results from significant deposition of gravel and fine sediments. Although some bar formation is natural, extensive bar formation indicates channel instability related to frequent and intense high flows that quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions.

Channel alteration (poor) was identified as significantly associated with degraded biological conditions in 31% of the stream miles with poor to very poor biological conditions in the Lower Gunpowder Falls. Channel alteration measures large-scale modifications in the shape of the stream channel due to the presence of artificial structures (channelization) and/or bar formations. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Epifaunal Substrate (marginal to poor) was identified as significantly associated with degraded biological conditions in 32% of the stream miles with poor to very poor biological conditions in the Lower Gunpowder Falls. Epifaunal substrate is a visual

observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Like embeddedness and in-stream habitat, epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

The watershed of the Lower Gunpowder Falls and its tributaries contain extensive areas with high-density urban development, including Towson, Carney, and Parkville. Many portions of these areas were built before modern stormwater runoff controls were required by the State. The realization that human activities can seriously harm and degrade our waterways led to the authorization of sediment control regulations in the early 1960s, but a statewide sediment and erosion control program did not exist until 1970. About ten years later, in 1982, the Maryland General Assembly passed the State Stormwater Management Act, designed to address stormwater runoff generated during the land development process. Stormwater management helps to settle and filter many pollutants before runoff is discharged into a receiving body of water. But research indicates that most conventional stormwater management controls can still harm streams and rivers. Accelerated flow from stormwater management discharges can scour streambeds, erode banks, deposit sediment, and decrease overall stream health, stability, and habitat diversity (FCG 2009).

Thirty-three percent of the Lower Gunpowder Falls watershed consists of urban land uses. As development and urbanization increased in the Lower Gunpowder Falls 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. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams, causing urban 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 stream channel alteration and streambed scouring. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. Some of the impacts associated with sedimentation are smoothing of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of the stream bottom (Hoffman et al. 2003). All of these processes result in

an unstable stream ecosystem that impacts habitat and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004). An unstable stream ecosystem often results in a loss of available habitat and continuous displacement of biological communities from scouring that requires frequent re-colonization and the loss of sensitive taxa, with a shift in biological communities to more tolerant species. All of the stressors identified for the sedimentation parameter groups (e.g., bar formation, channel alteration, and epifauanal substrate) are the typical effects of the scouring associated with a "flashy" hydrological regime.

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 61%, suggesting these stressors impact a considerable proportion of the degraded stream miles in the Lower Gunpowder Falls (See Table 6).

In-stream Habitat Conditions

BSID analysis results for the Lower Gunpowder Falls identified five in-stream habitat parameters that have statistically significant association with poor to very poor stream biological condition: *in-stream habitat structure (marginal to poor), riffle/run quality (marginal to poor & poor), channelization present,* and *concrete/gabion present.*

In-stream habitat structure (marginal to poor) was identified as significantly associated with degraded biological conditions in the Lower Gunpowder Falls, and found to impact approximately 33% of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High in-stream habitat scores are evidence of the lack of sediment deposition. Like embeddedness, in-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Riffle/run quality was identified as significantly associated with degraded biological conditions and found to impact approximately 57% (marginal to poor) and 27% (poor) of the stream miles with poor to very poor biological conditions in the Lower Gunpowder Falls. Riffle/run quality is a visual observation and quantitative measurement based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase in the 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. Riffle/run quality conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal to poor, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity.

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 39% of the degraded stream miles in the Lower Gunpowder Falls. This stressor measures the presence/absence of channelization in stream banks and its presence is a metric for the channel alteration rating. It describes both the straightening of channels and their fortification with concrete or other hard materials. Channelization inhibits the natural flow regime of a stream resulting in increased flows during storm events that can lead to scouring and, consequently, displacement of biological communities. The resulting bank/channel erosion creates unstable channels and excess sediment deposits downstream.

Concrete/gabion present was identified as significantly associated with degraded biological conditions in the Lower Gunpowder Falls, and found to impact approximately 35% of the stream miles with poor to very poor biological conditions. *Concrete/gabion present*, like 'channelized,' inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

The stressors identified for the in-stream habitat parameter group are intricately linked with habitat heterogeneity. The presence these in-stream habitat stressors lower the diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The scouring of streambeds, which often occurs in streams with "flashy" hydrologic regimes, results in a more homogeneous in-stream habitat.

