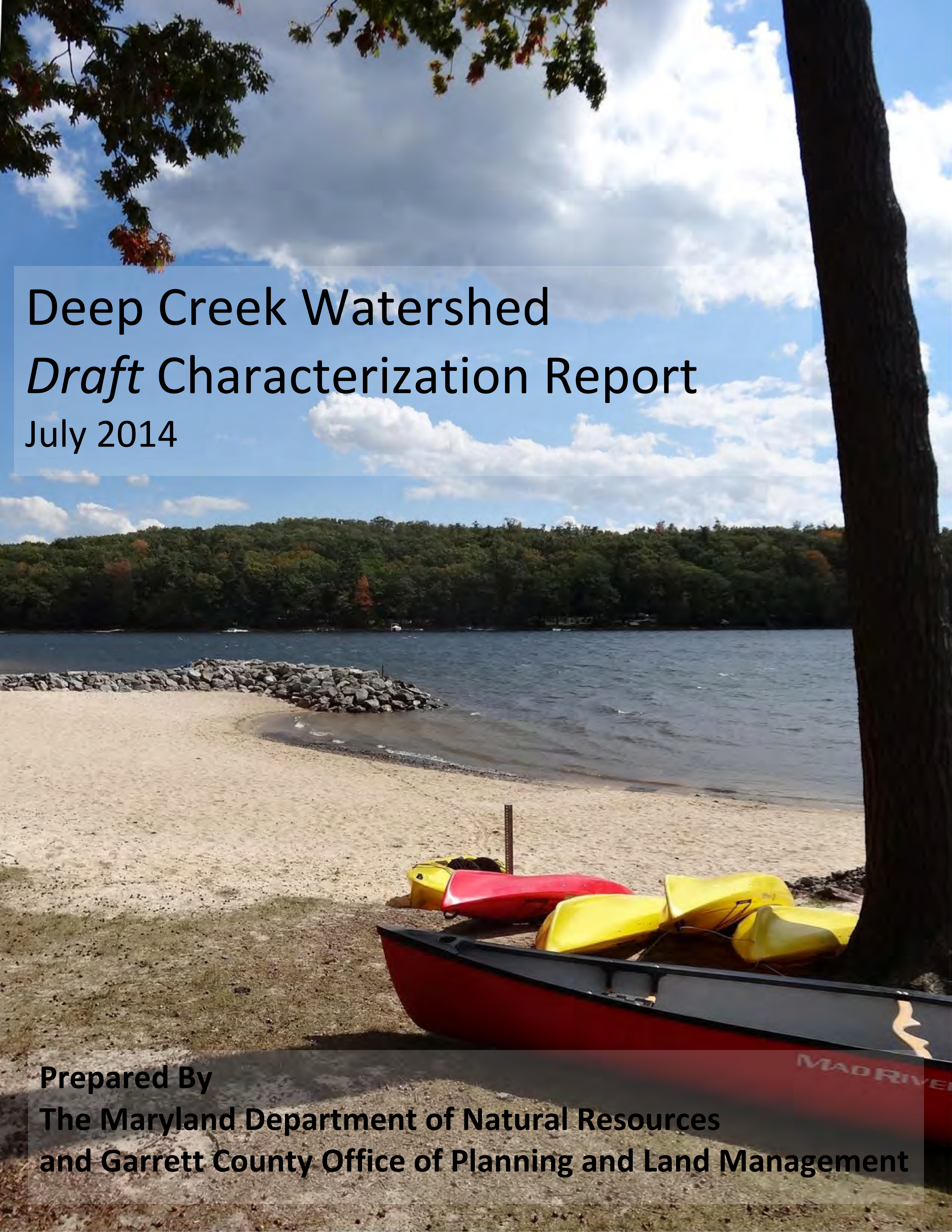


Deep Creek Watershed
Draft Characterization Report

July 2014

Prepared By
The Maryland Department of Natural Resources
and Garrett County Office of Planning and Land Management

Deep Creek Watershed: Characterization Report

Table of Contents

Deep Creek Watershed: Characterization Report

Introduction

The characterization report provides a comprehensive collection of information and data on past and existing conditions and the attributes in and around the Deep Creek Lake watershed related to water quality, natural resources, and land use. Additional information referenced in this report can be found in the separate document *Deep Creek Watershed Characterization Appendices.* This information will be used to make informed and scientifically-based recommendations to help guide future strategies and planning efforts for the protection and restoration of the Deep Creek watershed.

Background

Garrett County is the western most county in Maryland and is bordered on the north by Pennsylvania, on the west and south by West Virginia. The county is rural with a total land area of 423,678 acres and a population of 30,097 persons as recorded by the 2010 Census. Deep Creek Lake (DCL) is a popular vacation destination causing the population of the County to nearly double during peak summer vacation times.

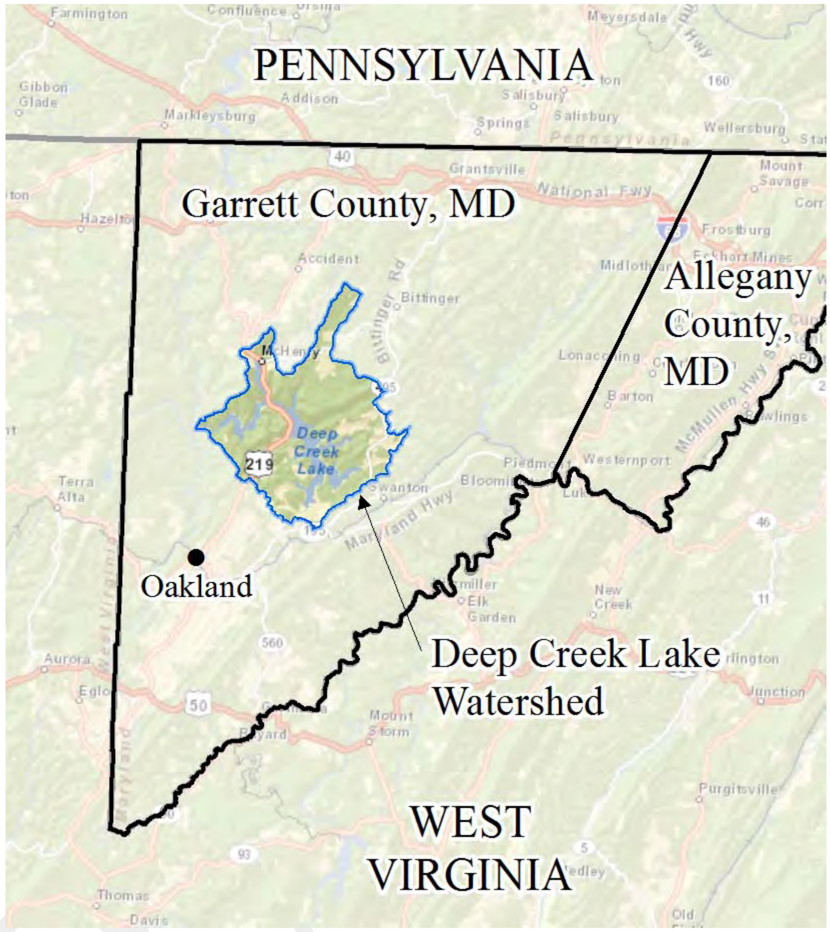
Deep Creek Lake is Maryland's largest reservoir. with a surface area of 3,900 acres and 68 miles of shoreline, The lake is composed of a main stem, branches, and multiple small, shallow coves fed by four major tributaries and more than 50 smaller streams. The lake's 180,000 acre watershed is located west of the eastern continental divide, ultimately draining into the Gulf of Mexico."

Because Deep Creek Lake is a reservoir, the water level fluctuates seasonally due to managed releases and hydrographic conditions, resulting in low water levels at times in very shallow coves. The lake drains into the Youghiogheny River which flows north into Pennsylvania, shown in Figure 1. Youghiogheny is an Algonquin word meaning "a stream flowing in a contrary direction.

Figure 2 shows the watershed in Garrett County

Figure 1

Figure 2



The lake was built in 1925 for hydroelectric power generation. Over the years it has become a four-season travel destination with endless recreational opportunities, particularly in the last thirty years since the completion of Interstate 68. Communities have grown up around the lake, and much of the lake's shore is now lined with hotels, condominiums, and private homes. The northern portion of the lake watershed is primarily composed of businesses, residential areas, and forested land. The southern portion of the lake watershed is dominated by agricultural land.

A Tourism Marketing Report and Economic Analysis survey was conducted by the Garrett County Chamber of Commerce in conjunction with the University of West Virginia in 2009 to better understand the uses and needs of visitors in the County. They found that there were approximately 1,117,744 visitors per year resulting in 347.65 million dollars in total impact and 5,041 jobs. Twenty-five percent of the visitors surveyed owned a second home in Garrett County. Also of note is that 93.5% of visitors come to Garrett County for the scenery, with 89% visiting state parks and forests. Also listed as 75% or greater reasons to come to Garrett County include: fall foliage, trails, festivals and events, and waters sports. For the full report, visit: http://www.mde.maryland.gov/programs/Water/Water_Supply/Documents/Deep%20Creek%20Lake/2009%20WVU%20Survey%20and%20Economic%20Impact.pdf

Land Use, Growth, and Recreation

Garrett County has traditionally been the epitome of a traditional Appalachian community, with its economy historically supported by such industries as agriculture, timber and coal mining. Deep Creek watershed sits in the middle of the county and has been the center of much of the growth in the county due to an insurgence of tourism and second home buyers surrounding Deep Creek Lake. The lake was formed as part of a hydroelectric project in the 1920s. From the time of its creation Deep Creek Lake has attracted vacationers from the surrounding cities of Pittsburgh PA, Baltimore MD, Washington DC and the growing Morgantown WV area. Growth within the watershed, specifically near the lake, grew steadily between the 1940s and 1970s, however the completion of Interstate 68 in the 1980s facilitated more visitors from the Eastern part of the state and resulted in more rapid growth. Recreation on Deep Creek Lake is popular and varied, and weather is ideal for both summer and winter sports: from swimming, fishing, boating, and jet skiing, to downhill and cross-country skiing and tubing in the wintertime.

Planning in Garrett County began in 1972 with a plan for the Deep Creek Lake area. It was closely followed by the County's first comprehensive plan "A Development Plan for Garrett County", adopted in 1974. Subsequent comprehensive plans were competed in 1995 and 2008. Following the 1975 plan, zoning was adopted in the Deep Creek Watershed. To date, this watershed and six municipalities are the only areas of the county where zoning exists.

Land use has not changed significantly over the almost 30 year span, with the majority of land in forests or barren lands (Figure 3). Figure 2 shows the timeline for planning regulations within the county and the relevant state regulations that influenced Garrett County planning updates and implementations. The state began having more influence in local planning implementation with the passage of the 1992 Economic Growth, Resource Protection and Planning Act, which led to the implementation of both the Subdivision Ordinance and the Sensitive Areas Ordinance in 1997. The development of those ordinances necessitated an update in the Deep Creek Watershed Zoning Ordinance in the same year.

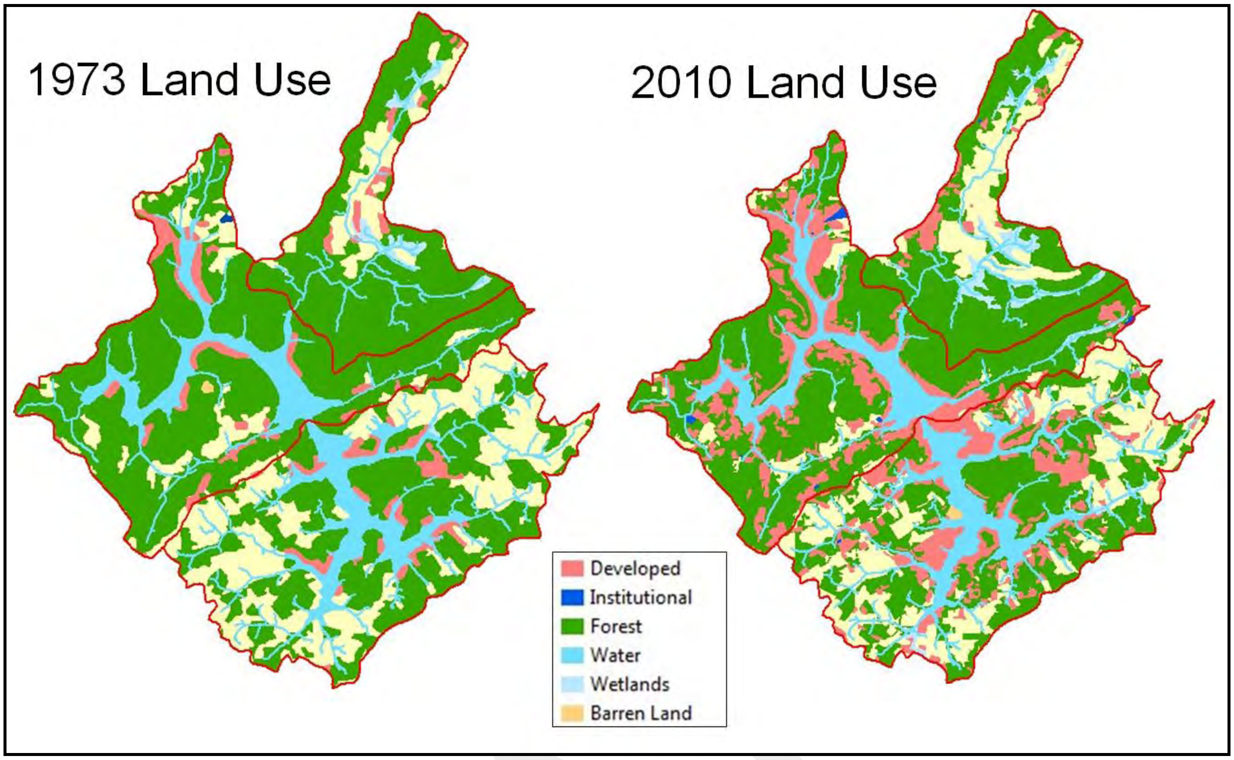


Figure 3: Deep Creek Lake land use trends from 1973 and 2010.

Also in 1997 the state of Maryland required the designation of Priority Funding Areas based on a set of criteria provided to local governments. These designated areas were to be given priority for any growth projects that required state funding. Due to the nature of growth in the county and specifically the number of second homes in Deep Creek watershed that do not count as part of the county's population numbers, Garrett County's priority funding areas encompass less than 3% of our county. There are four Priority Funding Areas (PFA) in the Deep Creek watershed and they are McHenry, Thayerville, the McHenry Business Park/Garrett County Airport site and the Sand Flat/219 intersection (see Figure 4).

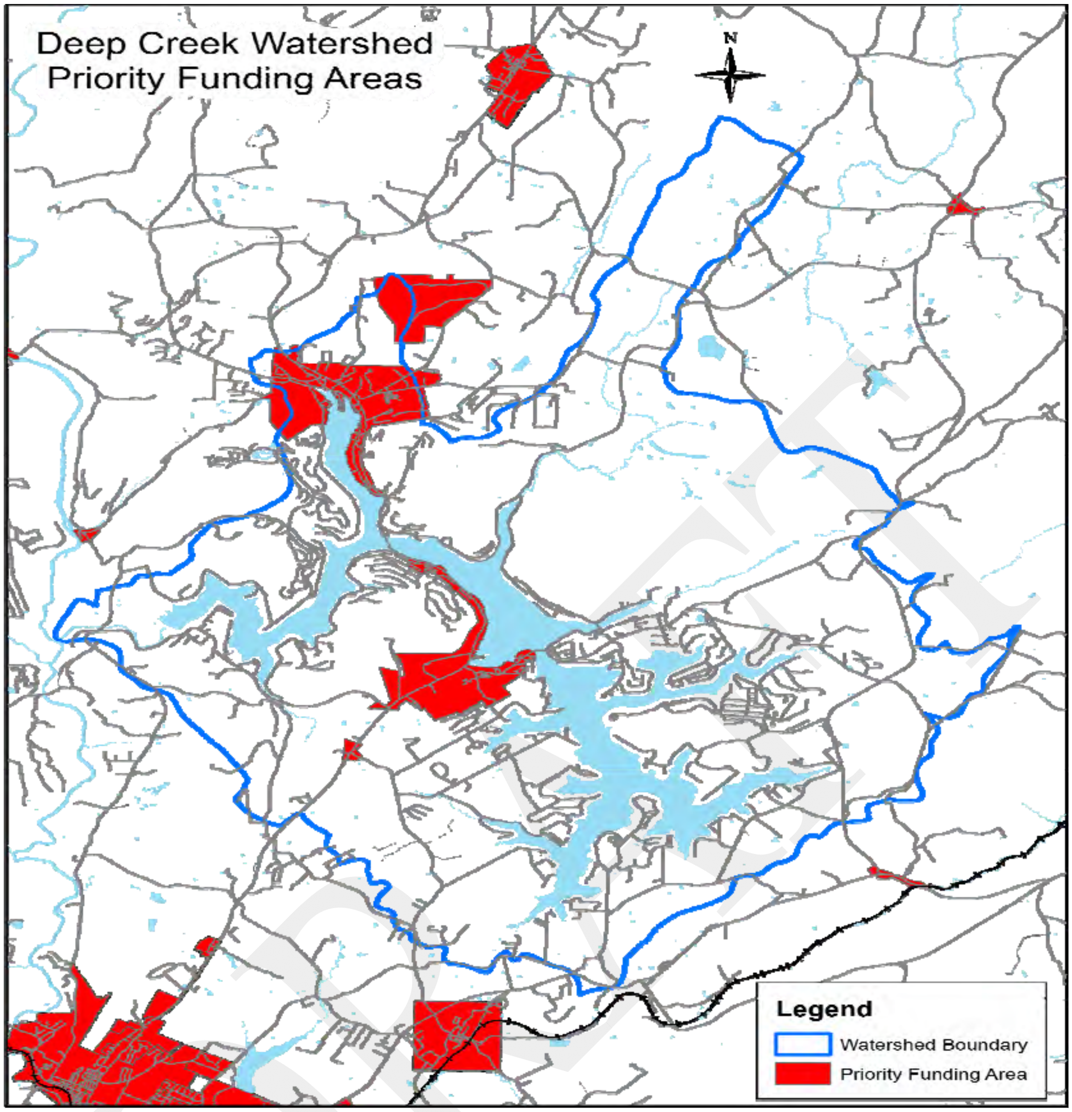


Figure 4

In 2004 the Deep Creek Lake Watershed Economic Growth & Planning Analysis Study was conducted in response to concerns from residents about how future growth might affect the beauty of the lake. At the time of that study, an unprecedented escalation in real estate values and increased investor and visitor interest prompted the concerns. Since that time the economy has seen a marked downturn and growth in the watershed has significantly declined. Figure 5 is a chart found in the 2013 Annual Report prepared by the Garrett County Planning Commission. It clearly shows the decline in housing units the county and the watershed has been experiencing over the last five years.

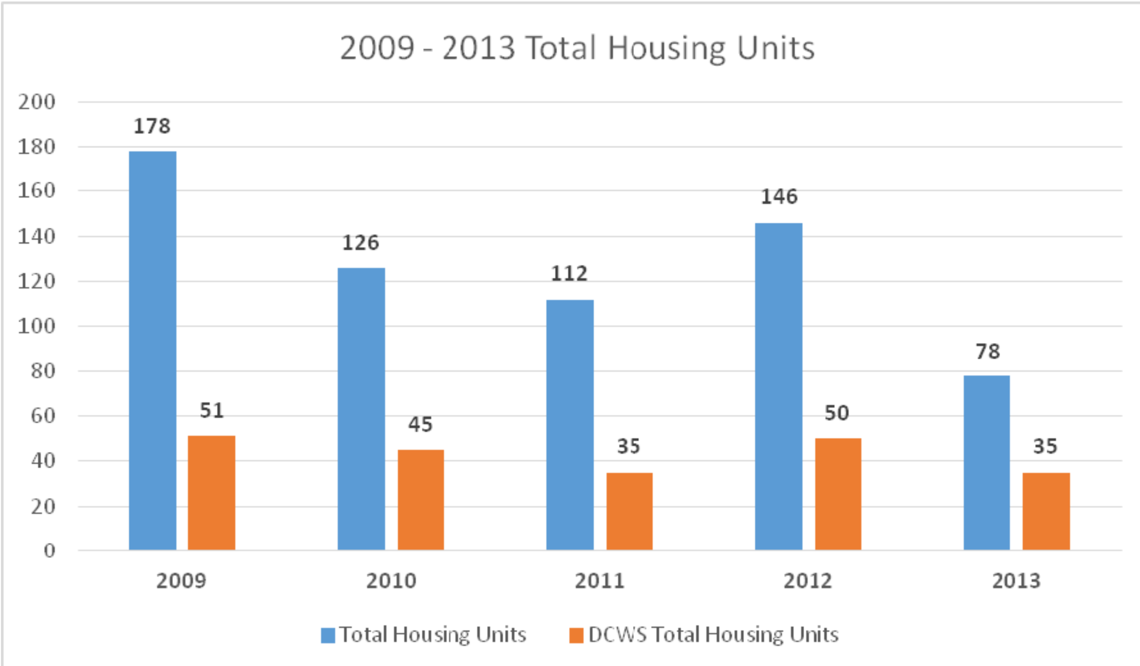


Figure 5

In addition the Sustainable Growth & Agricultural Preservation Act of 2012, has significantly changed the picture of future growth in Garrett County. This Act required the county to designate all areas of the county as tiers 1, 2, 3 or 4. The purpose of these tiers was to identify where major residential subdivisions may be located and what type of sewerage system will serve them. The tiers can be classified as follows:

- Tier I – currently served by public sewerage systems
- Tier II – planned to be served by public sewerage systems (Garrett County has no such areas until the Water & Sewer Master Plan is approved). Major subdivisions in this area must connect to the public sewer system.
- Tier III – not planned to be served by public sewerage systems. Growth on septic systems can occur. Planning Commission must review and approve all proposed new major subdivisions via public hearing. Specifically the Commission will have to review them with respect to environmental impacts & adequate public facilities.
- Tier IV – planned for preservation and conservation or dominated by agriculture or forest. Major residential subdivisions (more than 7 lots) are prohibited.

As Garrett County has a limited amount of public sewer and is mostly dominated by agriculture and forest, much of the county's residential growth is now very limited. The tier designations within the Deep Creek watershed are shown in Figure 6.

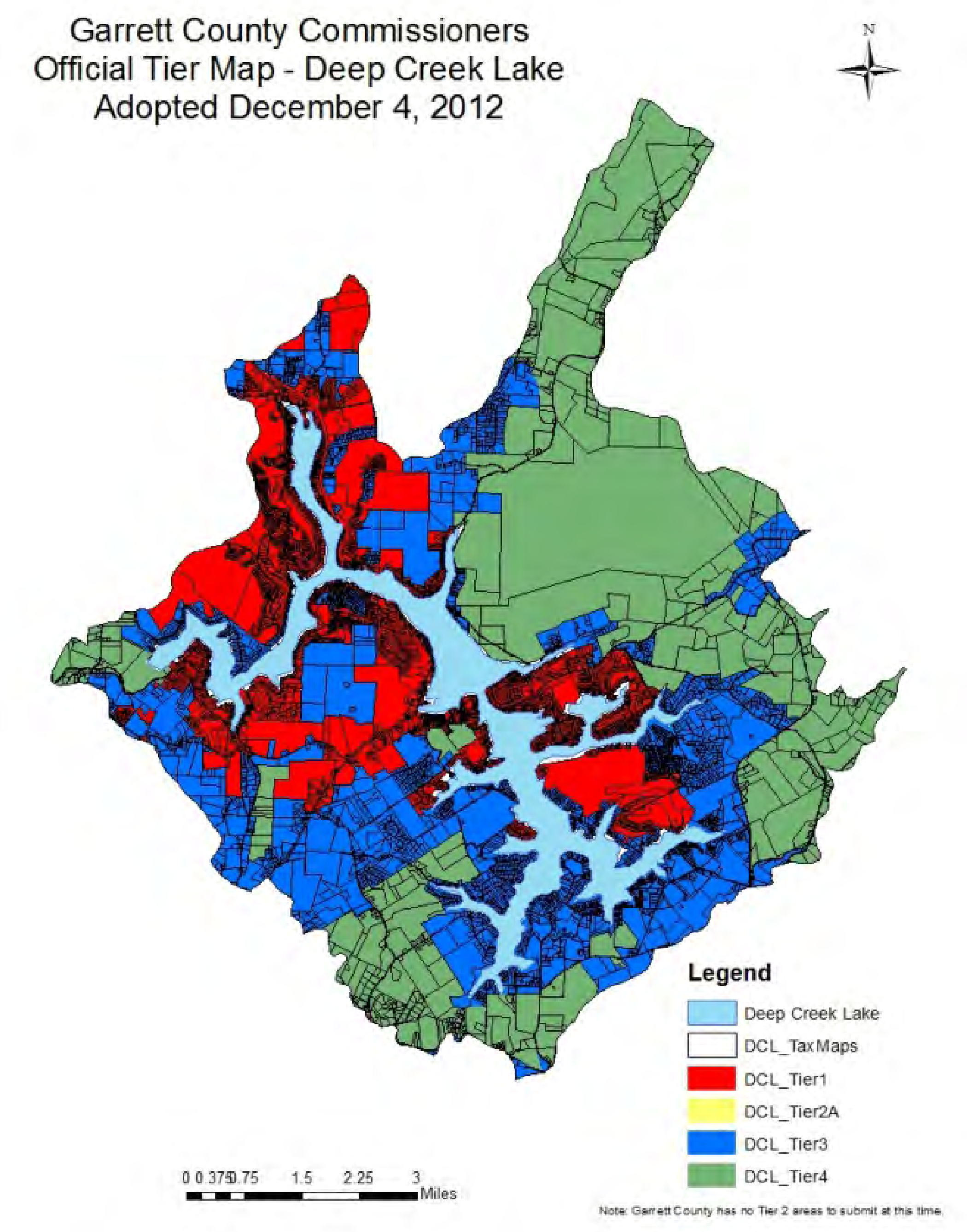


Figure 6

A development capacity analysis, sometimes also referred to as "build-out analysis" or "buildable lot inventory," is an estimate of the total amount of residential development that may be built in an area under a certain set of assumptions, including applicable land-use laws, policies (e.g., zoning) and environmental constraints. In April of 2014, the Maryland Department of Planning calculated Garrett County's development capacity numbers in an effort to incorporate the restrictions imposed by the regulations in the Sustainable Growth & Agricultural Preservation Act and their model indicates that the residential development potential for the county is estimated to have been cut by 56% for any area not within a PFA (see Figure 7).

Pre-Tier Map

PFA	New Household Capacity
Inside	5,203
Outside	95,609

Reflects Adopted Growth Tier Map

PFA	New Household Capacity
Inside	5,203
Outside	42,149

Figure 7

By necessity future residential growth in the watershed will be limited in all areas designated as tier 4. Tier 3 areas allow major subdivisions but the process for approval of the subdivision will be more complex and lengthy. This fact may limit the number of subdivisions as well. Tier 2 areas will be designated after the County's latest Water & Sewer Master Plan is adopted (anticipated in 2014). Tier 1 & 2 areas are the areas with the possibility of major residential subdivisions by right because they have or have planned public sewer service.
The Garrett County Department of Community Planning and Development, Office of Planning and Land Management will be initiating the Comprehensive Plan updating process during Fiscal Year 2016. This process will develop the policies by which future growth is guided and directed. During that process the recommendations found in the Deep Creek Watershed Plan will be re-visited for inclusion in the document.

Geology, Hydrology and Soils

GEOLOGY

The Deep Creek Lake watershed is located within the Appalachian Plateaus Physiographic Province of Maryland (Edwards, 1981). The bedrock at the surface in this region consists principally of gently folded sedimentary rock comprised primarily of shale, siltstone, sandstone, and conglomerates with more localized occurrences of coal and limestone. Most of these strata are of non-marine origin, but some of the older rocks are marine. Tectonic folding of the rock layers was produced during the formation of the Appalachian Mountains. These folds consist of elongated arches, or anticlines and synclines, trending NE to SW across the area. The oldest rocks exposed are Devonian and Mississippian in age and are found in the upwarped, anticlinal areas in the southeast. The synclinal basins in the northwest contain younger, coal-bearing strata of Pennsylvanian and Permian ages. In the Deep Creek area these two regions are approximately divided by the Hammel Glade – Meadow Mountain Run lowlands southeast of Thayerville.

These geologic features partition the Deep Creek watershed into two distinct sediment sources: the dissected uplands northwest of Thayerville and the rolling hills and glades to the southeast. Each of the two regions supply distinct sediment types to the Deep Creek Basin, due to combinations of differing source rocks and topographic influences on sediment transport to the basin.

The northwest half of the watershed is located on a broad syncline, called the Casselman Basin. The topography of this region is characterized by steep slopes, small drainage basins, and a thin soil profile. Figure 8 shows the geologic formations of the Deep Creek watershed. The rocks exposed here are composed of Mississippian brown to tan colored sandstones and reddish to gray shales of Mississippian Mauch Chunk Formation and those of the Pennsylvanian Pottsville Formation to Conemaugh Group. Underlying the State Park and immediate areas of the lake is an interval 200 to 300 feet thick composed primarily of limestone. This interval is known as the Greenbrier Formation. The Greenbrier Formation contributes calcium carbonate to the water which may buffer the lake from acidic runoff from coal deposits of Pennsylvanian age, located farther to the northwest. The Cherry Branch tributary drains the coal bearing formations and Pleistocene peat bogs, and is thought to contribute significant acidity to the lake (MDE, 2002). The combination of geology and topography in this region results in the creation of fine grained sediment. However due to the steeper slopes and smaller watersheds, this material is typically moved through the landscape to stream valleys and the lake. Steep slopes also allow the transport of coarser-grained material more readily than more gently-sloping areas to the southeast.

The southeastern half of the watershed lies within the Deer Park Anticline, which is composed of Mississippian conglomerates, sandstones and shales of the Purslane Formation; brown colored sandstones and shales of the Rockwell Formation (350 million years old). Devonian rocks occur further southeast in the Deer Park

Anticline, including red to reddish brown sandstones and shales of the Hampshire Formation (365 million years old); and the Foreknobs Formation, comprised of predominately greeninsh gray greywacke, siltstone, shale, sandstones and conglomerates. Unlike the northern half of the watershed which contains steep sandstone ridges, the topography in this southeastern half of the watershed lies upon more easily eroded rocks within the Deer Park anticline resulting in a flatter and gentler topography. The rocks in this region weather to sands and fine-grained material. The lower relief and basin-like topography of this region prevents the removal of fine-grained sediments, and for millions of years has allowed the development of thicker soils.

The recent drowning of these historical valleys by the reservoir has changed the weathering and geologic processes affecting the surficial geology. The construction of Deep Creek Lake has submerged the previously formed valley soils, and it allows them to be reworked by different geologic processes than they have been exposed to for millions of years. This is particularly evident in the southeastern half of the watershed where the deposited fine-grained soils covered a broad, low-energy valley.

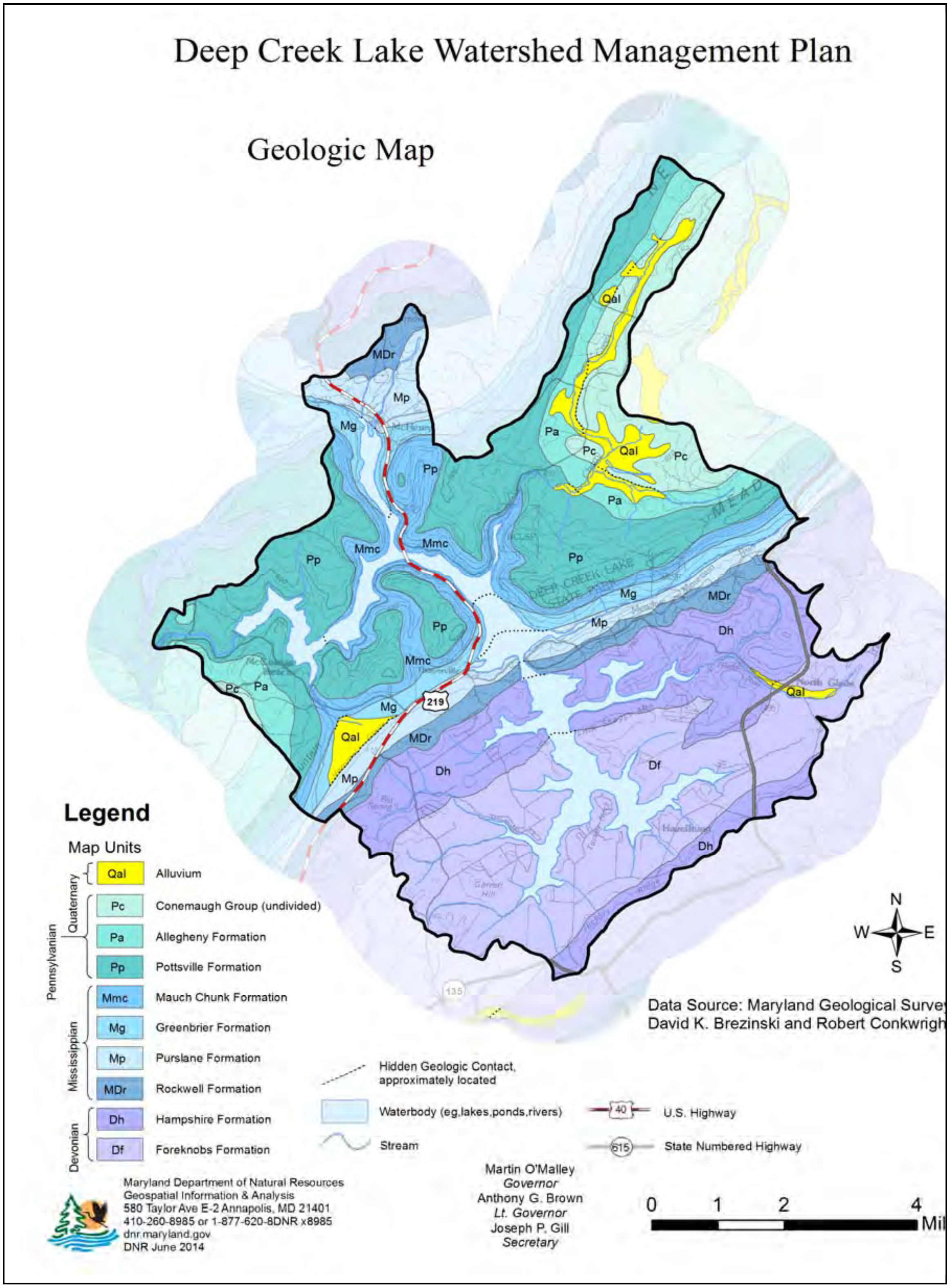

Deep Creek Lake Watershed Management Plan
Geologic Map
Legend
Map Units
Quaternary
Pennsylvanian
Mississippian
Devonian
Qal Alluvium
Pc Conemaugh Group (undivided)
Pa Allegheny Formation
Pp Pottsville Formation
Mmc Mauch Chunk Formation
Mg Greenbrier Formation
Mp Purslane Formation
MDr Rockwell Formation
Dh Hampshire Formation
Df Foreknobs Formation
Hidden Geologic Contact, approximately located
Waterbody (eg,lakes,ponds,rivers)
Stream
U.S. Highway
State Numbered Highway
Data Source: Maryland Geological Survey
David K. Brezinski and Robert Conkwright
Maryland Department of Natural Resources
Geospatial Information & Analysis
580 Taylor Ave E-2 Annapolis, MD 21401
410-260-8985 or 1-877-620-8DNR x8985
dnr.maryland.gov
DNR June 2014
Martin O'Malley
Governor
Anthony G. Brown
Lt. Governor
Joseph P. Gill
Secretary
0 1 2 4 Miles
N
S
E
W

Figure 8

SOILS

Soils in the watershed are similarly divided between the northern and southern halves of the watershed. The general soils map is shown in Figure 9. Soils are generalized and classified with hydrologic soil groups (HSG) ranging from “A” to “D” where “A” soils are well drained with high infiltration rates and a low level of runoff; “D” soils are typically clay soils which are poorly drained with very low infiltration rates and demonstrate the highest amount of runoff. “B” and “C” soils grade between the “A” and “D” classes. The majority of the Deep Creek watershed is “C” soils with bands of “B” soils throughout. The northern half of the watershed has a very low amount of “D” soils (<1%); however, the southern half of the lake grades to a higher proportion of “D” soils (5%-19%). (NRCS, 1976).

As previously discussed, these soils are generated by the weathering erosion of the geologic layers immediately below the land surface. Low lying areas also become depositional areas for the soils eroded within their drainage basin. Throughout the watershed, the majority of the rock layers contain abundant clays that weather to a fine-grained material. Sandstone ridges such as Meadow Mountain are underlain by resistant sandstones and, as such, produce a decreased amount of coarser-grained material. This explains the predominate HSG classification of “C” throughout the watershed. The increased amount of “D” soils in the southern half of the watershed is due to the depositional nature of broad valleys. The coarser grained material is not mobilized in the lower energy environment of the low, rolling hills and the finer grained material is eroded but then deposited in the lower energy areas of the broad valleys.

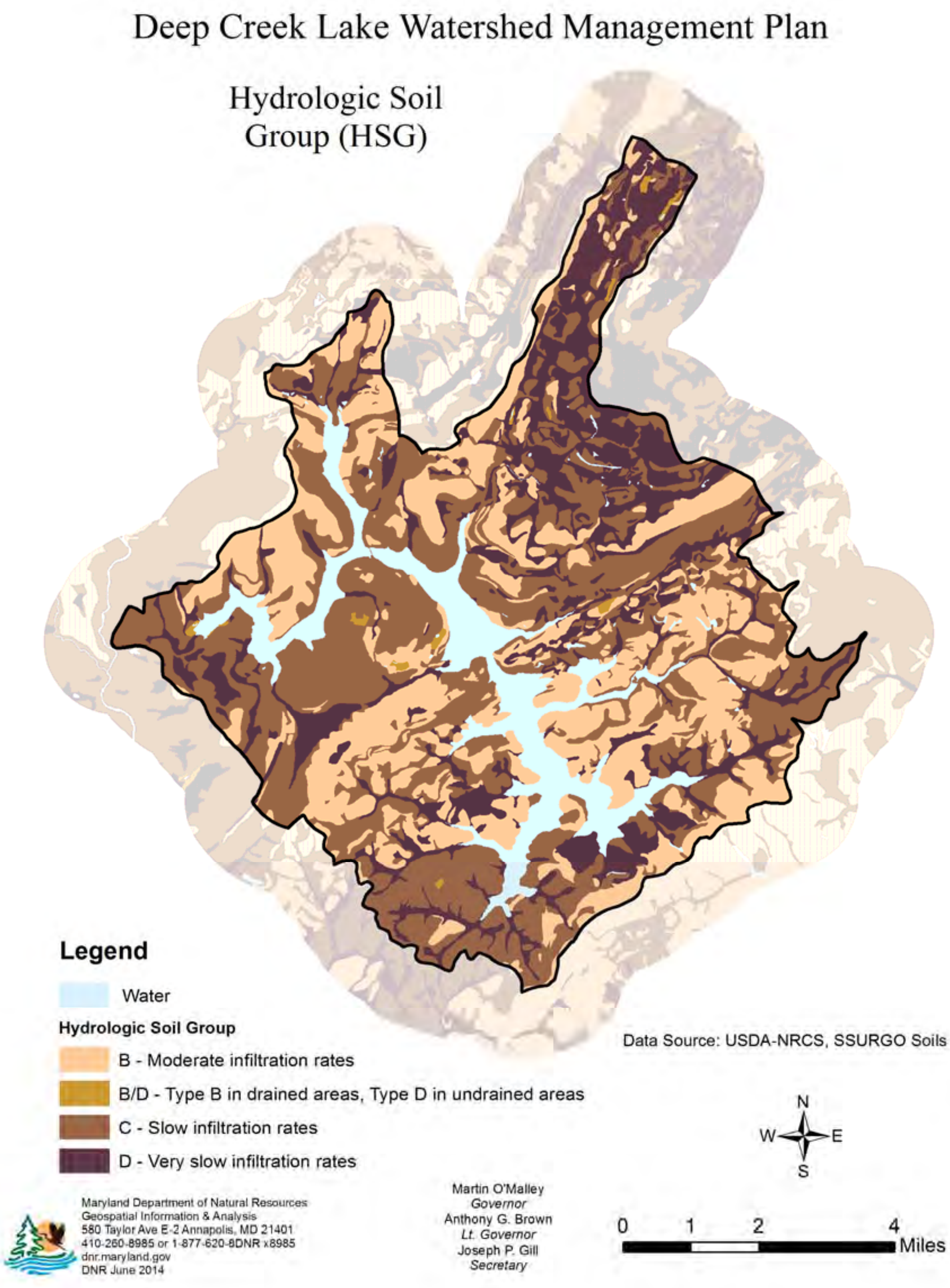

Deep Creek Lake Watershed Management Plan
Hydrologic Soil Group (HSG)
Legend
Water
Hydrologic Soil Group
B - Moderate infiltration rates
B/D - Type B in drained areas, Type D in undrained areas
C - Slow infiltration rates
D - Very slow infiltration rates
Data Source: USDA-NRCS, SSURGO Soils
N
W
E
S
0
1
2
4
Miles
Maryland Department of Natural Resources
Geospatial Information & Analysis
580 Taylor Ave E-2 Annapolis, MD 21401
410-260-8985 or 1-877-620-8DNR x8985
dnr.maryland.gov
DNR June 2014
Martin O'Malley
Governor
Anthony G. Brown
Lt. Governor
Joseph P. Gill
Secretary

Figure 9

Stream Water Quality and Habitat Condition

This section of the Deep Creek watershed management plan provides detailed information on the streams including: the importance of and statistics on the streams, historic and current studies conducted in the watershed, historic and current conditions of streams, threats and stressors adversely impacting the streams. Recommended management actions to protect and restore these important aquatic resources can be found in the appendices to this report.

BENEFITS PROVIDED BY STREAMS

Streams, also referred to as lotic systems (lotic means flowing water), are an important component of landscapes and one of our most important natural resources. Streams provide numerous benefits to humans, including clean drinking water, reduction of flooding and erosion to downstream areas, groundwater recharge (to shallow and deep aquifers), pollution reduction (e.g., uptake of nutrients), and are economically important for manufacturing, recreational, and agricultural activities. Streams are also complex ecosystems, providing unique and diverse habitats that are utilized by a plethora of flora and fauna. Streams provide habitat for fishes, herpetofauna, freshwater mussels, benthic macroinvertebrates, crayfish, and other plant and animal life. For more information on the stream types and their associated benefits, please visit **http://water.epa.gov/type/rsl/streams.cfm**.

STREAM STATISTICS

The DCL watershed is 41,435 acres in size and located in the Youghiogheny River Basin (which is part of the Mississippi River Drainage). The watershed is one of 137, "8-digit" watersheds in Maryland defined by the Maryland Department of Natural Resources (DNR). The DCL watershed is further divided into 3, "12-digit" subwatersheds. Based on the United States Geological Survey's (USGS) National Hydrography Dataset (NHD: 1:24,000 scale), there are 49.4 miles of streams within the DCL watershed, some of which have been assigned a name (Figure 1). There are approximately 35.1 miles of headwater streams (also referred to as first order streams), 11.8 miles of second order streams (form when two first order streams converge), and 2.5 miles of third order streams (form when two second order streams converge) (Table 1). For more information on the USGS National Hydrography Dataset, please visit http://nhd.usgs.gov/.

