Watershed Report for Biological Impairment of the Deep Creek Lake Watershed in Garrett County, Maryland Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

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List of Abbreviations

AMD	Acid Mine Drainage
ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MD	Maryland
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
mg/L	Milligrams per liter
NADP	National Atmospheric Deposition Program
NH_3	Un-ionized Ammonia
NH_4	Ionized Ammonia
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
PA	Pennsylvania
SO_4	Sulfate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the 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 Deep Creek Lake watershed (basin code 05020203), located in Garrett County, was identified on the 2008 Integrated Report under Category 5 as impaired by phosphorus (1996 listing [8-digit watershed], 1998 listing [impoundment]), methylmercury in fish tissue (2002 listing [impoundment]), low pH (1996 listing) (Cherry Creek), and by impacts to biological communities (2002 listing). TMDLs for the low pH in the Cherry Creek sub-watershed (050202030029) and for methylmercury in the impoundment were established in 2004 following EPA approval of the TMDLs addressing these impairments.

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, 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 a significant deviation 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 Deep Creek Lake and its tributaries is Use III-P - (*Nontidal Cold Water and Public Water Supply*) (COMAR 2009a,b,c). Use III-P also includes all uses designated for Use I (*Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life*) (COMAR 2009a,c). The Deep Creek Lake 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 has 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 Deep Creek Lake 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 there are two underlying issues which are responsible for degraded biological conditions in the Deep Creek Lake watershed; low pH and stream morphology.

Water quality monitoring conducted through out the Deep Creek Lake watershed by the State of Maryland determined that Cherry Creek, a subwatershed, was impaired by acid mine drainage (AMD) as indicated by low pH measurements. Cherry Creek is impaired from its headwaters all the way to its confluence with Deep Creek Lake. The low pH is due in part to AMD. However, surveys and studies done by several state agencies and consulting companies demonstrate that some areas of the creek with low pH measurements are caused not only by AMD but also by natural sources of acidity (MDE 2003).

Stream morphology is also an underlying cause of observed biological community degradation in the Deep Creek Lake watershed. The topography of the drainage area is composed of two extreme land surfaces, nearly flat and nearly vertical causing a dominance of low gradient streams in the watershed. The absence of physical turbulence in surface waters due to areas of nearly flat terrain and the presence of wetlands/bogs in the watershed are likely contributors to low dissolved oxygen levels. The BSID analysis identified numerous sediment and habitat stressors, this may be interpreted as a result of excess sediment loading. However, these stressors more likely reflect sedimentation due to the dominance of low gradient streams in the watershed. Anthropogenic alterations exacerbate degraded stream morphology in the Deep Creek Lake watershed. The watershed contains a higher proportion of 1st order streams than other watersheds in the region because higher order streams are submerged by the impoundment. This characteristic is important because 1st order streams typically have less diverse habitat and biological community structure.

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

- Acidity is a cause of biological impairment in the sub-watershed of Cherry Creek with in the Deep Creek Lake watershed, as indicated by low pH and low Acid Neutralizing Capacity (ANC). A TMDL was developed by MDE to address low pH in Cherry Creek and was approved by the USEPA in 2003.

- The BSID process suggests that stream biological communities in the Deep Creek Lake Watershed are likely degraded due to elevated sulfate concentrations. The presence of AMD in the watershed is a potential source of sulfate. The BSID results thus support a Category 5 listing for sulfates as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Deep Creek Lake watershed.

- The BSID process suggests that stream biological communities in the Deep Creek Lake Watershed are likely degraded due to stressors associated with stream morphology (flow/habitat homogeneity). Identification of stressors like high embeddedness, poor epifaunal substrate, poor in-stream habitat, and poor riffle/run quality that could be interpreted as resulting from excess sediment loading, more likely reflect the occurrence of fine sediment due to the dominance of low gradient streams in the watershed. Large and small-scale human activity also amplifies homogeneity of physical habitat throughout the Deep Creek Lake Watershed. The BSID results thus support a Category 5 listing of total suspended solids as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Deep Creek Lake watershed.

- The proximity of wetlands, bogs, and seeps to stream stations and the dominance of flat terrain in the watershed are probable explanations for low dissolved oxygen, as well as contributing to low pH and high sulfate concentrations in the watershed.

1.0 Introduction

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

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments is normally limited to the round two of the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000 – 2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. However, only one site in the Deep Creek Lake watershed was surveyed during the round two sampling; therefore, MDE decided to use both round one and two datasets (eight stations) for the BSID 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 Deep Creek Lake watershed and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Deep Creek Lake Watershed Characterization

2.1 Location

The Deep Creek Lake watershed is located in the center of Garrett County, Maryland just west of the Eastern Continental Divide (see Figure 1). The watershed is a high plateau bounded by several mountains (Marsh Mountain, Meadow Mountain, Snaggy Mountain, and Roman Nose Hill) that has its single, deeply incised valley flooded by a hydroelectric dam. Deep Creek Lake has a surface area of approximately 3,900 acres (which is approximately 9% of the 41,408 acre drainage area) with a storage volume of approximately 106,000 acre-ft. The watershed area is located in the Highlands eco-region identified in the MBSS Index of Biotic Integrity (IBI) metrics (Southerland et al. 2005) (Figure 2).

