Water Quality Analysis of Eutrophication for Deep Creek Lake and the Deep Creek Watershed, Garrett County, Maryland

DRAFT

MARYLAND
DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

Submitted to:

Watershed Protection Division
U.S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

August 2010

EPA Submittal Date:
EPA Approval Date:

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
BSID	Biological Stressor Identification
CBOD	Carbonaceous Biochemical Oxygen Demand
Chla	Chlorophyll *a*
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
EPA	Environmental Protection Agency
EPSC	Environmental Permit Service Center
EPT	*Ephemeroptera*, *Plecoptera*, and *Trichoptera*
FIBI	Fish Index of Biologic Integrity
GIS	Geographic Information System
IBI	Index of Biotic Integrity
lbs	Pounds
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MGD	Millions of Gallons per Day
mg/l	Milligrams per liter
MS4	Municipal Separate Stormwater System
NBOD	Nitrogenous Biochemical Oxygen Demand
NPS	Nonpoint Source
NPDES	National Pollutant Discharge Elimination System
NS	No Sample
OP	Orthophosphate
PS	Point Source
TDN	Total Dissolved Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United Stated Geological Survey

WQA	Water Quality Analysis
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) 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. This list of impaired waters is commonly referred to as the 303(d) List. 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 (CFR 2010). 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 Maryland Department of the Environment (MDE) has identified the waters of 1) the Deep Creek Lake Impoundment and 2) the Deep Creek Watershed as two listings on the State's 303(d) List as impaired by the following (water type and years listed in parentheses): total phosphorus (watershed – 1996, impoundment – 1998), low pH (Cherry Creek – 1996), impacts to biological communities (1^{st} through 4^{th} order streams – 2002), methylmercury (impoundment – 2002), and fecal coliform (watershed – 2006) (MDE 2008). Deep Creek Lake and its tributaries are designated as Use III-P waterbodies (Non-tidal Cold Water and Public Water Supply) (COMAR 2007a, b). The 1996 'nutrients' listing was refined in Maryland's 2008 Integrated Report to a listing for phosphorus for both 1) Deep Creek Lake Impoundment and 2) the Deep Creek Watershed as the specific impairing nutrient substance. This report addresses the aforementioned nutrient listings for both the impoundment (Deep Creek Lake) and the Deep Creek Watershed.

A TMDL to address the low pH in Cherry Creek, a sub-basin of the Deep Creek watershed, was approved by the EPA in 2003 (MDE 2003), and a TMDL to address the mercury impairment of Deep Creek Lake, an impoundment in the Deep Creek watershed, was approved by the EPA in 2004 (MDE 2002).

A data solicitation for nutrients was conducted by MDE in 2007, and all readily available data for the time period of 2000 – 2009 have been considered.

Deep Creek Watershed

Currently, there are no specific numeric criteria for nutrients for free-flowing streams in Maryland's water quality standards. Nutrients typically do not have a direct impact on aquatic life; rather, they mediate impacts through excessive algal growth leading to low dissolved oxygen. Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient-related parameters (i.e., dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair designated uses in the Deep Creek Lake watershed (in this case, protection of aquatic life and wildlife, fishing, and swimming).

The 1st through 4th order streams in the Deep Creek Lake watershed are listed for biological impacts. Recently, MDE developed a biological stressor identification (BSID) methodology to identify the most probable cause(s) of the existing biological impairments in 1st through 4th order streams in Maryland 8-digit watersheds based on the suite of available physical, chemical, and land use data (MDE 2009a). An analysis using the BSID methodology performed on Round 3 Maryland Biological Stream Survey (MBSS) data found no evidence that nutrients are potential stressors associated with biological impairments. The BSID analysis for the Deep Creek Lake watershed (MDE, 2010) identifies sediment and pH as possible biological stressors.

An analysis of dissolved oxygen and chlorophyll *a* monitoring data from the Deep Creek Lake watershed shows that there is no indication that nutrient over-enrichment is the cause of impairments to designated uses in the Deep Creek Lake watershed.

Deep Creek Lake Impoundment

Maryland has developed guidelines for application of the narrative criteria to chlorophyll *a* concentrations in drinking water reservoirs. The 90th percentile instantaneous chlorophyll *a* concentration is not to exceed 30 µg/l and a 30-day moving average concentration is not to exceed 10 µg/l. No observed chlorophyll a concentration in Deep Creek Lake exceeds 30 µg/l, and only about 2% of the observations are above 10 µg/l.

Maryland has an interim interpretation of the non-tidal DO standard for reservoirs that recognizes that thermal stratification can have an impact on DO concentrations. In the case of impoundments designated as Use III-P, the interim interpretation requires (1) that a minimum DO concentration of 5.0 mg/l and a daily average of 6.0 mg/l be maintained throughout the water column during periods of complete and stable mixing; (2) that a minimum DO concentration of 5.0 mg/l and a daily average of 6.0 mg/l be maintained in the surface layer during periods of stratification; and (3) that the degree of stratification and reservoir morphology should be taken into account when addressing DO concentrations below 5 mg/l in the bottom layers during periods of stratification.

Observed DO concentrations during periods of complete mixing are above 6 mg/l at all depths in Deep Creek Lake. All DO concentrations are above 5 mg/l and over 99 % of observed concentrations are above 6 mg/l in the surface layer under stratified conditions. A computer simulation model of Deep Creek Lake under all-forested conditions demonstrates that the observed DO concentrations below 5 mg/l in the bottom layers under stratified conditions are a result of thermal stratification and reservoir morphology (*i.e*., due to natural conditions). Based on the analysis of monitoring data and computer simulation, the Deep Creek Lake impoundment is meeting the interim interpretation of the non-tidal DO standard for reservoirs.

Although the Deep Creek Lake impoundment is meeting water quality standards at the scale of its listing in the 2008 Integrated Report, qualitative observations reported by stakeholders provide evidence that nutrients may be causing excess algal and macrophyte growth in localized areas in some near-shore coves. MDE will conduct monitoring to determine the geographic extent of any localized eutrophication problems and to quantify their impacts. Water quality monitoring, consisting of nutrient-related physical and chemical analysis including chlorophyll, is planned for July, August and September in both 2010 and 2011. Additionally, MDE plans a dye study in spring of 2011. MDE reserves the right to place localized areas of Deep Creek Lake as Category 5 waters impaired by nutrients at a 12-digit watershed scale or smaller, and to develop a formal TMDL for those areas in the future, to address any local nutrient impacts identified during the course of this monitoring.

* * *

Barring the receipt of contradictory data, this report will be used to support a revision of the phosphorus listing for: 1) the Deep Creek Lake impoundment and 2) the Deep Creek Lake watershed; from Category 5 ("waterbody is impaired, does not attain the water quality standard, and a TMDL is required") to Category 2 ("waterbodies meeting some [in this case nutrients-related] water quality standards, but with insufficient data to assess all impairments") when MDE proposes the revision of the Integrated Report.

1.0 INTRODUCTION

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) 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. This list of impaired waters is commonly referred to as the 303(d) List. For each WQLS, the State is required 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 that water quality standards are being met (CFR 2010).

A segment identified as a WQLS may not require the development and implementation of a TMDL if more recent information invalidates previous findings. The most common scenarios that would eliminate the need for a TMDL are: 1) analysis of more recent data indicating that the impairment no longer exists (i.e., water quality standards are being met); 2) results of more recent and updated water quality modeling which demonstrates that the segment is attaining standards; 3) refinements to water quality standards or to the interpretation of those standards accompanied by analysis demonstrating that the standards are being met; or 4) identification and correction of errors made in the initial listing.

The Maryland Department of the Environment (MDE) has identified the waters of the Deep Creek Lake basin on the State's 303(d) List as impaired by the following (water type and years listed in parentheses): total phosphorus (watershed – 1996, impoundment – 1998), low pH (Cherry Creek – 1996), impacts to biological communities (1^{st} through 4^{th} order streams – 2002), methylmercury (impoundment – 2002), and fecal coliform (watershed – 2006) (MDE 2008). Deep Creek and its tributaries (including Deep Creek Lake) are designated as Use III-P waterbodies (Non-tidal Cold Water and Public Water Supply) (COMAR 2007a, b). The 1996 nutrients listing was refined in Maryland's 2008 Integrated Report to a listing for phosphorus as the specific impairing nutrient substance. Therefore, the listed impairment of phosphorus will henceforth be referred to in this report and the term "nutrients" should be read as interchangeable with "phosphorus" in this case.

A data solicitation for nutrients was conducted by MDE in 2007, and all readily available data for the time period of 2000 – 2009 have been considered. A TMDL to address the low pH in Cherry Creek, a sub-basin of the Deep Creek watershed, was approved by the EPA in 2003 (MDE 2003), and a TMDL to address the mercury impairment of Deep Creek Lake, an impoundment in the Deep Creek watershed, was approved by the EPA in 2004 (MDE 2002). The listings for fecal coliform and impacts to biological communities will be addressed separately at a future date.

This report provides an analysis of recent data and computer simulation modeling that supports the removal of the nutrients (phosphorus) listings for Deep Creek Lake and the Deep Creek Lake watershed when MDE proposes the revision of the State's Integrated Report. The remainder of this report lays out the general setting of the Deep Creek Lake watershed area, presents a discussion of the water quality characteristics in the basin in terms of the existing water quality standards relating to nutrients, and presents an analysis of the available nutrient data. This analysis supports the conclusion that the waters of Deep Creek Lake and the Deep Creek Lake watershed overall do not display signs of eutrophication or nutrient over-enrichment.

2.0 GENERAL SETTING AND WATERSHED DESCRIPTION

2.1 General Setting

Location

The Deep Creek Lake watershed is located within the Western Maryland Sub-basin in Garrett County, Maryland (Figure 1) and is a sub-basin of the Youghiogheny watershed. The watershed includes the lake and its drainage area, and extends from the lake to the confluence of Deep Creek and the Youghiogheny River. The watershed is primarily rural, although there has been significant development around the lake itself. The unincorporated communities of McHenry and Thayerville are the commercial centers of the watershed (DNR, 2001).

The watershed drains an area of 41,435 acres and is characterized by forested mountain slopes, rich river valleys and abundant wildlife. Approximately 3,929 acres of the watershed are covered by water, with Deep Creek Lake accounting for almost all of it.

Deep Creek Lake was created in 1925 when the Youghiogheny Hydroelectric Company constructed a dam across Deep Creek. Today, the lake is owned by the State of Maryland. The lake receives inflow from several tributaries, including Cherry Creek, Meadow Mountain Run, North Glade Run, Green Glade Run, Pawn Run, and Red Run. Deep Creek Lake, the largest inland water body in Maryland, not only provides water for hydroelectric generation, but also is the focal point of an economically important tourism industry that includes water sports, boating, and fishing. Table 1 gives the physical characteristics of the lake.

Table 1: Physical Characteristics of Deep Creek Lake[1]

Location:	Garrett County, MD Lat. 39˚ 30' 30" N Long. 79˚ 23' 30" W
Surface Area[2]:	3,900 acres
Normal Reservoir Depth:	50 feet
Purpose:	Water Supply Recreation
Basin Code:	05-02-02-03
Volume:	93,000 acre-feet
Drainage Area to Reservoir:	64.7 mi^2
Average Discharge[3]:	306 cfs

[1] Weisberg et al. (1985)
[2] DNR (2001)
[3] MDE (2002)

Geography/Soils

The Deep Creek watershed lies within the Allegheny Mountains, which is a subdivision of the Appalachian Plateau Physiographic Province. The watershed is framed by Backbone Mountain, Big Savage Mountain, Meadow Mountain, and Negro Mountain. Elevations rise to over 3,000 feet above sea level.

The bedrock consists primarily of sandstones and shales from the Mississippian age. The area around Deep Creek Lake State Park is underlain by Greenbrier Limestone, which provides some buffering capacity to the lake. The areas adjacent to the dam are underlain with sandstone, shale, and exposed coal in the Upper Youghiogheny coal basin from the Pennsylvanian age (DNR, 2001).

Soils in the watershed are moderately deep to deep and well-drained. In the southern part of the watershed (e.g. below Routes 163 and 219), soils are primarily well drained loams of the Ungers series. Soils in the northwest part of the watershed consist of deep, moderately well-drained channery loams belonging to the Cookport and Dekalb series, with some Ungers present north of Routes 219 and 170. Soils found in the Cherry Creek subwatershed belong mostly to the Cookport series, but some Armagh silt loam, which is poorly drained, is also present (USDA, 2007).

