Watershed Report for Biological Impairment of the Seneca Creek Watershed in Montgomery County, Maryland Biological Stressor Identification Analysis Results and Interpretation

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MH	Mantel-Haenzel
mg/L	Milligrams per liter
NH_3	Ammonia
NPDES	National Pollution Discharge Elimination System
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. 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.

Seneca Creek (basin number 02140208), located in Montgomery County, was identified in Maryland's Integrated Report as impaired by nutrients, sediments (1996 listings), and impacts to biological communities (2002). Clopper Lake, located within the watershed, was listed as impaired by nutrients and sediments (1998 listings). Except for Clopper Lake, all impairments are listed for non-tidal streams. The 1996 nutrients listing were refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. TMDLs for Clopper Lake were completed in 2001.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score less than 3, and calculating whether this is significant from a reference condition watershed (i.e., healthy stream, <10% stream miles degraded).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of Seneca Creek is Use I-P (Water Contact Recreation, Protection of Nontidal Warmwater Aquatic Life, and Public Water Supply). Two tributaries, Little Seneca Creek (and its tributaries) from the stream's confluence with Bucklodge Branch to the B&O railroad bridge, and Wildcat Branch (and its tributaries), are designated as Use III-P (Nontidal Cold Water and Public Water Supply). The remaining portion of Little Seneca Creek and its tributaries is designated as Use IV-P (Recreational Trout Waters and Public Water Supply) (COMAR 2009a,b,c). The Seneca Creek 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 this stressor have on the degraded sites in the watershed.

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

This Seneca Creek watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the degradation of biological communities in Seneca Creek is strongly influenced by urban land use and its concomitant effects: altered hydrology and elevated levels of ammonia, pH, chlorides, and conductivity (a measure of the presence of dissolved substances). The urbanization of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

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

- The BSID process has determined that the biological communities in Seneca Creek are likely degraded due to inorganic pollutants (i.e., chlorides and conductivity) and elevated ammonia concentrations, and are influenced by high pH. Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 78% of the stream miles with very poor to poor biological conditions in the Seneca Creek watershed. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) and extent of the impairment. MDE scientists also recommend a more intense analysis of all available data to determine if there is an ammonia toxicity impairment in these waters.

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

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

1.0 Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met. In 2002, the State began listing biological impairments on the Integrated Report. Maryland Department of the Environment (MDE) has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings.

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or 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 Seneca Creek watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Seneca Creek Watershed Characterization

2.1 Location

Seneca Creek is the largest watershed located entirely within Montgomery County (see Figure 1). The Seneca Creek watershed originates near Damascus in the northwest portion of the County, flowing in a southerly direction through Germantown and Gaithersburg, until it joins the Potomac River near the town of Seneca. Two large tributary systems flow into Seneca Creek: Little Seneca Creek and Dry Seneca Creek. The drainage area of the Maryland 8-digit watershed Seneca Creek is 82,000 acres. The watershed is located in the Highland region of the three distinct eco-regions identified in the MBSS indices of biological integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

