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Watershed Report for Biological Impairment of the Jones Falls Watershed in Baltimore City and Baltimore County, Maryland
Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

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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
Cu	Copper
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
NPDES	National Pollutant Discharge Elimination System
Pb	Lead
PCBs	Polychlorinated biphenyls
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
Zn	Zinc

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 Jones Falls watershed (basin code 02-13-09-04), located in Baltimore County and Baltimore City, was identified on the States list of WQLSs and listed in the Integrated Report under Category 5 as impaired by chlordane, copper (Cu), lead (Pb), zinc (Zn), nutrients, suspended sediments (1996 listings), fecal coliform, polychlorinated biphenyls (PCBs) in fish tissue, and evidence of impacts to biological communities (2002 listings). The chlordane and PCBs listings are designated for the Lake Roland impoundment while the remaining listings apply to the non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. The Jones Falls watershed was de-listed for heavy metals in 2004 following USEPA concurrence with Maryland Department of the Environment's (MDE) analysis of heavy metal data collected during 2001-2002, which showed no heavy metals impairment, except for basin code 02-13-09-04-10-32 where there were indications of Cu. A WQA for basin code 02-13-09-04-10-32, requesting delisting for Cu, was included as an appendix to Maryland's 2008 Integrated Report and approved by USEPA in 2008. TMDLs were approved for chlordane in 2001 and fecal coliform in 2008. A WQA of Zn was completed in 2003.

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 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 Jones Falls watershed is Use III – *nontidal cold water* for the mainstem and all tributaries above Lake Roland, and Use IV – *recreational trout waters* for the mainstem from North Avenue to Lake Roland, and Stony Run and its tributaries

(COMAR, 2009 a,b,c). In addition, COMAR requires these waterbodies to support at a minimum the Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life*. The Jones Falls watershed is not attaining its designated use of supporting aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact this stressor 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 Jones Falls watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the biological communities of the Jones Falls watershed are strongly influenced by urban land use and its concomitant effects: altered hydrology and elevated levels of sulfate, chlorides, and conductivity (a measure of the presence of dissolved substances). 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 analysis, and the probable causes and sources of the biological impairments in Jones Falls watershed can be summarized as follows:

- The BSID analysis has determined that the biological communities in the Jones Falls watershed are likely degraded due to inorganic pollutants (i.e., chlorides, conductivity, sulfate). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 95% of the stream miles with very poor to poor biological conditions in the Jones Falls watershed.

The Jones Falls watershed was de-listed for heavy metals in 2004 and 2008 following USEPA concurrence with Maryland Department of the Environment's (MDE) WQA of heavy metal data. Since there is no significant metals impairment, the probable source of inorganic pollutant loading is run-off from impervious surfaces and urban landscapes. Impacts on water quality due to conductivity, chlorides, and sulfates are dependent on prolonged exposure; future monitoring of these inorganic pollutants will help in determining the spatial and temporal extent of this impairment 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. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) of impairment.

- The BSID analysis has determined that biological communities in the Jones Falls watershed are also likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the 1996 Category 5 listing for total suspended solids as an impairing substance in the Jones Falls watershed, and links this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Jones Falls watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization to be a form of 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 Jones Falls watershed based on channelization being present in approximately 51% of degraded stream miles.

- It is recommended for the assessment of this basin for the Integrated Report that the FIBI and water chemistry for stations JONES-102-R-2002 be vetted. Since BIBI score is below 3, there would be no change in the biological listing for the watershed.

- Although there is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report, the BSID analysis did not identify any nutrient stressors (i.e., total nitrogen, total phosphorus, dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

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 black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is 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 Department of Natural Resources Maryland Biological Stream Survey (MDDNR 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 Jones Falls watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Jones Falls Watershed Characterization

2.1 Location

The Jones Falls watershed is located in the Patapsco River region of the Chesapeake Bay watershed within Maryland (see Figure 1). The watershed covers a portion of Baltimore County and Baltimore City and totals 37,300 acres. The headwaters of the Jones Falls begin in Greenspring Valley and the stream meanders east through several farms, country clubs, and private schools, until it reaches Lake Roland. At Lake Roland the river merges with the eastern tributaries and then continues southward over the dam and through Baltimore City. It finally emerges from a tunnel in Baltimore City's Inner Harbor. The watershed area is located in two (Coastal and Eastern Piedmont) of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