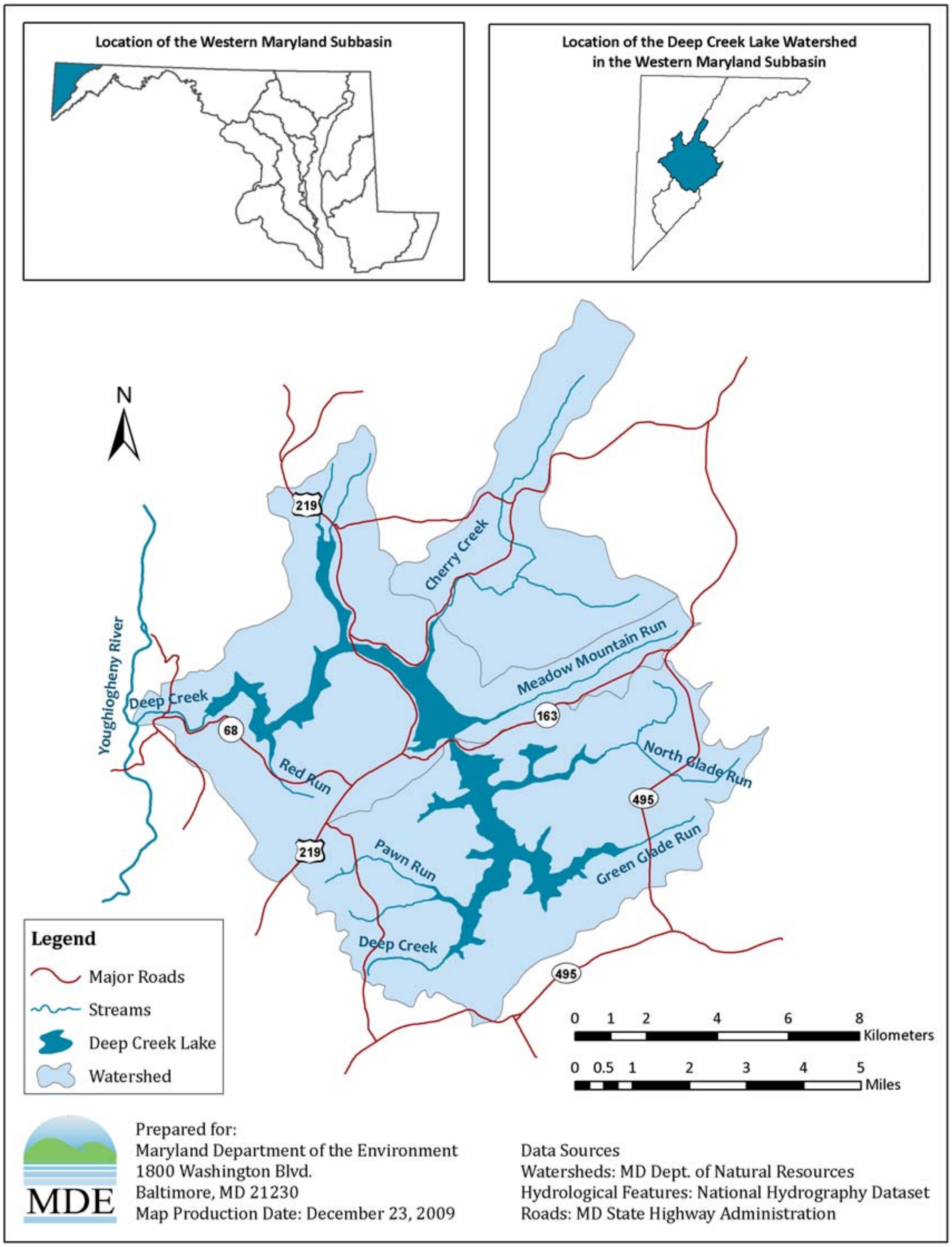

Figure 1: Location Map of Deep Creek Lake Watershed in Garrett County, Maryland

Land Use

The Deep Creek Lake watershed contains primarily forest land use (54%). Agricultural land use (20%) is secondary and supports livestock/feeding, cropland, and pasture/hay operations. Urban land use contributes 16% and water 9% to the land use distribution (Figure 2) (MDP 2002).

Point Sources

There are one municipal and two mining point source facilities with permits to discharge in the Deep Creek Lake Watershed. Only the municipal wastewater treatment plant (WWTP) is regulated by a National Pollution Discharge Elimination System (NPDES) permit for the discharge of nutrients (see Table 2 below). The reader should note that it does not discharge to the lake, but rather, downstream from the dam.

Table 2: Municipal Permit Data

				TP
Facility Name	**NPDES #**	**MDE Permit #**	**Flow (MGD)**	**Permit Avg. Concentration (mg/l)**
DEEP CREEK LAKE WWTP	MD0054348	93DP1357	2.2	1.0 (< 1.5 MGD) 0.7 (1.5 -2.2 MGD)

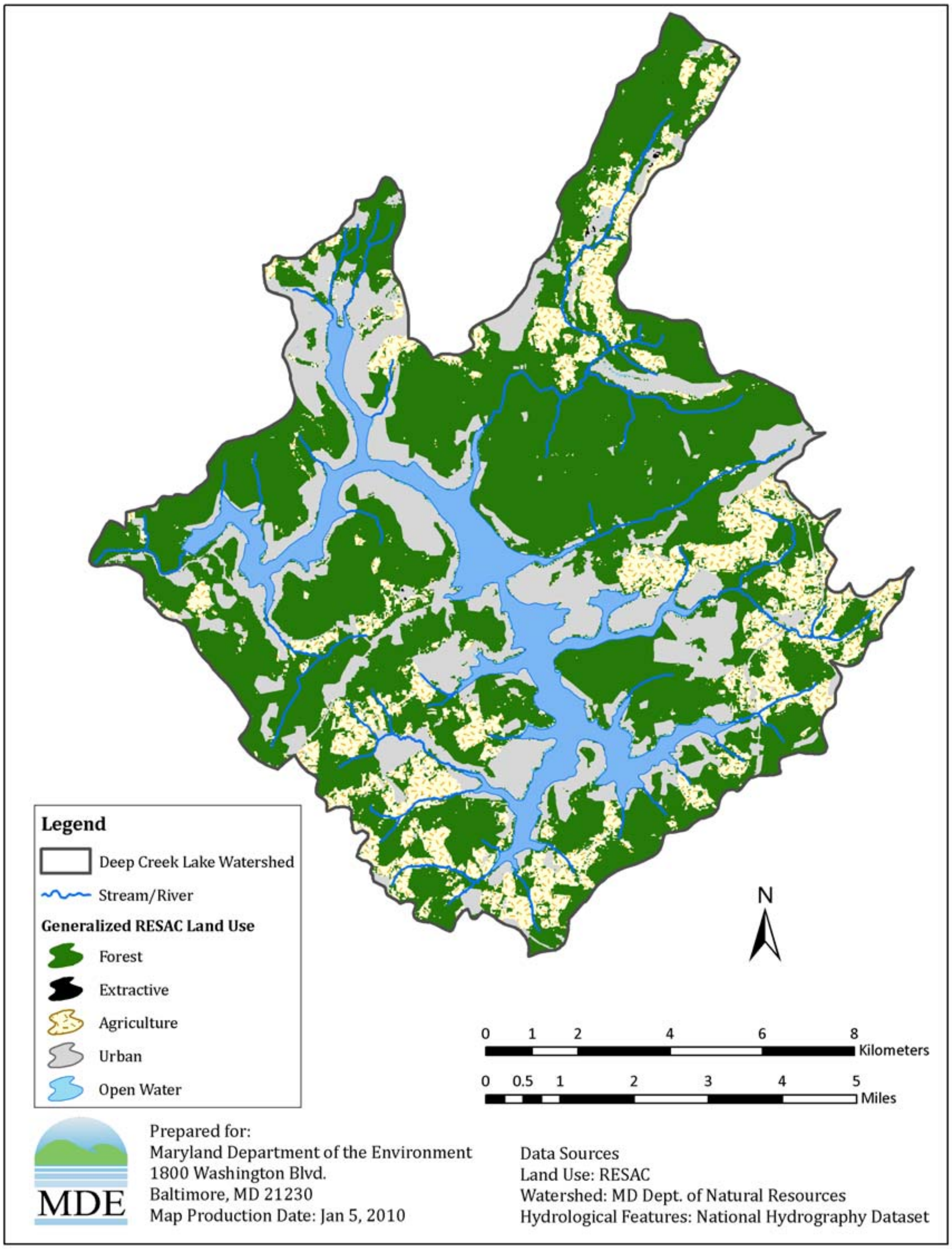

Figure 2: Land Use of the Deep Creek Watershed

3.0 RESERVOIR WATER QUALITY CHARACTERIZATION

Section.3.0 will provide a water quality characterization of Deep Creek Lake. Section 4.0 will provide a water quality characterization for the rest of the Deep Creek watershed.

3.1 Water Quality Monitoring Programs

Both MDE and the Department of Natural Resources (DNR) have performed water quality monitoring in Deep Creek Lake in the past decade. MDE performed a special water quality monitoring study in support of TMDL development in 2000 and again in 2008. Samples were collected monthly at 14 locations in the lake. Temperature and DO samples were taken every meter starting from the surface when the lake was stratified and every two meters during periods without thermal stratification. Water quality samples were taken at the surface, epilimnion, thermocline, and hypolimnion during stratification, as judged by the field temperature profile; during periods without stratification samples were taken from the surface, bottom, and the midpoint between them. DNR performed water quality monitoring in Deep Creek Lake in 2009. Samples were collected monthly at 18 locations. Most of the samples were taken at locations where MDE sampled, but four other embayments close to the lake shore were also sampled. Temperature and DO measures were recorded every meter from the surface; water quality samples were taken at the surface and bottom in mainstem lake sites, but only at the surface in lake embayment sites. Table 3 lists the water quality constituents reported from the analysis of DNR and MDE samples. Table 4 lists the location of the monitoring stations. Figure 3 shows their location.

Table 3: Characterization of Reservoir Monitoring Programs

Characteristic	**DNR**	**MDE**
Collection Period	4/2009-01/2010	4/2000-9/2008
Number of locations (lake monitoring stations)	18	14
Temperature and DO measurements	One per meter starting from surface to bottom	One per meter from surface to bottom for stratified profiles. One per every two meters for mixing profiles
Water quality samples per location	Surface and bottom (0.5m)	Surface, bottom, and middle
Key water quality constituents	DOC,DON,DOP, NH3, NO2,NO3, PC,PN, PO4,PP, TDN,TDP,TN,TP Chlorophyll *a*, TSS, Turbidity, *Secchi* depth	BOD,DIN,DOC,DON,DOP, NH3,NO2,NO3 PC,PIP,PN,PO4,PP, TDN,TDP,TIP, TKN,TN,TOC,TON,TOP,TP, Chlorophyll *a*, TSS, Turbidity, *Secchi* depth