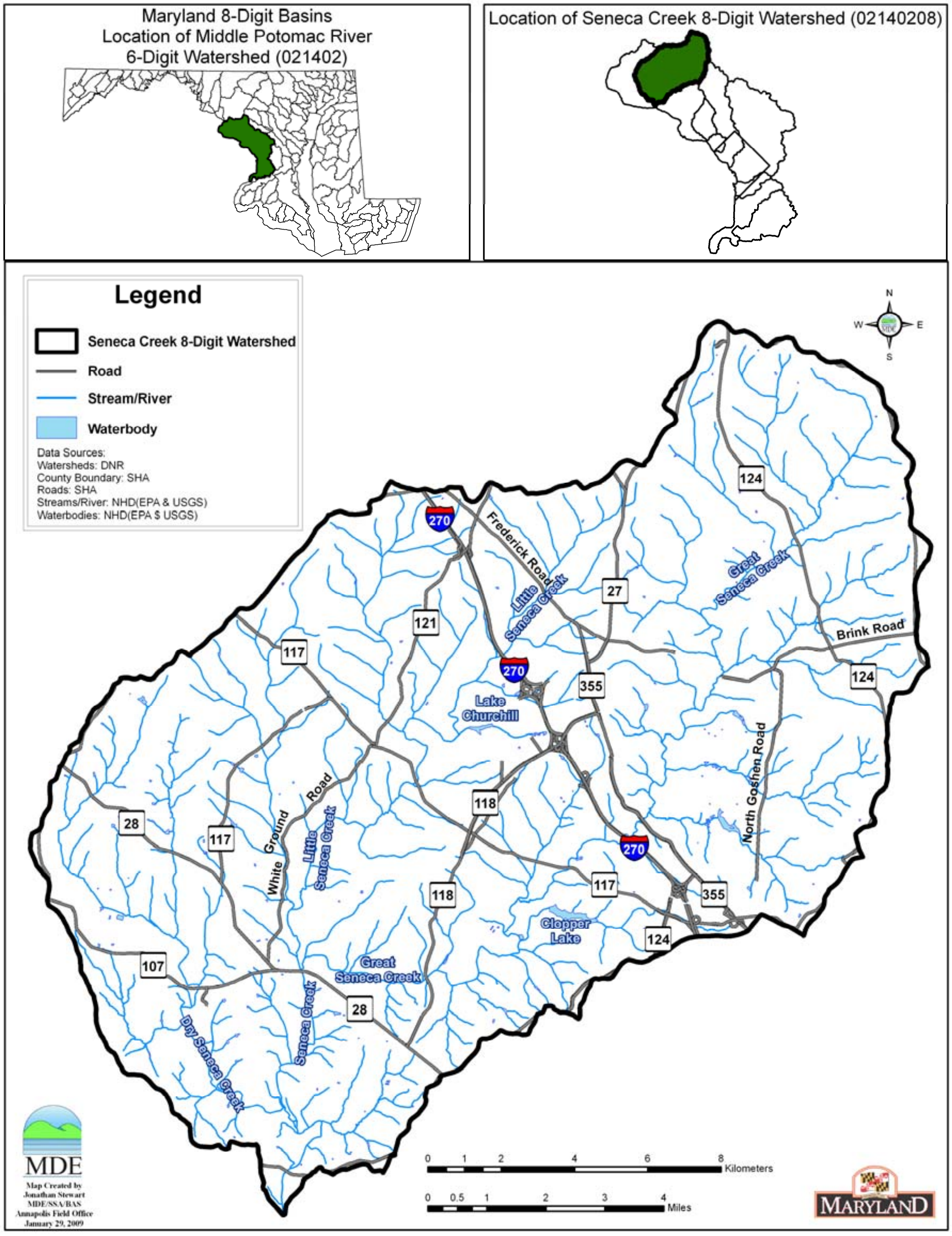

Figure 1. Location Map of Seneca Creek Watershed

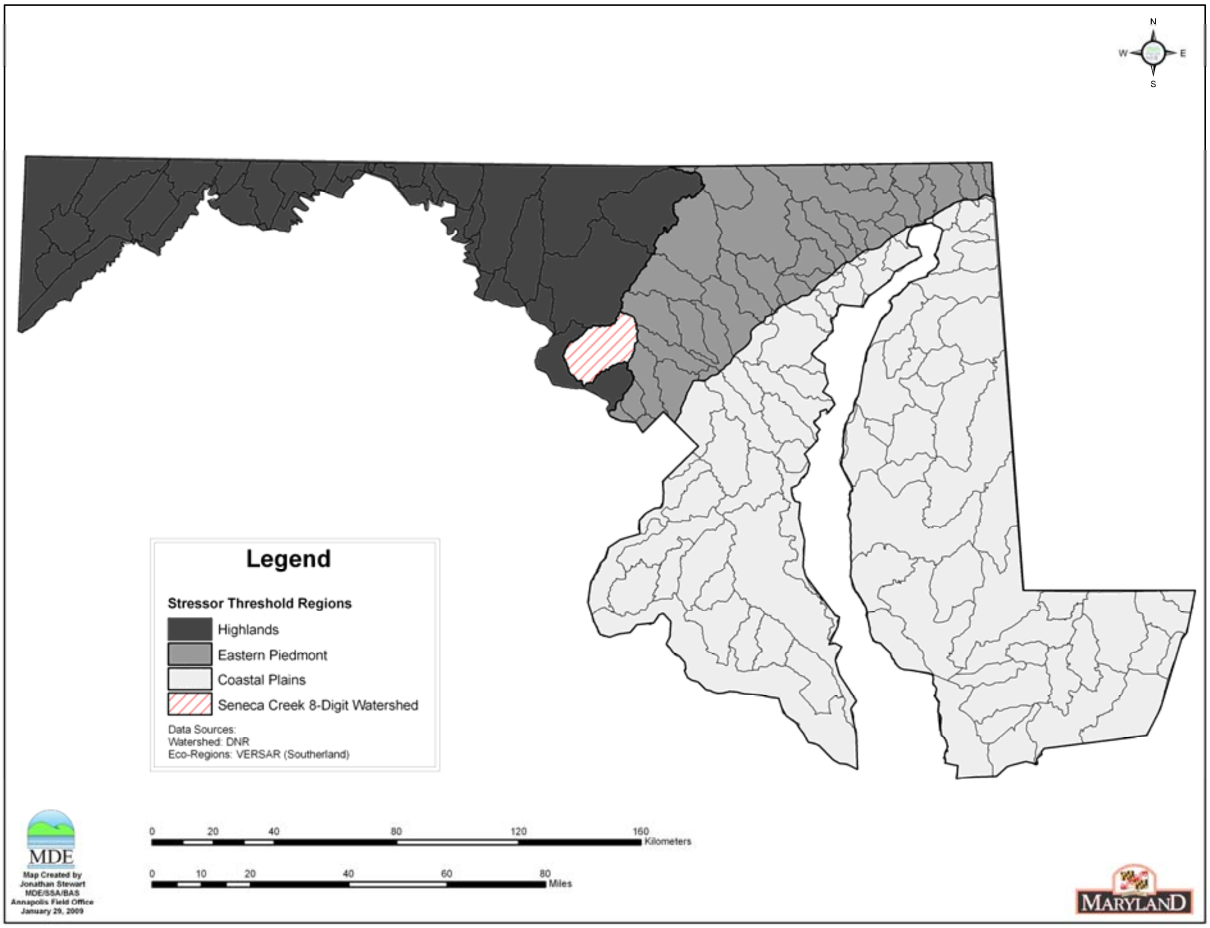

Figure 2. Eco-Region Location Map for Seneca Creek Watershed

2.2 Land Use

The Great Seneca Creek headwaters begin southeast of Damascus and flow through low density residential and agriculture areas. It then passes through commercial areas in Damascus and continues through low to medium density residential areas. Great Seneca Creek then flows through the Montgomery Village area, where land use densities increase considerably. Below Route 355, it picks up additional drainage from high density urban areas in Gaithersburg and Germantown. Many portions of these urban areas were built during the 1970s before modern stormwater runoff controls were required by the State (GHS 2009). Great Seneca then transitions back to low density residential and agricultural land uses from approximately Riffle Ford Road in south Germantown down to the Potomac River. Major tributaries in this portion of Great Seneca Creek include Whetstone Run, Gunners Branch, and Long Draught Branch. These three tributaries all originate in high density residential areas and each have in-stream impoundments: Lake Whetstone, Gunners Lake, and Clopper Lake. Below Germantown, some tributary areas of Great Seneca are changing from agriculture to low and medium density residential. Major tributaries in this portion of Great Seneca include Little Seneca Creek and Dry Seneca Creek. The upper reaches of Little Seneca Creek contain the in-stream impoundment Little Seneca Lake. Overall, the Seneca Creek watershed contains an equal mixture of urban, agricultural, and forested land use (see Figure 3). The land use distribution in the watershed is approximately 33% forest/herbaceous, 33% urban, 33% agricultural and 1% water (see Figure 4) (MDP 2002).