The USGS StreamStats Program is a web-based Geographic Information System (developed through a cooperative effort of the USGS and ESRI, Inc.) that generates streamflow statistics and drainage basin characteristics for all streams in Maryland. By utilizing this tool, it was determined that 67 streams flow into DCL. Of the 67 streams, 20 contribute approximately 77% of the surface flow to DCL, while 7 streams contribute approximately half. The largest contributor of surface flow to DCL is Cherry Creek at 18% (Table 2). For more information on the USGS StreamStats Program, visit http://water.usgs.gov/osw/streamstats/maryland.html.

Deep Creek Lake (Total)	1st Order	2nd Order	3rd Order	Total Miles
Miles	35.1	11.8	2.5	49.4
Percent of Total	71.1%	23.9%	5.0%	
12-digit Watersheds				
DCL South (0027)	1st Order	2nd Order	3rd Order	Total Stream Miles
Miles	16.4	5.2	0	21.6
Percent of Total	75.9%	24.1%	0%	
DCL North (0028)	1st Order	2nd Order	3rd Order	Total Stream Miles
Miles	11.7	2.9	0	14.6
Percent of Total	80.1%	19.9%	0%	
Cherry Creek (0029)	1st Order	2nd Order	3rd Order	Total Stream Miles
Miles	7.0	3.7	2.5	13.2
Percent of Total	53.0%	28.0%	18.9%	

Table 1. Deep Creek Lake stream miles by watershed, sub-watershed and stream order.

Stream Name	PK2 (cfs)	% Total	% Total
Shingle Camp Hollow	32.6	1.6	
Unnamed Tributary 6, East of Brenneman Lane	33.1	1.6	
Poland Run	34	1.7	
Unnamed Tributary 40 crossing Steiding Church Road	35.4	1.7	
Unnamed Tributary - North Glade Cove	34.6	1.7	
Unnamed Tributary 43, east of Pine Tree Point Road	37.3	1.8	
Hoop Pole Run	37.4	1.8	
Unnamed Tributary 3 west of Mosser Hollow Drive	44.1	2.1	
Unnamed Tributary 39 crossing Ardsley Farm Road	45.8	2.2	
Gravelly Run	46.6	2.3	
Smith Run	48.5	2.4	
Unnamed Tributary 36, North of Garrett Hill	63	3.1	
Deep Creek	67.3	3.3	
Unnamed Tributary 29 crossing Glendale Road	69.4	3.4	3.4
Green Glade Run	74.5	3.6	3.6
Pawn Run	93.2	4.5	4.5
Red Run	136	6.6	6.6
North Glade Run	139	6.8	6.8
Meadow Mountain Run	142	6.9	6.9
Cherry Creek	369	17.9	17.9
PK2 = maximum instantaneous flow that occurs on average once in 2 years		**76.9**	**49.7**

Table 2. USGS StreamStats results for major (top 20) Deep Creek Lake tributary streams (cfs - cubic feet per second).

WATER QUALITY STANDARDS

Maryland's water quality standards (designed to protect, maintain and improve the quality of Maryland's surface waters) are the Maryland Department of the Environment's (MDE) responsibility and consist of three specific components: designated uses, water quality criteria to protect the designated use, and the antidegradation policy. Information can be found at http://www.mde.state.md.us/programs/Water/TMDL/Water%20Quality%20Standards/Pages/Programs/WaterPrograms/TMDL/wqstandards/index.aspx.

All streams within the DCL watershed are designated use III-P (i.e., non-tidal coldwater and public water supply). The selected uses for Use III-P waters include: growth and propagation of fish (including trout), other aquatic life and wildlife, leisure activities involving direct contact, fishing, and agricultural, industrial, and public water supply. There are specific numeric and narrative water quality criteria (component two of the water quality standards) that are designed to protect Use III-P waters. A subset of the criteria follow and will be utilized/referenced in the water quality portion of this stream section. For Use III-P waters, the dissolved oxygen concentration cannot be less than 5 mg/L at any time with a minimum daily average of ≥ 6.0 mg/L; temperature may not exceed 68°F (20°C) outside of the mixing zone, and turbidity may not exceed 150 Nephelometric Turbidity Units (NTUs) at any time or 50 NTUs as a monthly average. Regarding the Antidegradation policy of the Clean Water Act, there are currently no Tier II (i.e, High Quality Waters) or Tier III (Outstanding National Resource Waters) waters in the DCL watershed. Additional monitoring could identify candidate Tier II or Tier III waters. Statewide, there are approximately 250 stream segments designated by MDE as Tier II waters (data support provided by DNR). No surface waters in Maryland are currently designated Tier III.

Land use, current and past, differs among the three subwatersheds that make up the DCL watershed. DCL North (Figure 2a) is the most developed subwatershed, with 27.5% urban land use in 2010----a 3+ fold increase since 1973. With only a small amount of agricultural land, development in DCL North has come at the expense of forest lands---a decrease from 80.4% to 65.5% between 1973 and 2010. By comparison, DCL South (Figure 2b) had (in 1973) and still had in 2010 the most agricultural land---42.6% and 33.2% respectively. Urban land use in DCL South increased almost 4 fold in the 37 years between 1973 and 2010, at the expense of both forested and agricultural lands. Of the three subwatersheds, Cherry Creek was and still is the most heavily forested and the least developed (Figure 2c). Interestingly, agricultural land use increased from 16.6% in 1973 to 23.8% in 2010 in the Cherry Creek subwatershed.

STUDIES, REPORTS AND DATA SETS ASSOCIATED WITH TRIBUTARIES TO DEEP CREEK LAKE

DNR staff conducted an exhaustive search to determine what data have been (or are being) collected from DCL streams and any associated reports. Table 3 provides a general summary of what agency/individuals conducted (or are conducting) work in DCL streams, the time period covered, if and when a report was published, and what data were (or are being) collected or utilized (Appendix A provides a detailed description of each – the numbers in Table 3 (column 1) correspond to the numbers in Appendix A). The rows in Table 3 that are shaded yellow were used to determine the historic (prior to 2000) conditions of streams in the DCL watershed. The rows in Table 3 that are shaded light green were utilized to determine current conditions of DCL streams, including water quality, physical habitat, aquatic life, and stream health. Rows that are not shaded were not used to describe historic or current conditions but are listed in Table 3 for completeness of reporting.

			Data Collected or Utilized			
Agency/Researcher	**Data Collection Time Period**	**Report (Y/N)**	**Biota**	**Water Chemistry**	**Habitat**	**Other**
1. Skelly and Loy	Late 60s/early 70s	Yes - 1973	X	X		
2. DNR	Early 70s	Yes - 1974				X
3. Ferrier et al.	1980 - 1984	Yes (1980-84)		X	X	
4. Pavol	1985	Yes - 1985	X			
5. Knapp et al. – MSSCS*	1987	Yes - 1988		X		
6. MDE/BOM	1971 - 1994	Yes - 1994		X		
7. Pavol et al.	1996	Yes - 1997	X			
8. Morgan et al.	1997 - 1998	Yes - 2000	X	X	X	
9. MDE and DNR: RBP	1989 - 1996	Yes - 1997	X			
10. MDE/BOM	Existing Data Used	Yes - 2001				
11. MDE/SSA	2000 – 2008	No		X		
12. MDE/BOM	2000-2012	No		X		
13. MDE	Existing Data Used	Yes - 2003				
14. DNR – Fisheries Serv.	2004	Yes - 2004	X	X		
15. MDE	Existing Data Used	Yes - 2012				
16. DNR – Poland Run	2009 – 2012	No		X	X	
17. DNR – MSSCS*	2012	Yes - 2013		X		
18. DNR – DCL Office	2011 – 2012	Yes - 2012	X			
19. DNR – Core/Trend	Mid 1970s - present	Yes - 2009	X	X		
20. DNR – MBSS*	1995 - present	No	X	X	X	X
21. DNR – Stream Waders	2000 - present	No	X			
22. DNR – MMC*	2012 – present	No	X	X		

Table 3. Historic and current studies/monitoring programs conducted in streams in the Deep Creek Lake watershed. Data collected may include biota (fish, benthic macroinvertebrates, and other animal groups), water chemistry (e.g., nutrients, metals), habitat, and others (e.g., land use).

*MSSCS = Maryland Synoptic Stream Chemistry Survey; MDE/BOM = Maryland Department of the Environment, Bureau of Mines; MDE/SSA = Maryland Department of the Environment, Science Services Administration; MBSS = Maryland Biological Stream Survey; MMC = Marcellus Shale Stream Monitoring Coalition

HISTORIC (PRIOR TO 2000) CONDITIONS OF STREAMS IN THE DEEP CREEK LAKE WATERSHED

Of the 67 streams that flow into DCL (some only intermittently), only a few were sampled prior to 2000 to assess their ecological condition. Because of a long history of coal mining and associated degradation of stream health caused by several sources of acid mine drainage (AMD), Cherry Creek has been studied the most and the longest. A 1974 DNR report concluded that Cherry Creek is polluted only by AMD, and the subwatershed was therefore assigned the highest priority for AMD remediation. The DNR report estimated that Cherry Creek was contributing 2,270 pounds of acid/day to DCL, and that 27% of this acidity was coming from coal mines, while the remaining 73%

was coming from natural and non-mining related sources. Although not mentioned, presumably one of the non-mining sources was atmospheric deposition (or ‘acid rain’ as it is more commonly called).

CURRENT (2000 TO PRESENT) CONDITIONS OF STREAMS IN THE DEEP CREEK LAKE WATERSHED

Figure 10 provides a map of sites (with associated sampling programs) that were used to determine current conditions (2000-present) of DCL streams, including water quality, physical habitat, aquatic life, and stream health.

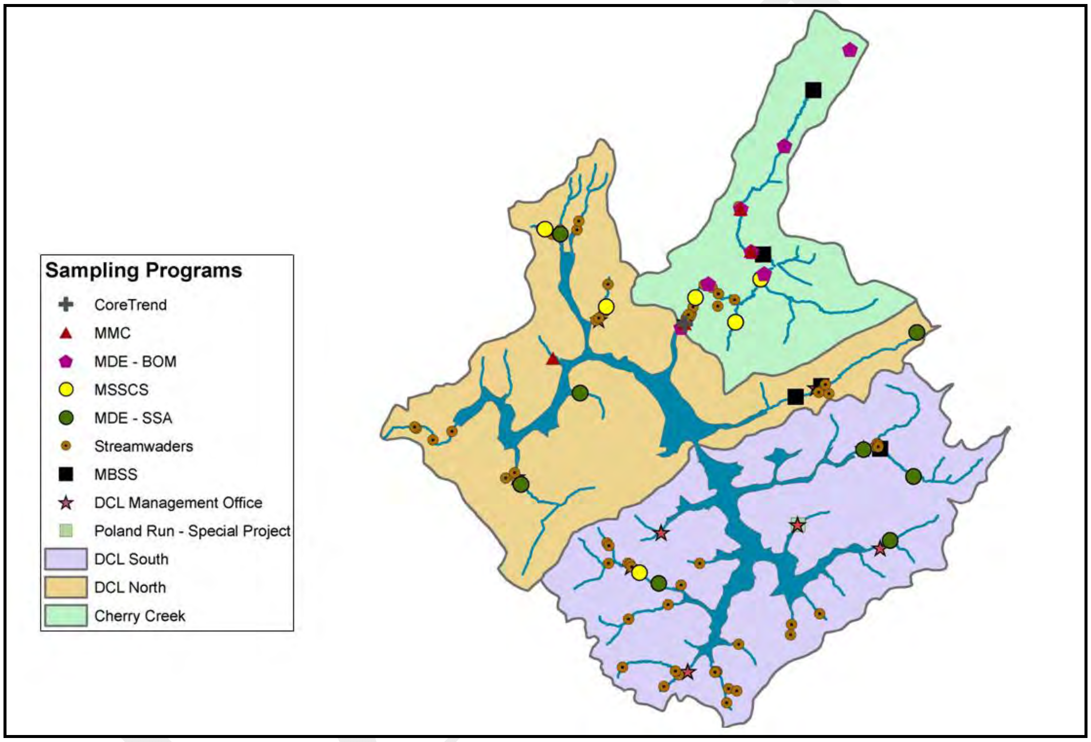


Figure 10. Stream sampling programs in the DCL watershed, 2000-2013.

Water Quality

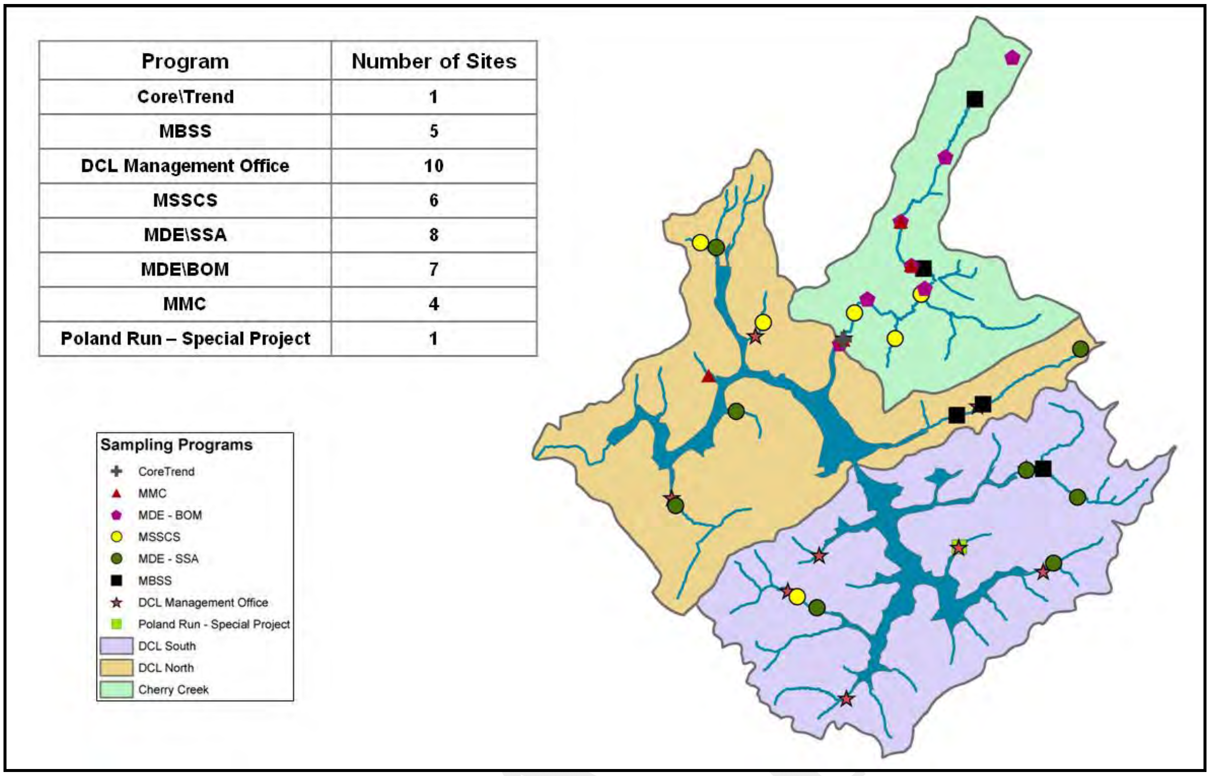
Water chemistry data from all available sources were combined to evaluate water quality conditions in streams throughout the DCL watershed. Datasets included Core/Trend, MBSS, DCL Office, MSSCS, MDE/SSA, MDE/BOM, MMC, and the Poland Run Special Project (Figure 11). It is important to note that some sites (e.g., the Core/Trend site in Cherry Creek) were sampled repeatedly. The parameters discussed in this section were consistent among the various programs and considered most useful to determine current stream conditions in the DCL watershed.

Acidity and Buffering Capacity

The average pH (field-measured) among all samples (300) was 6.7 – weakly acidic. The maximum pH was 8.8 (basic) and the minimum was 3.5 (strongly acidic). The lowest and highest pH readings were taken in Cherry Creek – likely due to AMD (low pH) and concomitant mitigation efforts (high pH from liming). Maryland water quality criteria for pH range from 6.5 to 8.5 for Use III-P waters – most measurements in DCL watershed streams fall within this range. Cherry Creek is experiencing pH measurements (particularly low values) that violate the State water quality criteria for pH.

Acid Neutralizing Capacity (ANC) ranged from -68 µeq/L (Cherry Creek) to 580 µeq/L (Marsh Run), with an average of 154 µeq/L. Values ranged widely throughout the watershed. There are no Maryland water quality criteria for ANC, but waters with ANC values < 0 µeq/L are acidic, values of 0 – 50 µeq/L are highly sensitive to acidification, waters with ANC ranging from 50-200 µeq/L are considered sensitive to acidification and waters with values > 200 µeq/L are not sensitive to acidification. Only 10 samples were used for ANC reporting because most of the sampling programs included did not measure ANC.

Sulfate concentrations averaged 43 mg/L among 552 samples. Minimum and maximum concentrations were 2 mg/L and 205 mg/L, respectively. The highest sulfate concentrations occurred in Cherry Creek and were associated with AMD. There are no Maryland surface water quality criteria for sulfate.



Program	Number of Sites
Core\Trend	1
MBSS	5
DCL Management Office	10
MSSCS	6
MDE\SSA	8
MDE\BOM	7
MMC	4
Poland Run – Special Project	1

Figure 11. Water chemistry monitoring locations in the DCL watershed by sampling program (2000-2013).

Nutrients (Total Nitrogen and Total Phosphorus)

Total nitrogen concentrations ranged from 0.1 to 2.0 mg/L, with an average of 0.6 mg/L. Although Maryland’s water quality standards do not include a total nitrogen criterion for free flowing streams, concentrations less than 1.5 mg/L are considered low (see **http://www.dnr.state.md.us/streams/pdfs/ea-05-11_stressors.pdf**; page 14-29). Only 13 of the 404 samples (~3%) had total nitrogen concentrations above 1.5 mg/L.

Four hundred three samples were analyzed for total phosphorus. The mean concentration was 0.02 mg/L, with a range of 0.004 mg/L to 0.33 mg/L. Total phosphorus concentrations below 0.025 mg/L are considered low while those between 0.025 and 0.07 mg/L are considered moderate. Maryland’s water quality standards lack total phosphorus criterion for free flowing streams.

Dissolved Oxygen

Dissolved oxygen (DO) ranged from 3.4 mg/L to 13.6 mg/L (average 9.9 mg/L) among the 399 field measurements. The Maryland water quality criterion for DO 5.0 mg/L (with a minimum daily average ≥ 6.0 mg/L). There were three occurrences of low DO – two in Green Glade Run and one in Cherry Creek. Most DO readings were within the expected range.

Conductivity

Six hundred seventy-five samples were analyzed for conductivity and values ranged from 28 to 346 micromhos/cm. The highest conductivity values were found in Cherry Creek – likely the result of AMD or the addition of buffering materials to the stream. Stream water conductivities above 300 micromhos/cm are considered elevated.

Water Quality Conclusion

Most water quality parameters fall within the expected ranges defined by the water quality criteria for Use III-P waters. Violations of the water quality criteria occur primarily in Cherry Creek due to the impacts associated with AMD. Based on the data analyzed by DNR for this streams report, no issues related to nutrient enrichment are apparent in DCL streams. This is a consistent with conclusions presented in a 2010 MDE report stating that streams in the DCL watershed do not display signs of eutrophication or nutrient over-enrichment. The MDE report can be viewed here:
http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/WQA_Deep_Creek_Nut_07292011_final.pdf

For more information on Cherry Creek, including AMD impacts, how Maryland has worked to mitigate these issues, and the water quality improvements observed, please see the following links:
http://www.mde.maryland.gov/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/Cherry%20Creek%20pHTMDL_final.pdf **and**
http://water.epa.gov/polwaste/nps/success319/upload/md_cherry-2.pdf
and 2013 summary by Joe Mills (MDE/BOM) in Appendix A.

Physical Habitat

Limited physical habitat data are available for five MBSS sites sampled in Cherry Creek (2 sites), Meadow Mountain Run (2 sites), and North Glade Run (1 site) from 2004 – 2009. Two parameters most important to fish and benthic macroinvertebrate communities – Instream Habitat and Epifaunal Substrate – were rated primarily as optimal, suboptimal, or marginal. Three of the five sites had Embeddedness ratings above 50%, suggesting elevated sedimentation. Four sites were moderately or poorly shaded, indicating the lack of a well-vegetated riparian buffer. For more information on the MBSS habitat assessment protocols, please see page 30 of the sampling manual found here:
http://www.dnr.state.md.us/irc/docs/00014977.pdf

Aquatic Life

Data from the MBSS, Stream Waders, DCL Office, DNR Fisheries Service, and DNR Core/Trend Program were used to compile an aquatic life inventory for sites sampled from 2000 – 2013. A detailed accounting of aquatic fauna detected in the DCL watershed can be found in Appendix B.

Fish data sources were the MBSS and DNR Fisheries Service. Twenty-one species of fish were found in DCL streams and in the lake itself. This report includes lake fish since all species observed could inhabit free-flowing streams that feed the lake. The sunfish family was most diverse (6 species), followed by three perch species, three minnow species, three trout species, and three species in the pickerel family. Two species of catfish and one species of sucker were observed. Maryland's only native trout – the brook trout – was observed, along with introduced brown and rainbow trout. The brook trout is on Maryland's "watch list" as is the Johnny darter (also detected in DCL streams). Among all 21 fish species, 6 are introduced (the two trout, chain and redfin pickerel, northern pike, and common carp). Thirteen of the 21 species are considered non-game fishes. In comparison, the Youghiogheny River watershed contains 38 fish species based on MBSS data collected from streams and rivers throughout this much larger watershed.

Ten species of amphibians were found among the five MBSS sites. Salamanders included the eastern red-back, long-tailed, northern dusky, northern two-lined, and seal salamander. The four species of frogs and toads included the American bullfrog, northern green frog, northern spring peeper, and the eastern American toad. No lizards or turtles were observed. As a comparison, 29 species of reptiles and amphibians have been observed in the Youghiogheny River Watershed. No listed species (rare, threatened, or endangered) were observed in DCL stream sites.

Four programs sampled benthic macroinverbrates in DCL streams – MBSS, Stream Waders, DCL Lake Management Office and CORE/Trend. A total of 237 genera (149 families, 23 orders) were sampled among the four programs. Diptera (true flies) was the most diverse order (52 genera), followed by Trichoptera (caddisflies; 23 genera), Ephemeroptera (mayflies; 17 genera), Plectoptera (stoneflies; 17 genera), and Coleoptera (beetles; 8 genera). No obligate coldwater benthic taxa (i.e., benthic macroinvertebrate taxa associated with Maryland's coldest streams) were observed in DCL streams nor were any freshwater mussels. As a comparison, the MBSS has identified 478 benthic macroinvertebrate genera from statewide sampling.

Among the benthic macroinvertebrates, crayfish are of special concern due to the spreading of introduced species and competition with native species. Six crayfish species were observed in DCL streams – Allegheny crayfish, rock crayfish, upland burrowing crayfish, virile crayfish, White River crayfish, and little brown mudbug. The latter three species are introduced.

Stream Health

The numbers and types of fish, stream insects, and other types of invertebrates are used by DNR as one indication of stream health. Stream health is tightly linked to physicochemical factors, representing the cumulative physical and chemical conditions of streams. Stream health information was gathered from MBSS fish (Fish Index of Biotic Integrity; FIBI) and benthic macroinvertebrate (Benthic Index of Biotic Integrity, BIBI) and Stream Waders benthic macroinvertebrate data (BIBI). For information on how Maryland's IBIs were developed, see **http://dnr.maryland.gov/streams/pdfs/ea-05-**

13_new_ibi.pdf. Twenty percent of all MBSS sites in the DCL watershed were rated Fair and the remainder rated Poor, based on the FIBI. It is important to note that the five MBSS sites were only in the eastern portion of the DCL watershed, and two of the five were in the Cherry Creek subwatershed. MBSS BIBI results yielded the same results as the FIBI (Figure 12). Twelve percent of all Stream Waders sites rated Good, 31% Fair, and 57% Poor. Stream Waders sites were scattered around the watershed fairly evenly and likely represent a good picture of the current health of streams in the DCL watershed, based on the benthic macroinvertebrate assemblages (Figure 13).

Figure 12. Deep Creek Lake MBSS site locations with benthic and fish IBI scores (2000-2013).

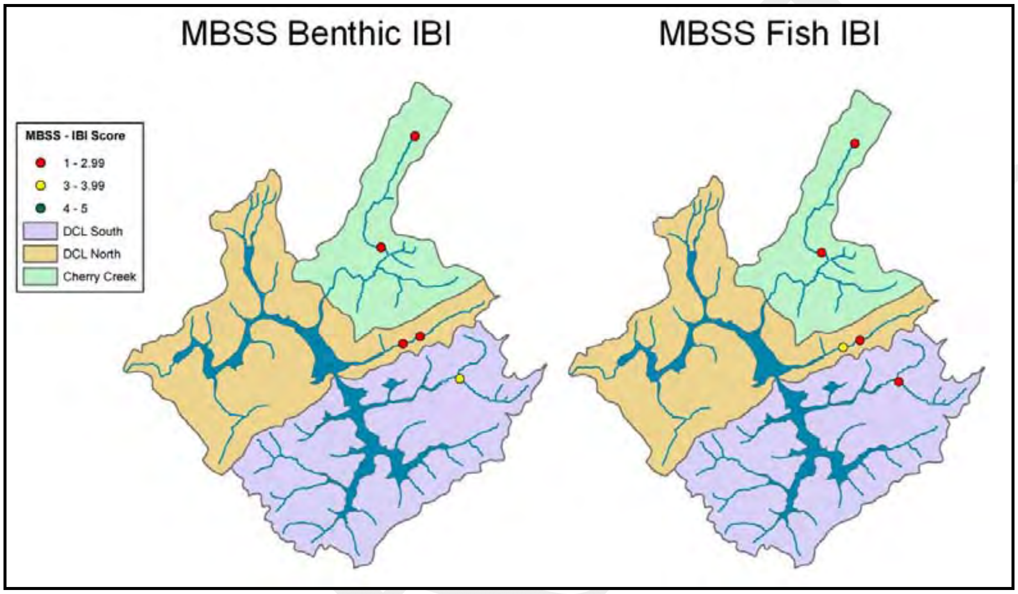
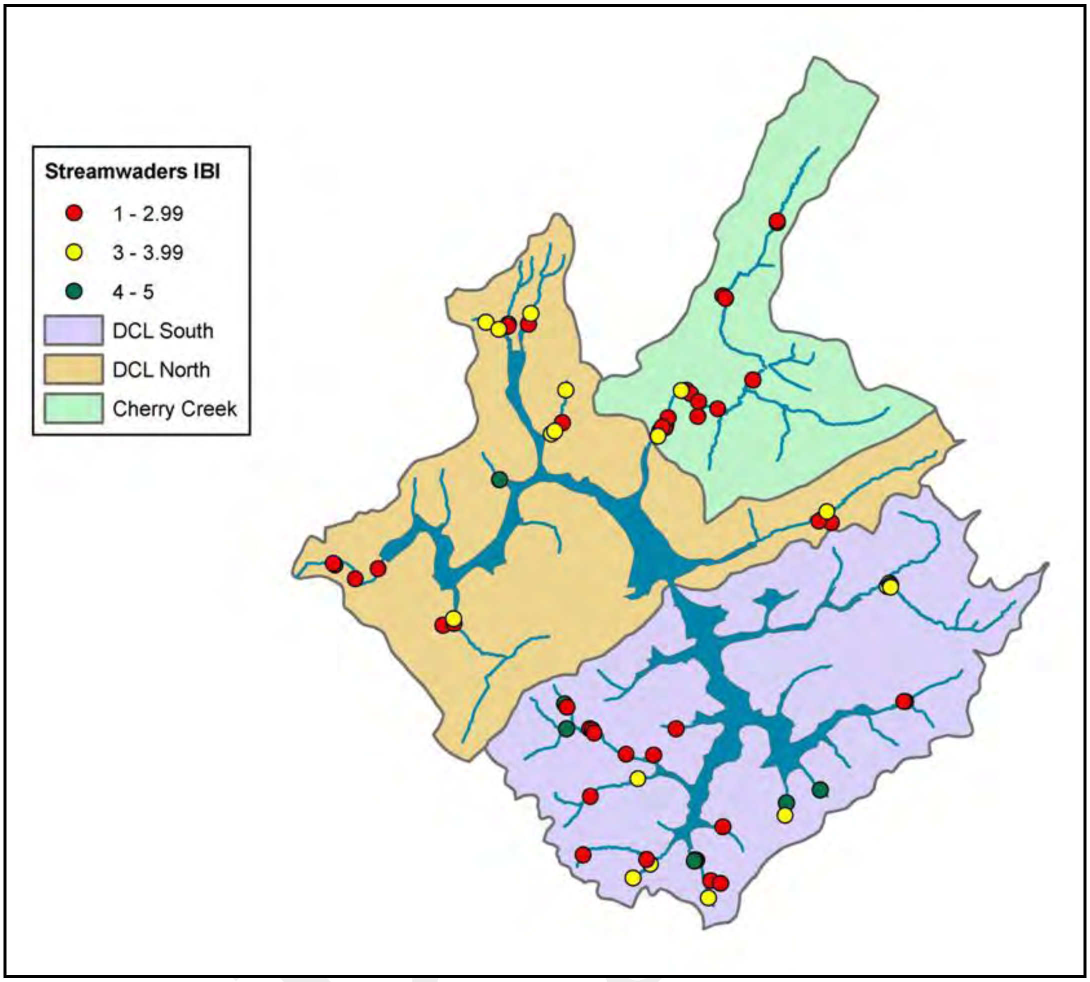


Figure 13. Deep Creek Lake Stream Waders (2000-2012) site locations and benthic IBI scores.



To compare DCL watershed stream health with that of nearby streams, MBSS and Stream Waders data were compiled for all sites sampled in Garrett County (2000 – 2013 samples). Fifty-five percent of the 203 MBSS sites were rated Good based on the FIBI scores and 14% were rated Fair. The remaining 31% were rated Poor. MBSS BIBI results for the County were similar, with 52%, 23%, and 25% of the sites rated Good, Fair, and Poor, respectively (Figure 14). Stream Waders results were comparable. Of the 486 volunteer sites sampled, 46% were rated Good, 28% were rated Fair, and 26% were rated Poor based on BIBI scores (Figure 15). Comparing county-wide sampling with DCL stream health indicates that the latter group of streams are degraded relative to most Garrett County streams.

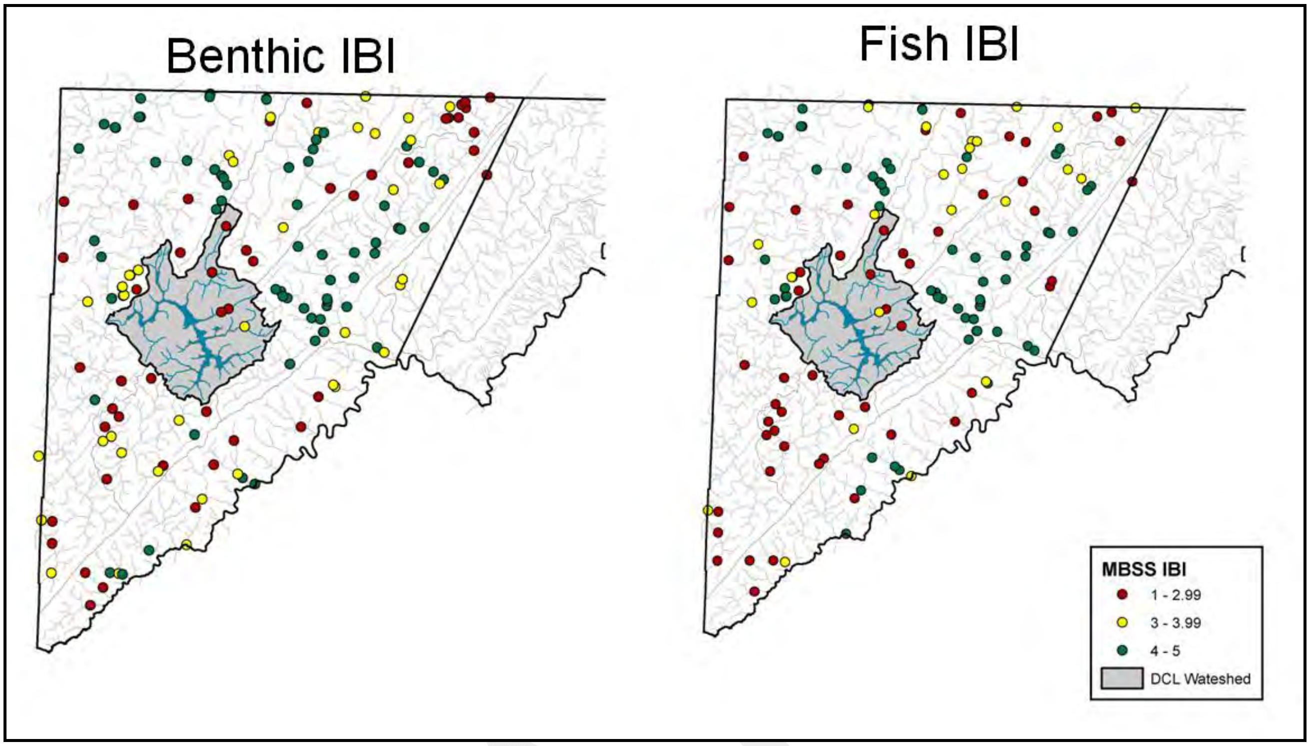


Figure 14. Garrett County MBSS site locations with benthic and fish IBI scores (2000-2013).

DRAFT

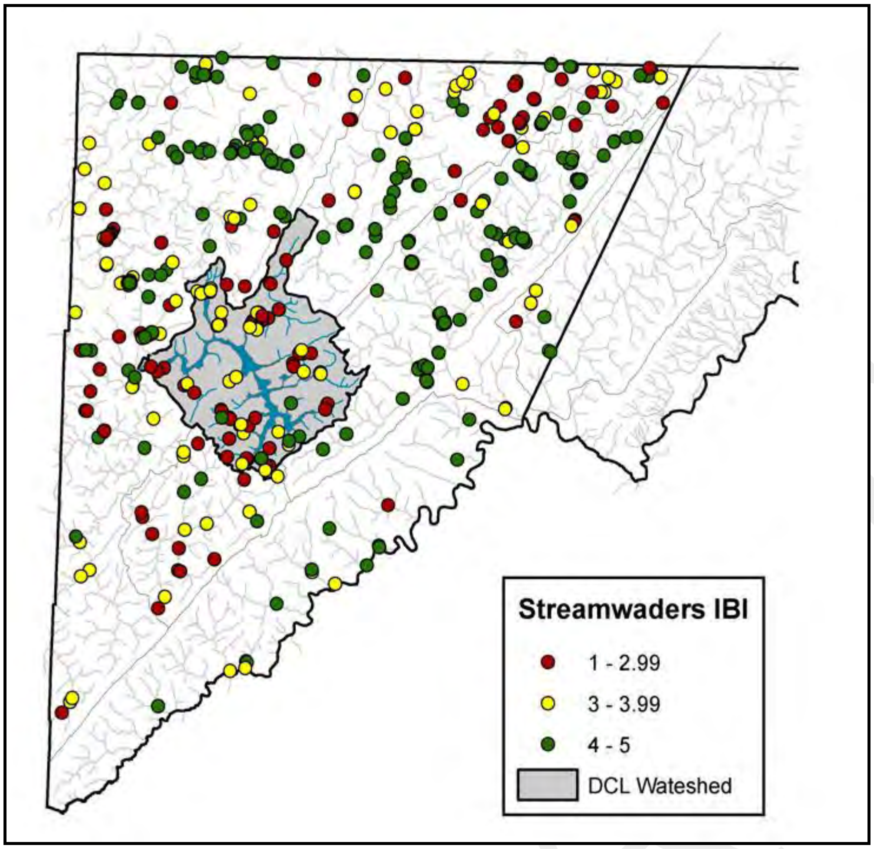


Figure 15. Garrett County stream waders sample locations and benthic IBI scores (2000-2012).

<u>Threats and Stressors to Streams in the Deep Creek Lake Watershed</u>

Human influences, through direct and indirect alterations to the land and water within a stream's watershed, impact hydrology, hydraulics, and physical and chemical conditions present in a stream. These changes can have direct deleterious impacts on stream biodiversity and ecological health.

Based on DNR's MBSS data, MDE placed the DCL watershed on Maryland's list of "Impaired" watersheds. Impaired watersheds are considered to be in need of restoration to improve their health. MDE, through the Biological Stressor Identification (BSID) effort, http://www.mde.state.md.us/programs/Water/TMDL/Pages/Programs/WaterPrograms/tmdl/bsid_studies.aspx, determines the relative likelihood of any particular stressor being the cause of degradation of streams in a watershed. MDE's BSID report for the DCL watershed can be found here: http://www.mde.state.md.us/programs/Water/TMDL/Documents/BSID_Reports/DeepCreek_BSID_Report_012412_revisedfinal.pdf. The BSID report concluded that the probable causes and sources of the biological impairment for streams in the DCL watershed include the following:

- Acidity is the cause for biological impairment in the Cherry Creek subwatershed, as indicated by low pH and low Acid Neutralizing Capacity (ANC);
- Biological impairment is likely also due to elevated sulfate concentrations. The presence of AMD is a potential source;
- Biological impairment is likely associated with stream morphology stressors, including,
    - High embeddedness scores
    - Poor epifaunal substrate
    - Poor instream habitat
    - Poor riffle/run quality

  that degrade stream habitat for aquatic biota;
- Large and small-scale human activities are likely to be amplifying the homogeneity of the physical habitat present in DCL watershed streams.

For Cherry Creek, abandoned coal mines have contributed to high levels of acidity and sulfate. As mentioned earlier, Maryland has exerted significant effort to address the AMD issue with some success. Stressors associated with stream morphology are primarily driven by sedimentation. However, the MDE report states that high sediment loads (via excessive erosion) are likely not the cause of sedimentation, but the presence of low gradient streams that do not transport the fine sediments downstream. Fine sediments can have drastic effects on stream habitat by filling in deep pools and the interstitial spaces in the substrate where stream-dwelling animals live. Sedimentation directly impacts the four physical habitat metrics identified above in bullet 3.

The MDE BSID report suggests that large and small-scale human activities are also impacting the physical habitat conditions (and therefore biological conditions) present in DCL streams. DNR examined development trends in the DCL watershed from 1973 to 2010 using the Maryland Department of Planning's (MDP) Land Use/Land Cover data (for more information, see here: http://planning.maryland.gov/OurWork/landuse.shtml**.** During this time period, approximately 5150 acres of land was converted from agricultural or forested land use to developed land use (e.g., residential, commercial or industrial use). This represents a 12.6% increase in developed land, a 4% decrease in agricultural land, and a 10% decrease in forested land (Figure 8). Although development has occurred throughout the watershed, the majority is along the shoreline of DCL.

DNR also determined, using MDP's MdProperty View centroid data, the number of structures built by decade in the DCL watershed (information on MDProperty View is found here: http://planning.maryland.gov/OurProducts/PropertyMApProducts/MDPropertyViewProducts.shtml**.** Each record in MD Property View that had a "Year Built" for a structure was included in the analysis. The records were aggregated by decade. For each decade, the number of structures, the average size of the parcel the structure was built upon and the average size of the structure were compiled. DNR determined that since 1970, approximately 4282 new structures (e.g., houses, commercial buildings, condominiums, etc.) were constructed in the DCL watershed. In addition, lot size generally decreased while the average size of the structure increased (Figure 16).

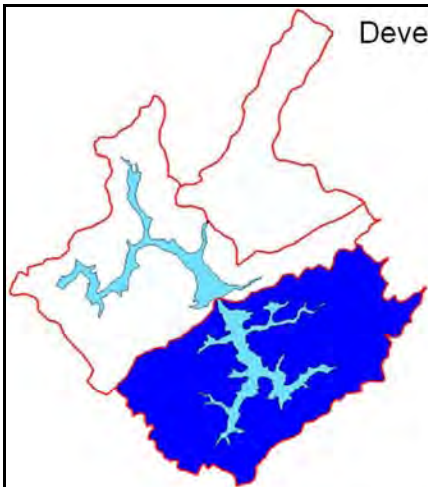
The most recent and imminent threat to stream quality in the DCL watershed may come from the construction of housing developments, other structures, roads and additional infrastructure to accommodate growth. With growth, there will be a subsequent loss of forested land within the watershed (as demonstrated by the 10% decrease from 1973 – 2010). Many scientific investigations unequivocally report severe impacts to streams and lakes due to urbanization and the associated addition of impervious land cover (pavement, roofs, etc.) that accompany development. Several recent scientific investigations have also shown that the detrimental effects of urbanization are extremely difficult to reverse given current restoration technologies.

Additional threats and stressors to streams in the DCL watershed include the following:

- *Lack of adequate forested riparian buffers* - riparian buffers are among the most diverse and functionally-important landscape features because of their unique position as an interface (ecotone) between aquatic and terrestrial habitats. Intact riparian buffers are vital components of watersheds and provide important ecological services. Buffers serve to protect surface and ground water quality from impacts associated with human land uses. Tree and large shrub buffers also shade streams to keep water cool during the hot summer months. Buffers provide food and habitat for an array of plants and animals (i.e., they support high biodiversity) and, if wide enough, provide corridors essential for terrestrial wildlife movements and breeding areas for forest interior-dwelling birds. Although riparian buffers comprise a small percentage of a watershed area, they often harbor a disproportionately high number of plants and animals. Riparian buffers along headwater (1^{st}, 2^{nd}, and 3^{rd} order) streams have much more influence on overall water quality than buffers occurring downstream along larger streams. Within the DCL watershed, it is currently unknown whether adequate forested riparian buffers exist along all streams to protect/improve water quality or conserve biodiversity.
- *Water withdrawals* – water withdrawn from streams is used for many purposes (as stated in the benefits section of this report). The need for adequate quantities of water in streams to maintain stream health is obvious. Without adequate water, stream-dependent plants and animals are adversely impacted (and there can be direct impacts at the withdrawal point). Currently, there are no permitted water withdrawals from the streams that flow into DCL, so this is a potential threat.
- *Stream blockages* – a continuous, unimpeded stream network is vitally important to many stream dwelling animals. They must be able to move freely to different parts of the stream network to feed, breed, and find refuge during certain stochastic events (e.g., floods, droughts, acute spates of pollution). Blockages can be detrimental to survival without free movement upstream or downstream. The number and extent of blockages in DCL streams is currently unknown.

