Watershed Report for Biological Impairment of the Liberty Reservoir Watershed in Baltimore and Carroll Counties, Maryland
Biological Stressor Identification Analysis
Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
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 Siemens per centimeter
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
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 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 Liberty Reservoir watershed (basin code 02130907), located in Baltimore and Carroll Counties, was identified on the Integrated Report under Category 5 as impaired by chromium (Cr), lead (Pb), nutrients, suspended sediments (1996 listings), methylmercury (2002 listing), and fecal coliform and evidence of biological impacts (2004 listings) (MDE 2010). The Cr, Pb, nutrients, suspended sediment and methylmercury impairments were listed for the impoundment, and the fecal coliform and biological impairments were listed for the non-tidal streams. The 1996 nutrients listing was refined in the 2008 Report and phosphorus was identified as the specific impairing substance in the impoundment. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids in the impoundment. The Cr and Pb impairments in the impoundment were delisted by way of a WQA submitted to the USEPA in 2003. A TMDL for methylmercury in fish tissue in the impoundment was submitted to the USEPA in 2002. A TMDL for fecal coliform, for the non-tidal streams, to address the 2002 bacteria listing was submitted to the USEPA in 2008.

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score less than 3, and calculating whether this is significantly different 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 Liberty Reservoir and all tributaries upstream have been designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply*. Middle Run from the headwaters to the confluence with Prugh Branch, and an unnamed tributary of Little Morgan have been designated as Use I - *water contact recreation and* *protection of warmwater aquatic life.* Roaring Run has been designated as Use III – *nontidal cold water*. Beaver Run, Cooks Branch, East Branch Patapsco River, Keysers Run, Locust Run, Morgan Run, Norris Run, Snowdens Run and all their tributaries have been designated as Use III-P – *nontidal cold water and public water supply*. The mainstem of the North and West Branches of the Patapsco River above Liberty Reservoir, and Cranberry Branch and its tributaries have been designated as Use IV-P – *recreational trout waters and public water supply* (COMAR 2009 a, b, c, d, e). The Liberty Reservoir 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, sources of stressors and the biological community, and the likely impact these stressors would have on the degraded sites in the watershed.

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

This Liberty Reservoir 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 2010). Data suggest that the degradation of biological communities in the Liberty Reservoir watershed is strongly influenced by urban land use and its concomitant effects: altered hydrology and elevated levels of nutrients, inorganic pollutants and conductivity (a measure of the presence of dissolved substances). The urban development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized and agricultural landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process has determined that the biological communities in the Liberty Reservoir watershed are likely degraded due to inorganic pollutants (i.e., chlorides). Chloride levels are significantly associated with degraded biological conditions and found in approximately 55% of the stream miles with poor to very poor biological conditions in the Liberty Reservoir watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listing of chloride for the watershed.
- There is presently a Category 5 listing for phosphorus (impoundment) in Maryland’s 2010 Integrated Report; BSID analysis identified TN, not phosphorus, as a potential water chemistry stressor in the Liberty Reservoir watershed. The presence of TN in the Liberty Reservoir watershed shows a possible association (33% of stream miles) with degraded biological conditions. Because nitrogen generally exists in quantities greater than necessary to sustain algal growth, excess nitrogen per se is not the cause of the biological impairment in the Liberty Reservoir watershed. MDE considers phosphorus to be the limiting nutrient species in an ecosystem, and since phosphorus was not identified as a potential stressor, reduction of nitrogen loads would not be an effective means of ensuring that the watershed is free from impacts on aquatic life from eutrophication.

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 2010). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two Maryland Biological Stream Survey (MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Liberty Reservoir watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Liberty Reservoir Watershed Characterization

2.1 Location

The Liberty Reservoir watershed is located within Baltimore (17%) and Carroll (83%) Counties, Maryland. The North Branch Patapsco River is the main tributary flowing into the watershed; the stream system then empties into the Maryland 8-Digit Lower Patapsco River watershed (see Figure 1). The river's west branch begins north of Westminster and the east branch begins south of Manchester. Flowing south, the river becomes Liberty Reservoir, a 3,100-acre drinking water supply (and recreational impoundment) for Carroll and Baltimore Counties, and Baltimore City. The major tributaries include Beaver Run, Morgan Run, Middle Run, and Little Morgan Run. The drainage area of the Maryland 8-digit watershed Liberty Reservoir is 101,400 acres. The watershed is located the Eastern Piedmont region, one of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005a) (see Figure 2).

