ENVIRONMENTAL RESOURCES MANAGEMENT

REPORT

Assessment of Water Quality Impacts from Potential Land Development

Deep Creek Lake
Garrett County, Maryland

May 2007

Environmental Resources Management
350 Eagleview Blvd., Suite 200
Exton, PA 19341
www.erm.com

ERM

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SUMMARY

In this study, ERM's Surfacewater Modeling Group assessed the impact of potential land development in the Deep Creek Lake watershed on the water quality of Deep Creek Lake. The study was undertaken to inform land use planning in the Deep Creek Lake watershed for the 2007 Garrett County Comprehensive Plan.

The study consisted of an examination of water quality data, an estimate of current and projected nutrient loads into the lake, a Vollenweider analysis of the lake's trophic status, and two commonly-used models, BATHTUB and CE-QUAL-W2. A lack of consistent water quality data precluded calibration of CE-QUAL-W2, which requires frequent and extensive in-lake data to calibrate its water quality algorithms[1]. For this study, estimates of the current and projected trophic status of Deep Creek Lake were based primarily on the Carlson Trophic State Index (TSI), determined through the application of the BATHTUB model to Deep Creek Lake. The study conclusions are dependant on the results of modeling performed by the Interstate Commission on the Potomac River Basin that estimates existing runoff of nutrients and solids into the tributaries which feed Deep Creek Lake.

CE-QUAL-W2 ("W2") was used to examine spatial and seasonal variations of flow and temperature using its time-varying, laterally-averaged 2-D framework. W2, unlike BATHTUB's fully-mixed approach, allows separate consideration of each of Deep Creek Lake's sub-watersheds, branches and tributaries. For this reason, W2 is more compatible with land use planning activities, which focus on particular parcels of land in specific locations. W2 is a true hydrodynamic model which computes flow fields, temperatures, and constituents at many locations in the longitudinal and vertical directions. These capabilities were used to provide estimates of circulation, stratification, total suspended solids, and water age at various locations in Deep Creek Lake. Although there are insufficient data to calibrate W2's water quality algorithms, the model as currently configured provides an excellent tool for continued study of Deep Creek Lake. Calibration of W2, the recommended model for future studies, is dependent on obtaining a seasonally intensive and spatially-detailed water quality dataset for calibration of the model.

The potential land development in the Deep Creek Lake watershed is likely to have minor impacts on the lake in terms of changing the trophic

---

[1] See "Appendix A: Glossary" for an explanation of technical terms.

state. However, a conclusive determination cannot be rendered at this time due to the uncertainty related to the lack of long-term and spatially comprehensive water quality observations and to overestimates of nonpoint source runoff. From the data available, our best professional judgment is that the lake is currently mesotrophic, i.e. containing some degree of excess nutrients such that algal growth is excessive, but not at a critical point (eutrophic). Lake concentrations of nutrients (phosphorus and nitrogen) are expected to increase during storm events, while increased numbers of septic systems may potentially cause a significant increase in nitrogen loads under the capacity analysis scenario.

The moderate and rapid development scenarios are predicted to produce a minor degradation in water clarity (secchi depth) and a slight shift toward eutrophic conditions. Projections for the capacity analysis indicate an even greater shift towards eutrophic conditions. The large nitrogen increase from septic sources does little to stimulate algal growth when there is not a similar increase in phosphorus; both nutrients are needed because phosphorus concentration appears to be the limiting nutrient. Predictions indicate a potentially significant but brief increase in suspended solids loads to the lake during storm events. However, the likely effect will be little or no long term turbidity increase.

This report first presents and discusses the datasets used and the current and projected nutrient loads in the Deep Creek Lake watershed. Analysis with respect to the lake's trophic status begins with the simple Vollenweider analysis, proceeds to the more complex, fully-mixed BATHTUB model and finally to the spatially- and temporally-detailed CE-QUAL-W2 model. Conclusions and recommendations for further studies are summarized in the last section of the report. A glossary of technical terms used in this report is provided in Appendix A.

2. *DEEP CREEK LAKE DATASETS AND WATERSHED LOADS*

Deep Creek Lake has a storage volume at a water surface elevation of 2462 feet of approximately 115.8 x 10^6 m^3 with a surface area of 14.6 km^2 (3,600 acres) and widths ranging from 0.2 km (0.1 mi) to 2.0 km (1.2 mi). The average depth is 8 m (26 ft). The flow through the lake travels from southeast to west, and then joins the Youghiogheny River. The distance from the southernmost end to Deep Creek Dam is approximately 17 km (11 mi). The lake has a drainage area of 64 mi^2 (including the lake) and is part of the Youghiogheny River Watershed, which encompasses 298 mi^2 and extends northward in Maryland and westward into West Virginia. Eight main tributaries entering the lake were examined in this study: Pawn Run, Hoop Pole Run, Poland Run (including Green Glade Run), North Glade Run (including the North Glade Run Branch), Meadow Mountain Run, Cherry Creek, and Marsh Run Cove (Figure 2-1).

Figure 2-1 Deep Creek Lake and tributaries

2.1. *DATA INVENTORY*

Models of the type used in this study of Deep Creek Lake require two kinds of data: (1) spatial data, primarily shoreline and depth, but also locations of inflows and outflows and (2) temporal data, that is, time-varying data defining inflow rate, temperature, and nutrient load; outflow rate; and, meteorological data. The latter are sometimes referred to as boundary condition data. All deterministic models require continuous time-varying boundary condition data. There can be no long gaps in the record and all required datasets must be available during the span of the proposed simulation period. The model applications to Deep Creek Lake were based only on existing data; no new data were collected for this study.

For this study, the Garrett County Health Department, the Maryland Department of the Environment, the Maryland Department of Natural Resources (MDDNR), the Interstate Commission on the Potomac River Basin, and Brookfield Power were contacted to obtain data and any previous studies. All these organizations were cooperative and helpful.

The spatial data were used to estimate the physical dimensions of the lake and, for the W2 model, to describe the lake in the form of a longitudinal-vertical grid, which divides the lake into segments and layers. Time-varying data were used to build the time series input files for the chosen simulation period. Continuous flow and meteorological data were obtained for Deep Creek Lake from January 2001 to October 2006. The study required using the most recent complete year of data (2005) applicable for all aspects of the Comprehensive Plan. Simulations for the year 2005 for existing conditions constitute the Base Case.

2.1.1. GIS and Mapping

Topographic quadrangle maps were acquired from the USGS to create a digitized representation of Deep Creek Lake in the form of an ArcView shapefile. Dimensions determined using Geographical Information Systems (GIS) software were used as input to the BATHTUB model. Grids were constructed in CE-QUAL-W2 using dimensions measured from this electronic map.

