Watershed Report for Biological Impairment of the Patapsco Lower North Branch Watershed in Anne Arundel, Baltimore, Carroll, and Howard Counties and Baltimore City, Maryland
Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

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List of Abbreviations

ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
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
µeq/L	Micro equivalent per liter
µS/cm	Micro Seimens per centimeter
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

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

The Lower North Branch of the Patapsco River (Patapsco LNB) (basin code 02-13-09-06), located in Anne Arundel, Baltimore, Carroll, and Howard Counties and in Baltimore City, was identified on the Integrated Report under Category 5 as impaired by nutrients, sediments, and heavy metals (1996 listing); fecal coliform and impacts to biological communities (2002 listing); and polychlorinated biphenyls (PCBs) in fish tissue (2008 listing). All impairments are listed for 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 Patapsco LNB was delisted for heavy metals in 2005, following USEPA concurrence with the Maryland Department of Environment (MDE) analysis of heavy metal data collected during 2001-2002. The analysis showed no heavy metals impairment, except for Herbert Run where there are indications of levels of copper (Cu) and lead (Pb). A WQA for Herbert Run, requesting delisting for Cu and Pb, was included as an appendix to Maryland's 2008 Integrated Report, approved by USEPA in 2008. Herbert Run was delisted for Cu and Pb following USEPA approval.

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 are degraded, and calculating whether they differ significantly from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of the Patapsco LNB is Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life), with one tributary, Brice Run (and its tributaries), designated as Use III (Nontidal Cold Water) (COMAR 2008a,b,c). The Patapsco LNB watershed is not attaining its designated use of protection of aquatic life because of biological impairments. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors and the biological community, and the likely improvement of biology if a given stressor were removed.

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 under 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 Patapsco LNB 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 degradation of biological communities in the Patapsco LNB is strongly associated with 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 the Patapsco LNB, can be summarized as follows:

- The BSID analysis has determined that the biological communities in the Patapsco LNB are likely degraded due to inorganic pollutants (i.e., chlorides, conductivity, sulfate). 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 Patapsco LNB 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 2008 Category 5 listing for total suspended solids as an impairing substance in the Patapsco LNB, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Patapsco LNB 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 Patapsco LNB watershed based on channelization being present in approximately 41% of degraded stream miles.

- 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 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 under Category 5 of 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 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 Patapsco LNB watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Patapsco Lower North Branch Watershed Characterization

2.1 Location

The Patapsco LNB watershed is located in the Patapsco River region of the Chesapeake Bay watershed within Maryland (see Figure 1). The watershed covers portions of Anne Arundel, Baltimore, Carroll, and Howard Counties and Baltimore City and totals 75,800 acres. The Patapsco LNB watershed drains from northwest to southeast into the tidal portion of the Patapsco River main stem. The watershed area is located in two of three distinct eco-regions identified in the MBSS IBI metrics (Southerland et al. 2005) (see Figure 2).

