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

REVISED FINAL

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List of Abbreviations

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

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the United States 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.

Gwynns Falls, located in Baltimore County and Baltimore City was identified in Maryland's Integrated Report as impaired by nutrients, sediments (1996 listings), bacteria (fecal coliform) , and combination benthic/fishes bio-assessment (2002 listings) (MDE 2008). All impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 sediments listing was refined in the 2008 Integrated Report to a listing for total suspended solids. A TMDL addressing the 2002 bacteria impairment was approved by the USEPA in 2008.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, 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 Gwynns Falls are as follows: Gwynns Falls and tributaries above Reisterstown Road – Use III - *Nontidal Cold Water*; Dead Run and tributaries – Use IV - *Recreational Trout Waters* (COMAR 2009 a,b,c,d) . 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 Gwynns 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 these 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 Gwynns 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 Gwynns Falls is strongly associated with urban land use and its concomitant effects: altered hydrology and elevated levels of ammonia, 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 the Gwynns Falls, can be summarized as follows:

- The BSID analysis has determined that the biological communities are likely degraded due to inorganic pollutants (i.e., chlorides and conductivity). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 76% of the stream miles with very poor to poor biological conditions in the Gywnns Falls watershed. Impacts on water quality due to conductivity and chlorides 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 the biological communities in Gwynns Falls 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 Gwynns Falls, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Gwynns 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 Gwynns Falls watershed based on channelization being present in approximately 34% of degraded stream miles.
- The BSID analysis has identified one water chemistry stressor present (ammonia) at two sites showing a possible association with degraded biological conditions. A more intensive analysis of all available data is recommended to determine if there is an ammonia toxicity impairment in the Gwynns Falls 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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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 (MDDNR) 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 Gwynns Falls watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Gwynns Falls Watershed Characterization

2.1 Location

The Gwynns Falls originates in Glyndon, Baltimore County just south of where Highway 795 ends and turns into Route 128. The River flows southeast through the heavily suburbanized area of Reisterstown and Owings Mills crossing under Rt. 140 and Hwy. 795 in the Owings Mills Industrial Park and Corporate Campus areas. Gwynns Falls continues southeast with Red Run and Horsehead Run tributaries entering the main stem, which roughly flows parallel to Hwy. 795. Gwynns Falls again crosses under Hwy. 795 and then Hwy. 695 roughly flowing southeast and paralleling Hwy. 695. The tributary Scotts Level Branch flows into the main stem, which then crosses under Rt. 26 (Liberty Road) before crossing over the Baltimore County/City line. Gwynns Falls flows through Gwynns Falls Park where the tributary Dead Run joins into the main stem where the river, still flowing in a roughly southeasterly direction, crosses under Rt. 40, Rt. 144, Rt. 1, and Hwy. 95 where the tributary Maidens Choice Run joins it. Gwynns Falls then flows past the Carroll Camden Industrial Area and empties into the Middle Branch of the Patapsco River immediately after crossing under the Hwy. 295 and 95 interchange. The drainage area of the Gwynns Falls watershed is 41,700 acres. The location of the watershed is depicted in Figure 1. The watershed area is located in two of three distinct eco-regions identified in the MBSS Index of Biotic Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