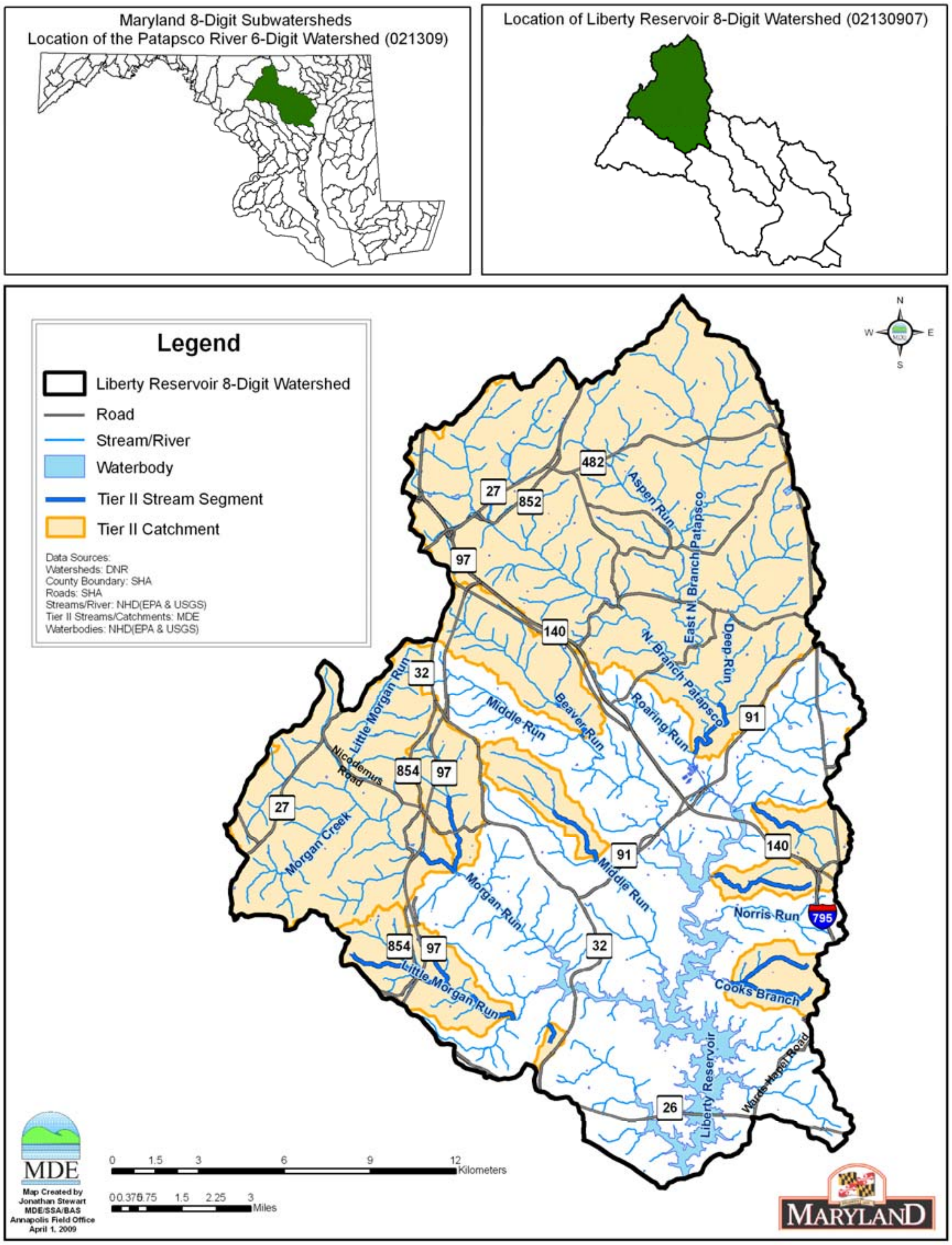

Figure 1. Location Map of the Liberty Reservoir Watershed

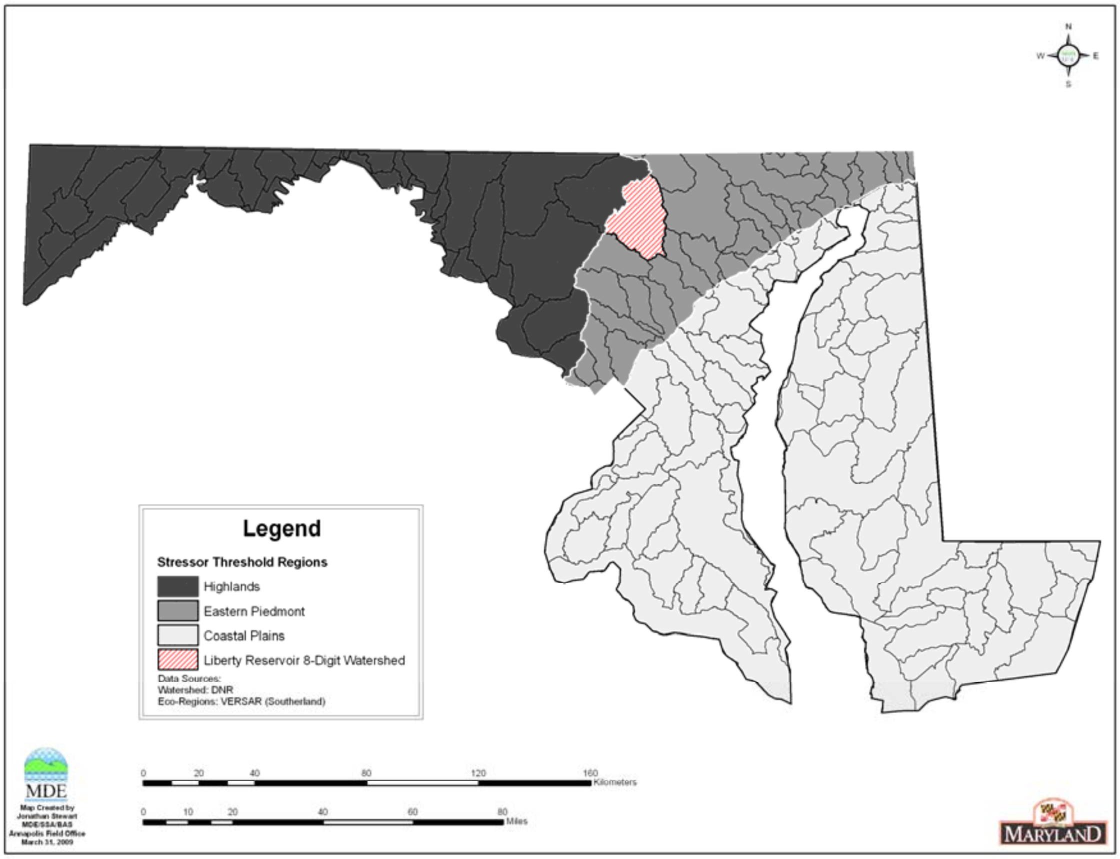

Figure 2. Eco-Region Map of the Liberty Reservoir Watershed

2.2 Land Use

The Liberty Reservoir watershed lies entirely in the Piedmont Plateau Physiographic Province. This province is characterized by gentle to steep rolling topography, low hills, and ridges. The Liberty Reservoir watershed contains primarily agricultural land use, specifically cropland and livestock/feeding operations (see Figure 3). There are three large urban areas within the watershed including Hampstead, Manchester, and Westminster, and two smaller urban areas, Eldersburg, Finksburg, and Reisterstown. Interstate 795 and other State and county paved roads (i.e., Routes 26, 27, 32, 97, and 140) connect urban areas within the region. Maryland Routes 26 and 140 cross over the Liberty Reservoir impoundment. Forests are located primarily around Liberty Reservoir, maintained by the City of Baltimore to protect the quality of the drinking water, and along Morgan Run tributary. Two Natural Environmental Areas (NEAs) are located within the watershed, Morgan Run NEA and Soldier's Delight NEA southeast of the impoundment. The land use distribution in the watershed is approximately 39% agriculture/pasture, 31% forest/herbaceous, 27% urban, and 3% water (see Figure 4)

(MDP 2002). Urban impervious surface is 3% of the total land use in the watershed (USEPA 2008).

