Watershed Report for Biological Impairment of the Baltimore Harbor Watershed in Baltimore City, Baltimore, and Anne Arundel 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
BOD	Biological Oxygen Demand
BSID	Biological Stressor Identification
cm	Centimeter
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
ICM	Impervious Cover Model
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
m	Meters
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
PCBs	Polychlorinated Biphenyls
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
µS/cm	Micro Siemens per centimeter
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 Baltimore Harbor watershed (basin code 02130903), located in Baltimore City, as well as portions of Baltimore and Anne Arundel Counties, has a number of different bay listing segments in the 2012 Integrated Report (MDE 2012). There are mesohaline (Upper Chesapeake Bay and Patapsco River) and estuarine portions of the Baltimore Harbor Watershed. There is also a non-tidal portion of the 8-digit watershed. Below is a table identifying the listings associated with this watershed.

Table E1. 2012 Integrated Report Listings for Baltimore Harbor Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Baltimore Harbor	02130903	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Upper Chesapeake Bay Mesohaline	CB3MH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	-	TN	4a
				-	TP	4a
			Aquatic Life and Wildlife	2008	Impacts to Estuarine Biological Communities	4a
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	4a

Table E1. 2012 Integrated Report Listings for Baltimore Harbor Watershed (Cont'd)

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Upper Chesapeake Bay Mesohaline	CB3MH	Tidal	Seasonal Deep-Water and Shellfish Subcategory	1996	TN	4a
				1996	TP	4a
			Aquatic Life and Wildlife	2006	Impacts to Estuarine Biological Communities	5
			Seasonal Deep-Channel Refuge Use	1996	TN	4a
				1996	TP	4a
Patapsco River Mesohaline	PATMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	1996	TN	4a
				1996	TP	4a
			Aquatic Life and Wildlife	1996	Mercury, Copper, Nickel, & Cyanide	4b
			Aquatic Life and Wildlife	1996	Chromium, Zinc, & Lead in Sediments	5
			Water Contact Sports	1998	Enterococcus	5
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	-	TSS	4a
			Aquatic Life and Wildlife	2004	Impacts to Estuarine Biological Communities	4a
			Seasonal Deep-Channel Refuge Use	1996	TP	4a
				1996	TN	4a

Table E1. 2012 Integrated Report Listings for Baltimore Harbor Watershed (Cont'd)

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
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				1996	TN	4a
			Aquatic Life and Wildlife	2008	Debris/Trash	5
Baltimore Harbor	02130903	Tidal	Aquatic Life and Wildlife	1998	TSS	4a
Baltimore Harbor	02130903	Tidal	Fishing	1998	PCBs	5
Rock Creek	02130903	Tidal	Water Contact Sports	-	Fecal Coliform	2
Furnace Creek	02130903	Tidal	Water Contact Sports	1998	Enterococcus	5
Marley Creek	02130903	Tidal	Water Contact Sports	1998	Enterococcus	5
Bear Creek	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc, Chromium (in Sediments) & PCBs (Sediments & Fish Tissue)	5
Middle Harbor	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments)	5
Curtis Bay Creek	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments) & PCBs (Sediments & Fish Tissue)	5
Bear Creek	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments)	5
Middle Branch – Northwest Harbor	02130903	Tidal	Water Contact Sports	2010	Enterococcus	5

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of the Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, TMDLs are developed, and implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds by measuring the percentage of stream miles that have poor to very poor biological conditions, and calculating whether this is significantly different from a reference condition watershed (i.e., healthy stream, <10% stream miles with poor to very poor biological condition).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Baltimore Harbor and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, most of the estuary portions of the watershed are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2013 a, b, c). 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 degraded 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 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 Baltimore Harbor watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the biological communities of the Baltimore Harbor watershed are strongly influenced by urban land use and its concomitant effects: altered hydrology and increased pollutant loading from urban runoff resulting in elevated levels of sediments, chlorides, and sulfates. 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 Baltimore Harbor watershed can be summarized as follows:

- The BSID process has determined that the biological communities in the Baltimore Harbor River watershed are likely degraded due to inorganics (i.e., chloride and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in approximately 79% and 29% of the stream miles with poor to very poor biological conditions in the watershed. The BSID results thus support a Category 5 listing of chloride and sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Baltimore Harbor 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 which 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 process has determined that biological communities in Baltimore Harbor watershed are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and impervious surfaces have resulted in channel erosion, scouring, and transport of suspended sediments in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the establishment of a total suspended solids (TSS) TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediments on biological communities in the Baltimore Harbor watershed. The BSID results thus support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Baltimore Harbor watershed.

- The BSID process has also determined that biological communities in the Baltimore Harbor watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Baltimore Harbor watershed based on channelization being present in approximately 37% of degraded stream miles.

- The BSID process has also determined that biological communities in the Baltimore Harbor watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. MDE recommends a Category 4c listing for the Baltimore Harbor watershed based on inadequate riparian buffer zones in approximately 28% of degraded stream miles.

- No nutrient stressors were identified in the BSID analysis as having significant association with degraded biological conditions in the watershed. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and decomposition of organic matter. Nutrient reductions are mandated by the 2010 Chesapeake Bay TMDL and a 2007 nutrient TMDL for the tidal portions of the watershed; therefore, no other management actions requiring additional nutrient reductions are necessary.

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 2009). 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, less than 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. A Category 5 listing can be amended to a Category 4a if a TMDL was established and approved by USEPA or Category 4b if other pollution control requirements (i.e., permits, consent decrees, etc.) are expected to attain water quality standards. If the state can demonstrate that the watershed impairment is a result of pollution, not a specific pollutant, the watershed is listed under Category 4c.

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 and three Maryland

Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2009) 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 Baltimore Harbor watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Baltimore Harbor Watershed Characterization

2.1 Location

The Baltimore Harbor Watershed is located immediately south east of Baltimore City and includes Old Road Bay and other small tributaries to the Patapsco River and Chesapeake Bay. Smaller tributaries feeding the Harbor are the Gwynns Falls (upper Middle Branch of the Harbor), Jones Falls (Northwest Branch of Baltimore Harbor), Bear Creek, Furnace Creek, Marley Creek, Rock Creek, Stony Creek, and Curtis Creek (see Figure 1). The Harbor is a tidal estuary located on the western shore of the Chesapeake Bay, just south of Back River. Baltimore Harbor lies in the Patapsco watershed and it is estimated that 60 percent of the total freshwater entering Baltimore Harbor comes from the Patapsco River (QLME, 1973). The watershed is approximately 117 square miles, and includes parts of Baltimore City, as well as portions of Anne Arundel, and Baltimore Counties.