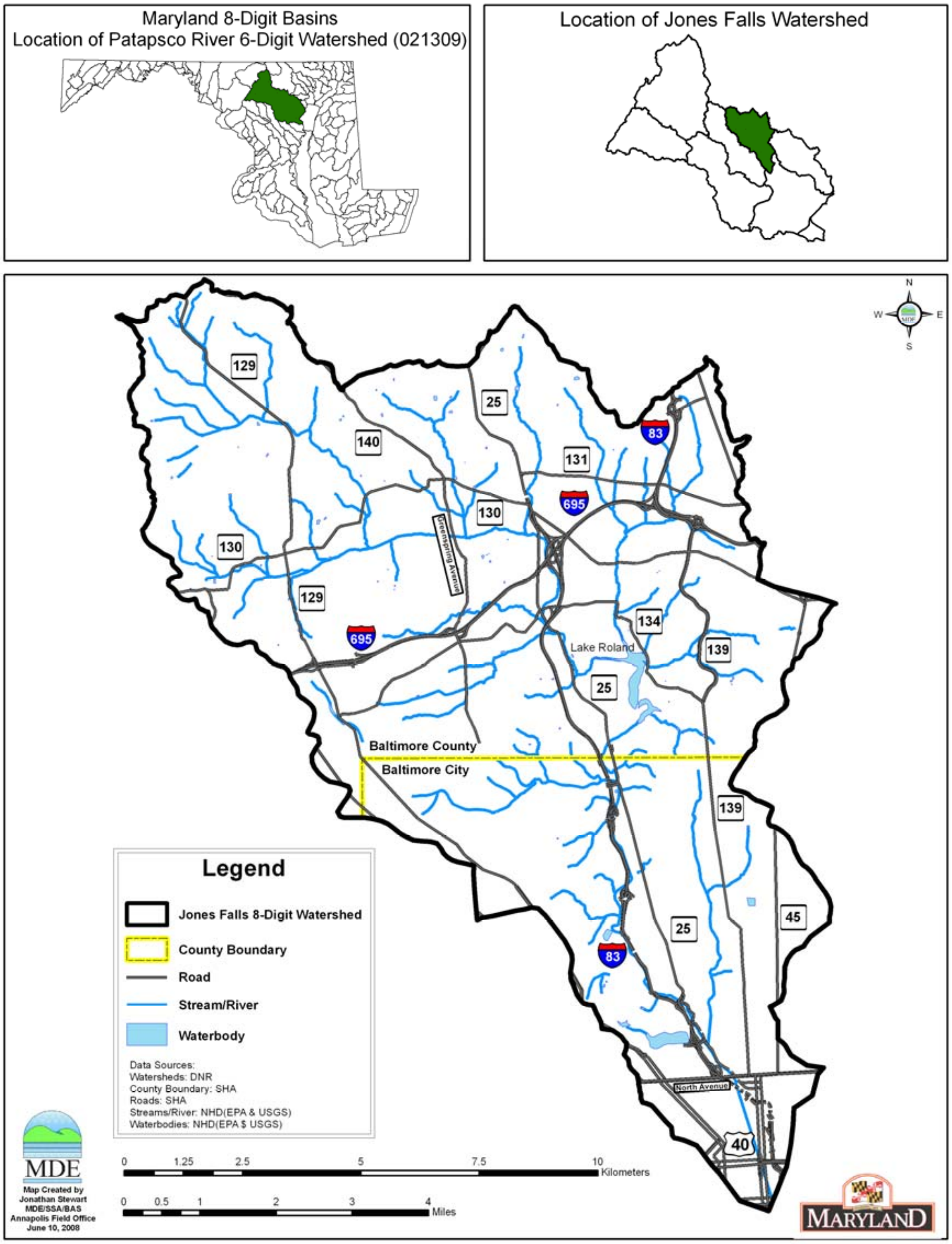

Figure 1. Location Map of the Jones Falls Watershed

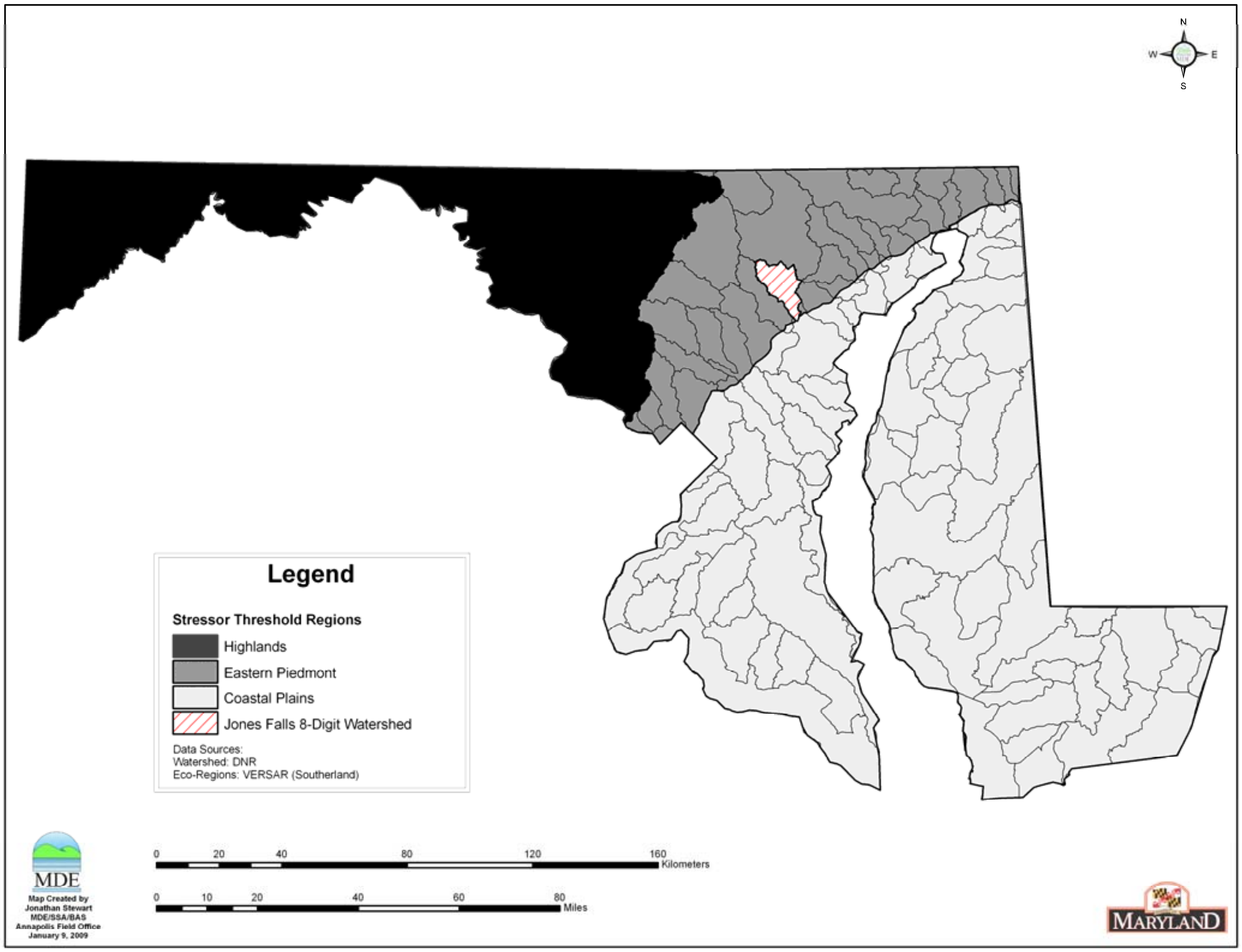

Figure 2. Eco-Region Location Map of Jones Falls Watershed

2.2 Land Use

The primary land use in the Jones Falls watershed is developed urban land. This watershed is divided by the County's urban rural demarcation line (URDL) with the less developed countryside at the headwaters to the west and highly urbanized areas to the east. The Jones Falls watershed contains primarily urban land use (see Figure 3). The land use distribution in the watershed is approximately 16% forest/herbaceous, 76% urban, 8% agricultural, and 0% (0.4%) water (see Figure 4) (MDP 2002).

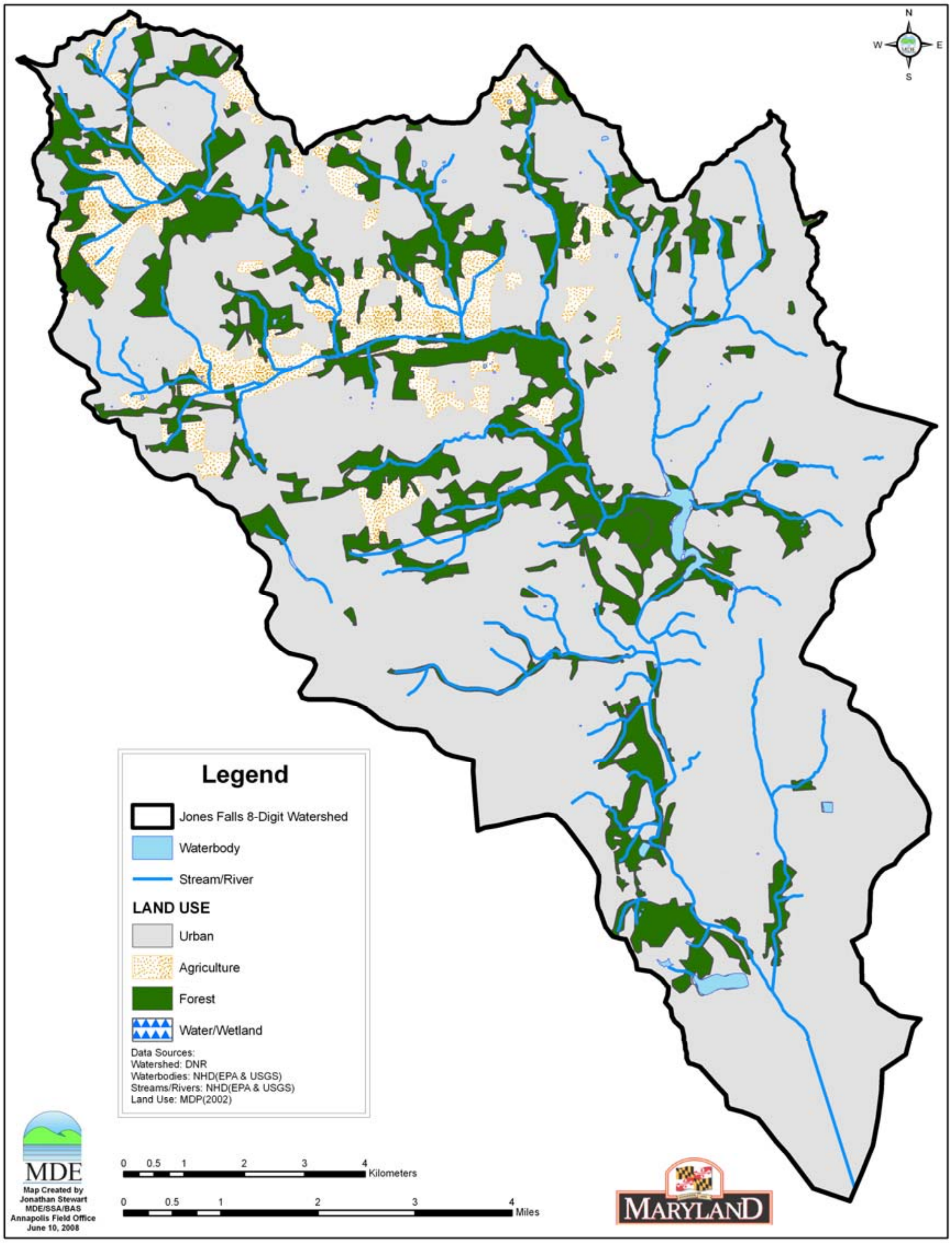

Figure 3. Land Use Map of the Jones Falls Watershed

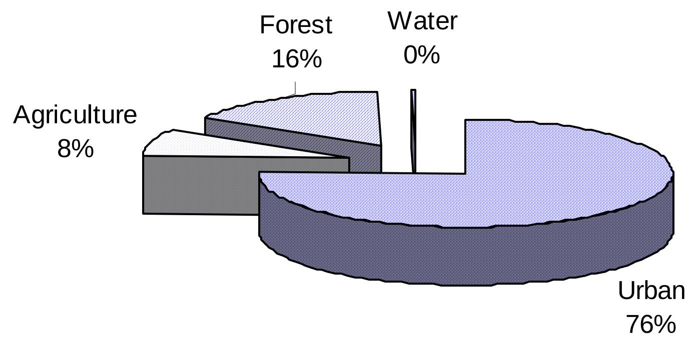

Figure 4. Proportions of Land Use in the Jones Falls Watershed

2.3 Soils/hydrology

The Jones Falls watershed is predominately within the Piedmont Plateau Physiographic Province of central Maryland with the lower tip extending slightly into the Coastal Plain provinces (Edwards 1981). The Piedmont Plateau Physiographic Province is characterized by gentle to steep rolling topography, low hills and ridges. Broad upland areas with low slopes and gentle drainage characterize the coastal province. The Jones 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 680 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 into the soft, flat Coastal Plain sediments (CES 1995). 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 the 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 and the Piedmont Provinces (CES 1995).