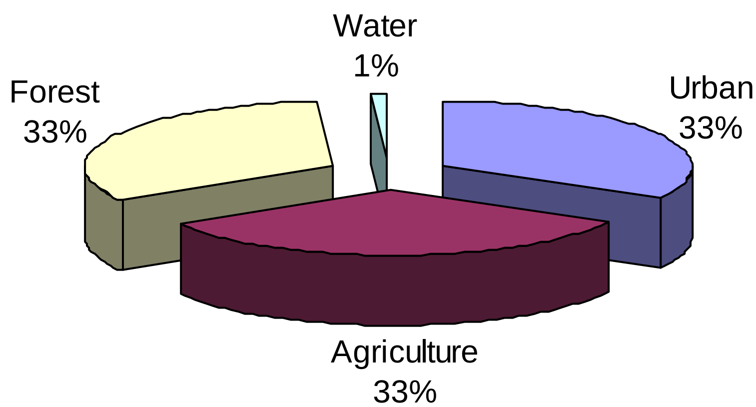

Figure 3. Proportions of Land Use in the Seneca Creek Watershed

2.3 Soils/hydrology

The Seneca Creek watershed lies within the Piedmont Plateau province of Central Maryland. The Piedmont Plateau province is characterized by gentle to steep rolling topography, low hills and ridges. Numerous rather deep and narrow stream valleys have been incised into it; the streams often show relatively steep gradient with many rapids (MGS 2007). The Piedmont Plateau Province is composed of hard, crystalline igneous and metamorphic rocks and extends from the inner edge of the Coastal Plain westward to Catoctin Mountain, the eastern boundary of the Blue Ridge Province. Bedrock in the eastern part of the Piedmont consists of schist, gneiss, slate, and other highly metamorphosed sedimentary and igneous rocks of probable volcanic origin. In several places these rocks have been intruded by granitic plutons and pegmatites (MGS 2007). Soils typically found in the Seneca Creek watershed are the chrome, baile, penn, and Waynesboro series. The Chrome series consists of moderately deep, well drained soils. The Baile series consists of very deep, poorly drained, moderately low to moderately high saturated hydraulic conductivity, soils on upland depressions and footslopes. The Penn series consists of moderately deep, well drained soils formed in residuum weathered from noncalcareous reddish shale, siltstone, and fine-grained sandstone of the Triassic age. The Waynesboro series consist of very deep, well drained, moderately permeable soils that formed in old alluvium or unconsolidated material of sandstone, shale, and limestone origin (U.S. Department of Agriculture (USDA) 1977).