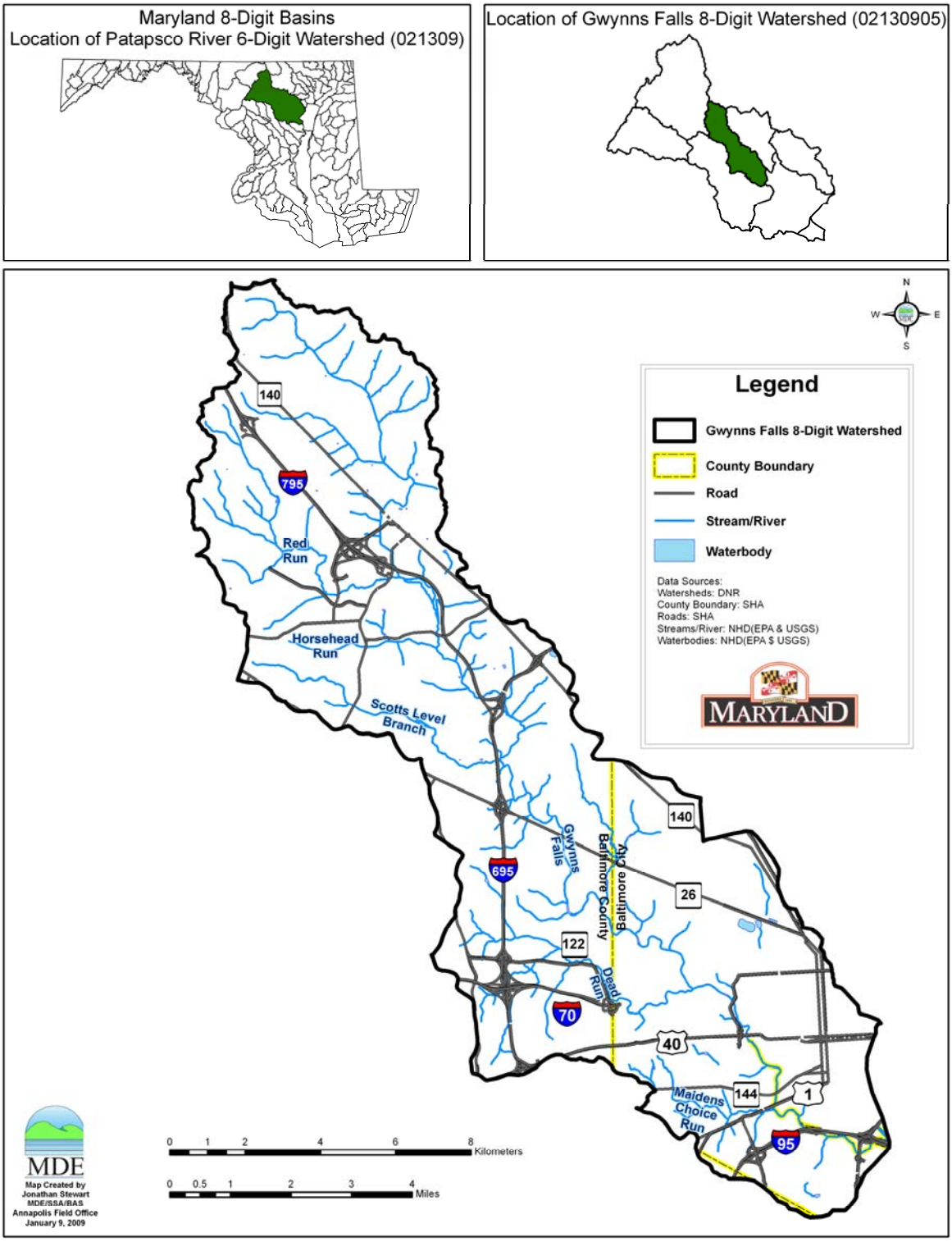


Figure 1. Location Map of the Gwynns Falls Watershed

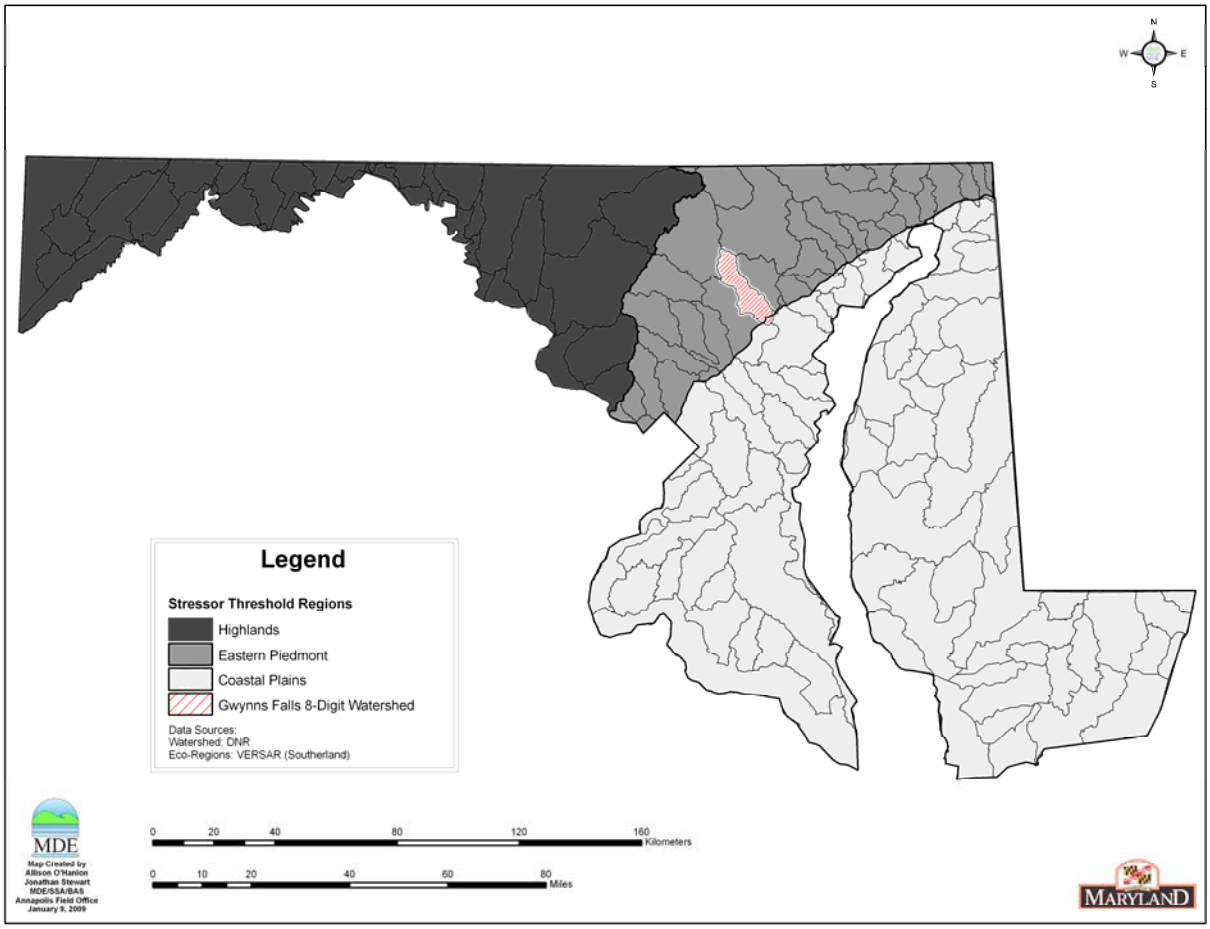


Figure 2. Eco-Region Location Map of Gwynns Falls Watershed

2.2 Land Use

The Gwynns Falls watershed is approximately 41,700 acres in size. The land use in the Gwynns Falls watershed is primarily urban. The watershed contains approximately 33,000 acres (79%)of urban land use. The watershed consists of agricultural land use at 1,400 acres (3%) and 7,000 acres (17%)of forest lands, with the forest found primarily along the main stem and tributaries of Gwynns Falls. Approximately 195 acres of the watershed consist of water. The land use distribution is based on land use/land cover data from the Maryland Department of Planning (MDP 2002). The spatial distributions for each land use are presented in Figure 3 and the land use percentage distribution for the Gwynns Falls watershed is displayed in Figure 4.