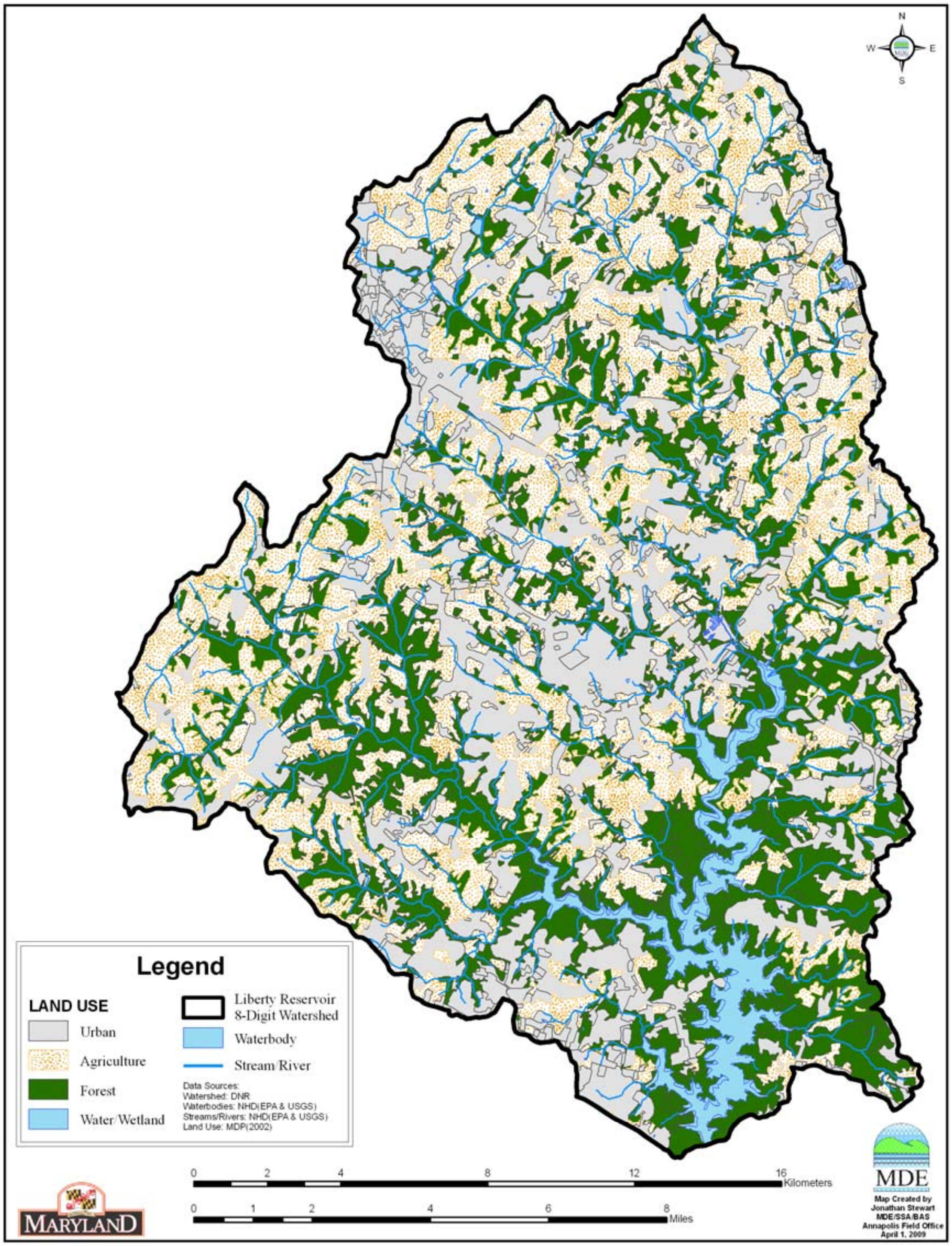

Figure 3. Land Use Map of the Liberty Reservoir Watershed

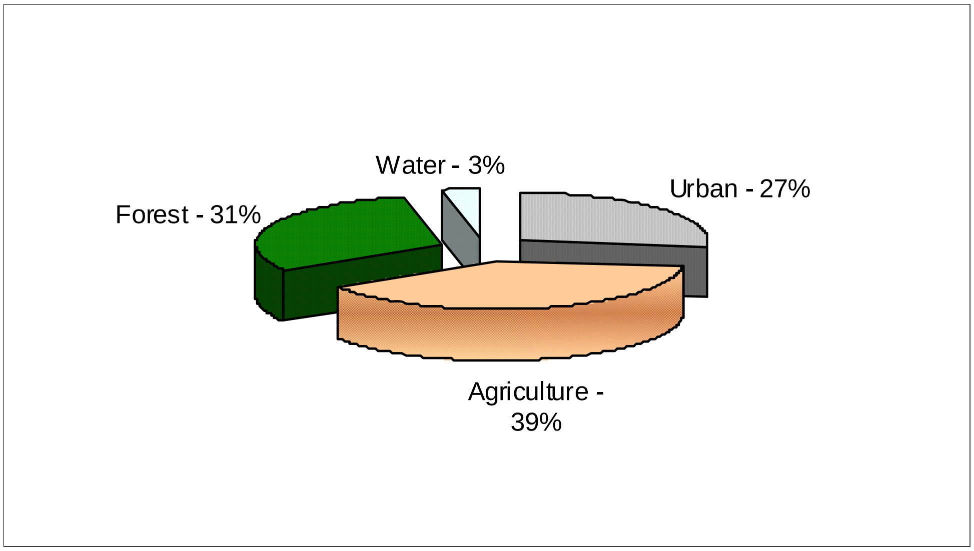

Figure 4. Proportions of Land Use in the Liberty Reservoir Watershed

2.3 Soils/hydrology

The Liberty Reservoir watershed lies within the north central Piedmont Plateau Physiographic Province and is characterized by gentle to steep rolling topography, low hills and ridges. Hard, crystalline igneous and metamorphic rocks of volcanic origin consisting primarily of schist and gneiss characterize the surficial geology of the watershed (Edwards 1981). The watershed drains in a northwest to southeast direction, following the dip of the underlying crystalline bedrock in the province. The surface elevations range from approximately 980 feet to 420 feet at the Liberty Reservoir Spillway. Stream channels of the sub-watersheds are well incised in the Eastern Piedmont, and exhibit relatively straight reaches and sharp bends, reflecting their tendency to following zones of fractured or weathered rock (CES 1995).