The watershed is comprised primarily of B and C type soils with the soil distribution within the watershed being approximately 1.2% soil group A, 65.4% soil group B, 14.8% soil group C and 18.1% soil group D. Soil data were obtained from Soil Survey Geographic (SSURGO) coverages created by the National Resources Conservation

Service. Four hydrologic soil groups developed by the Soil Conservation Service (SCS) categorize soil type. The definitions of the groups are as follows: 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 with very slow infiltration rates, mainly clay soils, soils with a permanently high water table, and shallow soils over nearly impervious material (SCS 1976).

3.0 Jones Falls Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Jones Falls watershed (basin code 02-13-09-04), located in Baltimore County and Baltimore City, was identified on the States list of WQLSs and listed in the Integrated Report under Category 5 as impaired by chlordane, copper (Cu), lead (Pb), zinc (Zn), nutrients, suspended sediments (1996 listings), fecal coliform, polychlorinated biphenyls (PCBs) in fish tissue, and evidence of impacts to biological communities (2002 listing). The chlordane and PCBs listings are designated for the Lake Roland impoundment while the remaining listings apply to the non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. The Jones Falls watershed was de-listed for heavy metals in 2004 following USEPA concurrence with MDE's analysis of heavy metal data collected during 2001-2002, which showed no heavy metals impairment, except for basin code 02-13-09-04-10-32 where there were indications of Cu. A WQA for basin code 02-13-09-04-10-32, requesting delisting for Cu, was included as an appendix to Maryland's 2008 Integrated Report, and approved by USEPA in 2008. TMDLs were approved for chlordane in 2001 and fecal coliform in 2008. A WQA of Zn was completed in 2003.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Jones Falls watershed is Use III – *nontidal cold water* for the mainstem and all tributaries above Lake Roland, and Use IV – *recreational trout waters* for the mainstem from North Avenue to Lake Roland and Stony Run and its tributaries (COMAR 2009 a,b,c). In addition, COMAR requires these waterbodies to support a Use I designation - *water contact recreation, fishing, and protection of nontidal warmwater aquatic life.* 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. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. 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 Jones Falls watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Approximately 36% of stream miles in the Jones Falls watershed are estimated as having benthic and/or fish 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 twenty-two stations. Eight of the twenty-two have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, ie MBSS Round 2 contains twelve MBSS sites; with five having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Jones Falls watershed.