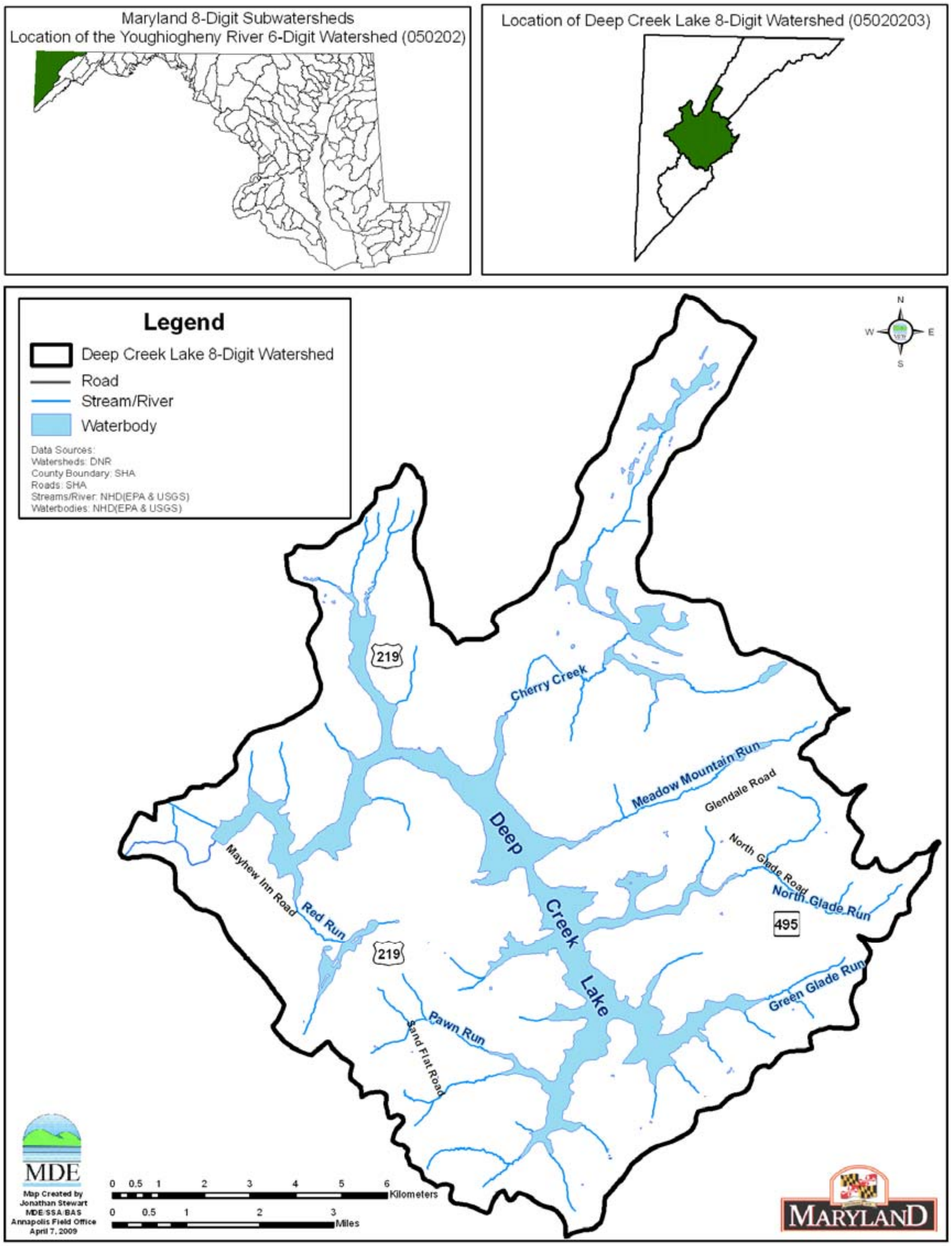

Figure 1. Location Map of the Deep Creek Lake Watershed

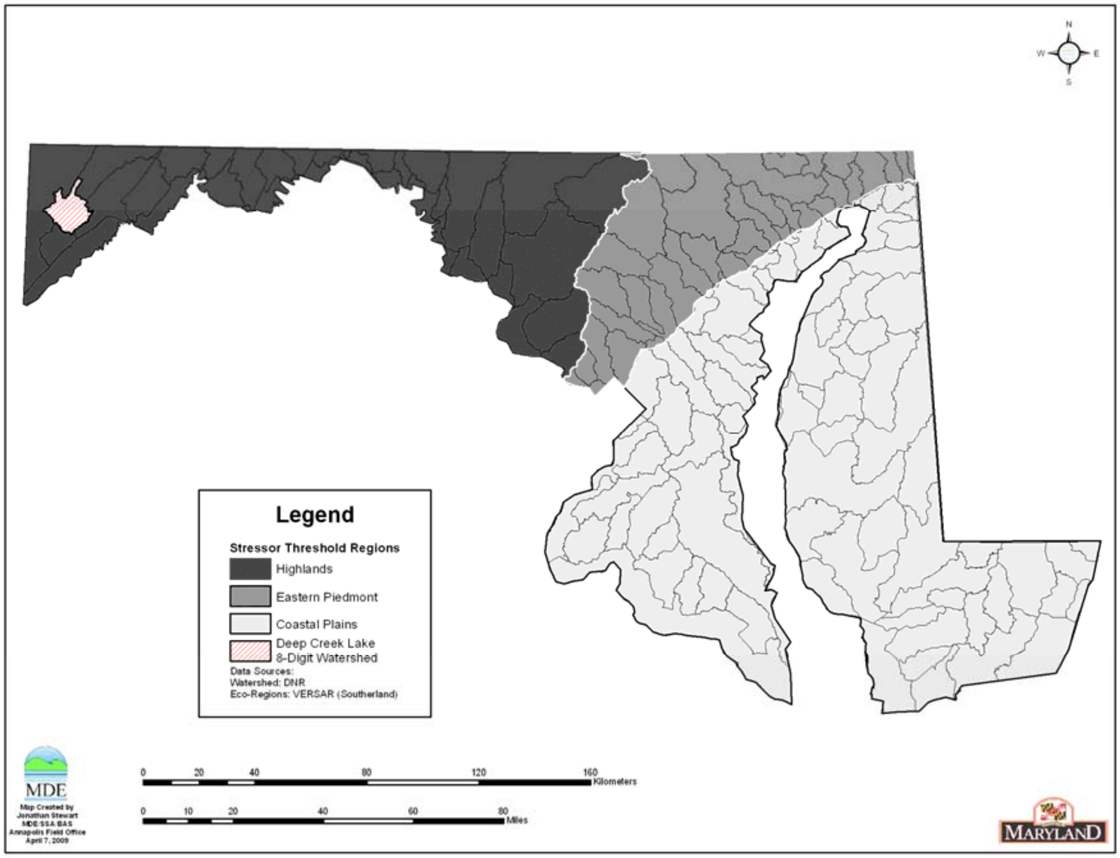

Figure 2. The Eco-Region Location Map for the Deep Creek Lake Watershed

2.2 Land Use

Deep Creek Lake is the premier destination for tourism and recreation in western Maryland. Although development in the watershed continues to increase, the basin is still mostly forested. Seasonal and permanent residences line most of the lake perimeter, with two general areas of concentrated development, McHenry and Thayerville, each containing restaurants, stores, churches, and banks. McHenry is located northeast from the dam at the top of Marsh Cove and includes the Wisp Ski Resort and county fairgrounds. Thayerville is defined as the development that lines Route 219 between the bridge over the lake and Mayhew Inn Road. Developed areas on the northern portion of the lake have sewer collection, whereas most developed areas on the southern side of the lake use septic systems to dispose of waste. A large proportion of land area is used for agriculture in southern areas of the watershed. According