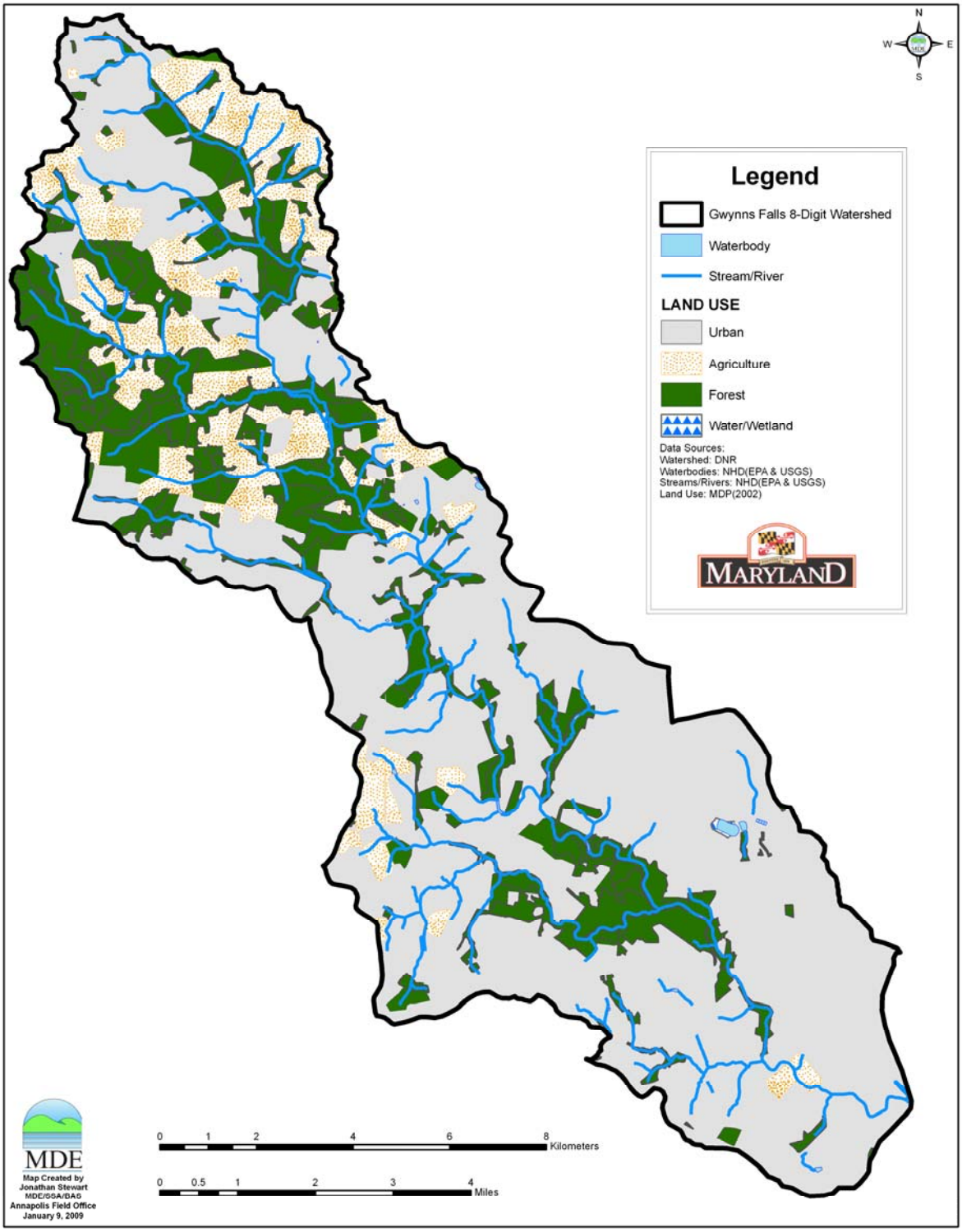


Figure 3. Land Use Map of the Gwynns Falls Watershed

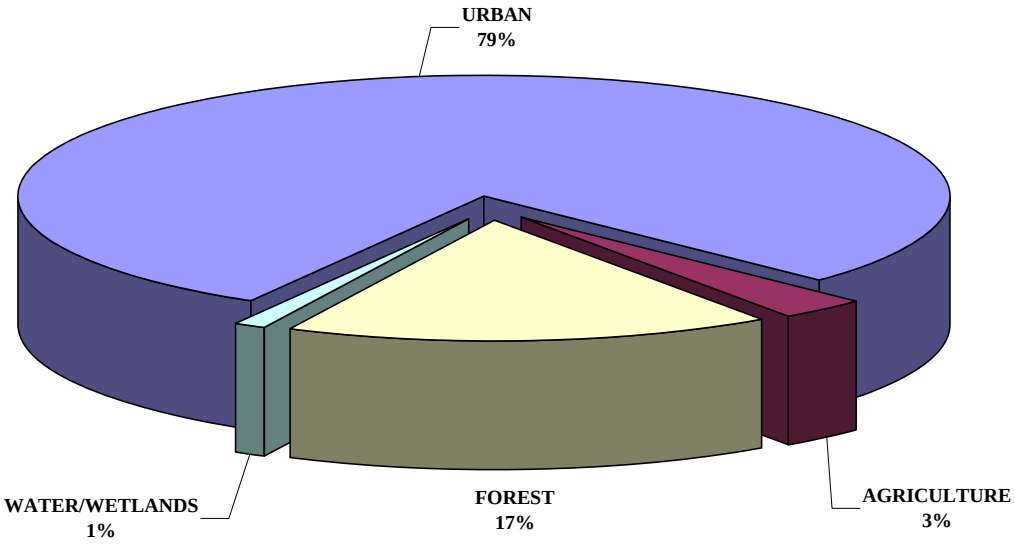


Figure 4. Proportions of Land Use in the Gwynns Falls Watershed

2.3 Soils/hydrology

The Gwynns Falls watershed lies within the Piedmont and Atlantic 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 surface 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 surface geology. The deposits include clays, silts, sands and gravels. In the areas around the head of tide, the topography is flat, with elevations below 100 feet. The elevations steadily increase going north to approximately 600 feet in the headwaters. Streambeds throughout the basin are comprised of rock and rubble with gradually sloped stream banks.

The Gwynns Falls watershed lies predominantly in the Baile and Lehigh soil series. The Lehigh soil series consists of somewhat poorly drained to moderately well drained, rather shallow soils. The Baile soil series consists of deep, poorly drained, nearly level to gently sloping, dominantly gray soils of the Piedmont Plateau (USDA SCS 1977).