- *Marcellus Shale natural gas development* – Although currently not permitted in Maryland, Marcellus Shale natural gas development could be a future threat/stressor to DCL streams. Threats include increased stormwater runoff into streams from well pads and associated infrastructure (e.g., roads, pipeline corridors, and compressor stations), water withdrawals, and contamination of streams from accidental or intentional discharges of chemical solutions or flowback water. Maryland is making a significant effort to reduce impacts to the environment and natural resources from Marcellus Shale natural gas development (if permitted) through the development of effective Best Management Practices for all aspects of this industrial process. For more information, please see **http://www.mde.state.md.us/programs/Land/mining/marcellus/Pages/MSReportPartII_Draft_for_Public_Comment.aspx**

Development: DCL South (0027)



Decade	Number of Parcels	Acres per Parcel	Average Structure Size (square feet)
1860-1899	10	54.7	1,860
1900	11	50.7	2,015
1910	11	38.0	1,503
1920	10	41.9	2,349
1930	22	15.0	1,803
1940	89	1.1	1,512
1950	189	2.9	1,494
1960	279	2.0	1,429
1970	312	3.0	1,470
1980	393	2.3	1,739
1990	400	2.0	2,099
2000	548	1.8	2,319
2010-2013	72	1.2	2,692
Total	2,346	3.1	1,868

61.5 square kilometers (non-water)

38.2 parcels per square kilometer

Development: DCL North (0028)

Decade	Number of Parcels	Acres per Parcel	Average Structure Size (square feet)
1850-1899	7	101.1	2,739
1900	8	22.8	1,185
1910	4	11.9	1,860
1920	11	9.5	2,432
1930	48	7.8	1,761
1940	103	1.4	1,550
1950	181	1.7	1,443
1960	193	10.9	1,774
1970	223	2.8	1,517
1980	637	1.2	1,871
1990	555	1.4	2,162
2000	980	4.5	2,319
2010-2013	59	2.4	5,775
Total	3,009	34.4	2,078

57.3 square kilometers (non-water)

52.5 parcels per square kilometer

Development: Cherry Creek (0029)

Decade	Number of Parcels	Acres per Parcel	Average Structure Size (square feet)
1870-1899	2	161.5	1,668
1900	2	37.6	1,154
1910	3	1,141.32	2,704
1920	1	90.5	1,665
1930	2	23.0	930
1940	2	72.9	1,608
1950	3	18.8	1,262
1960	10	2.1	4,135
1970	22	4.2	1,429
1980	27	8.2	1,592
1990	23	4.9	1,793
2000	24	2.1	1,733
2010-2013	7	18.9	1,404
Total	128	37.4	1,818

32.0 square kilometers (non-water)

4.0 parcels per square kilometer

Figure 16. Deep Creek Lake sub-watershed development trend. Tables include number of structures, the average size of the parcel and the average size of the structure, per decade.

Lake Water Quality

Knowing the chemical, physical and biological attributes of natural waters are necessary to:

- define the potential use and limits of a water body - whether it may serve as a potable water source, a water source for commercial (industrial or agricultural) needs, provide the right conditions for supporting a desired biological community, or as a system that supports recreational activities;
- define conditions that limit water uses and measure degradation when pollution occurs and improvements when source(s) of pollutants are managed and reduced, and
- measure responses to environmental changes that occur naturally or are accelerated in response to changes within the surrounding environment, and

This section of the report defines some results of water monitoring activities conducted in Deep Creek Lake by the Department of Natural Resources in 2009-2013, as well as results of other water quality studies conducted by the Department of the Environment and the Garrett County Department of Health within the same general timeframe.

BACKGROUND

Some of the first water quality studies in Deep Creek Lake were reported in the late 1940's with fisheries managers collecting water quality measures (temperature, oxygen, alkalinity, and pH) and fish surveys to assess the potential for a productive sport fishery. Over time, managers have defined a sustainable dynamic of predator gamefish species and prey making the lake a destination for recreational fishing and a source of many trophy fish.

Beginning in the early 1970's, occasional water monitoring activities in the lake focused on defining existing nutrient levels (as a designated National Eutrophication Survey study lake by the US Environmental Protection Agency), along with other studies examining the influence of Cherry Creek mine drainage on lake water quality, some short-term system studies, implementation of a seasonal, bathing area monitoring effort and a number of water quality/resource studies by the Department of the Environment on impairments by specific pollutant issues (impaired waters) and to assess complaints. Most studies have been focused on samples collected from the main stem lake. With the State's purchase of the lake property in 2000, Department of Natural Resources' Park Service managers have had an increased need for information to help make management decisions regarding lake activities. In 2007, Park Service contracted with the US Geological Survey to establish stream load monitoring sites on Cherry Creek and Poland Run and to assess the rate of sedimentation in the lake. Park managers also had discussions with DNR's Resource Assessment Service staff about a lake-wide water monitoring effort and additional information needs to respond to complaints and requests.

Beginning in 2009 and continuing into 2014, DNR implemented a baseline monitoring plan to:

- define water quality condition (*physical and chemical characteristics, including nutrient levels and primary productivity*) of representative sites in the main stem lake and selected embayments;
- establish baseline conditions to evaluate changes in water quality as trends;
- define the phytoplankton community; and
- expand monitoring in selected tributaries to quantify annual loading of nutrients and sediments.

Climate

Like the rest of Maryland, the climate of Garrett County is humid and temperate, although it generally records the most precipitation, the heaviest snowfall, and the coldest temperatures of all the Maryland counties. The extremes are here are due to its mountainous terrain, its high elevation mostly atop the Appalachian Plateau and distance from moderating coastal waters.

The mean annual temperature is 48 degrees Fahrenheit, with a summer temperature of 66.6°F and a winter temperature of 29.1°F. Air temperatures in the county usually average 5-10 degrees cooler than in the rest of Maryland The mean annual precipitation is 47.6 inches. Snowfall averages 85.7 inches during the winter season. Unlike the remainder of Maryland, Garrett County receives much of its snowfall from air masses generated over the Great Lakes that rise and cool as they cross the Allegheny Plateau. In addition, the county has to deal with dense fog conditions during many precipitation events when low hanging clouds hamper visibility - on average more than 50 times annually. Temperature inversions also cause foggy conditions as warmer air contacts accumulated snow or hangs over Deep Creek Lake.

In Maryland, prevailing winds are seasonal - from the northwest much of the year (October-June) and the southwest in late summer (July-September). Many of the lake's segments and embayments are aligned with prevailing winds which may contribute to shoreline erosion. Around the mostly northern portion of the lake, the mountains break up the winds and create local rain shadows.

Natural Rhythms And Cycles

Many of the water quality measures in Deep Creek Lake follow a natural annual or seasonal cycle. There are several seasonal patterns that greatly affect water quality in lakes like Deep Creek. For example, in the temperate latitudes, the sun's seasonal warming follows the cycle of the sun in terms of the length of daylight and the elevation of the sun in the sky, which peak in late June. (Figure 17). Air temperature is influenced by solar radiation and the peak air temperature cycle trails the sun's peak by about a month (July) (Figure 18). Surface waters of the lake take longer to warm and peak surface water temperatures also trail the solar radiation peak (Figure 19).

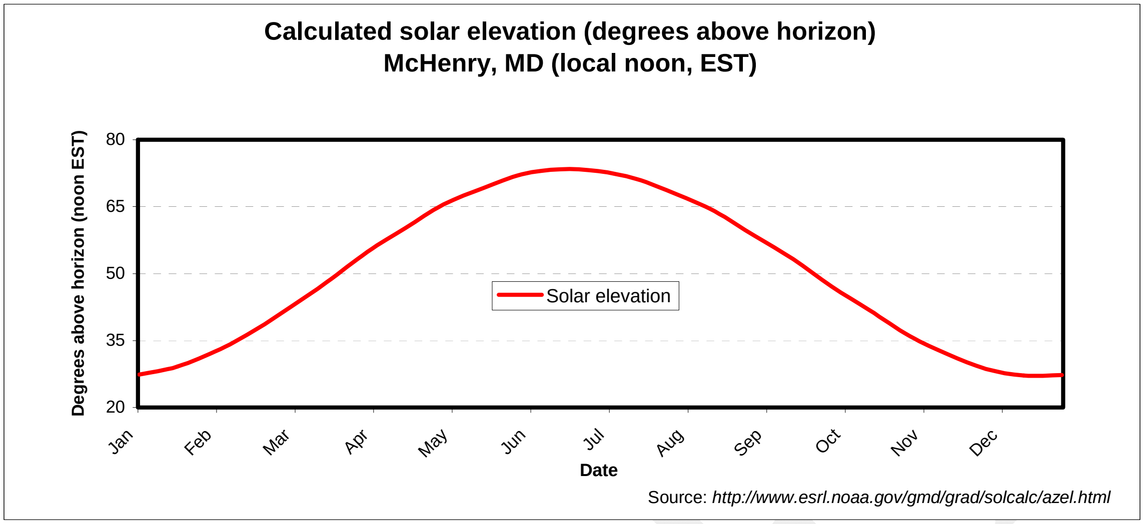


Figure 17a-c Annual cycles at Deep Creek Lake - solar elevation, air and water temperature

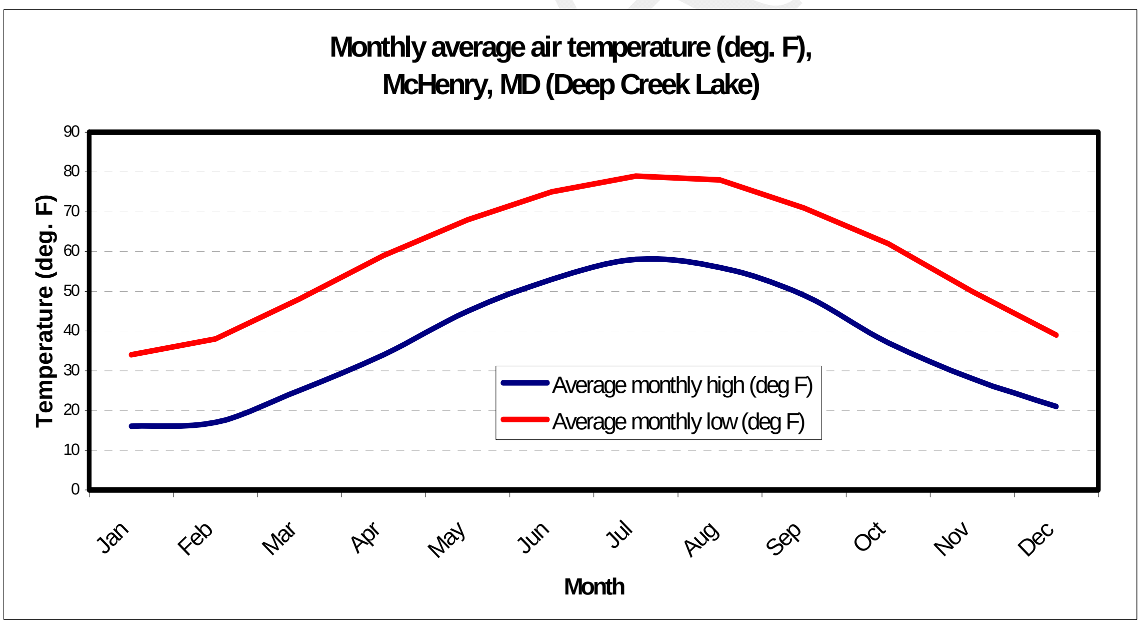


Figure 18

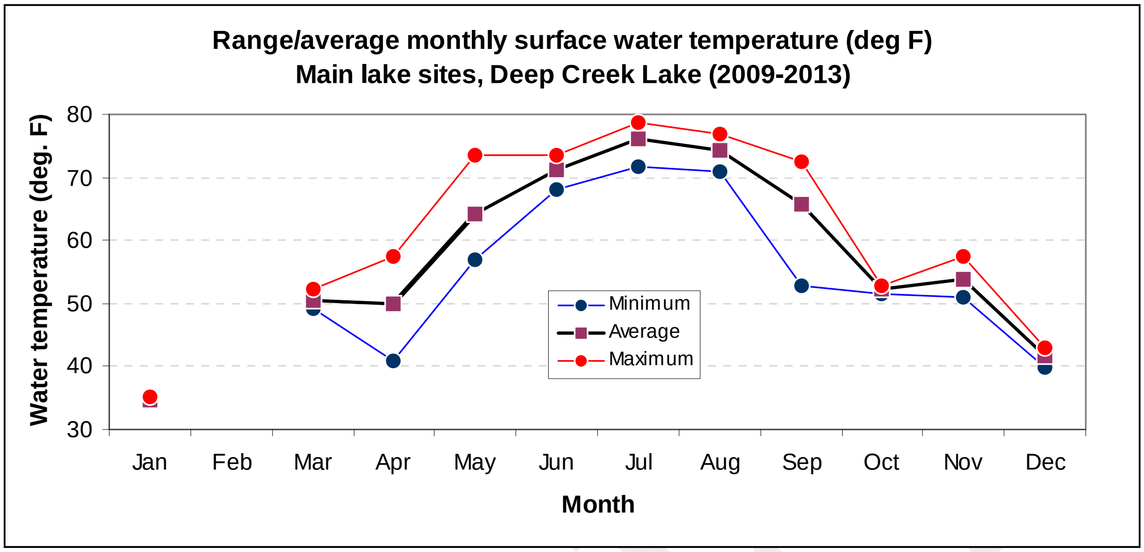


Figure 19

Other natural cycles can be so variable from year-to-year (e.g., monthly precipitation) that an underlying cycle is difficult to discern (Figure 20). Water levels in Deep Creek Lake are seasonally managed to meet competing needs for power generation and recreation levels in the lake, support seasonal flow needs downstream to support aquatic species, recreation and reduce threats of flooding while taking advantage of a natural water supply (precipitation) (Figure 21).

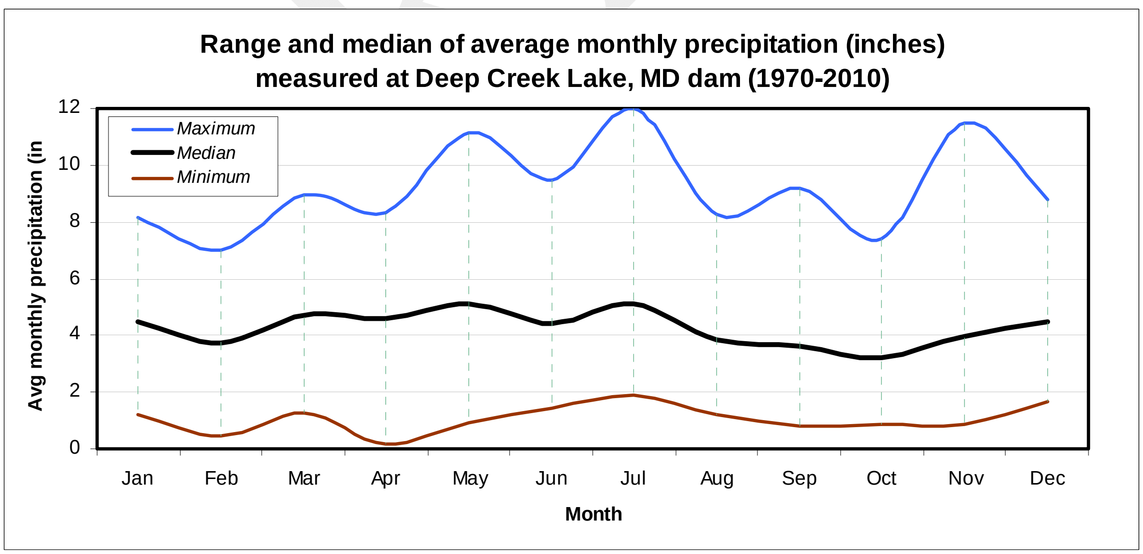


Figure 20. Complex variable pattern nearly masks long-term seasonal median

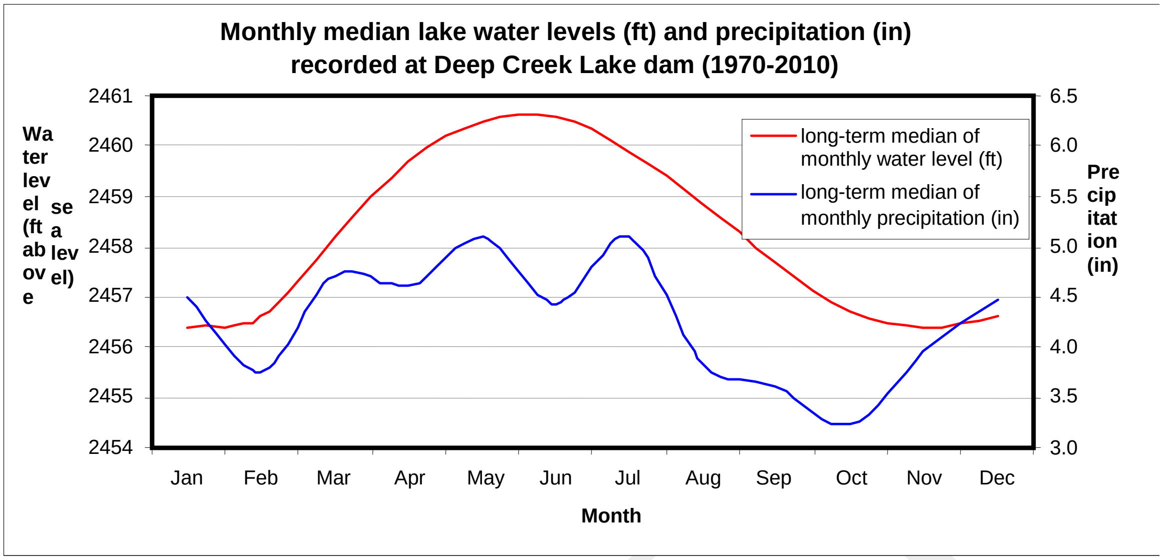


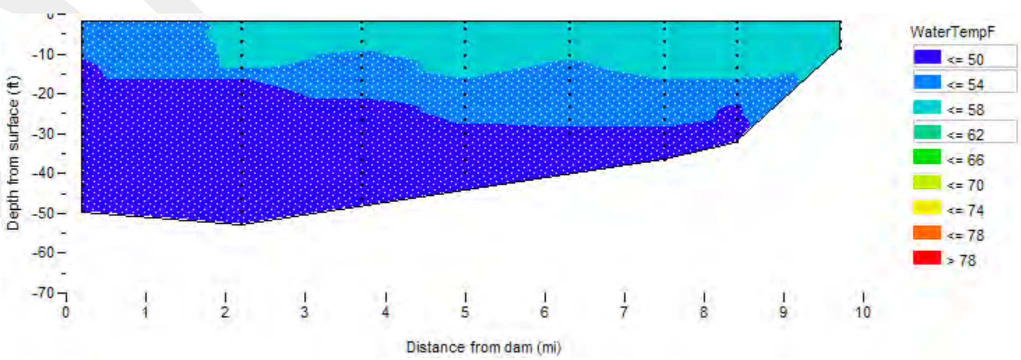
Figure 21. Long term seasonal precipitation supports overall lake water levels Median precipitation mirrors seasonal median precipitation

Other cycles are even more complex. Water density is principally a function of its temperature – the colder the temperature of water, the higher the density – to a point. Then, the relationship changes and as water temperatures approach freezing, the coldest waters are less dense and float on waters a few degrees warmer.

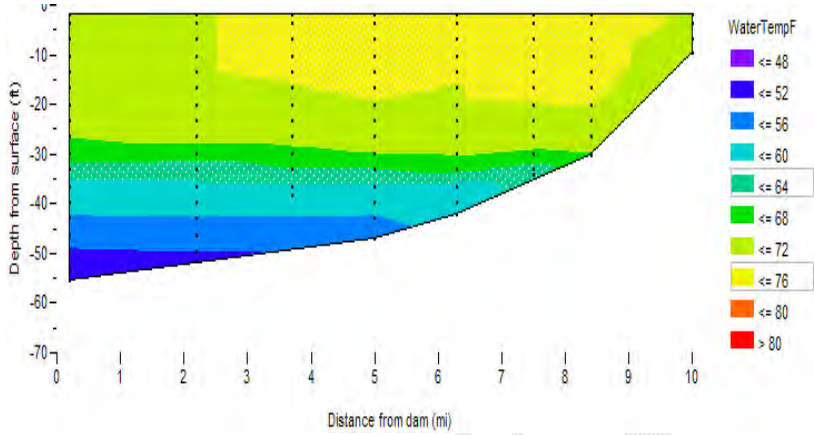
Within a year, Deep Creek Lake will have a strongly stratified summer density pattern, a reversed stratified pattern in winter separated by well mixed conditions in the spring and fall (Figure 22).

Figure 22. Seasonal stratification in Deep Creek Lake

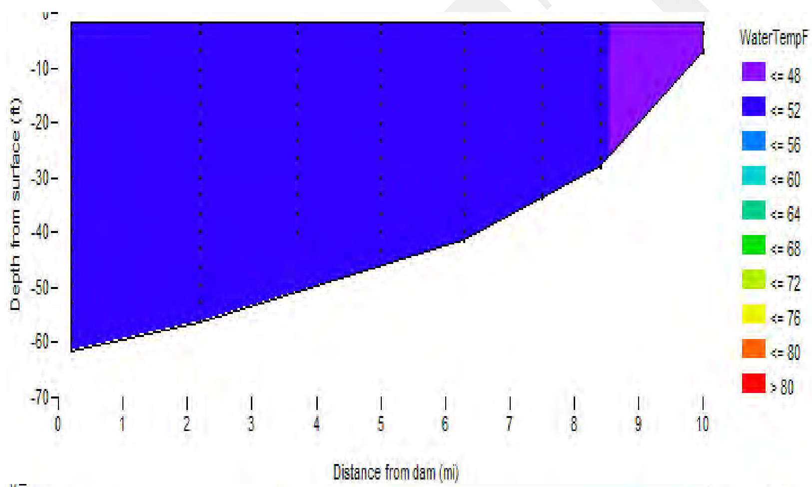
Spring
- April
post-spring
turnover
47-58 deg F



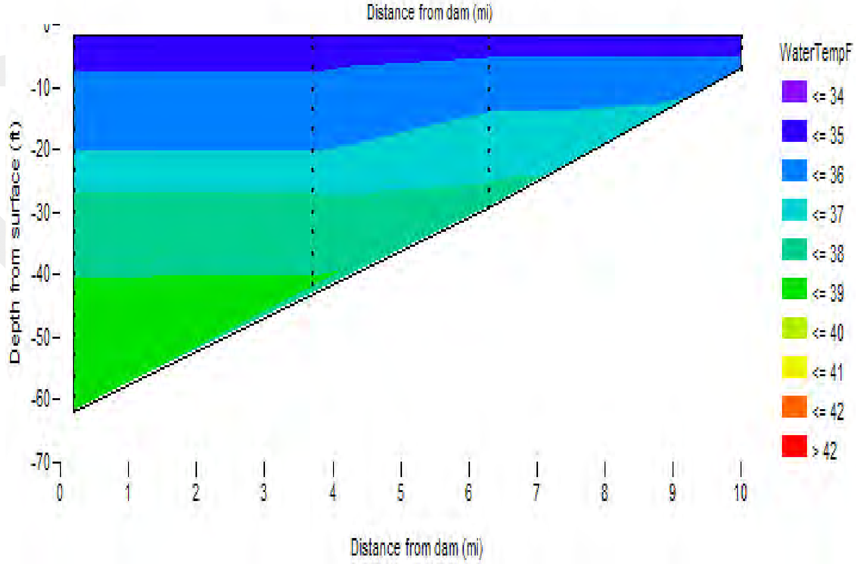
Summer
 - July
summer
stratification
52-78 deg F



Fall
 - November
Post-fall
 turnover
49-52 deg F



Winter
 - January
winter
 stratification
39-32 deg F



Lakes and streams are not static environments - they are dynamic systems that are constantly responding to the physical settings, climate, living resources, and sometimes, how we "manage" the water resource. Change often occurs with little, if any, notice, but change does occur and here - change is routine. Living resources in, on and around these waters adjust continuously to both external (environmental) cycles and their internal ones. Most changes in living resources (e.g., succession of phytoplankton blooms, spawning of fish and invertebrates, and growth of fungi and bacteria) go unseen, but others, like seasonal migration of wildlife, flower plants and growth/dieoff of aquatic plants, can be dramatic. Finally, human rhythms - tied into our environment, our genes, and to a human social calendar that defines rhythms with a pattern of vacations, weekends and holidays demonstrated by the seasonal migration of lake area residents and their docks, surges of vacationers, boating activity lawn and garden care and diurnal patterns of traffic and sewage flow. Understanding how the lake "works", how it responds to different conditions, how living resources (plants, animals and people) interact - is important to answering questions from visitors and residents alike ("where did the water go?"; "why is there a dead fish floating near my dock"; "why don't geese poop somewhere else") and developing a management plan to optimize our water resources that that will work within the setting, climate and water and living resources at hand.

DEEP CREEK LAKE DESIGNATED USES AND DEFINED WATER QUALITY IMPAIRMENTS

"Water quality" generally describes the condition of a waterbody in relation to human needs or values. A lake may be suitable for fishing, swimming, boating or a combination of activities. As different users may perceive lake water quality differently (e.g., a lake that is "good" for fishing may not be "good" for boating), water quality is often reported as a relative, rather than an absolute measure.

The federal Clean Water Act requires States to define uses of their waters and identify minimum and/or maximum levels of physical, chemical and biological measures that will support these uses. In Maryland, defined uses for waters in Deep Creek Lake watershed (the lake and tributary streams) are documented in the Code of Maryland Regulations (COMAR 26.08.02.02 and 26.08.02.02-1) (map of designated uses in Garrett County available online at: http://www.mde.state.md.us/programs/Water/TMDL/Water%20Quality%20Standards/Documents/www.mde.state.md.us/assets/document/Garrett_Cnty_DUs.pdf).

The Maryland Department of the Environment classifies Deep Creek Lake (and all waters in the watershed) as Class III-P for supporting uses including:

- swimming, boating, fishing and all other recreational activities involving water contact,
- protection of aquatic life and wildlife,
- agricultural supply and industrial water supply,
- propagation and growth of natural trout waters, and

• public water supply.

There are specific criteria (limits) listed in COMAR to protect/maintain these uses with defined maximum/minimum water quality limits on water temperature, dissolved oxygen, pH, bacteria and a long listing of toxic substances, including metals, inorganic and organic contaminants, are defined in COMAR 26.08.02.03-1 and 26.08.02.03-2).

Every two years, the MD Department of the Environment releases an Integrated Water Quality Report which lists water bodies in the State in which defined water uses are 'impaired' because of one or more pollutants. Within this report, the following is a listing of impaired waters within the Deep Creek watershed (basin code 05020203) (pollutant; affected waters; year of listing – see:
http://www.mde.state.md.us/programs/Water/TMDL/Integrated303dReports/Pages/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/index.aspx

- low pH in Cherry Creek (1996)
- high water temperatures in Cherry Creek (2014)
- methylmercury in select fish species in the lake (2002), and
- total suspended solids impacting aquatic life in tributary streams (2012).

Once a waterbody is listed as being impaired (one or more water uses are not met) additional work is scheduled to define a Total Maximum Daily Load for each pollutant, which requires an analysis of the sources and sinks of a pollutant, how it is transported and creates an impaired condition and what the maximum load (e.g., tons/day) of a pollutant would be that would still allow the water body to support all defined uses. Sometimes this process defines that the polluting substance is not the source of poor water quality.

MDE presently identifies four impairments in Deep Creek Lake and its watershed:

• Cherry Creek, the largest tributary watershed to Deep Creek Lake is impaired because of low pH due to past mining practices that released acid mine wastewater into tributary streams. pH levels were so low (acidic) that aquatic life was nearly absent. In 2004, MDE documented this problem, identified acidic sources and defined a TMDL that, if met, would reduce acidic mine drainage in the tributary stream and allow aquatic animals to repopulate the stream. The Total Maximum Daily Load report on this impairment is available online at:
http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/Programs/WaterPrograms/TMDL/approvedfinaltmdl/tmdl_cherrycreek_final_ph.aspx .

• Cherry Creek has been listed in the draft 2014 Integrated Water Quality Report as being impaired due to elevated water temperatures. Water temperatures measures there exceeded criteria (> 20 deg. C) and no coldwater obligate species were found (M. Stover, MD Dept. Environment, Science Svcs. Admin., 2014, pers. comm.).

• In 2012, tributary streams to Deep Creek Lake were listed as being impaired due to elevated Total Suspended Solids levels that impair Aquatic Life and Wildlife uses. Previously listed in 2002 as a biological impairment because of poor community health data in DNR's Statewide biological stream survey, biostressor analysis by MDE identified Total Suspended Solids as the impairment cause.

• Deep Creek Lake is impaired because of mercury contamination in tissue samples of specific species. In 2002, MDE documented elevated methylmercury levels in the edible flesh of several fish species in the lake. The report on this impairment identifies the major source of methylmercury being air deposition on the watershed from coal-fired power plants in the US Midwest. These compounds are carried into the lake, taken up and concentrated through the food chain until it reaches top predator species. Because fishers and their families catch and consume these fish and may accumulate methylmercury levels that can harm their health, MDE issued a warning suggesting that the public limit their monthly consumption of Chain Pickerel, Yellow perch and Small- and Largemouth bass taken from Deep Creek Lake (and many other lakes in the State). The Total Maximum Daily Load report on this impairment is available online at: http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/www.mde.state.md.us/assets/document/Deep%20Creek%20Lake_122702_final(2).pdf

MDE has a regular fish tissue monitoring effort that examines toxic contaminants that can accumulate in commercial and recreationally-caught fish and shellfish. MDE maintains a Fish Consumption Advisory website which identifies all water bodies in the State where public health advisory is listed: http://www.mde.state.md.us/programs/Marylander/CitizensInfoCenterHome/Documents/www.mde.state.md.us/assets/document/Maryland%20Fish%20Advisories%202011.pdf

MDE also has a website with recommendations for safe consumption limits of select fish species and sizes for adults, women of childbearing age and children: http://www.mde.state.md.us/programs/marylander/citizensinfocenterhome/pages/citizensinfocenter/fishandshellfish/index.aspx.

As an example how water quality data and modeling can identify a waterbody impairment and then define that there really is none, in 1996, MDE identified Deep Creek Lake tributaries as being impaired because the streams were transporting nutrients (phosphorus) to the lake, contributing to eutrophication that was creating anoxic conditions in the deep, seasonal hypolimnion of the lake, and limiting habitat for aquatic life. Additional monitoring and modeling work was conducted and analysis now 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. These findings were documented in: http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Pages/wq a_final_deep_creek_Nut.aspx In 2012, these impairments were removed from a revised listing of the State's impaired waters list

DEEP CREEK LAKE: RECENT (2009-2013) WATER QUALITY CONDITIONS

The goal of the current monitoring survey was not to assess whether Deep Creek Lake was impaired or whether water quality met the criteria for its designated uses and should be listed as impaired. Available lake data were compared to published criteria as an initial level of review. Where there appears to be an exceedance of criteria, there is some discussion about why these are/should not be considered as impaired waters.

A simple review of data collected in the surface layer (1m depth) of main stem and tributary cove sites showed that, out of 454 water column profile sampled (April 2009-September 2013):

- no (0) observations of surface dissolved oxygen concentrations were less than the minimum criterion (5 mg/L), and
- 1 one (1) observation of surface pH was below the minimum of 6.5 standard units (value of 6.0 at Cherry Creek Cove site) while no (0) observations exceeded the maximum pH criterion of 8.5.

Bacteria samples are collected by the Garrett County Health Department between the Memorial and Labor Day holidays at 23 community beach sites on Deep Creek Lake that show low levels of *Escherichia (E. col).* Samples also collected at the State Park Beach also show acceptably low bacteria densities. During the summer season, results are routinely posted on the State's online Beach Notification System: (http://www.marylandhealthybeaches.org/notification.aspx **).**

For certain water quality measures, some field-collected data **appear** to exceed specific water quality criteria, but, by definition, do not. For example, out of 80 summer season (May – August) lake surface water observations (2009-2013), 64 (80 percent) "exceeded" the maximum 68 degrees F temperature criterion for Class III-P use. These warm waters stress cold-water species (e.g., brown trout) which will seek out colder waters to thrive (e.g., deeper, well oxygenated lake waters, cold, underwater spring sources or coldwater streams). A natural process cannot create an impairment (defined in the Clean Water Act) so as the source is solar radiation and not a heated discharge, warm waters in Deep Creek Lake are not an impairment. If the lake had a lower use classification (Class I-P), there would be no temperature "exceedance", but waters are classified for their "highest" (environmentally restrictive) use, not the most convenient. Thus, the higher water temperatures are not considered to be an impairment and the lake is not considered to have been misclassified.

The same discussion addresses the seasonally stratified deep water mass where dissolved oxygen is not mixed or easily diffused through the thermocline. But as bacteria, phytoplankton, clams and fish in the hypolimnion respire, the oxygen concentration continues to decline until oxygen can be completely absent and only anoxic bacteria survive. Out of 80 summer season (May – August) lake bottom layer observations (2009-2013), 62 (78 percent) "exceeded" the maximum 68 degrees F temperature criterion for a Class III-P use. In this instance, because the development of the thermocline barrier and oxygen-depletion are existing, natural processes, seasonally low oxygen in the hypolimnion is not considered to be an impairment. A lake which originally had no hypoxic condition now does because of nutrient enrichment may be impaired.

Water Temperature

Water temperature is an important water quality measure as it governs seasonal stratification of the lake, the rate of biogeochemical and ecological processes, including reproduction and growth of aquatic organisms. Water temperature also affects how people interact with the lake - paddleboard or snow machine?

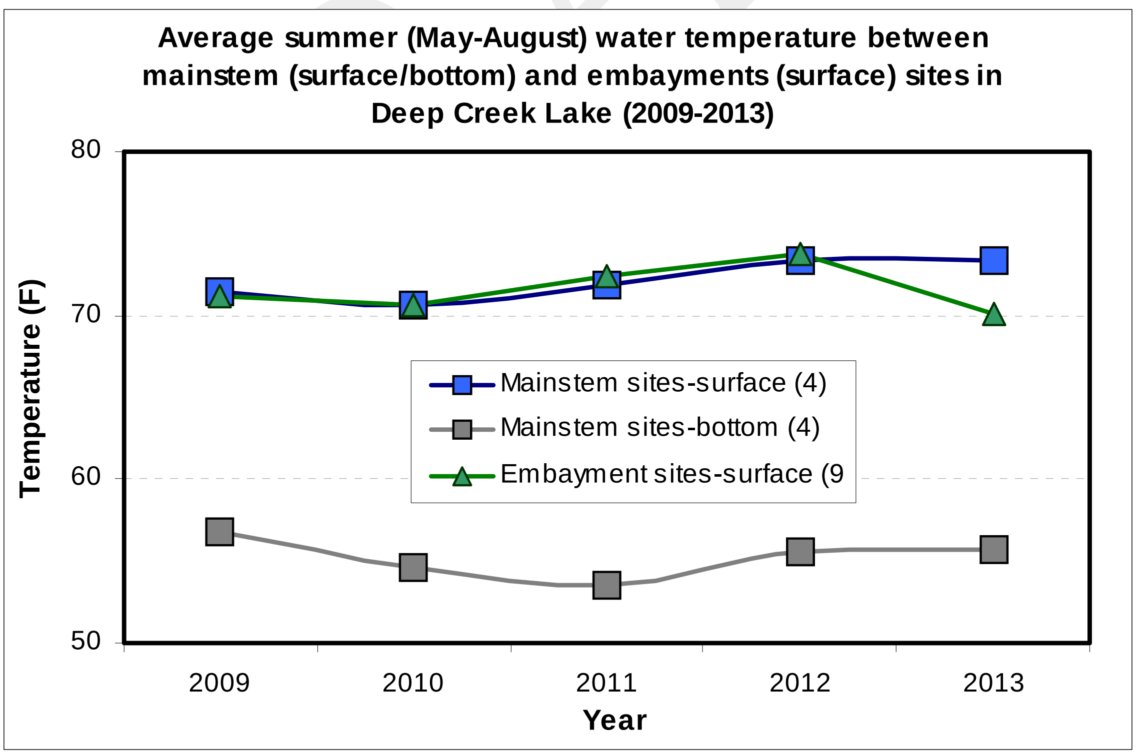
Range (2009-2013):

Lake main stem: 34.3 – 78.8 degrees F
Lake embayments: 39.7 – 79.3 degrees F

The coldest temperatures occurred at the surface (under ice cover, but opened for sampling purposes) in January 2010; the warmest temperatures were observed at the surface in July 2011.

Summary

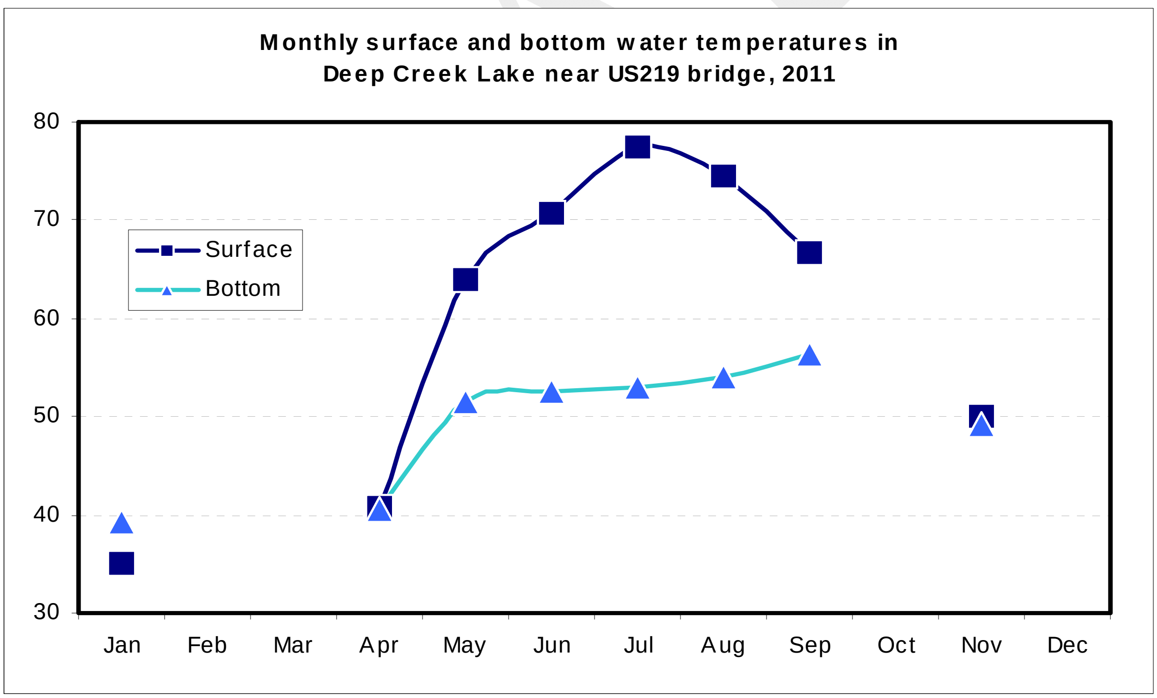
A comparison of average annual summer season (May-August) surface water temperatures are shown in Figure 23 below.



Generally, there is little difference between surface water temperatures at lake sites in the main stem and in embayments. At deeper sites during summer (May to September), two distinct seasonal water masses are identified, separated by a sharp break in temperature (thermocline) at about 13-45 feet below the surface. Water temperatures in the summer bottom water mass (hypolimnion), are 14-18 degrees (F). colder than at the "surface".

A comparison of average monthly water temperatures near the surface and bottom at one main stem lake site near the US219 crossing (DPR0056) show similar temperatures in April and in November 2011 as the entire water column is well mixed (Figure 24). From May through September in 2011, water temperatures increase near the surface faster than temperatures rise in deeper waters. The water column will stratify into two water masses - a warmer, less dense surface water layer (epilimnion) riding over a cooler, more dense deep water mass (hypolimnion). This stratification will remain into September even as surface water temperature decline. The density of the two water masses would become nearly equal before mixing thoroughly (fall overturn) in September-October. When the lake is ice-covered (January data is shown here), a weak stratification event occurs as warmer lake waters have a greater density than colder waters and cold waters rest above a warmer layer. After ice-out in early spring, surface waters warm and density declines, creating a less turbulent mixing event (overturn).

Figure 24. Surface/bottom water temperature in Deep Creek Lake at US 219 bridge, 2011

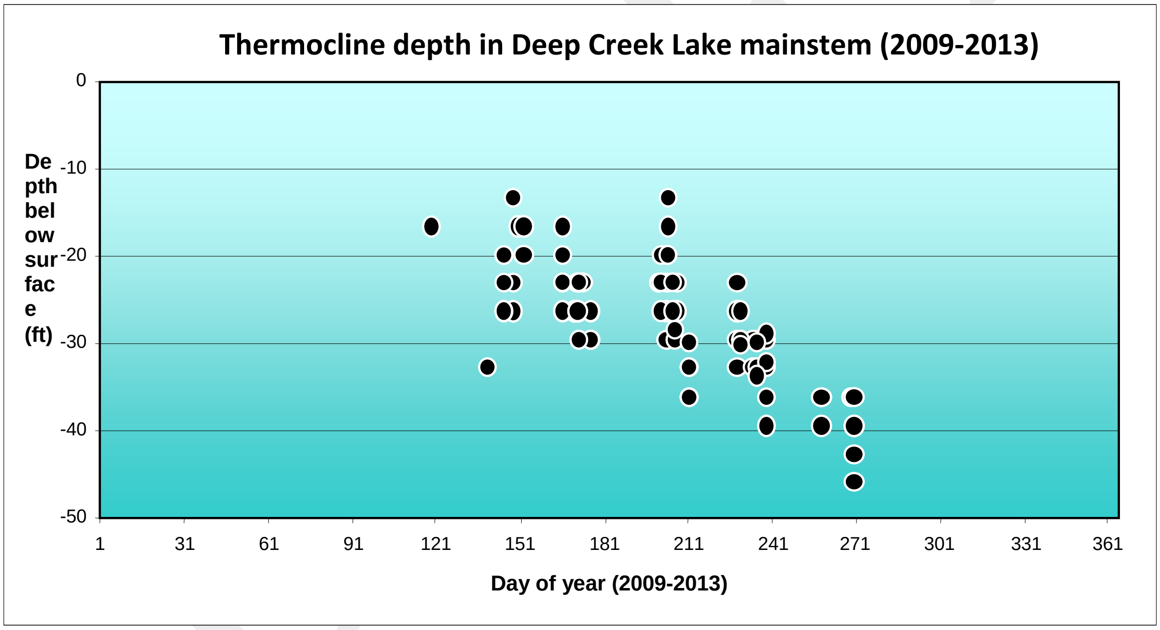


Thermocline review

From the data collected in this study, the presence and depth of the seasonal thermocline is defined by a Relative Thermal Resistance to Mixing (RTRM). This simple index quantifies thermal stratification in lakes. This method identifies and locates the steepest density gradient as the depth and intensity of the thermocline.

A review of the summer seasonal thermocline in Deep Creek Lake shows that, over the summer season, the depth of the thermocline declines (Figure 25). In some reservoirs, this often indicates that summer, wind-driven mixing continues to modify the surface layer and increasing the depth and volume of the epilimnion (surface water mass). In Deep Creek Lake, however, it is likely that the volume of the hypolimnion is being reduced as water is discharged from the lake near the dam at an elevation 43 to 51 feet below normal pool elevation (2,462 ft above sea level). The release of water from Deep Creek Lake's seasonal hypolimnion reduces the lakes' nutrient load (principally ammonium and phosphorus) and may reduce a possible fall algal bloom that often occurs in other temperate reservoirs which discharge water from the epilimnion (surface) layer. Management of the seasonal hypolimnion may become part of any eutrophication management plan for Deep Creek Lake.