In April 2001, USEPA began investigating opportunities in the Baltimore metropolitan area to study streams that were targeted for restoration to improve physical function and in-stream habitat. Minebank Run, a small urban tributary of the Lower Gunpowder Falls near Towson, Maryland, was selected for study because of the opportunity to collect and interpret several different types of data prior to its physical restoration in 2004 and 2005. In October 2001, the U.S. Geological Survey (USGS), the USEPA, and the Institute of Ecosystem Studies (IES) jointly initiated a study in a selected reach of Minebank Run to investigate the effects of stream restoration on stream hydrology, denitrification, and overall water quality. Results of longitudinal profiles indicated noticeable changes in the percentage and distribution of riffles, pools, and runs through the study reach between 2002 and 2004. Major changes to the channel profile were observed as a result of storm runoff events. The cross-sectional surveys showed net increases in cross-sectional area, mean depth, and channel width at several locations between 2002 and 2004, which indicate channel degradation and widening. Data from scour chains identified several

locations where significant scouring (1.0–1.4 feet) occurred during storm events (Doheny et al. 2007).

Channelization and concrete/gabion has been used in the Lower Gunpowder Falls watershed for flood control. The purpose is to increase channel capacity and flow velocities so water moves more efficiently downstream. However, channelization is detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those in channelized streams. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats (Bolton and Schellberg 2001). Channelization also removes refuge cavities, which provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates. Subsequently, channelized streams retained less leaf litter and supported lower densities of detritivore invertebrates than natural streams. The overall densities and biomasses of macroinvertebrates in channelized streams are very low by comparison with intact natural streams (Laasonen et al. 1998, Haapala & Muotka 1998). Consequently, streams with extensive channelization often have impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 70 % suggesting these stressors impacts a considerable proportion of the degraded stream miles in the Lower Gunpowder Falls (See Table 6).

Riparian Habitat Conditions

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

Water Chemistry

BSID analysis results for the Lower Gunpowder Falls identified four water chemistry parameters that have 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 *ammonia acute with salmonid present, low dissolved oxygen saturation, high conductivity, chlorides,* and *sulfates.*

Ammonia acute with salmonid present is significantly associated with degraded biological conditions in the Lower Gunpowder Falls, and found to impact approximately 20% of the stream miles with poor to very poor biological conditions. Acute ammonia toxicity refers to potential exceedances of species tolerance caused by a one-time, sudden, high exposure of ammonia. Ammonia acute with salmonid present is a USEPA water quality criterion for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present or absent (USEPA 2006). Two MBSS stations were reported to have acute ammonia with salmonid present toxicity levels. Both these stations were located in urban developed areas containing a mixture of residential septic systems and municipal sewer service. Failing wastewater infrastructure or septic system could be a potential source of ammonia; however, the BSID analysis for the watershed did not identify any other nutrient stressors as having significant association with degraded biological conditions.

There are ten MBSS stations in the Lower Gunpowder River watershed and minimal sampling for ammonia was conducted (onetime sample) at each station. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. However, chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time. To make an accurate determination of acute and chronic ammonia toxicity, MDE reviewed additional data to determine if there is ammonia toxicity impairment in these waters. During the years of 1999, 2000, and 2007, MDE collected one hundred and eight water quality samples from Lower Gunpowder River watershed. Samples were collected at six stations through out the watershed, with most stations being sampled monthly for approximately a year. None of the samples showed exceedances of any of the four USEPA and MDE criteria for ammonia: acute criterion when salmonid fish are present, acute criterion when salmonid fish are absent, chronic criterion when early life stages are present or chronic criterion when early life stages are absent (USEPA 2006). Due to these results from the MDE water quality data analysis, it was determined that ammonia toxicity is not a significant stressor in the Lower Gunpowder River watershed.