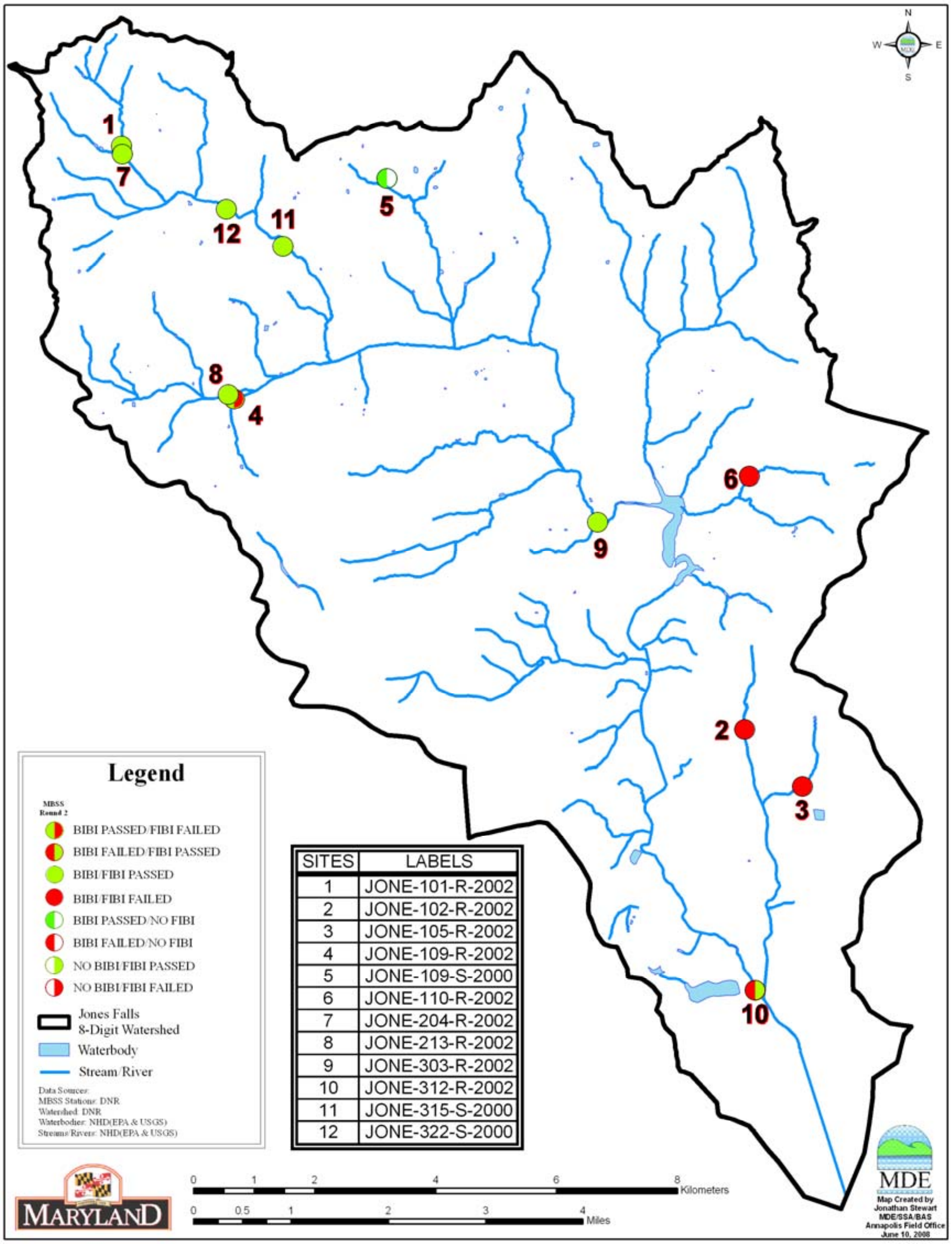

Figure 5. Principal Dataset Sites for the Jones Falls Watershed

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 – 1^{st} and 2^{nd}-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 data analysis, MDE identified sediment, in-stream habitat parameters, water chemistry parameters, and potential sources significantly associated with poor to very poor fish and/or benthic biological conditions in the Jones Falls watershed. As shown in Table 1 through Table 3, parameters from the sediment, in-stream habitat, and water chemistry groups are identified as possible biological stressors in the Jones Falls watershed. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. Table 5 shows the summary of combined AR values for the stressor groups in the Jones Falls watershed. Table 6 shows the summary of combined AR values for the source groups in the Jones Falls watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Jones Falls 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 Fish or Benthic IBI)	Controls (Average number of reference sites per strata 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 stressor 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	12	5	91	40%	13%	No	----
	moderate bar formation present	12	5	90	80%	41%	No	----
	bar formation present	12	5	91	80%	91%	No	----
	channel alteration marginal to poor	12	5	90	100%	40%	Yes	59%
	channel alteration poor	12	5	90	60%	12%	Yes	48%
	high embeddedness	12	5	90	60%	8%	Yes	52%
	epifaunal substrate marginal to poor	12	5	90	40%	14%	No	----
	epifaunal substrate poor	12	5	90	40%	3%	Yes	38%
	moderate to severe erosion present	12	5	90	40%	62%	No	----
	severe erosion present	12	5	90	40%	12%	No	----
	poor bank stability index	12	5	90	40%	6%	Yes	35%
	silt clay present	12	5	90	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Jones Falls 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 Fish or Benthic IBI)	Controls (Average number of reference sites per strata 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 stressor 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	12	5	91	60%	9%	Yes	51%
	instream habitat structure marginal to poor	12	5	90	40%	13%	No	----
	instream habitat structure poor	12	5	90	40%	1%	Yes	39%
	pool/glide/eddy quality marginal to poor	12	5	90	80%	53%	No	----
	pool/glide/eddy quality poor	12	5	90	0%	1%	No	----
	riffle/run quality marginal to poor	12	5	90	60%	19%	Yes	42%
	riffle/run quality poor	12	5	90	40%	1%	Yes	39%
	velocity/depth diversity marginal to poor	12	5	90	80%	53%	No	----
	velocity/depth diversity poor	12	5	90	40%	0%	Yes	40%
	concrete/gabion present	12	5	91	60%	1%	Yes	59%
	beaver pond present	12	5	90	0%	4%	No	----
Riparian Habitat	no riparian buffer	12	5	91	60%	25%	No	----
	low shading	12	5	90	20%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Jones Falls 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 Fish or Benthic IBI)	Controls (Average number of reference sites per strata 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 stressor 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	12	5	165	20%	47%	No	----
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	12	5	165	0%	5%	No	----
	ammonia acute with salmonid absent	12	5	165	0%	3%	No	----
	ammonia chronic with salmonid present	12	5	165	0%	15%	No	----
	ammonia chronic with salmonid absent	12	5	165	0%	4%	No	----
	low lab pH	12	5	165	0%	2%	No	----
	high lab pH	12	5	165	0%	2%	No	----
	low field pH	12	5	164	0%	4%	No	----
	high field pH	12	5	164	20%	2%	No	----
	high total phosphorus	12	5	165	0%	6%	No	----
	high orthophosphate	12	5	165	0%	8%	No	----
	dissolved oxygen < 5mg/l	12	5	164	20%	1%	Yes	19%
	dissolved oxygen < 6mg/l	12	5	164	20%	2%	No	----
	low dissolved oxygen saturation	12	5	152	20%	1%	Yes	19%
	high dissolved oxygen saturation	12	5	152	20%	0%	Yes	20%
	acid neutralizing capacity below chronic level	12	5	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	12	5	165	0%	7%	No	----
	high chlorides	12	5	165	100%	5%	Yes	95%
	high conductivity µS/cm	12	5	165	100%	6%	Yes	94%

high sulfates	12	5	165	60%	4%	Yes	56%

Table 4. Stressor Source Identification Analysis Results for the Jones Falls Watershed

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 per strata 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	12	5	164	100%	3%	Yes	97%
	high % of high intensity urban in watershed	12	5	165	100%	21%	Yes	79%
	high % of low intensity urban in watershed	12	5	165	100%	5%	Yes	95%
	high % of transportation in watershed	12	5	165	60%	9%	Yes	51%
	high % of high intensity urban in 60m buffer	12	5	164	100%	4%	Yes	96%
	high % of low intensity urban in 60m buffer	12	5	164	100%	6%	Yes	94%
	high % of transportation in 60m buffer	12	5	164	60%	6%	No	54%