Figure 25. Reported depth of the thermocline in Deep Creek Lake main stem stations



Conductivity

Conductivity (specific conductance), measures the ability of water to conduct an electric current. Conductivity is reported in microSiemens per centimeter (µSi/cm) and is directly related to the total dissolved inorganic chemicals in the water, including salts (fertilizers, septage, runoff). As water temperature can affect conductivity, sensors and instruments used to record conductivity correct for ambient measures to a standard temperature (77 degrees F).

Range (2009-2013):

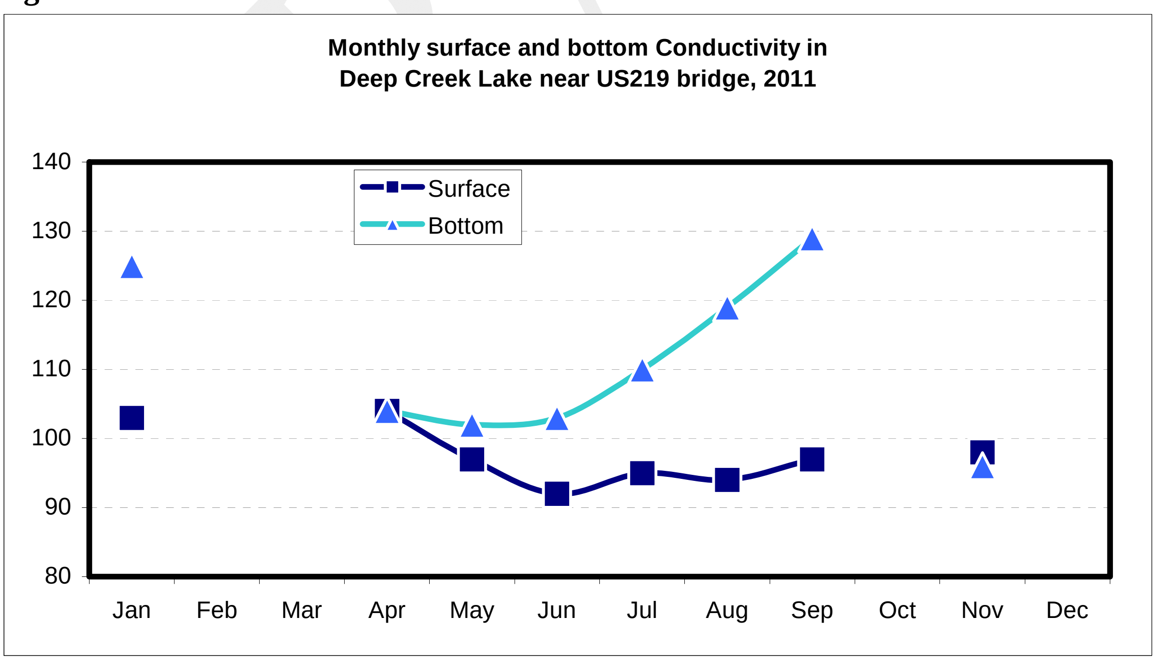
Lake main stem: 81 - 127 µSi/cm
Lake embayments: 81 - 122 µSi/cm

Summary

Average conductivity levels have varied widely from year-to-year but the annual variability is similar between main stem and embayment sites. Conductivity in main stem sites is usually slightly higher than observed values in embayment sites (Figure 26).

While there may not be much difference in conductivity between sites (at the same depth), the figure shows that there are times when there are significant differences in conductivity between the surface and bottom waters of Deep Creek Lake - likely as result of hypoxic (low-oxygen) or anoxic (absence of oxygen) conditions in the deep hypolimnion resulting in dissolved inorganic chemicals (e.g., ammonium; phosphorus) being released from organic sediments.

Figure 26



<u>Dissolved oxygen</u>

Oxygen (O_2) is an important gas, since most aquatic organisms need it to survive. The solubility of oxygen and other gases in water depends on water temperature. The colder the water, the more gas it can hold. Oxygen dissolves in water diffusion - across the air-water interface, through physical entrainment and more importantly through photosynthesis. Through the chlorophyll molecule in green plants and with sunlight as the energy source, using carbon dioxide and water to produce simple sugars for growth and oxygen as a waste product. In aquatic plants, photosynthesis occurs only to the depths where sunlight penetrates, but the process also depends on nutrient availability, and water temperatures.

Range (2009-2013):

0.0 - 13.4 (main stem lake)
0.1 - 12.3 (lake embayments)

Summary

A comparison of average annual summer season (May-August) dissolved oxygen (DO) levels are shown in Figure 27. Surface DO levels in open surface waters of the lake (main stem and embayment sites) are similar from the fall through the spring. As solar heating, rainfall and runoff warm lake waters, surface waters of the lake warm faster than heat can be transferred to deep waters. The difference in water temperature between surface and bottom waters grows and a sharp thermal gradient (thermocline) forms separating surface water layer (epilimnion) from a deep layer (hypolimnion). Dissolved oxygen cannot easily diffuse to colder deep waters and light does not penetrate to the depth of the deep layer so respiration (principally by bacteria) exceeds any oxygen source and by mid-summer, oxygen levels are too low to support aerobic life.

The process is shown in Figure 28 where dissolved oxygen levels in the epilimnion (surface layer) (see squares) gradually decline during the summer (principally a result of increasingly warmer water that holds less dissolved oxygen) while oxygen levels in the hypolimnion (deep level near the bottom) (see triangles) rapidly decline to zero.

Figure 27

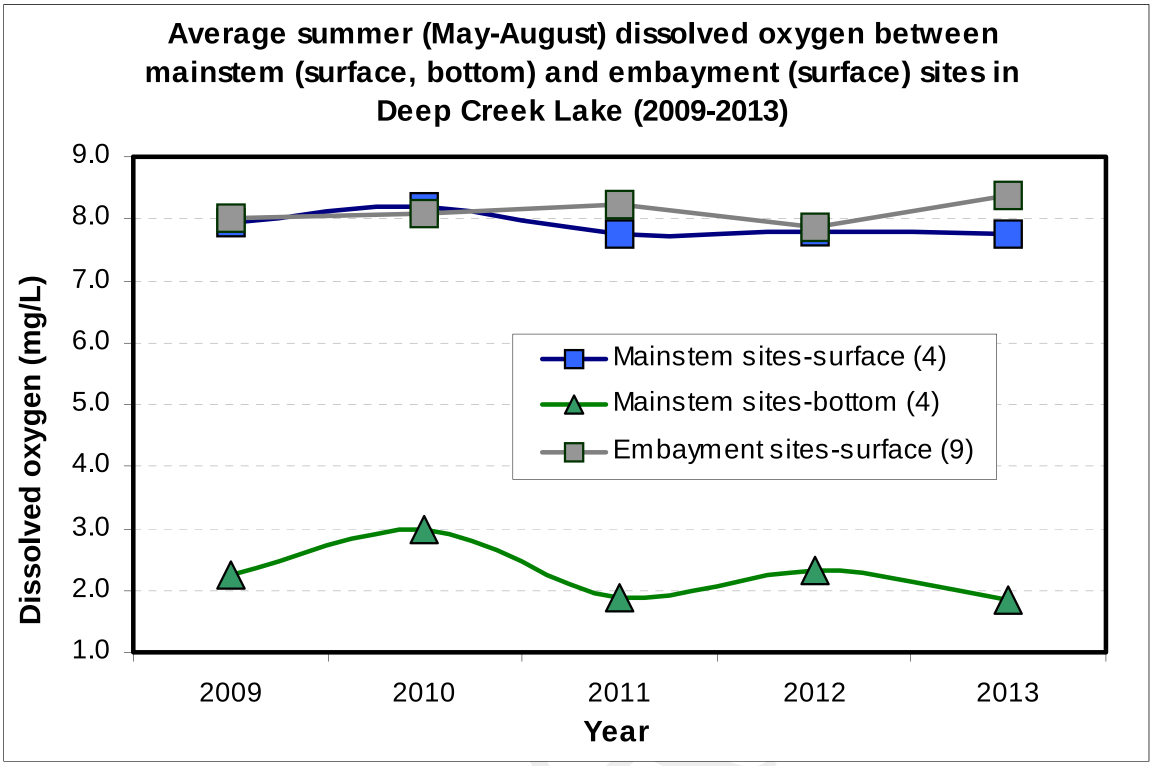
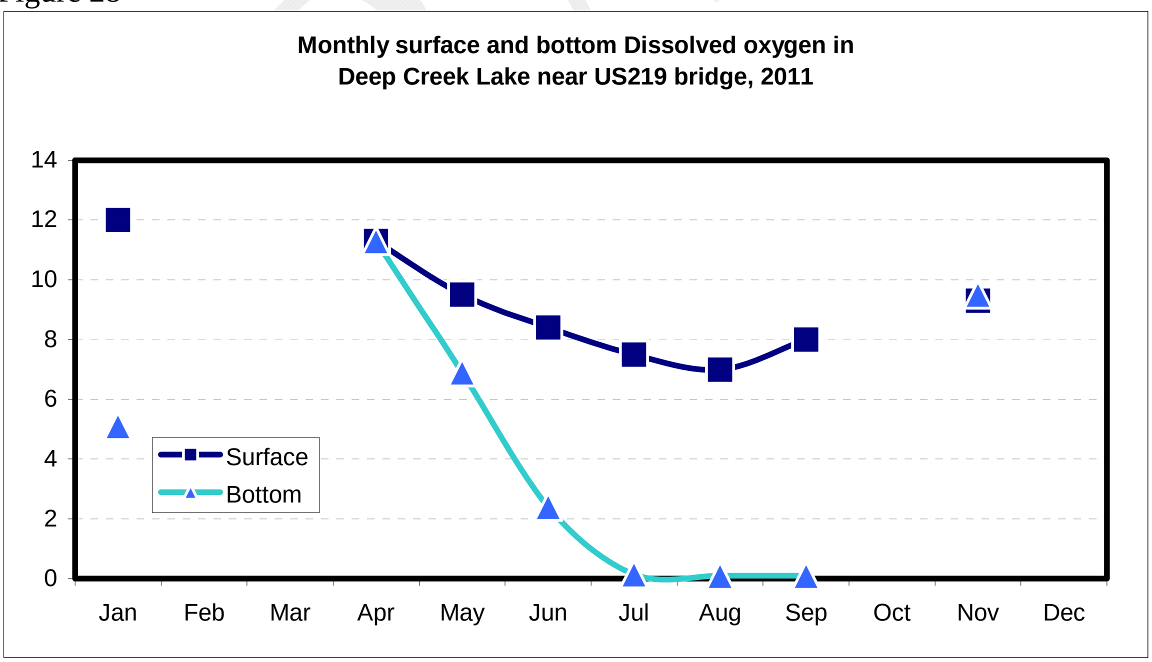


Figure 28



In early fall when surface waters cool and the temperature of the epilimnion and hypolimnion are nearly equal, the water column will mix and deep waters will be reoxygenated.

pH

An index of a lake's acid level, pH is an important component of the carbonate system. It is the negative logarithm of the hydrogen ion (H^+) concentration. The pH scale is inverse to concentration so, lower pH waters have *more* hydrogen ions and are *more acidic* than higher pH waters.

pH ranges from 1 to 14. A water sample with pH of 7 ; a pH of 7 is neutral and A pH of 7 is neutral. Water with a pH of 7 has equal amounts of hydrogen (H^+) and hydroxide ions (OH^-). Pure, distilled water without any carbon dioxide has a pH value of 7.

Range (2009-2013):

Lake (surface): 6.7 to 7.7
Lake (bottom): 6.3 to 7.7
Embayment (surface):6.0 to 8.2

pH levels elevated above 7.0 may be caused by aquatic plants and/or algal productivity which would also show elevated levels of dissolved oxygen, higher chlorophyll measurements and, in summer, higher water temperatures

Summary

A comparison of average annual summer season (May-August) pH levels are shown in Figure 29 below. Surface pH readings in the main stem lake or in lake embayments are similar. pH in the summer hypolimnion has a significantly lower pH that may approximate the lake's pH without the influence of photosyntheses/

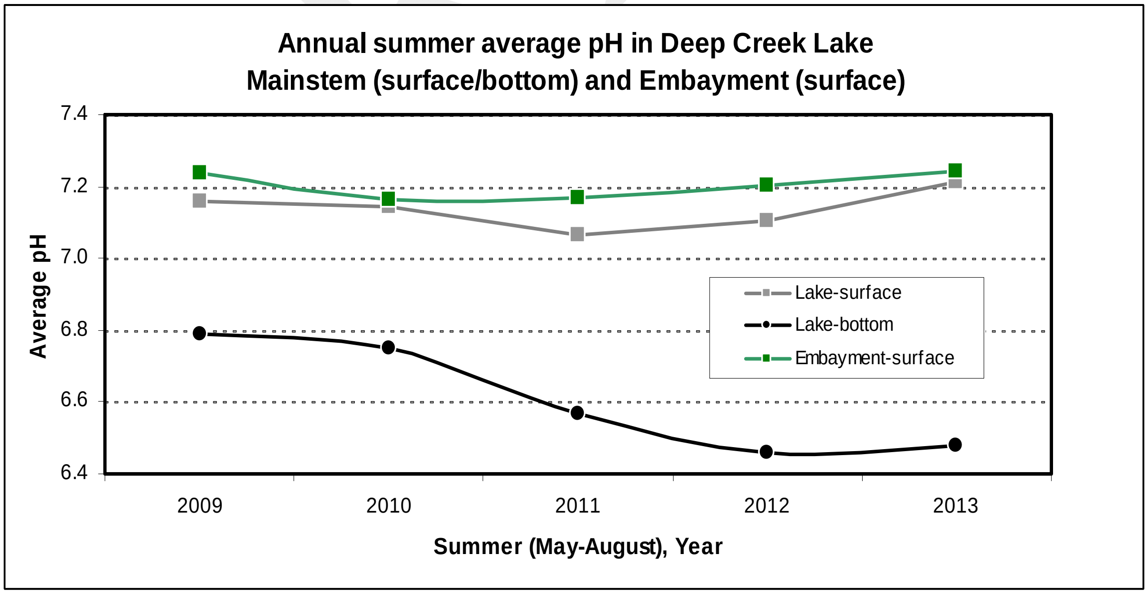


Figure 29

Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids and is expressed as milligrams per liter or parts per million calcium carbonate (mg/L or ppm $CaCO_3$). This measure defines how well the water is buffered that protects aquatic organisms against changes in pH. Carbonates and bicarbonates are the most common and most important components of alkalinity, but other bases include hydroxides and phosphates. Typical surface water alkalinities range from 20-200 meq/L.

Observed range (2009-2013):

Lake (surface): 8 to 26 meq/L
Lake (bottom): 10 to 32 meq/L
Embayment (surface): 9 to 25 meq/L

Summary

In the main stem lake, total alkalinity measures are low- likely a result of the dominant shale geology in the surrounding watershed. Alkalinity doesn't vary much throughout the year in the lake's surface waters. With low alkalinity (buffering capacity), the range of observed pH is rather wide. It should be expected that waters near an intense algal bloom, where nearly all carbon dioxide is withdrawn for photosynthesis, will alter the carbonate equilibrium and pH of the water would decline.

The seasonal increase in alkalinity in the bottom waters of the main stem lake (Figure 30) would, for a short time, improve buffering capacity of the water, but no impacts to wider swings of pH have been defined in Deep Creek Lake.

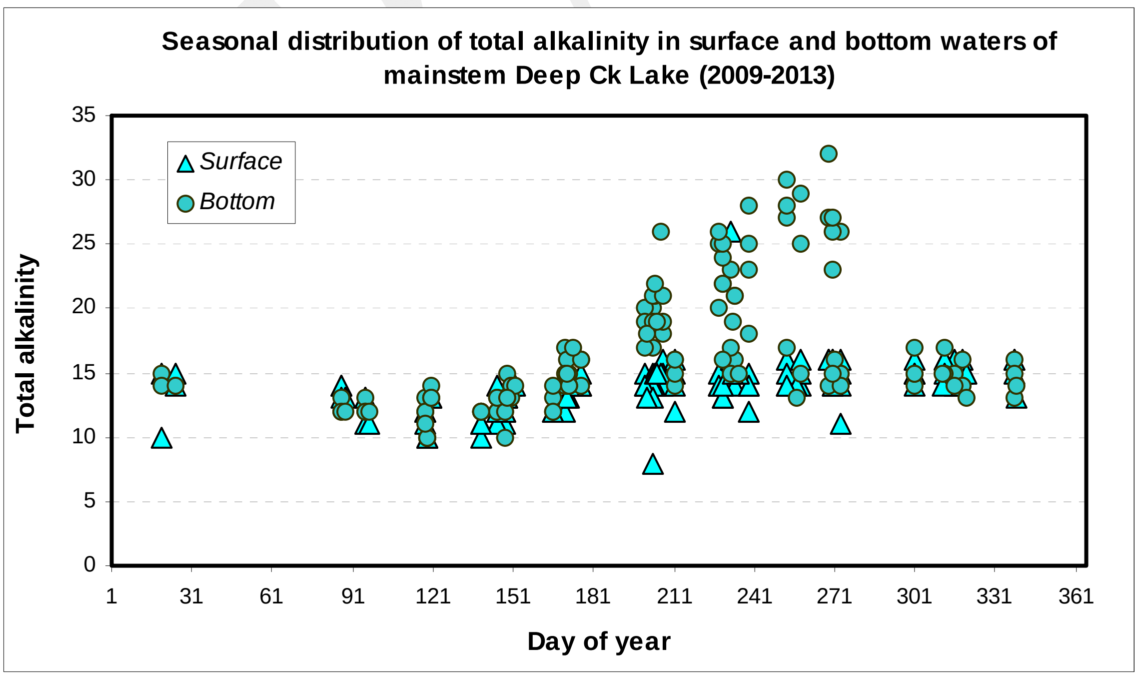


Figure 30

Water Clarity

Water clarity is influenced both by the color of the water and turbidity caused by suspended fine inorganic particles and microscopic plants and animals. Measured with an 8-inch Secchi disk, water clarity is recorded as the depth below the surface where the disk, with black and white quadrants, disappears/appears when lowered and viewed from the sunlit side of the boat. Secchi depth is not measured in free-flowing streams. There are no regulatory limits for water clarity though waters with low Secchi depths (higher turbidity and/or darker water color) is often considered less appealing for recreational use than lighter, clear waters.

Range (2009-2013):

Lake main stem: 5.9 to 23.0+ feet
Lake embayments: 1.6 to 16.4 feet

Summary

Waters of the main stem of Deep Creek Lake nearly always have clearer water (greater Secchi depths) than nearby sites in embayments or in the distal transition zones - averaging nearly 2 feet of greater visibility (Figure 31). Some interpretation problems occur when clarity is high and “actual” data are unknown. For example, at shallow sites the Secchi disk is clearly visible but resting on the bottom - clarity results are recorded as “greater than” the measured depth. In another instance, we have sometimes reached the limit of our calibrated tether (7 meters), but again we can still see the 8” diameter disk - though we are nearing the limit of discerning white quadrants because of the apparent small size of the target disk. These data are recorded as exceeding the measurements and are not useful in some analyses.

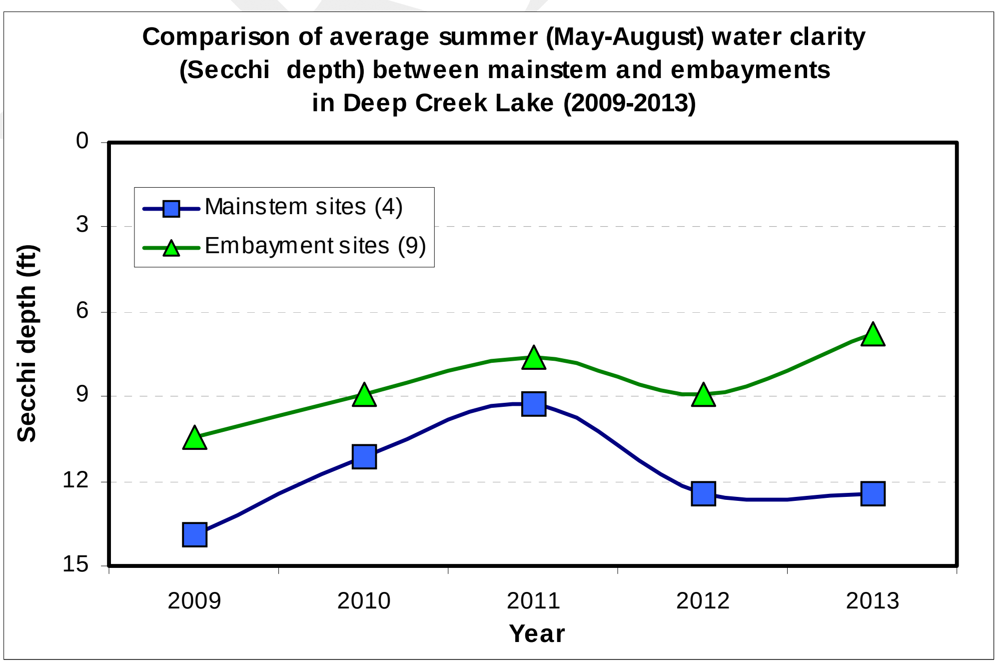


Figure 31

A comparison of results between years show some differences with lower water clarity (shallower Secchi disk depths) during wet summers (2010, 2011) than in dry summers (2009).

Water clarity is not used to define trophic status in Deep Creek Lake, even though equations have been published to do so. Using Carlson's Trophic State Indicator (chlorophyll) suggests that the lake is generally mesotrophic which, if similarly defined using Secchi depth measures, would be defined within an extremely wide range of Secchi depths - **6.6** to **26.2** feet! Use of the Secchi disk in some embayments cannot be done if the visual limit of water clarity is deeper than water depth. Where there is more inorganic turbidity - due to nearby sources of runoff, shore erosion and turbulent mixing, an assessment of the lake's trophic state becomes affected by factors other than biological productivity.

Turbidity/Total Suspended Solids (TSS)

Turbidity is a measure of light transmission through the water. It is similar to measurements by Secchi disks, in that it is affected by color of water and particulate material (organic cells or inorganic matter). Technically, the optical measurement is different than what a Secchi disk measures and it is measured using a calibrated instrument and can be done at night and at different depths in the water. Both approaches can be used to estimate the amount of total suspended solids, which block or the path of light in the water. Samples of unfiltered water can be analyzed in the lab to determine the exact amount of suspended material as well as having a sample that can be inspected to determine source of the turbidity.

Observed range (2009-2013)

Turbidity:

- Lake (surface): 0.4 to 6.7 NTU
- Lake (bottom): 0.3 to 69.0 NTU
- Embayment (surface): 0.5 to 7.5 NTU

Total Suspended Solids (TSS)

- Lake (surface): 1 to 9 mg/L
- Lake (bottom): 1 to 100 mg/L
- Embayment (surface): 1 to 11 mg/L

NTU - *Nephelometric Turbidity Units*

Summary

Turbidity measurements in Deep Creek Lake is generally good in surface waters of the open main stem lake tear round. The first 6 months of the year, turbidity is equally good in deep bottom waters, however, as the hypolimnion becomes more anoxic, dissolved and particulate organic matter is released from the sediment near the bottom creating a more turbid environment near the bottom (Figure 32).

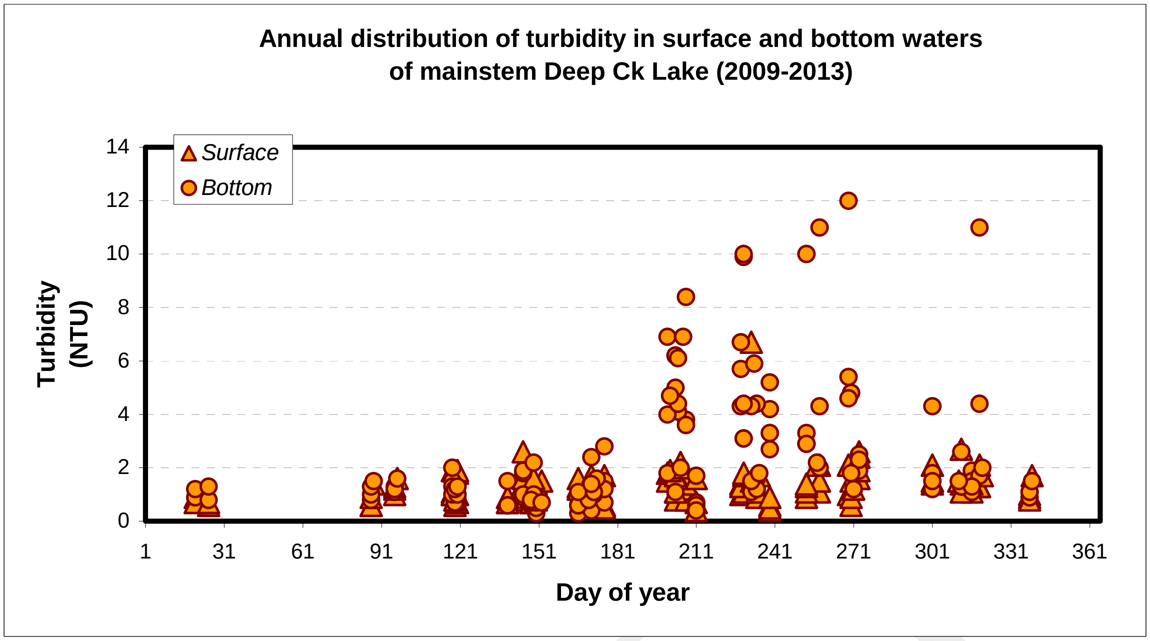


Figure 32

A similar pattern occurs with total suspended solids, which a measure of the mass of suspended particles collected near the surface and bottom (Figure 33)

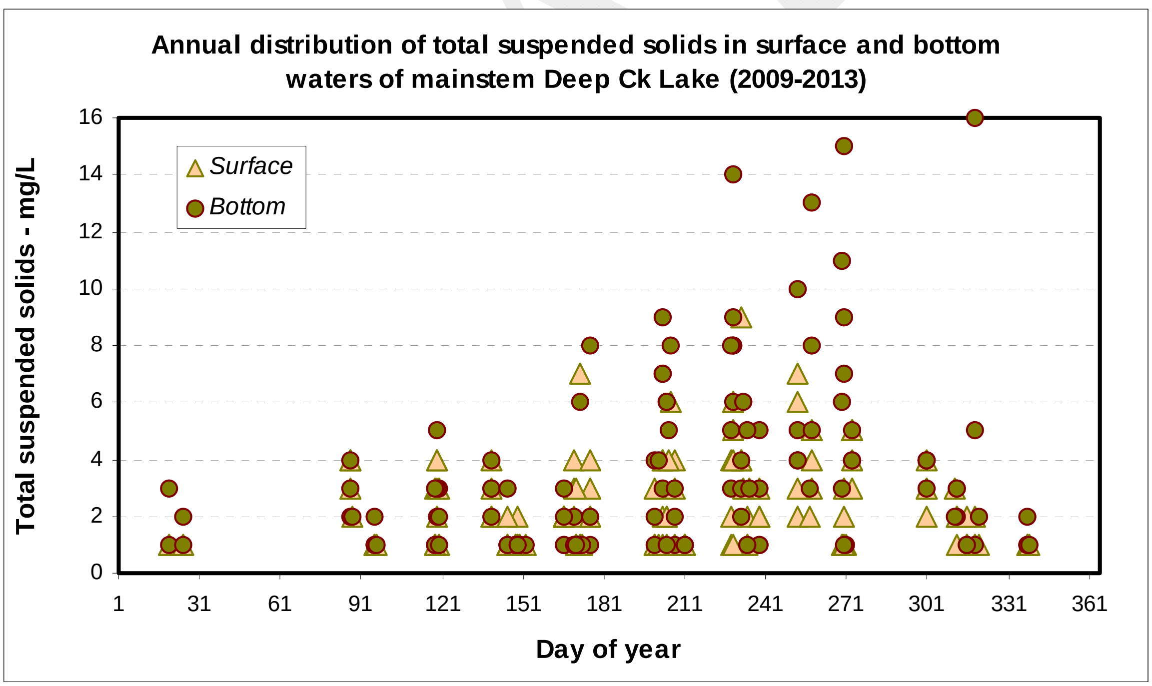


Figure 33

Nutrients - Phosphorus

Phosphorus is one of a number of elements that serve as a basic building block for life and, in an aquatic system it is an element that promotes growth of plant life. In most lakes, it is the key nutrient affecting the amount of algae and plant growth in a lake. Phosphorus originates from a variety of sources, including human and animal wastes, soil erosion, detergents, septic systems and runoff from land into waterways.

An assessment of phosphorus in a lake often includes both *soluble reactive phosphorus* and *total phosphorus*. Soluble reactive phosphorus (orthophosphate) is dissolved and readily aids plant growth. Its concentration varies widely as plants absorb it for growth and release it upon death. Total phosphorus is often considered to a better indicator of a lake's nutrient status because its levels remain more stable - including both soluble (available) and particulate (biomass) phosphorus.

In most instances, there is sufficient phosphorus in Deep Creek Lake to support a larger plant biomass, but additional growth is likely limited by the amount of available phosphorus in the system. Several forms of phosphorus are measured

Range

Orthophosphate (PO_4)(2009-2013)

Lake (surface): 0.0 to 0.004 mg/L
Lake (bottom): 0.0 to 0.009 mg/L
Embayment (surface): 0.0 to 0.005 mg/L mg/L

Dissolved Phosphate (TDP) (2009-2013)

Lake (surface): 0.001 to 0.031 mg/L
Lake (bottom): 0.001 to 0.1 mg/L
Embayment (surface): 0.001 to 0.12

Particulate phosphate (PP)(2009-2013)

Lake (surface): 0.002 to 0.014 mg/L
Lake (bottom): 0.002 to 0.057 mg/L
Embayment (surface): 0.002 to 0.037 mg/L mg/L

Phosphorus -calculated (TP) (2009-2013)

Lake (surface): 0.0 to 0.034 mg/L
Lake (bottom): 0.00 to 0.106 mg/L
Embayment (surface): 0.004 to 0.132

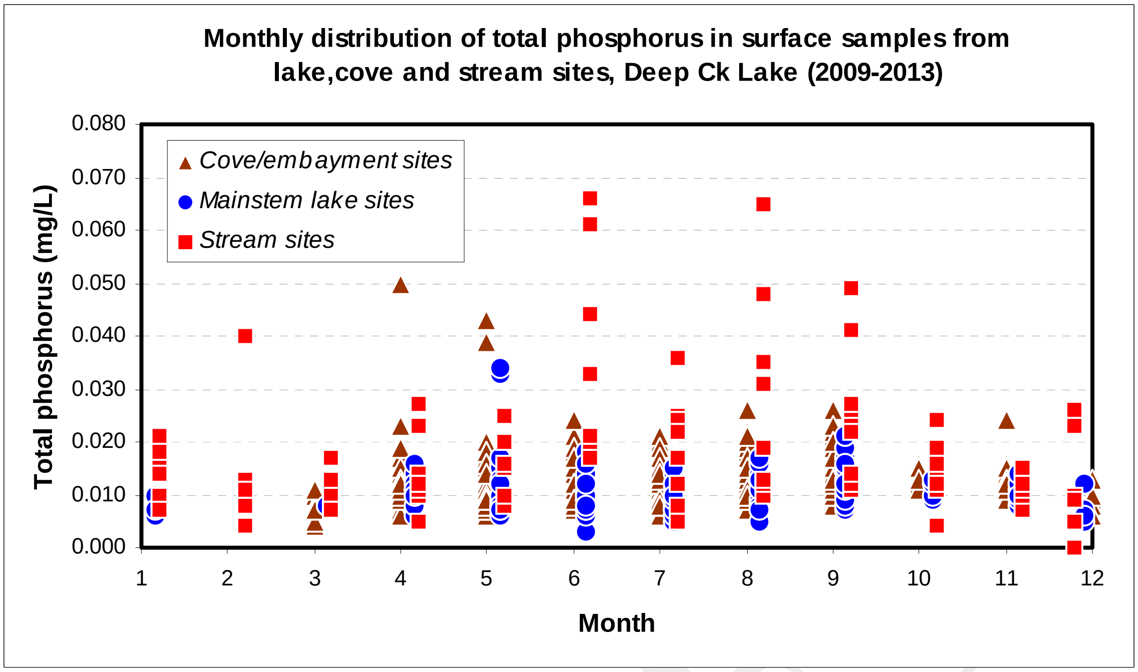
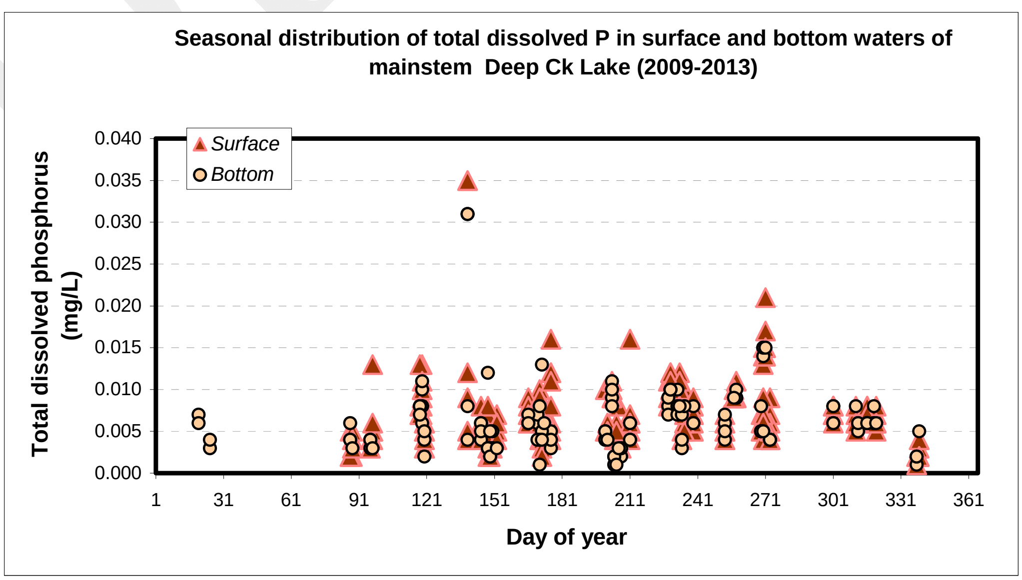


Figure 34

Total phosphorus levels (calculated as dissolved P + particulate P) from watershed sites are low overall. In many samples, total phosphorus tends to decline further from the source (stream,> embayment > open main lake waters) as particulates containing phosphorus settle to the bottom. (Figure 34)

Surface and bottom concentrations of total dissolved phosphorus (TDP) (Figure 35) and particulate phosphorus (PP) (Figure 36) are often low, with higher concentrations often found in surface waters. During the summer stratification period (May-September), there is also an increase in TDP in the hypolimnion as, under low oxygen conditions, phosphorus may be released from sediments and organic matter on the bottom.

Figure 35



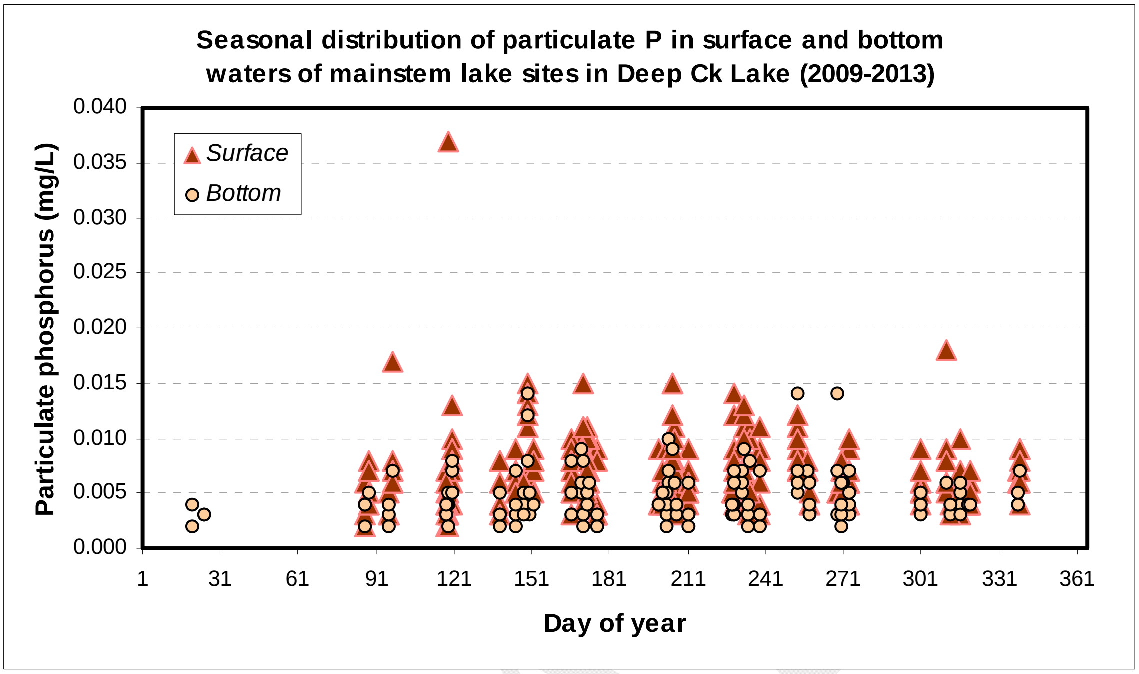


Figure 36

Nutrients - Nitrogen

Like phosphorus, nitrogen is an important element that serves as a building block for life and a nutrient to stimulate growth. Like phosphorus, nitrogen is found in a variety of sources

In most instances, there is an excess of nitrogen in lakes and reservoirs. This is not utilized by plants because of limited availability of the other principal nutrient, phosphorus.

During the present water monitoring effort (2009-2013), a various nitrogen compounds have been assessed with samples collected from the surface layer at all sites and in the bottom waters of deep, main stem lake sites. Nitrogen compounds that are analyzed include ammonium, nitrate+nitrite, nitrite, total dissolved nitrogen, and particulate nitrogen. From these measures, nitrate and total nitrogen are calculated.

Total dissolved nitrogen (TDN)(2009-2013)
Lake (surface): 0.132 to 0.40 mg/L
Lake (bottom): 0.132 to 0.708 mg/L
Embayment (surface): 0.127 to 0.677 mg/L

Ammonium (NH4) (2009-2013)
Lake (surface): 0.00 to 0.234 mg/L
Lake (bottom): 0.00 to 0.55 mg/L
Embayment (surface): 0.00 to 0.117 mg/L

Nitrite (NO2)(2009-2013)
Lake (surface): 0.00 to 0.01 mg/L
Lake (bottom): 0.00 to 0.026 mg/L

Nitrate (NO3) - calculated (2009-2013)
Lake (surface): 0.00 to 0.265 mg/L
Lake (bottom): 0.00 to 0.264 mg/L

Embayment (surface): 0.00 to 0.017 mg/L

Embayment (surface): 0.00 to 0.48 mg/L

Particulate nitrogen (PN)(2009-2013) 2013)

Lake (surface): 0.012 to 0.171 mg/L
Lake (bottom): 0.007 to 0.23 mg/L
Embayment (surface): 0.011 to 0.273 mg/L

Total nitrogen (TN) - calculated (2009-

Lake (surface): 0.171 to 0.504 mg/L
Lake (bottom): 0.172 to 0.824 mg/L
Embayment (surface): 0.157 to 0.775 mg/L

Examining monthly total nitrogen by sample group (Deep Creek Lake watershed streams, embayments, main stem) (Figure 37) show that stream samples (Cherry Creek, Poland Run) often have the highest concentration of nitrogen in comparison to embayment samples. This is clearly seen in the following figures showing annual nitrate (Figure 38) and ammonium (Figure 39) distributions in main stem Deep Creek Lake

During the summer stratification period (May to September), ammonium and nitrate in surface waters are depleted by phytoplankton uptake. Nitrogen remains in particulate form in the food chain or as waste - often a dissolved organic form.

In the hypolimnion, nitrate levels decline (Figure 38) and are converted (denitrified) to ammonium. Decomposition of organic matter (ammonification) contributes to increases in ammonium (Figure 40). As the fall overturn occurs, ammonia released to other open waters of the lake are quickly absorbed by phytoplankton or released to the atmosphere (Figure 38). In many reservoirs, an algal bloom follows the fall turnover as nutrients are made available to phytoplankton

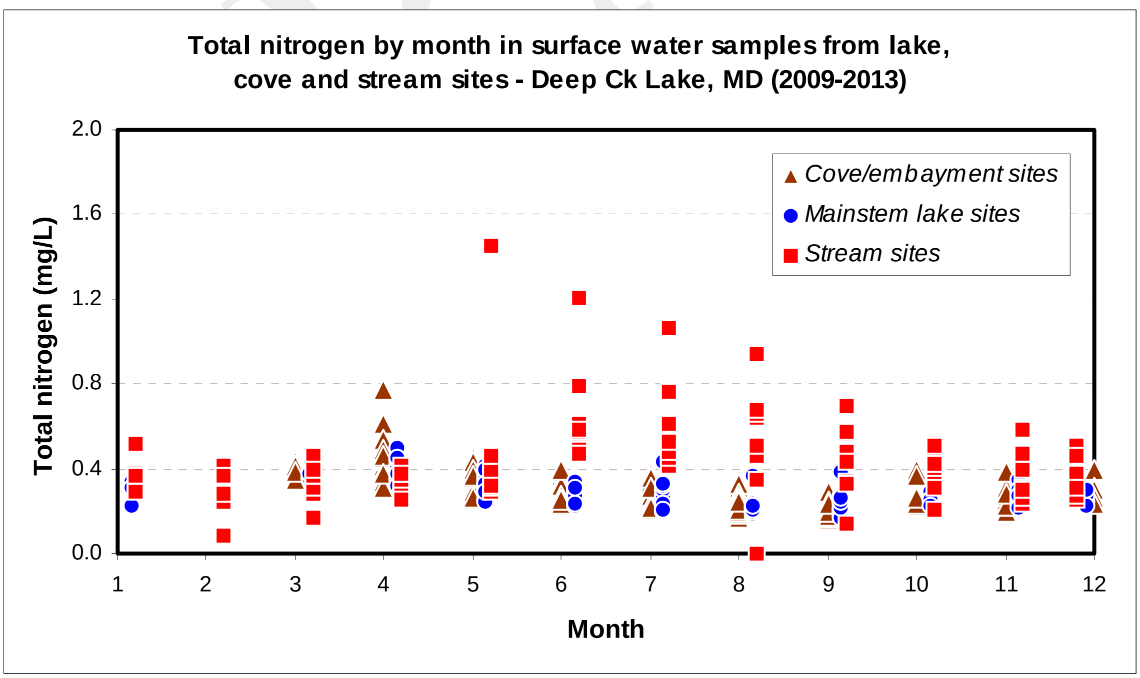


Figure 37

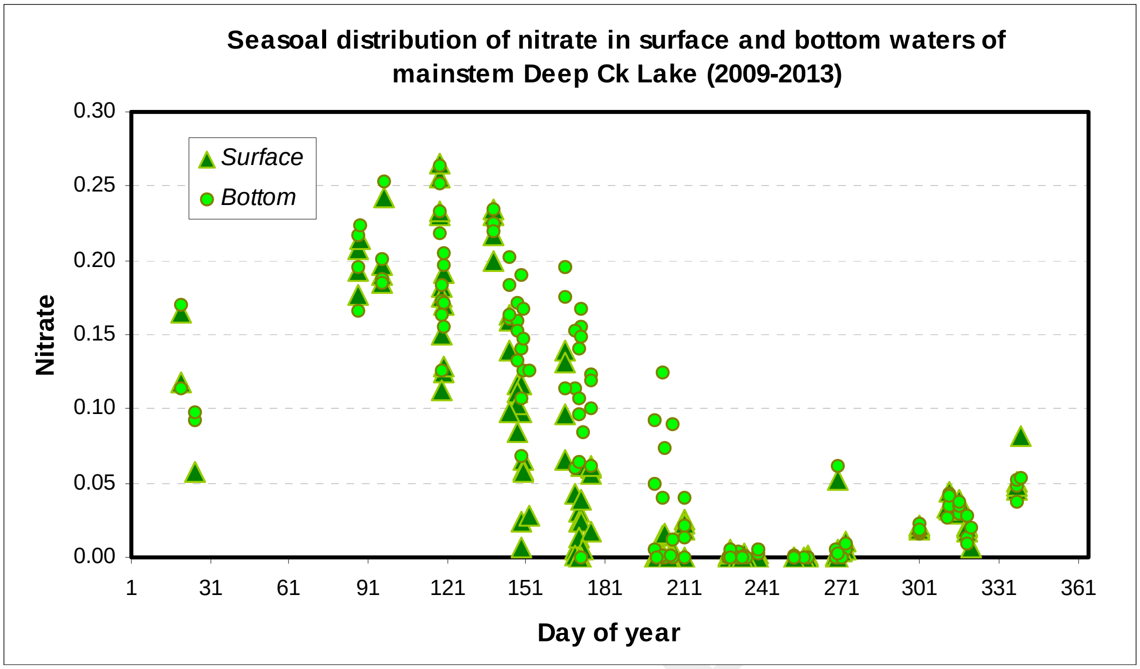


Figure 38

Reduced nitrogen (ammonium) concentrations increase within the seasonal hypolimnion. In late summer, it is likely that ammonium diffuses through the thermocline into the deep portions of the epilimnion where low oxygen conditions have been observed - possibly a result of microbial respiration. As surface water temperatures cool in the early fall, a turnover occurs mixing the nitrogen-rich waters of the old hypolimnion with nutrient-poor surface waters.