3.0 Liberty Reservoir Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Maryland Department of the Environment has identified the waters of Liberty Reservoir on the State's Integrated Report under Category 5 as impaired by chromium (Cr), lead (Pb), nutrients, suspended sediments (1996 listings), methylmercury (2002 listing), and fecal coliform and evidence of biological impacts (2004 listings). The Cr, Pb, nutrients, suspended sediment and methylmercury impairments were listed for the impoundment, and the fecal coliform and biological impairments were listed for the non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance in the impoundment. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids in the impoundment. The Cr and Pb impairments in the impoundment were delisted by way of a WQA submitted to the USEPA in 2003. A TMDL for methylmercury in fish tissue in the impoundment was submitted to the USEPA in 2002. A TMDL for fecal coliform, for the non-tidal streams, to address the 2002 bacteria listing was submitted to the USEPA in 2008.

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Liberty Reservoir watershed and all tributaries upstream have been designated as Use I-P – *water contact recreation, protection of aquatic life, and public water supply*. Middle Run from the headwaters to the confluence with Prugh Branch, and an unnamed tributary of Little Morgan have been designated as Use I - *water contact recreation and protection of warmwater aquatic life.* Roaring Run has been designated as Use III – *nontidal cold water*. Beaver Run, Cooks Branch, East Branch Patapsco River, Keysers Run, Locust Run, Morgan Run, Norris Run, Snowdens Run and all their tributaries have been designated as Use III-P – *nontidal cold water and public water supply*. The mainstem of the North and West Branches of the Patapsco River above Liberty Reservoir, and Cranberry Branch and its tributaries have been designated as Use IV-P – *recreational trout waters and public water supply* (COMAR 2009 a, b, c, d, e). 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 Liberty Reservoir watershed is designated as a Tier II (i.e., Maryland's antidegradation policy) waterbody; this Tier II designation protects surface water that is better than the minimum requirements specified by water quality standards. Liberty Reservoir watershed's Tier II catchments are Cooks Branch, Beaver Run, Joe Branch, Keysers Run, Little Morgan, Middle Run, Morgan Run, North Branch Patapsco, and the North Branch Patapsco UT (COMAR 2009f).

The Liberty Reservoir watershed is listed under Category 5 of the 2010 Integrated Report as impaired for impacts to biological communities. Approximately 22% of stream miles in the Liberty Reservoir watershed are estimated as having fish and/or benthic indices of biological impairment in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include seventy-four stations. Fourteen of the seventy-four 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, i.e. MBSS Round 2, contains thirty-eight sites; with ten having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Liberty Reservoir watershed.