2.1.2. Water Quality

The Garrett County Health Department provided water quality data collected during the summer months between 1988 and 2003. Not all of these data were used in the water quality modeling, but the data are presented in this report as a record of all available and known data collected in Deep Creek Lake to this date. These data include:

- Secchi depth measurements (i.e., the depth of light penetration measured with a standard black-and-white disk) at four locations collected monthly May through September from 1993 to 2003. Secchi depths range from 2.5 to 19 feet with an average depth of 8.8 feet.
- Nitrate levels at one location collected sporadically May through August from 1994 to 2003. Concentrations range from 0.0 to 0.4 mg/L and are reported with a high detection limit.
- Nitrate and phosphate levels at three locations collected monthly May through September from 1993 to 2003. Nitrate concentrations

range from 0.0 to 0.6 mg/L and phosphate concentrations range from 0.0 to 0.2 mg/L. Both nitrate and phosphate have average concentrations less than the usual detection limit of 0.2 mg/L.
- pH measurements at 21 stations collected monthly May through September in the years 1988 through 2001 and 2003. These data were not used in the present water quality study.
- Fecal coliform data at 21 stations collected monthly May through September from 1993 to 2003. Fecal coliform concentrations range from 0 to 1986.3 #/100mL. Also included in these data are monthly total coliform measurements from May to September in the years 1995 and 1996. Total coliform concentrations range from 0 to 1601 #/100mL. These data were not used in the present study.

The phosphate and both sets of nitrate data have detection limits greater than 0.1 mg/L and are of limited use in the model calibration process because values of interest are typically below these detection limits. Tables presenting all of the Garrett County Health Department data are provided electronically.

Water quality data were also provided by the Maryland Department of the Environment (MDE) for Deep Creek Lake - Basin Code 05020203. The following parameters were measured sporadically from March 1998 through November 2005:

- Secchi depth
- Meteorological data including temperature, wind, precipitation, and cloud cover measurements
- Salinity and conductivity
- pH
- Water temperature
- Biochemical Oxygen Demand (BOD)
- Nitrogen, phosphorus, carbon, and silica in various chemical forms
- Select metals measurements
- Turbidity
- Hardness

The MDE database includes data collected at various water depths from 25 stations on Deep Creek Lake. The majority of the data were gathered from November 1999 through November 2000 and October 2002 through September 2003.

With respect to data collected by the USGS, a query of Station 3076000 (Deep Creek Lake) showed no water quality data. Station 03076010 (Deep Creek Lake Outflow) had data available for three dates in 1979 including temperature, dissolved oxygen (DO), pH, sulfate, and metals, but no nitrogen or phosphorus.

Water quality models require significantly more data for calibration than are available for Deep Creek Lake. Water quality models can track the complex interactions between nutrient concentrations, algal levels, and the effects that algae have on light penetration (measured as secchi depth). In order to mathematically model these biological and chemical processes, an exhaustive set of chlorophyll, secchi depth, nitrogen, and phosphorus data is required. In general, algal growth depends on the availability of the dissolved, inorganic forms of phosphorus and nitrogen (orthophosphate for phosphorus and ammonia, nitrite, and nitrate for nitrogen). Thus, for nitrogen and phosphorus the ideal dataset would include total phosphorus, inorganic versus organic phosphorus, particulate versus dissolved phosphorus (e.g., orthophosphate), total nitrogen, inorganic versus organic nitrogen, and particulate versus dissolved nitrogen (e.g., ammonia, nitrite, and nitrate). Since these data were not available over an extended time period, comprehensive model calibration was unable to be performed; however, enough data were available to generally guide the modeling process.

2.1.3. Flow Data

There are no continuous flow gauges operating at any of the upstream tributaries entering into Deep Creek Lake. Estimates of daily flow were instead made using data obtained from USGS Station 3076500 (Figure 2-2), as described in Section 5.2.2. The location of this gauge relative to the watershed is shown in Figure 2-3 and relative to other local USGS flow gauges and Deep Creek Lake is shown in Figure 2-4.