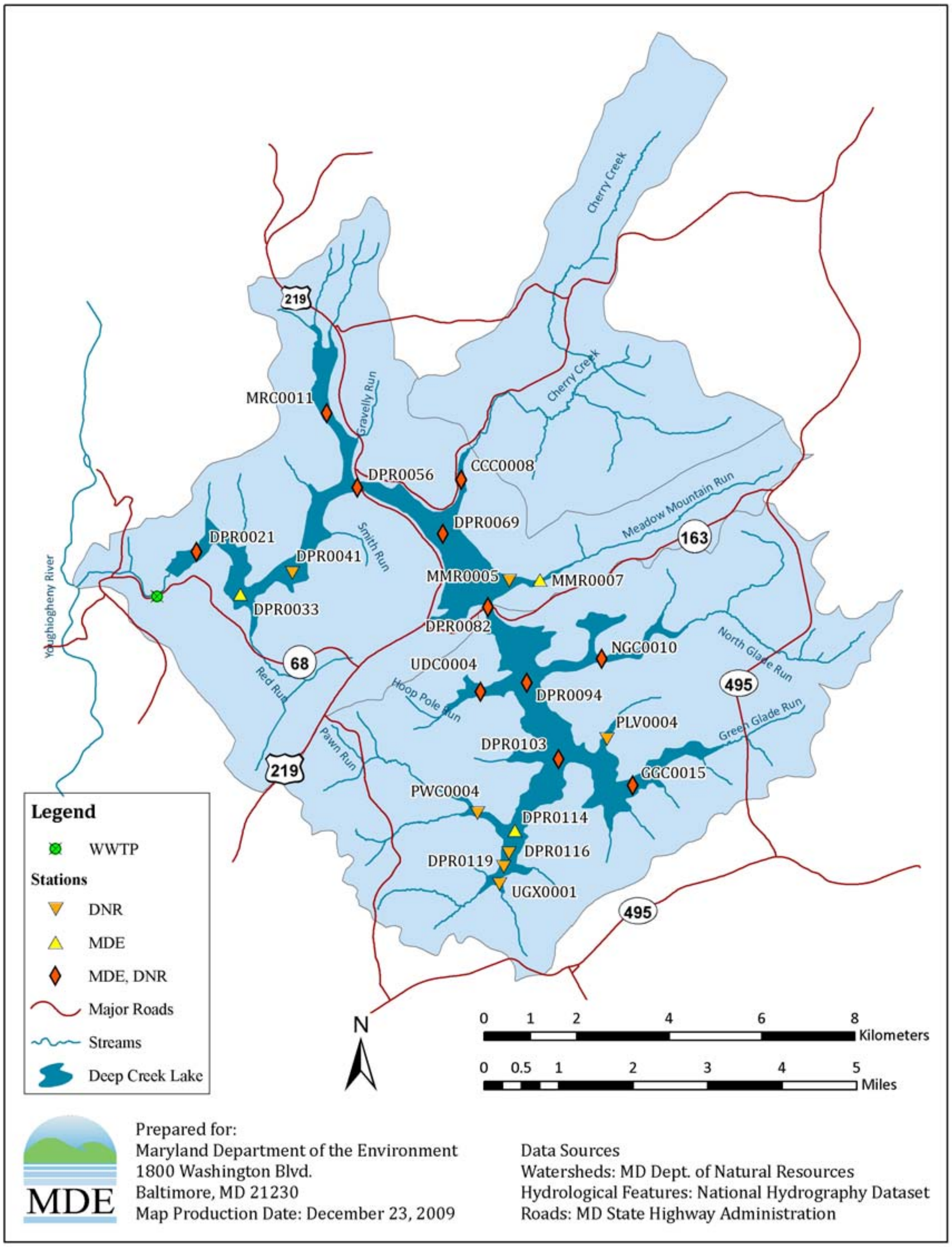

Figure 3: Sampling Locations in Deep Creek Lake

Table 4: Deep Creek Lake Sampling Locations

Station	Sponsor	Stream Name	Latitude (dec degree)	Longitude (dec degree)
CCC0008	MDE, DNR	Cherry Creek Cove	39.530	-79.319
DPR0021	MDE, DNR	Deep Creek Lake	39.514	-79.385
DPR0033	MDE	Deep Creek Lake	39.505	-79.374
DPR0041	DNR	Deep Creek Lake	39.306	-79.216
DPR0056	MDE, DNR	Deep Creek Lake	39.528	-79.345
DPR0069	MDE, DNR	Deep Creek Lake	39.520	-79.323
DPR0082	MDE, DNR	Deep Creek Lake	39.506	-79.311
DPR0094	MDE, DNR	Deep Creek Lake	39.491	-79.301
DPR0103	MDE, DNR	Deep Creek Lake	39.477	-79.290
DPR0114	MDE, DNR	Deep Creek Cove	39.463	-79.302
DPR0116	DNR	Deep Creek Cove	39.275	-79.182
DPR0119	DNR	Deep Creek Cove	39.273	-79.182
GGC0015	MDE, DNR	Green Glade Cove	39.473	-79.273
MMR0005	DNR	Meadow Mountain Run Cove	39.307	-79.184
MMR0007	MDE	Meadow Mountain Run	39.512	-79.298
MRC0011	MDE, DNR	Marsh Run Cove	39.542	-79.354
NGC0010	MDE, DNR	North Glade Cove	39.497	-79.282
PLV0004	DNR	Poland Run Cove	39.289	-79.168
PWC0004	DNR	Pawn Run Cove	39.279	-79.187
UDC0004	MDE, DNR	Hoop-Pole Cove	39.489	-79.312
UGX0001	DNR	Unnamed cove	39.271	-79.183

3.2 Temperature Stratification

Deep Creek Lake regularly exhibits temperature stratification starting in late spring and lasting up to late summer or early fall. Under stratified conditions during the summer and early fall, bottom waters in the lake can become hypoxic, because stable density differences inhibit the turbulent mixing that transports oxygen from the surface. Under such conditions, the lake can be divided vertically into a well-mixed surface layer, or epilimnion; a relatively homogeneous bottom layer or hypolimnion; and a transitional zone between them, the metalimnion, characterized by a sharp density gradient. In the fall, cooling temperatures cause the lake to overturn, restoring well-mixed conditions.

Contour plots of isotherms effectively illustrate seasonal position of the well-mixed surface layer or epilimnion. Figure 4 presents a contour plot of isothermals for DPR0021, the water monitoring station just upstream of the dam. In the winter, isothermal lines are vertical, showing that the reservoir has fairly uniform temperature. In spring, isothermal lines begin to tilt away from the vertical, until by summer at depths greater than about four meters they are nearly parallel to each other horizontally. At the surface, isothermal lines run vertically to a depth of about four meters; this defines the epilimnion.

Generally, the epilimnion is limited to a depth of no more than four or five meters in the summer. For the purposes of data analysis, the surface layer is considered to be less than five meters deep, with the understanding that in spring and fall the epilimnion can extend deeper than six to seven meters, and in the summer it is likely as shallow as one to two meters. For screening purposes, samples taken at depths of ten meters or greater are considered to be in the bottom layer or hypolimnion.

Appendix A list all temperature observations made in Deep Creek Lake, 2000 -2009.

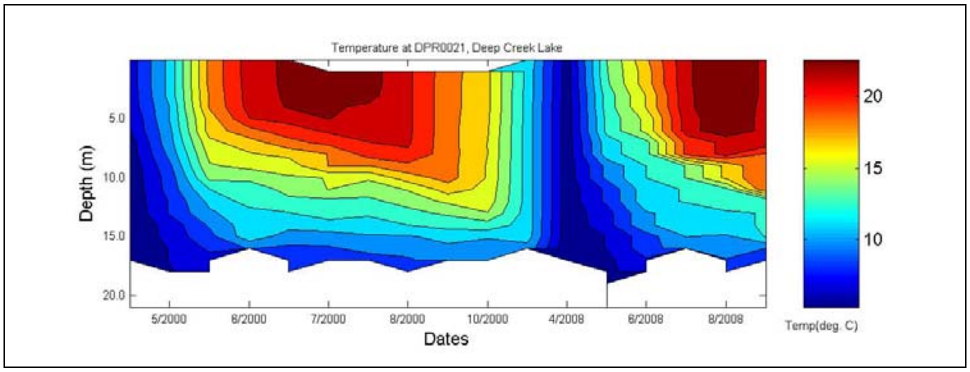

Figure 4: Isothermal Contours, Deep Creek Lake at DPR0021, 2000-2008

3.3 Dissolved Oxygen

Figure 5 shows a contour plot of observed DO concentrations at DPR0021 in Deep Creek Lake, 2000-2008, corresponding to the temperature contour plot in Figure 4. There is a clear seasonal pattern to DO concentrations. In the early spring and late fall, DO concentrations are fairly uniform with depth. Between mid-November and mid-May, there are no observed DO concentrations less than 6 mg/l at any depth in the lake. As temperature stratification sets in, DO concentrations in the surface layer remain relatively uniform, but the metalimnion shows a gradient in DO concentrations that grows stronger as the summer progresses. A region of hypoxia in the hypolimnion increases with thickness from late spring through summer. The fall overturn restores the lake to well-mixed conditions in which DO concentrations are relatively uniform with depth.

Figure 6 shows the distribution of observed DO concentrations in the surface layer (less than 5 m deep). All DO concentrations observed in the surface layer are greater than 5 mg/l. Only 0.5% of the observations of DO in the surface layer are less than 6 mg/l.

Appendix A list all DO observations made in Deep Creek Lake, 2000 -2009.

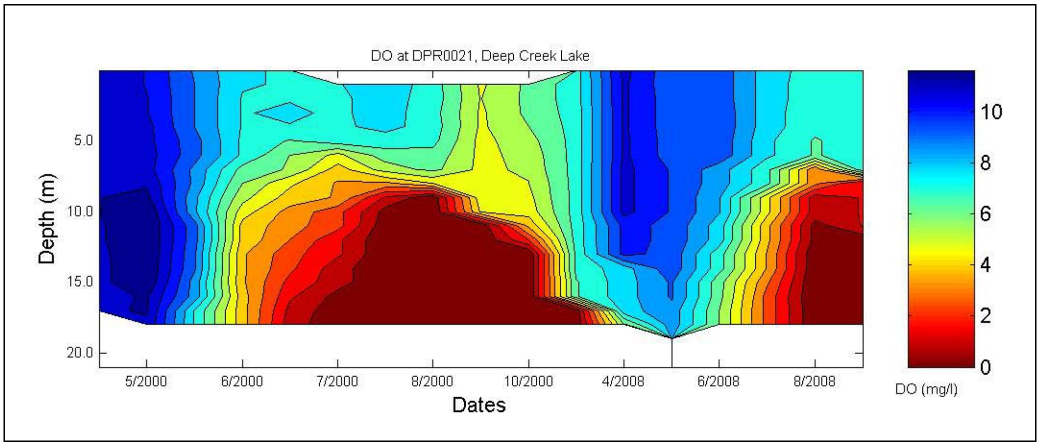

Figure 5: DO Contour, Deep Creek Lake at DPR0021, 2000-2008

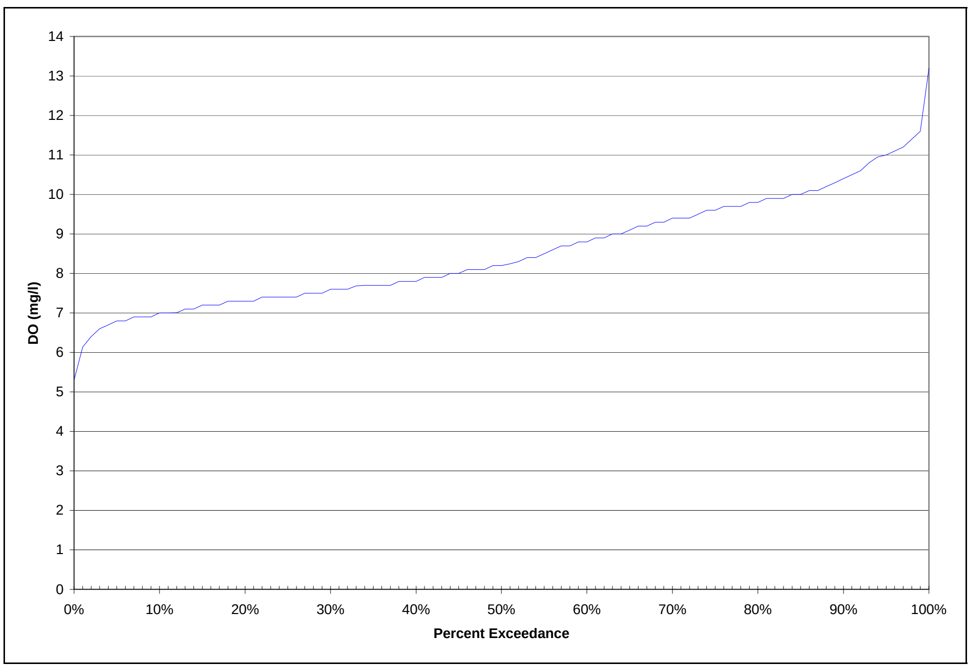

Figure 6: Cumulative Frequency Distribution of Observed DO Concentrations (mg/l) in Surface Layer (< 5 m) of Deep Creek Lake, 2000-2009

3.4 Nutrients

Figure 7 shows the observed total nitrogen (TN) concentrations in the surface layer (less than 5 m) of Deep Creek Lake for the period 2000 through 2009. Figure 8 shows the observed TN concentrations in the bottom layer of Deep Creek Lake for the same period.

The surface concentration of TN lies in a fairly narrow range. The average concentration is 0.37 mg/l; the median concentration is 0.27 mg/l, with 50% of the values lying between 0.24 and 0.37 mg/l. Almost 98% of the observed concentrations are less than 1 mg/l.

Although the mean (0.52 mg/l) and median (0.47 mg/l) bottom concentrations are slightly higher than their observed counterparts, observations of TN in the bottom layers also lie in a narrow range. The interquartile range of bottom nitrogen concentration lies between 0.35 and 0.65 mg/l; only about 2% of the observed concentrations are greater than 1 mg/l.

Figure 9 shows the observed total phosphorus (TP) concentrations in the surface layer of Deep Creek Lake for the period 2000 through 2009. Figure 10 shows the observed TP concentrations in the bottom layer of Deep Creek Lake for the same period.