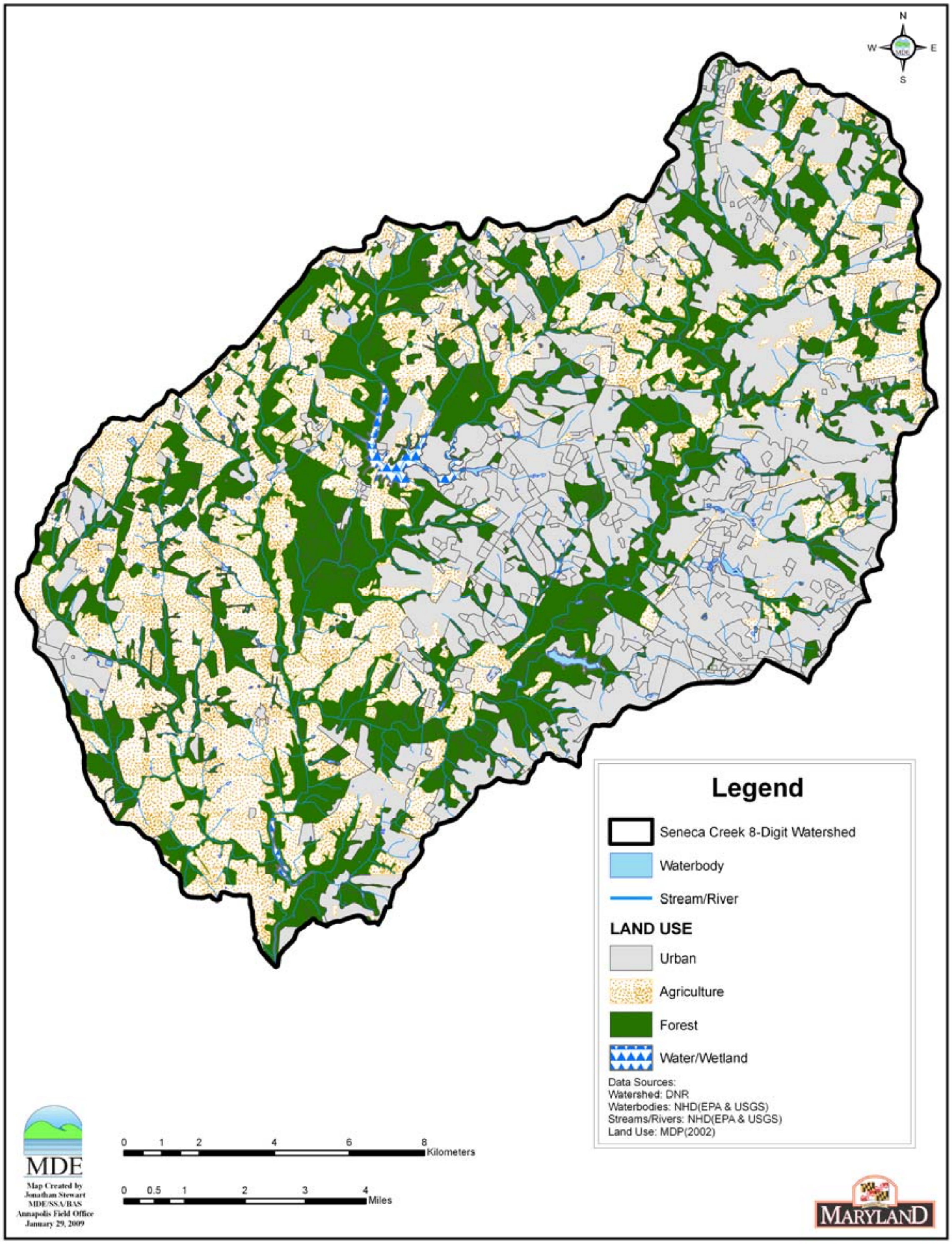

Figure 4. Land Use Map of the Seneca Creek Watershed

3.0 Seneca Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

Seneca Creek (basin number 02140208) was identified in Maryland's Integrated Report as impaired by nutrients, sediments (1996 listings), and impacts to biological communities (2002). Clopper Lake, located within the watershed, was listed as impaired by nutrients and sediments (1998 listings). Except for Clopper Lake, all impairments are listed for non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. TMDLs for Clopper Lake were completed in 2001.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of Seneca Creek is Use I-P (Water Contact Recreation, Protection of Nontidal Warmwater Aquatic Life, and Public Water Supply). Two tributaries, Little Seneca Creek (and its tributaries) from the stream's confluence with Bucklodge Branch to the B&O railroad bridge, and Wildcat Branch (and its tributaries), are designated as Use III-P (Nontidal Cold Water and Public Water Supply). The remaining portion of Little Seneca Creek and its tributaries is designated as Use IV-P (Recreational Trout Waters and Public Water Supply) (COMAR 2009a,b,c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Seneca Creek watershed is listed under Category 5 of the 2008 Integrated Report as impaired for impacts to biological communities. Approximately 89% of stream miles in the Seneca Creek 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 thirty-two stations. Twenty-two of the thirty-two stations have 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 fourteen MBSS sites with eleven having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Seneca Creek watershed.