3.0 Gwynns Falls Water Quality Characterization

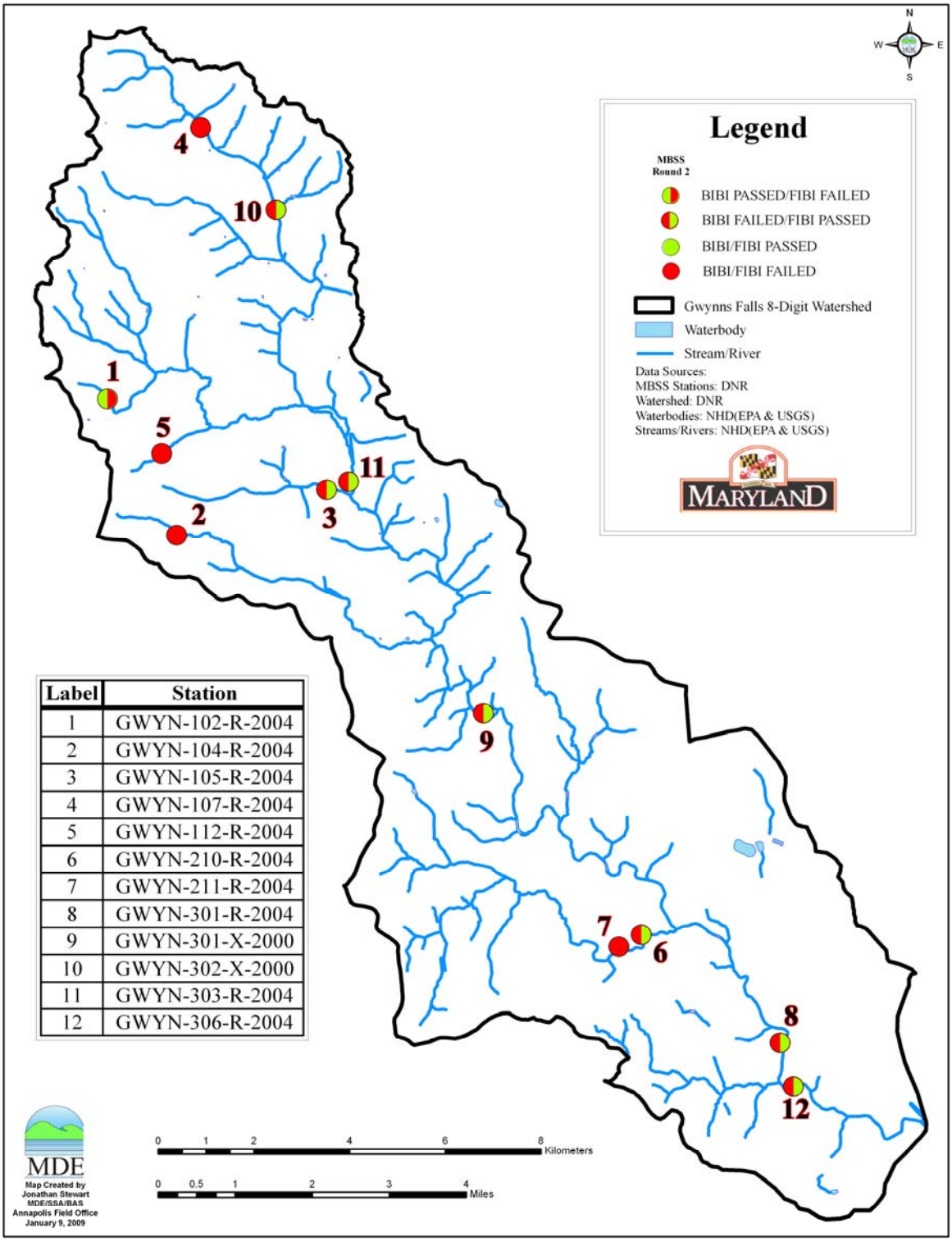
3.1 Integrated Report Impairment Listings

Gwynns Falls was identified in Maryland's Integrated Report as impaired by nutrients, sediments (1996 listings), bacteria (fecal coliform) , and combination benthic/fishes bio-assessment (2002 listings) (MDE 2008). All impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 sediments listing was refined in the 2008 Integrated Report to a listing for total suspended solids. A TMDL addressing the 2002 bacteria impairment was approved by the USEPA in 2008.

3.2 Biological impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Gwynns Falls are as follows: Gwynns Falls and tributaries above Reisterstown Road – Use III - *Nontidal Cold Water*; Dead Run and tributaries – Use IV *Recreational Trout Waters* (COMAR 2009 a,b,c,d). 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*. 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 Gwynns Falls watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Approximately 79% of stream miles in the Gwynns Falls watershed are estimated as having benthic and/or fish indices of biological integrity (BIBI/FIBI) 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 that include twenty-eight stream sites. Twenty-two of the twenty-eight sites have BIBI and or FIBI scores significantly lower than 3.0. The BSID analysis uses the principal data set, containing MBSS Round 2 data only, which includes fifteen sites in the Gwynns Falls watershed. Eleven of the twelve sites have BIBI/FIBI scores significantly lower than 3.0. Figure 5 illustrates the location of principal dataset sites within the Gwynns Falls Watershed.



Label	Station
1	GWYN-102-R-2004
2	GWYN-104-R-2004
3	GWYN-105-R-2004
4	GWYN-107-R-2004
5	GWYN-112-R-2004
6	GWYN-210-R-2004
7	GWYN-211-R-2004
8	GWYN-301-R-2004
9	GWYN-301-X-2000
10	GWYN-302-X-2000
11	GWYN-303-R-2004
12	GWYN-306-R-2004