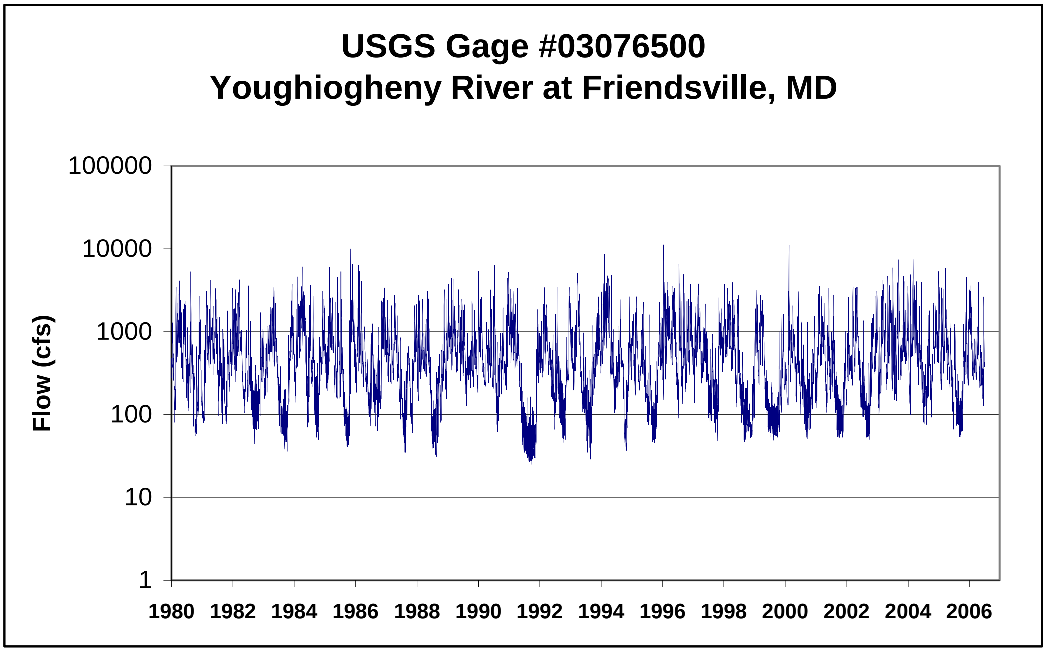

Figure 2-2 Youghiogheny River Flow Record

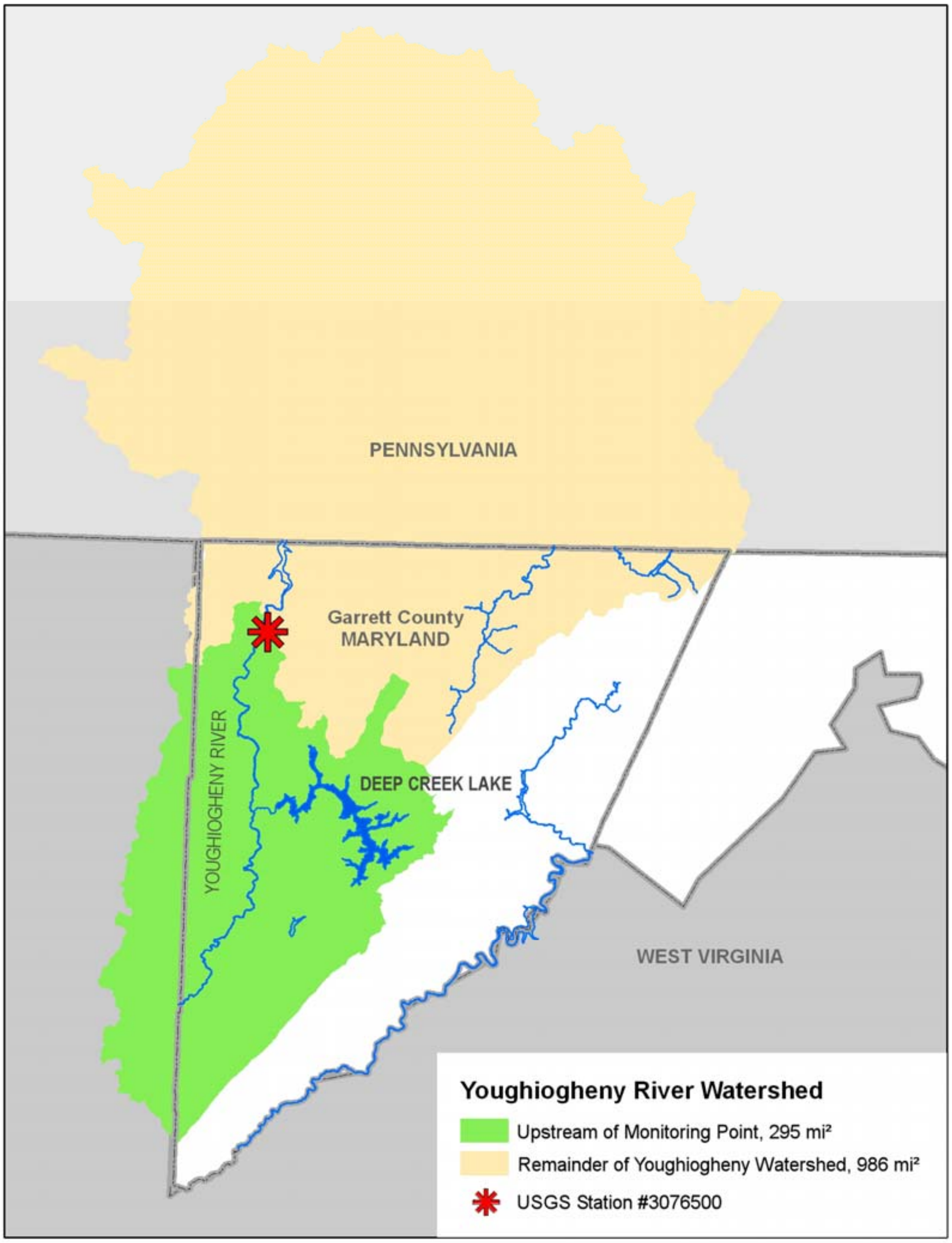

Figure 2-3 Youghiogheny Watershed and USGS Station 3076500

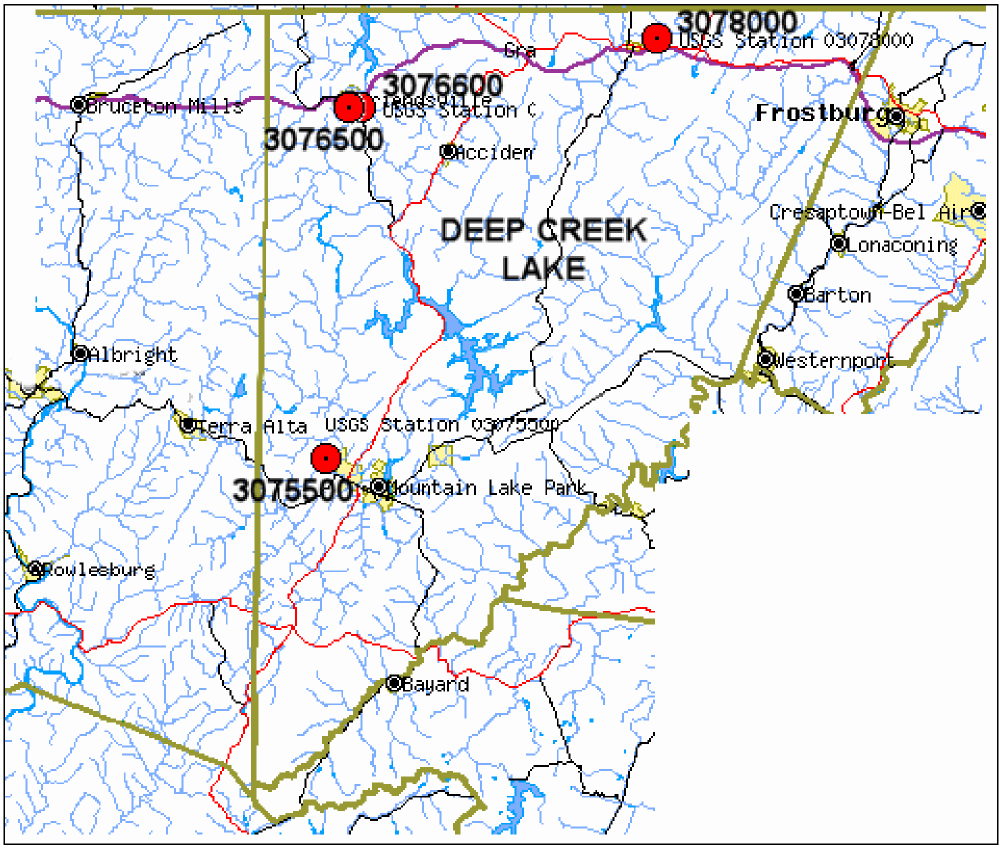

Figure 2-4 USGS Flow gauges in the vicinity of Deep Creek Lake (source: USGS, 2006)

2.1.4. *Water Surface Elevation Data*

Surface elevation data in Deep Creek Lake is available from Brookfield Power Company and the Deep Creek Hydro Electric Power Plant. Values were available from August 2002 through July 2006. Water surface elevation values were used to estimate inflow rates from ungaged tributaries to Deep Creek Lake.

2.1.5. *Land Use*

Land use coverage shapefiles used in this analysis were obtained from the Maryland Department of Planning (MDP). Base case land use values were adjusted from MDP's 2002 data into 2005 values (see Table 2-1).