Like TN, TP concentrations observed in the surface of Deep Creek Lake are low; over 98% of the observed concentrations are less than 0.03 mg/l and 80% are less than 0.015. The mean concentration in the surface is 0.012 mg/l and the median is 0.01 mg/l.

The distribution of observed TP concentrations in the bottom layer of Deep Creek Lake is very similar to the surface. The average concentration is 0.011 mg/l and the median concentration is 0.008 mg/l. Over 99% of the concentrations are below 0.03 mg/l, and about 97% are below 0.02 mg/l.

Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the “limiting nutrient.” Since the uptake of the abundant nutrient is limited by the less available nutrient, reducing the nutrient in excess supply is not effective in controlling algae growth. In general, a total nitrogen to total phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the TN:TP ratio is less than 5:1, nitrogen tends to be limiting (Chiandani et al., 1974).

Only 3% of the observed TN:TP ratios in the surface of Deep Creek Lake are less than 10. The average value of the TN:TP ratio is 41 and the median value is 30. Thus phosphorus is the limiting nutrient in Deep Creek Lake.

Appendix A list all observations of ammonia, nitrate, total nitrogen, dissolved inorganic phosphorus, and total phosphorus made in Deep Creek Lake, 2000 -2009.

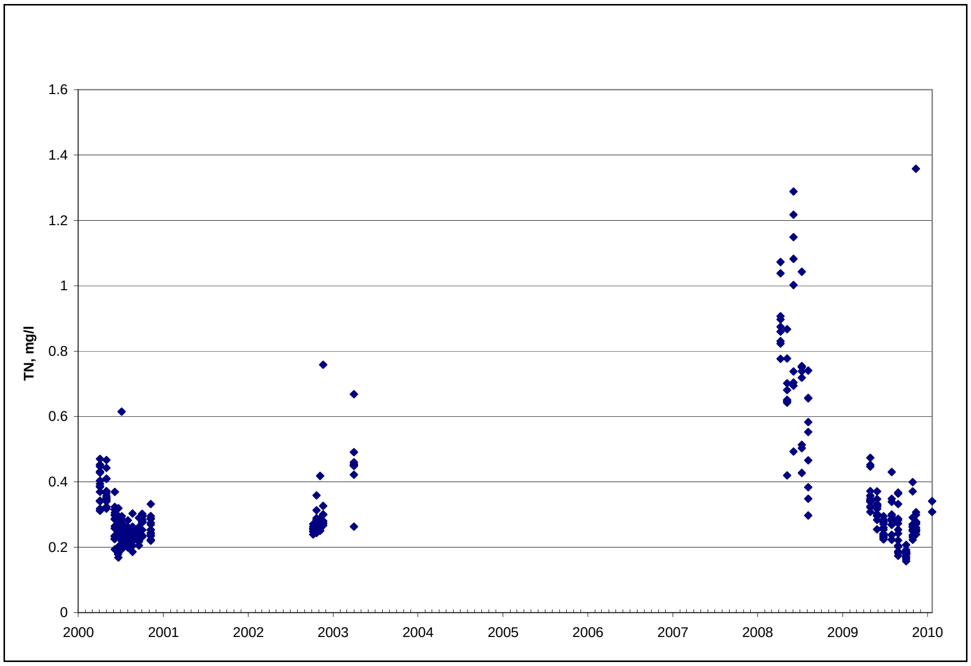

Figure 7: Surface Deep Creek Lake TN Data from 2000 through 2009

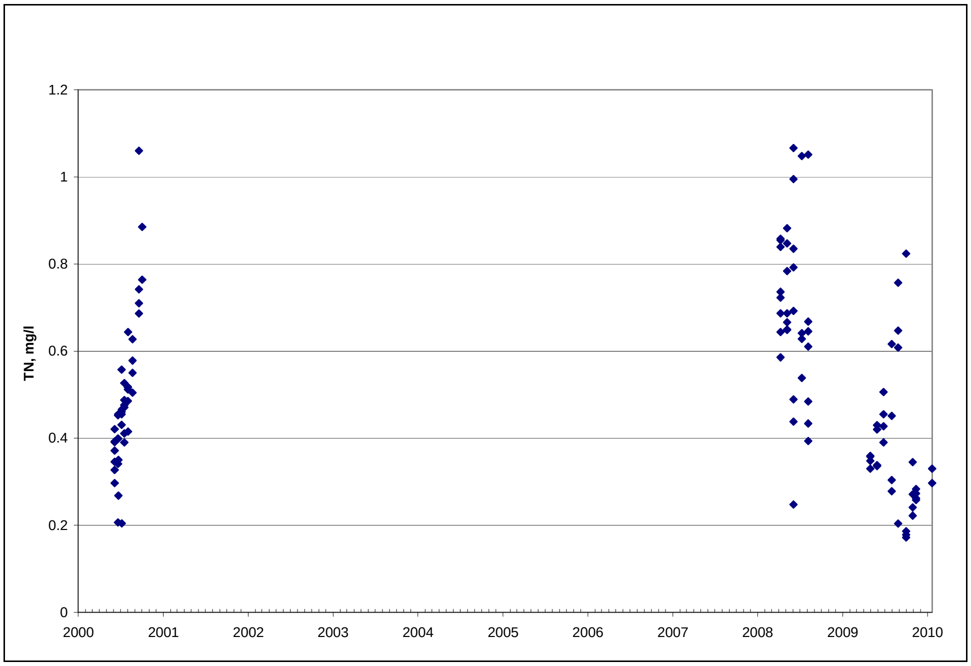

Figure 8: Bottom Deep Creek Lake TN Data from 2000 through 2009

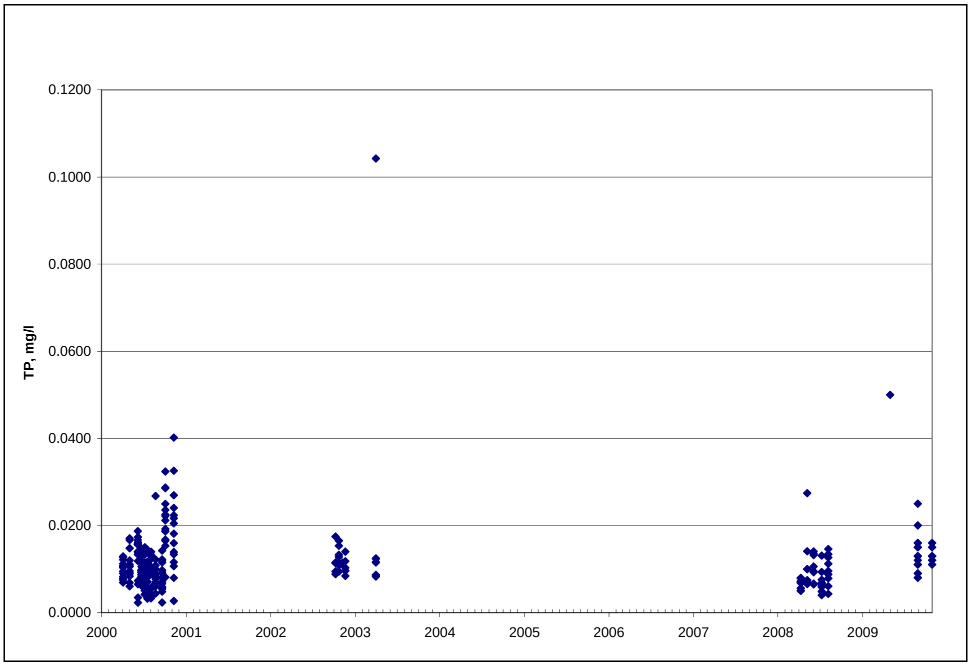

Figure 9: Surface Deep Creek Lake TP Data from 2000 through 2009

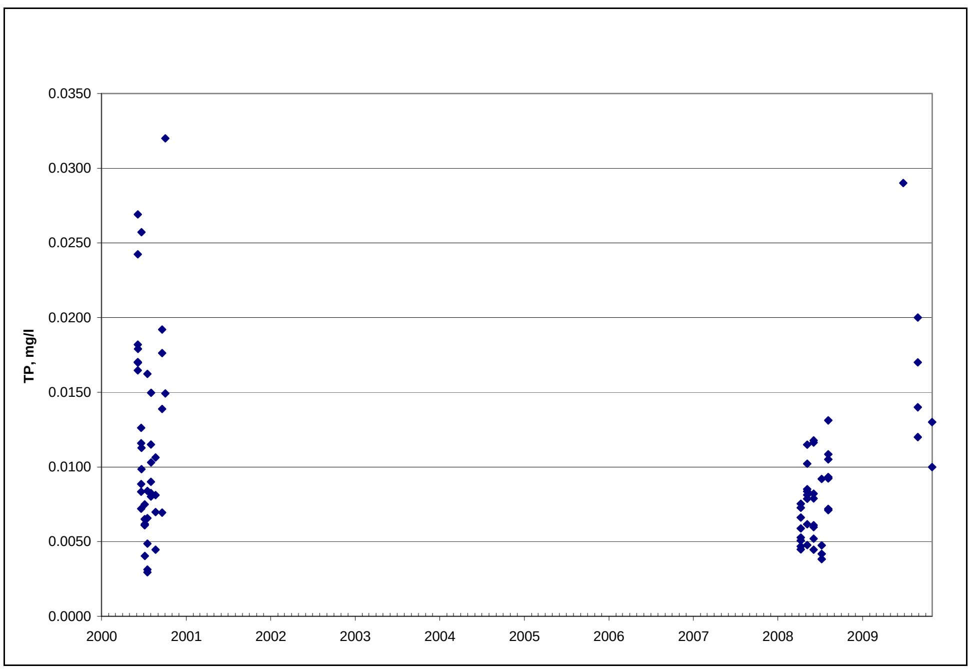

Figure 10: Bottom Deep Creek Lake TP Data from 2000 through 2009

3.5 Chlorophyll *a*

Figure 11 shows the observed Chlorophyll *a* concentrations in the surface of Deep Creek Lake, 2000-2009.

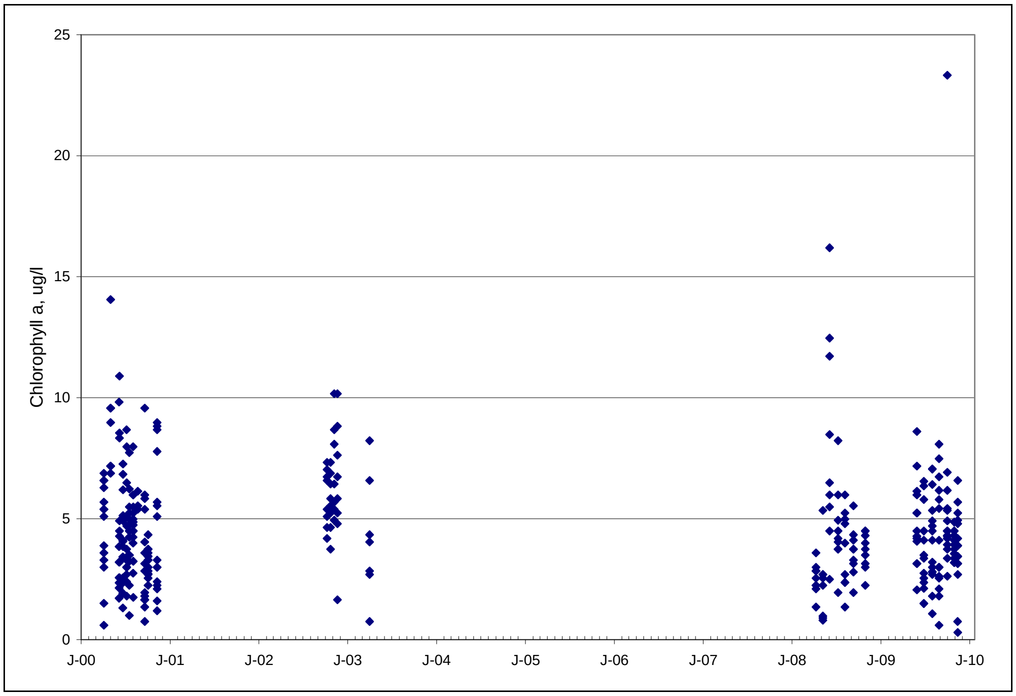

Figure 11: Surface Deep Creek Lake Chlorophyll *a* Data from 2000 through 2009

Observed Chlorophyll *a* concentrations in Deep Creek Lake are consistently and almost uniformly low. No observations of Chlorophyll *a* were greater than 30 µg/l. Only one observation, in an unnamed cove, was recorded greater than 20 µg/l, and only about 2% of the observations are above 10 µg/. The mean concentration is 4.5 µg/l and the median concentration is 4.2 µg/l. More than half the observed Chlorophyll *a* concentrations lie between 3 and 6 µg/l.