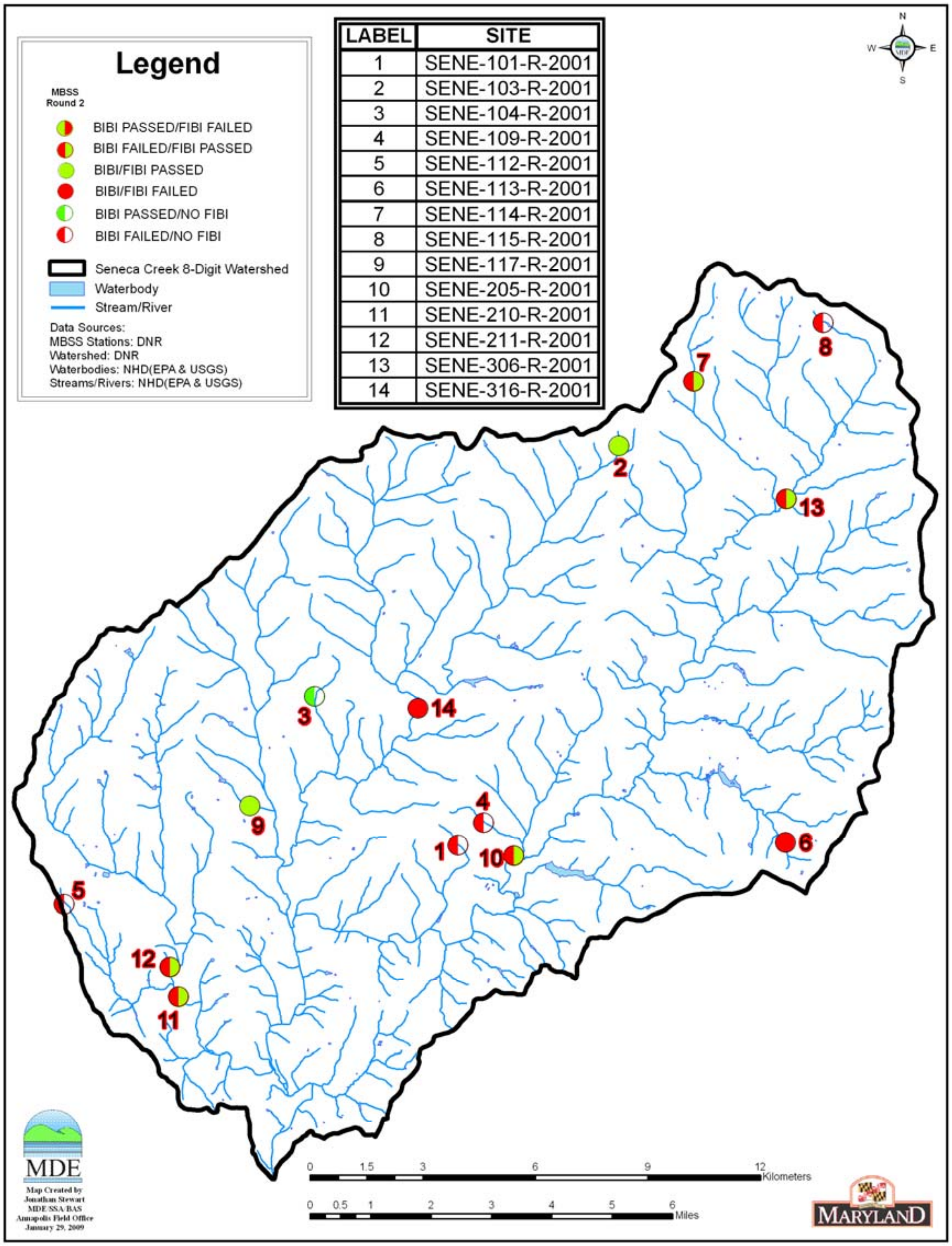

Figure 5. Principal Dataset Sites for the Seneca Creek Watershed

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

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are very poor to poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and very poor to poor biological conditions, and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

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

Through the BSID analysis, MDE identified sediment, in-stream habitat, riparian habitat, water chemistry parameters, and potential sources significantly associated with poor to very poor benthic and/or fish biological conditions. As shown in Table 1 through Table 3, parameters from the sediment, in-stream habitat, and water chemistry groups are identified as possible biological stressors in Seneca Creek. 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 Seneca Creek watershed. Table 6 shows the summary of combined attributable risk (AR) values for the source groups in the Seneca Creek watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for Seneca Creek

Parameter Group	Stressor	Source of Threshold Value	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	DNR	14	11	83	9%	13%	No	----
	moderate bar formation present	DNR	14	11	83	45%	42%	No	----
	bar formation present	DNR	14	11	83	100%	91%	No	----
	channel alteration marginal to poor	DNR	14	11	83	45%	42%	No	----
	channel alteration poor	DNR	14	11	83	9%	12%	No	----
	high embeddedness	MDE	14	11	83	9%	9%	No	----
	epifaunal substrate marginal to poor	DNR	14	11	83	18%	11%	No	----
	epifaunal substrate poor	DNR	14	11	83	18%	2%	Yes	16%
	moderate to severe erosion present	DNR	14	11	83	45%	61%	No	----
	severe erosion present	DNR	14	11	83	9%	13%	No	----
	poor bank stability index	MDE	14	11	83	0%	4%	No	----
	silt clay present	DNR	14	11	83	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for Seneca Creek

Parameter Group	Stressor	Source of Threshold Value	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	DNR	14	11	84	27%	10%	No	----
	instream habitat structure marginal to poor	DNR	14	11	83	27%	10%	Yes	18%
	instream habitat structure poor	DNR	14	11	83	9%	1%	No	----
	pool/glide/eddy quality marginal to poor	DNR	14	11	83	45%	41%	No	----
	pool/glide/eddy quality poor	DNR	14	11	83	18%	1%	Yes	18%
	riffle/run quality marginal to poor	DNR	14	11	83	45%	15%	Yes	32%
	riffle/run quality poor	DNR	14	11	83	18%	1%	Yes	17%
	velocity/depth diversity marginal to poor	DNR	14	11	83	55%	42%	No	----
	velocity/depth diversity poor	DNR	14	11	83	9%	0%	Yes	9%
	concrete/gabion present	DNR	14	11	84	18%	2%	Yes	16%
	beaver pond present	DNR	14	11	83	0%	3%	No	----
Riparian Habitat	no riparian buffer	MDE	14	11	84	18%	23%	No	----
	low shading	MDE	14	11	83	9%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for Seneca Creek

Parameter Group	Stressor	Source of Threshold Value	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	MDE	14	11	165	36%	47%	No	----
	high total dissolved nitrogen	MDE	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	COMAR	14	11	165	18%	5%	No	----
	ammonia acute with salmonid absent	COMAR	14	11	165	18%	3%	Yes	15%
	ammonia chronic with salmonid present	COMAR	14	11	165	27%	15%	No	----
	ammonia chronic with salmonid absent	COMAR	14	11	165	18%	4%	No	----
	low lab pH	COMAR	14	11	165	9%	2%	No	----
	high lab pH	COMAR	14	11	165	27%	2%	Yes	25%
	low field pH	COMAR	14	11	164	18%	4%	No	----
	high field pH	COMAR	14	11	164	0%	2%	No	----
	high total phosphorus	MDE	14	11	165	18%	6%	No	----
	high orthophosphate	MDE	14	11	165	18%	8%	No	----
	dissolved oxygen < 5mg/l	COMAR	14	11	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	COMAR	14	11	164	0%	2%	No	----
	low dissolved oxygen saturation	MDE	13	11	152	0%	1%	No	----
	high dissolved oxygen saturation	MDE	13	11	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	Literature	14	11	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	Literature	14	11	165	9%	7%	No	----
	high chlorides	Literature	14	11	165	45%	5%	Yes	40%
	high conductivity	MDE	14	11	165	64%	6%	Yes	58%
	high sulfates	MDE	14	11	165	9%	4%	No	----