The watershed is predominately located within the Coastal Plain physiographic region with the exception of the northern tip, which extends into the Piedmont region. There are three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

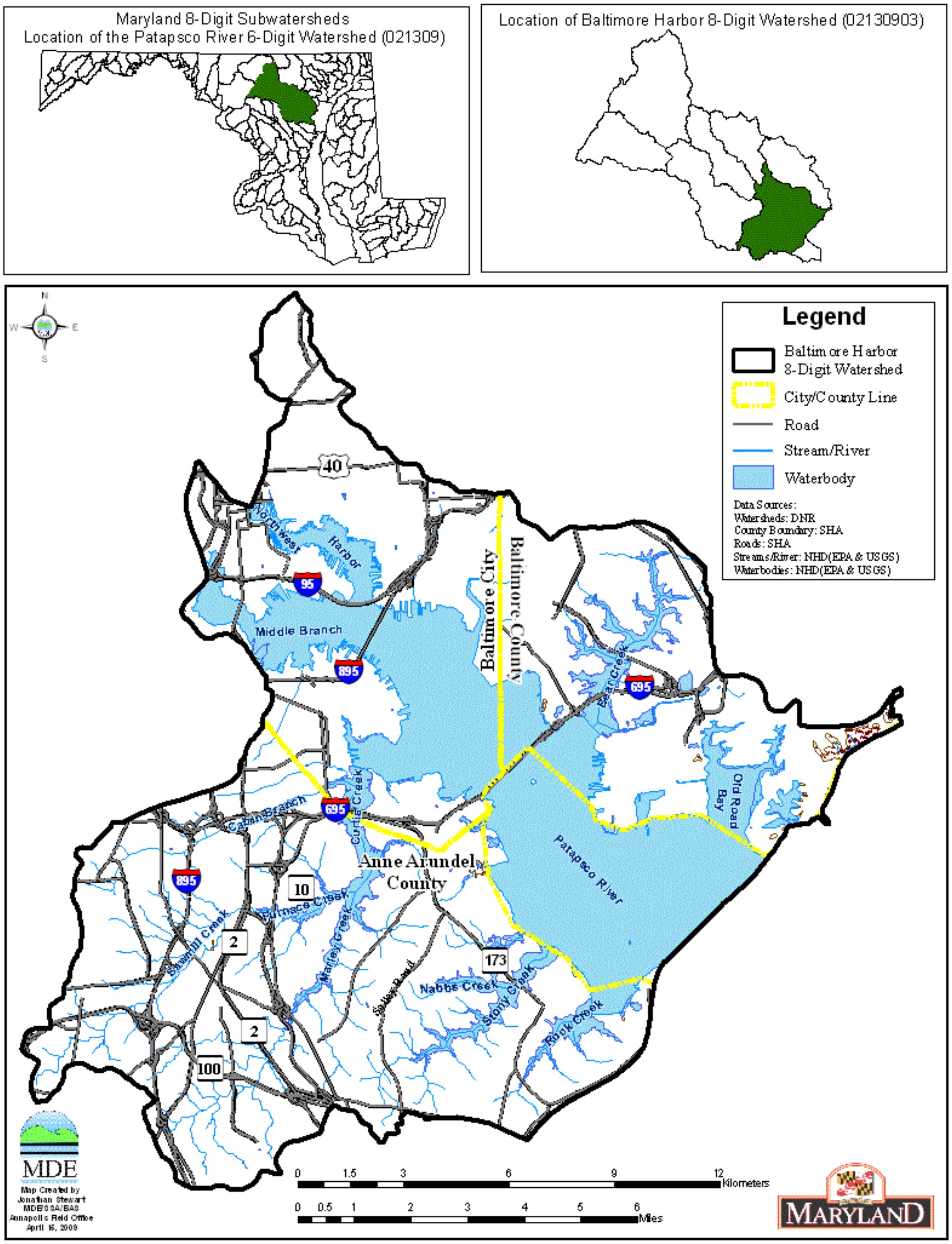

Figure 1. Location Map of the Baltimore Harbor Watershed

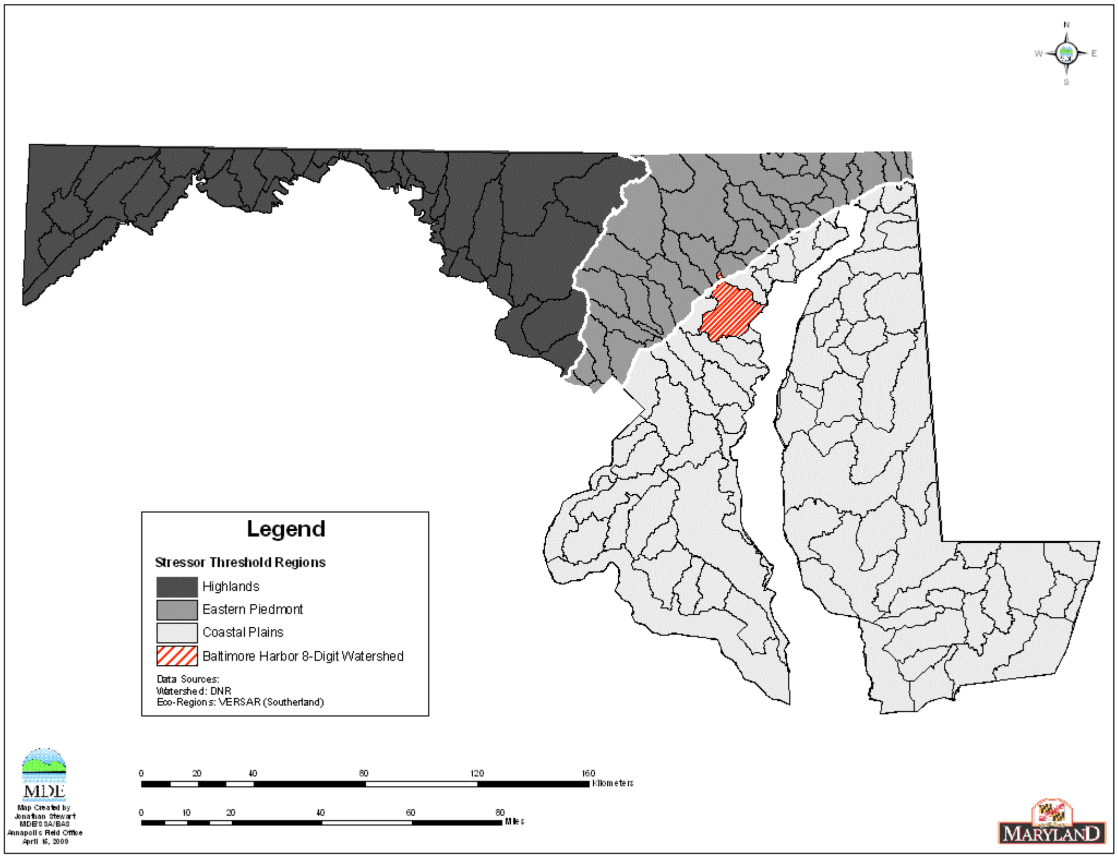

Figure 2. Eco-Region Location Map of the Baltimore Harbor Watershed

2.2 Land Use

Land uses in the Baltimore Harbor watershed consist primarily of older residential, commercial and industrial development including large tracts occupied by heavy industry such as the shipyard and steel plant at Sparrows Point. Some parcels of open space exist, including parkland, agricultural and forested areas. Some of the heavily urbanized areas in the watershed are Dundalk, Eastpoint, Northpoint, Sparrows Point, and Edgemere. The main transportation corridors in the watershed are Maryland Routes 2, 10, 173, and 100 across the southern section and Interstates 95, 895, and 695 across the northern half of the watershed. According to the Chesapeake Bay Program's Phase 5.2 watershed model land use, the Baltimore Harbor watershed is approximately 46% pervious urban, 41% impervious surfaces, 12% forest/herbaceous, and 1% agricultural (USEPA 2010) (see Figure 3 and Figure 4).