DNR also performed a sampling cruise around the perimeter of Deep Creek Lake in August, 2008. The maximum chlorophyll *a* concentration recorded during the cruise was 5.2 µg/l.

Appendix A list all Chla observations made in Deep Creek Lake, 2000 - 2009.

3.6 Reported Observations of Algal Blooms and the Growth of Aquatic Vegetation

Stakeholders have reported observing algal blooms and excessive growth of submerged aquatic vegetation (SAV) in the near-shore coves of Deep Creek Lake in the summers of 2008 and 2009. Friends of Deep Creek Lake (2010) have provided photographic documentation of their observations.

It is difficult to quantify at what point SAV growth is excessive. SAV growth is unsightly to some and presents problems for boating, but has beneficial uses as fish habitat and is a natural part of well-functioning lake ecosystems (DNR, 2001). DNR's 2008 sampling cruise of Deep Creek Lake occurred during some of the times algal blooms were reported; as described in Section 3.5, no chlorophyll *a* concentrations greater than 10 µg/l were observed during the cruise. The blooms seem confined to near-shore areas and occupy only a small volume of the lake.

Because the reported algal blooms seem to occupy only small volume in the near-shore areas of coves, they do not occur at the scale of the listing of either the impoundment or the watershed. Section 5.3 will discuss the steps MDE plans to address any potential localized nutrient-related impacts.

4.0 WATERSHED WATER QUALITY CHARACTERIZATION

The Maryland water quality standards surface water use designation for Deep Creek and its tributaries, including Deep Creek Lake, is Use III-P ((Non-tidal Cold Water and Public Water Supply) (COMAR 2007a,b,c,d,e). 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.

Currently, there are no specific numeric criteria for nutrients in free-flowing streams in Maryland's water quality standards. The State does have interim numeric standards in place for chlorophyll *a* in lakes and reservoirs; these have been used successfully as endpoints for phosphorus TMDLs in impoundments, and it is believed that they will soon be formally approved as criteria and incorporated into COMAR. Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient-related parameters (*i.e.*, dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair designated uses in the Deep Creek watershed. The DO concentration to protect Use III-P waters "may not be less than 5 milligrams per liter (mg/l) at any time" (COMAR 26.08.02.03-3B(1)). Use III-P waters must also maintain a daily average DO concentration of 6 mg/l. (COMAR 26.08.02.03-3D). Maryland's general water quality criteria prohibit pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere with designated uses (COMAR 26.08.02.03B(2)). Excessive eutrophication, indicated by elevated levels of chlorophyll *a*, can produce nuisance levels of algae and interfere with designated uses such as fishing, swimming, and protection of aquatic life.

In addition to the DO and chlorophyll *a* data analysis, nutrients can be implicated in the cause of biological impairments. MDE has developed a new biological stressor identification (BSID) methodology which can demonstrate whether any biological impairment in the watershed is associated with nutrient enrichment. A BSID analysis was performed for the Deep Creek Lake watershed (MDE, 2010) using the results of the Maryland Biological Stream Survey (MBSS) Round 1 and Round 2 surveys. Unfortunately, only one Round 2 sample was taken from the Deep Creek watershed, and to evaluate whether nutrients are associated with biological impairments, the BSID requires sufficient samples from Round 2, during which nitrogen and phosphorus monitoring data were collected concurrently with benthic or fish data. To supplement the results of the BSID analysis, the BSID methodology was applied to Round 3 samples to evaluate whether biological impairments in the watershed are associated with nutrients.

A data solicitation was conducted in 2007. All available resources, including DNR, the U.S. Geological Survey (USGS), and the Chesapeake Bay Program (CBP), were also contacted to determine if there were other available data in the Deep Creek watershed. All readily available water quality data were considered for this analysis.

Water quality data from MDE surveys conducted in the Deep Creek watershed from January 2000 through December 2008 were used. DNR data used in the analysis were from April 2009 through December 2009, and MBSS data from the spring and summer of 2004, 2008, and 2009. Figures 13 through 16 provide graphical representation of the collected data for the parameters discussed below. The data is presented in tabular form in Appendix A.

4.1 Deep Creek Lake Watershed Monitoring Stations

A total of 17 water quality monitoring stations (in the free-flowing portions of the watershed, i.e., outside the lake but not below the the dam) were used to characterize the Deep Creek Lake Watershed. DNR sampled at seven stations, including five MBSS stations and one biological monitoring station from the Maryland Core/Trend monitoring network, located on Cherry Creek, the largest tributary to Deep Creek Lake. MDE also sampled at the Core/Trend station and at ten additional locations. The stations are presented in Figure 12 and listed in Table 5.

Table 5: Monitoring Stations in the Deep Creek Watershed

Station	Sponsor	Site Type	Stream Name	Latitude (dec degree)	Longitude (dec degree)
GGR0030	MDE	Water Quality	Green Glade Run	39.482967	-79.246117
MMR0016	MDE	Water Quality	Meadow Mountain Run	39.516567	-79.287467
NGR0028	MDE	Water Quality	North Glade Run	39.506083	-79.255683
PAW0013	MDE	Water Quality	Pawn Run	39.470350	-79.322167
RRN0007	MDE	Water Quality	Red Run	39.494950	-79.368617
SMI0001	MDE	Water Quality	Smith Run	39.518900	-79.349867
ZWF0001	MDE	Water Quality	UT to Marsh Run Cove	39.559683	-79.357767
DPR0005	MDE	Water Quality	Deep Creek	39.509167	-79.405100
DPR0017	MDE	Water Quality	Deep Creek	39.508433	-79.391783
MD0054348	MDE	Water Quality	Deep Creek	39.504167	-79.394683
CCR0001 (03075905)	MDE, DNR (USGS)	Water Quality, Core, (Flow)	Cherry Creek	39.537433	-79.316100
PLD0001 (03075800)	DNR (USGS)	Water Quality, (Flow)	Poland Run	39.486417	-79.276612
DCRL-102-R-2009	DNR	MBSS Round 3	Cherry Creek	39.598369	-79.275174
DCRL-103-B-2008	DNR	MBSS Round 3	Cherry Creek	39.555750	-79.290440
DCRL-105-B-2008	DNR	MBSS Round 3	Meadow Mountain Run	39.522240	-79.270050
DCRL-106-B-2008	DNR	MBSS Round 3	Meadow Mountain Run	39.519280	-79.278520
DCRL-109-R-2004	DNR	MBSS Round 2	North Glade Run	39.506477	-79.250109
GA-A-011-301-97	DNR	MBSS Round 1	Cherry Creek	39.546779	-79.309367
GA-A-011-317-97	DNR	MBSS Round 1	Cherry Creek	39.544787	-79.304137
GA-A-143-103-97	DNR	MBSS Round 1	Cherry Creek	39.576000	-79.289000
GA-A-143-105-97	DNR	MBSS Round 1	Cherry Creek	39.587371	-79.283184
GA-A-010-205-95	DNR	MBSS Round 1	Deep Creek Lake UT1	39.462726	-79.329909
GA-A-142-118-95	DNR	MBSS Round 1	Deep Creek Lake UT1	39.460881	-79.339774
GA-A-235-215-95	DNR	MBSS Round 1	North Glade Run	39.506590	-79.254392
GA-A-235-224-95	DNR	MBSS Round 1	North Glade Creek	39.503161	-79.262731
GA-A-548-317-95	DNR	MBSS Round 1	Cherry Creek	39.545941	-79.293210

A total of 17 water quality monitoring stations were used to characterize the Deep Creek Lake Watershed. DNR sampled at seven stations, including five MBSS stations and one biological monitoring station from the Maryland Core/Trend monitoring network, located on Cherry Creek, the largest tributary to Deep Creek Lake. The USGS instituted stream flow monitoring in 2007 on Cherry Creek and Poland Run in conjunction with DNR's Deep Creek Lake monitoring program. MDE also sampled at the Core/Trend station and at ten additional locations. The stations are presented in Figure 12 and listed in Table 5.

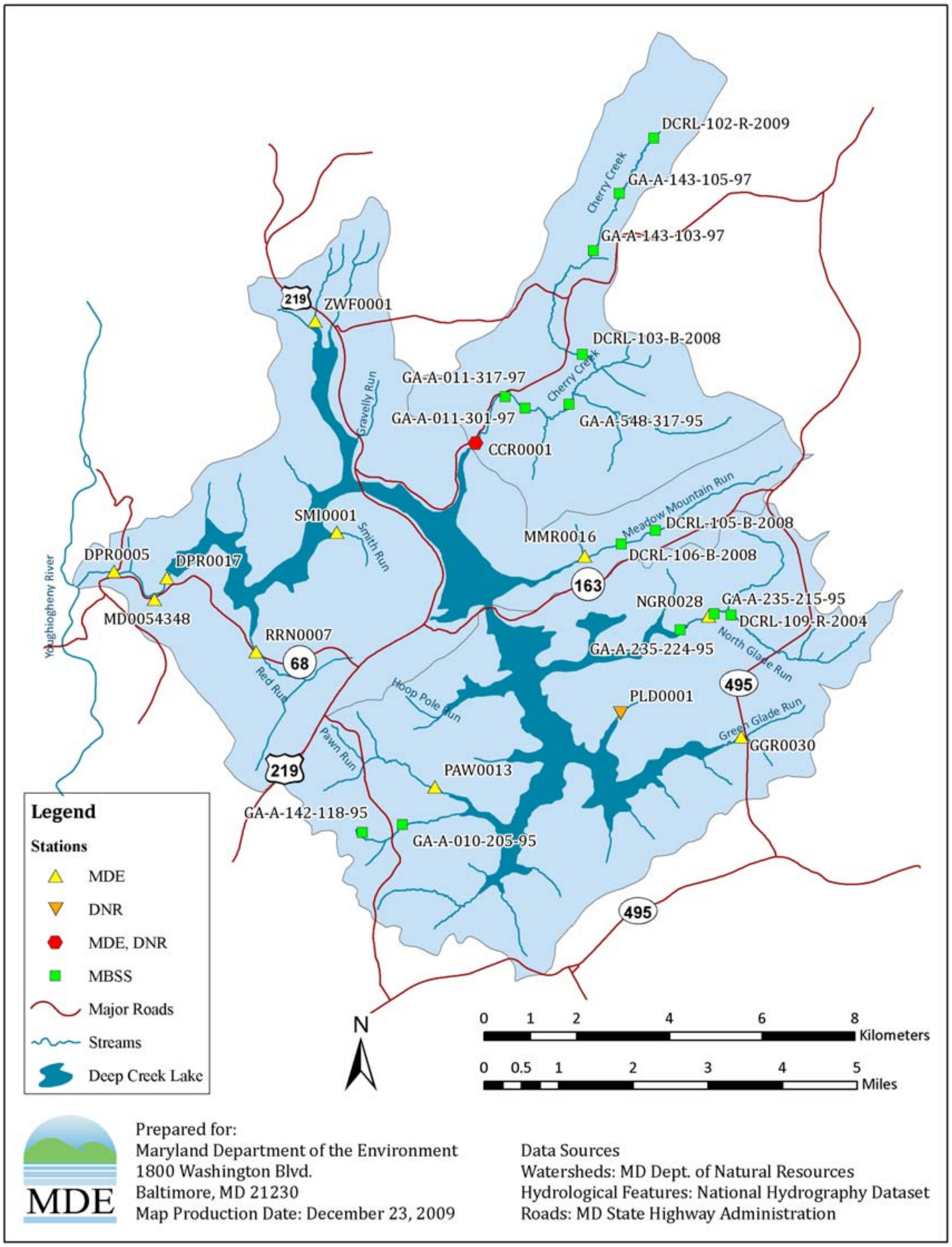

Figure 12: Monitoring Stations in the Deep Creek Watershed

4.2 Biological Assessment and Stressor Identification

4.2.1 Maryland Biological Stream Survey Analysis

MBSS samples were collected at 12 locations in the Deep Creek watershed. Seven samples were collected in Round 1, one sample was taken in Round 2, and four samples were taken in Round 3. All but one Fish Integrated Biological Indicators (FIBI) were below 3, and all but two of the Benthic Integrated Biological Indicators (BIBI) were below 3. Table 11 shows the sample sites and the results of the integrated assessment. A score below 3 indicates that the sampling site is rated fair or poor with respect to the reference sites with healthy biological communities. Because of the MBSS results, the Deep Creek watershed was placed on the State's 2003 Integrated List because of impacts on its biological communities.