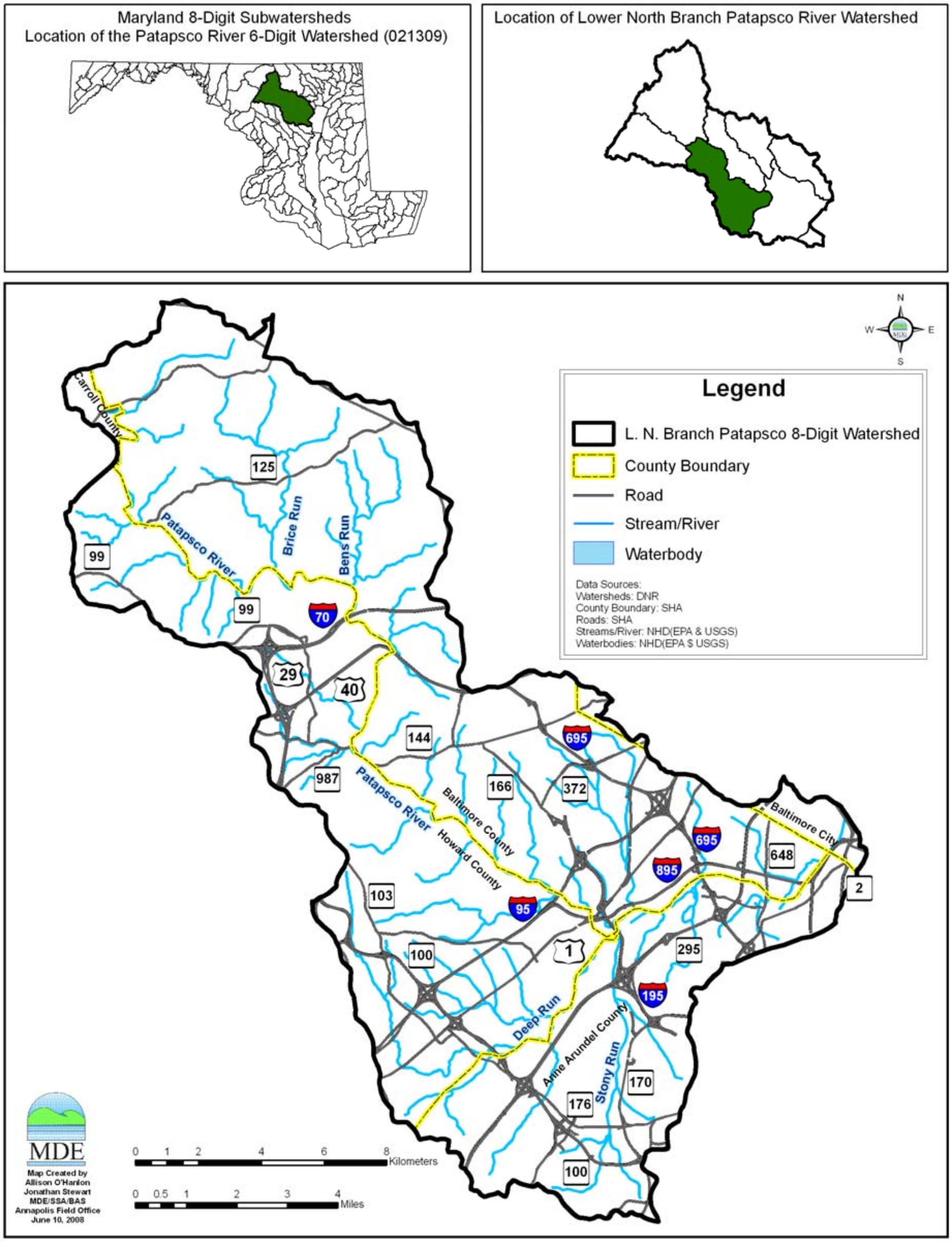


Figure 1. Location Map of the Patapsco Lower North Branch Watershed

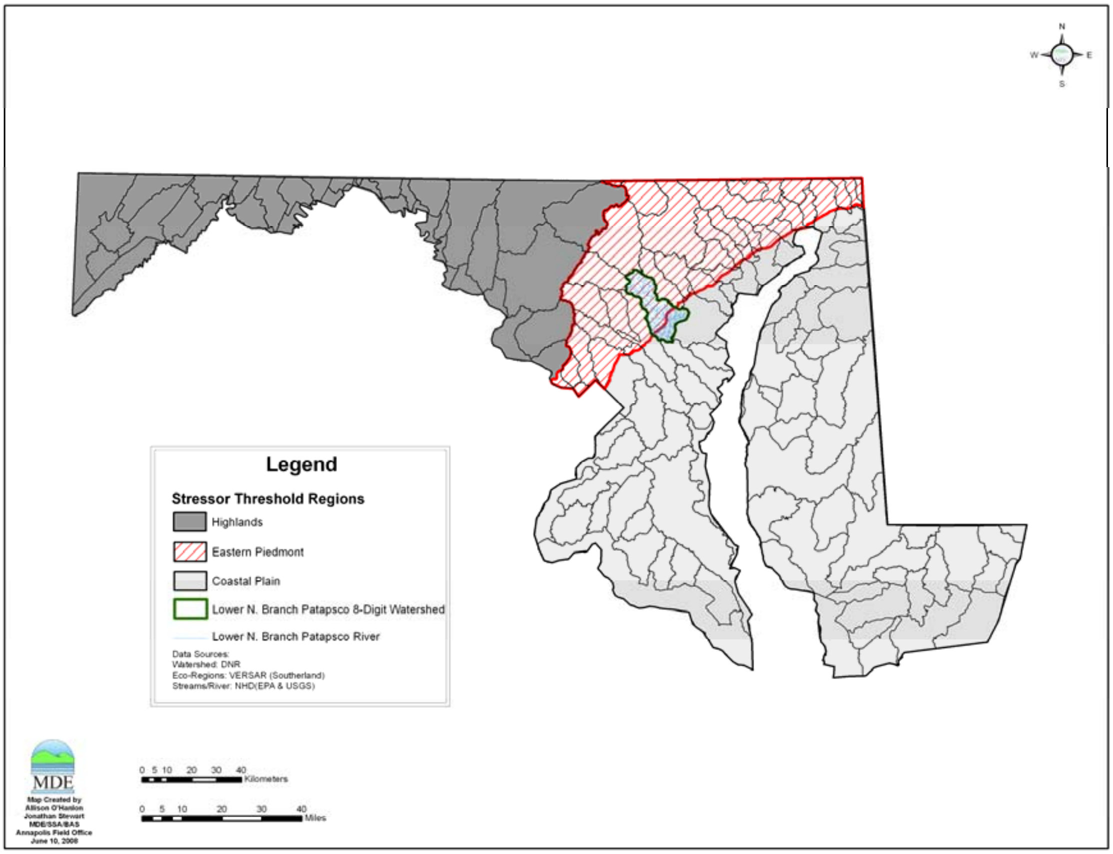


Figure 2. Eco-Region Location of Patapsco Lower North Branch Watershed

2.2 Land Use

The Patapsco LNB watershed contains mostly urban and forest land use (see Figure 3). The forested areas are mainly along the Patapsco River. The urban areas are more prevalent in the downstream portion of the watershed. The land use distribution in the watershed is approximately 50% urban; 39% forest/herbaceous; 10% agricultural; and 1% water. (see Figure 4) (MDP 2002).