to the Chesapeake Bay Phase 5.2 Model land use data the basin contains 62% forest, 13% urban, 16% agriculture land use (Figure 4). A large amount of land area (~9%) is water.

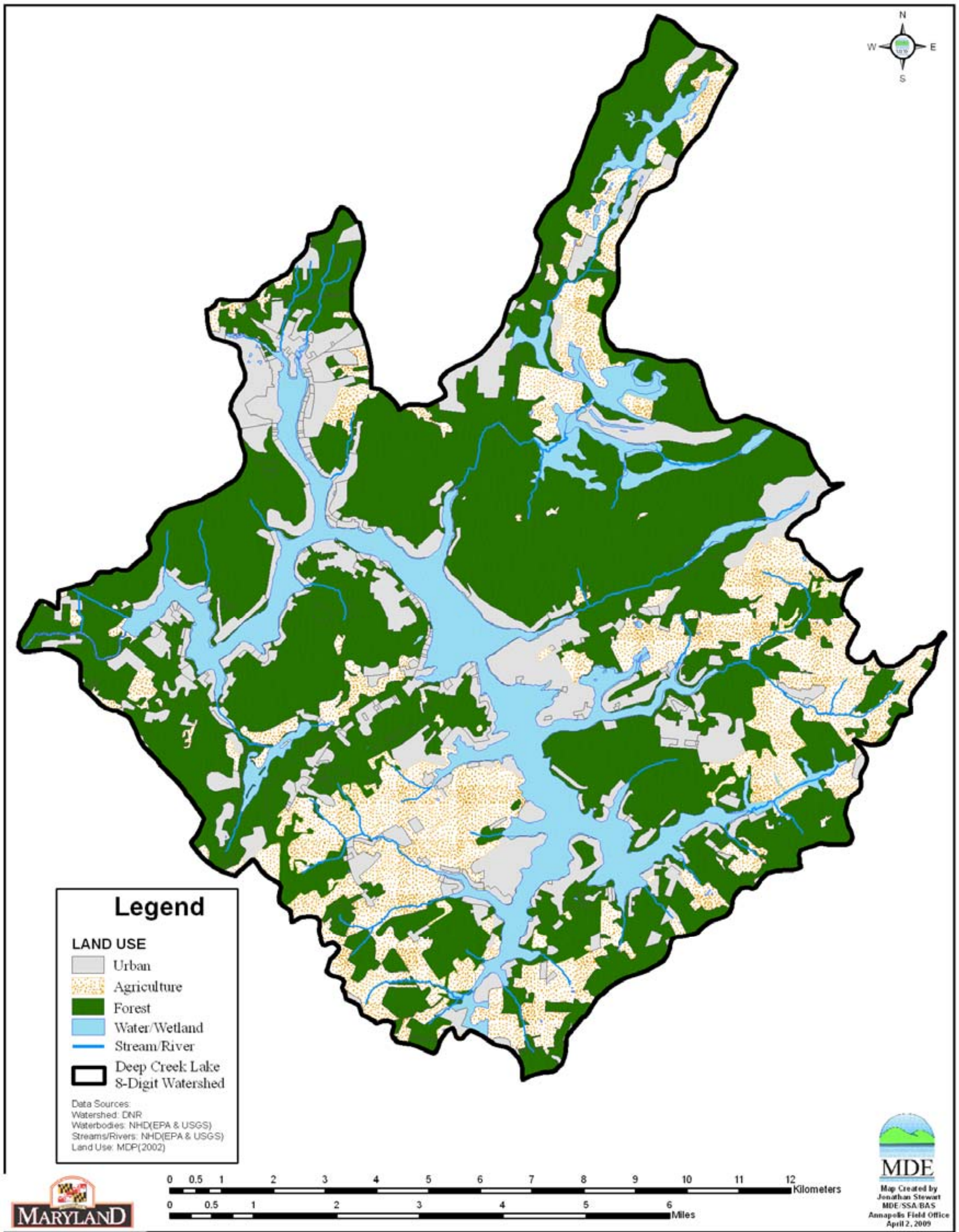

Figure 3. Land Use Map of the Deep Creek Lake Watershed

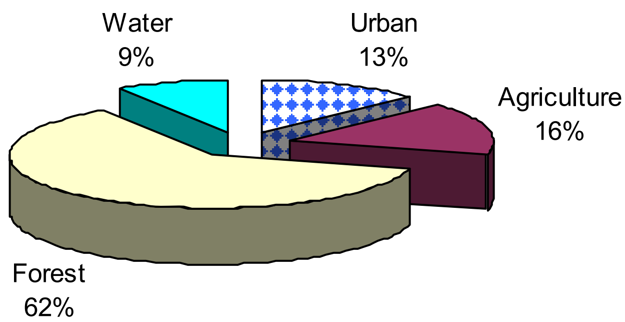

Figure 4. Proportions of Land Use in the Deep Creek Lake Watershed

2.3 Soils/hydrology

Low, rolling hills and wetlands best describes the terrain of the drainage area surrounding Deep Creek Lake. The northern half of the Deep Creek Lake watershed (north of Meadow Mountain Run) is located on the Casselman Syncline where rock formations approximately 335 to 325 million years old from the Mississippian Era rock are exposed. Meadow Mountain is the eastern border of this formation. Rock formations exposed here include brown colored sandstones and shales, as well as coal beds from the Allegheny and Pottsville formations. The southern half of the Lake lies in the Deer Park Anticline where older rock (350 to 385 million years old) from the lower Mississippian and upper Devonian geology is exposed.