Low dissolved oxygen saturation was significantly associated with degraded biological conditions and found in 14% of the stream miles with very poor to poor biological conditions in the Lower Gunpowder Falls watershed. Dissolved Oxygen (DO) saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Percent saturation is relative to the amount of oxygen that water can hold, as determined by temperature and atmospheric pressure. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production, enabling stressor risk analyses. DO saturation levels less than 60% saturation (like DO concentrations <5mg/L) is considered to demonstrate high respiration associated with excessive decomposition of organic material.

Additionally, DO saturation greater than 125% is considered to demonstrate oxygen production associated with high levels of photosynthesis. Sources are agricultural, forested and urban land uses. Only one station was reported to have low DO saturation values and the BSID analysis for the watershed did not identify any nutrient stressors other than ammonia as having significant association with degraded biological conditions. There is no evidence that excessive primary production is occurring in the watershed.

High conductivity levels was identified as significantly associated with degraded biological conditions in the Lower Gunpowder Falls, and found to impact approximately 81% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban runoff, road salts, agricultural runoffs (i.e., fertilizers), and leaking wastewater infrastructure are typical sources of inorganic compounds.

High chloride levels are significantly associated with degraded biological conditions in Lower Gunpowder Falls, and found to impact approximately 45% of the stream miles with poor to very poor biological conditions. High concentrations of chlorides can result from natural causes, metals contamination, industrial discharges, impervious surface runoff, and application of road salts. The Lower Gunpowder Falls was delisted for heavy metals in 2003, following USEPA concurrence with the Maryland Department of Environment (MDE) analysis of heavy metal data collected during 2001-2002. There are two minor industrial facilities in the watershed; however, National Pollution Discharge Elimination System (NPDES) permitting enforcement does not require chlorides testing at these facilities, data was not available to verify/identify chlorides as a specific pollutant. Smith et al. (1987) have identified that, although chloride can originate from natural sources, in urban watersheds road salts can be a likely source of high chloride and conductivity levels.

High sulfates concentrations are significantly associated with degraded biological conditions and found to impact approximately 46% of the stream miles with very poor to poor biological conditions in the Lower Gunpowder Falls watershed. Sulfates in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. There are three minor municipal wastewater treatment plants (WWTPs) in the Lower Gunpowder Falls watershed, and two minor industrial facilities. Since NPDES permitting enforcement does not require sulfate testing at any of these facilities, data was not available to verify/identify sulfates as a specific pollutant in this watershed.

Currently in Maryland there are no specific numeric criteria that quantify the impact of

conductivity, chlorides, and sulfates 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 all the different compounds of inorganic pollutants found in urban runoff from the BSID analysis.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Impervious surfaces allow many types of pollutants, derived from a variety of sources, to accumulate upon them. Many of these pollutants are subsequently washed into water bodies by storm water runoff, severely degrading water quality. Land development and increased impervious surfaces within the Lower Gunpowder Falls watershed has lead to increases in contaminant loads from nonpoint sources by adding sediments and inorganic pollutants to surface waters. Increased levels of many pollutants like chlorides and sulfates can be toxic to aquatic organisms and lead to exceedences in species tolerances.

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 water chemistry stressor group is approximately 84%, suggesting that these stressors impact a substantial proportion of degraded stream miles in the Lower Gunpowder Falls (Table 6).

Sources

All eight stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Lower Gunpowder Falls watershed BSID analysis, are representative of impacts from urban landscapes. The southern portion of the watershed contains mostly high and low-density urban centers including, Towson, Carney, Parkville, the commercial corridor along Joppa Road, and newer, rapidly developing areas such as Perry Hall. Many of these areas were built before modern stormwater runoff controls were required by the State.

The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer et al. 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 et al. 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.

Urban streams commonly display flashy streamflow due to rapid runoff from impervious surfaces. The flashy streamflow can alter the bed and banks of the stream channel considerably over time. The erosive power that is generated in urban streams often leads to degradation and widening of stream channels, bank failure, increased sediment supply, and instability of riffle and pool features along the channel profile (Paul and Meyer, 2001). 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 5) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for all the source groups is approximately 95% suggesting that urban development and impervious surfaces potentially impacts a substantial proportion of the degraded stream miles in Lower Gunpowder Falls (Table 7).