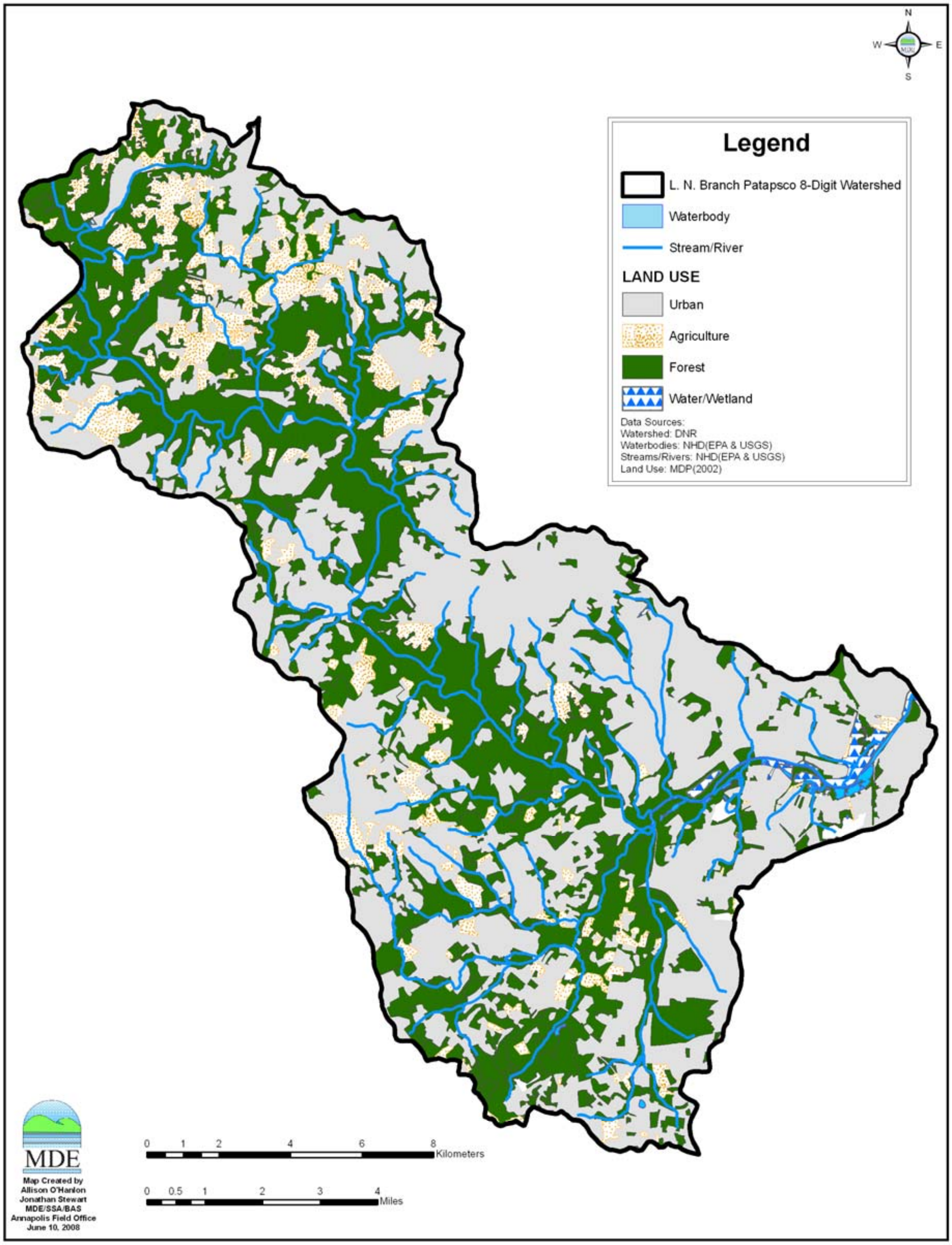


Figure 3. Land Use Map of the Patapsco Lower North Branch Watershed

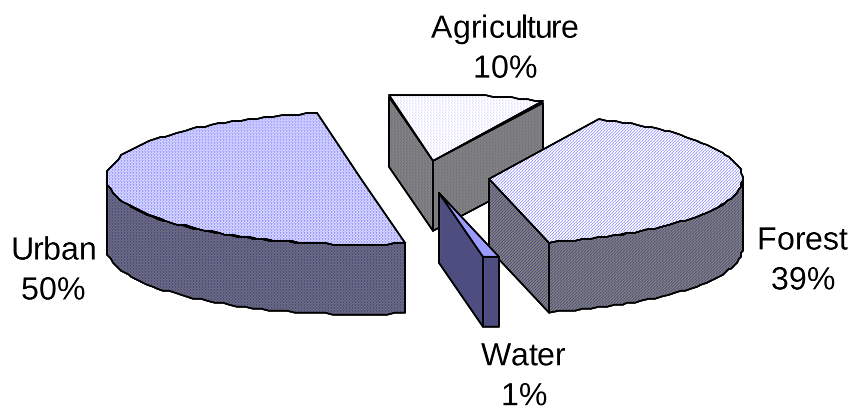


Figure 4. Proportions of Land Use in the Patapsco Lower North Branch Watershed

2.3 Soils/hydrology

The Patapsco LNB watershed lies within the Piedmont and Coastal Plain provinces of Central Maryland. The Piedmont province is characterized by gentle to steep rolling topography, low hills and ridges. The Coastal Plain province is characterized by broad upland areas with low slopes and gentle drainage.

The Patapsco LNB watershed drains from northwest to southeast, following the dip of the underlying crystalline bedrock in the Piedmont province. The surface elevations range from approximately 