The Natural Resources Conservation Service (NRCS) has defined four hydrologic soil groups providing a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils (Group D) that are poorly drained have the lowest infiltration rates with the highest amount of runoff, while sandy soils (Group A) that are well drained have high infiltration rates, with little runoff. The Deep Creek Lake watershed mostly consists of C soils, with a narrow area of Group B soils located northwest of the lake between McHenry and the dam. Group C soils typically have slow infiltration rates. Most soils in this classification include a layer that impedes downward water movement and/or have a moderately fine to fine texture. Group B soils are deep, well drained, fine to coarse textured, and have moderate infiltration rates (NRCS 1976).

A large portion of the Deep Creek Lake watershed is occupied by a 662 square mile reservoir created by a hydroelectric dam constructed in 1925. The watershed occurs on a high plateau where there are few obvious watershed boundaries. Watershed boundaries are frequently determined, for example, by the deeply incised valleys of streams from neighboring watersheds like the Savage River and Little Youghiogheny River to the east and south, respectively, or by neighboring wetlands that separate flow to the Casselman River to the north. The topography surrounding the northern lake perimeter demonstrates the steep valley sides that descend into the narrow valley of the former Deep Creek. Land ascends rapidly from the lake edge in this area to high rolling plateaus, while in the southern portion of the lake the ascent of the terrain is barely noticeable. Low order streams that flow into the lake radiate away from the lake in all directions. Approximately twenty-three of the twenty-five miles of stream length in the drainage basin are first order streams. There are no streams larger than second order in the watershed due to submersion in the lake volume.

3.0 Deep Creek Lake Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Deep Creek Lake watershed (basin code 05020203), located in Garrett County, was identified on the 2008 Integrated Report under Category 5 as impaired by phosphorus (1996 listing [8-digit watershed], 1998 listing [impoundment]), methyl mercury in fish tissue (2002 listing [impoundment]), low pH (1996 listing) (Cherry Creek), and by impacts to biological communities (2002 listing). TMDLs for the low pH in the Cherry Creek sub-watershed (050202030029) and for methylmercury in the impoundment were established in 2004 following EPA approval of the TMDLs.

3.2 Biological impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Deep Creek Lake and its tributaries is Use III-P - (*Nontidal Cold Water and Public Water Supply*) (COMAR 2009a,b,c). Use III-P also includes all uses designated for Use I (*Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life*) (COMAR 2009 a,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. 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 Deep Creek Lake watershed is listed under Category 5 of the 2008 Integrated Report as impaired for biological impacts. One hundred percent of stream miles in the Deep Creek Lake basin are estimated as having fish and 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 eight monitoring stations. All eight stations 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 round 2, has insufficient data (only one station) to accommodate BSID analyses, so round 1 data is also utilized in stressor identification (Figure 5). Only parameters contained in both round one and round two datasets were used for the BSID results. Many sediment and water chemistry parameters were not collected during the round one sampling.