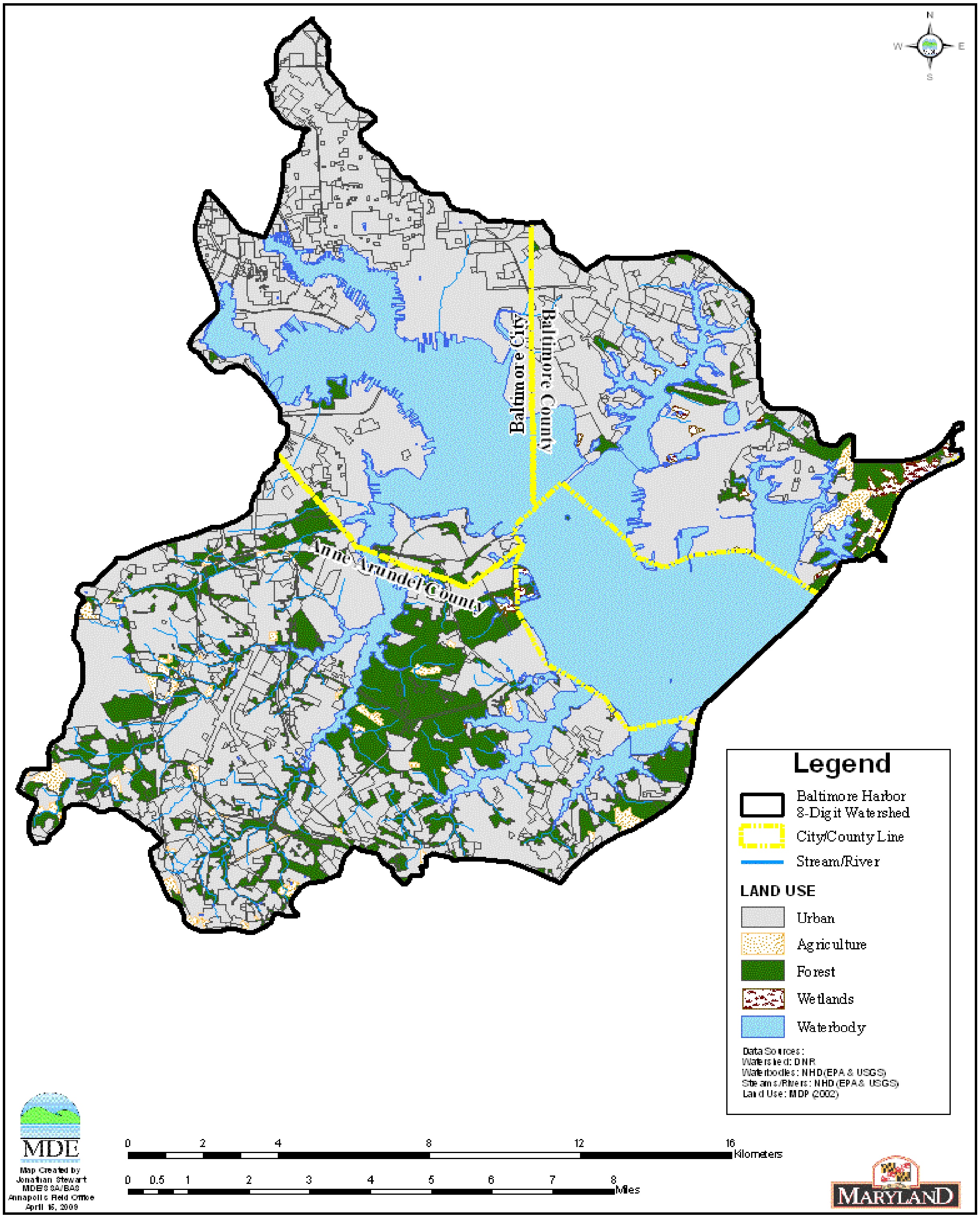

Figure 3. Land Use Map of the Baltimore Harbor Watershed

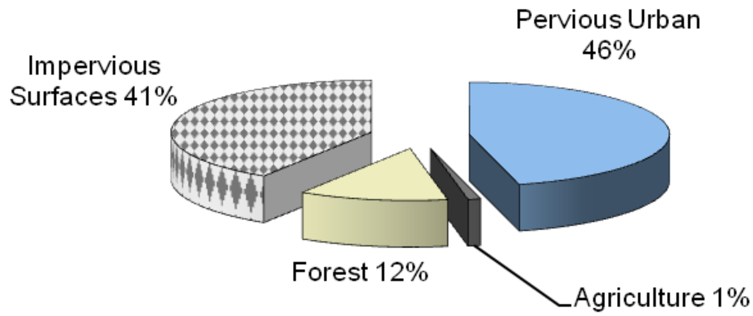

Figure 4. Proportions of Land Use in the Baltimore Harbor Watershed

2.3 Soils/hydrology

The watershed lies within two physiographic provinces, the Piedmont and the Coastal Plain, whose division runs through the northern tip of the watershed. The northern portion of the watershed is in the Piedmont Plateau province, characterized by steep stream valleys and well-drained loamy soils underlain by Precambrian crystalline rocks. The Piedmont portion of the watershed is higher and more rugged than that of the coastal plain due to the greater resistance to erosion, and streambeds tend to be rocky, with relatively steep gradients. The remainder of the basin lies within the Coastal Plain province, a wedge-shaped mass of primarily unconsolidated sediments of the Lower Cretaceous, Upper Cretaceous and Pleistocene ages covered by sandy soils. The Coastal Plain portion of the watershed is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2007).

Soils typically found in the Baltimore Harbor watershed are the Beltsville, Evesboro, Westbrook, and Othello series. The Beltsville series consist of very deep, moderately well drained soils on uplands. Saturated hydraulic conductivity is moderately low or low in the fragipan. The Evesboro series consist of very deep excessively drained on coastal plain uplands. Saturated hydraulic conductivity is high in the subsoil and high to very high in the substratum. The Westbrook series consist of very deep, very poorly drained soils formed in organic deposits over loamy mineral material. They are in tidal marshes subject to inundation by salt water twice daily. Saturated hydraulic conductivity is moderately high to very high in the organic layers and low to high in the underlying mineral sediments. The Othello series consist of very deep, poorly drained soils, with saturated hydraulic conductivity being moderately high (USDA 1977).

3.0 Baltimore Harbor Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Baltimore Harbor watershed (basin code 02130903), located in Baltimore City, as well as portions of Baltimore and Anne Arundel Counties, has a number of different bay listing segments in the 2012 Integrated Report (MDE 2012). There are mesohaline and (Upper Chesapeake Bay and Patapsco River) and estuarine portions of the Baltimore Harbor Watershed. There is also a non-tidal portion of the 8-digit watershed. Below is a table identifying the listings associated with this watershed.