620 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 follow 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. Thick, unconsolidated marine sediments deposited over the crystalline rock of the Piedmont province characterize the Atlantic Coastal Plain province surficial geology. The deposits include clays, silts, sands and gravels (CES 1995).

The watershed is comprised primarily of B and C type soils with the soil distribution within the watershed being approximately 5.1% soil group A, 41.8% soil group B, 40.9% soil group C and 12.2% 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 Patapsco Lower North Branch Water Quality Characterization

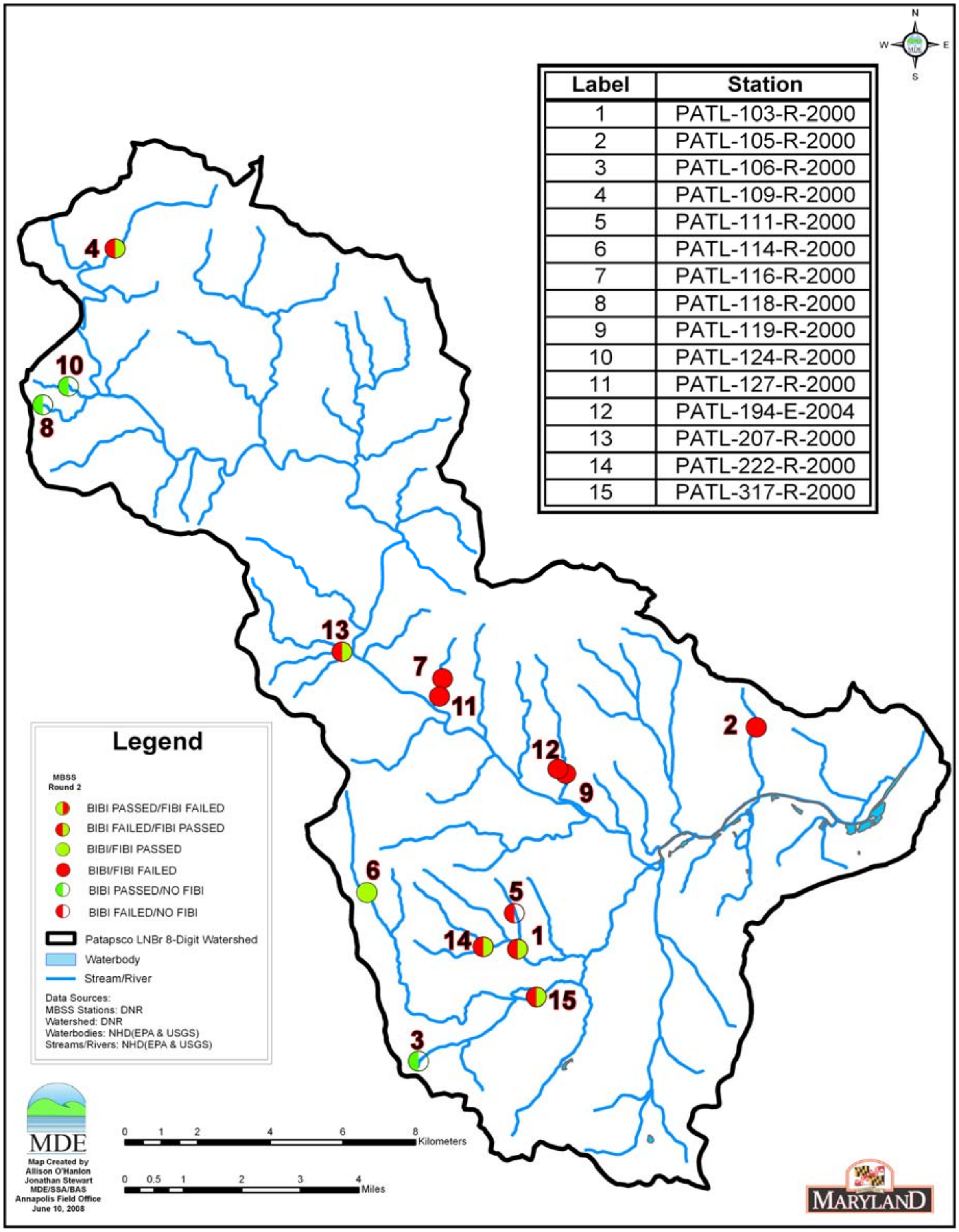
3.1 Integrated Report Impairment Listings