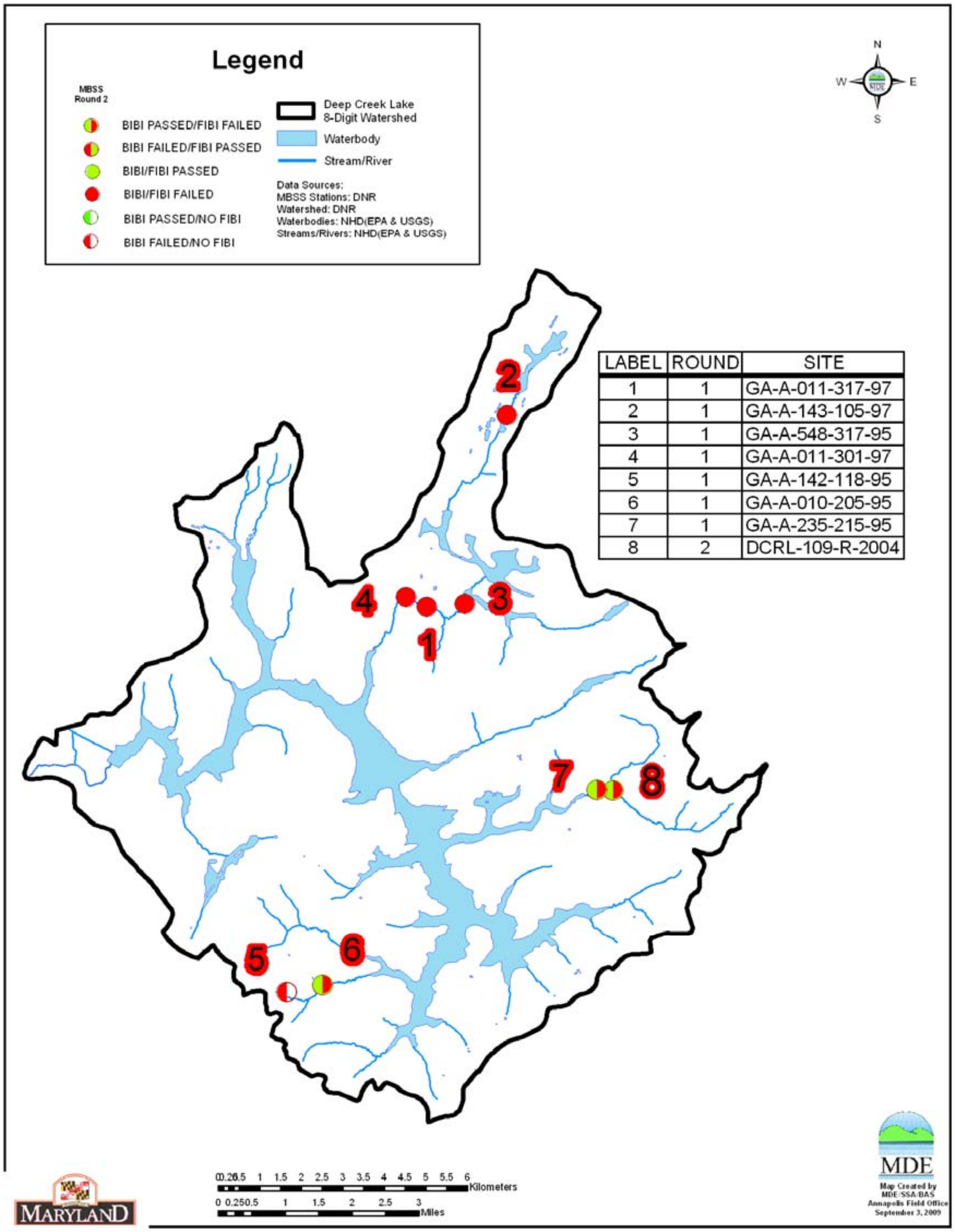

Figure 5. Principal Dataset Sites for the Deep Creek Lake Watershed

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 determines 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} through 4^{th} order streams), 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, 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 case 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, water chemistry parameters, and sources significantly associated with poor to very poor fish and/or benthic biological conditions. As shown in Table 1 through Table 3 parameters from the sediment, habitat, riparian, and water chemistry groups are identified as possible biological stressors in the Deep Creek Lake Watershed. Parameters identified as representing possible sources are listed in Table 4. Table 5 summarizes the combined AR for each stressor group in the Deep Creek. A summary of combined AR values for each source group is shown in Table 6.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Deep Creek Lake Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by **Stressor**
Sediment	extensive bar formation present	1	1	80	0%	8%	No	----
	moderate bar formation present	1	1	80	100%	40%	No	----
	bar formation present	1	1	80	100%	88%	No	----
	channel alteration moderate to poor	8	8	152	88%	38%	Yes	50%
	channel alteration poor	8	8	152	75%	9%	Yes	66%
	high embeddedness	8	8	152	63%	6%	Yes	56%
	epifaunal substrate marginal to poor	8	8	152	88%	28%	Yes	60%
	epifaunal substrate poor	8	8	152	75%	14%	Yes	61%
	moderate to severe erosion present	1	1	80	0%	24%	No	----
	severe erosion present	1	1	80	0%	0%	No	----
	poor bank stability index	1	1	80	0%	3%	No	----
	silt clay present	1	1	80	100%	99%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Deep Creek Lake Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	8	8	155	0%	10%	No	----
	instream habitat structure marginal to poor	8	8	152	25%	20%	No	----
	instream habitat structure poor	8	8	152	25%	2%	Yes	22%
	pool/glide/eddy quality marginal to poor	8	8	152	38%	33%	No	----
	pool/glide/eddy quality poor	8	8	152	25%	6%	No	----
	riffle/run quality marginal to poor	8	8	152	88%	31%	Yes	54%
	riffle/run quality poor	8	8	152	75%	7%	Yes	67%
	velocity/depth diversity marginal to poor	8	8	152	75%	46%	No	----
	velocity/depth diversity poor	8	8	152	13%	5%	No	----
	concrete/gabion present	8	8	155	0%	4%	No	----
	beaver pond present	8	8	151	13%	1%	No	----
Riparian Habitat	no riparian buffer	8	8	155	25%	25%	No	----
	low shading	8	8	152	25%	15%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Deep Creek Lake Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	1	1	159	0%	8%	No	----
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	1	1	159	0%	2%	No	----
	ammonia acute with salmonid absent	1	1	159	0%	1%	No	----
	ammonia chronic with salmonid present	1	1	159	100%	4%	No	---
	ammonia chronic with salmonid absent	1	1	159	0%	2%	No	----
	low lab pH	8	8	295	50%	5%	Yes	45%
	high lab pH	8	8	295	0%	0%	No	----
	low field pH	8	8	289	38%	11%	Yes	26%
	high field pH	8	8	289	0%	0%	No	----
	high total phosphorus	1	1	159	0%	3%	No	----
	high orthophosphate	1	1	159	0%	4%	No	----
	dissolved oxygen < 5mg/l	8	8	290	0%	3%	No	----
	dissolved oxygen < 6mg/l	8	8	290	25%	6%	Yes	19%
	low dissolved oxygen saturation	7	7	205	0%	3%	No	----
	high dissolved oxygen saturation	7	7	205	0%	0%	No	----
	acid neutralizing capacity below chronic level	8	8	295	50%	5%	Yes	45%
	acid neutralizing capacity below episodic level	8	8	295	75%	48%	No	----
	high chlorides	1	1	159	0%	7%	No	----
	high conductivity	8	8	295	0%	2%	No	----
	high sulfates	8	8	295	38%	3%	Yes	34%

Table 4. Stressor Source Identification Analysis Results for the Deep Creek Lake Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources	high impervious surface in watershed	1	1	156	0%	1%	No	----
	high % of high intensity urban in watershed	8	8	295	0%	2%	No	----
	high % of low intensity urban in watershed	8	8	295	0%	4%	No	----
	high % of transportation in watershed	8	8	295	0%	5%	No	----
	high % of high intensity urban in 60m buffer	8	8	295	0%	3%	No	----
	high % of low intensity urban in 60m buffer	8	8	295	0%	4%	No	----
	high % of transportation in 60m buffer	8	8	295	0%	5%	No	----
	high % of agriculture in watershed	8	8	295	13%	11%	No	----
	high % of cropland in watershed	8	8	295	13%	3%	No	----
	high % of pasture/hay in watershed	8	8	295	38%	16%	No	----
	high % of agriculture in 60m buffer	8	8	295	13%	10%	No	----
	high % of cropland in 60m buffer	8	8	295	13%	2%	No	----
	high % of pasture/hay in 60m buffer	8	8	295	25%	16%	No	----
	high % of barren land in watershed	8	8	295	0%	4%	No	----
	high % of barren land in 60m buffer	8	8	295	0%	3%	No	----