Table 4. Stressor Source Identification Analysis Results for Seneca Creek

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Agriculture	high impervious surface in watershed	14	11	164	27%	3%	Yes	24%
	high % of high intensity urban in watershed	14	11	165	64%	21%	Yes	42%
	high % of low intensity urban in watershed	14	11	165	27%	5%	Yes	22%
	high % of transportation in watershed	14	11	165	27%	9%	Yes	18%
	high % of high intensity urban in 60m buffer	14	11	164	36%	4%	Yes	32%
	high % of low intensity urban in 60m buffer	14	11	164	27%	6%	Yes	21%
	high % of transportation in 60m buffer	14	11	164	27%	6%	Yes	21%
	high % of agriculture in watershed	14	11	165	0%	22%	No	----
	high % of cropland in watershed	14	11	165	0%	3%	No	----
	high % of pasture/hay in watershed	14	11	165	27%	29%	No	----
	high % of agriculture in 60m buffer	14	11	164	0%	13%	No	----
	high % of cropland in 60m buffer	14	11	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	14	11	164	18%	23%	No	----

Table 4. Stressor Source Identification Analysis Results for Seneca Creek (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Barren	high % of barren land in watershed	14	11	165	18%	10%	No	----
	high % of barren land in 60m buffer	14	11	164	27%	10%	No	----
Sources Anthropogenic	low % of forest in watershed	14	11	165	36%	8%	Yes	28%
	low % of forest in 60m buffer	14	11	164	27%	9%	Yes	19%
Sources Acidity	atmospheric deposition present	14	11	165	0%	5%	No	----
	AMD acid source present	14	11	165	0%	0%	No	----
	organic acid source present	14	11	165	0%	0%	No	----
	agricultural acid source present	14	11	165	9%	2%	No	----

Table 5. Summary AR Values for Stressor Groups for Seneca Creek

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	16%	88%
In-Stream Habitat	51%	
Riparian Habitat	----	
Water Chemistry	78%	

Table 6. Summary AR Values for Source Groups for Seneca Creek

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	58%	58%
Agriculture	----	
Barren Land	----	
Anthropogenic	28%	
Acidity	----	

Sediment Conditions

BSID analysis results for Seneca Creek identified one sediment parameter that has a statistically significant association with poor to very poor stream biological condition: e*pifaunal substrate (poor).*

Epifaunal substrate (poor) was identified as significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 16% of the stream miles with poor to very poor biological conditions. This stressor 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. 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. 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.

As development and urbanization increased in the Seneca Creek watershed so did morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Increases in impervious surface cover that accompanies urbanization alters stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, thus decreasing the amount of time it takes water to reach streams causing urban streams to be more "flashy" (Walsh et al. 2005). When stormwater flows through stream channels faster, more often, and with more force, the results are stream channel widening and streambed scouring. The scouring associated with these increased flows leads to accelerated channel erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. A poor rating for epifaunal substrate is an indicator that stable substrate is lacking and stream bottom is cover with fine layer of sediment. Some of the impacts associated with sedimentation are smoothing of benthic communities, reduced survival rate of fish eggs, and reduced habitat quality from embedding of stream bottom (Hoffman et al. 2003). Poor epifaunal substrate levels could be the combined result of the broad influence of urbanization along with large-scale flow modification affected by dams (Lake Whetstone, Gunners Lake, Clopper Lake, and Little Seneca Lake) that could decrease stream habitat diversity by attenuating storm flows. All of these processes result in an unstable stream ecosystem that impacts habitat heterogeneity and the dynamics (structure and abundance) of stream benthic organisms (Allan 2004).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the sediment stressor group is approximately 16% suggesting that this stressor group impacts a significant percentage of degraded stream miles in the Seneca Creek watershed (Table 5).

In-stream Habitat Conditions

BSID analysis results for Seneca Creek identified six in-stream habitat parameters that have a statistically significant association with poor to very poor stream biological condition: *instream habitat structure (marginal to poor), pool/glide/eddy quality (poor), riffle/run quality (marginal to poor & poor), velocity/depth diversity (poor),* and *concrete/gabion present.*

In-stream habitat structure (marginal to poor) was identified as significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 18% 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. High in-stream habitat scores are evidence of the lack of sediment deposition. Like embeddedness, in-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks, causing sediment inputs to fill pools and other fish habitats. In-stream habitat is considered marginal to poor when there is 30-10% stable habitat observed in the stream.

Pool/glide/eddy quality (poor) was identified as significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 18% of the stream miles with poor to very poor biological conditions. Pool/glide/eddy quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment referred to as pool/glide/eddy. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the pool/glide/eddy habitat decreases valuable habitat for fish species. Poor pool/glide/eddy quality conditions are defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely.

Riffle/run quality (marginal to poor & poor) was identified as significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 32% (*marginal to poor* rating) and 17% (*poor* rating) 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. Like pool quality, an increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity. 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 Seneca Creek, and found to impact approximately 9% 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 pool quality and riffle 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 marginal or poor diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime.