Table 4. Stressor Source Identification Analysis Results for the Jones Falls Watershed (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 per strata 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 Agriculture	high % of agriculture in watershed	12	5	165	0%	22%	No	----
	high % of cropland in watershed	12	5	165	0%	3%	No	----
	high % of pasture/hay in watershed	12	5	165	0%	29%	No	----
	high % of agriculture in 60m buffer	12	5	164	0%	13%	No	----
	high % of cropland in 60m buffer	12	5	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	12	5	164	0%	23%	No	----
Sources Barren	high % of barren land in watershed	12	5	165	0%	10%	No	----
	high % of barren land in 60m buffer	12	5	164	0%	10%	No	----
Sources Anthropogenic	low % forest in watershed	12	5	165	100%	8%	Yes	92%
	low % of forest in 60m buffer	12	5	164	100%	9%	Yes	91%

Table 4. Stressor Source Identification Analysis Results for the Jones Falls Watershed (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 per strata 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 Acidity	atmospheric deposition present	12	5	165	0%	5%	No	----
	AMD acid source present	12	5	165	0%	0%	No	----
	organic acid source present	12	5	165	0%	0%	No	----
	agricultural acid source present	12	5	165	0%	2%	No	----

Table 5. Summary of Combined Attributable Risk Values of the Stressor Group in the Jones Falls Watershed

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	93%	98%
In-Stream Habitat	95%	
Riparian Habitat	----	
Water Chemistry	97%	

Table 6. Summary of Combined Attributable Risk Values of the Source Group in the Jones Falls Watershed

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	97%	97%
Agriculture	----	
Barren Land	----	
Anthropogenic	92%	
Acidity	----	

<u>Sediment and Habitat Conditions</u>

BSID analysis results for the Jones Falls watershed identified five sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *channel alteration (marginal to poor and poor)*, *epifaunal substrate (poor)*, *bank stability index (poor)*, and *high embeddedness.*

Channel alteration was identified as significantly associated with degraded biological conditions in the Jones Falls watershed, and found to impact approximately 59% (marginal to poor rating) and 48% (*poor* rating) of the stream miles with poor to very poor biological conditions. This stressor 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 was identified as significantly associated with degraded biological conditions and found in 38% (*poor* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. This stressor measures the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. The Jones Falls watershed is classified as a high gradient stream; the detrimental effects of flashy flows and streambed scouring are exacerbated by this geomorphologic characteristic, thereby reducing the availability of productive substrates.

Bank stability index was identified as significantly associated with degraded biological conditions and found in 35% (*poor* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. This stressor measures the degree of channel erosion a stream, it is a composite score based on the presence or absence of stabilizing bank materials with quantitative measures of erosion extent and erosion severity. Lower scores on this index are considered to demonstrate that discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy. The index may further identify conditions in which stream banks are vulnerable regardless of flood severity or frequency, thus demonstrating increased probability of high sediment loadings.

Embeddedness was identified as significantly associated with degraded biological conditions and found in 52% (*high* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls River watershed. This stressor measures the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. 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), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

As development and urbanization increased in the Jones Falls watershed so did morphological changes that affected the 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, bank erosion, 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. All the stressors identified in the sediment parameter group are related to sedimentation caused by altered hydrology.

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 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 from sedimentation, continuous displacement of biological communities that require frequent re-colonization and the loss of sensitive taxa, with a shift in biological communities to more tolerant species.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 93% suggesting that this stressor group impacts almost all of the degraded stream miles in the Jones Falls watershed (Table 5).

In-stream Habitat Conditions

BSID analysis results for the Jones Falls watershed identified six habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *channelization present, in-stream habitat structure (poor), riffle/run quality (marginal to poor and poor), velocity/depth diversity (poor), and concrete/gabion present.*

Channelization present was identified as significantly associated with degraded biological conditions and found in 51% of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. 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 and found in 59% of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. The presence or absence of concrete is determined by a visual observation within the stream segment, resulting from the field description of the types of channelization. Like 'channelization present', concrete 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.

Instream habitat structure was identified as significantly associated with degraded biological conditions and found in 39% (*poor* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. Instream habitat structure 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. Low in-stream habitat values can be caused by high flows that collapse undercut banks, sediment inputs that fill pools and other fish habitats. A poor rating of this measure indicates excessive erosion and/or sedimentation.

Riffle/run quality was identified as significantly associated with degraded biological conditions in the Jones Falls watershed, and found to impact approximately 42% (*marginal to poor* rating) and 39% (*poor* rating) of the stream miles with poor to very poor biological conditions. Riffle/run quality is a visual observation including quantitative measurements based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Velocity/depth diversity was identified as significantly associated with degraded biological conditions and found in 40% (*poor* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. Velocity/depth diversity is a visual observation including quantitative measurements based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The 'poor' diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.).

All the stressors identified for the in-stream habitat parameter group are intricately linked with habitat heterogeneity. The lower the ratings for these habitat parameters, the lower the diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The flashiness and channelization of the Jones Falls watershed have resulted in significant channel and streambed alteration within the watershed. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and decreasing habitat heterogeneity. Channelization has been used extensively in urban landscapes for flood control. Fifty-nine percent of the degraded stream miles in the Jones Falls watershed have concrete or gabion reinforced channels. 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 Shellberg 2001). The refuge cavities removed by channelization not only 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 and Muotka 1998). The combination of the altered flow regime, increased sediment, and artificial channelization in Jones Falls has resulted in loss of available habitat and an unstable stream ecosystem, characterized by a continuous displacement of biological communities that require frequent re-colonization. Consequently, an impaired biological community with poor IBI scores is observed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 95% suggesting that this stressor group impacts almost all of the degraded stream miles in the Jones Falls watershed (Table 5).