Table 2-1 2005 estimated Deep Creek Lake watershed land use areas (source: MDP)

Land use category	Acres
Agriculture	8002
Commercial	307
Extractive	411
Forest	20527
Other Developed	357
Residential-HD	112
Residential-LD	4824
Residential-MD	1646
Wetlands	1060
Water	3691
TOTAL	40937

The projected land use resulting from development has been estimated in a separate analysis by ERM (see Appendix B for details of this projection methodology). Three future development scenarios have been defined: Moderate Growth Scenario, Rapid Growth Scenario, and the Capacity Analysis Scenario. These scenarios are considered "snapshots" of the conditions once these developments are in place, and do not incorporate the effects of the land conversion process on the water quality. The majority of the projected changes involve a shift from agricultural and forest lands into low density residential land. The resulting changes to land use compared to the 2005 estimated Existing Case are summarized in Figure 2-5.

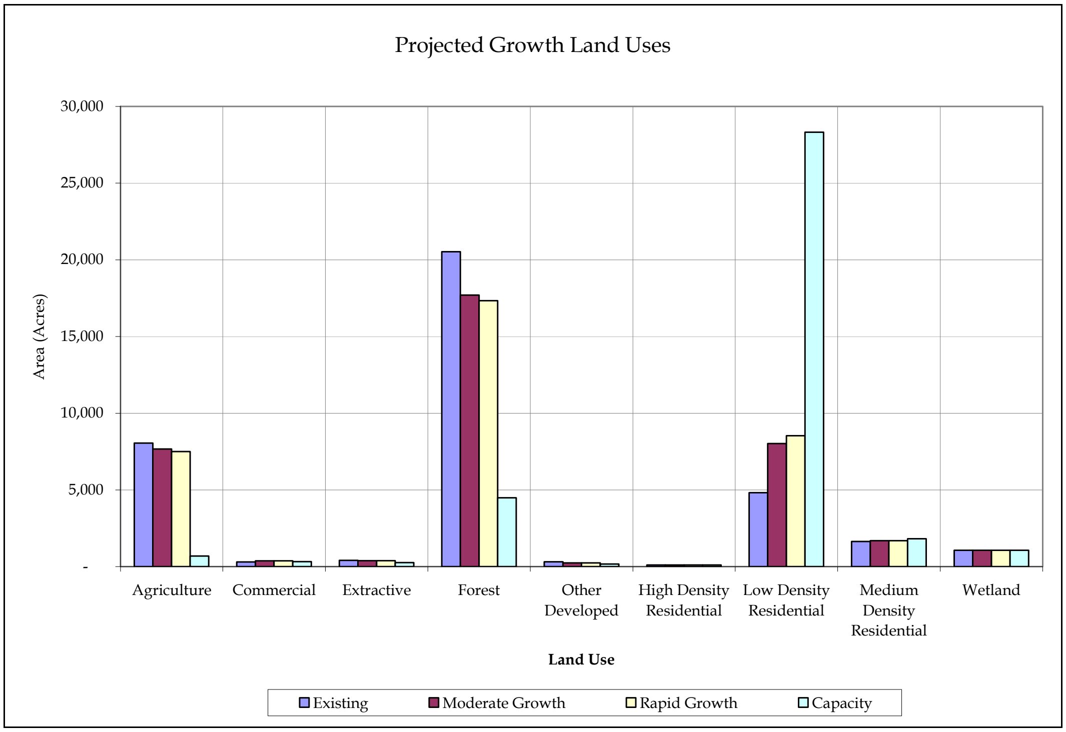

Figure 2-5 Existing and potential land uses for Deep Creek Lake (source: MDP 2006)

2.2. RUNOFF FLOW AND LOAD ESTIMATES

The principal variable for comparison between the Base Case and the development scenarios is the estimated nonpoint source nutrient loads. These loads, estimated using values from an independent nonpoint source model as described in Section 2.2.2, contain a degree of uncertainty, but represent the best available estimates. These nutrient load estimates form the basis of the Vollenweider analysis, the BATHTUB modeling and the CE-QUAL-W2 modeling.

2.2.1. Runoff Flow Estimates

As noted earlier, to model Deep Creek Lake, historical continuous stream flow rates for each tributary are required. Figure 2-1 shows the tributaries and Figure 2-6 shows sub-watersheds of Deep Creek Lake. Inflows from these tributaries and sub-watersheds are not measured.

To estimate the tributary inflows, known flows from a nearby, gauged watershed were proportioned to sub-watershed and tributary drainage areas. Using 1:24,000 USGS topographic quadrangles photorevised in 1974, 18 sub-watersheds within the Deep Creek Lake watershed were delineated. These sub-watersheds maintained the already-defined boundaries of the 8-digit Deep Creek Lake watershed (as defined by the MDE), as well as the three 12-digit sub-watersheds (as defined by the Maryland Department of Natural Resources). Based on these delineations, land areas of these sub-watersheds were calculated using GIS software (see Appendix B). The drainage areas for these watersheds are provided in Table 2-2.

Table 2-3 shows the drainage area for the Youghiogheny River at Friendsville (Station 3076500), which is inclusive of Deep Creek Lake (Figure 2-3). Flow measurements at this station were selected to determine daily tributary inflow rates for Deep Creek Lake. The fraction of runoff flow entered Deep Creek Lake from each sub-watershed was determined by multiplying the flow recorded at the Friendsville station by the fraction of the watershed within each sub-watershed. For example, on January 1, 2002, the flow recorded at Friendsville was 0.132 cms (4.67 cfs). The Marsh Run sub-watershed drainage area is 4.7 mi^2 (Table 2-2), 1.6% of the total drainage area (295 mi^2). Therefore, the flow on January 1 for Marsh Run was estimated to be 1.6% of the Friendsville value, or 0.074 cms (2.61 cfs).

Table 2-2 Sub-watershed drainage areas surrounding Deep Creek Lake

Sub-watershed Name	**Drainage Area (mi^2)**
North Glade Run	7.6
Green Glade Run	7.3
Hoop Pole Run	2.2
Pawn Run	4.1

Sub-watershed Name	Drainage Area (mi²)
Marsh Run	4.7
Meadow Mountain Run	3.7
Cherry Creek Cove	2.6
Lower Deep Creek	4.4
Shingle Camp Hollow	1.2
Upper Deep Creek	4.4
Blakeslee	1.0
Cherry Creek	9.7
Meadow Mountain	2.7
Thayerville	1.6
Roman Nose Hill	1.3
Smith Run	1.0
Red Run	3.4
Bee Tree Hollow	0.9
Total	63.8

Table 2-3 USGS station summary

Station ID	Drainage Area (mi²)	Station Name	Longitude	Latitude	Record start time	Record end time
3076500	295	Youghiogheny River at Friendsville	79.41	39.65	1940	current