The Patapsco LNB was identified on Maryland's Integrated Report as impaired by nutrients, sediments, and heavy metals (1996 listing); fecal coliform and impacts to biological communities (2002 listing); and polychlorinated biphenyls (PCBs) in fish tissue (2008 listing). All impairments are listed for 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 Patapsco LNB was delisted for heavy metals in 2005, following USEPA concurrence with the Maryland Department of Environment (MDE) analysis of heavy metal data collected during 2001-2002. The analysis showed no heavy metals impairment, except for Herbert Run where there are indications of levels of copper (Cu) and lead (Pb). A WQA for Herbert Run, requesting delisting for Cu and Pb, was included as an appendix to Maryland's 2008 Integrated Report, approved by USEPA in 2008. Herbert Run was delisted for Cu and Pb following USEPA approval.

3.2 Biological impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of the Patapsco LNB is Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life), with one tributary, Brice Run (and its tributaries), designated as Use III *(*Nontidal Cold Water) (COMAR 2008a,b,c). 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 Patapsco LNB watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Greater than 69% of stream miles in the Patapsco LNB basin are estimated as degraded based on fish and and/or benthic indices of biological impairment in the very poor to poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include thirty-two sites. Twenty-two of the thirty-two have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., very poor to poor). The principal dataset contains fifteen MBSS sites, with twelve having degraded BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Patapsco LNB watershed.



Label	Station
1	PATL-103-R-2000
2	PATL-105-R-2000
3	PATL-106-R-2000
4	PATL-109-R-2000
5	PATL-111-R-2000
6	PATL-114-R-2000
7	PATL-116-R-2000
8	PATL-118-R-2000
9	PATL-119-R-2000
10	PATL-124-R-2000
11	PATL-127-R-2000
12	PATL-194-E-2004
13	PATL-207-R-2000
14	PATL-222-R-2000
15	PATL-317-R-2000

Figure 5. Principal Dataset Sites for the Patapsco Lower North Branch Watershed

4.0 Stressor Identification Results

The BSID process uses results from the BSID 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 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 degraded biological conditions. 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. 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. 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.

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) is the portion of the cases with very poor to poor biological conditions that are a result of 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 defined for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute

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

Through the BSID analysis, MDE identified habitat parameters, water chemistry parameters, and potential sources significantly associated with degraded 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 the Patapsco LNB. 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 attributable risk (AR) values for the stressor groups in the Patapsco LNB. Table 6 shows the summary of combined attributable risk (AR) values for the source groups in the Patapsco LNB.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Patapsco Lower North Branch

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	14	12	89	42%	13%	Yes	28%
	moderate bar formation present	14	12	89	100%	42%	Yes	58%
	bar formation present	14	12	89	100%	90%	No	----
	channel alteration marginal to poor	14	12	89	100%	41%	Yes	59%
	channel alteration poor	14	12	89	42%	12%	Yes	29%
	high embeddedness	14	12	89	17%	8%	No	----
	epifaunal substrate marginal to poor	14	12	89	17%	13%	No	----
	epifaunal substrate poor	14	12	89	8%	3%	No	----
	moderate to severe erosion present	14	12	89	50%	62%	No	----
	severe erosion present	14	12	89	25%	12%	No	----
	poor bank stability index	14	12	89	8%	5%	No	----
	silt clay present	14	12	89	92%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Patapsco Lower North Branch