Summary

The BSID analysis results suggest that degraded biological communities in the Lower Gunpowder Falls watershed are a result of increased urban land uses causing alteration to hydrology, repeated streambed scouring, and increased sedimentation, resulting in an unstable stream ecosystem that eliminates habitat heterogeneity. High proportions of these land uses also typically results in increased contaminant loads from point and nonpoint sources by adding sediments and inorganic pollutants to surface waters, resulting in levels that can potentially be toxic to aquatic organisms. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade the Lower Gunpowder Falls, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 85%, suggesting that altered hydrology/sediment, habitat, and water chemistry stressors adequately account for the biological impairment in the Lower Gunpowder Falls.

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.

Final Causal Model for the Lower Gunpowder Falls

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, 1991and USEPA 2009). 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 conceptual model for the Lower Gunpowder Falls, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

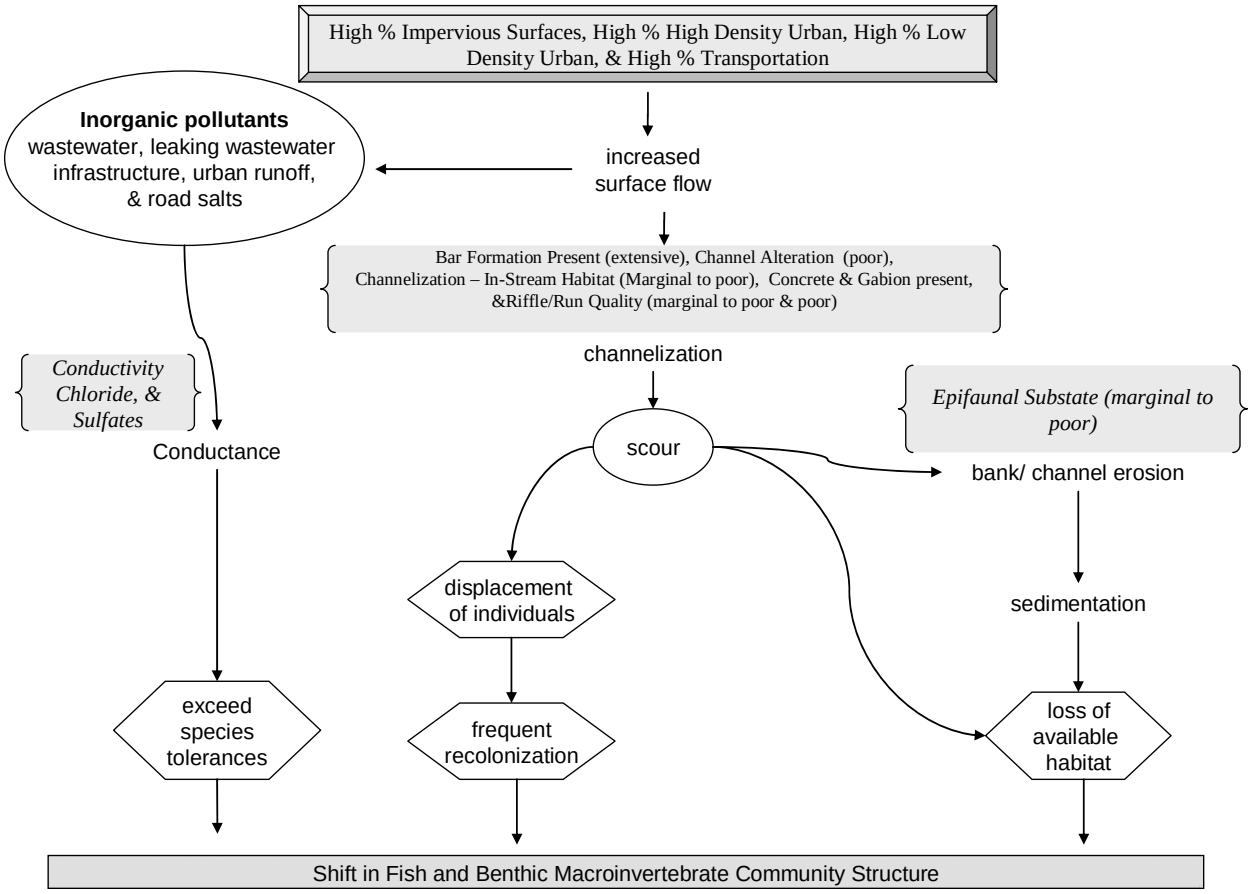

Figure 6. Final Causal Model for the Lower Gunpowder Falls Watershed

5.0 Conclusion

Data suggest that the Lower Gunpowder Falls watershed's biological communities are strongly influenced by urban land uses, which alters the hydrologic regime resulting in increased channel alteration, streambed scouring, loss of available habitat, and inorganic 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 contaminant loads from runoff. Based upon the results of the BSID process, the probable causes and sources of the biological impairments of the Lower Gunpowder Falls are summarized as follows:

- The BSID process has determined that the biological communities in the Lower Gunpowder Falls 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 approximately 45% and 46% of the stream miles with poor to very poor biological conditions in the watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listings of chloride and sulfates as an appropriate management action to begin addressing these stressor's impacts on the biological communities in the Lower Gunpowder Falls watershed.
- The BSID process has determined that biological communities in Lower Gunpowder Falls are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and impervious surfaces have resulted in channel alteration, channel erosion, scouring, and transport of suspended sediments in the watershed, which are in turn probable causes of impacts to biological communities. The BSID results confirm the tidal 2010 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Lower Gunpowder Falls watershed. In addition, the BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Lower Gunpowder Falls.