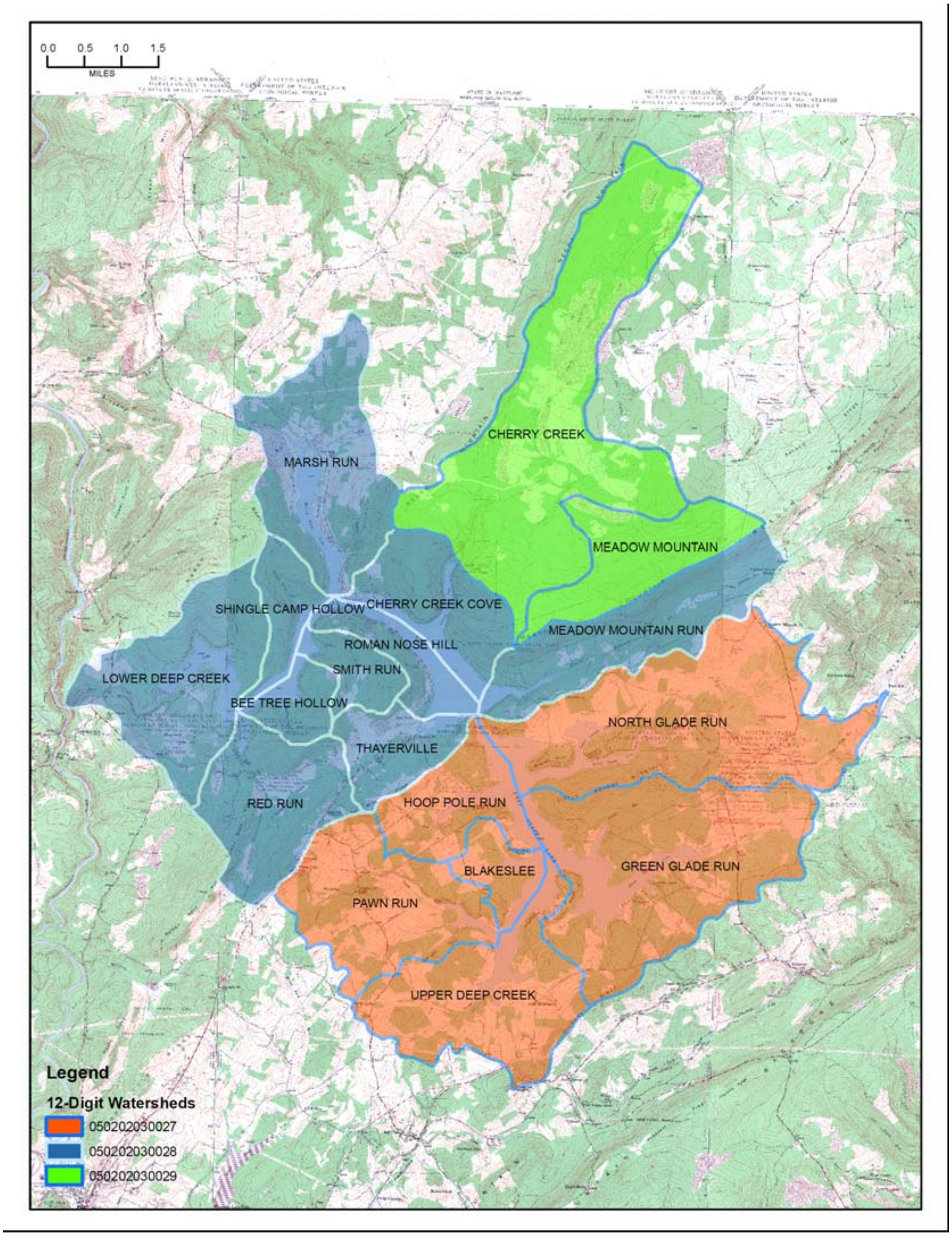

Figure 2-6 Deep Creek Lake sub-watersheds

2.2.2. *Load Estimation Methodology*

The constituents of concern for this analysis are forms of nitrogen and phosphorus which act as nutrients feeding microscopic and macroscopic plant growth. In addition, total suspended solids (TSS) are also of interest because excessive suspended solids cloud the water, reducing light penetration and therefore the clarity of the lake. These constituents can come from either point sources, the tributaries draining the lake's sub-watersheds, septic systems, or the atmosphere. According to a search of NPDES permits, there are no important, point sources of nutrients discharging directly to the lake or to the tributaries. The source of potential water quality impairments to Deep Creek Lake is nonpoint source runoff entering the lake. To assign nonpoint source nutrient and suspended solids loads to these land uses, the Interstate Commission on the Potomac River Basin (ICPRB) recommended using values from their Phase V HSPF (Hydrological Simulation Program – FORTRAN) modeling provided by the Chesapeake Bay Program (CBP) compiled for 2002, the most recent set of values available (Table 2-4). The ICPRB stated that these are preliminary estimates, subject to change, but are the best values currently available. The CBP modeling performed for Deep Creek Lake is limited by the sparseness of data in this watershed. Since it is outside the Chesapeake Bay watershed, less emphasis was made when calibrating this region of the model. New values, with expected lower nitrogen and phosphorus load estimates, may not be available until later in 2007. For this analysis, the 2002 load estimates were used to approximate the runoff load rates for total nitrogen, total phosphorus and TSS for the various land use categories. ICPRB also provided estimates for atmospheric nutrient and septic loads.

The CBP land use categories do not match those used by MDP[2]. For example, there are 16 CBP land use categories which align with the single MDP agricultural category that is being used for the Garret County Comprehensive Plan (Table 2-4). Such discrepancies exist because the intended uses of the two land use categorization methods are different. The MDP categories are designed for planning purposes, for example, differentiating residential areas in terms of housing unit density. The CBP categories, however, are intended for watershed analysis and runoff computations, as seen in the urban category (Table 2-4) which is divided in terms of rainfall permeability. Note: the barren /construction CBP land use category was allocated to the commercial land use category as the closest category in terms of low to no detritus, animal waste, and fertilizers as sources of nutrients. The permeability of barren / construction land is variable.

For this analysis, to be consistent with other land use analyses and assessments being conducted for the Comprehensive Plan, it was decided

---

[2] For example, the total area for the agriculture category according to CBP is 6,821 acres, 1,181 acres less than the MDP value. Though the total area of the watershed is similar in both datasets, comparisons when aggregated by area using the common categories in the last column in (Table 2-4) show discrepancies (Table 2-5). One possible explanation for the discrepancies may be the higher resolution used by the CBP. MDP uses an analysis area of 10 acres, while the CBP values are at a one acre resolution. MDP may also use a broader definition of agriculture including smaller garden plots, some large-lot residential areas, and small stands of forest. Also, the CBP values were for 2002, while Garrett County adjusted the MDP estimates for 2005. Regardless, the calculated loads are only applied to the MDP acreage values; the areas from the CBP estimate are only used to proportion the areas from the CBP land categories in order to consolidate into the MDP categories and to calculate a weighted average runoff load estimate as described below.

to assess current and projected nutrient runoff using MDP land use and land use categories.