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	15	12	90	50%	9%	Yes	41%
	instream habitat structure marginal to poor	14	12	89	8%	13%	No	----
	instream habitat structure poor	14	12	89	0%	1%	No	----
	pool/glide/eddy quality marginal to poor	14	12	89	33%	51%	No	----
	pool/glide/eddy quality poor	14	12	89	0%	1%	No	----
	riffle/run quality marginal to poor	14	12	89	33%	19%	No	----
	riffle/run quality poor	14	12	89	0%	1%	No	----
	velocity/depth diversity marginal to poor	14	12	89	25%	51%	No	----
	velocity/depth diversity poor	14	12	89	0%	0%	No	----
	concrete/gabion present	15	12	90	8%	1%	No	----
	beaver pond present	14	12	89	8%	4%	No	----
Riparian Habitat	no riparian buffer	15	12	90	33%	24%	No	----
	low shading	14	12	89	0%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Patapsco Lower North Branch

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	15	12	165	0%	47%	No	----
	high total disolved nitrogen	14	11	56	0%	45%	No	----
	ammonia acute with salmonid present	15	12	165	0%	5%	No	----
	ammonia acute with salmonid absent	15	12	165	0%	3%	No	----
	ammonia chronic with salmonid present	15	12	165	0%	15%	No	----
	ammonia chronic with salmonid absent	15	12	165	0%	4%	No	----
	low lab pH	15	12	165	0%	2%	No	----
	high lab pH	15	12	165	8%	2%	No	----
	low field pH	14	12	164	8%	4%	No	----
	high field pH	14	12	164	0%	2%	No	----
	high total phosphorus	15	12	165	8%	6%	No	----
	high orthophosphate	15	12	165	0%	8%	No	----
	dissolved oxygen < 5mg/l	14	12	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	14	12	164	0%	2%	No	----
	low dissolved oxygen saturation	14	12	152	0%	1%	No	----
	high dissolved oxygen saturation	14	12	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	15	12	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	15	12	165	0%	7%	No	----
	high chlorides	15	12	165	83%	5%	Yes	78%
	high conductivity	15	12	165	92%	6%	Yes	86%

	high sulfates	15	12	165	83%	4%	Yes	79%

Table 4. Stressor Source Identification Analysis Results for the Patapsco Lower North Branch

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	15	12	164	83%	3%	Yes	80%
	high % of high intensity urban in watershed	15	12	165	83%	21%	Yes	62%
	high % of low intensity urban in watershed	15	12	165	67%	5%	Yes	61%
	high % of transportation in watershed	15	12	165	50%	9%	Yes	41%
	high % of high intensity urban in 60m buffer	14	12	164	75%	4%	Yes	71%
	high % of low intensity urban in 60m buffer	14	12	164	83%	6%	Yes	77%
	high % of transportation in 60m buffer	14	12	164	67%	6%	Yes	61%
Sources – Agriculture	high % of agriculture in watershed	15	12	165	0%	22%	No	----
	high % of cropland in watershed	15	12	165	0%	3%	No	----
	high % of pasture/hay in watershed	15	12	165	0%	29%	No	----
	high % of agriculture in 60m buffer	14	12	164	0%	13%	No	----
	high % of cropland in 60m buffer	14	12	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	14	12	164	0%	23%	No	----
Sources – Barren Land	high % of barren land in watershed	15	12	165	8%	10%	No	----
	high % of barren land in 60m buffer	14	12	164	8%	10%	No	----

Table 4. Stressor Source Identification Analysis Results for the Patapsco Lower North Branch (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 – Anthropogenic	low % of forest in watershed	15	12	165	33%	8%	Yes	25%
	low % of forest in 60m buffer	14	12	164	58%	9%	Yes	50%
Sources – Acidity	atmospheric deposition present	15	12	165	0%	5%	No	----
	AMD acid source present	15	12	165	0%	0%	No	----
	organic acid source present	15	12	165	0%	0%	No	----
	agricultural acid source present	15	12	165	0%	2%	No	----

Table 5. Summary of Combined Attributable Risk Values for the Stressor Groups in the Patapsco Lower North Branch

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	70%	93%
In-Stream Habitat	41%	
Riparian Habitat	----	
Water Chemistry	87%	

Table 6. Summary of Combined Attributable Risk Values for the Source Groups in the Patapsco Lower North Branch

<table>
<tr><th>Source Group</th><th colspan="2">Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)</th></tr>
<tr><td>Urban</td><td>89%</td><td rowspan="5">89%</td></tr>
<tr><td>Agriculture</td><td>----</td></tr>
<tr><td>Barren Land</td><td>----</td></tr>
<tr><td>Anthropogenic</td><td>50%</td></tr>
<tr><td>Acidity</td><td>----</td></tr>
</table>

Sediment Conditions

BSID analysis results for the Patapsco LNB identified four sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *channel alteration (marginal to poor* & *poor), and bar formation present (moderate & extensive).*

Channel alteration was identified as significantly associated with degraded biological conditions in the Patapsco LNB, and found to impact approximately 59% (*moderate to poor* rating) and 29% (*poor* rating) of the stream miles with poor to very poor biological conditions. *Channel alteration* measures large-scale modifications in the shape of the stream channel due to the presence of artificial structures (channelization) and/or bar formations. Marginal to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Bar formation was identified as significantly associated with degraded biological conditions and found in 55% (*moderate* rating) and 28% (*extensive* rating) of the stream miles with very poor to poor biological conditions in the Patapsco LNB. This stressor measures the movement of sediment in a stream system, and typically results from significant deposition of gravel and fine sediments. Although some bar formation is natural, extensive bar formation indicates channel instability related to frequent and intense high flows that quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions.