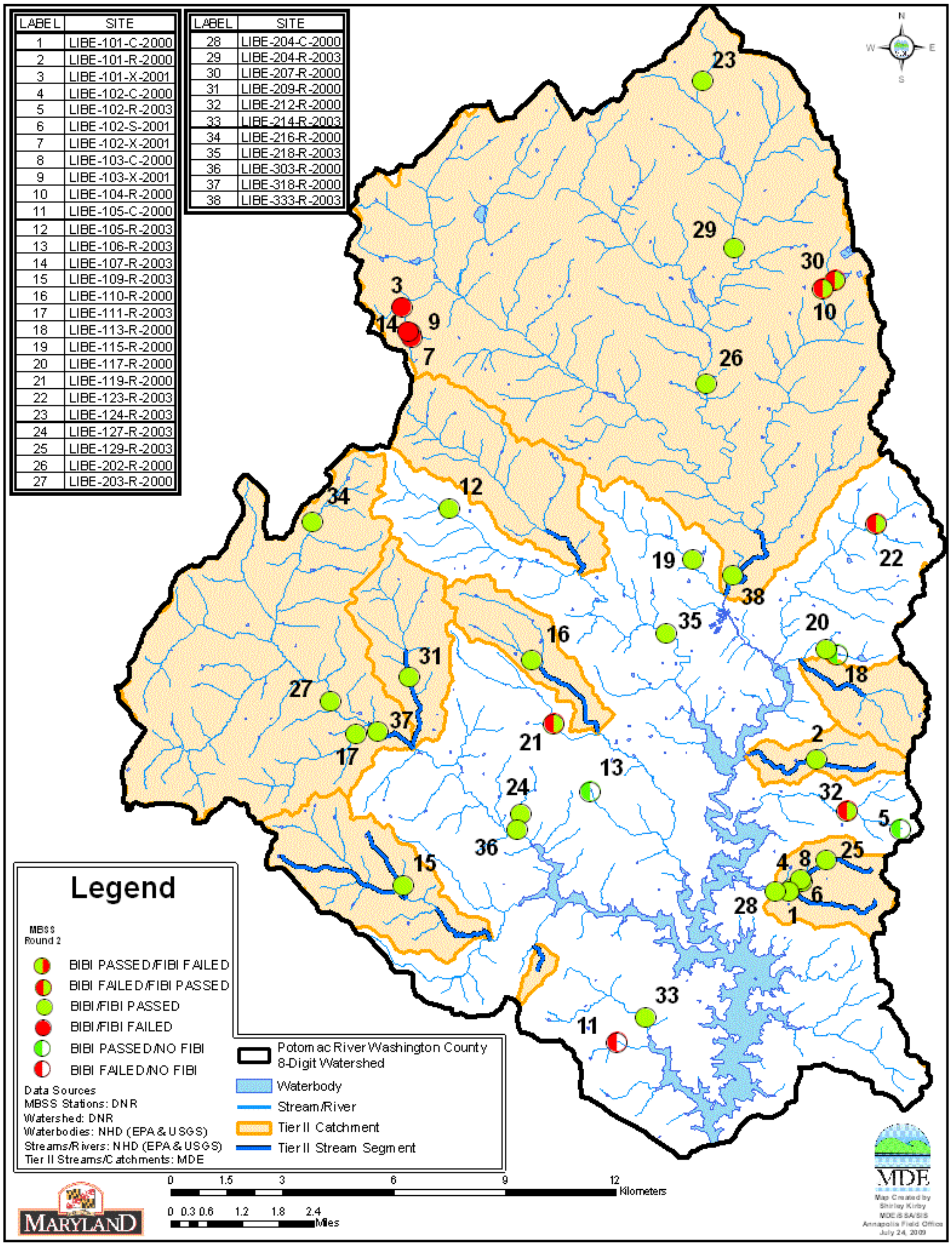

Figure 5. Principal Dataset Sites for the Liberty Reservoir Watershed

4.0 Stressor Identification Results

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

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenszel (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 poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are 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 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 2010).

Through the BSID data analysis, MDE identified 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, but only parameters from the water chemistry group are identified as possible biological stressors in the Liberty Reservoir watershed. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. Table 5 shows the summary of combined attributable risk (AR) values for the stressor groups in the Liberty Reservoir watershed. Table 6 shows the summary of combined attributable risk (AR) values for the source groups in the Liberty Reservoir watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Liberty Reservoir Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata1 with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	38	10	90	20%	13%	No	----
	moderate bar formation present	38	10	90	60%	41%	No	----
	bar formation present	38	10	90	100%	90%	No	----
	channel alteration moderate to poor	38	10	90	60%	40%	No	----
	channel alteration poor	38	10	90	0%	12%	No	----
	high embeddedness	38	10	90	0%	8%	No	----
	epifaunal substrate marginal to poor	38	10	90	20%	14%	No	----
	epifaunal substrate poor	38	10	90	0%	3%	No	----
	moderate to severe erosion present	38	10	90	80%	62%	No	----
	severe erosion present	38	10	90	10%	12%	No	----
	poor bank stability index	38	10	90	0%	6%	No	----
	silt clay present	38	10	90	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Liberty Reservoir Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds or 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	38	10	91	10%	9%	No	----
	instream habitat structure marginal to poor	38	10	90	20%	13%	No	----
	instream habitat structure poor	38	10	90	0%	1%	No	----
	pool/glide/eddy quality marginal to poor	38	10	90	50%	53%	No	----
	pool/glide/eddy quality poor	38	10	90	0%	1%	No	----
	riffle/run quality marginal to poor	38	10	90	20%	19%	No	----
	riffle/run quality poor	38	10	90	0%	1%	No	----
	velocity/depth diversity marginal to poor	38	10	90	40%	53%	No	----
	velocity/depth diversity poor	38	10	90	0%	0%	No	----
	concrete/gabion present	38	10	91	0%	1%	No	----
	beaver pond present	38	10	90	0%	4%	No	----
Riparian Habitat	no riparian buffer	38	10	91	20%	25%	No	----
	low shading	38	10	90	10%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Liberty Reservoir Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds or 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	38	10	165	80%	47%	Yes	33%
	high total dissolved nitrogen	20	5	56	60%	45%	No	----
	ammonia acute with salmonid present	38	10	165	30%	5%	Yes	25%
	ammonia acute with salmonid absent	38	10	165	30%	3%	Yes	27%
	ammonia chronic with salmonid present	38	10	165	40%	15%	Yes	25%
	ammonia chronic with salmonid absent	38	10	165	30%	4%	Yes	26%
	low lab pH	38	10	165	0%	2%	No	----
	high lab pH	38	10	165	0%	2%	No	----
	low field pH	38	10	164	0%	4%	No	----
	high field pH	38	10	164	0%	2%	No	----
	high total phosphorus	38	10	165	10%	6%	No	----
	high orthophosphate	38	10	165	10%	8%	No	----
	dissolved oxygen < 5mg/l	38	10	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	38	10	164	0%	2%	No	----
	low dissolved oxygen saturation	35	10	152	0%	1%	No	----
	high dissolved oxygen saturation	35	10	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	38	10	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	38	10	165	0%	7%	No	----
	high chlorides	38	10	165	60%	5%	Yes	55%
	high conductivity	38	10	165	50%	6%	Yes	44%
	high sulfates	38	10	165	10%	4%	No	----

Table 4. Stressor Source Identification Analysis Results for the Liberty Reservoir Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	38	10	164	50%	3%	Yes	47%
	high % of high intensity urban in watershed	38	10	165	90%	21%	Yes	69%
	high % of low intensity urban in watershed	38	10	165	40%	5%	Yes	35%
	high % of transportation in watershed	38	10	165	60%	9%	Yes	51%
	high % of high intensity urban in 60m buffer	38	10	164	50%	4%	Yes	46%
	high % of low intensity urban in 60m buffer	38	10	164	40%	6%	Yes	34%
	high % of transportation in 60m buffer	38	10	164	20%	6%	No	----
Sources Agriculture	high % of agriculture in watershed	38	10	165	0%	22%	No	----
	high % of cropland in watershed	38	10	165	0%	3%	No	----
	high % of pasture/hay in watershed	38	10	165	0%	29%	No	----
	high % of agriculture in 60m buffer	38	10	164	10%	13%	No	----
	high % of cropland in 60m buffer	38	10	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	38	10	164	30%	23%	No	----
Sources Barren	high % of barren land in watershed	38	10	165	0%	10%	No	----
	high % of barren land in 60m buffer	38	10	164	0%	10%	No	----
Sources Anthropogenic	low % of forest in watershed	38	10	165	70%	8%	Yes	62%
	low % of forest in 60m buffer	38	10	164	80%	9%	Yes	71%
Sources Acidity	atmospheric deposition present	38	10	165	0%	5%	No	----
	AMD acid source present	38	10	165	0%	0%	No	----
	organic acid source present	38	10	165	0%	0%	No	----
	agricultural acid source present	38	10	165	0%	2%	No	----

Table 5. Summary of Combined Attributable Risk Values of the Stressor Group in the Liberty Reservoir Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	----	75%
Instream Habitat	----	
Riparian Habitat	----	
Water Chemistry	75%	

Table 6. Summary of Combined Attributable Risk Values of the Source Group in the Liberty Reservoir Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	83%	84%
Agriculture	----	
Barren Land	----	
Anthropogenic	72%	
Acidity	----	

<u>Sediment Conditions</u>

BSID analysis results for the Liberty Reservoir watershed did not identify sediment parameters that have statistically significant associations with poor to very poor stream biological condition.