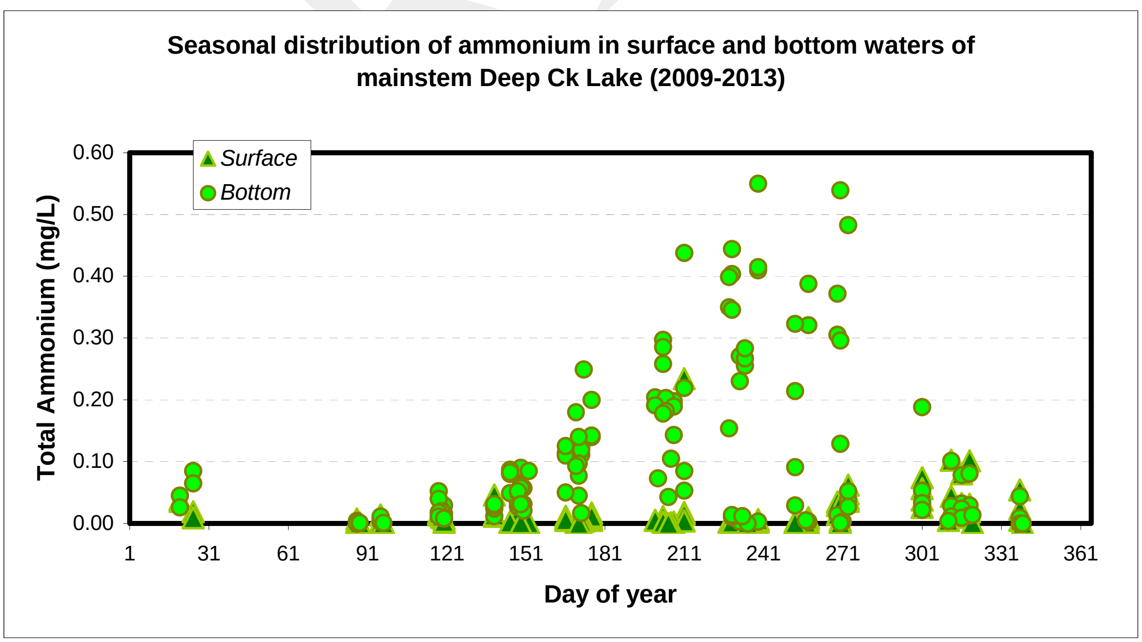


Figure 39

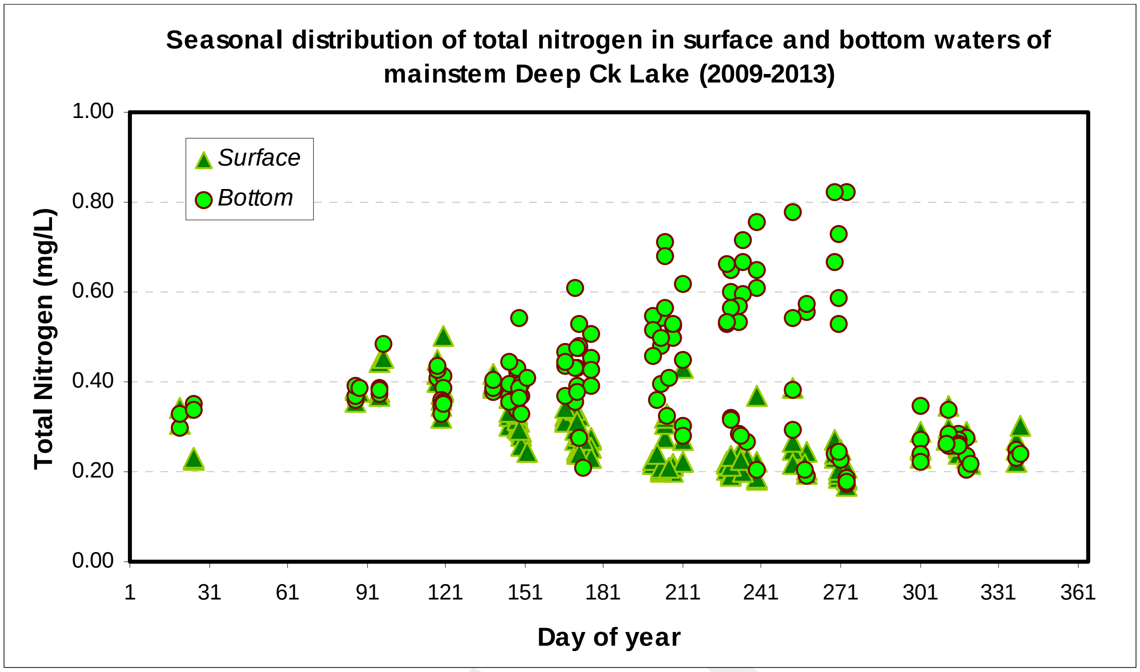


Figure 40

In many reservoirs, an algal bloom often follows the fall turnover as nutrients are made available to phytoplankton near the surface. Because of the monthly monitoring interval and lack of samples in fall, the presence of an algal bloom in fall is not known.

Chlorophyll

The measure of chlorophyll-α, the principal photosynthesis molecule in many plants, provides a direct measure of phytoplankton abundance without counting and identifying each plant cell and an easy-to-assess approach to measuring algal biomass.

Range

Chlorophyll-α (2009-2013):

Lake (surface): 0.5 to 22.7 µg/L
Lake (bottom): 0.2 to 8.6 µg/L
Embayment (surface): 0.3 to 36.3 µg/L

Chlorophyll levels were often higher in lake embayments (surface) than in open lake waters which is likely due to exposure to warm waters (higher metabolism) and higher nutrient (phosphorus) concentrations.

Trophic assessment

Chlorophyll measurements provide a direct measurement of phytoplankton biomass. When collected from the surface in open lake waters during summer, the average result can be directly applied to assessing the trophic condition of a lake. See Trophic State - next section.

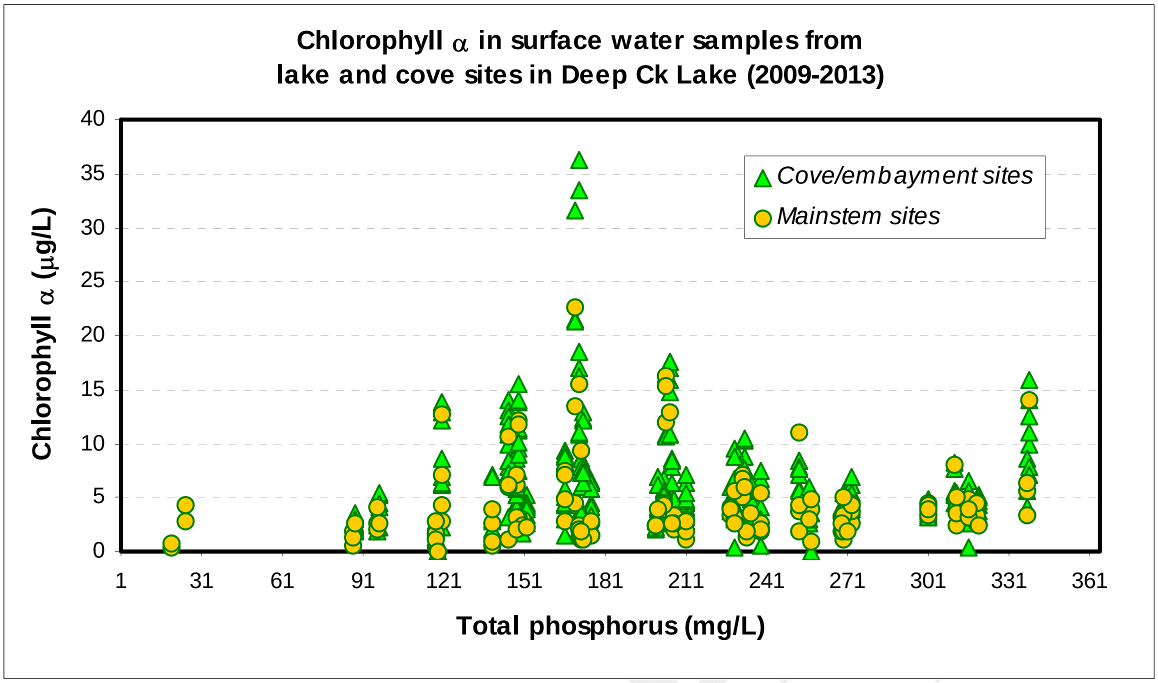


Figure 41

N:P Ratio

In areas where algal blooms are considered a nuisance and in need of control, one management approach is to define and manage or limit the nutrient "controlling" growth. An approach often used is to define what nutrient is the controlling nutrient by measuring the ratio of total nitrogen and total phosphorus concentrations. By comparing the abundance of one essential nutrient to another (usually Total Nitrogen and Total Phosphorus), it may be possible to limit plant growth if the less abundant nutrient can be limited ("limiting nutrient").

Range/mean

TN:TP ratio (2009-2013):

Lake (surface):	minimum: 10.7	maximum: 82.3	mean: 29.1
Embayment (surface):	minimum: 2.3	maximum: 91.3	mean: 24.2

The graph below (Figure 42) shows the seasonal and spatial relationship between TN:TP ratio, location and time of year based on surface water quality samples collected at Deep Creek Lake main stem and embayment sites. Less than 1 percent of the embayment sites had a TN:TP ratio less than 10; in lake sites, none (0) of the 144 observations had a TN:TP ratio less than 10. As presented, phosphorus is the limiting nutrient - at least where samples were collected.

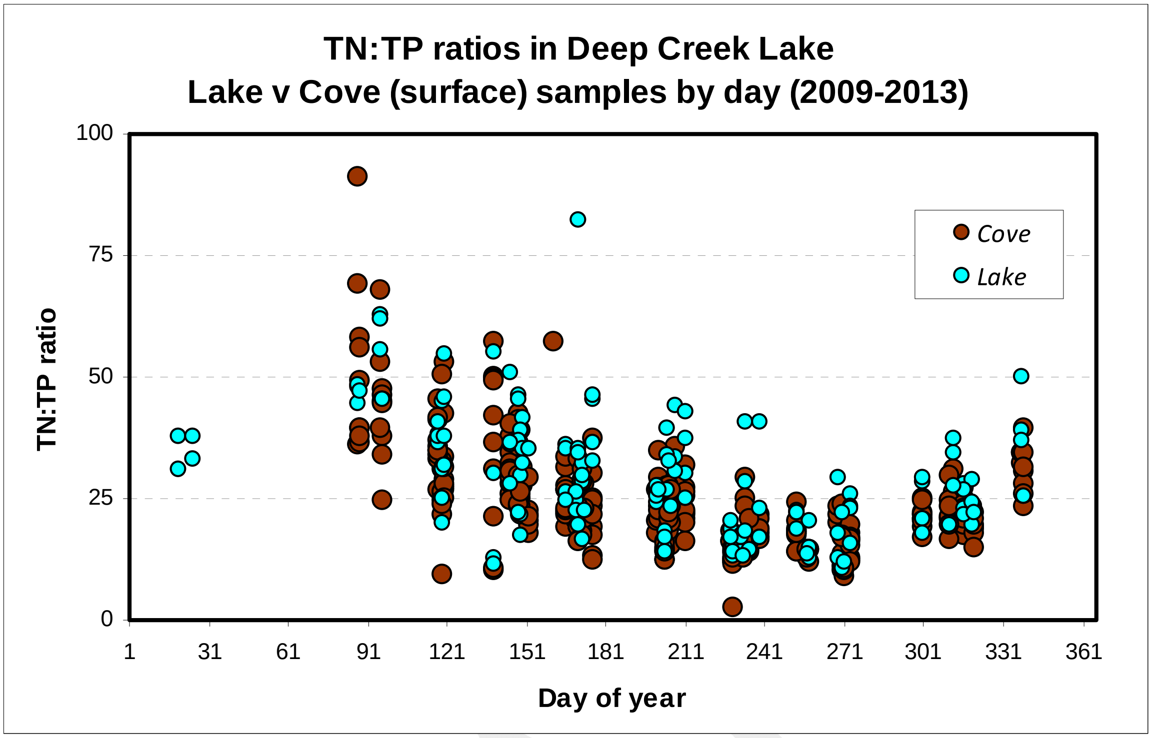


Figure 42

The figure above shows seasonality and considerable variation. Results when nutrient levels are very high or very low or when algal blooms are present may not accurately define limiting nutrients. Results may be more meaningful if water samles are collected closer to sources of nutrients or near sites where chronic algal blooms occur (near shorelands or in reservoir transition areas). Bioassays would likely provide more quantitative results

Trophic state

"Trophic state" is defined as the total weight of living biological material (*biomass*) in a waterbody. It is the biological response to factors such as nutrient additions, but it also is modified by factors such as season, grazing, mixing depth, and so on. As a result, trophic state does not defining a static type of lake, but rather a continuum of condition.

Trophic state is often used to describe lake water quality, but it is an absolute measure describing the biological condition of a waterbody, not a relative measure that is subject to change. A lake defined as *eutrophic* has attributes of production that remain constant no matter what the use of the water or where the lake is located. For the trophic state terms to have meaning at all, they must be applicable in any situation in any location.

Carlson's (1977) trophic state index (TSI) defines these states using chlorophyll pigment levels, but other, independent measures for Secchi depth, and total phosphorus also can be used to independently estimate algal biomass. As a direct measure of biomass, trophic state is best defined by chlorophyll measurements with supplemental assessments possible using Secchi depth and total phosphorus. (Table 4)

Equations often used to calculate Carlson's Trophic State Index from Secchi disk depth (SD), Chlorophyll-a (CHL) and Total Phosphorus (TP) include (where 'Ln' is natural logarithm):

- TSI - TP = 14.42 * Ln [TP] + 4.15 ;   with phosphorus units in μg/L
- TSI - CHL = 30.6 + 9.81 Ln [CHL];   with chlorophyll a units in μg/L
- TSI - SD = 60 - 14.41 * Ln [SD] ;   with Secchi depth units in meters

Trophic state, the general measurement ranges, general attributes and possible fisheries and recreation impacts are shown in the following table.

Summary:

The average chlorophyll levels in the Deep Creek Lake main stem in summer 2013 were more than twice as high as any of the previous 4 years of monitoring - resulting in the Trophic State of Deep Creek Lake in 2013 being identified as *Eutrophic*. In 2012, the average chlorophyll data was the lowest over the past five years and the trophic state of the lake was identified as *Oligotrophic*. Such wide swings aren't really unusual in environmental studies. Additional work is needed to review these findings (examining weather and runoff records, site-specific reviews, checking QA samples for field/laboratory problems, and so on). Over the last 5-year period, most of the data collected has shown that the trophic status of Deep Creek Lake should be considered ***Mesotrophic***.

Table 4. Lake trophic status index and water quality (Carlson, 1977)

Trophic state	Trophic State Indicator –TSI Score	Secchi depth (m)	Total phosphorus (μg/L)	Chlorophyll a (μg/L)	Water quality conditions
Oligotrophic	<30	16 - 64	0.75 - 3	0.04 - 0.34	clear water; high DO throughout the year in hypolimnion
	30 - 40	8	6	0.94	clear water; periods of limited hypolimnetic anoxia
Mesotrophic	40 - 50	2 - 4	12 - 24	2.6 - 6.4	moderately clear water; increasing chance of hypolimnetic anoxia in summer; fully supportive of all swimmable/aesthetic uses

Eutrophic	50 - 60	1	48	20	decreased clarity; anoxic hypolimnion; macrophyte problems; warm-water fisheries only; supportive of all swimmable/aesthetic uses but "threatened"
	60 - 70	0.5	96	56	blue-green algae dominance; scums possible; extensive macrophytes problems
Hypereutrophic	70 - 80	0.25	192	154	heavy algal blooms possible throughout summer; dense macrophyte beds
	>80	0.125 - 0.0625	384 - 768	427 - 1,183	algal scums; summer fish kills; algal shading limitsmacrophytes; rough fish dominance

Using the summer season average of Secchi depth, and surface samples of chlorophyll in main stem lake sites, the following results are obtained (Table 5):

Table 5. Deep Creek Lake annual trophic status index, 2009-2013

Year	Average surface chlorophyll a (ug/L)	Trophic State Indicator - chlorophyll	Trophic state
2009	3.0	41	**Mesotrophic**
2010	3.7	43	**Mesotrophic**
2011	4.1	44	**Mesotrophic**
2012	2.3	39	**Oligotrophic**
2013	10.5	54	**Eutrophic**

Trends

With five consecutive years of data, there are insufficient data to define long-term water quality trends with lake data collected by this program. There are, however, some quantitative water quality measures have been collected in Deep Creek Lake at various times back to 1970. Assessing trends with some measures can be difficult if sampling and analysis methods have changed, but several measures have not changed significantly. Using data from the same or nearby sites and only during the same summer period, long term water quality trends appear to show changes in some lake measures over time.

Long-term changes in pH in select Deep Creek Lake stations, 1970 - 2013

The figure below does not show any significant change in pH over the last 43 years (Figure 46). Data collected in the early 1970's show substantial variability that may be due to measurement or analysis techniques which could mask any underlying trends. pH in samples collected later show much less seasonal/sampling variance. While there may be an increasing trend in the last 15 years, annual variability is too great to define a significant trend. It might be expected that continuing reductions of acidic air deposition, and reductions or changes in the quality streams affected by abandoned coal mine drainage or increases in algal / plant productivity would result in an increasing trend in pH.

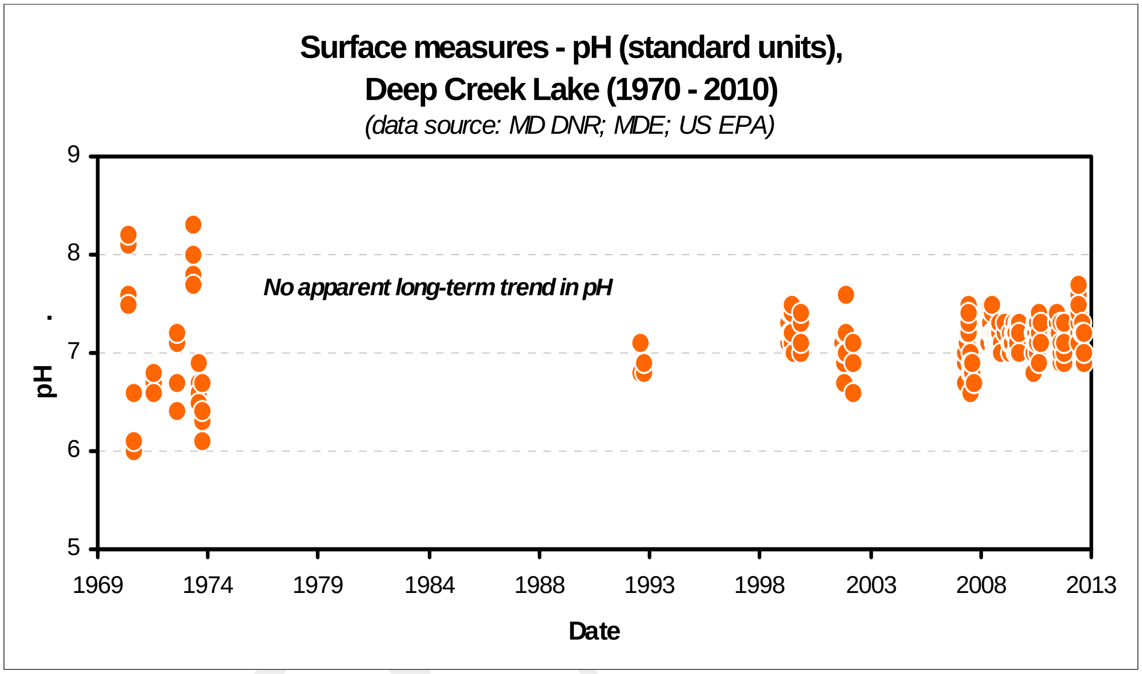


Figure 46

Long-term changes in specific conductivity in select Deep Creek Lake stations, 1970 – 2013

Specific conductivity is a measure of dissolved ions in water, so materials that will dissolve in water (e.g., salts, as in deicing material, fertilizers and septic wastes) can be tracked. The figure below shows that there has been a substantial increase in specific conductivity between 1970 and 2013 (Figure 47).

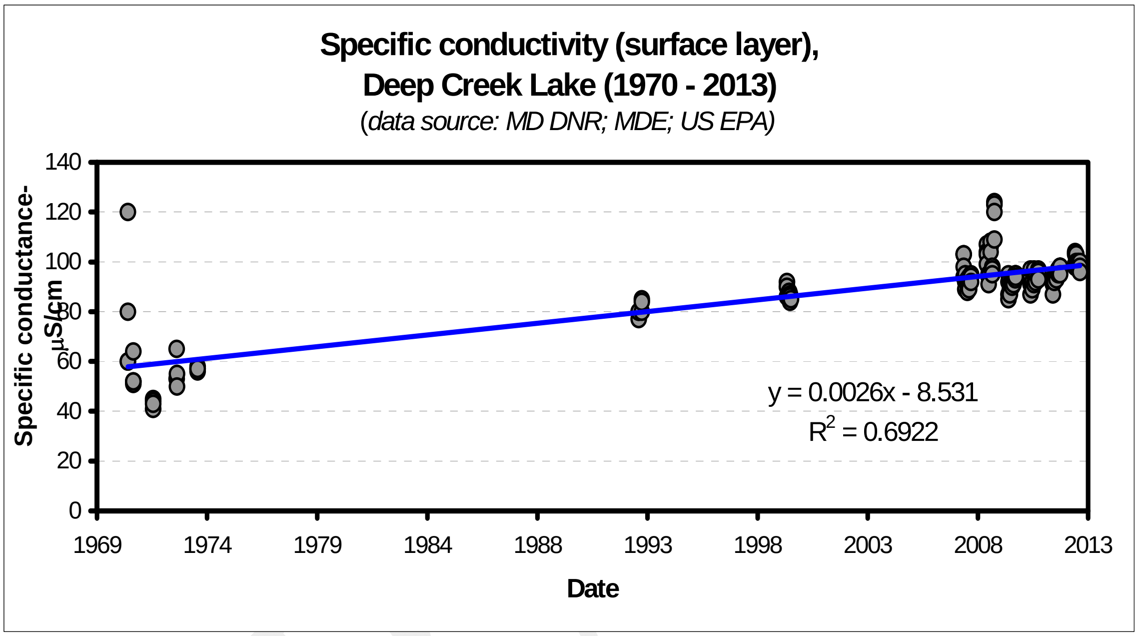


Figure 47

At present, conductivity levels in the lake are well below any level that would affect aquatic life , but if this trend continues or, if it is due to changes in land use in the lake watershed, then if conductivity continues to increase (to 200 uS/cm+), the aquatic community will start to change.

Long-term changes in trophic state in select Deep Creek Lake stations, 1970 - 2013

Has the trophic state of Deep Creek Lake (determined by Trophic State Indicator – TSI) changed over the past 43 years? Using available data and chlorophyll concentrations to define trophic state show the following as an annual assessments of the lake's trophic state (Figure 48):

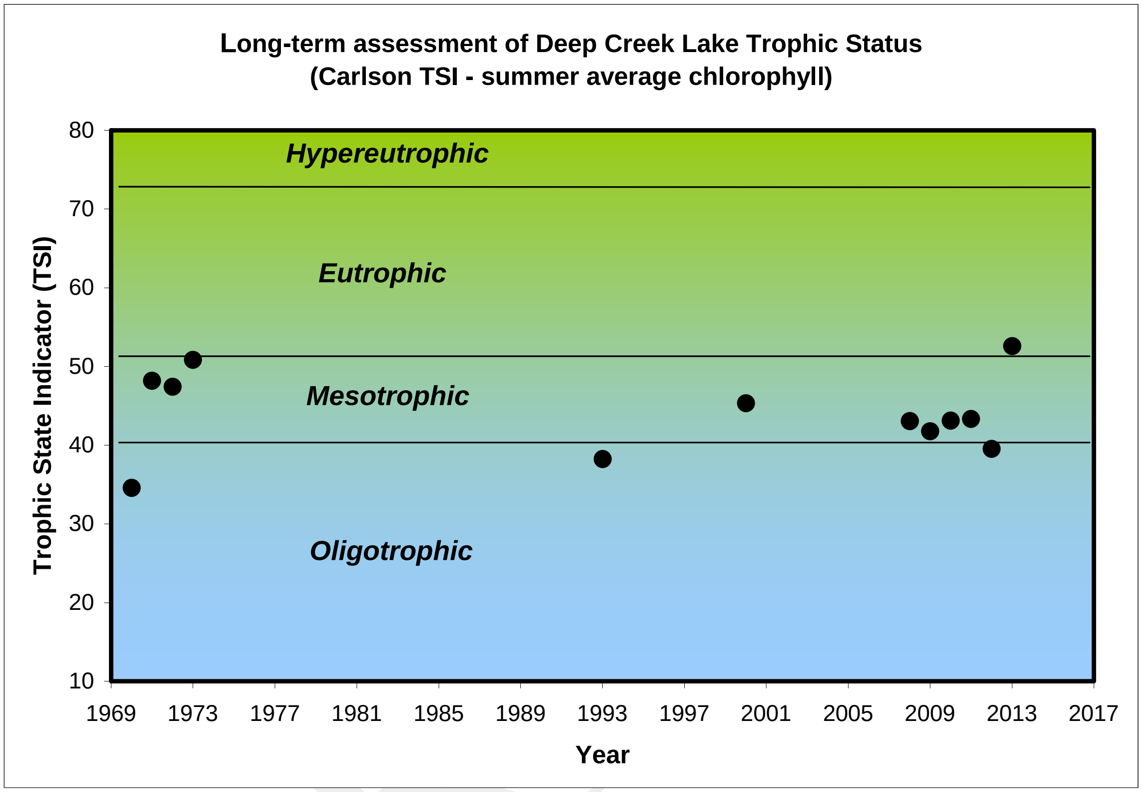


Figure 48

While it appears that there may no trend in the calculated TSI over the past 43 years, there is enough variance in the data that there is no significant trend. Annual variations occur and, while 2014 had the highest level of chlorophyll reported in more than four decades, chlorophyll levels in 2013 was one of the lowest recorded. A long-term measure of Trophic State should be considered as a standard reporting indicator for assessing management of Deep Creek Lake and its watershed.

Conclusions

With a few exceptions, water quality conditions in Deep Creek Lake meet water quality standards, support various recreational activities (swimming, fishing, boating), support aquatic life and commercial and industrial uses of lake waters.

Exceptions to this statement must address the existing consumption advisory on key sportfish due to mercury contamination from sources outside of the watershed. In addition, the biological community in watershed streams are poor in comparison to other western Maryland streams for unknown reasons and low pH conditions, while having been improved, still persist in Cherry Creek due to past coal mining activities.

Naturally-occurring, seasonally low oxygen conditions in the deep portion of the lake creates poor habitat conditions for fish, but it does not adversely affect recreational uses of the lake.

Biological productivity in the lake is moderate and the lake state is clearly mesotrophic. The lake supports a diverse population of phytoplankton and higher plants which helps support a diverse grazing/prey and predator chain.

Submerged Aquatic Vegetation (SAV)

During the summer 2013 field season, Maryland Department of Natural Resources (DNR) Resource Assessment Service (RAS) biologists conducted a fourth year of submerged aquatic vegetation (SAV) monitoring in Deep Creek Lake (DCL). Despite its inherent ecological benefits, SAV can be an impediment to recreation and boat traffic in shallow areas, or in areas with fluctuating water levels. Due to concerns raised by some DCL residents regarding the density of SAV during the summer season, RAS biologists implemented an SAV transect monitoring plan in summer 2010 and repeated the survey in summers 2011, 2012, and 2013. The 2012 summer survey was expanded to include a comprehensive shoreline survey of *Myriophyllum* species (including Eurasian Watermilfoil, an invasive species). This survey was repeated in 2013. An additional shoreline survey was initiated in October 2013 to document the spatial extent of the newly observed *Hydrilla verticillata* (also an invasive species) in the lake. Our monitoring objectives were to define the distribution and relative abundance of SAV species present in the lake and to record their change over time via the study of representative transects, and to identify the location and extent of *Myriophyllum* and *Hydrilla* via the shoreline surveys. This work is a component of the comprehensive water quality and habitat monitoring program in DCL which began in April 2009.

BACKGROUND

Deep Creek Lake is located in Garrett County, western Maryland. The lake was formed in 1925 when Deep Creek was impounded for hydro-electric power generation. Following its creation, DCL was owned by multiple power companies until 2000, when the State of Maryland purchased the lake bottom and shoreline buffer zone. The State's acquisition of DCL has presented many unique and challenging management issues, particularly to DNR's RAS and Park Service.

With a surface area of 3,900 acres and 68 miles of shoreline, DCL is Maryland's largest reservoir. The lake is composed of a mainstem, branches, and multiple small, shallow coves fed by four major tributaries and more than 50 smaller streams. The lake's 180,000 acre watershed is located west of the eastern continental divide, ultimately draining into the Gulf of Mexico. Because it is a reservoir, the water level fluctuates seasonally due to managed releases and hydrographic conditions, resulting at times in very shallow coves.

Beginning in late spring when temperatures increase, SAV begin growing throughout the lake's photic zone, particularly in the shallower coves, which are the first to receive nutrient-enriched runoff from the surrounding watershed, and are warmer due to shallower depths. Similar to their terrestrial counterparts, SAV are underwater grasses which provide a myriad of important ecological functions. Through the process of photosynthesis, SAV produce oxygen that is vital to the survival of all lake organisms. They provide food, habitat, and nursery grounds for many species of fish and invertebrates, as well as waterfowl. They absorb nutrients, which in turn decreases the likelihood of algal blooms, and they improve water clarity by locking sediments in their root systems. SAV also diminish the effects of shoreline erosion by reducing the impacts of currents and waves (generated by wind as well as heavy boat wakes), also improving water clarity. Additionally, healthy native aquatic plant communities help prevent the establishment and spread of invasive plants like Eurasian watermilfoil (*Myriophyllum spicatum*) and *Hydrilla verticillata,* both of which are found in Deep Creek Lake.

There are approximately 70 species of *Myriophyllum* (watermilfoil), submersed aquatic plants that are most commonly recognized for their long stems and whorled leaves that are finely, pinnately divided. The name *Myriophyllum* comes from Latin, "myrio" meaning "too many to count", and "phyllum" meaning "leaf". *Myriophyllum* fruits and leaves are an important food source for waterfowl, which are thought to play an important role in seed and clonal dispersal (Jacobs and Margold, 2009). *Myriophyllum spicatum,* or Eurasian Watermilfoil, is one of three species of *Myriophyllum* found in Deep Creek Lake, but it is the only invasive variety.

The genus *Hydrilla*, on the other hand, has a single species, *H. verticillata*, which is considered an exotic invasive throughout the United States. The strain found in Deep Creek Lake is thought to be the monoecious strain introduced to Delaware in 1976. This plant is a rooted aquatic plant that forms dense mats in still or slowly moving water. *Hydrilla* is very similar in appearance to the native waterweed *Elodea canadensis*, which is found throughout Deep Creek Lake.

METHODS

In June 2010, RAS biologists, accompanied by local SAV experts from Frostburg State University, identified six areas to survey in Deep Creek Lake. These areas were selected based on spatial distribution (two north/western, two central, and two south/eastern) and the presence of SAV. These locations are as follows: Red Run Cove (-79.3711, 39.49977), an area near the town of McHenry (-79.35787, 39.55087), an area near the Honi Honi Bar and Restaurant in Oakland (-79.32091, 39.50485), Meadow Mountain Run Cove (-79.30334, 39.51182), Deep Creek Cove (-79.30904, 39.45368), and Green Glade Cove (-79.26206, 39.47844). See Figure 49 for a map of locations and Table 6 for a list of site abbreviations.

At the time each transect location was established in June 2010, the extent of the SAV bed was identified by dive-certified SAV biologists using SCUBA. Along the shoreward edge of the bed, a spot was randomly selected to begin a transect. Rebar was used to mark each point and secure a transect tape. A biologist then swam the tape out, perpendicular to shore, to the deep edge of the SAV bed where a weighted buoy was placed to mark the point and secure the opposite end of the tape. If conditions were considered unsafe due to heavy boat traffic, transects were terminated

Figure 49. Aerial map of Deep Creek Lake with MD DNR SAV transect locations indicated by red dots.

Table 6. Transect names and abbreviations.

Site	Abbreviation
Red Run Cove	RRC
McHenry	McH
Honi Honi Oakland	HHO
Meadow Mountain Run	MMR
Deep Creek Cove	DCC
Green Glade Cove	GGC

prior to the edge of bed. If the SAV bed extended farther than 200 meters from shore, transects were terminated at 200 meters. Both ends of the transect were recorded using a handheld Garmin Global Positioning System (GPS) device so that all future surveys could be repeated in the same location. If the SAV beds expanded or contracted, a new point was recorded and the transect was terminated at the current edge of bed.

During each sampling event, SAV biologists sampled eleven $0.25m^2$ quadrats per transect. To establish the sampling positions, the transect lengths were divided by 10 for a total of 11 quadrats per transect. For example, if a transect was 100 meters long, quadrats were sampled at 0m, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90, and 100m from the shoreward edge of bed. Within each quadrat, the percent cover of both underwater grasses and macroalgae (MA) were visually quantified for each species present. A total SAV percent cover was also estimated, as well as a total macroalgae percent cover. In this case, SAV is any vascular plant present, whereas macroalgae is any non-vascular plant present. The two groups are quantified and recorded separately because of their differing responses to water quality dynamics. [Note: SAV and MA were not originally separated, so results in this report regarding previous years may vary from results in past reports. Additionally, MA was previously identified to the genus level. In 2013, MA was only identified as MA and previous years data were clumped to reflect the lack of differentiation]. Canopy height for each species present was recorded when possible, as well as water depth at each quadrat. Shoot counts for each species were completed within a smaller square in the bottom right corner of the quadrat when feasible. If the plant could not be identified to the species level, only the genus was recorded.

Transects were surveyed on August 5th and September 16th, 2010, on June 14th, August 9th and September 12th, 2011, on June 27th, August 22nd, and September 19th, 2012, and on June 20th, August 15th, and September 27th, 2013. In August, 2013, the transect at McHenry was not surveyed due to a sewage spill in the vicinity.
On June 16th, 2013, the *Myriophyllum* survey was conducted of the entire 68-mile shoreline to determine the location and extent of the plant, and to determine change in extent from 2012. The survey was conducted over a two-day period using three boats. Each boat was equipped with a driver and one to two on-board "observers", as well as Lowrance HDS echo-sounders (with side and down-scan functionality) and hand-held Garmin GPS units. The Lowrance echo-sounders display unique signatures for different species of SAV; that functionality combined with the on-board observers provided the ability to locate and geographically mark *Myriophyllum* using the hand-held GPS. Although there are three species of *Myriophyllum* present in DCL, only one, *Myriophyllum spicatum*, is invasive. Because it is physically similar to and difficult to differentiate from other species of the genus, all *Myriophyllum* observations were recorded.

On October 21st, 2013, after the discovery of the invasive species *Hydrilla verticillata* near the Deep Creek Cove transect on September 27, 2013, an additional survey was conducted of the entire 68-mile shoreline to determine the location and extent of *Hydrilla verticillata*. The survey was conducted over a two-day period using two boats and the same methodology as the *Myriophyllum* survey.

Data Analysis

Raw transect data were entered into a Microsoft Excel spreadsheet. Using color-blocking, Total SAV and Total Macroalgae data were used to create color-coded representations of the transects which were geographically overlaid onto a map of Deep Creek Lake. Species richness was defined for each transect and sampling event as the number of species observed per transect. Species diversity, which is a measure of both the number of species (richness) and the relative contribution of each of these species to the total number of individuals in a community, was also calculated and analyzed. Frequency of occurrence and density for each species or genera at each site were calculated using the following formulas:

Frequency of Occurrence = # of quadrats where observed /total # of quadrats

Density = sum of % cover values/ total # of quadrats.

Density and frequency of occurrence were used to determine which species were dominant at each site during each sampling event. Dominance was defined as density being equal to or greater than 10% or frequency of occurrence being equal to or greater than 50%. To determine dominance for sampling year 2010, a species/genus had to be found dominant during both sampling events that took place that year. For sampling years

2011-2013, in which three sampling events took place, a species/genus had to be found dominant during two of the three sampling events.

To graphically display observed changes in Total SAV and Total Macroalgae over time, density data were entered into Sigma Plot graphing software and bar charts were created. To show observed changes in *Myriophyllum* specifically, frequency of occurrence and density data for this genus were also entered into Sigma Plot graphing software. Bar graphs were created to show change in *Myriophyllum* density while point/line graphs were created and overlaid on density graphs to simultaneously show changes in frequency of occurrence over time.

To identify any significant differences in SAV among sites and changes over time, statistical analyses were performed using the SAS statistical software package (Enterprise Guide 5.1, SAS Institute Incorporated, Cary, NC). Species richness and diversity, Total SAV density and Total Macroalgae density were compared over time and among sites using 3-Way ANOVAs. Individual species density and frequency of occurrence were also assessed in order to determine differences over space and time using 1-Way ANOVAs. Homogeneity of variances was assessed using Levene's test. Following a significant ANOVA ($p \leq 0.05$), pairwise comparisons were performed using Bonferroni's test.

Data collected during the *Myriophyllum* and *Hydrilla* shoreline surveys were transferred from hand-held Garmin GPS units into ArcGIS for mapping and analysis (ArcGIS Desktop 9.3. Redlands, CA: Environmental Systems Research Institute). To determine the area affected by these invasive species, polygons were drawn based on GPS points and notes from the field and were merged to create maps of *Myriophyllum* and *Hydrilla* distribution.

RESULTS

We observed ten genera of vascular aquatic plants and two species of macroalgae during our 2010, 2011, 2012, and 2013 SAV surveys. These plants include *Vallisneria Americana*, *Sagittaria cristata*, *Elodea canadensis*, *Myriophyllum spp.* (including the native *M. sibiricum*, the native *M. heterophyllum*, and *M. spicatum*, or Eurasian watermilfoil, an Aquatic Invasive Species in North America), *Ceratophyllum demersum*, *Najas flexilis*, *Najas guadalupensis*, *Utricularia vulgaris*, *Isoetes spp*., and five species of *Potamogeton*, including *Potamogeton robbinsii*, a species thought to be extirpated from Maryland waters, *P. pusillus*, *P. vaseyii*, *P. spirillus*, and *P. diversifolius. Potamogeton amplifolius* (also believed to be extirpated from Maryland waters) and *P. nodosus* were also observed in DCL, as was *Hydrilla verticillata*, but because they were not on any of the transects, they were not included in the transect data analyses. The two macroalgae observed include *Nitella flexilis* and *Chara vulgaris.* In 2013 sampling, it was determined that *Nitella* and *Chara* would no longer be differentiated during sampling due to physical similarity and difficulty in differentiation while SCUBA diving. Common names and abbreviations for these species can be found in Table 7. Pictures and a brief description of each species are given in Appendix A.

Due to the difficulty in accurately identifying *Myriophyllum* to the species level, particularly while diving, *Myriophyllum spp*. were only identified and recorded at the genus level for the SAV transect survey. Samples collected throughout the lake, stored, and examined for species level identification in the lab confirmed that *M. spicatum*, *M. sibiricum*, and *M. heterophyllum* were all present in DCL.

Table 8 includes a summary of sampling results, including transect length, maximum water depth, Total SAV density, Total Macroalgae density, species richness, and density and frequency of occurrence for Total Macroalgae and each SAV species observed during each survey. Table 9 gives the dominant species observed during each sampling event and for the year. Figure 50 shows Total SAV and Total Macroalgae density graphed over time for each transect, with corresponding trendlines showing overall increasing, decreasing, or no-change trends. Maps of Deep Creek Lake with color-coded Total SAV and Total Macroalgae survey data, found in

Table 7. List of SAV species/genera observed in Deep Creek Lake during summers 2010-2013 SAV surveys. Also given are the abbreviations used in this report and the plant's common name. Note: * indicates that the plant was observed in the Lake, but not on a transect, so was not included in any analyses.