- The BSID process has also determined that biological communities in the Lower Gunpowder River watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization 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. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Lower Gunpowder Falls watershed based on channelization being present in approximately 39% of degraded stream miles.

- The BSID analysis did not identify any nutrient stressors present and/or nutrient stressors showing a significant association with degraded biological conditions, except acute ammonia. After analysis of MDE water quality data, it was determined that ammonia toxicity is not a significant stressor in the Lower Gunpowder Falls watershed.

References

Allan, J.D. 2004. *LANDSCAPES AND RIVERSCAPES: The Influence of Land Use on Stream Ecosystems*. Annual Review Ecology, Evolution, & Systematics. 35:257–84 doi: 10.1146/annurev.ecolsys.35.120202.110122.

Bolton, S and Shellberg, J. 2001. *Ecological Issues in Floodplains and Riparian Corridors*. University of Washington, Center for Streamside Studies, Olympia, Washington.

Booth, D. 1991. *Urbanization and the natural drainage system – impacts, solutions and prognoses.* Northwest Environmental Journal 7: 93-118.

CES (Coastal Environmental Service, Inc.). 1995. Patapsco/Back River Watershed Study, prepared for the Maryland Department of the Environment

COMAR (Code of Maryland Regulations). 2010a. *26.08.02.02*.
http://www.dsd.state.md.us/comar/26/26.08.02.02.htm (Accessed August, 2010).
_____. 2010b. *26.08.02.08 J.*
http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed August, 2010).
_____. 2010c. *26.08.02.08 J(3)(b).*
http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed August, 2010).
_____. 2010d. *26.08.02.08 J(3)(c).*
http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed August, 2010).

DEPRM (Baltimore County Department of Environmental Protection & Resource Managemant) 2009. Lower Gunpowder Falls. http://www.baltimorecountymd.gov/Agencies/environment/watersheds/ep_lowergpmain.html (Accessed August 10).

DNR (Maryland Department of Natural Resources). 2002. *Lower Gunpowder Falls of Recovery.* http://www.dnr.state.md.us/forests/anacostia/history.html (Accessed September, 2010).

Doheny, E.J., Starsoneck, R.J., Mayer, P.M., and Striz, E.A., 2007, *Pre-restoration geomorphic characteristics of Minebank Run*, Baltimore County, Maryland, 2002–04: U.S. Geological Survey Scientific Investigations Report 2007–5127, 49 p.

FCG (Fredrick County Government). 2009. *Monocacy River Report.* http://www.co.frederick.md.us/documents/Planning/Environmental%20Planning/MonocacyRiverFinalReport2009.PDF (Accessed 2010)

Haapala A., and Muotka T. 1998. *Seasonal dynamics of detritus and associated macroinvertebrates in a channelized boreal stream*. Archiv. Fuer. Hydrobiologie 142(2): 171-189.