Instream Habitat Conditions

BSID analysis results for the Liberty Reservoir watershed did not identify instream habitat parameters that have statistically significant associations with poor to very poor stream biological condition.

Riparian Habitat Conditions

BSID analysis results for the Liberty Reservoir watershed did not identify riparian habitat parameters that have statistically significant associations with poor to very poor stream biological condition.

Water Chemistry

BSID analysis results for the Liberty Reservoir watershed identified seven water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high total nitrogen, acute ammonia (with salmonid present and salmonid absent), chronic ammonia (with salmonid present and salmonid absent), high chlorides, and high conductivity.*

High total nitrogen (TN) concentrations are significantly associated with degraded biological conditions and found in 33% of the stream miles with poor to very poor biological conditions in the Liberty Reservoir watershed. This stressor is a measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedences of dissolved oxygen and pH levels. Runoff and leaching from agricultural land can generate high in-stream levels of nitrogen.

Ammonia (NH_3) *acute* concentrations were identified as significantly associated with degraded biological conditions in Liberty Reservoir watershed, and found to impact approximately 25% (*with salmonid present*) and 27% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. Acute NH_3 toxicity refers to potential exceedences of species tolerance caused by one-time, sudden, high exposure of NH_3. NH_3 acute with salmonid present and absent is a USEPA water quality criterion for NH_3 concentrations causing acute toxicity in surface waters where salmonid species of fish are present and absent (USEPA 2006). The NH_3 parameter is the measure of the amount of NH_3 in the water column. NH_3 is a nitrogen nutrient species; in excessive amounts it has potential toxic effects on aquatic life. NH_3 is associated with increased primary production, increased pH, increased sunlight exposure, and high water temperature. Increased nutrient loads from urban and agricultural development are a source of NH_3.

Ammonia chronic concentrations were identified as significantly associated with degraded biological conditions in Liberty Reservoir watershed, and found to impact approximately 25% (*with salmonid present*) and 26% (*with salmonid absent*) of the stream miles with poor to very poor biological conditions. Chronic NH_3 toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time, see USEPA 2006 reference.

Non-point source discharges are a potential source of pollutants (e.g., nutrient and suspended solids) to surface waters; they do not have one discharge point but occur over the entire length of a stream or waterbody. During rain events, surface runoff transports water over the land surface and discharges to the stream system. This transport is dictated by rainfall, soil type, land use, and topography of the watershed. The Liberty Reservoir watershed is comprised of 27% urban land use, it is located in Baltimore and Carroll Counties, both counties have individual National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permits. An MS4 is a conveyance or system of conveyances (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains) designed or used for collecting or conveying stormwater and delivering it to a waterbody. Stormwater runoff is an important source of water pollution;j MS4 programs are designed to reduce the amount of pollution that enters a waterbody from storm sewer systems to the maximum extent feasible. Roads tend to capture and export more stormwater pollutants than other land covers; as rainfall amounts become larger, previously pervious areas in most residential areas become more significant sources of runoff, sediment, nutrients, and landscaping chemicals (NRC 2008). Statements and information provided to MDE by the two Counties characterize much of the Liberty Reservoir watershed as essentially outside the reach of each County's stormwater system management plan (with the exception of the Westminster, Hampstead, and Manchester Phase II areas, and the Eldersburg Phase I urban area) (MDE 2008).

Non-point source contributions also arise from failing septic systems and their associated drain fields or from leaking infrastructure (i.e., sewer systems) (MDE 2008). The Liberty Reservoir watershed is serviced by both sewer systems and septic systems. Sewer systems are either present or planned in the towns of Westminster, Manchester, Hampstead, and Eldersburg, but the wastewater treatment plants (WWTPs) for these towns do not fall within the Liberty Reservoir watershed. On-site disposal (septic) systems are located throughout the Liberty Reservoir basin (MDE 2008). In urban areas such as Baltimore City that feature combined storm and sewer drains, high flow events result in elevated bacterial and nutrient levels, including potentially lethal concentrations of ammonia.

There are thirty-eight MBSS stations in the Liberty Reservoir watershed and minimal sampling for ammonia was conducted (onetime sample) at each station. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. However, chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time. To make an accurate determination of acute and chronic ammonia toxicity, MDE reviewed additional data to determine if there is ammonia toxicity impairment in these waters. During the years of 1999, 2000, 2003, 2004, 2005 and 2007, MDE collected one thousand six hundred and four water quality samples from the Liberty Reservoir watershed. Samples were collected at twenty-nine stations through out the watershed, with most stations being sampled monthly for approximately a year. None of the samples showed exceedances of any of the four USEPA and MDE criteria for ammonia: acute criterion when salmonid fish are present, acute criterion when salmonid fish are absent, chronic criterion when early life stages are present or chronic criterion when early life stages are absent (USEPA 2006). Due to these results from the MDE water quality data analysis, it was determined that ammonia toxicity is not a widespread problem in the Liberty Reservoir watershed.

The atmosphere can contribute various forms of nitrogen arising from the burning of fossil fuels and from automobile exhaust (MDDNR 2002a). According to MDDNR 2002a, the Liberty Reservoir watershed is among those with a high to excessive TN concentration based on data from one "core" non-tidal stream monitoring station in the watershed. Watersheds were ranked on a 1 (worst) to 10 (best) scale to allow comparison of TN among them using the Tributary Team reporting methods for status/trends; Liberty Reservoir watershed was ranked "2" for TN (MDDNR 2002a). In Wisconsin streams, Wang et al. (2006) found that many macroinvertebrate and fish measures were significantly correlated with nitrogen concentrations, implying that nutrients have direct and/or indirect links with those biological assemblages.