Species	Abbreviation	Common name
Sagittaria cristata	Sc	Crested arrowhead
Vallisneria americana	Va	Wild celery
Elodea canadensis	Ec	Canadian waterweed
Ceratophyllum demersum	Cd	Coontail
Myriophyllum spp.	Myr	Watermilfoil
*Hydrilla verticillata**	Hv	**Water thyme**
Najas flexilis	Nf	Slender/nodding naiad
Najas guadalupensis	Ng	Southern naiad
Utricularia vulgaris	Uv	Common bladderwort
Isoetes spp.	Iso	Quillwort
Potamogeton pusillus	Pp	Slender pondweed
Potamogeton robbinsii	Pr	Robbin's pondweed
Potamogeton vaseyi	Pv	Vasey's pondweed
Potamogeton spirillus	Ps	Spiral pondweed
Potamogeton diversifolius	Pd	Waterthread pondweed
*Potamogeton amplifolius**	Pa	Broad-leaved pondweed
*Potamogeton nodosus**	Pn	Longleaf pondweed
Chara vulgaris	Cv	Chara
Nitella flexilis	Nit	Nitella

Appendix B, compliment the bar charts in Figure 50 but more clearly display the quadrat by quadrat relationship between SAV and macroalgae. In most cases, there was an

inverse relationship between SAV and macroalgae; where SAV was dense, macroalgae was sparse, and
vice versa. Figure 51 shows *Myriophyllum* density and frequency of occurrence graphed over time for each transect.

Most species that were observed were seen throughout the lake, but each site was dominated by only a few species. The survey results for the SAV bed in Red Run Cove (RRC) (transect length from 90-127m and max depth of 4.1m, Table 8), in the northwestern portion of the lake near the dam, indicate that Macroalgae and *E. canadensis* dominated this bed in 2010 (Table 9). In 2011, *E. canadensis* maintained dominance, but *S. cristata* replaced Macroalgae. *Elodea canadensis* co-dominated with *Myriophyllum* and Macroalgae in 2012 and in 2013, *Sagittaria cristata* also co-dominated at this site. Total SAV in RRC showed a slightly decreasing though statistically insignificant trend from 2010-2013, despite a spike in SAV density in June 2013. There was, however, a significant overall decrease in Macroalgae at this site between 2010 and 2013, although data indicate that Macroalgae density oscillates over time (Figure 50). *Myriophyllum* was observed at low densities in RRC during every sampling event, but its frequency of occurrence spiked dramatically in 2013, as seen in Figure 51.

Table 8. Summary of sampling results, including date, transect length, maximum water depth, Total SAV density, Total Macroalgae density, species richness, and density and frequency of occurrence (in parentheses) for each SAV and macroalgae species observed during each survey.

Date	ID	Length (m)	Max Depth (m)	Richness	SAV Density	MA Density	*Sc*	*Va*	*Ec*	*Cd*	*Myr*	*Nf*	*Ng*	*Uv*	*Iso*	*Pp*	*Pr*	*Pv*	*Ps*	*Pd*
8/4/10	RRC	127	3.3	9	35	28(55)	6(18)	0(0)	5(55)	0(0)	3(9)	<1(18)	0(0)	<1(9)	<1(9)	10(18)	0(0)	9(45)	0(0)	0(0)
9/15/10	RRC	125	3.7	7	33	40(64)	9(18)	0(0)	10(55)	0(0)	<1(18)	0(0)	0(0)	<1(9)	0(0)	<1(9)	0(0)	11(27)	0(0)	0(0)
6/14/11	RRC	100	4.1	5	48	13(27)	2(18)	0(0)	9(55)	0(0)	5(36)	0(0)	0(0)	0(0)	0(0)	32(82)	0(0)	0(0)	0(0)	0(0)
8/9/11	RRC	110	3.7	7	71	2(18)	13(27)	0(0)	17(64)	0(0)	4(55)	<1(18)	0(0)	0(0)	0(0)	5(45)	0(0)	32(100)	0(0)	0(0)
9/12/11	RRC	100	3.3	6	41	0(0)	13(27)	0(0)	20(73)	0(0)	3(45)	2(9)	0(0)	0(0)	0(0)	3(45)	0(0)	<1(9)	0(0)	0(0)
6/27/12	RRC	100	3.6	7	58	34(45)	13(27)	0(0)	23(64)	0(0)	6(55)	0(0)	0(0)	<1(9)	0(0)	14(55)	0(0)	0(0)	0(0)	2(27)
8/22/12	RRC	110		7	42	15(27)	9(18)	0(0)	27(55)	0(0)	5(64)	<1(9)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)
9/19/12	RRC	100		7	39	18(36)	7(18)	0(0)	22(64)	0(0)	4(55)	0(0)	<1(9)	0(0)	0(0)	4(9)	0(0)	2(18)	0(0)	0(0)
6/20/13	RRC	100		6	71	1(9)	15(27)	0(0)	44(73)	0(0)	3(27)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	9(55)	0(0)	0(0)
8/15/13	RRC	100		9	29	17(64)	13(36)	0(0)	2(73)	0(0)	5(64)	<1(18)	0(0)	<1(9)	<1(9)	4(45)	0(0)	4(27)	0(0)	0(0)
9/27/13	RRC	90		7	31	6(55)	12(36)	0(0)	1(27)	0(0)	12(100	0(0)	0(0)	10(18)	<1(9)	0(0)	0(0)	<1(45)	0(0)	0(0)
8/4/10	McH	80	4.0	5	34	4(27)	2(18)	10(18)	12(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	9(45)	0(0)	0(0)	0(0)	0(0)
9/15/10	McH	90	4.0	7	14	5(18)	<1(18)	10(18)	2(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	<1(9)	0(0)
6/14/11	McH	77	5.3	4	4	53(82)	<1(9)	3(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)
8/9/11	McH	90	4.8	8	10	32(82)	<1(18)	7(18)	<1(27)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	<1(36)	0(0)	<1(9)	0(0)	0(0)
9/12/11	McH	60	4.0	7	16	8(64)	<1(9)	10(27)	<1(27)	0(0)	<1(27)	0(0)	0(0)	<1(18)	0(0)	3(45)	0(0)	0(0)	0(0)	0(0)
6/27/12	McH	100	5.4	7	12	55(73)	0(0)	8(18)	3(27)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)
8/22/12	McH	90		5	30	26(64)	<1(9)	5(9)	13(73)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	3(36)	0(0)	0(0)	0(0)	0(0)
9/19/12	McH	75		7	30	18(64)	7(18)	14(18)	<1(36)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	<1(36)	0(0)	<1(9)	0(0)	0(0)
6/20/13	McH	50		6	19	16(64)	0(0)	11(45)	4(73)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	3(91)	0(0)	0(0)
8/15/13	McH	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
9/27/13	McH	30		3	35	0(0)	<1(9)	34(82)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)
8/5/10	HHO	195	5.8	6	38	30(55)	15(36)	0(0)	1(27)	0(0)	21(64)	<1(18)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)
9/15/10	HHO	200	3.0	5	46	8(40)	6(27)	0(0)	2(18)	0(0)	31(55)	0(0)	0(0)	0(0)	0(0)	0(0)	8(9)	0(0)	0(0)	0(0)
6/14/11	HHO	150	5.6	7	40	20(64)	7(45)	0(0)	14(18)	<1(9)	16(36)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	<1(9)	0(0)
8/9/11	HHO	180	5.0	9	44	25(64)	15(45)	0(0)	3(18)	0(0)	5(18)	<1(27)	2(18)	15(45)	0(0)	<1(9)	0(0)	2(18)	0(0)	0(0)
9/12/11	HHO	162	4.1	8	29	15(18)	7(36)	0(0)	6(27)	0(0)	6(45)	3(18)	0(0)	3(9)	0(0)	11(27)	<1(9)	0(0)	0(0)	0(0)
6/27/12	HHO	180	6.3	7	37	41(45)	15(36)	0(0)	4(36)	0(0)	3(45)	0(0)	0(0)	6(27)	0(0)	5(36)	4(27)	0(0)	0(0)	0(0)
8/22/12	HHO	180		6	36	34(55)	15(36)	0(0)	6(27)	0(0)	12(45)	0(0)	0(0)	<1(27)	0(0)	3(18)	0(0)	0(0)	0(0)	0(0)
9/19/12	HHO	190		6	72	7(18)	17(36)	0(0)	27(64)	0(0)	27(73)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	<1(9)	0(0)	0(0)
6/20/13	HHO	150		8	39	10(27)	19(45)	0(0)	10(55)	0(0)	4(36)	0(0)	<1(9)	4(27)	<1(9)	<1(27)	0(0)	0(0)	0(0)	0(0)
8/15/13	HHO	150		6	22	6(36)	5(27)	0(0)	<1(18)	0(0)	11(45)	0(0)	<1(18)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)
9/27/13	HHO	140		5	23	<1(9)	11(36)	0(0)	<1(9)	0(0)	11(64)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)
8/5/10	MMR	63	3.0	6	51	0(0)	30(82)	21(55)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	<1(9)	0(0)	<1(9)	0(0)	0(0)
9/15/10	MMR	60	3.9	3	51	0(0)	34(64)	17(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
6/14/11	MMR	55	4.1	4	35	0(0)	29(82)	6(73)	0(0)	0(0)	0(0)	<1(36)	0(0)	0(0)	0(0)	<1(18)	0(0)	0(0)	0(0)	0(0)
8/9/11	MMR	55	2.9	8	46	<1(9)	37(91)	5(18)	<1(9)	0(0)	0(0)	2(36)	0(0)	2(82)	0(0)	<1(18)	0(0)	<1(45)	0(0)	0(0)
9/12/11	MMR	60	4.0	4	51	0(0)	34(73)	17(55)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	<1(9)	0(0)	0(0)	0(0)	0(0)
6/27/12	MMR	55	4.2	7	46	2(9)	34(82)	11(64)	1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(18)	<1(9)	0(0)	0(0)	0(0)	0(0)
8/22/12	MMR	60		7	54	5(27)	35(73)	16(45)	<1(9)	0(0)	0(0)	0(0)	0(0)	4(18)	1(9)	0(0)	0(0)	0(0)	2(18)	0(0)
9/19/12	MMR	60		5	65	3(18)	40(73)	23(64)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)
6/20/13	MMR	50		6	46	0(0)	36(91)	7(55)	1(18)	0(0)	0(0)	<1(9)	0(0)	0(0)	<1(9)	0(0)	0(0)	2(45)	0(0)	0(0)
8/15/13	MMR	55		4	57	0(0)	40(82)	15(64)	<1(27)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)
9/27/13	MMR	45		3	67	0(0)	53(82)	13(64)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
8/5/10	DCC	200	2.5	7	87	13(18)	<1(18)	0(0)	60(82)	<1(18)	7(9)	0(0)	0(0)	0(0)	0(0)	11(27)	0(0)	9(36)	0(0)	0(0)
9/16/10	DCC	200	2.3	7	68	7(18)	2(27)	0(0)	44(73)	17(36)	0(0)	0(0)	0(0)	0(0)	<1(9)	3(18)	0(0)	<1(9)	0(0)	0(0)
6/14/11	DCC	200	3.0	4	70	0(0)	7(27)	0(0)	36(82)	14(45)	0(0)	0(0)	0(0)	0(0)	0(0)	13(36)	0(0)	0(0)	0(0)	0(0)
8/9/11	DCC	200	2.7	8	58	0(0)	5(9)	0(0)	24(64)	3(27)	8(9)	0(0)	0(0)	0(0)	0(0)	1(9)	0(0)	1(9)	<1(9)	13(27)
9/12/11	DCC	200	3.7	6	54	2(9)	7(18)	0(0)	31(64)	14(45)	0(0)	0(0)	0(0)	0(0)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)
6/27/12	DCC	200	3.0	6	29	30(55)	4(27)	0(0)	18(73)	2(55)	<1(9)	0(0)	0(0)	0(0)	0(0)	4(36)	0(0)	0(0)	0(0)	0(0)
8/22/12	DCC	200		4	52	22(55)	6(18)	0(0)	43(73)	2(18)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
9/19/12	DCC	200		6	68	7(27)	12(18)	0(0)	54(73)	<1(9)	<1(18)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
6/20/13	DCC	200		8	38	21(55)	1(27)	0(0)	16(64)	3(45)	<1(9)	3(9)	0(0)	0(0)	0(0)	<1(18)	0(0)	15(45)	0(0)	0(0)
8/15/13	DCC	200		10	55	32(73)	6(18)	0(0)	20(55)	3(36)	9(36)	2(18)	0(0)	0(0)	1(9)	<1(9)	0(0)	5(27)	0(0)	7(9)
9/27/13	DCC	200		8	41	47(91)	5(9)	0(0)	23(55)	<1(9)	2(36)	<1(9)	0(0)	0(0)	0(0)	4(18)	0(0)	5(9)	0(0)	0(0)
8/5/10	GGC	70	3.0	5	49	11(64)	20(55)	0(0)	27(36)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(27)	0(0)	<1(18)	0(0)	0(0)
9/15/10	GGC	70	3.5	4	31	30(45)	20(36)	0(0)	13(27)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(18)	0(0)	0(0)	0(0)	0(0)
6/14/11	GGC	65	3.4	5	26	4(27)	13(36)	0(0)	6(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	7(82)	0(0)	0(0)
8/9/11	GGC	55	3.6	7	68	2(18)	21(45)	0(0)	9(36)	0(0)	6(9)	0(0)	0(0)	11(73)	0(0)	15(55)	0(0)	6(36)	0(0)	0(0)
9/12/11	GGC	54	4.0	5	36	8(45)	20(36)	0(0)	4(9)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	8(18)	0(0)	5(18)	0(0)	0(0)
6/27/12	GGC	65	3.4	4	48	7(18)	14(45)	0(0)	23(45)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	11(27)	0(0)	0(0)	0(0)	0(0)
8/22/12	GGC	66		6	31	5(36)	20(45)	0(0)	11(45)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	0(0)
9/19/12	GGC	80		6	48	7(9)	25(36)	0(0)	22(55)	0(0)	<1(9)	0(0)	0(0)	0(0)	0(0)	<1(18)	0(0)	<1(9)	0(0)	0(0)
6/20/13	GGC	50		8	26	<1(9)	18(55)	0(0)	1(45)	0(0)	<1(27)	<1(9)	0(0)	0(0)	<1(18)	<1(9)	0(0)	5(64)	0(0)	0(0)
8/15/13	GGC	40		7	38	2(73)	28(64)	0(0)	<1(9)	0(0)	<1(9)	0(0)	0(0)	0(0)	<1(9)	<1(36)	0(0)	7(36)	0(0)	0(0)
9/27/13	GGC	40		7	26	8(55)	23(55)	0(0)	2(45)	0(0)	<1(36)	0(0)	0(0)	0(0)	<1(9)	<1(18)	0(0)	<1(18)	0(0)	0(0)

The SAV bed surveyed near McHenry (McH) (transect length from 30-100m and max depth of 5.4m, Table 8), also in the northern portion of the lake but in the eastern arm, showed no true dominant in 2010, although *E. canadensis* dominated in August (Table 9). Macroalgae dominated the bed in 2011 and again in 2012, but was outcompeted by *V. americana* as the only dominant in 2013. We did not survey this transect in August, 2013 due to a sewage spill in the vicinity. Interestingly, Macroalgae density was relatively high at this site in June, 2013. By September, post sewage spill, Macroalgae was completely absent on the transect. It appears that the raw sewage may have acted to smother the Macroalgae growing near the bottom while the *V. americana* was unaffected because its leaves extended high into the water column. Regardless of missing data from August 2013, Total SAV and Total Macroalgae showed opposite trends at this location (Figure 8). SAV increased between 2010 and 2013, while Macroalgae decreased. *Myriophyllum* was only observed in trace amounts and low frequencies during five of the eight sampling events (Figure 9), and it did not change significantly over time.

The SAV bed surveyed near the Honi Honi in Oakland (HHO), on the western shore of the central lake area, was a long transect (ranging from 140-200m) with the greatest maximum depth (6.3m) (Table 8). This SAV bed was dominated by *Myriophyllum* in 2010, by Macroalgae in 2011, and by *S. cristata, Myriophyllum,* and Macroalgae in 2012. In 2013, there were two dominants*: S. cristata* and *Myriophyllum* (Table 9). Both Total SAV and Total Macroalgae density graphs show decreasing trendlines at this location, but statistical analyses indicate that the change was not significant (Figure 50). *Myriophyllum* was commonly observed at this transect, but it did not change significantly over time either in density or frequency of occurrence (Figure 51).

Table 9. Dominance by site and year, where dominance is defined as density being equal to or greater than 10% <u>or</u> frequency of occurrence being equal to or greater than 50%. To determine dominance for 2010, a species/genus had to be found dominant during both sampling events that took place that year. For years 2011, 2012, and 2013, in which three sampling events took place, a species/genus had to be found dominant during two of the three sampling events.

2010

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	8/5/10	Ec, Pp, Cv, MA	*Elodea canadensis,* Macroalgae
	9/16/10	Ec, Pv, MA	
McH	8/5/10	Ec	no dominant for year
	9/16/10	none	
HHO	8/5/10	Sc, Myr, MA	*Myriophyllum*
	9/16/10	Myr	
MMR	8/5/10	Sc, Va	*Sagittaria cristata, Vallisneria americana*
	9/16/10	Sc, Va	
DCC	8/5/10	Ec, Pp, MA	*Elodea canadensis*
	9/16/10	Ec, Cd	
GGC	8/5/10	Sc, Ec, MA	*Sagittaria cristata, Elodea canadensis,* Macroalgae
	9/16/10	Sc, Ec, Cv, MA	

2011

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/14/11	Ec, Pp, MA	*Sagittaria cristata, Elodea canadensis*
	8/9/11	Sc, Ec, Myr, Pv	
	9/12/11	Sc, Ec	
McH	6/14/11	MA	Macroalgae
	8/9/11	MA	
	9/12/11	Va, MA	
HHO	6/14/11	Ec, Myr, MA	Macroalgae
	8/9/11	Sc, Uv, MA	
	9/12/11	Pp, MA	
MMR	6/14/11	Sc, Va	*Sagittaria cristata, Vallisneria americana*
	8/9/11	Sc, Uv	
	9/12/11	Sc, Va	
DCC	6/14/11	Ec, Cd, Pp	*Elodea canadensis, Ceratophyllum demersum*
	8/9/11	Ec, Pd	
	9/12/11	Ec, Cd	
GGC	6/14/11	Sc, Pv	*Sagittaria cristata*
	8/9/11	Sc, Uv, Pp	
	9/12/11	Sc	

2012

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/27/12	Sc, Ec, Myr, Pp, MA	*Elodea canadensis, Myriophyllum,* Macroalgae
	8/22/12	Ec, Myr, MA	
	9/19/12	Ec, Myr, MA	
McH	6/27/12	MA	Macroalgae
	8/22/12	Ec, MA	
	9/19/12	Va, MA	
HHO	6/27/12	Sc, MA	*Sagittaria cristata, Myriophyllum,* Macroalgae
	8/22/12	Sc, Myr, MA	
	9/19/12	Sc, Ec, Myr	
MMR	6/27/12	Sc, Va	*Sagittaria cristata, Vallisneria americana*
	8/22/12	Sc, Va	
	9/19/12	Sc, Va	
DCC	6/27/12	Ec, Cd, MA	*Elodea canadensis,* Macroalgae
	8/22/12	Ec, MA	
	9/19/12	Sc, Ec	
GGC	6/27/12	Sc, Ec, Pp	*Sagittaria cristata, Elodea canadensis*
	8/22/12	Sc, Ec	
	9/19/12	Sc, Ec	

2013

Site	Date	Dominant Species for Event	Dominant Species for Year
RRC	6/20/13	Sc, Ec, Pv	*Sagittaria cristata, Elodea canadensis, Myriophyllum,* Macroalgae
	8/15/13	Sc, Ec, Myr, MA	
	9/27/13	Sc, Myr, Utr, MA	
McH	6/20/13	Va, Ec, Pv, MA	*Vallisneria americana*
	8/15/13	no data	
	9/27/13	Va	
HHO	6/20/13	Sc, Ec, MA	*Sagittaria cristata, Myriophyllum*
	8/15/13	Myr	
	9/27/13	Sc, Myr	
MMR	6/20/13	Sc, Va	*Sagittaria cristata, Vallisneria americana*
	8/15/13	Sc, Va	
	9/27/13	Sc, Va	
DCC	6/20/13	Ec, MA	*Elodea canadensis,* Macroalgae
	8/15/13	Ec, MA	
	9/27/13	Ec, MA	
GGC	6/20/13	Sc, Pv	*Sagittaria cristata,* Macroalgae
	8/15/13	Sc, MA	
	9/27/13	Sc, MA	

Across the lake from Honi Honi, the SAV bed surveyed offshore of the State Park in Meadow Mountain Run Cove (MMR) was dominated by *S. cristata* and *V. americana* during all four summers (Table 9). This transect ranged from 45-63m with a max depth of 4.2m (Table 8). Both Total SAV and Total Macroalgae showed increasing trends at this location, but neither increased significantly between 2010 and 2013. Macroalgae was only present in very low densities in 2012 (Figure 50). *Myriophyllum* was never observed at this transect.

In the southern portion of the lake, Deep Creek Cove (DCC) had one of the longest transects (constant length of 200m and max depth of 3.7m, Table 8). This expansive bed was dominated by *E. canadensis* in 2010, but in 2011, *C. demersum* was found to be co-dominant with *E. canadensis* (Table 9). In 2012 and 2013, *E. canadensis* co-dominated with Macroalgae. Total SAV in DCC decreased between 2010 and 2013, while Total Macroalgae increased significantly (Figure 50). *Myriophyllum* was present in low densities during most sampling events, and did not change over time. Frequency of occurrence increased between 2010 and 2013, but not significantly (Figure 51). At this site during the September 2013 survey, *Hydrilla verticillata* was discovered floating near the transect. A search led to the source of the floating plants in a nearby cove and later to an entire shoreline survey to determine the extent of the invasion. These results are discussed later in this report.

Green Glade Cove (GGC), east of DCC in the southeastern portion of the lake, had transect lengths ranging from 40-80m and a max depth of 4m (Table 8). This SAV bed was dominated by *S. cristata*, *E. canadensis*, and Macroalgae in 2010. In 2011, the dominant plant observed was *S. cristata* and in 2012, *S. cristata* and *E. canadensis* co-dominated. In 2013, Macroalgae joined *S. cristata* as a co-dominant (Table 9). Both Total SAV and Total Macroalgae showed a decreasing trend between 2010 and 2013, but only macroalgae decreased significantly (Figure 50). *Myriophyllum* was present in low densities during most sampling events, but it did not change significantly over time. Frequency of occurrence increased significantly in 2013 (Figure 51).

In general, species zonation was apparent at all sites. *Sagittaria cristata*, a plant with low canopy height, was observed at all sites during every sampling event, with the exception of the transect at McH during the June 2012 and June 2013 sampling. In all cases, it was observed at its highest densities along the shallow edge of the SAV beds. Along transects with little slope and minimal depth, *S. cristata* maintained high densities father from shore. As transects moved offshore and got deeper, *S. cristata* was generally replaced by *Potamogeton spp.*, *V.americana*, *C.demersum*, or a combination thereof. Along the deeper edges of the SAV beds, we observed more *C. demersum, E. canadensis, Myriophyllum,* and the two species of macroalgae (which have lower light requirements), *C. vulgaris* and *Nitella flexilis*.

Sagittaria cristata, *E. canadensis* and Macroalgae were the dominant species observed at our sites during the four year monitoring period (2010-2013). *Potamogeton pusillus* and

P. vaseyii were observed at least once at all six sites, but at very low densities. The greatest densities and highest frequencies of occurrence of *S. cristata* and *V. americana* were observed at MMR. *Elodea canadensis* and *C. demersum* densities and frequencies of occurrence were significantly higher at DCC than at the other sites. *Myriophyllum* density was significantly higher at HHO (13) than other sites (0-4.5), and *Myriophyllum* was also observed more frequently at HHO (48% of quadrats) and RRC (48%) than at other sites (0-12%).

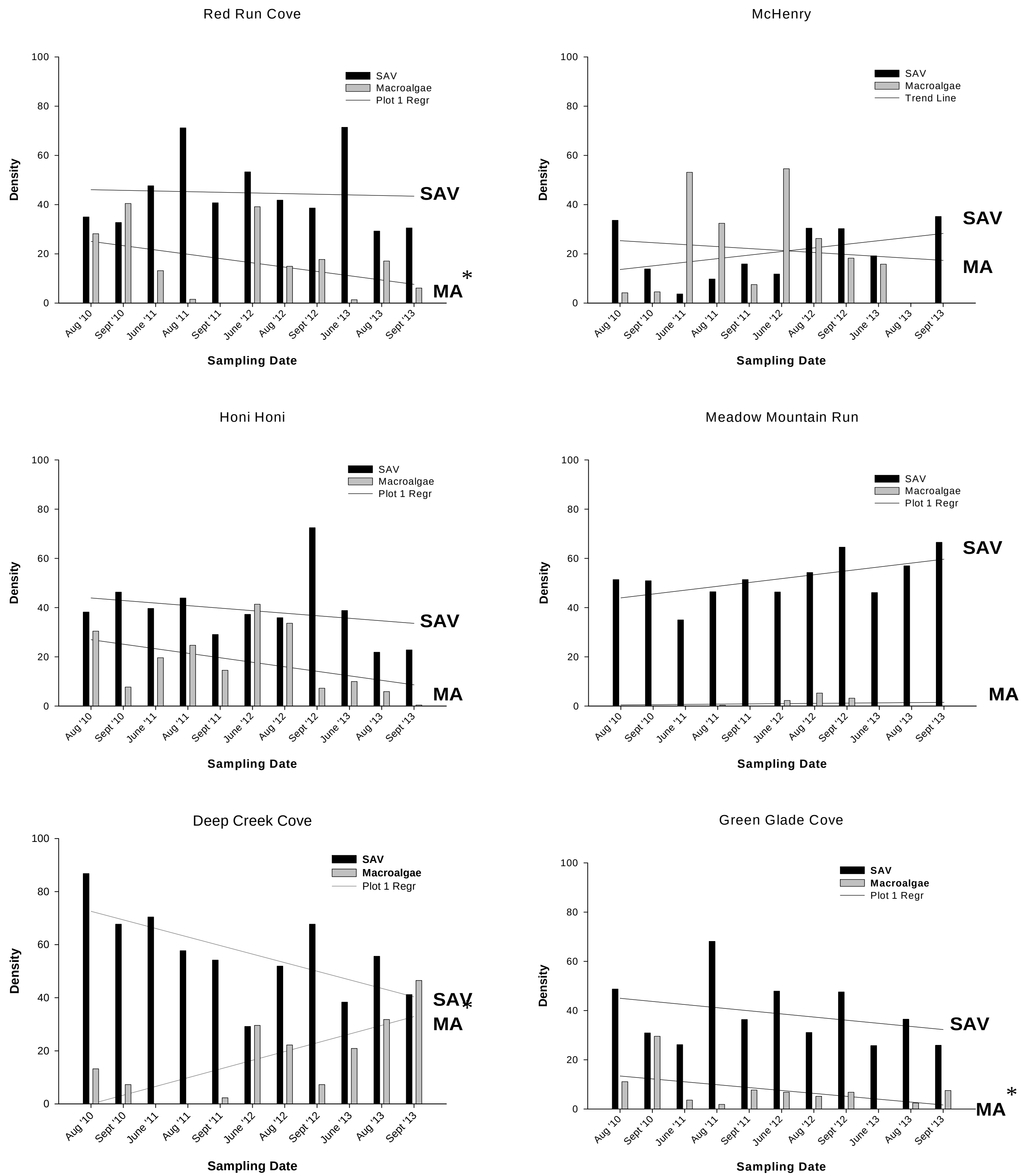


Figure 50. Total SAV and Total Macroalgae Density (where Density = sum of % cover values/total # of quadrats) graphed over time for each transect, with corresponding trend-lines showing overall increasing, decreasing, or no-change trends. Asterisks (*) indicate significant ($p \leq 0.05$) change from 2010 to 2013.

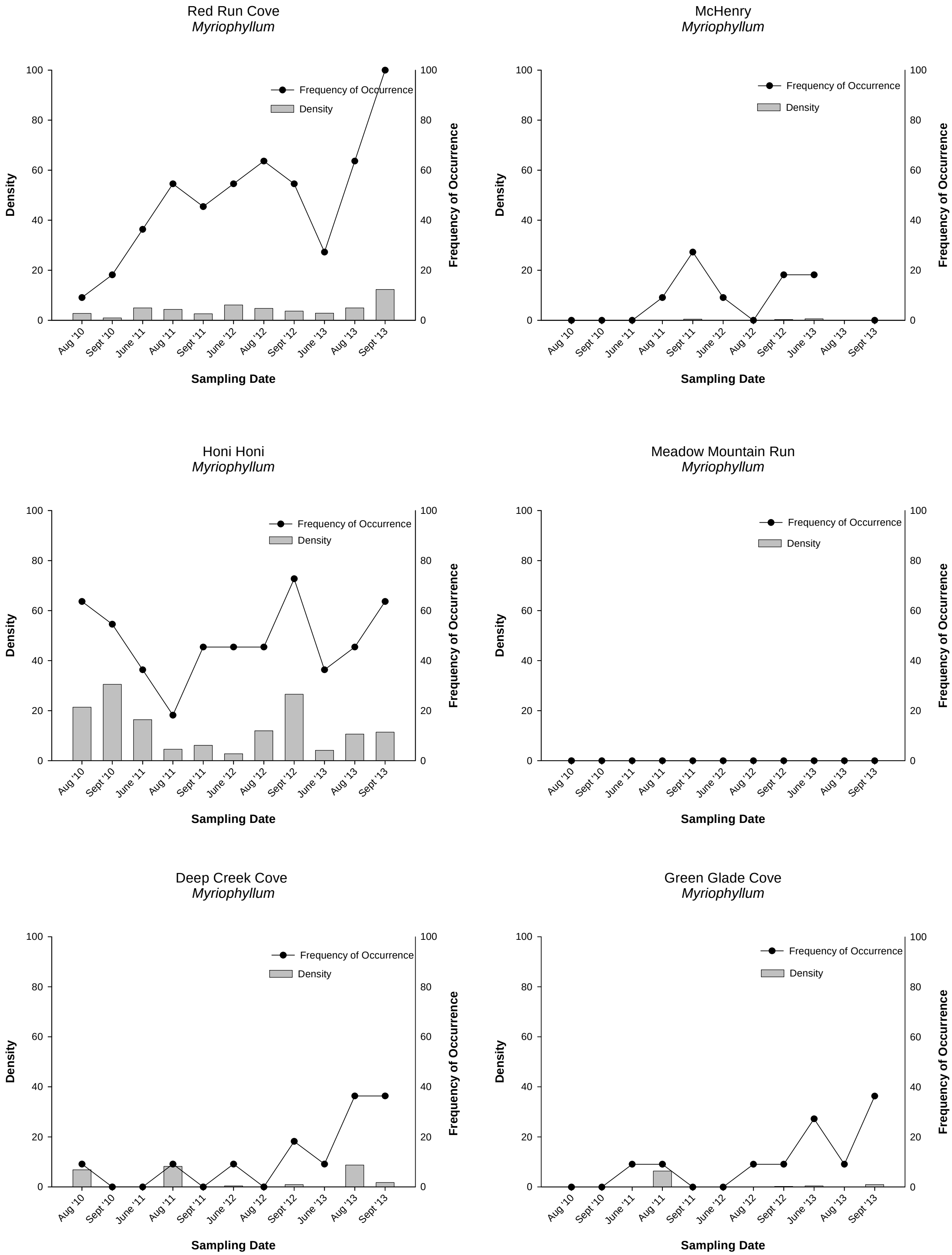


Figure 51. *Myriophyllum* Density (bars, where Density = sum of % cover values/total # of quadrats) and Frequency of Occurrence (point and line, where Frequency = # of quadrats where observed/total # quadrats) graphed over time for each transect.

Total SAV density, Total Macroalgae density, species richness and species diversity were all significantly different among sites. DCC contained the highest SAV coverage. MMR also had significantly higher SAV coverage and the lowest percent cover of Macroalgae. Observed macroalgae cover was significantly higher at McH, HHO, DCC, and RRC compared to the other sites. RRC also had the highest species richness and diversity, while McH had the fewest species observed. SAV cover and species diversity were significantly lower at McH than any other site.

While the SAV transects surveyed represent the lake as a whole, the comprehensive shoreline survey for *Myriophyllum* allowed us to map the lake-wide spatial extent of that genus specifically. With this sampling design, in 2012 we identified 130 locations with *Myriophyllum*, totaling approximately 86 acres where *Myriophyllum* was present at varying densities. Using bathymetry data collected by the Maryland Geological Survey, 86 acres represents approximately 2.3% of the lake surface and 5.8% of the waters less than six meters deep, the photic zone in which plants may grow in Deep Creek Lake. The remaining 94.2% of habitat within the photic zone was free of *Myriophyllum*.

This survey was repeated in June 2013. During this survey, *Myriophyllum* was only identified at 69 locations throughout the lake (Figure 52), totaling approximately 29 acres where *Myriophyllum* was present at varying densities. Twenty-nine acres represents 0.74% of the lake surface, and 1.96% of bottom available within the photic zone.

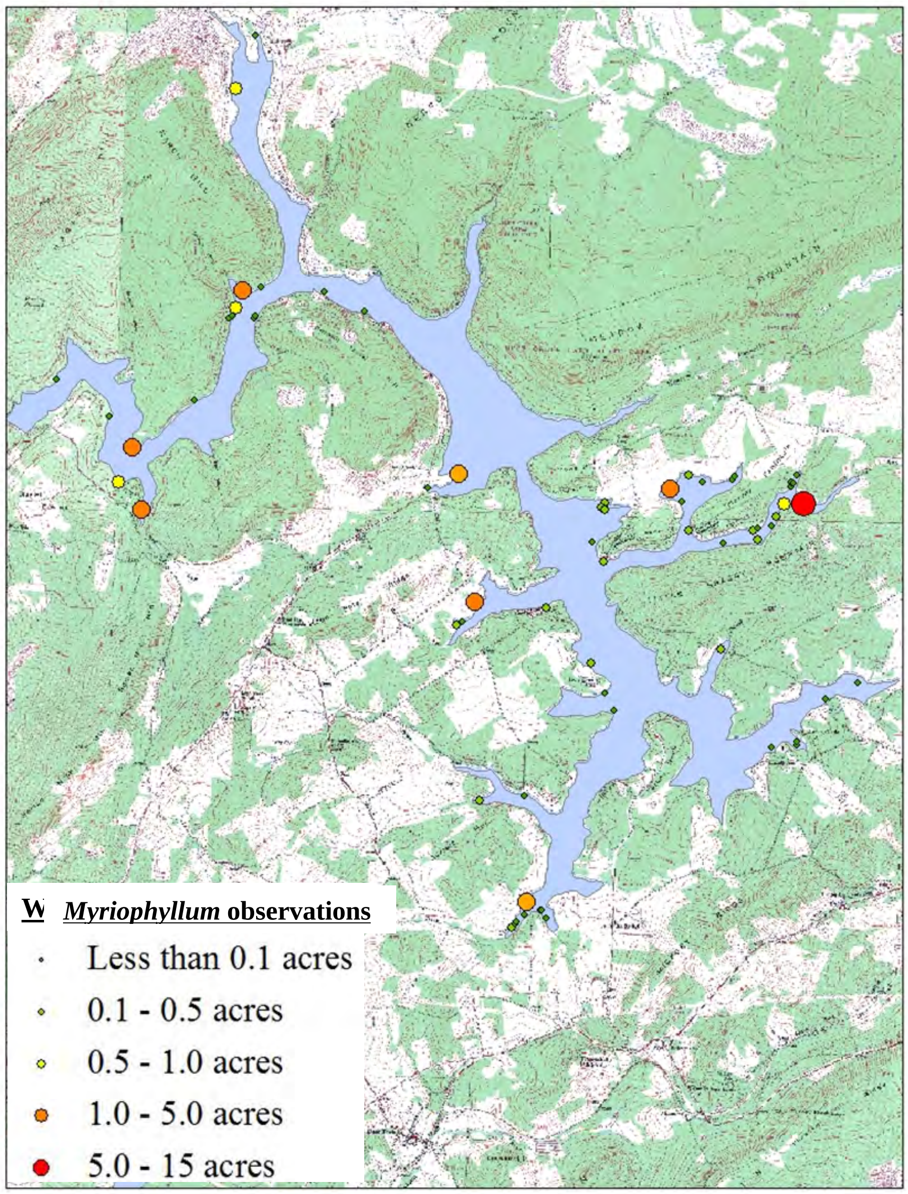


Figure 52. Results of 2013 *Myriophyllum* shoreline survey. *Myriophyllum* observations are shown in acres, with symbol size proportional to patch size.

Appendix C includes more detailed maps of both the 2012 and 2013 *Myriophyllum* observations throughout the lake with symbol size proportional to patch size. In 2012, during the survey, the majority of *Myriophyllum* was observed in the southern portion of the lake (Figure C1, C5-C7). In 2013, larger patches are not concentrated in the southern lake.

The *Hydrilla* survey was conducted in an identical manner to the *Myriophyllum* survey. The entire lake shoreline was surveyed, but *Hydrilla* was only observed at 14 locations, all in the southwest leg of the lake (Figure 53). The patches at the 14 sites range in size from 1 square foot to 5 acres. In most instances, *Hydrilla* was observed as small patches throughout SAV beds composed of several other species.

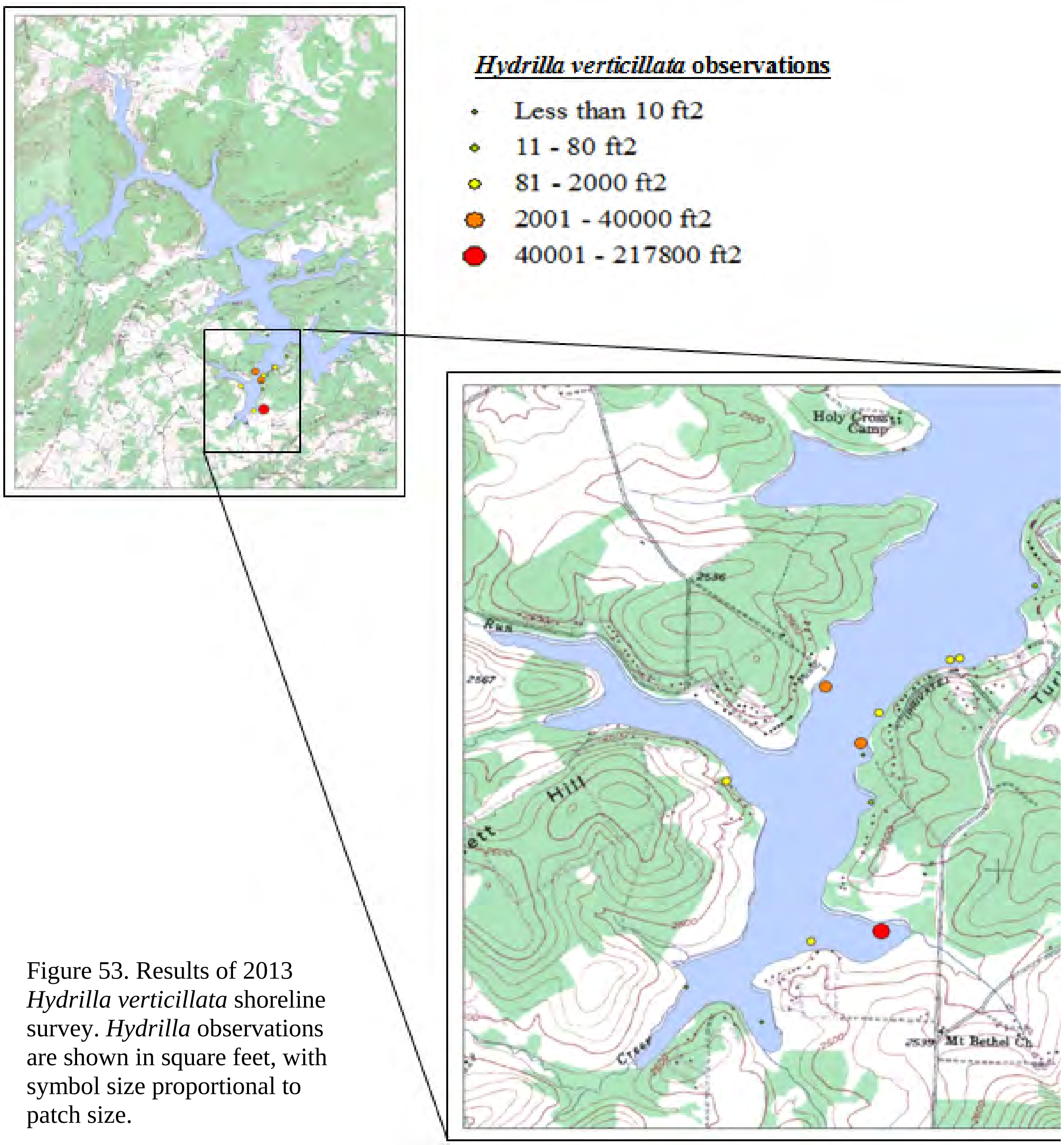


Figure 53. Results of 2013 *Hydrilla verticillata* shoreline survey. *Hydrilla* observations are shown in square feet, with symbol size proportional to patch size.

DISCUSSION and CONCLUSION

The goal of the SAV transect survey was to define the distribution and density of the SAV community at several representative sites throughout Deep Creek Lake. As such, the results of the survey provide a comprehensive analysis of the Lake's SAV community as a whole and how this community changes in space and time. The transect survey methodology is a globally accepted method to identify changes in an SAV community; it does not focus on any one species over another, as did our *Myriophyllum* and *Hydrilla* shoreline surveys. Our results indicate that DCL supports a healthy and diverse population of SAV, including 10 genera of vascular plants and 2 species of macroalgae. These SAV observations include two rare species of *Potamogetons* thought to be extirpated from Maryland waters. The distribution and density of these species differ primarily by site, with annual variations occurring occasionally. The majority of observed species, as well as the physical characteristics of each survey site, showed no significant change in density or distribution from 2010 to 2013.

Aside from some shallow water areas, the water in Deep Creek Lake is clear and allows light to penetrate to impressive depths. SAV and macroalgae were observed growing as deep as 5-6 m on some transects with species zonation apparent at every site. Zonation is an inherent characteristic of any SAV bed, but could be particularly exaggerated in Deep Creek Lake as a direct result of the winter water level draw-down, which limits the shoreward expansion of canopy forming species. *Sagittaria cristata*, commonly known as Crested arrowhead, was observed at each site during almost every sampling event. This plant, which is short in stature and can withstand extensive periods of exposure during lake level draw down, was most prevalent along the shallow edges of the SAV beds. *Potamogeton spp.* (also present to some extent in the shallows), *Vallisneria americana*, and/or *Ceratophyllum demersum* replaced *S. cristata* as the transects extended into deeper water. All of these species can form canopies from 0.5-2m or more. *Potamogeton spp.* were seen reaching the surface at shallow to mid-depths during the August and September sampling events due to their reproductive strategy. During late summer/early fall, the *Potamogetons* send their reproductive structures to the surface to take advantage of its two dimensional aspect. Along the deeper edge of the transects and SAV beds, we were more likely to observe *Elodea canadensis, Myriophyllum*, and Macroalgae. *Elodea canadensis* and *Myriophyllum* can form canopies greater than 2m in clear water. One of the most notable observations made was an SAV bed extending into greater than 5m of water at the transect site near the Honi Honi in Oakland. Submerged aquatic vegetation observed here included *Myriophyllum* that grew nearly to the surface, and Macroalgae

Myriophyllum density and frequency of occurrence was higher at HHO than at the other sites. Although we observed a dramatic increase in frequency of occurrence of *Myriophyllum* at RRC from 2010 to 2013, density did not change over time in that cove. Neither *Myriophyllum* density nor frequency of occurrence changed significantly over time in any of the other surveyed coves except GGC, where frequency of occurrence increased significantly by 2013. The 2013 *Myriophyllum*-specific shoreline survey indicated that this nuisance plant was present at varying densities in 29 acres of the lake and occupies less than 2% of available benthic space for vegetative growth. This number is down from 2012 when 130 patches were observed covering 86 acres. The reduction in *Myriophyllum* observations is most likely due to abnormally high lake levels, higher turbidity, and a very cool spring. In June, 2013, there was consequently less grass, and because of the conditions, it was more difficult to locate. By September, 2013, it was clear that *Myriophyllum* had not, in fact, decreased in abundance, although it was likewise observed that *Myriophyllum* was still not forming monoculture stands to the exclusion of native species. It remains the opinion of DNR SAV biologists that *Myriophyllum* is currently not a problem in Deep Creek Lake, but that it should be monitored carefully.