Hill, A. B. 1965. *The Environment and Disease: Association or Causation?* Proceedings of the Royal Society of Medicine, 58: 295-300.

Hoffman D. J., Rattner B. A. , Burton G. A.. 2003. *Handbook of ecotoxicology* Edition: 2, Published by CRC Press: 598-600.

Iowa Department of Natural Resources (IDNR). 2008. *Iowa's Water Quality Standard Review –Total Dissolved Solids (TDS).* http://www.iowadnr.gov/water/standards/files/tdsissue.pdf (Accessed September, 2010)

Karr, J. R. 1991. *Biological integrity - A long-neglected aspect of water resource management*. Ecological Applications. 1: 66-84.

Konrad, C. P., and D. B. Booth. 2002. *Hydrologic trends associated with urban development for selected streams in the Puget Sound Basin*. Western Washington. Water-Resources Investigations Report 02-4040. US Geological Survey, Denver, Colorado.

Laasonen, P., Muotka, T., Kivijaervi, I. 1998. *Recovery of macroinvertebrate communities from stream habitat restoration*. Aquat. Conserv. Mar. Freshwat. Ecosyst. 8: 101-113.

Mantel, N., and W. Haenszel. (1959) Statistical aspects of the analysis of data from retrospective studies of disease. Journal of the National Cancer Institute, 22, 719-748.

Maryland Soil Conservation Service, Montgomery County, Maryland, 1995.

MDE (Maryland Department of the Environment). 2008. *Final Integrated Report of Surface Water Quality in Maryland*. Baltimore, MD: Maryland Department of the Environment. Available at http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2008_303d_pubnotice.asp (Accessed September, 2010).

_____. 2006. *A Methodology for Addressing Sediment Impairments in Maryland's Non-tidal Watersheds.* Baltimore, MD: Maryland Department of the Environment. Available at http://www.mde.state.md.us/assets/document/NT-Sediment_TMDL_Methodology_Report(1).pdf (Accessed September, 2010).

MDP (Maryland Department of Planning). 2002. *Land Use/Land Cover Map Series*. Baltimore, MD: Maryland Department of Planning.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. *Stream ecosystem function in urbanizing landscapes.* Journal of the North American Benthological Society. 24:602–612.

Paul, M. J., and J.L Meyer. 2001. *Streams in the urban landscape.* Annual Review of Ecology and Systematics. 32:333-365.

SCS (Soil Conservation Service). 1976. Soil Survey of Baltimore County, MD.

Smith, R. A., R. B. Alexander, and M. G. Wolman. 1987. *Water Quality Trends in the Nation's Rivers.* Science. 235:1607-1615.

Southerland, M. T., G. M. Rogers, R. J. Kline, R. P. Morgan, D. M. Boward, P. F. Kazyak, R. J. Klauda and S. A. Stranko. 2005. *New biological indicators to better assess the condition of Maryland Streams.* Columbia, MD: Versar, Inc. with Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment Division. CBWP-MANTA-EA-05-13. Also Available at http://www.dnr.state.md.us/streams/pubs/ea-05-13_new_ibi.pdf

USEPA (United States Environmental Protection Agency). 2006. *National Recommended Water Quality Criteria.* EPA-822-R-02-047. Office of Water, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC http://www.epa.gov/waterscience/criteria/wqctable/nrwqc-2006.pdf (Accessed August, 2009)

_____. 2008. *Chesapeake Bay Phase 5 Community Watershed Model*. Annapolis MD:Chesapeake Bay Program Office. http://www.chesapeakebay.net/model_phase5.aspx?menuitem=26169 (Accessed March, 2011)

USEPA – CADDIS (U.S. Environmental Protection Agency). 2009. The Causal Analysis/Diagnosis Decision Information System. hhtp://www.epa.gov/caddis

Van Sickle, J., and Paulson, S.G. 2008. *Assessing the attributable risks, relative risks, and regional extents of aqautic stressors*. Journal of the North American Benthological Society 27: 920-931.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan. 2005. *The urban stream syndrome: current knowledge and the search for a cure.* Journal of the North American Benthological Society 24(3):706–723.