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			Seasonal Deep-Channel Refuge Use	1996	TN	4a
				1996	TP	4a
Patapsco River Mesohaline	PATMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory	1996	TN	4a
				1996	TP	4a
			Aquatic Life and Wildlife	1996	Mercury, Copper, Nickel, & Cyanide	4b
			Aquatic Life and Wildlife	1996	Chromium, Zinc, & Lead in Sediments	5
			Water Contact Sports	1998	Enterococcus	5
			Open Water Fish and Shellfish	1996	TN	4a
				1996	TP	4a
			Seasonal Shallow Water Submerged Aquatic Vegetation	-	TSS	4a
			Aquatic Life and Wildlife	2004	Impacts to Estuarine Biological Communities	5
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Baltimore Harbor	02130903	Tidal	Fishing	1998	PCBs	5
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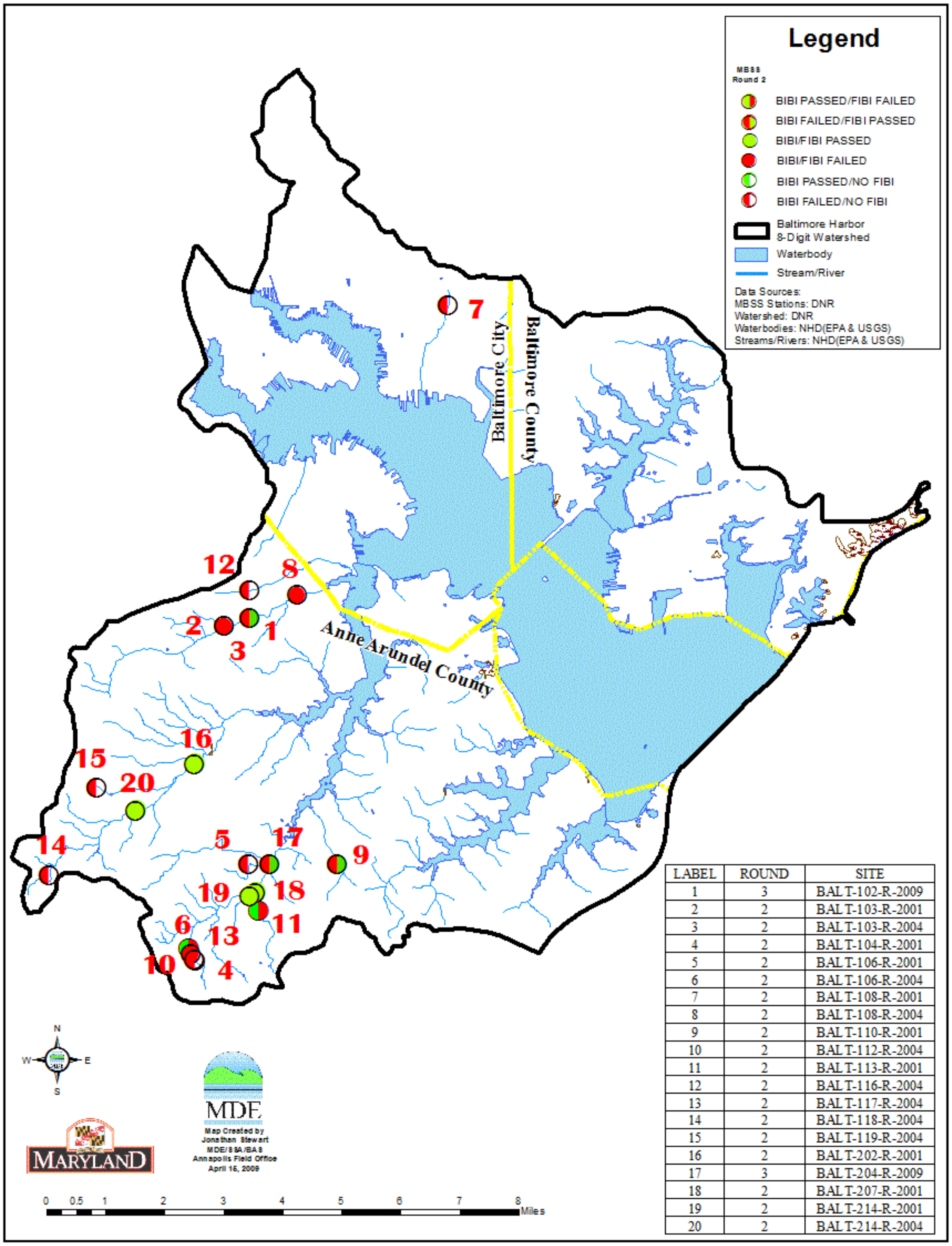
Middle Harbor	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments)	5
Curtis Bay Creek	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments) & PCBs (Sediments & Fish Tissue)	5
Bear Creek	02130903	Tidal	Aquatic Life and Wildlife	1998	Zinc (in Sediments)	5
Middle Branch – Northwest Harbor	02130903	Tidal	Water Contact Sports	2010	Enterococcus	5

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Baltimore Harbor and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, most of the estuary portions of the watershed are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2013 a, 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 trout waters. 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 Baltimore Harbor watershed is listed under Category 5 of the 2012 Integrated Report for impacts to biological communities. Approximately 71% of stream miles in the Baltimore Harbor watershed are estimated as having benthic and/or fish indices of biological integrity 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 twenty-eight stations. Twenty-one of the twenty-eight have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS rounds two and three, contains twenty MBSS sites, with sixteen having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Baltimore Harbor watershed.



LABEL	ROUND	SITE
1	3	BALT-102-R-2009
2	2	BALT-103-R-2001
3	2	BALT-103-R-2004
4	2	BALT-104-R-2001
5	2	BALT-106-R-2001
6	2	BALT-106-R-2004
7	2	BALT-108-R-2001
8	2	BALT-108-R-2004
9	2	BALT-110-R-2001
10	2	BALT-112-R-2004
11	2	BALT-113-R-2001
12	2	BALT-116-R-2004
13	2	BALT-117-R-2004
14	2	BALT-118-R-2004
15	2	BALT-119-R-2004
16	2	BALT-202-R-2001
17	3	BALT-204-R-2009
18	2	BALT-207-R-2001
19	2	BALT-214-R-2001
20	2	BALT-214-R-2004

Figure 5. Principal Dataset Sites for the Baltimore Harbor 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 lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4^{th} order), that have fair to good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (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 associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR for each stressor, the AR for a group of stressors is also calculated from individual sites' characteristics (stressors present at that site). The only difference is that the group AR calculations combine each site's lowest relative stressor risk among the controls. The same process is run for all land use sources.

After determining the AR for each stressor/sources and the AR for groups of stressors/sources, the AR for all potential stressors/sources 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/sources were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors/sources have been identified for an acceptable proportion of cases (MDE 2009).

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Baltimore Harbor watershed, MDE identified sources, sediment, in-stream habitat, riparian habitat, and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 2 and includes various anthropogenic, impervious, and urban land use types. Table 3 shows the summary of combined AR values for the source groups in the Baltimore Harbor watershed. As shown in Table 4 through Table 6, numerous parameters from the sediment, in-stream habitat group and water chemistry parameters were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Baltimore Harbor watershed.