Table 6: MBSS Results in the Deep Creek Watershed

Site ID	Round	Location	BIBI	FIBI
GA-A-010-205-95	1	Deep Creek Lake UT1	3	2
GA-A-142-118-95	1	Deep Creek Lake UT1	2.25	2
GA-A-235-215-95	1	North Glade Run	4	1
GA-A-548-317-95	1	Cherry Creek	1.5	2
GA-A-011-301-97	1	Cherry Creek	2	2
GA-A-011-317-97	1	Cherry Creek	1.5	2
GA-A-143-105-97	1	Cherry Creek	1.5	2
DCRL-109-R-2004	2	North Glade Run	3	2.5
DCRL-103-B-2008	3	Cherry Creek	1.75	2
DCRL-105-B-2008	3	Meadow Mountain Run	1.75	2
DCRL-106-B-2008	3	Meadow Mountain Run	2.5	3.5
DCRL-102-R-2009	3	Cherry Creek	2.25	1.7

Although all sites in the Deep Creek watershed are assessed as fair or poor on either the FIBI or BIBI, some mitigating factors should be taken into account that may suggest that water quality in the watershed is not as bad as the IBI scores suggest. First, half of the MBSS sites are in the Cherry Creek watershed, which is known to be impacted by acid mine drainage and naturally-occurring acidic wetlands. Second, low FIBI scores are primarily due to the absence of brook trout and sculpins. Because the reservoir prevents upstream migration, once these species are extirpated, they cannot return to the watershed, even if streams provide suitable water quality and habitat. Third, because of the reservoir, 1st order streams predominate; some of these streams are so small that they are unlikely to support significant fish populations even with good water quality.

4.2.2 Biological Stressor Identification Analysis

MBSS does not determine the cause or source of the biological impairment. The BSID was developed to determine the source and causes of biological impairments in the 1st to 4th order streams subject to MBSS sampling. The BSID uses habitat and water quality monitoring data to determine which potential causes, such as sediments, nutrients, pH, etc., are associated with biological impairments in the watershed. The BSID also uses habitat data and land use data to determine the potential sources for these causes, such as acid mine drainage, atmospheric deposition, urban runoff, or agricultural activities. The cornerstone of the BSID is the calculation of an odds ratio, which expresses how the extent to which a source or cause is more likely to be associated with an impaired site in a watershed, compared to the association of the source or cause with unimpaired reference sites. If the probability of the presence of the source or cause is greater at impaired sites in a watershed than in the population of reference sites, then the source or cause is a potential stressor of the biological community in the watershed.

A BSID analysis was performed for the Deep Creek Lake watershed based on the seven MBSS Round 1 samples and the single Round 2 sample collected in the watershed. As mentioned in the previous section, samples from MBSS Round 2 are required to use the BSID to determine if nutrients are associated with the biological impairments in a watershed, because water chemistry samples taken during Round 1 were not analyzed for nutrients. Although the BSID analysis was not capable of determining if nutrients were associated with biological impairments, other potential stressors were associated with biological impairments in the Deep Creek watershed. The results are shown in Table 12. As the table shows, pH and sediment are leading causes associated with the impaired sites. The fact that pH is associated with impairment in the Deep Creek watershed is not surprising, considering that half of the MBSS samples were taken in the Cherry Creek watershed, which is known to have acid mine impacts and naturally low pH due to the presence of peat bogs.

Table 7: Biological Stressor Identification Analysis, Deep Creek Watershed

Stressor or Source	Percent of Impaired Stream Miles Impacted
Sediment	91%
Habitat	77%
DO < 6 mg/l	19%
Lab pH	45%
Field pH	26%
Low Acid Neutralizing Capacity	45%
High Sulfides	34%
Acid Mine Drainage	44%
Low % forest in 60 m buffer	67%

For details on the BSID analysis, please refer to the document "Watershed Report for Biological Impairment of the Deep Creek Lake Watershed in Garrett County, Maryland - Biological Stressor Identification Analysis Results and Interpretation" (MDE 2010).

4.2.3 MBSS Nutrient Water Quality Monitoring Data

Water quality monitoring data, including observations of nutrient concentrations, are available from Round 3 of the MBSS program. Table 8 shows all of the nitrogen and phosphorus data collected in the Deep Creek Lake watershed in the first three rounds of MBSS sampling. MDE has not yet incorporated Round 3 data into the BSID analysis. For a potential stressor to be associated with biological impairments, the values of the stressor at impaired sites must be greater than the threshold value determined for that stressor, and the fraction of impaired samples with values above the threshold must be greater than the proportion of samples above the threshold among the control or reference sties. The thresholds for TN, total dissolved nitrogen (TDN), TP, and orthophosphate (OP) are 3.0 mg/l, 3.0 mg/l, 0.06 mg/l, and 0.02 mg/l, respectively. As shown in Table 8, none of the nutrient concentrations observed at the MBSS sampling sites is greater than their respective thresholds. If the BSID methodology is applied to all available MBSS data, there is no evidence that nutrients are associated with biological impairments in the Deep Creek Lake watershed.

Table 8: MBSS Nutrient Water Quality Monitoring Data

Site	Year	Stream Name	Round	TN	TDN[1]	TP	OP[2]
GA-A-010-205-95	1995	Deep Creek Lake UT1	1				
GA-A-142-118-95	1995	Deep Creek Lake UT1	1				
GA-A-235-215-95	1995	North Glade Run	1				
GA-A-548-317-95	1995	Cherry Creek	1				
GA-A-235-224-95	1995	North Glade Creek	1				
GA-A-011-301-97	1997	Cherry Creek	1				
GA-A-011-317-97	1997	Cherry Creek	1				
GA-A-143-105-97	1997	Cherry Creek	1				
GA-A-143-103-97	1997	Cherry Creek	1				
DCRL-109-R-2004	2004	North Glade Run	2	1.267	0.9602	0.032	0.0025
DCRL-103-B-2008	2008	Cherry Creek	3	0.3452	0.1771	0.011	0.0011
DCRL-105-B-2008	2008	Meadow Mountain Run	3	0.3201	0.1956	0.0049	0.0011
DCRL-106-B-2008	2008	Meadow Mountain Run	3	0.2935	0.1867	0.0041	0.0011
DCRL-102-R-2009	2009	Cherry Creek	3	0.243	0.0323	0.0125	0.0011

1 Total Dissolved Nitrogen
2 Orthophosphate

4.2 Dissolved Oxygen

DNR samples were taken in the Deep Creek watershed from April 2009 through December 2009, and MBSS samples were taken the summer of 2004, 2008, and 2009. MDE samples were taken from January 2000 through December 2008. Samples taken during the growing season (May through October) show DO concentrations ranging from 2.6 to 11.5 mg/l, with only seven of 92 samples below 6 mg/l and three samples below 5 mg/l. These data are presented graphically in Figure 13 and in tabular form in Appendix A.

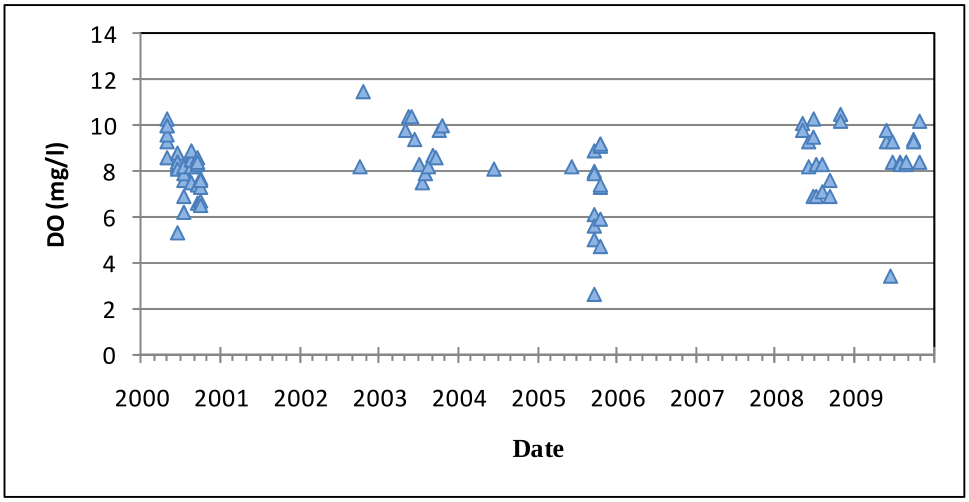

Figure 13: Deep Creek Dissolved Oxygen Data from 2000 through 2009

4.3 Nutrients

During the growing season DNR and MDE have total nitrogen (TN) concentrations ranging from 0.14 to 1.7 mg/l and total phosphorus (TP) concentrations ranging from 0.0 to 0.09 mg/l. These data are presented graphically in Figures 14 and 15.

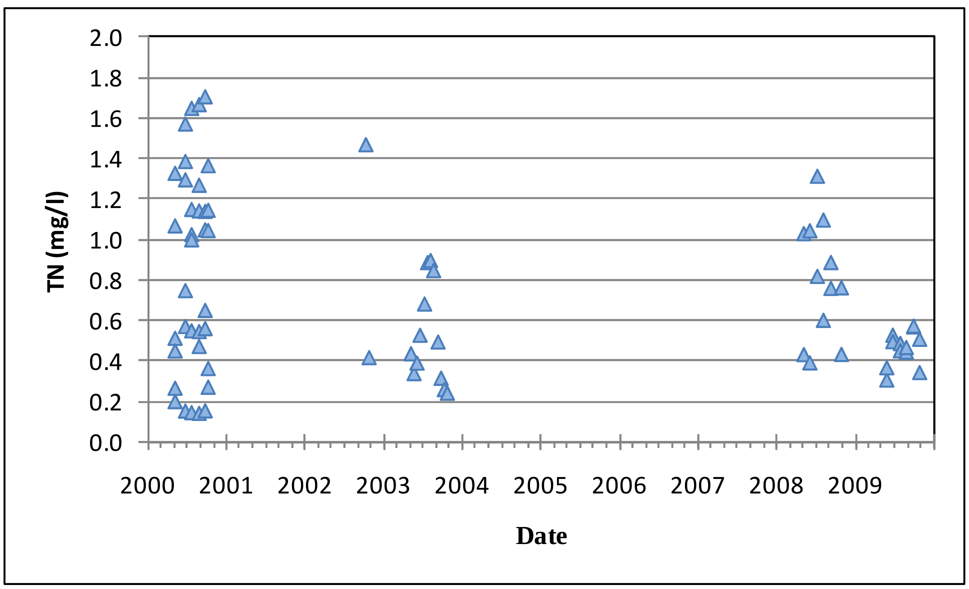

Figure 14: Deep Creek Total Nitrogen Data from 2000 through 2009

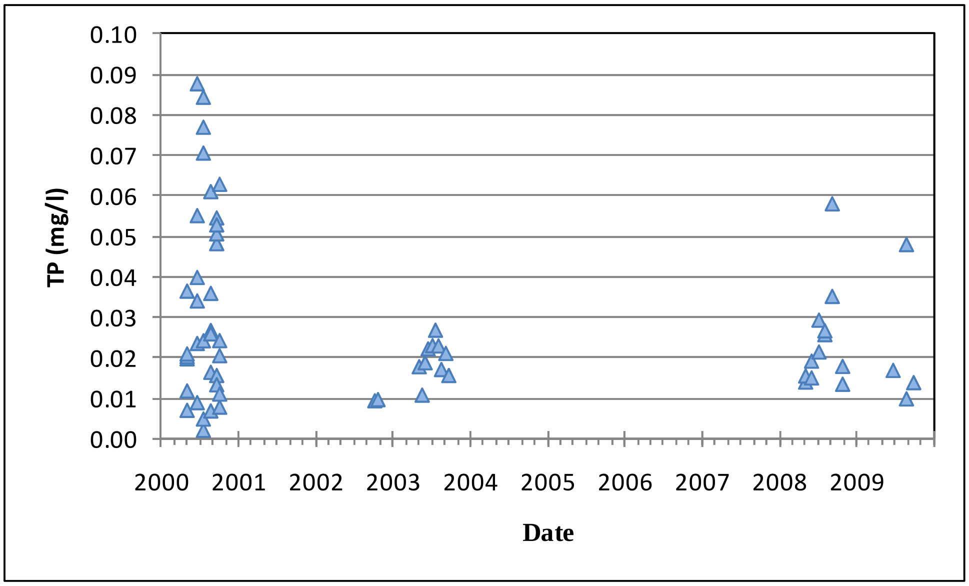

Figure 15: Deep Creek Total Phosphorus Data from 2000 through 2009

There were only two of 63 samples among two surveys where the TN:TP ratio was less than 10. The average TN:TP ratio across both surveys is 34.4. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting (Chiandani et al., 1974). The observed data strongly implies that the streams in the Deep Creek watershed are phosphorus limited.