Table 4. Stressor Source Identification Analysis Results for the Deep Creek Lake Watershed (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 with source present	Possible stressor (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
	low % of forest in watershed	8	8	295	0%	7%	No	----
	low % of forest in 60m buffer	8	8	295	75%	8%	Yes	67%
	atmospheric deposition present	8	8	295	25%	44%	No	----
	AMD acid source present	8	8	295	50%	6%	Yes	44%
	organic acid source present	8	8	295	0%	2%	No	----
	agricultural acid source present	8	8	295	0%	2%	No	----

Table 5. Summary AR Values for Stressor Groups for Deep Creek Lake Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	91%	96%
In-Stream Habitat	77%	
Riparian Habitat	----	
Water Chemistry	59%	

Table 6. Summary AR Values for Source Groups for Deep Creek Lake Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	----	68%
Agriculture	----	
Barren Land	----	
Anthropogenic	67%	
Acidity	44%	

<u>Sediment Conditions</u>

BSID analysis results for the Deep Creek Lake identified five sediment parameters that have statistically significant associations with poor to very poor stream biological condition, including *channel alteration (marginal to poor & poor), epifaunal substrate (marginal to poor & poor), and high embeddedness.*

Channel alterations (moderate to poor & poor) were identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed, and found to impact approximately 50% (*moderate to poor* rating) and 66% (*poor* rating) of the stream miles with poor to very poor biological conditions. Channel alteration is a rating of large-scale changes in the shape of a stream channel. This rating addresses deliberate stream manipulations within a 75 meter sample station (e.g., concrete channels, artificial embankments, obvious straightening of the natural channel, rip-rap, or other structures), as well as stream alterations resulting from large changes in hydrologic energy (e.g., recent bar development). Conditions indicating biological degradation are set at two levels. The first level, poor channel alteration, is defined as heavy deposits of fine material and/or extensive bar development, or recent channelization, or evidence of dredging, or greater than 80% of the banks artificially armored. The second level, moderate to poor channel alteration, is defined as recent but moderate deposition of gravel and sand on bars and/or embankments; and/or 40% to 80% of banks artificially armored or channel lined in concrete. Moderate to poor and poor ratings are expected in unstable stream channels that experience frequent high flows.

Epifaunal substrate (marginal to poor & poor) were identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed, and found to impact approximately 60% (*marginal to poor* rating) and 61% (*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. Like embeddedness and in-stream habitat, 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. 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.

High embeddedness was identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed, and found in 56% of the stream miles with very poor to poor biological conditions. Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition. High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

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 sediment stressor group is approximately 91%, suggesting these stressors impact almost all the degraded stream miles in the Deep Creek Lake watershed (Table 5).

<u>In-stream Habitat</u>

BSID analysis results for the Deep Creek Lake identified three in-stream habitat parameters that have statistically significant associations with a very poor to poor stream biological condition, including *riffle/run quality (marginal to poor & poor) and in-stream habitat structure (marginal to poor & poor)*.

Riffle/run quality (marginal to poor & poor) were identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed, and found to impact approximately 54% (*marginal to poor* rating) and 67% (*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. 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.

In-stream habitat structure (poor) was identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed, and found in 22% of the stream miles with very poor to 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 and by sediment inputs that fill pools and other fish habitats. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habit 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.

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 in-stream habitat stressor group is approximately 77%, suggesting that this stressor impacts a substantial proportion of the degraded stream miles in the Deep Creek Lake watershed (Table 5).

Riparian Habitat

BSID analysis results for the Deep Creek Lake did not identify any riparian habitat parameters as a statistically significant association with poor to very poor stream biological condition.

Water Chemistry

BSID analysis results for the Deep Creek Lake Watershed identified five 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 include *low acid neutralizing capacity (ANC, below chronic level), low lab pH, low field pH, high sulfates, low dissolved oxygen (<6mg/L).*

Acid Neutralizing Capacity (ANC) below chronic level was identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed and found in approximately 45% of the stream miles with poor to very poor biological conditions. ANC is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids. ANC can be used as an index of the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. Repeated additions of acidic materials may cause a decrease in ANC. ANC values less than 50µeq/l are considered to demonstrate chronic (highly sensitive to acidification) exposures for aquatic organisms, and values less than 200µeq/l are considered to demonstrate episodic (sensitive to acidification) exposures (Kazyak et al 2005, Southerland et al 2007).

Low lab pH was identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed and found in approximately 45% of the stream miles with poor to very poor biological conditions. pH is a measure of acidity that uses a logarithmic scale ranging from 0 to 14, with 7 being neutral. Lab pH is measured during spring stream sampling by MBSS when groundwater usually represent lower, less consistent proportions of stream flow. Most stream organisms prefer a pH range of 6.5 to 8.5. The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2007). Low pH values (less than 6.5) can be damaging to aquatic life. Most organisms have a well defined range of pH tolerance. If the pH falls below the tolerance range, death will occur due to respiratory or osmoregulatory failure (Kimmel, 1983). Low pH may also allow concentrations of toxic compounds (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

Low field pH was also identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed and found in approximately 26% of the stream miles with poor to very poor biological conditions. Field pH is measured during summer stream sampling by MBSS when groundwater usually represent greater, more consistent proportions of stream flow.