Table 2. Stressor Source Identification Analysis Results for the Baltimore Harbor 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sources - Acidity	Agricultural acid source present	20	16	274	0%	7%	0.609	No	_
	AMD acid source present	20	16	274	0%	0%	1	No	_
	Organic acid source present	20	16	275	0%	7%	0.61	No	_
Sources - Agricultural	High % of agriculture in watershed	20	16	279	0%	3%	1	No	_
	High % of agriculture in 60m buffer	20	16	279	0%	4%	1	No	_
Sources - Anthropogenic	Low % of forest in watershed	20	16	279	25%	6%	0.023	Yes	19%
	Low % of wetland in watershed	20	16	279	25%	11%	0.098	Yes	14%
	Low % of forest in 60m buffer	20	16	279	31%	8%	0.011	Yes	23%
	Low % of wetland in 60m buffer	20	16	279	25%	10%	0.089	Yes	15%
Sources - Impervious	High % of impervious surface in watershed	20	16	279	94%	4%	0	Yes	89%
	High % of impervious surface in 60m buffer	20	16	279	88%	5%	0	Yes	82%
	High % of roads in watershed	20	16	279	50%	0%	0	Yes	50%
	High % of roads in 60m buffer	20	16	279	81%	5%	0	Yes	77%
Sources - Urban	High % of high-intensity developed in watershed	20	16	279	88%	8%	0	Yes	80%
	High % of low-intensity developed in watershed	20	16	279	63%	6%	0	Yes	56%
	High % of medium-intensity developed in watershed	20	16	279	88%	2%	0	Yes	85%
	High % of early-stage residential in watershed	20	16	279	0%	5%	1	No	_
	High % of residential developed in watershed	20	16	279	63%	6%	0	Yes	56%
Sources - Urban	High % of rural developed in watershed	20	16	279	0%	5%	1	No	_

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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
	High % of high-intensity developed in 60m buffer	20	16	279	56%	6%	0	Yes	50%
	High % of low-intensity developed in 60m buffer	20	16	279	94%	5%	0	Yes	89%
	High % of medium-intensity developed in 60m buffer	20	16	279	88%	3%	0	Yes	84%
	High % of early-stage residential in 60m buffer	20	16	279	0%	7%	0.612	No	_
	High % of residential developed in 60m buffer	20	16	279	94%	5%	0	Yes	89%
	High % of rural developed in 60m buffer	20	16	279	0%	5%	1	No	_

Table 3. Summary of Combined Attributable Risk Values of the Source Group in the Baltimore Harbor Watershed

Source Group	% of degraded sites associated with specific source group (attributable risk)
Sources - Anthropogenic	31%
Sources - Impervious	92%
Sources - Urban	92%
All Sources	***93%***

4.1 Sources Identified by BSID Analysis

All the sources identified by the BSID analysis (Table 2) are the result of urban development within the Baltimore Harbor watershed. A significant amount of the watershed is comprised of urban land uses (87% with 41% being impervious surfaces). BSID results also show that urban and transportation development within the sixty meter riparian buffer zone has significant association with degraded biological conditions.

The scientific community (Booth 1991; Konrad and Booth 2002; and Meyer, Paul, and Taulbee 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, Paul, and Taulbee 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. Although symptoms of the urban stream syndrome correlate to watershed imperviousness and drainage connectivity, the symptoms are often a result of complex interactions. Many responses are inconsistent; therefore, an individual stream may not show all the symptoms.

In recent years impervious cover has emerged as a key indicator to explain and sometimes predict how severely streams change in response to different levels of watershed development (CWP 2003). The Center for Watershed Protection has integrated these research findings into a general watershed planning model, known as the impervious cover model (ICM). The ICM predicts that most stream quality indicators decline when watershed impervious cover exceeds 10%, with severe degradation expected beyond 25% impervious cover. The model classifies subwatersheds into one of three categories: sensitive (0-10%), impacted (11-25%), and non-supporting (over 25%).

The Baltimore Harbor watershed has approximately 41% impervious cover, which would place the watershed in the non-supporting category. Once watershed impervious cover exceeds 25%, stream quality crosses a second threshold. Streams in this category essentially become conduits for conveying stormwater flows, and can no longer support a diverse stream community. The stream channel becomes highly unstable, and many stream reaches experience severe widening, downcutting, and streambank erosion. Pool and riffle structure needed to sustain fish is diminished or eliminated and the substrate can no longer provide habitat for aquatic insects, or spawning areas for fish. Water quality is consistently rated as fair to poor, and water recreation often is no longer possible due to the presence of high bacterial levels. The biological quality of non-supporting streams is generally considered poor, and is dominated by pollution tolerant insects and fish. Most researchers acknowledge that streams with more than 25% impervious cover in their watersheds cannot support their designated uses or attain water quality standards and are severely degraded from a physical and biological standpoint. As a consequence, many of these streams are listed for non-attainment under the Clean Water Act and are subject to TMDL regulations (CWP 1998).

The BSID analysis identified transportation land use within the 60 meter riparian buffer zone as having significant association with degraded biological conditions. Fourteen of the sixteen MBSS sites with BIBI and/or FIBI below 3.0 were located in close proximity to transportation routes. 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 meters (average of 300 m) on each side of four-lane roads. Roads tend to capture and export more stormwater pollutants than other land covers. There are many main transportation corridors in the watershed including Maryland Routes 2, 10, 100, 173, and Interstate 95, 895, and 695.

The BSID source analysis (Table 2) identifies various types of anthropogenic, impervious, and urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 93%, suggesting land use sources are the most probable cause of biological impairments in the Baltimore Harbor watershed (Table 3).

The stressors identified by the BSID analysis in Table 4 through Table 6 of this report are typical symptoms of "urban stream syndrome" and are the result of urban development and anthropogenic disturbances within the watershed. The remainder of this section will discuss identified stressors and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for the Baltimore Harbor 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Sediment	Extensive bar formation present	20	16	157	6%	21%	0.205	No	_
	Moderate bar formation present	20	16	156	44%	49%	0.797	No	_
	Channel alteration moderate to poor	18	14	131	57%	60%	1	No	_
	Channel alteration poor	18	14	131	29%	26%	0.76	No	_
	High embeddedness	20	16	156	0%	0%	1	No	_
	Epifaunal substrate marginal to poor	20	16	156	81%	45%	0.007	Yes	36%
	Epifaunal substrate poor	20	16	156	50%	12%	0	Yes	38%
	Moderate to severe erosion present	20	16	156	56%	42%	0.302	No	_
	Severe erosion present	20	16	156	6%	12%	0.699	No	_

Table 5. Habitat Biological Stressor Identification Analysis Results for the Baltimore Harbor 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Instream Habitat	Channelization present	20	16	168	50%	13%	0.001	Yes	37%
	Concrete/gabion present	18	14	148	21%	1%	0.005	Yes	20%
	Beaver pond present	20	16	155	0%	7%	0.605	No	_
	Instream habitat structure marginal to poor	20	16	156	81%	39%	0.001	Yes	43%
	Instream habitat structure poor	20	16	156	31%	6%	0.005	Yes	25%
	Pool/glide/eddy quality marginal to poor	20	16	156	50%	45%	0.791	No	_
	Pool/glide/eddy quality poor	20	16	156	13%	3%	0.116	No	_
	Riffle/run quality marginal to poor	20	16	156	88%	52%	0.007	Yes	36%
	Riffle/run quality poor	20	16	156	31%	21%	0.339	No	_
	Velocity/depth diversity marginal to poor	20	16	156	63%	60%	1	No	_
	Velocity/depth diversity poor	20	16	156	38%	15%	0.032	Yes	23%
Riparian Habitat	No riparian buffer	18	14	140	43%	15%	0.019	Yes	28%
	Low shading	20	16	156	0%	3%	1	No	_