Hydrilla verticillata, on the other hand, does pose a threat to the health and biodiversity of Deep Creek Lake. *Hydrilla* has a greater competitive capacity than *Myriophyllum* over most native species for a number of reasons. It has the ability to grow under low-light conditions, much like macroalgae. It needs only 1% of sunlight to grow, allowing it to thrive under the canopy of other plants as well as deeper than other plants. Its low light requirements allow it to start photosynthesizing earlier in the morning, capturing and diminishing CO^2 that would otherwise be available for its competitors (Langeland, 1996). In addition to CO^2, *Hydrilla* can use bicarbonate as a carbon source when water column CO^2 is unavailable (Salvucci and Bowes, 1983), increasing the alkalinity of the water as it does, making conditions inhospitable to most native species.

Hydrilla also employs dispersal strategies that allow it start new beds far from parent beds. Like many SAV, *Hydrilla* uses vegetative fragmentation as a means of reproduction (Akers, 2010). When the plant is disturbed in a manner which breaks it into multiple pieces, those pieces float away and are capable of rooting where they land and forming new plants. In addition to vegetative fragmentation, *Hydrilla* reproduces by seed, turions, and tubers. Turions are growth structures which break from the main stem of the plant at the end of the growing season to drift, and much like vegetative fragmentation, eventually sink and start a new plant. Tubers are reproductive structures that store nutrients and are used by plants to survive winter and drought conditions, to provide energy and nutrients for re-growth during the next growing season or when environmental conditions are more suitable. Tubers are what make *Hydrilla* so successful and difficult to fully eradicate. The monoecious strain, which is most likely the strain present in DCL, can form tubers quickly during short photoperiods (Spencer and Anderson, 1986). One tuber can lead to the production of several hundred others in the course of one growing season, and they can survive for four to seven years in the sediment before sprouting, even if no water is present for much of that time (Akers, 2010). With that said, *Hydrilla* is between 93 to 95 percent water, so it can create huge volumes of biomass with very few resources. As a result, it can grow very rapidly, doubling its biomass every two weeks in summer conditions

As a final competitive edge, when *Hydrilla* was introduced into the United States, it came without the various natural controls that evolved with it, such as insects and diseases specialized for attacking it.

At this time, MD DNR has solicited the input of *Hydrilla* experts around the country, and has formed an advisory panel. The panel is currently formulating a *Hydrilla* Management Plan specific to the needs of Deep Creek Lake. Fortunately, *Hydrilla* has not been observed growing outside of the south-western leg of the lake. Having it isolated to one area will make management and control significantly more straightforward. Regardless, even carefully designed efforts to control aquatic plants may have unanticipated and adverse impacts on the lake ecosystem, so while management action will be forthcoming, it will not be implemented without extensive care and research.
The best possible way to prevent further expansion of either *Myriophyllum* or *Hydrilla* is to promote the growth of native species, to boat responsibly in areas where they are growing, and to develop ways to prevent further introduction or spread of any invasive species.

REFERENCES

Akers, P. 2010. The California Department of Food and Agriculture *Hydrilla* Eradication Program Annual Progress Report 2010.

Jacobs, J., and J. Margold. 2009. Plant Guide for Eurasian watermilfoil (*Myriophyllum spicatum* L.). USDA – Natural Resources Conservation Service, Montana State Office, Bozeman, MT 59715.

Kelsey, R.H., and S.L. Powell, 2011. Deep Creek Lake Baseline Assessment Report.

Langeland, K.A. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea 61:293-304.

The *Hydrilla* Taskforce of the Cayuga Lake Watershed. 2013. Cayuga Inlet *Hydrilla* Management Plan. **www.stophydrilla.org**

Salvucci, M. E. and G. Bowes. 1983. Two photosynthetic mechanisms mediating the low photorespiratory state in submersed aquatic angiosperms. Plant Physiology 73:488-96.

Spencer, D. F. and L. W. J. Anderson. 1986. Photoperiod responses in monoecious and dioecious *Hydrilla verticillata*. Weed Science 34:551-557.

Deep Creek Lake and Youghiogheny River Trout Fishery

DEEP CREEK LAKE HISTORICAL TRENDS

Deep Creek Lake supports at least nineteen fish species indicative of coldwater, coolwater, and warmwater fish community based on the 2012 fish population survey. Fish species composition in DCL was largely unchanged from that observed during the last ten-year study period (2001 – 2010) when eighteen fish species were collected. Largemouth Bass, Smallmouth Bass, and Walleye are the most popular sport fish, attracting anglers from throughout the mid-Atlantic Region. Annual stocking of adult Brown Trout and Rainbow Trout provide trout fishing opportunities throughout the year. The Yellow Perch and Bluegills are known for their large sized attained in DCL. Warmwater gamefish and panfish, except Walleye and Yellow Perch, are managed under Maryland's statewide regulations as described in the *Maryland Guide to Fishing 2013* (**www.dnr.maryland.gov**). Walleye and Yellow Perch are managed in DCL by special regulations. Walleye regulations include a closed season from 1 March through 15 April, a five fish daily creel limit, and a 15 inch minimum size limit the remainder of the year. Yellow Perch regulations include a ten fish creel limit, no closed season, and no minimum size restriction. Trout fishing is managed under Put and Take regulations as described in the *Maryland Guide to Fishing 2013*.

The list of common names, scientific names, and observed abundance of the nineteen fish species collected in DCL is contained in Table 10. These species representing seven Families are indicative of a warmwater/ coolwater/coldwater fishery. The panfish species Bluegills, Pumpkinseeds, Rock bass, and Yellow Perch are regarded as common to abundant. Smallmouth Bass, Largemouth Bass, and Walleye are the most abundant gamefish species. Golden Shiners are the most abundant forage fish. Only Brown Trout and Rainbow Trout are stocked on an annual basis, and the remaining fish species are self- sustaining.

Table 10. Common and scientific names and observed abundance of fish species in Deep Creek Lake.

Common Name	**Scientific Name**	**Observed Abundance**
Common Carp	*Cyprinus carpio*	Common
Golden Shiner	*Notemigonus crysoleucas*	Abundant
White sucker	*Catostomus commersoni*	Common
Yellow Bullhead	*Ameiurus natalis*	Common
Brown Bullhead	*Ameiurus nebulosus*	Common
Northern Pike	*Esox lucius*	Scarce
Redfin Pickerel	*Esox americanus*	Scarce
Chain Pickerel	*Esox niger*	Abundant
Rainbow Trout	*Oncorhynchus mykiss*	Scarce
Brown Trout	*Salmo trutta*	Scarce
Rock Bass	*Ambloplites rupestris*	Common
Pumpkinseed	*Lepomis gibbosus*	Common

Bluegill	*Lepomis macrochirus*	Abundant
Smallmouth Bass	*Micropterus dolomieu*	Abundant
Largemouth Bass	*Micropterus salmoides*	Common
Black Crappie	*Pomoxis nigromaculatus*	Scarce
Johnny Darter	*Etheostoma nigrum*	Scarce
Yellow Perch	*Perca flavescens*	Abundant
Walleye	*Sander vitreus*	Abundant
Total species = 19		

CURRENT CONDITIONS

Walleye

Deep Creek Lake supports a popular Walleye fishery. Regulation modifications first implemented in 1993 (increased the minimum size limit from 14 inches to 15 inches) and 1995 (established a closed season from March 1 through April 15) have resulted in improved age and size structures, characterized by an abundance of stock and quality-size fish. Fall electrofishing samples show Walleye had the highest abundance of any gamefish species during 2012. Natural reproduction in 2012 was very low, although 2011 had the highest reproductive level since 2004. The electrofishing and tournament capture samples both indicate that the majority of legal-size Walleye are between 15 inches and 17 inches, with opportunities to catch trophy-size fish greater than 20 inches. Results from the 2013 surveys are pending; however cursory results indicate that the Walleye population density is still regarded as abundant.

Yellow Perch

The Yellow Perch population in DCL is well balanced with stock ($\geq$ 5 inches), quality ($\geq$ 8 inches), preferred ($\geq$ 10 inches), and memorable ($\geq$ 12 inches) sized fish represented in the population. Reproductive success in 2012, described by the seining net index was considered excellent, similar to the indices from 2006 - 2011. A ten perch daily creel limit was implemented for DCL effective 1 January 2010. The regulation change, which was based on electrofishing sampling and creel census data from angler interviews, should maintain and enhance the Yellow Perch populations in DCL. The 2012 length frequency distribution shows a population characterized by a diverse size structure; from young of year size to memorable size (> 12 inches). The 2013 study results are pending; however cursory observations indicate that the Yellow Perch population continues to be outstanding.

Smallmouth Bass

Smallmouth Bass are one of the most sought after gamefish species in DCL. Smallmouth Bass continue to maintain sustainable harvest levels and adequate survival to older year-classes as evidenced by the diverse age and size structure in the electrofishing and tournament angler capture samples. Both proportional stock density and relative stock density values indicate a balance population. Reproduction was considered “good’ in 2012. Survey results are pending for 2013.

Largemouth Bass
Largemouth Bass were less abundant in the 2012 electrofishing sample than previous years. Tournament data show a slight decrease in Largemouth Bass catch ratios compared to the years 1996 – 2000 when the Smallmouth Bass to Largemouth Bass catch ratio was 1.8 to 1 compared to the 2012 catch ratio of 2.0 to 1. In July 2010, the Maryland Department of the Environment determined that abnormal high water temperatures aided the bacterium *Aeromonas hydrophila* and a protozoan gill parasite to cause a large fish kill in DCL. Most DCL fish species were affected, and an estimated 10,000 fish died. The reduced abundance of Largemouth Bass in 2012 may indicate that the 2010 fish kill had an adverse effect on the population size. Reproduction was considered "good" in 2012; however a corrective stocking of 10,000 Largemouth Bass fingerlings were stocked to enhance the population during spring 2012. Cursory results for 2013 show that Largemouth Bass showed an increase in abundance from 2012.

Northern Pike
Northern Pike are becoming more common in electrofishing samples, and this increase in abundance is the result of the increased minimum size restriction (24 inches to 30 inches, enacted in 2001). The increase in the minimum size allows the Northern Pike to reach sexual maturity before reaching harvestable size, thereby increase reproductive potential. Trophy size fish exceeding 40 inches are routinely captured in DCL.

Chain Pickerel
Chain Pickerel are very abundant; however angler interest in this species is relatively low in DCL. The proportional stock density and relative stock density values are indicative of a balanced population. Length frequency distribution of Chain pickerel collected in 2012 shows a diverse age and size structure.

Trout species
Brown Trout, Rainbow Trout, and Golden Trout are stocked annually in DCL. Adequate coldwater and oxygen in the hypolimnion during summer allows for year-round survival, creating angling opportunities in all seasons. A combined total of 4,805 Brown Trout, Rainbow Trout, and Golden Trout were stocked in DCL in 2012. However, trout are not routinely collected during electrofishing sampling efforts primarily due to their pelagic, deeper water habitat preferences.

Panfish species
Bluegill, Pumpkinseeds, and Rock Bass are common to abundant in DCL and the populations are characterized by having adequate quality-size fish to provide angler interest. Bluegill population data for 2012 indicated a population comprised of an abundance of quality and preferred size fish. Bluegill length frequency distribution further shows a diverse size and age structure from juveniles to memorable size (10 inches or greater) fish in the population.

Minnow species
Golden Shiners are the most abundant forage fish species in DCL. Common Carp are common and reach very large sizes (exceeding 20 pounds) in DCL, and there is increased angler interest in this species.

THREATS

Deep Creek Lake Fishkill

On 19 July 2010 MD DNR received the first report of a fishkill in the Beckman's Area of DCL of about 30 – 40 fish. Maryland Department of Environment (MDE) Fish Kill Investigators responded, and reported no unusual water quality conditions. On 21 July 2010, Beckman's area residents called MD DNR Fisheries and indicated more than 50 fish were dead in that area of the lake. MD DNR Fisheries personnel responded with a shoreline survey and counted 186 dead fish in a mile of shoreline in the Beckman's area. McHenry Cove and Rt. 219 Bridge areas were also surveyed and no fish kills were observed. Fish species included Yellow Perch, Walleye, Smallmouth Bass, Largemouth Bass, Northern Pike, Chain Pickerel, Bluegills, Rock Bass, Brown Bullheads, Golden Shiners, and crayfish. These fish species are considered cool water (prefer 65 - 70°F) and warmwater fish species (prefer 70 - 85°F). MDE and DCL Management Office were notified and plans were made to continue additional investigations. On 22 July 2010, DCL Management Office and MD DNR Fisheries investigated the extent of the fishkill and found dead fish scattered throughout the southern portion of the lake on the east shoreline, with the another concentration of dead fish in Green Glade Cove. Dead fish also observed in Meadow Mountain Cove north of Glendale Bridge. We observed about 500 dead fish on that date. On 23 July 2010, MDE and DNR used gill nets in Beckman's and Green Glade Area to collect live fish within the 10 to 30 foot water column. Ten Yellow Perch, one Walleye, and one Smallmouth Bass were collected. Bacteriological, histological and parasitological samples were obtained from each fish. The MDE Fish Kill Unit biologists determined that two pathogens affected the fish - one was the bacterium *Aeromonas hydrophila* and the other was a protozoan gill parasite. *Aeromonas hydrophila* is described as a "saprophytic" meaning it becomes pathogenic when fishes are physiologically unbalanced, nutritionally deficient or there are other abnormalities which allow opportunistic organisms to invade. This bacterium is common in most aquatic systems in Maryland and fish of all species serve as "reservoirs" for this bacterium. The temperature in Deep Creek Lake during July had been the highest ever recorded over several decades of temperature monitoring, and may have been a contributing factor for the outbreak. We estimated as many as 10,000 fish died during the summer of 2010, and based on 420 fish counted by species – we arrived at the percentage of affected fish by species: Yellow Perch (62.2 %), Walleye (13.8 %), Smallmouth Bass (13.1%), Brown Bullhead (4.0 %), Bluegill (3.1 %), Largemouth Bass (1.4 %), Chain Pickerel (1.0 %), Northern Pike (0.5 %), Rock Bass (0.5 %), Black Crappie (0.2 %), and Golden Shiner (0.2 %). By September 2010, the fishkill subsided, and anglers reported fishing success had improved.

YOUGHIOGHENY RIVER TROUT FISHERY: HISTORICAL TRENDS AND CURRENT CONDITIONS

The portion of the Youghiogheny River from the Deep Creek Hydro Station (DCHS) tailrace downstream approximately 4 miles to the Sang Run bridge was designated a Catch and Release Trout Fishing Area (C&R TFA) in 1993. Regulations limit terminal tackle to artificial lures and flies. Fishing is permitted year-round. Prior to 1993, this portion of the river was managed under Maryland's Designated Trout Stream regulations, which specified a two-fish daily creel limit with no minimum size, bait, or tackle restrictions. The fishery in the C&R TFA is maintained through put-and-grow stockings of fingerling Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss*. We strive to maintain a trout population density of 1,000 trout per mile as measured during fall sampling efforts. The current list of fish species and their observed abundance is in the Youghiogheny River Catch and Return Trout Fishing Area is contained in Table 11.

The current operating license for the DCHS requires temperature control (maintenance of < 25° C in the Youghiogheny River measured at Sang Run during June, July, and August), minimum flow maintenance (40 cfs in the Youghiogheny River measured at the DCHS tailrace outflow), and dissolved oxygen augmentation to meet State standards (≥ 6 ppm average, 5 ppm minimum in the DCHS discharge) for downstream coldwater fisheries enhancement. These combined measures were implemented beginning in 1995 as part of an operating license renewal agreement with the Maryland Department of the Environment, Water Resource Administration -Deep Creek Lake Project - Water Appropriation Permit No. GA92S009(01) and re-issued in 2007 with Water Appropriation Permit No. GA1992S009(07).

Trout standing crops, adult trout densities, and numbers of quality size trout in the Youghiogheny River C&R TFA have increased since catch and release regulations as well as minimum flow, dissolved oxygen augmentation, and coldwater temperature enhancement releases implemented at the DCHS beginning in 1995. Maintenance of water temperature and flow volume within a range which Brown and Rainbow Trout can tolerate has increased available habitat in the Youghiogheny River C&R TFA during critical mid-summer periods, increasing survival and supporting a larger population as well as a high quality fishery. We strive to produce an adult trout population of 1,000 trout per mile throughout the Youghiogheny River C&R TFA to maintain a high-quality trout fishery. The 2005 estimated trout population decreased significantly from previous post-temperature enhancement years. River temperatures during the summer of 2005 reached the critical thermal maxima or the temperature at which trout loses their ability to escape lethal conditions. The Maryland Department of the Environment issued a Notice of Violation of State Water Appropriation Permit to the operators of the DCHS. The notice charged the operators that Condition 16 of the permit was violated on six dates during June-August 2005. The DCHS operators acknowledged the non-compliance occurrences, and reported they were caused by protocol problems and operator error. Recovery took a number of years, but by 2009 and 2010, the trout density and standing crops have met the DNR management objective. The number of quality-size trout in the Youghiogheny River C&R TFA in the post-enhancement period was comparable to the very high quality trout population of Maryland’s Savage River Trophy Trout Fishing Area.

THREATS

During 2011 and 2012, the trout population densities and standing crops were reduced to levels observed prior to the temperature enhancement plan mainly due to the number and duration of temperature exceedances. The loss of trout densities in 2011 and 2012 was the greatest reduction (6.2 and 6.4-fold decrease respectively from 2010) since the temperature enhancement plan was instituted in 1995. In addition, changes made in the Brookfield Water Appropriation permit instituted by MDE’s Water Supply Program in June 2011 will further have a detrimental effect on the Youghiogheny River coldwater trout resource. The changes to Condition 17 along with operational changes resulting from the new verified estimate of wicket flow threaten the coldwater habitat and high quality trout fishery which exist in the Youghiogheny River downstream of the discharge. The USGS verified wicket flow at 17 cfs. It is likely that the historical estimate of 9 cfs was in error due to the use of less rigorous techniques. Previous modeling, management actions and permit conditions were all developed under the assumption of 9 cfs of cold water flowing to the river at all times, however, it more likely has been closer to the 17 cfs now observed. Operational changes resulting from adopting this new estimate will reduce the amount of cold water discharged to the river during critical low flow, high temperature periods. These changes alone will have negative implications for the coldwater resource downstream. The additional changes to the permit will elevate the risk to a high probability that environmental harm will occur throughout the downstream river reaches. Flow bypass volumes will be reduced in hot and drought conditions to maintain the 40 cfs in the river, thereby significantly decreasing by more than 50% available coldwater habitat previously (16 years) available under the water appropriations permit. The cold water reduction will have significant impacts on river temperatures below the tailrace and reduced the coldwater water refugia which have been present for trout in the river since operations started at the dam.

In addition to the adjustments for the new wicket flow estimate, MDE has directed Brookfield to close one penstock during non-discharge periods. This will further reduce coldwater discharge to the river and compound the impacts to downstream habitat and the fishery. This change will cut the minimum supply of coldwater which the river has historically received on a continual basis by half (8.5 cfs). The percentage of coldwater in the river at minimum flow will be reduced from 35% historically to 21%. This loss of cold water will have significant impacts on maximum and average temperatures below the tailrace and will severely reduce the coldwater water refugia for trout which has been present since operations started at the dam.

This operational change may also compromise the effectiveness of the TER protocols since they were developed with the 17 cfs wicket flow in place. Shreiner and Dew-Baxter (2011) reported that river temperatures at Sang Run exceeded 25°C on 18 days and maximum temperature reached 28°C for a three-hour duration during July 2011. Additionally, augmentation for minimum flow will now not occur until the river has dropped 8.5 cfs lower than in previous years, also having negative impacts to the coldwater resource.

Finally, the provision to suspend the 40 cfs minimum flow when lake elevation drops more than one foot below the lower rule band would very likely severely impact trout populations. This would occur after the use of shallow areas of the lake had already been compromised and would provide no immediate relief for lake users since is likely to occur during a low inflow scenario. Lake levels would recover quickly once precipitation returned to normal. However coldwater resources and the trout fishery would take 4 to 5 years to recover and a valuable public resource has been put at risk. Loss of this fishery is not just a degradation of Maryland's natural resources but it would result in a loss of local revenues in response to poor fishing and would impact the local economy and resource supported businesses.

Table 11. List of common and scientific names and relative abundance of fish species collected in the Youghiogheny River Catch and Release Trout Fishing Area, 2012.

Common Name	**Scientific Name**	**Observed Abundance**
River Chub	*Nocomis micropogon*	Abundant
Longnose Dace	*Rhinichthys cataractae*	Common
White Sucker	*Catostomus commersoni*	Scarce
Northern Hog Sucker	*Hypentelium nigricans*	Abundant
Margined Madtom	*Noturus insignis*	Scarce
Brook Trout	*Salvelinus fontinalis*	Scarce
Rainbow Trout	*Oncorhynchus mykiss*	Common
Brown Trout	*Salmo trutta*	Common
Mottled Sculpin	*Cottus bairdi*	Common
Bluegill	*Lepomis macrochirus*	Scarce
Rock Bass	*Ambloplites rupestris*	Common
Smallmouth Bass	*Micropterus dolomieu*	Common
Total species = 12		

Forest Resources

DEEP CREEK WATERSHED ANALYSIS & EVALUATION FOR RESTORATION & CONSERVATION OF FOREST RESOURCES

Located in Garrett County, Maryland, Deep Creek Lake was developed in the 1920's for hydro-electric power generation. Since then, the Lake and surrounding areas have turned into popular year round destinations for locals and travelers alike. The watershed for the Lake is comprised of 3 sub-watersheds that total 63.96 square miles. (Figure 54)

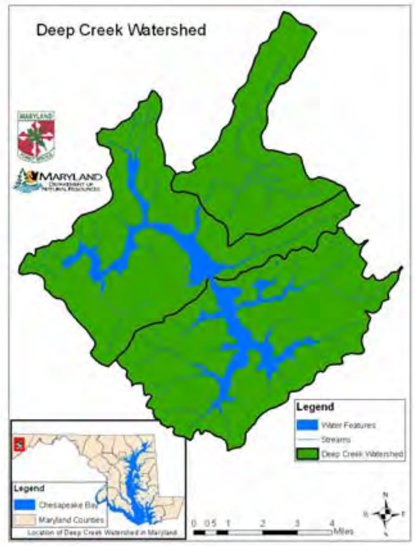


Figure 54: Deep Creek Lake and its watershed

A concern for such a desirable place is the fragmentation of forest by development. Forest fragmentation occurs when forest is cleared to build houses, roads or other infrastructure. As more and more people seek to have a second home in a resort area, chances are forest fragmentation will increase. Fragmented forests provide fewer natural benefits like less clean water, and less clean air, along with the disruption of animals that depend on large contiguous blocks of forest for their life cycles.

HEALTHY FORESTS FOR HEALTHY WATERSHEDS ANALYSIS:

Based on an earlier statewide analysis, sub-watersheds were evaluated based on their ability to produce clean water. Attributes of forests that affect water quality, such as steep slopes or headwater streams, were combined to create a "model." The higher the value, the more important it is to keep the area forested so it can continue providing natural benefits to the watershed.

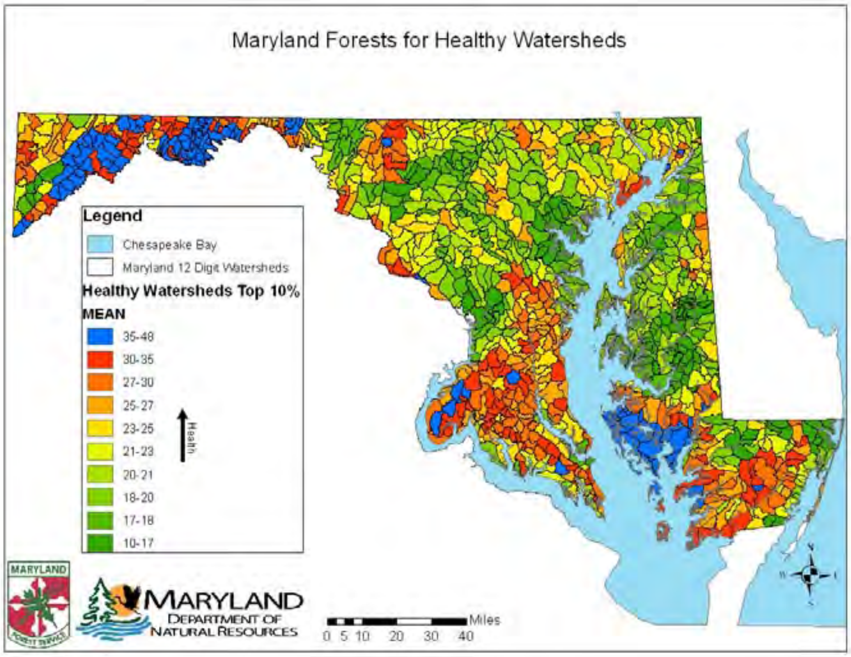


Figure 55: Statewide Maryland Forests for Healthy Watersheds Analysis

At a statewide level the Deep Creek Watershed averages out to a moderately ranked watershed. (Figure 55) A more focused map was clipped to the watershed to get a better look at the health of the watersheds. (Figure 56)

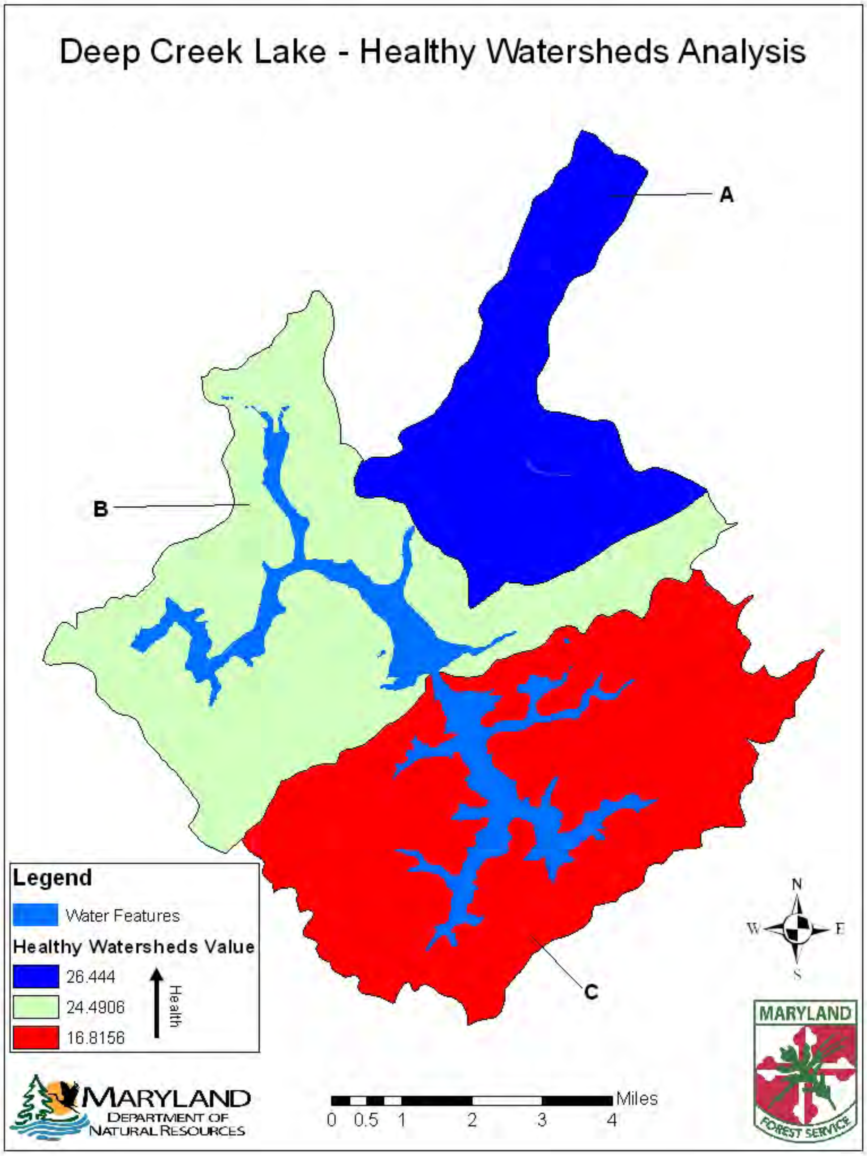


Figure 56: A zoomed in view of the Deep Creek Watershed for the Healthy Forests Healthy Watersheds Analysis.

The watersheds vary in their influence on clean water from moderate/low to high. Watershed A ranks high, with watershed B ranking high also; watershed C ranks moderate/low. The high ranking watersheds have more characteristics like wetlands, floodplains, and forest blocks, that overlap creating valuable areas where keeping the forests in forest should be a priority. Percent of watershed forested, wetlands, groundwater movement, and steep slopes are examples of the inputs that make a watershed important for clean water production, please see the matrix for this map in Appendix A for more information and an explanation of layers and reasoning.

CURRENT SUB-WATERSHED CONDITIONS:

There are many variables that contribute to the health of a body of water and its surrounding watershed. The following are some general observations about the status of some of the most important factors evaluated when looking at what influences water quality. There are strong trends that the healthiest watersheds are the ones with the most forest and most forested buffers.

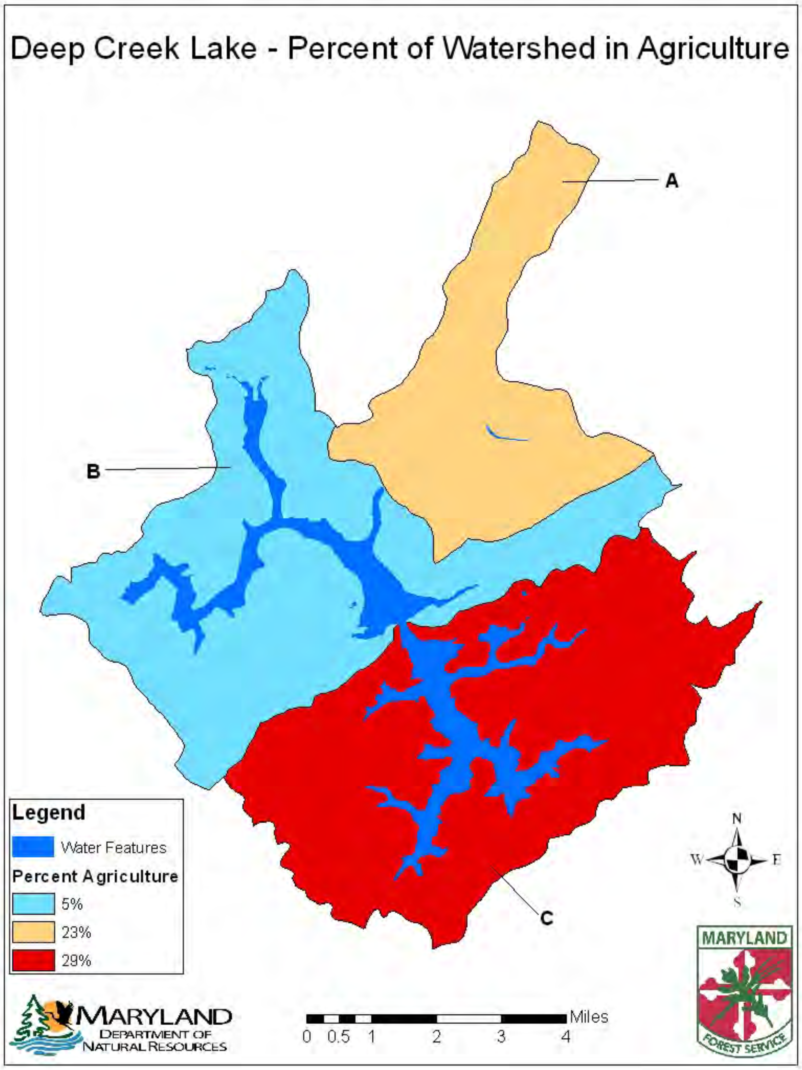


Figure 57: Percent of Watershed in Agriculture for the Deep Creek Watershed.

Figure 57 shows the amount of agriculture that occurs in the three watersheds of Deep Creek Lake. Percent in agriculture varies from five percent to twenty-nine percent. A watershed that is deficient in forest is less likely to produce as clean waters as a watershed that has abundant forest and forested buffers.

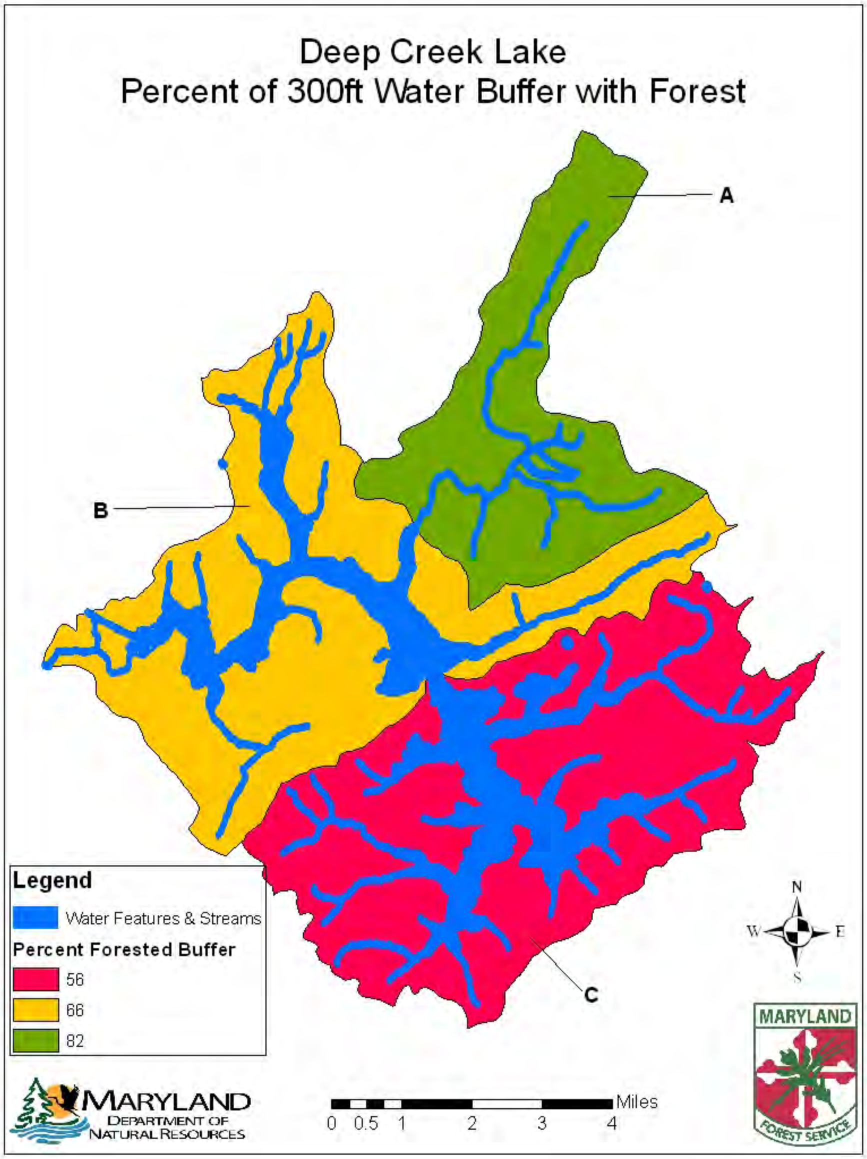


Figure 58: Percent of waterways by watershed with forest within 300 feet.

Figure 58 shows the percentage of waterways by watershed that are buffered by forests within 300 feet. The map shows that watershed A has the highest percent of buffered streams, watershed B has a moderate amount of buffered streams, and watershed C is lacking buffers on almost half of its streams.

A sub-watershed where the waterways are buffered by forest means that much of the surface and subsurface flow is able to be filtered by trees' roots before reaching creeks, streams, rivers, or lakes. Buffered waterways also maintain lower temperatures that benefit aquatic organisms since cooler water has higher dissolved oxygen content.

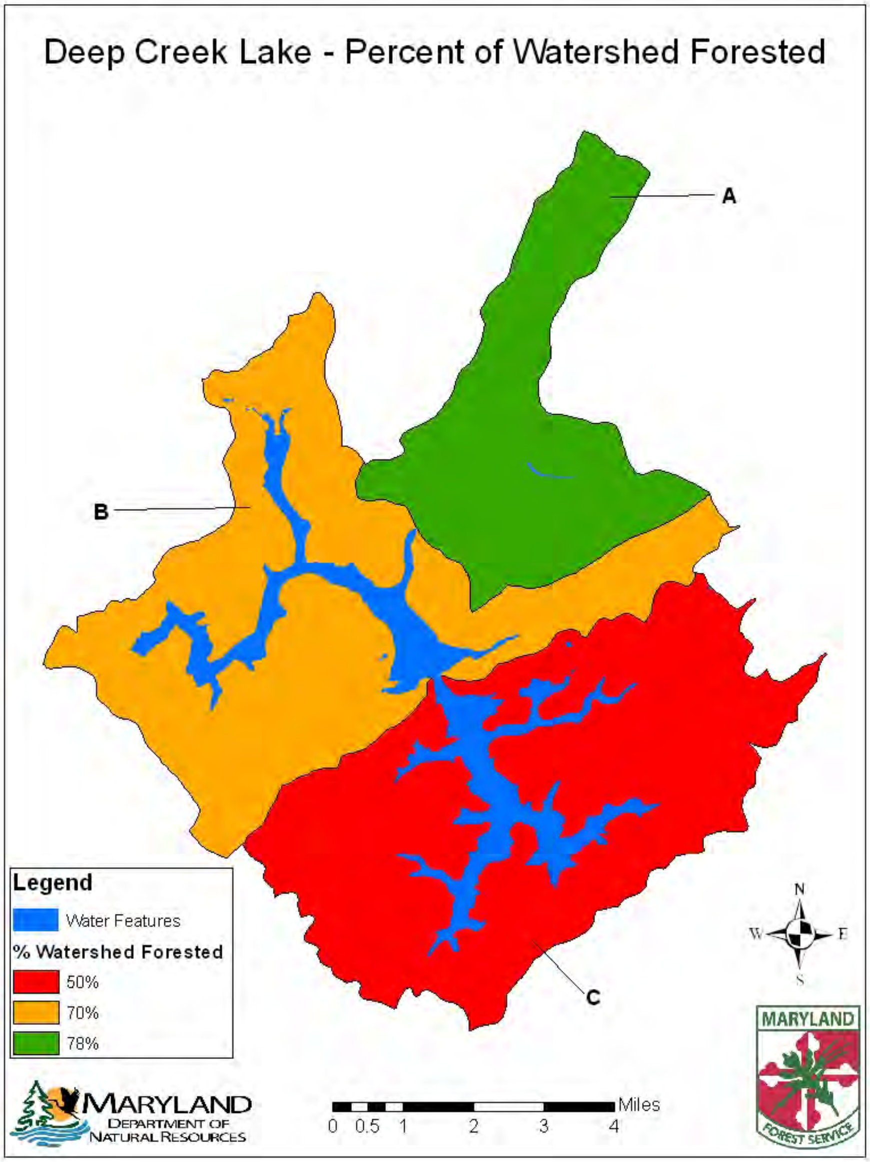


Figure 59: Percent of Watershed Forested for the Deep Creek Watershed.

Figure 59 depicts the amount of the watershed that is forested. Watersheds A and B rank seventy percent and above, while watershed C is fifty percent forested. Forests are the cleanest land use; in areas where forest cover is reduced due to agriculture or development, there is an increased likelihood that polluted runoff will enter waterways. In order to mitigate pollution inputs, it is recommended that Best Management Practices (BMPs) be implemented to keep waters clean, or improve them. Practices can include planting forest buffers along waterways, installing rain gardens in urban areas, or fencing cattle out of streams to name a few.

CONSERVATION AND RESTORATION TARGETING ANALYSIS

For statewide analysis, a sub-watershed scale is a good starting point. In a watershed as concentrated as Deep Creek though, a finer resolution is needed to pin-point opportunity. In an effort to target where forest conservation or restoration could occur at a more local level, two targeting maps were developed to aid the decision process.

A Conservation Targeting Map and a Restoration Targeting map (Figure 60) were developed to find forests that should be kept in forest, or areas that would benefit from the addition of trees. The layers for the models were selected on their ability to provide habitat, water quality, or forest productivity protection. All the layers were then weighted and added together.

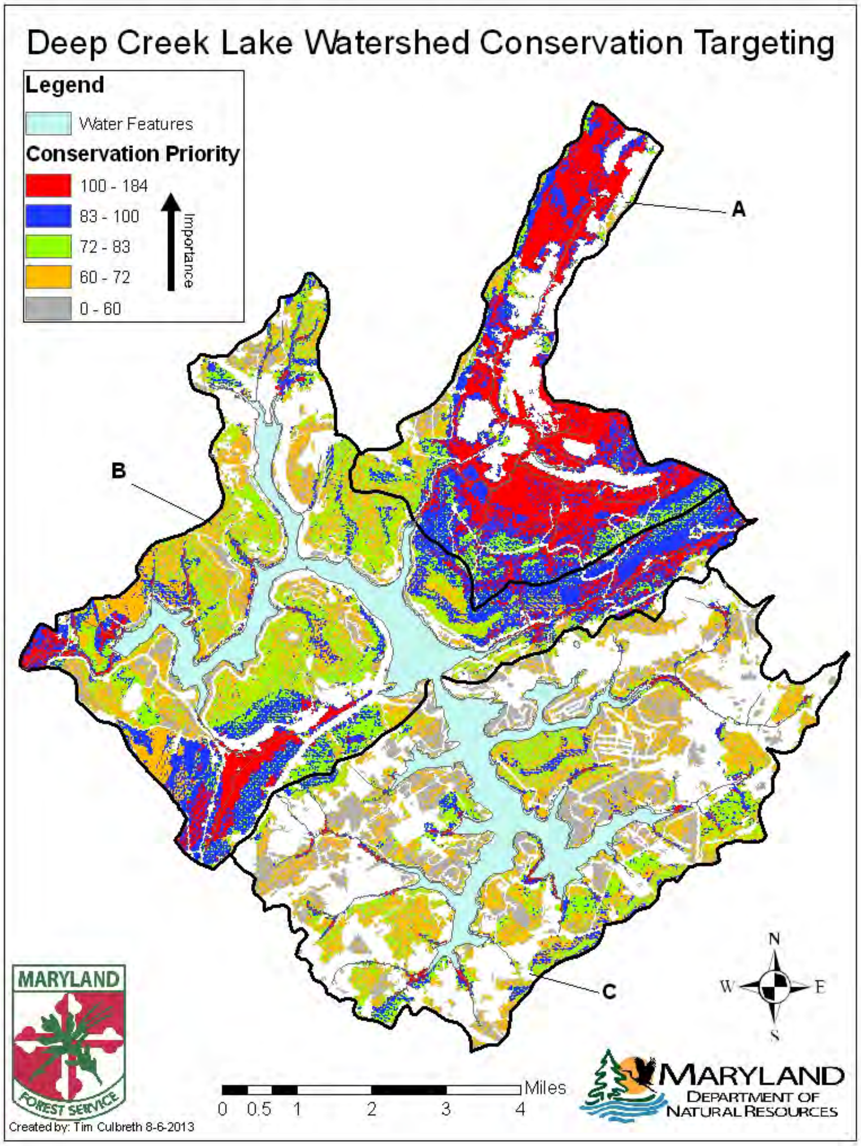


Figure 60: Conservation Targeting Map showing where resources should be targeted to keep forests in forests to continue the production of clean water and wildlife habitat.