Table 2-4 2002 CBP Phase 5 Watershed Model Land Use in the Deep Creek Lake Watershed, Garrett Co., MD

CBP Land Use	Area (acres)	Best match with MDP land use
Forest	21924	Forest
Harvested Forest	221	Forest
Low Intensity Pervious Urban	7608	Residential
High Intensity Pervious Urban	733	Residential
Low Intensity Impervious Urban	65	Commercial
High Intensity Impervious Urban	113	Commercial
Bare-construction	108	Commercial
Extractive	14	Extractive
Natural Grass	13	Wetlands
High Till Crop with manure	996	Agriculture
High Till Crop with Manure and Nutrient Management	0	Agriculture
High Till Crop with Nutrient Management but without manure	0	Agriculture
Low Till Crop with Manure	201	Agriculture
Low Till Crop with manure and Nutrient Management	0	Agriculture
High Till Crop without manure	12	Agriculture
Hay with nutrients	1402	Agriculture
Hay with nutrients and Nutrient Management	0	Agriculture
Hay without nutrients	282	Agriculture
Alfalfa	929	Agriculture
Alfalfa with Nutrient Management	0	Agriculture
Pasture	2914	Agriculture
Pasture with Nutrient Management	0	Agriculture
Trampled Pasture	15	Agriculture
Animal Feeding Operations	19	Agriculture
Nursery	53	Agriculture
Water	3407	Water
TOTAL	41027	

Table 2-5 Comparison of MDP to CBP land use area estimates

Land use category	MDP area (acres)	CBP area (acres)
Agriculture	8002	6821
Commercial	307	178
Extractive	411	14
Forest	20527	22145
Other Developed	357	108
Residential	6582	8341
Wetlands	1060	13
Water	3691	3407
TOTAL	**40937**	**41027**

For this assessment of current and projected nutrient runoff, the following methodology was used. The MDP land use area estimates (Table 2-5) were used to provide land use by sub-watershed, in categories consistent with the rest of the Comprehensive Plan. To assign nutrient loadings to the MDP land uses, it was assumed that the proportions of the various land use categories from the CBP were correct and useable for application to the MDP values (Table 2-6).

The annual areal nutrient load rates for each CBP land use category (Table 2-7) were used to generate a weighted average load rate applied to the areas within each MDP land use category for each sub-watershed (Table 2-8). For example, the CBP “Forest” and “Harvested Forest” categories were assigned to the MDP Forest land use category. The total area of Forest under the MDP data is 20,527 acres (Table 2-1). Those areas were proportioned using the CBP values (Table 2-4) of 21,924 acres (99%), Forest, 221 acres (1%) of Harvested Forest (Table 2-6). Thus, loads were estimated using a total of 20,321.73 acres of Forest and 205.27 acres of Harvested Forest multiplied by the areal loads (Table 2-7).

The results of the annual nutrient and TSS nonpoint source load rates for each sub-watershed are summarized in Table 2-8 for the Existing Case. Table 2-9 through Table 2-11 provide the Moderate Growth, Rapid Growth and Capacity Analysis sub-watershed areas for each land use category (see Appendix B). Table 2-12 through Table 2-15 provide the corresponding load rates. Figure 2-7 and Figure 2-8 illustrate the nitrogen and phosphorus load rates by land use category.

Overall, the phosphorus load rates increase from 4% to 9% above the existing conditions (Table 2-16). TSS increases from 12% to 62%. However, the nitrogen decreases below existing conditions from 13% to 15% for the three scenarios. This decrease is because the projected conversion of agricultural land with a high total nitrogen loading rate (21.8 lbs/acre-year , Table 2-7) into low density residential land with a much lower total nitrogen loading rate (8 lbs/acre-year) causes a net watershed wide reduction in nitrogen loads. This effect dominates the nitrogen load gained by converting forest lands (4.8 lbs/acre-year) into low density residential land. For total phosphorus, the loading rate differential is not as great between agricultural land (1.5 lbs/acre-year) and low density residential land (0.8 lbs/acre-year). It should be noted that the total phosphorus load rates for the forest land use appears high, while for residential appears low based on general literature values. However, these rates are the best available values and are derived from the latest CBP’s model.

Table 2-6 CBP land use proportions by MDP Land Use

CBP Land Use	MDP Land Use Category	Proportion
Forest	Forest	99.0%
Harvested Forest	Forest	1.0%
Low Intensity Pervious Urban	Residential	91.2%
High Intensity Pervious Urban	Residential	8.8%
Low Intensity Impervious Urban	Commercial	22.6%
High Intensity Impervious Urban	Commercial	39.6%
Bare-construction	Commercial	37.8%
High Till Crop with manure	Agriculture	10.2%
High Till Crop with Manure and Nutrient Management	Agriculture	0.0%
High Till Crop with Nutrient Management but without manure	Agriculture	0.0%
Low Till Crop with Manure	Agriculture	4.6%
Low Till Crop with manure and Nutrient Management	Agriculture	0.0%
High Till Crop without manure	Agriculture	0.3%
Hay with nutrients	Agriculture	22.0%
Hay with nutrients and Nutrient Management	Agriculture	0.0%
Hay without nutrients	Agriculture	4.9%
Alfalfa	Agriculture	11.1%
Alfalfa with Nutrient Management	Agriculture	0.0%
Pasture	Agriculture	45.8%
Pasture with Nutrient Management	Agriculture	0.0%
Trampled Pasture	Agriculture	0.2%
Animal Feeding Operations	Agriculture	0.3%
Nursery	Agriculture	0.5%

Table 2-7 CBP nutrient and solids nonpoint source load rates (Mandel, 2006)

Land Use Category	Load Rate (lbs/acre-year)		
	TN	TP	TSS
Agriculture	21.8	1.5	571.3
Commercial	21.7	1.6	2463.5
Extractive	20.0	2.9	2666.0
Forest	4.8	0.4	63.1
Other Developed	8.0	0.8	576.9
Residential	8.0	0.8	576.9
Wetlands	6.5	0.1	1181.7

Table 2-8 Existing Case (2005) – Deep Creek Lake sub-watershed land use areas

	Area (acres)									
Sub-Watershed	**Agriculture**	**Commercial**	**Extractive**	**Forest**	**Other Developed**	**High Density Residential**	**Low Density Residential**	**Medium Density Residential**	**Wetland**	**Total**
Bee Tree Hollow	-	-	-	298	-	-	118	60	-	476
Blakeslee	255	-	-	35	-	-	199	5	-	494
Cherry Creek	1,300	1	280	3,729	-	-	288	-	602	6,199
Cherry Creek Cove	1	-	-	1,091	44	1	148	23	-	1,308
Green Glade Run	678	1	-	2,646	-	2	326	311	113	4,077
Hoop Pole Run	533	-	-	203	-	14	191	148	-	1,089
Lower Deep Creek	151	8	-	1,956	-	1	336	83	-	2,534
Marsh Run	315	140	-	1,212	206	45	502	337	-	2,757
Meadow Mountain	3	-	119	1,393	-	-	-	-	185	1,700
Meadow Mountain Run	118	8	-	1,500	46	-	503	20	78	2,273
North Glade Run	1,899	9	-	1,417	3	5	882	177	10	4,403
Pawn Run	1,474	10	-	717	3	-	310	70	-	2,584
Red Run	207	28	-	1,548	4	-	289	54	-	2,131
Roman Nose Hill	4	30	-	187	4	22	106	125	-	477
Shingle Camp Hollow	-	-	-	492	-	-	98	44	-	634
Smith Run	11	-	-	475	-	-	89	22	-	596
Thayerville	146	72	12	601	4	22	69	49	-	975
Upper Deep Creek	959	1	-	1,027	5	-	360	116	72	2,540
Total	8,053	307	411	20,527	319	112	4,813	1,646	1,060	37,249