As development and urbanization increase in a watershed so do 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 accompany urbanization alter 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, and causing them 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 widening 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. 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). The combination of the altered flow regime and increased sediment results in an unstable stream ecosystem, characterized by a more homogenous habitat and 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 improvement of degraded stream miles, very poor to poor biological conditions, if the sediment stressor were removed. The combined AR for this stressor group (sediment) is approximately 70% suggesting that this stressor group impacts the majority of degraded stream miles in the Patapsco LNB (Table 5).

In-Stream Habitat Conditions

BSID analysis results for the Patapsco LNB identified one in-stream habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *channel alteration present.*

Channelization present was identified as significantly associated with degraded biological conditions and found in 41% of the stream miles with very poor to poor biological conditions in the Patapsco LNB. This stressor measures the presence/absence of channelization in stream banks. 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. Fortification of channels with concrete and other hard materials changes the in-stream habitat conditions within a stream that can potentially lead to loss of available habitat.

The combined AR is used to measure the improvement of degraded stream miles, very poor to poor biological conditions, if the altered habitat conditions were removed. The combined AR for this stressor group (in-stream habitat) is approximately 41% suggesting that this stressor group impacts a significant percentage of degraded stream miles in the Patapsco LNB (Table 5).

Riparian Habitat Conditions

BSID analysis results for the Patapsco LNB 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 Patapsco LNB 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 improved biological community). These parameters are *high conductivity*, *high chlorides*, and *high sulfates.*

High conductivity was identified as significantly associated with degraded biological conditions and found in 86% of the stream miles with very poor to poor biological conditions in the Patapsco LNB. Conductivity, chlorides and sulfates are closely related. Streams with elevated levels of chlorides and sulfates typically display high conductivity. 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).

High chlorides was identified as significantly associated with degraded biological conditions and found in 78% of the stream miles with very poor to poor biological conditions in the Patapsco LNB. 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 six minor industrial facilities that are regulated for various parameters including metals, temperature, and pH. Since 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. The Patapsco LNB was de-listed for heavy metals in 2005 following USEPA concurrence with MDE's analysis of heavy metals data collected during 2001-2002, which showed no heavy metals impairment, except for Herbert Run where there were indications of copper (Cu) and lead (Pb). Water column surveys conducted at four monitoring stations in the Patapsco LNB River from May 2001 to April 2002 were used to support this WQA. For every sample, dissolved concentrations of nine metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn) were determined. A WQA for Herbert Run, requesting delisting for Cu and Pb, was included as an appendix to Maryland's 2008 Integrated Report, approved by USEPA in 2008. Herbert Run was delisted for Cu and Pb following USEPA approval. 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 chloride can originate from natural sources and point source discharges, usually most of the chloride that enters the environment is associated with the storage and application of road salt (Smith et al. 1987). 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 (Church and Friesz 1993).

High sulfate was identified as significantly associated with degraded biological conditions and found in 79% of the stream miles with very poor to poor biological conditions in the Patapsco LNB. Sulfate in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. There are six minor NPDES industrial facilities that are regulated for various parameters including metals, temperature, and pH. Since NPDES permitting enforcement does not require sulfate testing at any of these facilities, data were not available to verify/identify sulfate as a specific pollutant in this watershed.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Land development causes an increase in contaminant loads from point and nonpoint sources by adding sediments, nutrients, road salts, toxics, petroleum products, and inorganic pollutants to surface and ground waters. Increased levels of many pollutants like chlorides and sulfates can be toxic to aquatic organisms and lead to exceedances in species tolerances.

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) from the array of potential inorganic pollutants inferred from the BSID analysis.

The combined AR is used to measure the improvement of degraded stream miles, very poor to poor biological conditions, if the inorganic pollutant stressors were removed. The combined AR for this stressor group (water chemistry) is approximately 87% suggesting that this stressor group impacts a significant percentage of degraded stream miles in the Patapsco LNB (Table 5).

Sources

All nine stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Patapsco LNB watershed BSID analysis are representative of impacts from 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 by adding sediments, road salts, toxics, and inorganic pollutants to surface waters. In virtually all studies, as the amount of impervious area in a watershed increases, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The BSID source analysis (Table 4) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for this source group is approximately 89% suggesting that urban development potentially impact almost all the degraded stream miles in the Patapsco LNB (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Patapsco LNB watershed are a result of increased urban land use causing alteration to hydrology and leading to loss of optimal habitat. The increased urbanization also results in an increase in contaminant loads from point and nonpoint sources by adding sediments, road salts, toxics, and inorganic pollutants to surface waters. Alterations to the hydrologic regime, physical habitat, and water chemistry, have all combined to degrade the Patapsco LNB, leading to a loss of diversity in the biological community.