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Baltimore Harbor 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 Benthic or Fish IBI)	Controls (average number of reference sites with fair to good Benthic or Fish IBI)	% of case sites with stressor present	% of control sites per stratum with stressor present	Statistical probability that the stressor is not impacting biology (p value)	Possible stressor (odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	% of case sites associated with the stressor (attributable risk)
Chemistry - Inorganic	High chlorides	20	16	279	88%	8%	0	Yes	79%
	High conductivity	20	16	279	88%	6%	0	Yes	81%
	High sulfates	20	16	279	38%	8%	0.002	Yes	29%
Chemistry - Nutrients	Dissolved oxygen < 5mg/l	20	16	261	44%	17%	0.016	Yes	27%
	Dissolved oxygen < 6mg/l	20	16	261	50%	25%	0.041	Yes	25%
	Low dissolved oxygen saturation	20	16	261	38%	6%	0.001	Yes	31%
	High dissolved oxygen saturation	20	16	261	0%	3%	1	No	_
	Ammonia acute with salmonid present	20	16	279	0%	0%	1	No	_
	Ammonia acute with salmonid absent	20	16	279	0%	0%	1	No	_
	Ammonia chronic with early life stages present	20	16	279	0%	0%	1	No	_
	Ammonia chronic with early life stages absent	20	16	279	0%	0%	1	No	_
	High nitrites	20	16	279	6%	3%	0.433	No	_
	High nitrates	20	16	279	0%	7%	0.61	No	_
	High total nitrogen	20	16	279	0%	6%	1	No	_
	High total phosphorus	20	16	279	6%	9%	1	No	_
	High orthophosphate	20	16	279	0%	5%	1	No	_
Chemistry - pH	Acid neutralizing capacity below chronic level	20	16	279	6%	9%	1	No	_
	Low field pH	20	16	262	38%	40%	1	No	_
	High field pH	20	16	262	0%	1%	1	No	_
	Low lab pH	20	16	279	13%	38%	0.059	No	_
	High lab pH	20	16	279	0%	0%	1	No	_

Table 7. Summary of Combined Attributable Risk Values of the Stressor Group in the Baltimore Harbor Watershed

Stressor Group	% of degraded sites associated with specific stressor group (attributable risk)
Sediment	59%
Instream Habitat	82%
Riparian Habitat	28%
Chemistry - Inorganic	81%
Chemistry - Nutrients	42%
All Chemistry	81%
All Stressors	***94%***

4.2 Stressors Identified by BSID Analysis

All fifteen stressor parameters, identified by the BSID analysis (Tables 4, 5, and 6) as being significantly associated with biological degradation in the Baltimore Harbor watershed, are emblematic of urban developed landscapes.

Sediment Conditions

BSID analysis results for the Baltimore Harbor watershed identified two sediment parameters that had statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). The parameters are *epifaunal substrate (marginal to poor and poor)* (Table 4).

Epifaunal substrate (marginal to poor & poor) were identified as significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 36% (*marginal to poor* rating) and 38% (*poor* rating) of the stream miles with poor to very poor biological conditions. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

As development and urbanization increase in a watershed, so do the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime causing streams to become more "flashy", i.e., they have more frequent, larger flow events (Walsh et al. 2005). The scouring associated with these increased flows can lead to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed and the settling of fine sediment in the stream substrate. These processes create an unstable stream ecosystem that can result in a loss of productive substrate and diverse habitat resulting in a shift within biological communities (i.e., sensitive taxa replaced by more tolerant species).

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 sediment stressor group is approximately 59% suggesting these stressors are the probable causes of biological impairments in the Baltimore Harbor watershed (Table 7).

In-stream Habitat Conditions

BSID analysis results for the Baltimore Harbor watershed identified six habitat parameters that have a statistically significant association with poor to very poor stream biological condition*: channelization present, concrete/gabion present, in-stream habitat structure (marginal to poor and poor), riffle/run quality (marginal to poor),* and *velocity/depth/diversity (poor)* (Table 5).

Channelization present was identified as significantly associated with degraded biological conditions and found to impact approximately 37% of the stream miles with poor to very poor biological conditions in the Baltimore Harbor watershed. Channelized describes a condition determined by visual observation of the presence or absence of the channelization of the stream segment and the extent of the channelization. Channelization is the human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete, rip rap, and ditching). Streams are channelized to increase the efficiency of the downstream flow of water. Channelization likely inhibits heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities.

Concrete/gabion present was identified as significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 20% of the stream miles with poor to very poor biological conditions. The presence or absence of concrete is determined by a visual observation within the stream. *Concrete/gabion present*, like ‘channelized,’ inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

In-stream habitat structure was identified as significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 43% (*marginal to poor* rating) and 25% (*poor* rating) of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. In-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). High in-stream habitat scores are evidence of the lack of sediment deposition. Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Riffle/run quality (marginal to poor) was identified as significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 36% of the stream miles with poor to very poor biological conditions. Riffle/run quality is a visual observation and quantitative measurement based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. An increase in the heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. Riffle/run quality conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal to poor, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity.

Velocity/depth/diversity (poor) was identified as significantly associated with degraded biological conditions in Baltimore Harbor watershed, and found to impact approximately 23% of the stream miles with poor to very poor biological conditions. Velocity/depth diversity is a visual observation and quantitative measurement based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The poor velocity/depth/diversity category could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime. Velocity is one of the critical variables controling the presence and number of species (Gore 1978). Many invertebrates depend on certain velocity ranges for either feeding or breathing (Brookes 1988).

Rain that falls on impervious surfaces will not soak into the ground, and in urban watersheds, it is usually directed to storm drain systems that discharge the water directly into streams. This water has a high amount of energy and typically results in stream erosion and degradation of stream habitat. The stream habitat (i.e., stream bed, banks, leaf litter packs, woody debris and the terrestrial riparian buffer) is the area where aquatic organisms live.

All the in-stream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity; the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. The scouring of streambeds, which often occurs in streams with "flashy" hydrologic regimes, results in a more homogeneous in-stream habitat and loss of available habitat.

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 in-stream habitat stressor group is approximately 82%, suggesting these stressors are the probable causes of biological impairments in the Baltimore Harbor (Table 7).

Riparian Habitat Conditions

BSID analysis results for the Baltimore Harbor watershed identified one riparian habitat parameter that has a statistically significant association with poor to very poor stream biological condition: *no riparian buffer* (Table 5).

No riparian buffer was identified as significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 28% of the stream miles with poor to very poor biological conditions. Riparian buffer width represents the minimum width of vegetated buffer in meters, looking at both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer. Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, moderate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee et al. 2004). Natural forested headwater streams generally rely on allochthonous input of leaf litter as the major energy source, but agricultural land use typically reduces or eliminates the trees in the riparian area that would contribute detritus. This reduction can have strong impacts on stream communities; exclusion of leaf litter can decrease invertebrate biomass and/or abundance in many of the invertebrate shredder, collector and predator taxa (Wallace et al. 1997). Decreased riparian buffer also leads to reduced amounts of large wood in the stream. Stable wood substrate in streams performs multiple functions, influencing channel features, flow, habitat, and providing cover for fish.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with very poor to poor biological conditions. The combined AR for the riparian habitat stressor group is approximately 28% suggesting these stressors are probable causes of biological impairments in the Baltimore Harbor watershed.