Concrete/gabion present was identified as significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 16% of the stream miles with poor to very poor biological conditions. The presence or absence of concrete/gabion is determined by a visual observation within the stream segment, resulting from the field description of the types of channelization. Concrete/gabion inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete or gabion channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization.

Seneca Creek and its tributaries pass through low to high-density urban areas including: Gaithersburg, Germantown, and Poolesville. . Many portions of these urban areas were built during the 1970's before modern stormwater runoff controls were required by the Stat. (GHS 2009). Increased stormwater run-off and flashiness of the stream flows in the Seneca Creek watershed have resulted in significant morphological changes that affect a stream's habitat as demonstrated by the statistically significant stressors associated with the overall in-stream habitat condition. The scouring of the streambed associated with these increased flows leads to loss of habitat heterogeneity and accelerated channel erosion, thereby increasing sediment deposition throughout the streambed. Urbanization along with large-scale flow modification affected by lake impoundments could decrease stream habitat diversity by attenuating storm flows. All of these processes result in an unstable stream habitat and degradation to habitat quality. Reinforcing stream banks with concrete and gabion has been used extensively in urban developed areas like Germantown and Gaithersburg for flood control. The purpose is to increase channel capacity and flow velocities so water moves more efficiently downstream. However, this type of channelization is detrimental for the "well being" of streams and rivers through the elimination of suitable habitat and the creation of excessive flows. Stream bottoms are made more uniform. Habitats of natural streams contain numerous bends, riffles, runs, pools and varied flows, and tend to support healthier and more diversified plant and animal communities than those with concreted or gabion streambeds. The natural structures impacting stream hydrology, which were removed for channelization, also provide critical habitat for stream species and impact nutrient availability in stream microhabitats. The refuge cavities removed by channelization not only provide concealment for fish, but also serve as traps for detritus, and are areas colonized by benthic macroinvertebrates (Bolton and Shellberg 2001).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the in-stream stressor group is approximately 51% suggesting that this stressor group impacts a high percentage of degraded stream miles in the Seneca Creek watershed (Table 5).

Riparian Habitat Conditions

BSID analysis results for Seneca Creek did not identify any riparian habitat parameters that have statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community).

Water Chemistry Conditions

BSID analysis results for Seneca Creek identified four water chemistry parameters that have statistically significant association with a very poor to poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *high conductivity*, *high chlorides, ammonia acute with salmonid absent*, and *high lab pH.*

High Conductivity levels are significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 58% of the stream miles with poor to very poor biological conditions. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Conductivity and chlorides are closely related. Streams with elevated levels of chlorides typically display high conductivity.

High chloride levels are significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 40% of the stream miles with poor to very poor biological conditions. High concentrations of chlorides can result from natural causes, industrial discharges, metals contamination, and application of road salts in urban landscapes. No industrial discharges were identified in MBSS watersheds. Also, Smith et al. (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.

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

Ammonia acute with salmonid absent is significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 15% of the stream miles with poor to very poor biological conditions. Acute ammonia toxicity refers to potential exceedances of species tolerance caused by a one-time, sudden, high exposure of ammonia. Ammonia acute with salmonid present or absent is a USEPA water quality criterion for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present or absent (USEPA 2006).

High lab pH levels above 8.5 are significantly associated with degraded biological conditions in Seneca Creek, and found to impact approximately 25% of the stream miles with poor to very poor biological conditions. pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. High pH may allow concentrations of toxic elements and high amounts of dissolved heavy metals to be mobilized for uptake by aquatic plants and animals. For example, as pH increases, aquatic organisms are more susceptible to ammonia toxicity. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from State regulations (COMAR 2009d).

The combined AR is used to measure the extent of stressor impact of degraded stream miles, very poor to poor biological conditions. The combined AR for the water chemistry stressor group is approximately 78% suggesting that water chemistry stressors impact a majority of the degraded stream miles in Seneca Creek (Table 5).

Sources

All nine stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Seneca Creek watershed BSID analysis are representative of impacts from urban developed landscapes. The scientific community (Booth 1991, Konrad and Booth 2002, and Meyer et al. 2005) has consistently identified negative impacts to biological conditions as a result of increased urbanization. A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed "urban stream syndrome" (Meyer et al. 2005). Symptoms of urban stream syndrome include flashier hydrographs, altered habitat conditions, degradation of water quality, and reduced biotic richness, with increased dominance of species tolerant to anthropogenic (and natural) stressors.

Increases in impervious surface cover that accompany urbanization alter stream hydrology, forcing runoff to occur more readily and quickly during rainfall events, decreasing the time it takes water to reach streams and causing them to be more "flashy" (Walsh et al. 2005). Land development can also cause an increase in contaminant loads from point and nonpoint sources. In virtually all studies, as the amount of impervious area in a watershed increases, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The BSID source analysis (Table 4) identifies various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 59% suggesting that urban development potentially impact a significant percentage of degraded stream miles in Seneca Creek (Table 6).