In summary, the altered hydrology has caused frequent high flow events and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat and experiences continuous displacement of biological communities that require frequent re-colonization. Due to the increased proportions of urban land use in the Patapsco LNB, 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. The combined AR for all the stressors is approximately 93%, suggesting that sediment, in-stream habitat and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Patapsco LNB (Table 5).

Final Causal Model for the Patapsco Lower North Branch

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

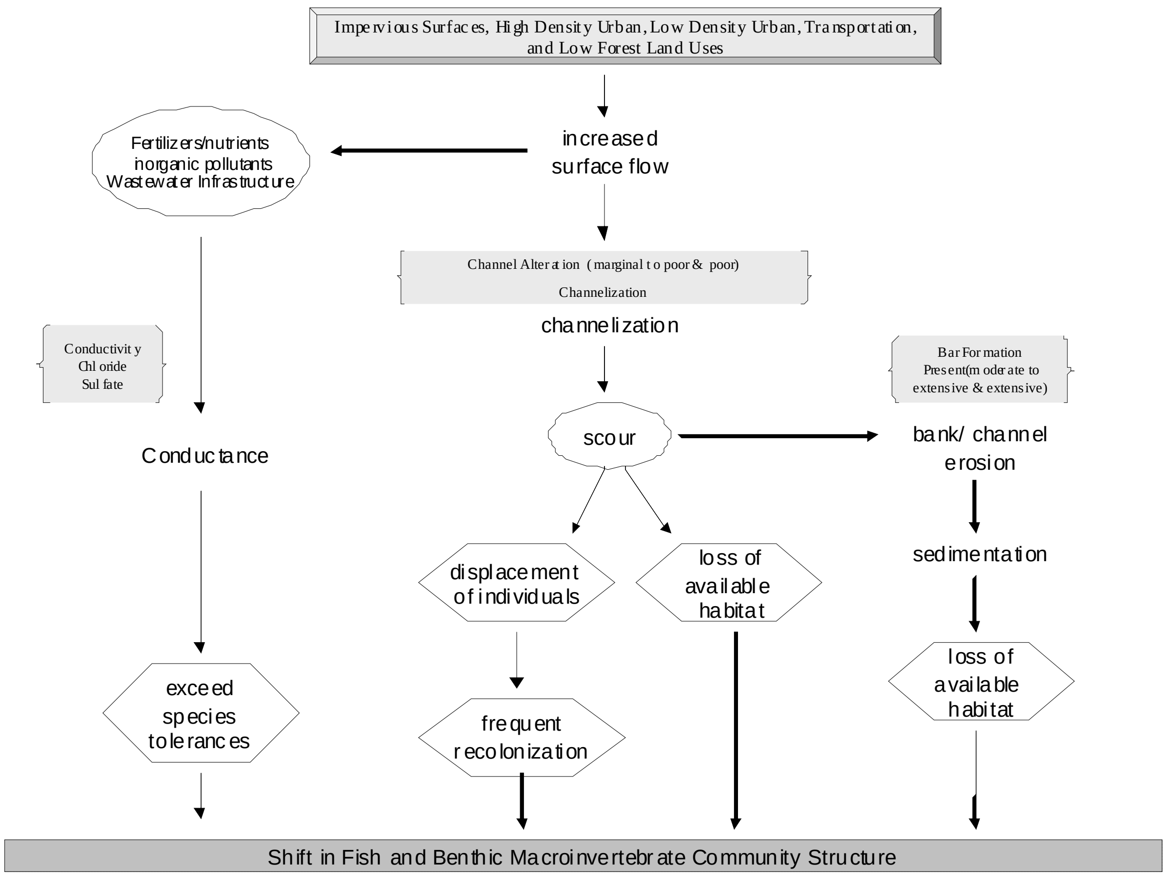


Figure 6. Final Causal Model for the Patapsco Lower North Branch Watershed

5.0 Conclusions

Data suggest that the Patapsco LNB 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 Patapsco LNB are summarized as follows:

- The BSID analysis has determined that the biological communities in the Patapsco LNB are likely degraded due to inorganic pollutants (i.e., chlorides, conductivity, sulfate). 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 Patapsco LNB 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 2008 Category 5 listing for total suspended solids as an impairing substance in the Patapsco LNB, and link this pollutant to biological conditions in these waters.

- The BSID process has also determined that biological communities in the Patapsco LNB 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 Patapsco LNB watershed based on channelization being present in approximately 41% of degraded stream miles.

- 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 present and/or nutrient stressors showing a significant association with degraded biological conditions.

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