Figure 5: Gwynns Falls Watershed Primary Dataset Site Locations

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 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 data analysis, MDE identified habitat parameters, water chemistry parameters, and potential sources significantly associated with poor to very poor fish and/or benthic biological conditions. As shown in Table 1 through Table 3, parameters from the sediment, habitat, and water chemistry groups are identified as possible biological stressors in Gwynns Falls. 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 Gwynns Falls watershed. Table 6 shows the summary of combined AR values for the source groups in the Gwynns Falls watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Gwynns 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 per strata with fair to good Fish and Benthic	% 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
Sediment	extensive bar formation present	12	11	78	36%	13%	Yes	23%
	moderate bar formation present	12	11	78	64%	43%	No	----
	bar formation present	12	11	78	100%	91%	No	----
	channel alteration marginal to poor	12	11	78	64%	43%	No	----
	channel alteration poor	12	11	78	36%	12%	Yes	24%
	high embeddedness	12	11	78	0%	9%	No	----
	epifaunal substrate marginal to poor	12	11	78	0%	9%	No	----
	epifaunal substrate poor	12	11	78	0%	1%	No	----
	moderate to severe erosion present	12	11	78	18%	60%	No	----
	severe erosion present	12	11	78	0%	13%	No	----
	poor bank stability index	12	11	78	0%	4%	No	----
	silt clay present	12	11	78	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Gwynns 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 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 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	12	11	79	45%	11%	Yes	34%
	instream habitat structure marginal to poor	12	11	78	0%	8%	No	----
	instream habitat structure poor	12	11	78	0%	0%	No	----
	pool/glide/eddy quality marginal to poor	12	11	78	18%	32%	No	----
	pool/glide/eddy quality poor	12	11	78	0%	0%	No	----
	riffle/run quality marginal to poor	12	11	78	27%	12%	No	----
	riffle/run quality poor	12	11	78	9%	1%	No	----
	velocity/depth diversity marginal to poor	12	11	78	36%	33%	No	----
	velocity/depth diversity poor	12	11	78	0%	0%	No	----
	concrete/gabion present	12	11	79	18%	2%	Yes	15%
	beaver pond present	12	11	78	0%	3%	No	----
Riparian Habitat	no riparian buffer	12	11	79	36%	21%	No	----
	low shading	12	11	78	0%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Gwynns 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 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 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	12	11	165	0%	47%	No	----
	high total dissolved nitrogen	2	2	56	0%	45%	No	----
	ammonia acute with salmonid present	12	11	165	18%	5%	No	----
	ammonia acute with salmonid absent	12	11	165	18%	3%	Yes	15%
	ammonia chronic with salmonid present	12	11	165	18%	15%	No	----
	ammonia chronic with salmonid absent	12	11	165	18%	4%	No	----
	low lab pH	12	11	165	0%	2%	No	----
	high lab pH	12	11	165	0%	2%	No	----
	low field pH	12	11	164	0%	4%	No	----
	high field pH	12	11	164	0%	2%	No	----
	high total phosphorus	12	11	165	0%	6%	No	----
	high orthophosphate	12	11	165	0%	8%	No	----
	dissolved oxygen < 5mg/l	12	11	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	12	11	164	0%	2%	No	----
	low dissolved oxygen saturation	12	11	152	0%	1%	No	----
	high dissolved oxygen saturation	12	11	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	12	11	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	12	11	165	0%	7%	No	----
	high chlorides	12	11	165	82%	5%	Yes	76%
	high conductivity	12	11	165	82%	6%	Yes	76%
	high sulfates	12	11	165	18%	4%	No	----

Table 4. Stressor Source Identification Analysis Results for the Gwynns 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 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	11	164	82%	3%	Yes	79%
	high % of high intensity urban in watershed	12	11	165	100%	16%	Yes	79%
	high % of low intensity urban in watershed	12	11	165	82%	5%	Yes	76%
	high % of transportation in watershed	12	11	165	100%	9%	Yes	91%
	high % of high intensity urban in 60m buffer	12	11	164	82%	4%	Yes	78%
	high % of low intensity urban in 60m buffer	12	11	164	91%	6%	Yes	85%
	high % of transportation in 60m buffer	12	11	164	45%	6%	Yes	39%
Sources Agriculture	high % of agriculture in watershed	12	11	165	0%	22%	No	----
	high % of cropland in watershed	12	11	165	0%	3%	No	----
	high % of pasture/hay in watershed	12	11	165	0%	29%	No	----
	high % of agriculture in 60m buffer	12	11	164	0%	13%	No	----
	high % of cropland in 60m buffer	12	11	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	12	11	164	0%	23%	No	----
Sources Barren	high % of barren land in watershed	12	11	165	0%	10%	No	----
	high % of barren land in 60m buffer	12	11	164	0%	10%	No	----
Sources Anthropogenic	low % of forest in watershed	12	11	165	73%	8%	Yes	65%
	low % of forest in 60m buffer	12	11	164	82%	9%	Yes	73%

Table 4. Stressor Source Identification Analysis Results for the Gwynns Falls (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	11	165	0%	5%	No	----
	AMD acid source present	12	11	165	0%	0%	No	----
	organic acid source present	12	11	165	0%	0%	No	----
	agricultural acid source present	12	11	165	0%	2%	No	----

Table 5. Summary of Combined AR Values for Stressor Groups for the Gwynns Falls Watershed

Parameter Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Sediment	24%	94%
In-Stream Habitat	40%	
Riparian Habitat	----	
Water Chemistry	77%	

Table 6. Summary of Combined AR Values for Source Groups for the Gwynns Falls Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (AR)	
Urban	96%	96%
Agriculture		
Barren Land		
Lack of Forest	74%	
Acidity		

Sediment Conditions

BSID analysis results for the Gwynns Falls identified two sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *channel alteration poor, and extensive bar formation present.*

Channel alteration poor was identified as significantly associated with degraded biological conditions in the Gwynns Falls, and found to impact approximately 24% of the stream miles with poor to very poor biological conditions. *Channel alteration poor* 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.