High sulfates were identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed and found in approximately 34% of the stream miles with poor to very poor biological conditions. Sulfate (SO_4) is an oxygenated chemical species of sulfur that is available for uptake by plants. Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. There is only one minor National Pollutant Discharge Elimination System (NPDES) permitted municipal discharge in the Deep Creek Lake watershed. Since NPDES permitting enforcement does not require sulfate testing at this facility, data was not available to verify/identify sulfate as a specific pollutant in this watershed. Surface waters receiving acid mine drainage (AMD) can contain significant concentrations of sulfate. Coal mining is very prevalent in the Appalachian Plateau region. The Deep Creek watershed contains abandoned mines and the Cherry Creek sub-watershed is affected by AMD. AMD could be potential sources of sulfate loads to Deep Creek Lake.

Low dissolved oxygen was identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed and found in approximately 19% of the stream miles with poor to very poor biological conditions. Dissolved Oxygen (DO) is a measure of the amount of oxygen dissolved in the water as a function of variables such as water temperature, atmospheric pressure, physical aeration, and chemical/biological oxygen demand. DO is generally reported as a concentration (mg/L). MDDNR MBSS measures DO in situ once during the summer. Low DO concentrations may indicate organic pollution due to heterotrophic oxygen consumption and may stress aquatic organisms. Low DO concentrations are considered to demonstrate excessive oxygen demand, primarily from decomposition of organic material. Sources are agricultural, forested, and urban land uses. The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR 2007.

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 water chemistry stressor group is approximately 59% suggesting these stressors impact a considerable proportion of the degraded stream miles in the Deep Creek Lake watershed (Table 5).

Sources

BSID analysis identified two source parameters significantly associated with biological degradation in the Deep Creek Lake watershed, including *low % of forest in 60m buffer* and *AMD acid source present*.

Low % of forest in 60m buffer was identified as significantly associated with degraded biological conditions in the Deep Creek Lake Watershed in approximately 67% of the stream miles. Low percentages of forest within the 60 meter stream buffers is an indication of anthropogenic development, and considered to be a potential source of biological stress.

AMD acid source present was identified as significantly associated with degraded biological conditions in the Deep Creek Lake watershed and found to impact approximately 44% of the stream miles with poor to very poor biological conditions (Table 6). Acid mine drainage (AMD) is the results of mineral pyrite oxidation (from mine spoils and abandoned mine shafts) and is known to cause extreme acidification of surface waters as well as affect stream physical substrate. Streams strongly affected by AMD exhibit high levels of sulfate, manganese, iron, aluminum, and conductivity. Highly acidic waters ($pH < 3$) can mobilize heavy metals and other toxic elements from soil and cause them to be transported into nearby surface waters. The high acidity of acid mine drainage and the high amounts of dissolved heavy metals (such as copper and zinc) generally make acid mine drainage extremely toxic to most organisms (Penreath, 1994).

The combined AR is used to measure the improvement of degraded stream miles, very poor to poor biological conditions, if the causal sources were removed. The combined AR for both source groups identified in the BSID is approximately 68% suggesting that the absence of forested stream buffers and the presence of AMD impact a considerable proportion of the degraded stream miles in the Deep Creek Lake (Table 6).

Summary

Data suggest that there are two underlying issues that are responsible for degraded biological conditions in the Deep Creek Lake watershed; sources of acidity and its concomitant effects of low pH and sulfates, and stream morphology. Water quality monitoring conducted through out the Deep Creek Lake watershed by the State of Maryland determined that Cherry Creek, a sub-watershed, was impaired by acid mine drainage (AMD) as indicated by low pH and high SO_4 concentrations. The low pH is due in part to AMD. However, surveys and studies done by several state agencies and consulting companies demonstrate that some areas of the creek with low pH measurements are caused not only by AMD but also by natural sources of acidity (MDE 2003). Natural sources of acidity in the watershed include the presence of peat bogs (organic carbon decomposition of the organic material in the water), and the low buffering capacity of the geologic formations in the area.

Small local deep mining began in the Cherry Creek watershed in the early 1800's. Extensive underground and surface mining conducted before adequate laws and regulations were enacted have produced numerous sources of uncontrolled AMD throughout the watershed. Studies by the MDE's Bureau of Mines and other state agencies, documented the degradation of miles of Cherry Creek by AMD from numerous abandoned coalmines (MDE 2003). Within the Deep Creek Lake watershed all the MBSS sites with low pH, ANC below chronic levels, and high sulfate concentrations are located in Cherry Creek, specifically in stream segments affected by AMD. The significance of low pH in the lab & field measurements demonstrates the condition is prevalent in both groundwater and run off to surface waters. A TMDL developed by MDE to address low pH in Cherry Creek was approved by the USEPA in 2003.

Stream morphology is also an underlying cause of biological community degradation in the Deep Creek Lake watershed. The topography of the drainage area is composed of two extreme land surfaces, nearly flat and nearly vertical causing a dominance of low gradient streams in the watershed. This landscape is a miniature model of the Appalachian Plateau Physiographic Province, which can be described as a broad plateau with deeply incised valleys. Identification of stressors like high embeddedness, poor epifaunal substrate, poor in-stream habitat, and poor riffle/run quality may be interpreted as a result of excess sediment loading. However, these stressors more likely reflect sedimentation due to the dominance of low gradient streams in the watershed; this is common in the Appalachian Plateau physiographic region, which contains high elevation plateaus. Anthropogenic alterations exacerbate the naturally low flow and habitat homogeneity in the Deep Creek Lake watershed. The watershed contains a higher proportion of 1st order streams than other watersheds in the region because higher order streams are submerged by the reservoir. Ninety-three percent of stream miles in the Deep Creek watershed are 1st order, as compared to 69% - 75% in neighboring watersheds. This characteristic is important because 1st order streams typically have less diverse habitat and biological community structure. Other anthropogenic influences that further increase the homogeneity of the physical habitat throughout the watershed is channel alteration and a low percentage of forested stream buffer. Development is often concentrated on more level surfaces in the watershed resulting in encroachment on stream buffers.