Water Chemistry Conditions

BSID analysis results for Baltimore Harbor identified six 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 chlorides, high conductivity, high sulfates, low dissolved oxygen < 5mg/l and < 6mg/l,* and *low dissolved oxygen saturation* (Table 6).

High chloride levels are significantly associated with degraded biological conditions in the Baltimore Harbor watershed, and found to impact approximately 79% of the stream miles with poor to very poor biological conditions. Chloride in surface waters can result from both natural and anthropogenic sources, such as run-off containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage, and seawater intrusion in coastal areas. Smith, Alexander, and Wolman (1987) have identified that, although chloride can originate from natural sources, in urban watersheds road salts can be a likely source of high chloride and conductivity levels. There are two municipal National Pollutant Discharge Elimination System (NPDES) permits and numerous industrial, general, and Municipal Separate Stormwater System (MS4) permitted dischargers in the Baltimore Harbor watershed. Since NPDES permitting enforcement does not require chlorides testing at many of these facilities, data was not sufficient to verify/identify chlorides as a specific pollutant. All MBSS sites with chloride concentrations above the threshold were located in close proximity to transportation routes.

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

High sulfates concentrations are significantly associated with degraded biological conditions and found in 29% of the stream miles with poor to very poor biological conditions in the Baltimore Harbor watershed. Sulfates in urban areas can be derived from natural and anthropogenic sources, including combustion of fossil fuels such as coal, oil, diesel, discharge from industrial sources, and discharge from municipal wastewater treatment facilities. Combustion of fossil fuels accounts for a majority of sulfur in the atmosphere, which can return to the surface as sulfate through precipitation or dry deposition (USGS 2007). There are two municipal NPDES permits and numerous industrial, general, and MS4 permitted dischargers in the watershed. Since NPDES permitting enforcement does not require sulfate testing at many of these facilities, data was not sufficient to verify/identify sulfates as a specific pollutant in this watershed.

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, Alexander, and Wolman 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). 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. The presence of salts also limits the DO concentration in water.

Surface flows due to the high imperviousness of the watershed are also a factor. According to Scorecard a Pollution Information website (2010), Baltimore City's emissions for sulfur dioxide in 1999 were over 35,000 tons, ranking the area in the ninetieth percent bracket for worst counties in the United States. In 2007, the Baltimore City community-wide criteria air pollutant emissions for sulfur dioxide were estimated at 24,650 tons (Baltimore Office of Sustainability 2007). The Baltimore Harbor watershed contains all the potential anthropogenic sources for sulfates.

Currently in Maryland there are no specific numeric criteria that quantify the impact of conductivity, chlorides, and sulfates on the aquatic health of non-tidal stream systems. Since the exact sources and extent of inorganic pollutant loadings are not known, MDE determined that current data are not sufficient to enable identification of all the different compounds of inorganic pollutants found in urban runoff from the BSID analysis.

Low (< 5mg/L) dissolved oxygen (DO) concentrations are significantly associated with degraded biological conditions and found in 27% of the stream miles with poor to very poor biological conditions in the Baltimore Harbor watershed. Low DO concentrations may indicate organic pollution due to excessive oxygen demand and may stress aquatic organisms. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR 2013d. *Low (< 6mg/L) dissolved oxygen* was also significantly associated with degraded biological conditions and found in 25% of the stream miles with poor to very poor biological conditions in the watershed.

Low (< 60%) *DO saturation* is also significantly associated with degraded biological conditions and found in 31% of the stream miles with poor to very poor biological conditions in the Baltimore Harbor watershed. Natural diurnal fluctuations can become exaggerated in streams with excessive primary production. High and low DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. High DO saturation is considered to demonstrate oxygen production associated with high levels of photosynthesis. Low DO saturation is considered to demonstrate high respiration associated with excessive decomposition of organic material.

Natural and anthropogenic changes to an aquatic environment can affect the availability of DO. The normal diurnal fluctuations of a system can be altered resulting in large fluctuations in DO levels which can occur throughout the day. The low DO concentration may be associated with the impacts of elevated nutrient loadings, low precipitation, low gradient streams, and the decomposition of leaf litter.

Although low DO concentrations are usually associated with surface waters experiencing eutrophication as the result of excessive nutrient loading, this might not necessarily be the cause in the Baltimore Harbor watershed. The watershed is predominately located in the Coastal Plains Physiographic Province, and major difference between the Coastal Plain and the other physiographic provinces in Maryland is the response of streams to organic enrichment. Because of the lower gradient and naturally limited capacity to mechanically aerate the water and replace oxygen lost via biochemical oxygen demand (BOD), streams in the Coastal Plain more often tend to become more over enriched than elsewhere in the State. Many first order streams in the Coastal Plain province tend to have very little or no flow during long stretches of the year. Low DO values are not uncommon in small low gradient streams with low or stagnant flows.

MDE analyzed water quality data collected in 2007 and 2011 by state agencies in the Baltimore Harbor non-tidal portion of the watershed. Fifty-five samples were collected. Only three incidences of low DO concentrations were reported, and no nutrient parameter concentrations exceeded the BSID threshold values. Reductions of nutrients are already being mandated in the watershed due to the 2010 Chesapeake Bay TMDL, and the 2007 nutrient TMDL for the tidal portion of the Baltimore Harbor. Hopefully with continued efforts in implementing and enforcing these nutrient TMDLs by State and local agencies, any significant nutrient loadings in the watershed will decrease, as well as occurrences of low DO levels.

Chloride, and sulfate toxicity identified by the BSID analysis can be indicative of urban development that degrades water quality by causing an increase in contaminant loads from various point and nonpoint sources especially during storm events. These sources can add variety of pollutants to surface waters at levels potentially toxic to aquatic organisms.

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 81% suggesting these stressors are the probable causes of biological impairments in the Baltimore Harbor watershed (Table 7).

4.3 Discussion

The Baltimore Harbor Watershed is largely comprised of highly urbanized land uses (87%), including large tracts occupied by heavy industry. The watershed has been an industrial location and densely populated for more than 150 years. According to the Bureau of the Census, between 1960 and 1990, the amount of land used for urban purposes in Baltimore, Maryland grew by about 170 percent.

The BSID analysis results suggest that degraded biological communities in the Baltimore Harbor watershed are a result of increased urban land use causing alterations to the hydrologic regime and stream morphology. These alterations have resulted in frequent high flow events and degradation to in-stream habitat quality, resulting in an unstable stream ecosystem that eliminates optimal habitat. High percentages of urban land uses in the watershed also results in increased contaminant loads from point and nonpoint sources, resulting in levels of chloride and sulfates that can be extremely toxic to aquatic organisms. Industrial point source discharges combined with polluted stormwater runoff over this long history has degraded the quality of the streams draining the watershed (Weston 2000).