Extensive Bar formation present was identified as significantly associated with degraded biological conditions and found in 23% of the stream miles with very poor to poor biological conditions in the Gwynns Falls. This stressor measures the movement of sediment in a stream system, and typically results from significant deposition of gravel and fine sediments and its presence is a metric for the channel alteration rating. 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.

Seventy- nine percent of the Gwynns Falls watershed is comprised of urban land uses. As development and urbanization increased in the Gwynns 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 erosion and sedimentation smothering the 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 from scouring 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, if the sediment stressor were removed. The combined AR for the sediment stressor group is approximately 24 % suggesting these stressors results in moderate impacts to the degraded stream miles in the Gwynns Falls (Table 5).

In-stream Habitat Conditions

BSID analysis results for the Gwynns Falls identified two in-stream habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *channelization present* and *concrete/gabion present.*

Channelization present was identified as significantly associated with degraded biological conditions and found in 34% of the degraded stream miles in the Gwynns 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 Gwynns Falls, and found to impact approximately 15% 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 habitat stressors lower the diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Channelization has been used in the Gwynns 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). 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 & 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, very poor to poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 40 % suggesting these stressors result in impacts to the degraded stream miles in the Gwynns Falls (See Table 5).

Riparian Habitat Conditions

BSID analysis results for Gwynns 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 Gwynns Falls identified three 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*, and *ammonia acute with salmonid absent.*

High conductivity levels was identified as significantly associated with degraded biological conditions in the Gwynns Falls, and found to impact approximately 76% 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). Conductivity and chlorides are closely related. Streams with elevated levels of chlorides typically display high conductivity.

High chloride levels was identified as significantly associated with degraded biological conditions in the Gwynns Falls, and found to impact approximately 76% of the stream miles with very poor to poor biological conditions. 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 municipal or industrial discharges in the watershed; however, there are twenty-six minor industrial facilities that are regulated for various parameters. Because NPDES permitting enforcement does not require chloride testing at any of these facilities, data was not available to verify/identify chlorides as a specific pollutant in this watershed. Since there is no metals impairment, application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt. A significant portion of the mainstem of Gwynns Falls parallels Interstate 695 (Baltimore Beltway), which is one of the primary transportation routes in and around 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.

Elevated *ammonia acute with salmonid absent* levels was identified as significantly associated with degraded biological conditions in the Gwynns Falls, and found to impact approximately 15% of the stream miles with very poor to poor biological conditions. Two of the twelve MBSS sites displayed exceedence in acute ammonia threshold concentrations. Elevated levels of ammonia can result from industrial discharges, agriculture, atmospheric deposition, and household applications. There are no major NPDES permitted municipal or industrial discharges in the watershed; however, there are twenty-six minor industrial facilities that are regulated for various parameters with zero of the twenty-six permits discharging into the stream segments displaying exceedence in ammonia. Atmospheric deposition would result in more MBSS sites showing elevated ammonia levels than the current two. Detailed analysis of the land use surrounding the two MBSS sites discounts agricultural land use as a potential source of ammonia. Since both sites are located in areas with high proportions of low density urban land use, leaking infrastructure and/or failing septic systems (household applications) could possibly be the source of localized elevated levels of ammonia in the streams. The two sites exceeding acute ammonia tolerances are located in the headwaters of their perspective streams and MBSS sites further down stream show no ammonia tolerance exceedence.

In summary, water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Land development within the Gwynns Falls watershed has lead 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 can be toxic to aquatic organisms and lead to exceedences in species tolerances. The BSID analysis results identified acute ammonia as having a statistically significant association with degraded biological condition in Gwynns Falls. There were two sites exceeding acute ammonia tolerances, which are located in the headwaters of their perspective streams, however MBSS sites further down stream show no ammonia tolerance exceedence. There are no exceedences of any numeric water quality criteria for nutrient impairment (Dissolved Oxygen (D.O.) & pH) within the watershed.

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 water chemistry stressor group is approximately 77% suggesting that these stressors results in impacts to the degraded stream miles in Gwynns Falls (See Table 5).

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity and chlorides 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) from the array of potential inorganic pollutants inferred from the BSID analysis.

Sources

All eight stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Gwynns Falls watershed BSID analysis are representative of impacts from urban 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 77% suggesting that urban development potentially impact almost all the degraded stream miles in Gwynns Falls (See Table 6).