Generally, in the absence of State water quality standards with specific numeric limits for nutrients, evaluation of potentially eutrophic conditions is based on whether nutrient-related parameters (i.e., dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair the designated uses in the Deep Creek watershed (in this case protection of aquatic life and wildlife, fishing, and swimming), and on the results of the BSID analysis, which is used to determine whether nutrients are associated with the biological impairments documented by MBSS. Consequently, nitrogen and phosphorus data are generally presented in Maryland nutrient TMDLs for informational purposes only.

4.4 Chlorophyll *a*

Currently, Maryland water quality standards do not specify numeric criteria for chlorophyll *a*. However, pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere with designated uses is prohibited (COMAR 26.08.02.03B(2)). Elevated chlorophyll *a* concentrations, a measure of algal growth, may indicate poor water quality that cannot support a water body's designated uses and may constitute a nuisance condition. Nuisance levels of algae can interfere with uses related to recreational activities such as fishing, boating, and aesthetic appreciation. High chlorophyll *a* levels can also present taste, odor, and treatment problems in water supply systems.

Narrative water quality criteria are an important component of the State's water quality standards, but are difficult to incorporate into quantitative water quality or TMDL analyses. In the case of free-flowing non-tidal waters, there is an insufficient understanding of the relationship between chlorophyll *a* concentrations and the water body's designated use impairment.

Maryland has developed guidelines for application of the narrative criteria in tidal waters and drinking water reservoirs. The guidelines for drinking water reservoirs, as described in previously approved TMDLs, are as follows:

> The chlorophyll *a* endpoints selected for public water supply reservoirs are (a) a ninetieth-percentile instantaneous concentration not to exceed 30 µg/l in the surface layers, and (b) a 30-day moving average concentration not to exceed 10 µg/l in the surface layers. The concentration of 10 µg/l corresponds to a score of approximately 53 on the Carlson's Trophic State Index (TSI). This is at the boundary of mesotrophic and eutrophic conditions, which is an appropriate trophic state at which to manage these reservoirs. Mean chlorophyll *a* concentrations exceeding 10 µg/l are associated with peaks exceeding 30 µg/l, which in turn are associated with a shift to blue-green assemblages, which present taste, odor and treatment problems (Walker 1984). Achieving these chlorophyll *a* endpoints should thus safeguard such reservoirs from nuisance algal blooms. (MDE 2008b).

MDE monitoring data in the Deep Creek watershed shows a growing season (May through October) average of 2.8 µg/l. Samples showed observed chlorophyll *a* concentrations during the growing season ranging from not detected to 53.5 µg/l. Using the above chlorophyll *a* criteria for public water supply reservoirs as screening values for non-tidal waters, five (out of 60) samples had concentrations greater than 10 µg/l and one sample had concentrations greater than 30 µg/l. The chlorophyll *a* data are presented graphically in Figure 16.

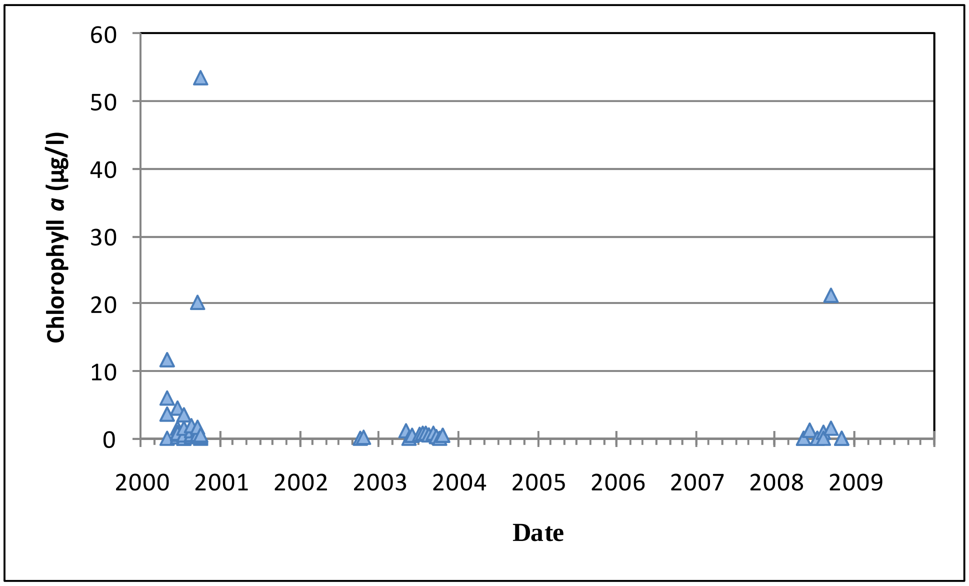

Figure 16: Deep Creek Chlorophyll *a* Data from 2000 through 2009

4.5 Deep Creek Core Monitoring Stations

Additional data for the Deep Creek Lake watershed was obtained from the Maryland DNR Core/Trend Program. The program collected benthic macroinvertebrate data between 1976 and 2006. These data were used to calculate four benthic community measures: total number of taxa, the Shannon-Weiner diversity index, the modified Hilsenhoff biotic index, and percent *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT). DNR has extensive monitoring information for one station in the Deep Creek Lake watershed through the Core/Trend Program. The station is located on Cherry Creek a tributary to Deep Creek Lake. Samples are taken from the middle of the bridge at State Park Road (see Table 8 and Figure 3). This station has 15 years of benthic macroinvertebrate data (DNR 2009). The result for the station is presented in Table 9.

Table 9: Deep Creek DNR Core Data

Site Number	Current Water Quality Status	Trend Since 1970s
CCR0001	Fair/Good	Slight Improvement

5.0 CONCLUSIONS

The Maryland water quality standards surface water use designation for the Deep Creek Lake, its tributaries, and mainstem Deep Creek below the dam to the confluence of Deep Creek with the Youghiogheny River, is Use III-P (Nontidal Cold Water and Public Water Supply) (COMAR 2007a,b,c,d,e). The possibility of phosphorus contributing to the impairment of the designated uses for the Deep Creek Lake watershed and the Deep Creek Lake impoundment will be taken up in turn below.

5.1 Deep Creek Lake Watershed

The analysis of data presented in the Section 4 of this report indicates that DO and chlorophyll *a* concentrations are meeting water quality criteria. The results of the Deep Creek Lake BSID analysis show that pH, sediment, poor habitat, and additional stressors other than nutrients are sufficient to explain the biological impairments in the Deep Creek Lake watershed. Moreover, the analysis of Round 3 biological and water quality data shows that nutrients are not associated with biological impairments in the Deep Creek Lake watershed. MDE concludes that currently the Deep Creek Lake watershed is not being impaired by nutrients. Barring the receipt of contradictory data, this report will be used to support a revision of the phosphorus listing for the Deep Creek Lake watershed, from Category 5 ("waterbody is impaired, does not attain the water quality standard, and a TMDL is required") to Category 2 ("waterbodies meeting some [in this case nutrients-related] water quality standards, but with insufficient data to assess all impairments"), when MDE proposes the revision of Maryland's Integrated Report.

5.2 Deep Creek Lake

Maryland's General Water Quality Criteria prohibit pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 26.08.02.03B(2)). Excessive eutrophication, indicated by elevated levels of Chlorophyll *a*, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. Excessive eutrophication is ultimately caused by nutrient overenrichment. The analysis of available water quality data in Section 2.3.5 shows that Chlorophyll *a* concentrations in Deep Creek Lake are consistently below nuisance levels that would prevent the lake from supporting its designated uses.

Use III-P waters are subject to DO criteria of not less 5.0 mg/l at any time and a daily average DO concentration of at least 6.0 mg/l (COMAR 26.08.02.03-3E(2)) unless natural conditions result in lower levels of DO (COMAR 26.08.02.03A(2)). New standards for tidal waters of the Chesapeake Bay and its tributaries take into account stratification and its impact on deeper waters. MDE recognizes that stratified reservoirs and impoundments (there are no natural lakes in Maryland) present circumstances similar to stratified tidal waters, and is applying an interim interpretation of the existing standard to allow for the impact of stratification on DO concentrations. This interpretation recognizes that, given the morphology of the reservoir or impoundment, the resulting degree of stratification, and the naturally occurring sources of organic material in the watershed, hypoxia in the hypolimnion is a natural consequence. The interim interpretation of the non-tidal DO standard, as applied to reservoirs, is as follows:

1. A minimum DO concentration of 5.0 mg/l and a daily average DO concentration of at least 6.0 mg/l will be maintained throughout the water column during

periods of complete and stable mixing, unless natural conditions result in lower levels;
2. A minimum DO concentration of 5.0 mg/l and a daily average DO concentration of at least 6.0 mg/l will be maintained in the mixed surface layer at all times, including during stratified conditions, except during periods of overturn or other naturally-occurring disruptions of stratification; and
3. Hypolimnetic hypoxia will be addressed on a case-by-case basis, taking into account morphology, degree of stratification, sources of diagenic organic material in reservoir sediments, and other such factors.

The analysis of available water quality data in Section 3.3 shows that DO concentrations in the epilimnion and mixed surface layer of Deep Creek Lake support the Nontidal Cold Water and Public Water Supply Designated Use, and that low DO concentrations in the hypolimnion are associated with seasonal thermal stratification.

To determine if the observed hypoxia in the hypolimnion is a naturally-occurring consequence of seasonal thermal stratification, a computer simulation model of Deep Creek Lake was developed, using the CE-QUAL-W2 ("W2") model. W2 is a laterally averaged two-dimensional computer simulation model, capable of representing the hydrodynamics and water quality of rivers, lakes, and estuaries. It is particularly suited for representing temperature stratification that occurs in reservoirs, and has been used to develop phosphorus TMDLs for the Gunpowder Reservoirs (MDE, 2006) and Patuxent Reservoirs (MDE, 2007). Cole and Wells (2003) give a general description of the CE-QUAL-W2 model. The accompanying report, *A Computer Modeling Framework for Supporting the Water Quality Analysis for Eutrophication for Deep Creek Lake* (Mandel et al., 2010), describes the implementation of the W2 model for Deep Creek Lake.

The Deep Creek Lake W2 model simulates temperature, DO, and eutrophication dynamics. Flows and nutrient loads from the Deep Creek Lake watershed were simulated using a refined version of the Chesapeake Bay Program's Phase 5 Watershed Model. The W2 model was calibrated against data collected by MDE in 2000.

Following the methodology used in the nutrient TMDLs for the Gunpowder Reservoirs (2006b) and Patuxent Reservoirs (MDE, 2008b), the calibrated W2 model was used to simulate eutrophication and dissolved oxygen dynamics that would occur in the lake if the surrounding watershed was entirely forested. This All-Forest Scenario represents Deep Creek Lake under natural conditions. The purpose of the All-Forest Scenario is to help determine whether hypoxia in the bottom layers Deep Creek Lake is primarily due to the stratification induced by reservoir morphology, or to input loads. If hypoxia occurs even under all-forested loading rates, then reservoir stratification is determined to be the primary cause of hypoxia and it can be concluded that the reservoir meets the water quality standards for DO as described above.

The All-Forest Scenario was simulated for the six year period, 2000-2005, to capture a variety of hydrological conditions and loading rates. For comparison, a Baseline Scenario, which represents the lake under current (calibration) conditions, was also simulated for the same six year period. Mandel et al. (2010) describe in greater detail the development of the Deep Creek Lake W2 model, its calibration, and the results of the All-Forest Scenario. Figure 17 compares average observed DO concentrations and the simulated average DO concentrations in the hypolimnion under the Baseline Scenario and the All-Forest Scenario at monitoring station DPR0021, just above the dam on Deep Creek Lake. The Baseline Scenario captures the observed DO concentrations in the hypolimnion in 2000, the year in the simulation period where data are available. The All-Forest Scenario shows that low DO concentrations would still be prevalent in the bottom layers of Deep Creek Lake under natural all-forested conditions, especially in wet years like 2003 or 2004. Figure 18 compares the distribution of observed average bottom DO concentrations in 2000 and the distribution of simulated concentrations from the Baseline and All-Forest Scenarios over the six-year simulation period. The distribution of DO concentrations in the Baseline Scenario matches the observed distribution. While average bottom DO concentrations increase under the All-Forest Scenario, indicating the impact of reduced loading rates of organic material, more than 20% of the simulated average bottom DO concentrations are less than 2 mg/l, with more than 40% not meeting the State's standard of 5 mg/l. Thus the All-Forest Scenario shows that hypoxia persists even under input loads associated with all-forested conditions, demonstrating that reservoir morphology and thermal stratification are the primary causes of hypoxia in the hypolimnion.