Low dissolved oxygen was identified as contributing to biological impairment in the watershed; low concentrations were found at MBSS sites located in areas with nearly flat terrain. The absence of physical turbulence typical in most low gradient streams is likely contributing to low dissolved oxygen levels. Furthermore the proximity of wetlands, bogs, and seeps to stream stations is another possible explanation for low dissolved oxygen, low pH, and sulfate concentrations. Wetlands foster the decomposition of plant and animal material that involves the consumption of oxygen.

In the Deep Creek Lake watershed low FIBI scores are primarily due to the absence of brook trout and sculpins. The dam structure of the reservoir is a fish passage barrier and prevents upstream migration of many fish species, once these species are extirpated, they cannot return to the watershed. Excluding the Cherry Creek sub-watershed, all the MBSS stations with FIBI score are lower than three, only one site has a benthic score below three.

Although all sites in the Deep Creek watershed have FIBI and/or BIBI scores lower than three, some mitigating factors should be taken into account that may suggest that water quality in the watershed is not as bad as the scores suggest. First, half of the MBSS sites are in the Cherry Creek watershed, which is known to be impacted by AMD and naturally-occurring acidic wetlands. Second, natural landscape conditions have caused a dominance of low gradient streams where excessive sedimentation is typical. Third, because of the reservoir, 1st order streams predominate resulting in a less diverse stream habitat and biological community structure. Fourth, absence of physical turbulence and proximity of wetlands contributes to low dissolved oxygen levels. Fifth, the reservoir prevents upstream migration and 1st order streams are often so small that they are unlikely to support significant fish populations even with good water quality.

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.

Final Causal Model for the Deep 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, 1991and USEPA 2007). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final causal model for the Deep Creek, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

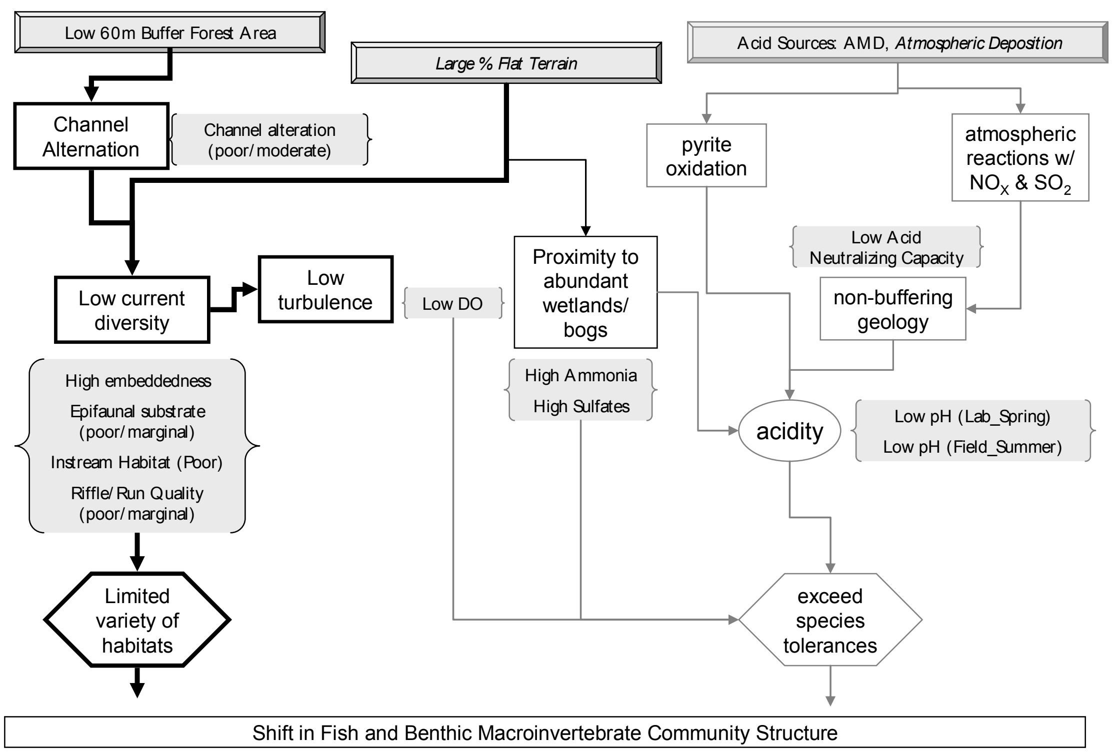

Figure 6. Final Causal Model for the Deep Creek Lake Watershed

5.0 Conclusions

Data suggest that low pH and stream morphology is the underlying causes of observed biological community degradation in the Deep Creek Lake watershed.

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

- Acidity is a cause of biological impairment in the sub-watershed of Cherry Creek with in the Deep Creek Lake watershed, as indicated by low pH and low Acid Neutralizing Capacity (ANC). A TMDL was developed by MDE to address low pH in Cherry Creek and was approved by the USEPA in 2003.

- The BSID process suggests that stream biological communities in the Deep Creek Lake Watershed are likely degraded due to elevated sulfate concentrations. The presence of AMD in the watershed is a potential source of sulfate. The BSID results thus support a Category 5 listing for sulfates as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Deep Creek Lake watershed.

- The BSID process suggests that stream biological communities in the Deep Creek Lake Watershed are likely degraded due to stressors associated with stream morphology (flow/habitat homogeneity). Identification of stressors like high embeddedness, poor epifaunal substrate, poor in-stream habitat, and poor riffle/run quality that could be interpreted as resulting from excess sediment loading, more likely reflect the occurrence of fine sediment due to the dominance of low gradient streams in the watershed. Large and small-scale human activity also amplifies homogeneity of physical habitat throughout the Deep Creek Lake Watershed. The BSID results thus support a Category 5 listing of total suspended solids as an appropriate management action to begin addressing the impacts of these stressors on the biological communities in the Deep Creek Lake watershed.

- The proximity of wetlands, bogs, and seeps to stream stations and the dominance of flat terrain in the watershed are probable explanations for low dissolved oxygen, as well as contributing to low pH, and high sulfates concentrations in the watershed.

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