Riparian Habitat Conditions

BSID analysis results for Jones 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 Conditions

BSID analysis results for the Jones Falls watershed identified six 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 an improved biological community). These parameters are *high conductivity, high chlorides, high sulfates, dissolved oxygen parameters (low dissolved oxygen < 5mg/L, and low and high dissolved oxygen saturation).*

High conductivity levels are significantly associated with degraded biological conditions and found in approximately 94% (*high* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed.. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chlorides, sulfates, carbonate, sodium, and phosphate (IDNR 2008). Conductivity, chlorides, and sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity.

High chlorides levels are significantly associated with degraded biological conditions and found in approximately 95% (*high* rating) of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. High concentrations of chlorides can result from industrial discharges, metals contamination, and application of road salts in urban landscapes. There are no major National Pollutant Discharge Elimination System (NPDES) permitted industrial discharges (point sources) of copper (Cu) or lead (Pb) within the watershed. There is one minor facility (Fleischmann's Vinegar Company, Inc) regulated for discharges of chlorine and Cu within the watershed. The facility has not exceeded chlorine detection limits from July 2003 to June 2008.

The Jones Falls watershed was de-listed for heavy metals in 2004 following USEPA concurrence with the Maryland Department of the Environment's (MDE) analysis of heavy metal data collected during 2001-2002 that showed no heavy metals impairment, except for the lower most 12-digit basin (basin code 02-13-09-04-10-32) where two exceedences for Cu were found. Water column surveys conducted at five monitoring stations in the Jones Falls watershed from May 2001 to April 2002 were used to support this WQA. For every sample, dissolved concentrations of Cu and Pb were determined. A WQA for (basin code 02-13-09-04-10-32), requesting de-listing for Cu was included as an appendix to Maryland's 2008 Integrated Report, approved by USEPA in 2008. Since there is no significant metals impairment, application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith et al. 1987). A significant portion of the mainstem of Jones Falls parallels Interstate 83, which is one of the primary transportation routes into Baltimore City. According to Church and Friesz (1993), road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating through soils and into groundwater aquifers.

High sulfates concentrations are significantly associated with degraded biological conditions and found in 56% of the stream miles with very poor to poor biological conditions in the Jones 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. Since NPDES permitting enforcement does not require sulfate testing at any of these facilities, data were not available to verify/identify sulfates as a specific pollutant in this watershed.

Low (< 5mg/L) dissolved oxygen (DO) concentrations are significantly associated with degraded biological conditions and found in 19% of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR 2007.

High (> 125%) and *low* (< 60%) *DO saturation* are also significantly associated with degraded biological conditions and found in 20% and 19% respectively, of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production. High and low DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. High DO saturation is considered to demonstrate oxygen production associated with high levels of photosynthesis. Low DO saturation is considered to demonstrate high respiration associated with excessive decomposition of organic material.

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 the specific pollutant(s) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

The BSID analysis identified dissolved oxygen stressors as having a significant association with degraded biological conditions in the Jones Falls watershed; however, only one of twelve sites had a dissolved oxygen level below the State standard of 5.0 mg/l. This location was sampled during summer drought conditions in 2002. The MDDNR MBSS field sampling comments indicated that the 75-meter length of the site consisted of "One pool approximately six meters long. Strong sewage smell". During drought conditions, streams can be reduced to stagnant standing pools with no flow; therefore, MDE scientists conclude that this site was sampled during conditions that would be unrepresentative of the watershed under normal flow conditions. Therefore, the water chemistry collected during the summer was excluded from this analysis.

During drought conditions, streams are often reduced to stagnant standing pools with no flow; these conditions cannot sustain a viable biological community. Therefore, the Stressor Identification Group concluded that the summer sampling conducted at site Jones-102-R-2002 was sampled during conditions that are not representative of the watershed under typical flow conditions, and recommend that the FIBI for the station and the associated water chemistry parameters (i.e., in situ measurements of DO, pH, and conductivity) be vetted for the 2010 Integrated Report. There is no evidence to support vetting the failing BIBI score, therefore the station will remain listed on the Integrated Report for BIBI only.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Land development in the Jones Falls watershed can lead to increases in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, petroleum products, 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, very poor to poor biological conditions, if the inorganic pollutants stressor were removed. The combined AR for the water chemistry stressor group is approximately 97% suggesting that inorganic pollutant stressors impact almost all the degraded stream miles in Jones Falls (Table 5).

Sources

All seventeen stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Jones Falls watershed BSID analysis are representative of impacts from urban developed landscapes. 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.

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. 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 4) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 97% suggesting that urban development potentially impact almost all the degraded stream miles in Jones Falls (Table 6).

Summary

The Jones Falls watershed has been significantly impacted by urban development. The upper portion of the watershed is not as heavily developed and development is limited by zoning and by the Urban Rural Demarcation Line (URDL), the boundary that establishes the extent of city water and sewer lines. The areas serviced by sewer and water systems are more heavily developed. In the city portion of the watershed, most of the streams have been buried, piped, and converted to storm water drains (JFWA 2008). The BSID analysis results suggest that degraded biological communities in the Jones Falls watershed are a result of increased urban land use causing alterations to hydrologic regime, channelization and altering in-stream habitat conditions. The channelization and altered hydrology has caused frequent high flow events, degradation to in-stream habitat quality, and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat.