Summary

The BSID analysis results suggest that degraded biological communities in the Seneca Creek watershed are a result of increased urban land use causing alteration to hydrology and leading to loss of habitat heterogeneity. Altered stormwater, base flows, and stressors associated with altered flow regimes were identified in all areas of the watershed (Van Ness & Haddaway 1999). The altered hydrology has caused frequent high flow events, degradation to in-stream habitat quality, and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat. Due to the increased proportions of urban land use in the Seneca Creek watershed, the watershed has experienced an increase in contaminant loads from point and nonpoint sources, resulting in levels of inorganic pollutants and ammonia that can potentially be extremely toxic to aquatic organisms. Alterations to the hydrologic regime, physical habitat, and water chemistry have all combined to degrade Seneca Creek, leading to a loss of diversity in the biological community. The combined AR for all the stressors is approximately 88%, suggesting that sediment, in-stream habitat and water chemistry stressors identified in the BSID analysis would adequately account for the biological impairment in the Seneca Creek watershed (Table 5).

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

Final Causal Model for Seneca Creek

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 2007). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final causal model for Seneca Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

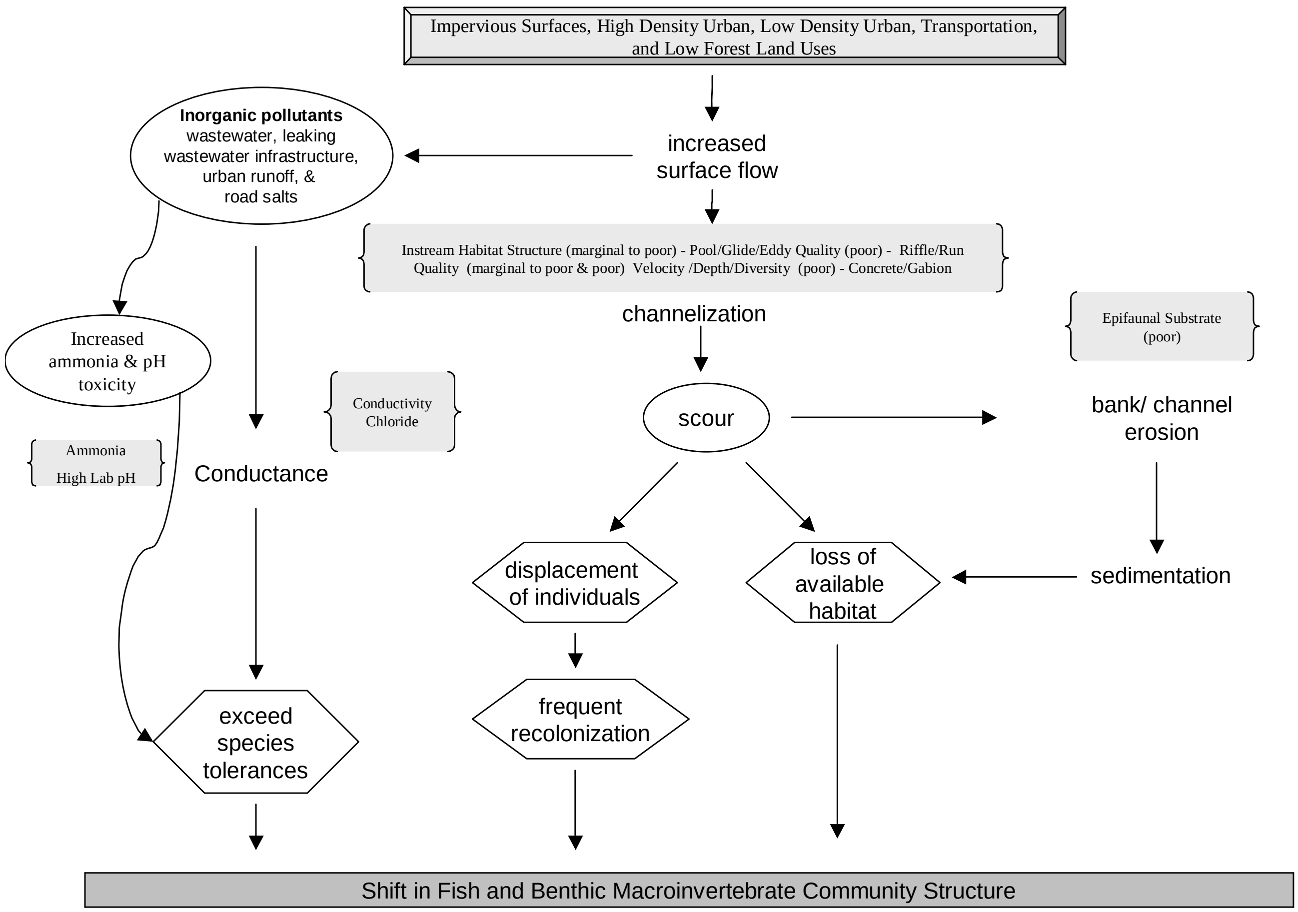

Figure 6. Final Causal Model for the Seneca Creek Watershed

5.0 Conclusion

Data suggest that the Seneca Creek watershed's biological communities are strongly influenced by urban land use, which alters the hydrologic regime, resulting in increased erosion, sediment, ammonia, 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 Seneca Creek are summarized as follows:

- The BSID process has determined that the biological communities in Seneca Creek are likely degraded due to inorganic pollutants (i.e., chlorides and conductivity) and elevated ammonia concentrations, and are influenced by high pH. Inorganic pollutants levels are significantly associated with degraded biological conditions and found in approximately 78% of the stream miles with very poor to poor biological conditions in the Seneca Creek watershed. Currently, there is a lack of monitoring data for many of these substances; therefore, additional monitoring of priority inorganic pollutants is needed to more precisely determine the specific cause(s) and extent of the impairment. MDE scientists also recommend a more intense analysis of all available data to determine if there is an ammonia toxicity impairment in these waters.

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

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

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