Agriculture is the dominant land use (39%) within the Liberty Reservoir watershed. Agricultural land use is an important source of pollution when rainfall carries sediment, fertilizers, manure, and pesticides into streams. One of the three major nutrients in fertilizers and manure is nitrogen. Livestock waste is one of the primary agricultural sources of TN; it is a greater contributor than commercial fertilizer (USEPA 2000). Developed landscapes, particularly the proportion of agriculture in the catchments and the riparian zone, often results in increased inputs of nitrogen to surface waters. The MDDNR MBSS data did not include photographs of cow access to streams, and only a few comments regarding cows in a stream and cow pastures. Most of the nutrient loads in the Liberty Reservoir watershed appear to be coming from non-point sources because point sources of nitrogen in the watershed are small (MDDNR 2002a).

Identification of high TN and NH_3 toxicity by the BSID analysis are possibly indicative of degradation to water quality, but in conditions of excessive nutrient loading (i.e., eutrophication), pH and/or dissolved oxygen are also affected; this result does not support a case of excessive nutrient loading in the Liberty Reservoir watershed. MDE considers phosphorus to be the limiting nutrient species in an ecosystem. Phosphorus is generally much less soluble than nitrogen; it is leached from the soil at a much slower rate than nitrogen. Consequently, phosphorus is much more important as a limiting nutrient in aquatic systems (Smith, Tilman, and Nekola 1999). A TN:TP ratio analysis of five years of MDE data was completed for the Liberty Reservoir watershed confirming that phosphorus is a limiting factor.

High chlorides levels are significantly associated with degraded biological conditions and found in approximately 55% (*high* rating) of the stream miles with poor to very poor biological conditions in the Liberty Reservoir watershed. High concentrations of chlorides can result from industrial discharges, metals contamination, and application of road salts in urban landscapes.

High conductivity concentrations are significantly associated with degraded biological conditions and found in 44% of the stream miles with poor to very poor biological conditions in the Liberty Reservoir watershed. This stressor is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Stream conductivity is determined primarily by the geology of the area through which the stream flows. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban and agricultural runoffs, e.g. fertilizers, as well as leaking wastewater infrastructure (point sources) are typical sources of inorganic compounds.

There are several NPDES permitted point source discharges in the Liberty Reservoir watershed; since none of the facilities are permitted for chlorides, application of road salts in the watershed is a likely source of the chlorides and high conductivity levels. Although chlorides can originate from natural sources, most of the chlorides that enter the environment are associated with the storage and application of road salt (Smith et al. 1987). For surface waters associated with roadways or storage facilities, episodes of salinity have been reported during the winter and spring in some urban watercourses in the range associated with acute toxicity in laboratory experiments (EC 2001). These salts remain in solution and are not subject to any significant natural removal mechanisms; road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality (Wegner and Yaggi 2001).

Currently in Maryland there are no specific numeric criteria that quantify the impact of chlorides and conductivity on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of the specific pollutant(s) causing degraded biological communities from the array of potential inorganic pollutants loading from urban development.

The Liberty Reservoir watershed is considered a high priority watershed for both restoration and protection, primarily because of its use as a drinking water supply (MDDNR 2002a). The BSID analysis results identify several parameters of water chemistry as significant stressors in the Liberty Reservoir watershed; water chemistry is a major determinant of the integrity of surface waters that is strongly influenced by land-use. Urban land development can cause an increase in contaminant loads from point and non-point sources by adding sediments, nutrients, road salts, toxics, and inorganic pollutants to surface waters. Physical habitats, when exposed to detrimental and chronic water chemistry effects, cease functioning efficiently and degrade.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 75% suggesting this stressor impacts a considerable proportion of the degraded stream miles in the Liberty Reservoir watershed (Table 5).

Sources

All seven stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Liberty Reservoir watershed and are representative of impacts from urban developed landscapes. Although agricultural landuse (39%) is the dominant land use in the Liberty Reservoir watershed, the BSID results identified urban development (27%) as significantly (83%) associated with poor to very poor biological conditions in the watershed. Urban land use was identified as significant not only in the watershed but also in the riparian buffer zone. According to a MDDNR assessment (Stranko 2001) of the Liberty Reservoir watershed, the relatively small amount of urbanization and abundance of habitat structure in most of the streams in the Liberty Reservoir watershed is indicative of minimal anthropogenic degradation; the most common kinds of stream degradation encountered were stream bank erosion and insufficient vegetated riparian buffers. MDDNR also reports that non-point source degradation from agricultural and urban development seem to be having the greatest negative influence on the ecology of this watershed (Stranko 2001). There is a small amount of urban development in the watershed; the majority of failing MDDNR MBSS stations are primarily located near the urban regions of the watershed, i.e. Hampstead, Reisterstown, and Westminster. The land use of these stations is influencing the source results of the BSID analysis.

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). In watersheds already experiencing anthropogenic stress, hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events (Southerland et al. 2005b). Due to the increase in impervious surface cover that is associated with urbanization, pollutants (e.g., inorganics, nutrients) are more readily delivered to a stream by surface runoff. According to Wang et al. 2001, even under the best-case urban development scenarios, stream fish communities will decline substantially in quality even while a watershed remains largely rural in character.

According to Forman and Deblinger (2000), there is a "road-effect zone" over which significant ecological effects extend outward from a road; these effects extend 100 to 1,000 m (average of 300 m) on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers; as rainfall amounts become larger, previously pervious areas in most residential landscapes become more significant sources of runoff (NRC 2008). According to the Liberty Reservoir Watershed Characterization report (MDDNR 2002a), on average 6.3% of the watershed surface cover is impervious, this exceeds the MDDNR MBSS limit of 4% for streams that rate "Fair" to "Good" for both fish and instream invertebrates. BSID results also identified transportation in the watershed as related to degraded stream miles (51%) in the Liberty Reservoir watershed. Interstate 795, and other State and county paved roads interconnect points within the region, routes 26 and 140 pass directly over the Liberty Reservoir impoundment. A strong relationship was established between increasing chloride levels and increasing road density (MDDNR 2002a). A likely source of these results is de-icing agents (i.e., road salts) used on roads and parking lots, which wash off of these surfaces during rain events into adjacent stream systems (MDDNR 2002a).