Established forests provide better water filtering ability than any other land use. Keeping forest in forest is more affordable and better for water quality than planting new forest somewhere else to try to mitigate that loss. The Conservation Targeting Map was developed to help find high value forests where efforts could be employed to keep these forests in forest. The areas that are highlighted in red are areas where many of the desired attributes of existing forests overlap. These “hot spot” areas are forests where you would expect to see things like high water tables, steep slopes, slow moving ground water, or buffered streams. An area with a high water table gives trees roots a chance to absorb some of the nutrients from subsurface water, pair that with slow moving ground water and tree roots will be in contact longer with the water; aiding in the filtering process. Forests on steep slopes provide good erosion protection; their well developed root systems hold soils in place and canopies reduce rain fall velocity. The analysis was restricted to existing forest. For an explanation of the layers and the matrix used to create the map, please see Appendix B.

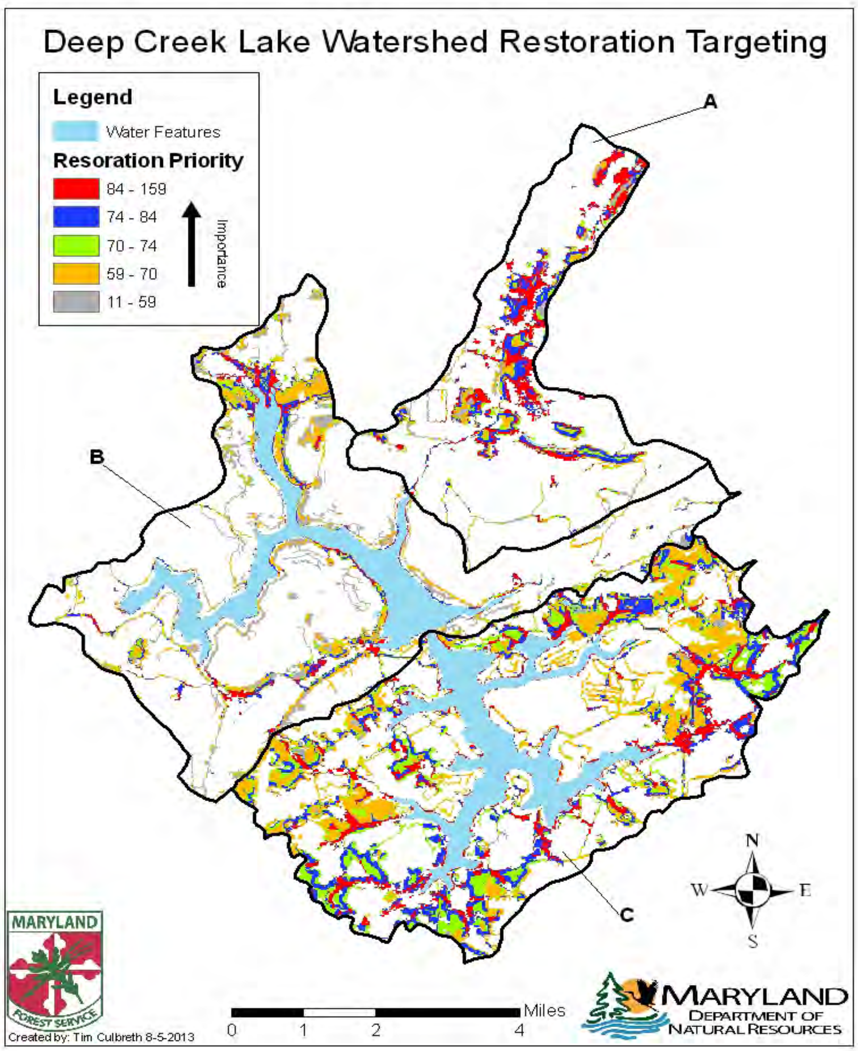


Figure 61: The Restoration Targeting Map shows where resources could be allocated to plant forest or install BMPs such as forest buffers and urban tree canopy initiatives.

The Restoration Targeting Map (Figure 61)is a tool designed to identify non-forested areas where the addition of forest would do the greatest good to increase the quality of water coming off the landscape. This analysis excluded forest. Areas of interest on this map are the red “hot spots.” You can expect to see overlap of priorities of non-forested streams, non-forested steep slopes, hydric soils, and adjacency to high priority wildlife areas contributing to the highlighted areas. Hydric soils are the soils where you can expect to see the development of wetlands if the conditions are created for them, adjacency to high priority wildlife areas will allow for the expansion of important wildlife habitat. For an explanation of the layers and a matrix of how the map was compiled please see Appendix C.

ASSISTANCE TO KEEP FOREST IN FOREST AND INCREASE FOREST COVER

There are many on-the-ground, programs from all over Maryland that can be emulated to maintain and increase forest cover around Deep Creek Lake. It is beneficial to package education and implementation together so landowners understand why they are being encouraged to do something.

The Conservation Reserve Enhancement Program (CREP) is a Federal program where producers enter into a contract with the Farm Service Agency where they are compensated on a per acre basis to plant riparian forest buffers along streams that cross their farm. The minimum width of buffer planting is 35 feet and the maximum width is 300 feet. There are signing bonuses and funding available to help with annual maintenance of the buffers.

Backyard Buffers is a program that began in western Maryland where landowners living along waterways that own fewer than 5 acres are given “buffers in a bag.” The bags contain about 25 free native tree seedlings for planting new streams or waters by homeowners’ yards. Identifying eligible landowners is a simple GIS exercise and seedlings are reasonably priced and available every year from the John S. Ayton State Tree Nursery on the Eastern Shore.

The Marylanders Plant Trees program was launched in 2009 to encourage and assist private landowners to plant more trees in their yards. The program offers a $25 discount off a $50 or more approved species of tree at participating nurseries. Montgomery County took it a step further and had an additional $25 off a $75 tree coupon. The coupons had the ability to be stacked which meant interested landowners were able to purchase a $75 tree for $25. If Garrett County has the resources available to sponsor additional discounts for larger stock, the benefits of the planted trees will be realized sooner.

Finally, encouraging forest owners to enroll their properties in Forest Conservation Management Agreements will mean less tax pressure on families. An FCMA reduces the assessed tax rate on the forested land for 15 years at a time; The Woodland Assessment Program is a similar program that works on a year-to-year basis with a reduced assessment rate, but not as low as an FCMA. Enrollment into any tax program requires a forest stewardship plan. Practicing forest management and making your forest work for you is a good way to keep forest in forest.

Rare Threatened and Endangered Species and Habitats

OVERVIEW : WILDLIFE AND RARE SPECIES HABITATS

In 2011, information on Maryland's wildlife and rare species habitats were synthesized and prioritized in a new targeting system called the Biodiversity Conservation Network or BioNet. The ultimate goal of this new system is to maintain the full complement of Maryland's native plants, animals, and habitats within Maryland's natural landscape. In this system, numerous separate geographic information system (GIS) data layers were compiled based on criteria that weight their relative value to biodiversity conservation in Maryland. The criteria used within BioNet primarily have a dual focus on both the most irreplaceable species and habitats, as well as on the habitats that concentrate larger numbers of species. In addition to focusing on vanishing species and habitats, and on high quality common habitats, the criteria also were designed to incorporate the larger landscapes required for migratory animals, population dispersal, and habitat shifts resulting from climate change.

BioNet specifically includes and prioritizes:

- Only known occurrences of species and habitats in Maryland
- Globally rare species and habitats
- State rare species and habitats
- Concentrations (aka "hotspots") of rare species and habitats
- Animals of Greatest Conservation Need
- Watch List plants and indicators of high quality habitats
- Animal assemblages (e.g., colonial nesting waterbirds, forest interior species)
- Wildlife corridors and concentration areas

In a nutshell, the rarest species and habitats, as well as concentrations of rare and vanishing species and the highest quality remaining habitats, are given the highest conservation value. The end result is one GIS data layer that assigns a relative priority to many undeveloped areas of the State. These areas are prioritized into a five-tiered system:

Tier 1 – Critically Significant for Biodiversity Conservation
Tier 2 – Extremely Significant for Biodiversity Conservation
Tier 3 – Highly Significant for Biodiversity Conservation
Tier 4 – Moderately Significant for Biodiversity Conservation
Tier 5 – Significant for Biodiversity Conservation

This five-tiered system was designed to capture and support the full array of biological diversity within Maryland – not just those places that are one-of-a-kind, but also the places that are needed to maintain viable populations of more common species. Keeping common species common is a goal that will provide enormous benefits to both our quality of life and our economy. We simply cannot afford to wait until herculean efforts are necessary to save species from the brink of extinction. The costs of these efforts are staggering. Therefore, even Tier 5 BioNet Areas are still significant to conserve, both for the species they directly support, as well as for maintenance of the larger fabric of our natural landscape.

The BioNet GIS data layer is somewhat dynamic because the data used to build it are continuously being updated as new information is gathered and processed into the various baseline data layers. These various baseline GIS layers are discussed separately below. Section 2 of this report provides a summary of the BioNet areas within the Deep Creek Lake Watershed and statistics on acreages of the various Tiered areas is reported in Table 1.

1. Ecologically Significant Areas (ESAs)

The Deep Creek Lake Watershed is home to nearly 40 plants and animals considered rare, threatened, or endangered (RTE) in Maryland by the Department of Natural Resources. A subset of these species are legally regulated and listed in COMAR as In Need of Conservation, Threatened, or Endangered. A list of these rare species is included in Table 2 below.

The locations where rare species and significant natural communities occur are grouped into places called Ecologically Significant Areas (ESAs). ESAs contain one or more rare plant, animal, or ecological community occurrences. The size and configuration of the ESAs are based upon proximity of the occurrences, life history needs of the species, and the type and extent of the supporting habitats. Many rare species occur within declining or limited habitats, such as bogs or seepage swamps. Others live in high-quality patches of more common habitats. ESAs are designed to contain not only the rare resource itself, but also their habitats and appropriate buffers (i.e., adjacent lands needed to conserve the species and habitats). Thus, they are intended to be used as conservation boundaries for the resources within them. ESAs are then assigned to prioritized BioNet Tiers based on the rarity, potential viability, and number of resources they contain. Section 2 provides details on the number of ESAs within the Deep Creek Lake Watershed and the resources contained within them. A summary description of each ESA is provided in Appendix B.

The Ecologically Significant Area boundaries should be considered as guidance maps rather than "hard" or unchanging boundaries. In fact, these boundaries are updated regularly as additional information is learned about the locations of rare species in areas that perhaps had not been surveyed previously. Also, the prioritized BioNet Tier rankings will change as new information becomes available on the resources and the viability of the resources within each area.

2. Species of Greatest Conservation Need (GCN) and Key Wildlife Habitats

In addition to the rare species discussed above, the Department of Natural Resources also keeps track of species that are uncommon and declining, as these are likely to become rare and in need of conservation efforts in the foreseeable future. In 2005, the Maryland Department of Natural Resources and numerous conservation partners developed a comprehensive Wildlife Diversity Conservation Plan. This Plan summarizes the types of

habitats important for wildlife in Maryland and condenses them into 35 different habitat groups called Key Wildlife Habitats. Chapter 4 of the Plan provides details for each of these Key Wildlife Habitats, including lists of animals of Greatest Conservation Need (GCN) that are found within them. The Wildlife Diversity Conservation Plan can be found online at:
http://www.dnr.maryland.gov/wildlife/Plants_Wildlife/WLDP/divplan_final.asp.

Of the approximately 500 GCN animals listed in the plan, 300 were already considered rare, threatened, or endangered, and therefore were already being conserved by DNR through various efforts. Some of the remaining 200 GCN species already were afforded some conservation attention as a group because of their similar habitat needs. These are known as Forest Interior Dwelling Species (FIDS), and conservation of their habitat is regulated in portions of Maryland.

Forest Interior Dwelling Species (FIDS) Habitat

Some of the birds that breed in forests require large, unbroken tracts of forest for optimal breeding success. These birds are called Forest Interior Dwelling Species (FIDS). These species are considered a surrogate or "poster child" for many other species of wildlife that are known or likely to use the interior of forests as their optimal habitat. The protection of forested areas used by FIDS was mandated within the 1000-ft Chesapeake Bay Critical Area during the mid-1980's by passage of the Critical Area Law and Criteria. However, much of Maryland's forests are fragmented into smaller pieces than FIDS can successfully utilize. Therefore, the protection of this habitat outside of the Critical Area is strongly recommended by DNR. Section 2 provides details on the FIDS habitat that is found within the Deep Creek Lake Watershed in Garrett County.

3. Impacts of Resident Canada Geese on Deep Creek Lake

General Biology - Canada geese are a valuable natural resource and a source of recreation to the general public, bird watchers, and hunters. Of all the waterfowl, geese are particularly opportunistic and can easily become accustomed to people. In many areas of the United States, resident Canada goose populations have increased dramatically since the 1960's. In certain areas, Canada geese have responded to landscape features that provide expanses of short grass for food, lack of natural predators, absence of hunting, and hand feeding by some people.

Although most people find a few geese acceptable, problems develop as local flocks grow and their droppings become excessive (a goose produces a pound of droppings per day). Problems include over-grazed lawns, accumulations of droppings and feathers, nutrient loading in ponds, public health concerns at beaches and drinking water supplies, aggressive behavior by nesting birds, and safety hazards near roads and airports. Geese can also damage agricultural crops by excessive grazing.

Resident geese, as their name implies, spend most of their lives in one area, although some travel hundreds of miles to wintering areas. Resident geese are distinct from migratory populations that nests in northern Canada. Banding studies have shown that resident geese are not simply migrant geese that stopped flying north to breed. In fact, Canada geese have a strong tendency to return to where they were born and use the same nesting and feeding sites year after year. This makes it hard to eliminate geese once they become settled in a local area.

Because of their short migrations and their association with non-hunted locales, resident Canada geese have low exposure to hunting in the fall and winter and have high survival compared to migrant geese. The result is that they live longer; 15-25-year old resident geese are common. They also tend to breed earlier in life and lay larger clutches of eggs and nest in a more hospitable environment than migrant geese.

Most resident geese begin breeding when they are 2-3 years old and they nest every year for the rest of their lives. They mate for life, but if one member dies, the other will mate again. Canada geese lay an average of 5 eggs per nest, and about half will hatch and become free-flying birds in the fall. A female goose may produce more than 50 young over her lifetime.

The annual life cycle for geese begins in late winter when adult pairs return to nesting areas in late February or March. Egg laying and incubation generally extend through April, with the peak of hatching in late April or early May, depending on location in the State. Geese will aggressively defend their nests, and may attack if approached. Non-breeding geese often remain nearby in feeding flocks during the nesting season. After hatching, goose families may move considerable distances from nesting area to brood-rearing area, appearing suddenly "out of nowhere" at ponds or lakes bordered by lawns.

After nesting, geese undergo an annual feather molt, a 4-5 week flightless period when they shed and re-grow their outer wing feathers. Molting occurs between mid-June and early July, and the birds resume flight in August. During the molt, geese congregate on ponds or lakes that provide a safe place to rest, feed, and escape danger. Severe problems often occur at this time of year because the geese concentrate on lawns next to water. Some geese without young travel hundreds of miles northward to remote molting areas. These "molt migrations" account for the disappearance of some local goose flocks in early June.

After the molt and through the fall, geese generally increase the distance of their feeding flights and are more likely to be found away from water. Large resident flocks, sometimes joined by migrant geese in the fall, may feed on athletic fields and other large lawns during the day, and return to larger lakes and ponds to roost at night. This continues until ice or snow eliminates feeding areas and forces birds to other open water areas nearby or to the south, where they remain until milder weather returns and nesting areas open up.

Damage Prevention: A Community Effort - Reducing damage caused by Canada geese takes the cooperation of the entire community. The Maryland DNR website (http://www.dnr.maryland.gov/wildlife/Hunt_Trap/waterfowl/geese/ResGeeseProblem.as

p) contains an exhaustive list of deterrents and management options such as exclusions (fencing & Mylar tape); harassment (flagging, balloons, and lawn sprinklers); chemical repellants; and lethal control that, due to current regulations, are prohibited in the Deep Creek Lake buffer strip.

Currently the most practical legal management options are:

- ***Limited Habitat modification*** **–** allowing grass to grow
- ***Control of nest production*** **–** oiling eggs
- ***Limited Lethal Control*** **–** hunting outside of the buffer strip

Limited Habitat Modification - Canada geese require upland and aquatic habitats for resting, feeding, and breeding. Habitat modification involves physically altering property to make it less attractive to geese. Modifications made to the property should focus on eliminating or reducing nesting sites and food sources, as well as the access between these items and to the pond or lake. Habitat modifications make a property less suitable to geese and limit the number that can exist on the property or area.

Because of the sensitive nature of the buffer strip around Deep Creek Lake, limited habitat modifications are permissible. The means to make the habitat less hospitable to geese are:

- ***Discontinue Supplemental Feeding by People*** **-** Feeding may cause large numbers of geese to congregate in unnatural concentrations. Feeding usually occurs in the most accessible areas, making a mess of heavily used lawns, walkways, roads, parking areas, and boat docks. Feeding of all waterfowl on both public and private property should be prohibited as an important step in controlling Canada goose problems.

- ***Manage Grass and Plants by Limiting Mowing*** **-** Geese feed on grass. Grass that is frequently mowed and is fertilized is an excellent food (proteins and carbohydrates) for geese. Mowed lawns also provide loafing areas where predators can be seen from a distance. By eliminating mowing at least 20 feet from shorelines or in even larger tracks of land, geese will be encouraged to shy away from these areas and look for safer spots with better food sources. Tall, poorly-fertilized grass is a poor food for geese and much less attractive. Canada geese are reluctant to walk through high vegetation; tall grass management limits the number of geese that can use an area. To make grass areas less attractive to geese: (1) limit lawn sizes; let grass grow 10 inches to 14 inches tall, (2) especially along shorelines; and (3) limit the application of fertilizer on grass areas to reduce the nutritional value of grass to the birds.

Control of Nest Production - Geese usually return in spring to the area where they hatched or where they nested previously. Over time, this results in increasing number of geese in areas that once had just a few birds. Local population growth may be controlled by preventing geese from nesting successfully. Egg addling or oiling of eggs prevents the embryo from developing and prevents hatching. This can be done by shaking, freezing, or applying 100% food grade corn oil to all of the eggs in a nest. The female goose will continue incubating the eggs until the nesting season is over. If the nest is simply destroyed, or the eggs removed, the female may re-nest and lay new eggs.

If you are a landowner, public land manager, or local government in Maryland,, you may obtain legal authorization to destroy Canada goose nests and eggs on your property between March 1 and June 30 to resolve conflicts with geese and to prevent injury to people, property, agricultural crops, or other interests.

Before any goose nests or eggs may be destroyed, landowners must go on-line at https://epermits.fws.gov/eRCGR/geSI.aspx to register with the U.S. Fish and Wildlife Service. Landowners must register employees or agents that may act on their behalf. Registration is free and is valid for one nesting season and must be renewed each year before nests and eggs may be destroyed. No State permit is required to destroy nests or eggs in Maryland.

Limited Lethal Control - Wherever possible, hunting should be encouraged during established hunting seasons in accordance with Federal, State, and local laws and regulations. Hunting is considered to be the most important management tool for controlling local Canada goose populations. Hunting should be strongly encouraged outside of the buffer strip area of Deep Creek Lake. Canada goose hunting that targets local flocks is permitted in Maryland during September, prior to the fall arrival of migratory Canada geese from Canada. An 80-day regular Canada goose season is also held in the fall and winter in central and western Maryland to target resident Canada geese. DNR's Website lists the licenses, stamps, and nontoxic shot ammunition requirements at: http://www.dnr.maryland.gov/huntersguide/index.asp.

Agricultural producers actively engaged in commercial agriculture may also kill Canada geese on lands that they personally control and where geese are damaging agricultural crops with proper authorization. While State authorization is required to conduct this control, a federal permit is not required. Goose nests and eggs may only be destroyed between March 1 and June 30, and geese may only be killed between May 1 and August 31. All management actions must occur on the premises of the depredation area. Geese may not be taken in a hunting manner, e.g., decoys and calls may not be used. For agricultural producers to obtain a free State permit, they may apply in person or by telephone to the USDA Wildlife Services, 1568 Whitehall Road, Annapolis, MD 21409, Tel. 1-877-463-6497.

WILDLIFE AND RARE SPECIES HABITATS:
ASSESSMENT OF THE WATERSHED ECOSYSTEM'S CHARACTERISTICS AND ATTRIBUTES

The most significant wetlands and other habitats for wildlife and rare species within Deep Creek Lake Watershed are found primarily in the northeastern portions of the area. Another significant wetland, Hammel Glade, occurs in the southwestern section of the watershed. According to Table 12, below, about15 percent of the Deep Creek Lake

Watershed provides significant habitat for Maryland's native plants, animals and natural communities. While portions of this watershed have been developed, much of the watershed still retains areas that are crucial for conserving the native flora and fauna of Garrett County.

Table 12. Summary of BioNet priority areas for the Deep Creek Lake Watershed**.**

BioNet Tier (Definition)	Acres	Percent of Watershed
Tier 1 (Critically Significant)	3,096	7.6 %
Tier 2 (Extremely Significant)	1,332	3.3 %
Tier 3 (Highly Significant)	1,286	3.1 %
Tier 4 (Moderately Significant)	144	0.4 %
Tier 5 (Significant)	73	0.2 %
TOTAL	**5,931**	**14.5 %**

The various natural resources that BioNet contains are detailed below. The acreages described in each section are not additive because many fall within the same areas. For example, many of the Ecologically Significant Areas for the protection of rare species are forested habitats and, therefore, are often also identified as potential forest interior dwelling species habitat. The map of BioNet areas (see Appendix E) displays them hierarchically, so that the most significant areas are overlain on top of areas with lesser significance for biodiversity conservation.

1. <u>Ecologically Significant Areas (ESAs)</u>

Ecologically Significant Areas are places where one or more rare species or habitat occurs that have been identified for some level of conservation attention. The Deep Creek Lake Watershed is home to 37 species of plants and animals considered rare, threatened, or endangered in Maryland by the Wildlife and Heritage Service: 16 plants, 5 dragonflies, 3 butterflies, 3 other invertebrates, 1 reptile, 6 birds, and 3 mammals. Twenty-two of these 38 species are legally regulated by the State of Maryland: 9 are listed as Endangered (E), 9 are listed as Threatened (T), and 4 are listed as In Need of Conservation (I). None are federally-listed as threatened or endangered. The list of species is included in Table 13, below. An explanation of the rank and status codes used in this table is provided in the Appendix A.

Table 13. Rare, Threatened, and Endangered (RTE) Species with current or recent populations in the Deep Creek Lake Watershed.

Scientific Name	Common Name	Global Rank*	State Rank*	State Status*
	PLANTS			
Aralia hispida	Bristly sarsaparilla	G5	S1	E
Carex buxbaumii	Buxbaum's sedge	G5	S2	T
Clintonia borealis	Yellow clintonia	G5	S2	T
Coptis trifolia	Goldthread	G5	S1	E
Geum aleppicum	Yellow avens	G5	S1	E
Lycopodiella inundata	Bog clubmoss	G5	S2	
Menyanthes trifoliata	Buckbean	G5	S1	E
Polemonium vanbruntiae	Jacob's-ladder	G3G4	S2	T
Sarracenia purpurea	Northern pitcher-plant	G5	S2	T
Scutellaria galericulata	Common skullcap	G5	S1	
Spiranthes lucida	Wide-leaved ladys' tresses	G5	S1	E
Taxus canadensis	American yew	G5	S2	T
Thelypteris simulata	Bog fern	G4G5	S2	T
Torreyochloa pallida var. fernaldii	Fernald's mannagrass	G5T4Q	S1	
Vaccinium oxycoccos	Small cranberry	G5	S2	T
Viola appalachiensis	Appalachian blue violet	G3	S2	
	ANIMALS			
Aeshna canadensis	Canada darner	G5	S2	
Ammodramus henslowii	Henslow's sparrow	G4	S1S2B	T
Caecidotea sp. 6	An Isopod	GNR	S2	
Chlosyne harrisii	Harris's checkerspot	G4	S2	T
Circus cyaneus	Northern harrier	G5	S2B	
Dactylocythere scotos	An Entocytherid ostracod	GNR	S1	
Empidonax alnorum	Alder flycatcher	G5	S2B	I
Gomphus rogersi	Sable clubtail	G4	S2	I
Leucorrhinia glacialis	Crimson-ringed whiteface	G5	S1	
Lycaena epixanthe	Bog copper	G4G5	S1	E
Lynx rufus	Bobcat	G5	S3	I
Nymphalis vaualbum	Compton tortoiseshell	G5	S1	E
Planaria dactyligera	A Planarian	GNR	S2	
Regulus satrapa	Golden-crowned kinglet	G5	S2B	
Sitta canadensis	Red-breasted nuthatch	G5	S1B	
Somatochlora elongata	Ski-tailed emerald	G5	S2	
Sorex dispar	Long-tailed shrew	G4	S2	I
Sorex palustris punctulatus	Southern water shrew	G5T3	S1	E
Stylurus scudderi	Zebra clubtail	G4	S1	
Troglodytes troglodytes	Winter wren	G5	S2B	
Virginia valeriae pulchra	Mountain earthsnake	G5T3T4	S1S2	E

* See Appendix A for an explanation of the Rank and Status codes.

The locations of these 34 species are grouped into 16 Ecologically Significant Areas that are either contained within or that overlap the Deep Creek Lake Watershed.

Of the 16 Ecologically Significant Areas, seven are wetland areas linked by drainages and stream valley corridors along the floodplain of Cherry Creek. Another two ESAs are located along Meadow Mountain Run, and two more are found along the edges of Deep Creek Lake.

Table 14, below, summarizes these 16 ESAs and provides information on their sizes and regulatory significance. Five of these areas are within the Deep Creek Lake NRMA or within waters of Deep Creek Lake and are afforded protection by the Department of Natural Resources. Additionally, 12 of these areas are currently regulated by the Maryland Department of the Environment as Wetlands of Special State Concern (WSSC). Finally, the "BioNet Tier" column provides the priority or relative conservation value of each area, ranging from Tier 1 as critically significant for biodiversity conservation through Tier 5 as significant for biodiversity conservation. More specific information on what is known about each of these ESAs, including why each is significant, have been compiled and provided in Appendix B. A map that shows the location of the ESAs within the watershed is provided in Appendix E.

Table 14. Ecologically Significant Areas of the Deep Creek Lake Watershed.

ID Number	ESA Name	BioNet Tier	Wetland of Special State Concern	Acres
1	Negro Mountain Powerline Bog	Tier 5	Yes	73
2	North Cherry Creek Bog	Tier 2	Yes	711
3	Anvil Bog	Tier 2	Yes	364
4	Rock House Bog	Tier 2	Yes	191
5	South Cherry Creek Complex	Tier 1	Yes	949
6	Meadow Mountain Bog North	Tier 3	Yes	327
7	Highest Bog	Tier 3	Yes	259
8	Meadow Mountain Run Swamp	Tier 3	Yes	604
9	Rhodes Fields	Tier 4		77
10	Warren's Beech Grove	Tier 4		61
11	Potato Farm Coves	Tier 2	Yes	66
12	Deep Creek Spillway	Tier 3		39
13	Lower Deep Creek Complex*	Tier 1	Yes	613
14	Hammel Glade	Tier 1	Yes	1,534
15	Keystone Swamp	Tier 3	Yes	57
16	McHenry Wetland South	Tier 4		6

* only a small portion of this area is within the Watershed boundary.

2. Species of Greatest Conservation Need (GCN) and Key Wildlife Habitats

The Deep Creek Lake Watershed contains a number of Key Wildlife Habitats, as described within DNR's Wildlife Diversity Conservation Plan (2005). Many of these habitats are relatively widespread within Maryland, such as Floodplain Forests, Mesic Deciduous Forests, and Forested Seepage Wetlands. However, a few are relatively restricted in the State or have their highest quality occurrences within Garrett County. Two Key Wildlife Habitats such as these are Bog and Fen Wetland Complexes and Northern Conifer – Hardwood Forests. The Deep Creek Lake Watershed contains a dense concentration of the former, also known as Mountain Peatlands. Descriptions of these two Key Wildlife Habitats, extracted from the Wildlife Diversity Conservation Plan, have been included in Appendix D.

In addition to those rare species that were listed in Table 2, above, a number of animal species of Greatest Conservation Need are known as residents or breeding species of the Deep Creek Lake Watershed. Some of these nearly 60 animals are birds regulated in Maryland as Forest Interior Dwelling Species (FIDS). Conservation of their forested habitat is required within the Chesapeake Bay Critical Area and strongly recommended and encouraged beyond the Critical Area. Conservation of the habitat for FIDS also helps to conserve numerous other forest species that are declining due to habitat fragmentation and loss. Most animals need large forests and forest patches connected by forested corridors because they need to move during some part of their lives, whether to find mates or better food sources or young dispersing to find their own territories. Providing sufficient habitat to support animal movement is a significant challenge that must be met if we are to stabilize populations and reverse the declines of these disappearing wildlife species.

<u>Additional Gcn Animals</u>

Common Name	**Scientific Name**
Acadian flycatcher	*Empidonax virescens*
Allegheny Mountain dusky salamander	*Desmognathus ochrophaeus*
American emerald	*Cordulia shurtleffi*
American redstart	*Setophaga ruticilla*
American woodcock	*Scolopax minor*
Appalachian blue	*Celastrina neglectamajor*
Aurora damsel	*Chromagrion conditum*
Band-winged meadowhawk	*Sympetrum semicinctum*
Barred owl	*Strix varia*
Beaverpond baskettail	*Epitheca canis*
Black-and-white warbler	*Mniotilta varia*
Black-throated blue warbler	*Dendroica caerulescens*
Black-throated green warbler	*Dendroica virens*
Blackburnian warbler	*Dendroica fusca*
Blue-headed vireo	*Vireo solitarius*
Bobolink	*Dolichonyx oryzivorus*
Broad-winged hawk	*Buteo platypterus*
Brown creeper	*Certhia americana*
Brown thrasher	*Toxostoma rufum*
Canada warbler	*Wilsonia canadensis*
Chalk-fronted skimmer	*Libellula julia*
Chestnut-sided warbler	*Dendroica pensylvanica*
Dot-tailed whiteface	*Leucorrhinia intacta*
Eastern box turtle	*Terrapene carolina*
Eastern hog-nosed snake	*Heterodon platirhinos*

Eastern meadowlark	*Sturnella magna*
Eastern red damsel	*Amphiagrion saucium*
Eastern towhee	*Pipilo erythrophthalmus*
Field sparrow	*Spizella pusilla*
Grasshopper sparrow	*Ammodramus savannarum*
Golden-winged warbler	*Vermivora chrysoptera*
Gray comma	*Polygonia progne*
Hairy woodpecker	*Picoides villosus*
Hermit thrush	*Catharus guttatus*
Hooded warbler	*Wilsonia citrina*
Indian Skipper	*Hesperia sassacus*
Kentucky warbler	*Oporornis formosus*
Least flycatcher	*Empidonax minimus*
Long-tailed salamander	*Eurycea longicauda*
Louisiana waterthrush	*Seiurus motacilla*
Magnolia warbler	*Dendroica magnolia*
Mottled sculpin	*Cottus bairdi*
Northern parula	*Parula americana*
Northern red salamander	*Pseudotriton ruber*
Ovenbird	*Seiurus aurocapillus*
Pileated woodpecker	*Dryocopus pileatus*
Red-eyed vireo	*Vireo olivaceus*
Red-shouldered hawk	*Melanerpes erythrocephalus*
Savannah sparrow	*Passerculus sandwichensis*
Scarlet tanager	*Piranga olivacea*
Seal salamander	*Desmognathus monticola*
Sedge sprite	*Nehalennia irene*
Timber rattlesnake	*Crotalus horridus*
Veery	*Catharus fuscescens*
Vesper sparrow	*Pooectes gramineus*
White-faced meadowhawk	*Sympetrum obtrusum*
Willow flycatcher	*Empidonax traillii*
Wood thrush	*Hylocichla mustelina*
Worm-eating warbler	*Helmitheros vermivorus*

This list was compiled from the recent breeding bird atlas project, the current amphibian and reptile atlas project, and from field data and experience of DNR's biologists. As more surveys are conducted in the future, additional GCN species are likely to be found within this Watershed.

B. Potential Forest Interior Dwelling Species (FIDS) Habitat

Much of the Deep Creek Lake Watershed is forested, and over 60% of the entire Watershed is potential FIDS habitat. Also, about 65% of the potential FIDS habitat within the watershed still exists as "core habitat" or the largest and highest quality blocks of unfragmented forests containing at least 500 acres of interior forest. The amount and potential quality of FIDS habitat in the Deep Creek Lake Watershed can be found in Table 15, below.

Within the Chesapeake Bay Critical Area, habitat protection for forest interior dwelling birds was mandated through regulations authorized by the Chesapeake Bay Critical Area Law (Natural Resources Article 8-1808, Annotated Code of Maryland). The regulations require that management programs be developed to protect and conserve riparian and upland forests used for breeding by FIDS within the Critical Area. DNR strongly encourages that protection programs for FIDS be extended beyond the Critical Area. Guidelines for determining FIDS habitat and conserving these areas are referenced in Appendix C. A map that shows the extent and quality of FIDS habitat within the watershed is provided in Appendix E.

Table 15. Amount of Potential Forest Interior Dwelling Species (FIDS) Habitat within the Deep Creek Lake Watershed.

Category (Defn.)	Acres	Hectares	Percent of Total
Class 1 (Core FIDS habitat)	18,617	7,534	66 %
Class 2 (High Quality habitat)	9,040	3,658	32 %
Class 3 (other FIDS habitat)	445	180	2 %
TOTAL	**28,102**	**11,372**	

Incorporating Resiliency into Water Resources Management: Strategies for a Future Climate

Climate change will mean planning for more uncertainty. Marylanders will need to consider the impacts on their livelihoods of rising temperatures, more rain in the fall and winter and less in the summer, and more extreme events. (Figure 62). Some of these changes will be positive, such as more growing days and longer recreational seasons, while others negative such as more flooding, impacting infrastructure, buildings, and public health. Local governments will need to assess the performance of engineering design standards, comprehensive plans, water and sewer plans, and hazard mitigation plans in light of climate change. Businesses should consider climate in their product supply chain and operations, an area that could be affected by both local and global impacts of climate change. Individuals and community organizations should implement and advocate for improved sustainability measures and protection of their homes and ecosystems. Those communities that prepare now for expected changes will be better adapted to the expected changes and positioned to benefit from the actions that will need to be taken to prepare for climate change. Opportunities exist to adopt climate change adaptation strategies into comprehensive land use plans, hazard mitigation plans, permitting programs, watershed implementation plans, natural resource restoration priorities, building codes, monitoring plans, and source water protection plans.

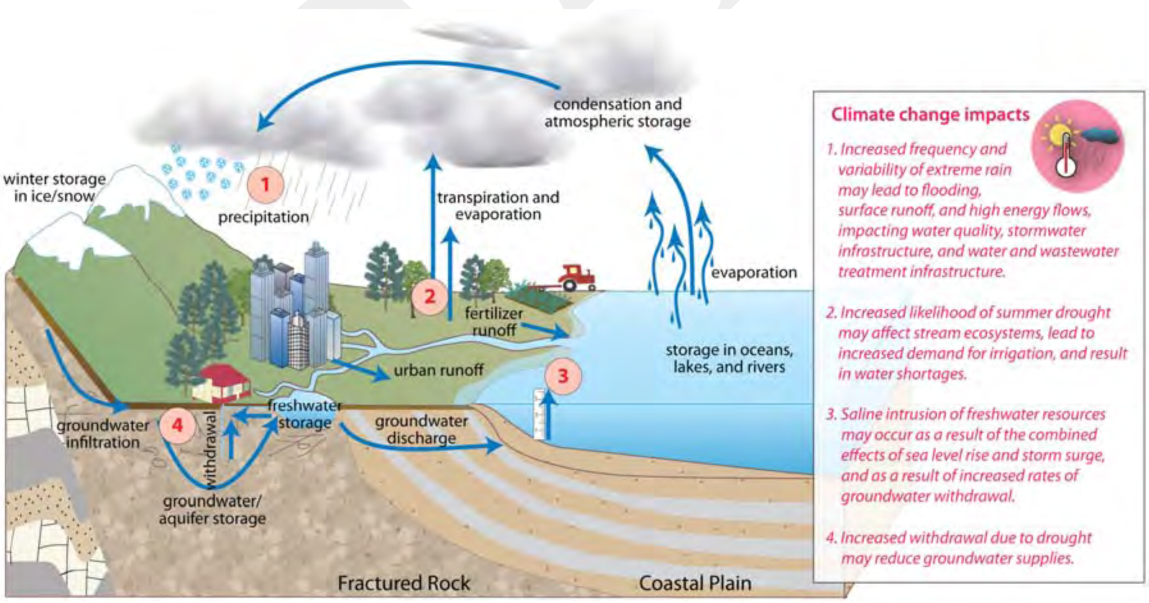


Figure 62. Expected impacts of climate change on water in Maryland. (IAN-UMCES 2011)

CLIMATE TRENDS IN MARYLAND

In the past 30 years, Maryland's climate has become wetter (particularly September and January) and hotter(http://www.nrcc.cornell.edu/). The Comprehensive Assessment of Climate Change Impacts in Maryland **(**http://www.mde.state.md.us/programs/Air/ClimateChange/Documents/FINAL-Chapt%202%20Impacts_web.pdf**)** projects that annual average temperature in the State is projected to increase by about 3 ° F by mid-century and potentially by as much as 9 ° F by the end of the century, with more heat waves occurring during the summer. While precipitation is projected to increase during the winter, it will become more episodic and occur in extreme events. It is possible for more droughts lasting several weeks to occur during the summer due to the more intermittent rainfall and increased evaporation brought on by higher temperatures. Western Maryland has cooler winters and summers and less precipitation during the winter than the rest of the state. Changes that occur will overlay these differences and may result in greater summer warming relative to what the Eastern Shore might experience.

CLIMATE CHANGE ALTERS FLOODING REGIMES AND IMPACTS OF STORMWATER

Development alters watershed hydrology. As land becomes covered with surfaces impervious to rain, water is converted from groundwater recharge and evapotranspiration to stormwater runoff. As the area of impervious cover increases, so does the volume and rate of runoff. An increase in the frequency and intensity of storm events resulting from climate change will likely amplify the impacts of development on stormwater runoff, further increasing the quantity of polluted runoff into our waterways. In Maryland, climate models predict more rain in the winter and less in the summer, which is likely to result in both more flooding events and more water shortages. Current projections indicate that flooding will increase: 100-year floods will increase by 10-20 %, 10-year storms will increase by 16-30 % and annual stream flows by as much as 50%. There is a greater likelihood that more powerful rain and windstorms will strike Maryland as ocean waters warm, accompanied by higher storm surges and rainfall http://www.umces.edu/sites/default/files/pdfs/global_warming_free_state_report.pdf**.**

Urban and developing areas will be particularly at risk. An increased frequency and magnitude of floods in watersheds with urban and suburban development have implications not only for flood protection and water allocation, but also for the design of treatment plants and culverts. Stormwater and flood management infrastructure in many older urban areas is already undersized by comparison with the flow volumes being generated from the upstream watershed, Consequently flooding occurs more often than would be observed in a rural watershed.

CLIMATE IMPACTS ON DROUGHT AND WATER SUPPLY

Groundwater is the primary source of drinking water for residents of the Deep Creek watershed. Availability and supply of drinking water provided by the fractured rock, unconfined aquifers in western Maryland is directly related to precipitation and temperature. The County notes in the 2008 Comprehensive Plan that the relationship between groundwater supply and surface water flows in Hoyes Run and other nearby streams should be taken into account as water withdrawals increase to support growth in the Deep Creek watershed and its influence area. Aquifers and their interconnected waterways will be directly affected by year-to-year variations and long term trends in precipitation and temperature. More intense storms and flooding have the potential to contaminate groundwater supplies, which could lead to human health risk and expensive remediation or expending resources to find alternate sources.

Additionally, less summer rain and lower soil moisture would increase irrigation needs in residential and agricultural areas. Unaccounted for irrigation withdrawals and increased withdrawals from commercial or residential properties during droughts could exacerbate declining water tables in unconfined aquifers. During the summer months, water supplies may become more stressed, as demand peaks during this time. Both agricultural and non-agricultural irrigation are likely to increase as a result of decreased rainfall and higher temperatures. Projected rising temperatures will increase rates of evaporation. The ability of the water supply to meet future demand is shaped by water resource availability, development and growth patterns and the degree of interconnection and collaborative management among users.

CLIMATE IMPACTS ON FRESH WATER HABITATS

Temperatures in streams and rivers are increasing and likely to worsen, causing heat stress, decreased water quality, or changes in food availability. In freshwater habitats, temperature increases particularly affect coldwater stream species, such as brook trout, which will exacerbate the negative influences of urbanization. Increasing need for water withdrawal because of population growth and drought will result in reduced summer streamflow. This will affect most fish species by reducing habitat and food, decreasing dissolved oxygen, and increasing toxin concentrations. Finding the balance between human and ecological water needs will be an important goal in a changing climate. Warmer winters and wetter autumns and early springs could create mismatches between species such as trout and mayflies and send more sediment and nutrients downstream. Earlier snowmelt can cause vegetation seed stranding and aquatic insect and fish life history cycles to be out of sync with critical river flows. Increased flooding due to heavy rains combined with already elevated stormwater volumes may increase soil erosion and degrade water quality. High temperatures and fast-moving, larger volumes of stormwater running off roads and other impervious surfaces will likely carry increased loads of sediments and pollutants into waterways, clouding the water and negatively impacting aquatic species, and smothering aquatic plant beds. Upstream migration of fish and benthics, away from higher temperatures and runoff, may be impaired by the existing blockages to fish passage (dams and other obstructions).

REFERENCE:

http://climatechange.maryland.gov/site/assets/files/1372/ian_newsletter_416.pdf