Table 2-9 Moderate Growth Scenario – Deep Creek Lake sub-watershed land use areas

	Area (acres)									
Sub-Watershed	**Agriculture**	**Commercial**	**Extractive**	**Forest**	**Other Developed**	**High Density Residential**	**Low Density Residential**	**Medium Density Residential**	**Wetland**	**Total**
Bee Tree Hollow	-	-	-	137	-	-	279	60	-	476
Blakeslee	175	-	-	22	-	-	293	5	-	495
Cherry Creek	1,219	1	259	3,683	-	-	434	-	602	6,199
Cherry Creek Cove	1	-	-	1,064	44	1	175	23	-	1,308
Green Glade Run	665	1	-	1,930	-	2	1,058	308	113	4,078
Hoop Pole Run	467	-	-	135	-	14	323	149	-	1,089
Lower Deep Creek	332	8	-	1,212	-	1	860	120	-	2,534
Marsh Run	170	167	-	1,047	133	47	869	325	-	2,758
Meadow Mountain	3	-	119	1,393	-	-	-	-	185	1,700
Meadow Mountain Run	116	9	-	1,437	46	-	568	20	78	2,274
North Glade Run	1,842	10	-	1,235	1	5	1,126	177	10	4,407
Pawn Run	1,387	11	-	689	3	-	424	70	-	2,584
Red Run	203	34	-	1,519	4	-	316	54	-	2,131
Roman Nose Hill	3	32	-	173	4	22	117	125	-	477
Shingle Camp Hollow	33	-	-	168	-	-	383	50	-	634
Smith Run	10	-	-	386	-	-	179	21	-	596
Thayerville	117	98	12	494	4	22	163	66	-	976
Upper Deep Creek	921	1	-	975	5	-	450	116	72	2,540
Total	7,667	373	391	17,700	244	114	8,018	1,690	1,060	37,256

Table 2-10 Rapid Growth Scenario – Deep Creek Lake sub-watershed land use areas

	Area (acres)									
Sub-Watershed	**Agriculture**	**Commercial**	**Extractive**	**Forest**	**Other Developed**	**High Density Residential**	**Low Density Residential**	**Medium Density Residential**	**Wetland**	**Total**
Bee Tree Hollow	**-**	**-**	**-**	**89**	**-**	**-**	**327**	**60**	**-**	**476**
Blakeslee	**126**	**-**	**-**	**15**	**-**	**-**	**348**	**5**	**-**	**495**
Cherry Creek	**1,219**	**1**	**259**	**3,683**	**-**	**-**	**434**	**-**	**602**	**6,199**
Cherry Creek Cove	**1**	**-**	**-**	**1,048**	**44**	**1**	**191**	**23**	**-**	**1,308**
Green Glade Run	**657**	**1**	**-**	**1,898**	**-**	**2**	**1,098**	**308**	**113**	**4,078**
Hoop Pole Run	**432**	**-**	**-**	**122**	**-**	**14**	**372**	**149**	**-**	**1,089**
Lower Deep Creek	**331**	**8**	**-**	**1,194**	**-**	**1**	**880**	**120**	**-**	**2,534**
Marsh Run	**163**	**167**	**-**	**1,011**	**133**	**47**	**913**	**325**	**-**	**2,758**
Meadow Mountain	**3**	**-**	**119**	**1,393**	**-**	**-**	**-**	**-**	**185**	**1,700**
Meadow Mountain Run	**115**	**9**	**-**	**1,425**	**46**	**-**	**581**	**20**	**78**	**2,274**
North Glade Run	**1,827**	**10**	**-**	**1,224**	**1**	**5**	**1,153**	**177**	**10**	**4,407**
Pawn Run	**1,368**	**11**	**-**	**680**	**3**	**-**	**451**	**70**	**-**	**2,584**
Red Run	**200**	**34**	**-**	**1,496**	**4**	**-**	**342**	**54**	**-**	**2,131**
Roman Nose Hill	**3**	**32**	**-**	**160**	**4**	**22**	**130**	**125**	**-**	**477**
Shingle Camp Hollow	**33**	**-**	**-**	**162**	**-**	**-**	**389**	**50**	**-**	**634**
Smith Run	**10**	**-**	**-**	**360**	**-**	**-**	**205**	**21**	**-**	**596**
Thayerville	**98**	**98**	**12**	**414**	**4**	**22**	**263**	**66**	**-**	**976**
Upper Deep Creek	**916**	**1**	**-**	**969**	**5**	**-**	**461**	**116**	**72**	**2,540**
Total	**7,502**	**373**	**391**	**17,344**	**244**	**114**	**8,538**	**1,690**	**1,060**	**37,256**

Table 2-11 Capacity Analysis Scenario – Deep Creek Lake sub-watershed land use areas

	Area (acres)									
Sub-Watershed	Agriculture	Commercial	Extractive	Forest	Other Developed	High Density Residential	Low Density Residential	Medium Density Residential	Wetland	Total
Bee Tree Hollow	-	-	-	49	-	-	367	60	-	476
Blakeslee	2	-	-	29	-	-	458	5	-	494
Cherry Creek	-	1	220	95	-	-	5,282	-	602	6,199
Cherry Creek Cove	1	-	-	560	44	1	679	23	-	1,308
Green Glade Run	140	1	-	549	-	2	3,029	243	113	4,077
Hoop Pole Run	153	-	-	105	-	14	680	137	-	1,089
Lower Deep Creek	34	8	-	233	-	1	2,180	79	-	2,534
Marsh Run	51	140	-	354	67	41	1,746	359	-	2,757
Meadow Mountain	3	-	28	166	-	-	1,319	-	185	1,700
Meadow Mountain Run	-	18	-	664	45	-	1,448	20	78	2,273
North Glade Run	-	9	-	355	3	5	3,874	148	10	4,403
Pawn Run	10	14	-	-	3	-	2,487	70	-	2,584
Red Run	135	31	-	419	-	-	1,482	63	-	2,131
Roman Nose Hill	3	30	-	105	4	22	182	132	-	477
Shingle Camp Hollow	-	-	-	371	-	-	219	44	-	634
Smith Run	11	-	-	253	-	-	313	19	-	596
Thayerville	56	72	12	54	-	18	448	315	-	976
Upper Deep Creek	87	1	-	130	4	-	2,135	110	72	2,540
Total	686	325	260	4,490	170	103	28,327	1,827	1,060	37,250