Deep Creek Lake therefore meets all three conditions specified by the interim interpretation of the non-tidal DO standard, as applied to reservoirs: (1) observed DO concentrations are greater than 6 mg/l in periods of stable mixing, as illustrated by Figures 4 and 5; (2) greater than 99% of the observed DO concentrations in the surface layer are greater than 6 mg/l in the surface layer at all times, including periods of stratification, as demonstrated by Figure 6; and (3) DO concentrations less than 5 mg/l in the bottom layers of Deep Creek Lake under stratified conditions are a naturally occurring consequence of reservoir morphology and thermal stratification, as demonstrated by the simulated All-Forest Scenario.

Based on the analysis of data presented in the preceding sections of this report, indicating that DO and chlorophyll *a* concentrations are meeting water quality criteria, and on the results of the computer simulation modeling of Deep Creek Lake under all-forested conditions, MDE concludes that currently Deep Creek Lake is not being impaired by nutrients. Barring the receipt of contradictory data, this report will be used to support a revision of the phosphorus listing for Deep Creek Lake, from Category 5 ("waterbody is impaired, does not attain the water quality standard, and a TMDL is required") to Category 2 ("waterbodies meeting some [in this case nutrients-related] water quality standards, but with insufficient data to assess all impairments"), when MDE proposes the revision of Maryland's Integrated Report.

5.3 Potential Localized Eutrophication Impacts in Deep Creek Lake

Although the analysis in Section 3 demonstrates that the Deep Creek Lake impoundment is meeting water quality standards at the scale of its listing in the 2008 Integrated Report, qualitative observations reported by stakeholders and associated photographic documentation referenced in Section 3.6 provide evidence that nutrients may be causing excess algal and macrophyte growth in localized areas in some near-shore coves. MDE will collaborate with DNR to determine the existence, magnitude and geographic extent of any localized eutrophication problems through additional water quality monitoring. Water quality monitoring, consisting of nutrient-related physical and chemical analysis including chlorophyll, is planned for July, August and September in both 2010 and 2011. Additionally, MDE plans a dye study in spring of 2011. MDE reserves the right to place localized areas of Deep Creek Lake as Category 5 waters impaired by nutrients at a 12-digit watershed scale or smaller, and to develop a formal TMDL for those areas in the future, to address any local nutrient impacts identified during the course of this monitoring.

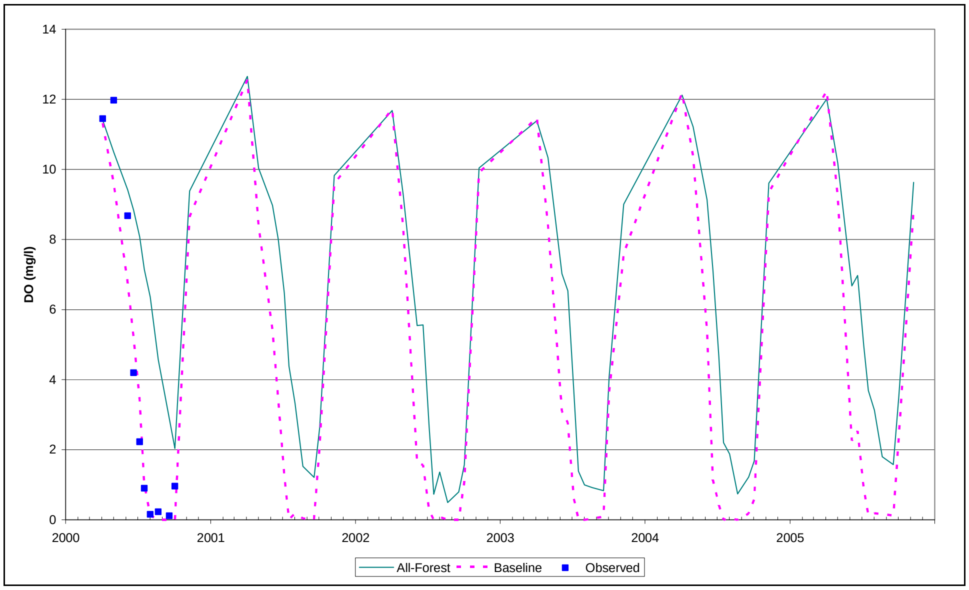

Figure 17: Average Bottom DO (mg/l) in Deep Creek Lake, DP0021

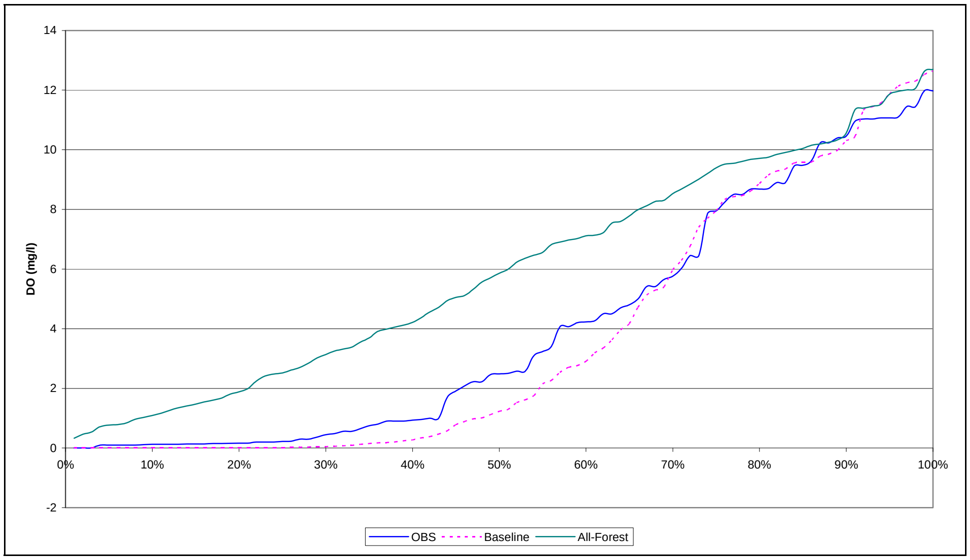

Figure 18: Distribution of Average Bottom DO (mg/l), Observed, Baseline, All-Forest Scenarios, 2000-2005, Deep Creek Lake

REFERENCES

Brookfield Power. 2010. The Deep Creek Hydro Website. http://www.deepcreekhydro.com/

Chiandani, G. and M. Vighi. 1974. The N:P Ratio and Tests with *Selanastrum* to Predict Eutrophication in Lakes. *Water Research*, Vol. 8, pp. 1063-1069.

CFR (Code of Federal Regulations). 2010. *40 CFR 130.7*. http://a257.g.akamaitech.net/7/257/2422/22jul20061500/edocket.access.gpo.gov/cfr_2006/julqtr/40cfr130.7.htm. (Accessed March, 2010).

Cole, T. M. and S. A. Wells. 2003. CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.2. User Manual. Washington, DC. U.S. Army Corps of Engineers. Instruction Report EL-03-1.

COMAR (Code of Maryland Regulations). 2009a. *26.08.02.02*. http://www.dsd.state.md.us/comar/26/26.08.02.02.htm(Accessed March, 2010).

___________. 2009b. *26.08.02.07*. http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed March, 2010).

___________. 2009c. *26.08.02.08 P(4)(h)*. http://www.dsd.state.md.us/comar/26/26.08.02.08.htm(Accessed March, 2010).

___________. 2009d. *26.08.02.08 P(6)(b)*. http://www.dsd.state.md.us/comar/26/26.08.02.08.htm(Accessed March, 2010).

___________. 2007e. *26.08.02.08 Q(4)(d)*. http://www.dsd.state.md.us/comar/26/26.08.02.08.htm (Accessed March, 2007).

________________. *COMAR 26.08.02.03-3, 26.08.02.03, and 26.08.02.07.* http://www.dsd.state.md.us/comar (Accessed March 2009).

DNR (Maryland Department of Natural Resources). 1996. *Maryland Water Quality Inventory, 1993-1995: A report on The Status of Natural Waters in Maryland Required by Section 305(b) of the Federal Water Pollution Control Act and Reported to the US Environmental Protection Agency and Citizens of the State of Maryland*. Annapolis, MD: Department of Natural Resources.

DNR. 2001. Deep Creek Lake Recreation and Land Use Plan http://dnr.maryland.gov/publiclands/dcreport.html

___________. 2007a. *Personal fax communication* *with Ellen Friedman.* Annapolis, MD: Department of Natural Resources, Monitoring and Non-Tidal Assessment Program.

___________. 2007b. *Physiography of Maryland*. http://www.dnr.state.md.us/forests/healthreport/mdmap.html (Accessed March, 2007).

___________. 2009. Benthic Macroinvertebrate Communities At Maryland's Core/Trend Monitoring Stations: Water Quality Status And Trends. Annapolis, MD: Department of Natural Resources.

____________. 2010. The Deep Creek Project. http://esm.versar.com/pprp/features/deepcrk/deepcrk.htm

Friends of Deep Creek Lake (FoDCL). 2010. http://friendsofdcl.org/

Mandel, R., S. Kim, A. Nagel, and J. Palmer. 2010. *A Computer Modeling Framework for Supporting the Water Quality Analysis for Eutrophication for Deep Creek Lake*. Rockville, MD: Interstate Commission on the Potomac River Basin.

MDE (Maryland Department of the Environment). 2000. *An Overview of Wetlands and Water Resources of Maryland*. Baltimore, MD: Maryland Department of the Environment.

___________. 2002. Total Maximum Daily Load of Mercury for Deep Creek Lake, Garrett County, Maryland. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/ApprovedFinalTMDL/TMDL_deepcreeklake_Hg_final.asp

___________. 2004. *2004 List of Impaired Surface Waters [303(d) List] and Integrated Assessment of Water Quality in Maryland Submitted in Accordance with Sections 303(d) and 305(b) of the Clean Water Act*. Baltimore, MD: Maryland Department of the Environment. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/final_2004_303dlist.asp.

_______________. 2006. *Total Maximum Daily Loads of Nitrogen and Phosphorus for the Upper and Middle Chester Rivers in Kent and Queen Anne's Counties, Maryland*. Baltimore, MD: Maryland Department of the Environment

————. 2006b. *Total Maximum Daily Loads of Phosphorus and Sediments for Loch Raven Reservoir and Total Maximum Daily Loads of Phosphorus for Prettyboy Reservoir, Baltimore, Carroll and Hartford Counties, Maryland*. Baltimore, MD: Maryland Department of the Environment. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/ApprovedFinalTMDL/TMDL_final_gunpowder_P_sed.asp

___________. 2007. *Maryland's 2006 Integrated Report*. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2006_303d_list_final.asp (Accessed March, 2007).

___________. 2008a. *2008 Integrated Report of Surface Water Quality in Maryland*. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2008_Final_303d_list.asp. (Accessed March, 2010).

————. 2008b. *Total Maximum Daily Loads of Phosphorus and Sediments for Triadelphia Reservoir and Total Maximum Daily Loads of Phosphorus for Rocky Gorge Reservoir, Howard, Montgomery and Prince George's Counties, Maryland*. Baltimore, MD: Maryland Department of the Environment. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/ApprovedFinalTMDL/TMDL_Pax_Res_P_Sed.asp.

————. 2009a. *Maryland Biological Stressor Identification Process*. Baltimore, MD: Maryland Department of the Environment.

________. 2009b. Addendum: Updates to *A Methodology for Addressing Sediment Impairments in Maryland's Non-tidal Watersheds*. Baltimore, MD: Maryland Department of the Environment.

________.2010. Watershed Report for Biological Impairment of the Deep Creek Lake Watershed in Garrett County, Maryland Biological Stressor Identification Analysis Results and Interpretation. Baltimore, MD: Maryland Department of the Environment.

MGS (Maryland Geological Survey). 2007. *A Brief Description of the Geology of Maryland*. http://www.mgs.md.gov/esic/brochures/mdgeology.html (Accessed March, 2010).

____________. 2007. *State Soil Geographic (STATSGO) Database for Maryland*. http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html (Accessed March, 2007).

Walker, W.W., Jr. 1984. *Statistical Bases for Mean Chlorophyll a Criteria*. Lake and Reservoir Management: Proceedings of Fourth Annual Conference. North American Lake Management Society, pp. 57 – 62.

Weisberg, S. B., K. A. Rose, B. S. Clevenger, and J. O. Smith. 1985. *Inventory of Maryland Dams and Assessment of Hydropower Resources*. Martin Marietta Environmental Systems. Columbia MD.

APPENDIX A – Watershed Characterization Data