Summary

Land use in the Gwynns Falls Watershed ranges from a mixture of uses in the upper sections to high percentages of industrial, residential, and other impervious surfaces in the middle and southern sections. By 1994, the watershed had 5.1% agricultural land, 18.1% forested land and 75.8% developed land. Most significantly, 42.2% of the land in the watershed was covered with impervious surface (GFWA 2008). The BSID analysis results suggest that degraded biological communities in the Gwynns Falls watershed are a result of increased urban land use causing channelization and alterations to hydrologic regime. 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 Gwynns Falls, the watershed 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 Gwynns Falls, leading to a loss of diversity in the biological

community. The combined AR for all the stressors is approximately 94%, suggesting that sediment, in-stream habitat and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Gwynns Falls watershed (See 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 Gwynns 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, 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 Gwynns Falls, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

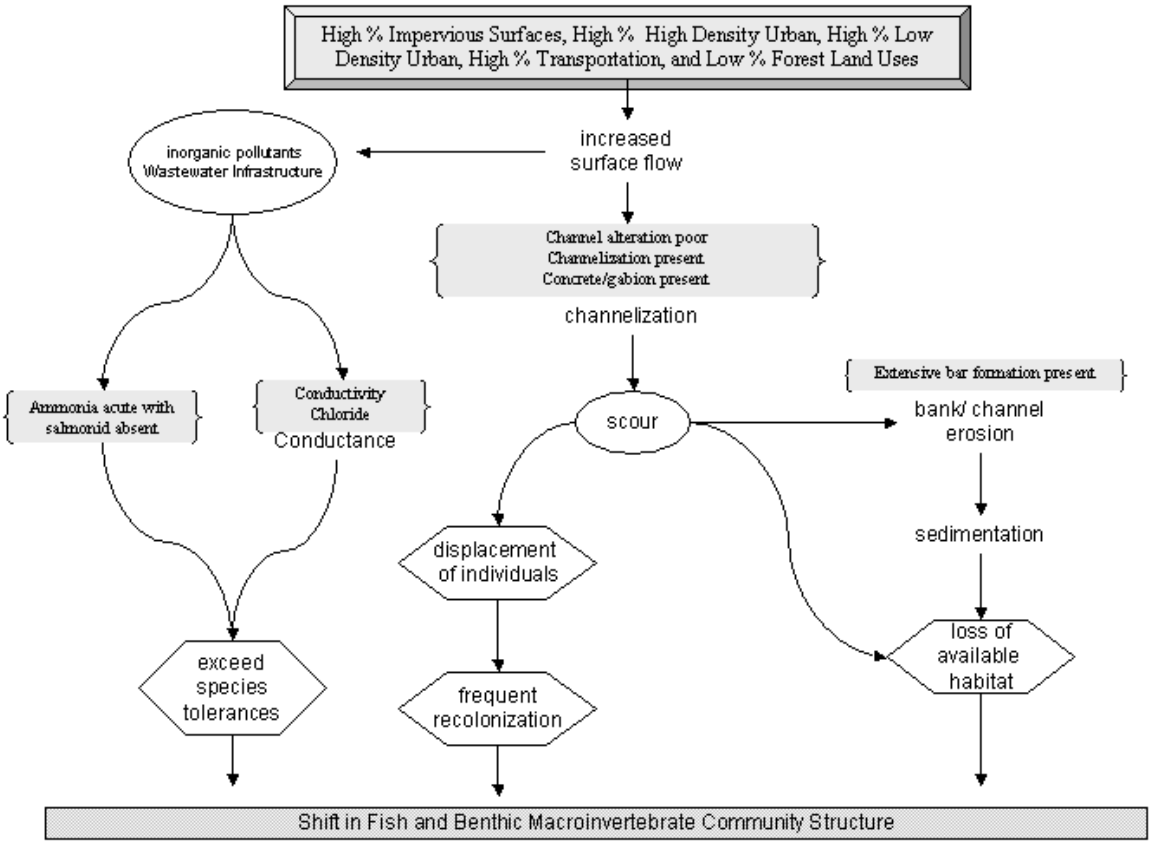


Figure 6. Final Causal Model for the Gwynns Falls

5.0 Conclusions

Data suggest that the Gwynns 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 Gwynns Falls watershed are summarized as follows:

- The BSID analysis has determined that the biological communities are likely degraded due to inorganic pollutants (i.e., chlorides and conductivity). Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 76% of the stream miles with very poor to poor biological conditions in the Gywnns Falls watershed. Impacts on water quality due to conductivity and chloride 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 the biological communities in Gwynns Falls 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 Gwynns Falls, and link this pollutant to biological conditions in these waters.
- The BSID process has also determined that biological communities in the Gwynns 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 Gwynns Falls watershed based on channelization being present in approximately 34% of degraded stream miles.
- The BSID analysis has identified one water chemistry stressor present (ammonia) at two sites showing a possible association with degraded biological conditions. A more

intensive analysis of all available data is recommended to determine if there is an ammonia toxicity impairment in the Gwynns Falls 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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