MDDNR also identified a significant increase in chloride levels and increasing conductivity readings since 1992; conductivity values serve as a suitable substitute when chloride values are absent (MDDNR 2002a). Several relationships were explored to determine the most likely causes of this increasing trend; the strongest relationship occurred between increasing chloride values and the amount of commercial and industrial land use. Typically, these land uses have very high percentages of impervious surfaces for parking and buildings. Fertilizers (e.g., potassium nitrate) from landscaping runoff from residential lawns, golf courses, and athletic fields, are also a source of salts. Fertilizer salts are soluble, they readily dissolve in water and leach with rainfall, in excess quantities salts can increase instream conductivity. Extended dry periods and low flow conditions also contribute to higher conductivity results. Conductivity levels may also be natural; the MDDNR WRAS synoptic (2002b) states that conductivity anomalies in four sub-watersheds (i.e., Snowden Run, Middle Run, Roaring Run and West Branch) were attributed to natural biological processes in the Carroll County portion of the Liberty Reservoir watershed.

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 83% suggesting that these stressors impact a substantial proportion of the degraded stream miles in Liberty Reservoir watershed (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Liberty Reservoir watershed are a result of increased urban land uses causing alteration to hydrology, resulting in an unstable stream ecosystem that eliminates habitat heterogeneity. High proportions of these land uses also typically result in increased contaminant loads from point and non-point sources by adding inorganic pollutants and nutrients to surface waters, resulting in levels that can potentially be toxic to aquatic organisms. Alterations to the hydrologic regime and water chemistry; have all combined to degrade the Liberty Reservoir watershed, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 75%, suggesting that water chemistry stressors and altered hydrology (e.g., roads, impervious surfaces) adequately account for the biological impairment in the Liberty Reservoir watershed.

The results of this analysis are not intended or implied to be absolute and unchanging. However, the results do configure the most probable pathway for biological impairment using the highest quality data currently available. BSID analysis evaluates numerous key stressors that could act independently or act as part of complex causal scenarios (e.g., eutrophication, urbanization, habitat modification). In this process, absence of a key stressor(s) can be as important as the presence of stressors to ultimately determine impairment causation. Uncertainty resulting from basic limitations of the principal dataset (e.g., temporal and spatial variability, sample size) is reduced, but not eliminated in BSID.

Final Causal Model for the Liberty Reservoir Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2009). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the Liberty Reservoir watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

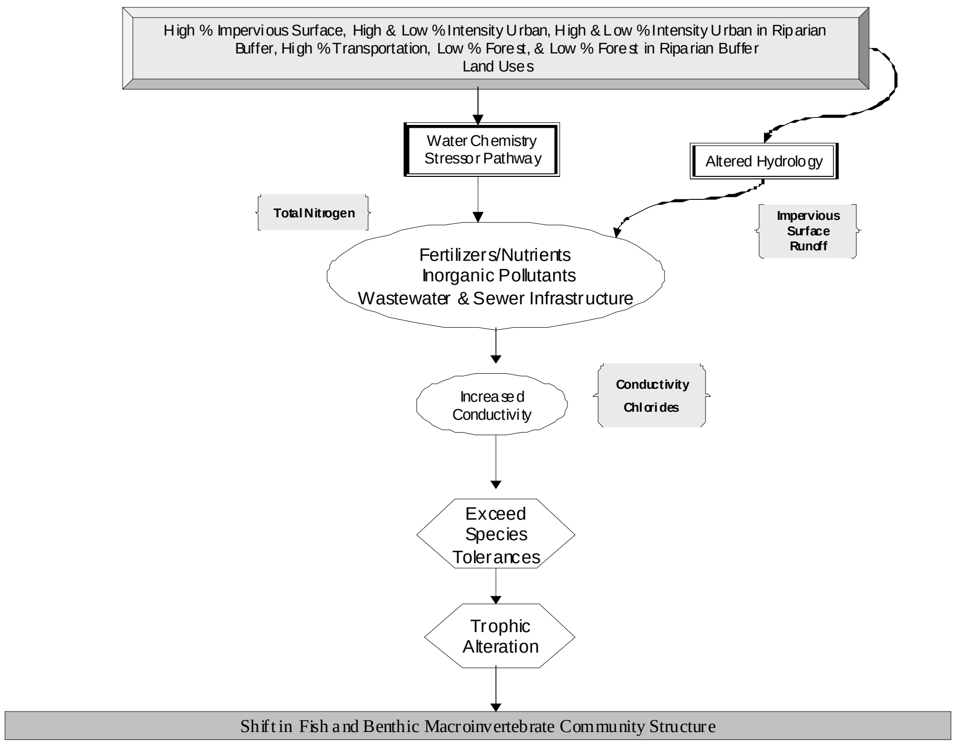

Figure 6. Final Causal Model for the Liberty Reservoir Watershed

5.0 Conclusions

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

- The BSID process has determined that the biological communities in the Liberty Reservoir watershed are likely degraded due to inorganic pollutants (i.e., chlorides). Chloride levels are significantly associated with degraded biological conditions and found in approximately 55% of the stream miles with poor to very poor biological conditions in the Liberty Reservoir watershed. Impervious surfaces and urban runoff cause an increase in contaminant loads from point and nonpoint sources by delivering an array of inorganic pollutants to surface waters. Discharges of inorganic compounds are very intermittent; concentrations vary widely depending on the time of year as well as a variety of other factors may influence their impact on aquatic life. Future monitoring of these parameters will help in determining the spatial and temporal extent of these impairments in the watershed. The BSID results thus support Category 5 listing of chloride for the watershed.
- There is presently a Category 5 listing for phosphorus (impoundment) in Maryland's 2010 Integrated Report; BSID analysis identified TN, not phosphorus, as a potential water chemistry stressor in the Liberty Reservoir watershed. The presence of TN in the Liberty Reservoir watershed shows a possible association (33% of stream miles) with degraded biological conditions. Because nitrogen generally exists in quantities greater than necessary to sustain algal growth, excess nitrogen per se is not the cause of the biological impairment in the Liberty Reservoir watershed. MDE considers phosphorus to be the limiting nutrient species in an ecosystem, and since phosphorus was not identified as a potential stressor, reduction of nitrogen loads would not be an effective means of ensuring that the watershed is free from impacts on aquatic life from eutrophication.

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