Due to the increased proportions of urban land use in the Jones Falls watershed, the stream has experienced an increase in contaminant loads from point and nonpoint sources, resulting in levels of inorganic pollutants that can potentially be extremely toxic to aquatic organisms. Alterations to the hydrologic regime, sedimentation, physical habitat, and water chemistry, have all combined to degrade the Jones Falls watershed, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 98%, suggesting that sediment, in-stream habitat and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Jones Falls watershed (Table 5).

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 scenarios (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 Jones Falls Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991 and USEPA 2007). 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 causal model for the Jones Falls watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

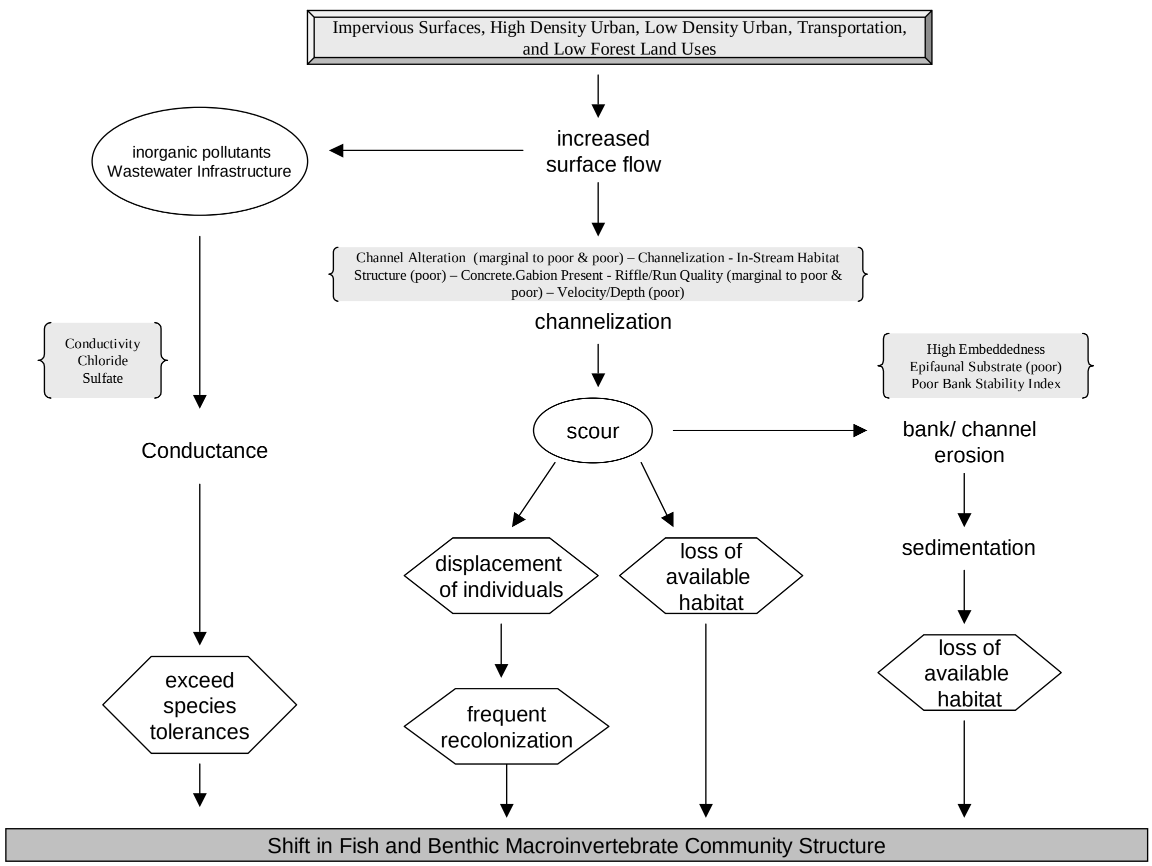

Figure 6. Final Causal Model for the Jones Falls Watershed

5.0 Conclusions

Data suggest that the Jones Falls watershed's biological communities are strongly influenced by urban land use, which alters the hydrologic regime resulting in increased erosion, sediment, 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 analysis, the probable causes and sources of the biological impairments of the Jones Falls watershed are summarized as follows:

- The BSID analysis has determined that the biological communities in the Jones Falls watershed are likely degraded due to inorganic pollutants (i.e., chlorides, conductivity, sulfate). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 95% of the stream miles with very poor to poor biological conditions in the Jones Falls watershed. The Jones Falls watershed was de-listed for heavy metals in 2004 and 2008 following USEPA concurrence with Maryland Department of the Environment's (MDE) WQA of heavy metal data. Since there is no significant metals impairment, the probable source of inorganic pollutant loading is run-off from impervious surfaces and urban landscapes. Impacts on water quality due to conductivity, chlorides, and sulfates are dependent on prolonged exposure; future monitoring of these inorganic pollutants will help in determining the spatial and temporal extent of this impairment 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. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) of impairment.

- The BSID analysis has determined that biological communities in the Jones Falls watershed are also likely degraded due to flow/sediment related stressors. Specifically, altered hydrology and increased runoff from urban impervious surfaces have resulted in channel erosion and subsequent elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the 1996 Category 5 listing for total suspended solids as an impairing substance in the Jones Falls watershed, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Jones Falls watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization to be a form of 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 Jones Falls watershed based on channelization being present in approximately 51% of degraded stream miles.

- It is recommended for the assessment of this basin for the Integrated Report that the FIBI and water chemistry for stations JONES-102-R-2002 be vetted. Since BIBI score is below 3, there would be no change in the biological listing for the watershed.

- Although there is presently a Category 5 listing for phosphorus in Maryland's 2008 Integrated Report, the BSID analysis did not identify any nutrient stressors, (i.e., total nitrogen, total phosphorus, dissolved oxygen, etc.) present and/or nutrient stressors showing a significant association with degraded biological conditions.

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