No nutrient stressors were identified in the BSID analysis as having significant association with degraded biological conditions in the watershed. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and decomposition of organic matter. Nutrient reductions are mandated by the 2010 Chesapeake Bay TMDL and a 2007 nutrient TMDL for the tidal portions of the watershed, therefore, no other management actions requiring additional nutrient reductions are necessary.

The combined AR for all the stressors is approximately 94%, suggesting that sediment, in-stream habitat, and water chemistry stressors identified in the BSID analysis are the most probable cause of biological impairments in the Baltimore Harbor watershed (Table 7).

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

4.4 Final Causal Model for the Baltimore Harbor 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 2013). 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 Baltimore Harbor watershed, with pathways to show the watershed's probable stressors as indicated by the BSID analysis.

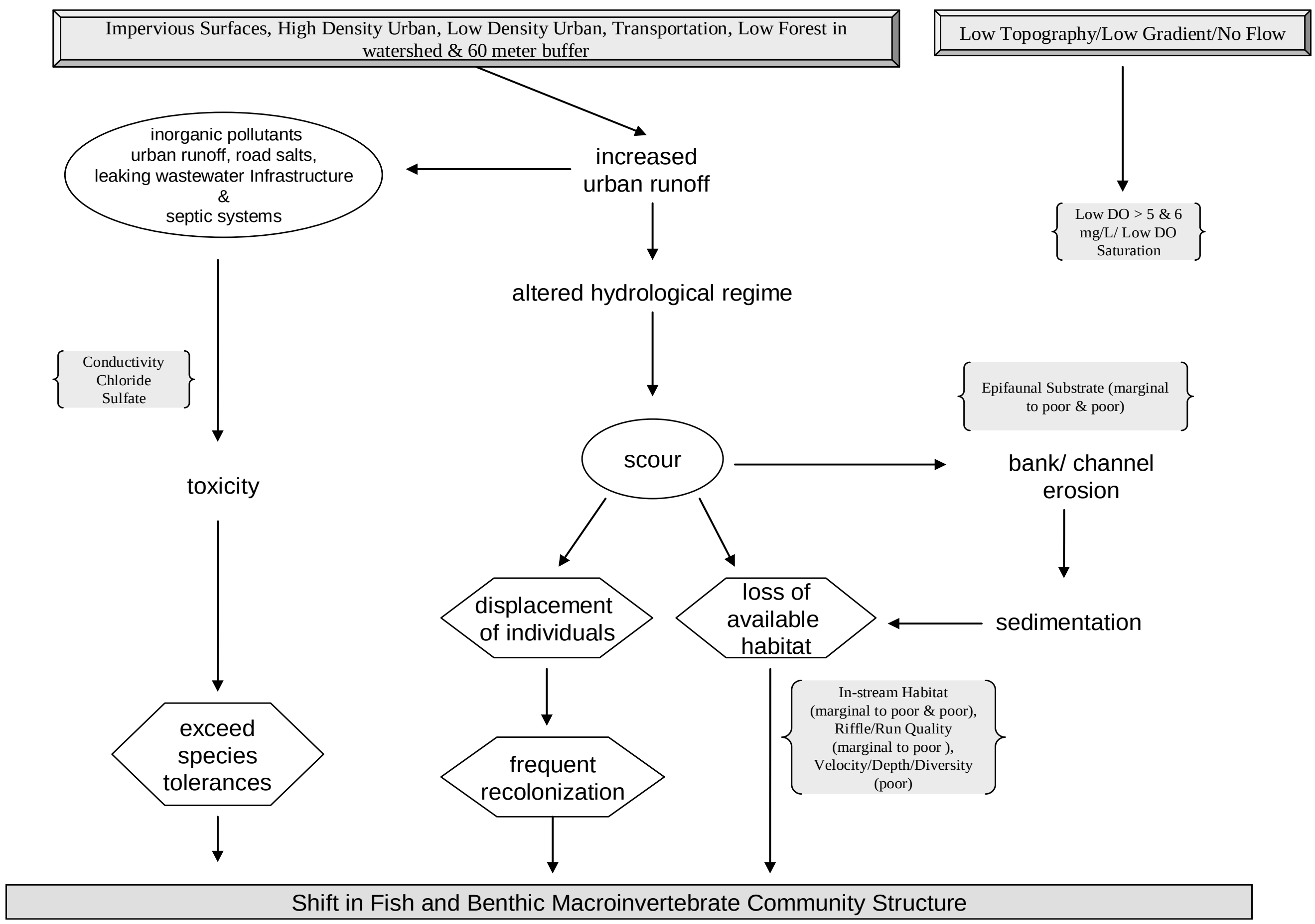


Figure 6. Final Causal Model for the Baltimore Harbor Watershed

5.0 Conclusions

Data suggest that the Baltimore Harbor watershed’s biological communities are strongly influenced by urban land use, which has altered the hydrologic regime resulting in loss of diverse habitat, unstable stream morphology, as well as sediment, chloride, and sulfate toxicity. 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 Baltimore Harbor watershed are summarized as follows:

- The BSID process has determined that the biological communities in the Baltimore Harbor River watershed are likely degraded due to inorganics (i.e., chloride and sulfates). Chloride and sulfate levels are significantly associated with degraded biological conditions and found in approximately 79% and 29% of the stream miles with poor to very poor biological conditions in the watershed. The BSID results thus support a Category 5 listing of chloride and sulfates for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Baltimore Harbor 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 which 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 process has determined that biological communities in Baltimore Harbor watershed are also likely degraded due to sediment and in-stream habitat related stressors. Specifically, altered hydrology and increased runoff from urban and impervious surfaces have resulted in channel erosion, scouring, and transport of suspended sediments in the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results thus confirm the establishment of a total suspended solids (TSS) TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin mitigating the impacts of sediments on biological communities in the Baltimore Harbor watershed. The BSID results thus support a Category 5 listing of TSS for the non-tidal portion of the 8-digit watershed as an appropriate management action to begin addressing the impact of these stressors on the biological communities in the Baltimore Harbor watershed.

- The BSID process has also determined that biological communities in the Baltimore Harbor watershed are likely degraded due to anthropogenic channelization of stream segments. MDE considers channelization as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. Category 4c listings include segments impaired due to stream channelization or the lack of adequate flow. MDE recommends a Category 4c listing for the Baltimore Harbor watershed based on channelization being present in approximately 37% of degraded stream miles.

- The BSID process has also determined that biological communities in the Baltimore Harbor watershed are likely degraded due to anthropogenic alterations of riparian buffer zones. MDE considers inadequate riparian buffer zones as pollution not a pollutant; therefore, a Category 5 listing for this stressor is inappropriate. However, Category 4c is for waterbody segments where the State can demonstrate that the failure to meet applicable water quality standards is a result of pollution. MDE recommends a Category 4c listing for the Baltimore Harbor watershed based on inadequate riparian buffer zones in approximately 28% of degraded stream miles.

- No nutrient stressors were identified in the BSID analysis as having significant association with degraded biological conditions in the watershed. The low dissolved oxygen levels observed in the watershed are probably due to a combination of low topographic relief of the watershed, seasonal low flow/no flow conditions, and decomposition of organic matter. Nutrient reductions are mandated by the 2010 Chesapeake Bay TMDL and a 2007 nutrient TMDL for the tidal portions of the watershed; therefore, no other management actions requiring additional nutrient reductions are necessary.

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