Table 2-12 Existing Case (2005) – Nonpoint source load estimates by sub-watershed

Sub-Watershed	**TN**	**TP**	**TSS**
Bee Tree Hollow	2,859.8	257.6	121,437
Blakeslee	7,349.7	560.5	265,576
Cherry Creek	58,179.3	4,446.7	2,602,506
Cherry Creek Cove	7,028.2	583.4	194,384
Green Glade Run	33,431.2	2,528.8	1,058,403
Hoop Pole Run	15,410.1	1,158.7	521,042
Lower Deep Creek	16,278.5	1,306.6	470,913
Marsh Run	23,730.1	2,012.9	1,228,829
Meadow Mountain	10,389.9	893.1	625,699
Meadow Mountain Run	15,037.3	1,223.1	601,786
North Glade Run	57,035.9	4,243.5	1,825,545
Pawn Run	38,875.9	2,786.3	1,133,228
Red Run	15,381.3	1,212.0	485,508
Roman Nose Hill	3,667.7	335.8	234,838
Shingle Camp Hollow	3,514.8	299.4	113,030
Smith Run	3,422.7	283.4	100,166
Thayerville	9,053.9	711.7	414,671
Upper Deep Creek	30,205.8	2,212.9	978,708
Total-DCL Load (lbs/year)	**350,852**	**27,056**	**12,976,268**
Total-DCL Load (lbs/day)	**961**	**74**	**35551**
Estimated DCL watershed Flow (cms)	**3.2**	**3.2**	**3.2**
Resultant Net Concentration (ppm)	**1.6**	**0.1**	**58.9**

Table 2-13 Moderate Growth Scenario – Nonpoint source load estimates by sub-watershed

Sub-Watershed	**TN**	**TP**	**TSS**
Bee Tree Hollow	3,361.2	331.9	204,305
Blakeslee	5,095.4	514.5	272,974
Cherry Creek	48,666.9	4,372.5	2,583,976
Cherry Creek Cove	7,104.2	595.6	207,954
Green Glade Run	30,965.3	2,851.5	1,426,914
Hoop Pole Run	11,527.9	1,146.6	556,166
Lower Deep Creek	18,847.4	1,768.4	853,197
Marsh Run	22,186.6	2,052.9	1,368,306
Meadow Mountain	10,367.8	893.1	625,697
Meadow Mountain Run	14,438.5	1,252.8	636,352
North Glade Run	44,309.0	4,293.6	1,922,920
Pawn Run	28,329.9	2,742.9	1,149,774
Red Run	14,121.0	1,227.9	511,560
Roman Nose Hill	3,724.9	344.4	247,520
Shingle Camp Hollow	4,753.0	470.2	279,283
Smith Run	3,617.8	323.8	145,615
Thayerville	8,536.1	762.7	517,869
Upper Deep Creek	23,573.2	2,212.2	1,005,910
Total-DCL Load (lbs/year)	**303,526**	**28,157**	**14,516,293**
Total-DCL Load (lbs/day)	**832**	**77**	**39771**
Estimated DCL watershed Flow (cms)	**3.2**	**3.2**	**3.2**
Resultant Net Concentration (ppm)	**1.4**	**0.1**	**65.9**

Table 2-14 Rapid Growth Scenario – Nonpoint source load estimates by sub-watershed

Sub-Watershed	TN	TP	TSS
Bee Tree Hollow	3,511.3	354.2	229,105
Blakeslee	4,775.2	485.9	276,695
Cherry Creek	48,666.9	4,372.5	2,583,976
Cherry Creek Cove	7,154.1	603.0	216,214
Green Glade Run	31,007.2	2,860.9	1,443,414
Hoop Pole Run	11,323.2	1,129.9	563,197
Lower Deep Creek	18,893.0	1,775.8	862,488
Marsh Run	22,249.9	2,065.0	1,387,030
Meadow Mountain	10,367.8	893.1	625,697
Meadow Mountain Run	14,468.5	1,257.6	642,379
North Glade Run	44,237.5	4,288.9	1,928,808
Pawn Run	28,227.3	2,734.9	1,154,516
Red Run	14,171.6	1,236.6	523,561
Roman Nose Hill	3,761.8	350.0	253,895
Shingle Camp Hollow	4,773.6	473.1	282,337
Smith Run	3,693.9	335.3	158,890
Thayerville	8,648.4	787.0	559,296
Upper Deep Creek	23,552.6	2,211.3	1,008,994
Total-DCL Load (lbs/year)	**303,484**	**28,215**	**14,700,493**
Total-DCL Load (lbs/day)	**831**	**77**	**40275**
Estimated DCL watershed Flow (cms)	**3.2**	**3.2**	**3.2**
Resultant Net Concentration (ppm)	**1.38**	**0.13**	**51.6**

Table 2-15 Capacity Analysis Scenario – Nonpoint source load estimates by sub-watershed

Sub-Watershed	TN	TP	TSS
Bee Tree Hollow	3,635.1	372.5	249,555
Blakeslee	3,876.2	398.5	270,352
Cherry Creek	50,767.8	5,146.0	4,352,384
Cherry Creek Cove	8,676.7	827.8	466,797
Green Glade Run	32,505.2	3,143.5	2,138,638
Hoop Pole Run	10,451.8	955.2	573,455
Lower Deep Creek	20,005.9	2,023.6	1,356,423
Marsh Run	23,459.9	2,270.9	1,672,400
Meadow Mountain	13,106.4	1,265.7	1,064,895
Meadow Mountain Run	16,150.4	1,540.2	1,052,109
North Glade Run	34,038.1	3,490.5	2,381,800
Pawn Run	20,891.3	2,162.4	1,517,857
Red Run	17,942.0	1,688.0	1,070,879
Roman Nose Hill	3,915.4	373.2	276,958
Shingle Camp Hollow	3,892.3	355.4	175,404
Smith Run	4,110.9	385.4	213,888
Thayerville	9,513.2	905.5	696,550
Upper Deep Creek	20,922.2	2,055.8	1,444,105
Total-DCL Load (lbs/year)	**297,861**	**29,360**	**20,974,450**
Total-DCL Load (lbs/day)	**816**	**80**	**57464**
Estimated DCL watershed Flow (cms)	**3.2**	**3.2**	**3.2**
Resultant Net Concentration (ppm)	**1.4**	**0.1**	**95.2**

Table 2-16 Nonpoint source load changes between development cases and base case

Case	TN	TP	TSS
Moderate Growth	-13%	4%	12%
Rapid Growth	-14%	4%	12%
Capacity Analysis	-15%	9%	62%

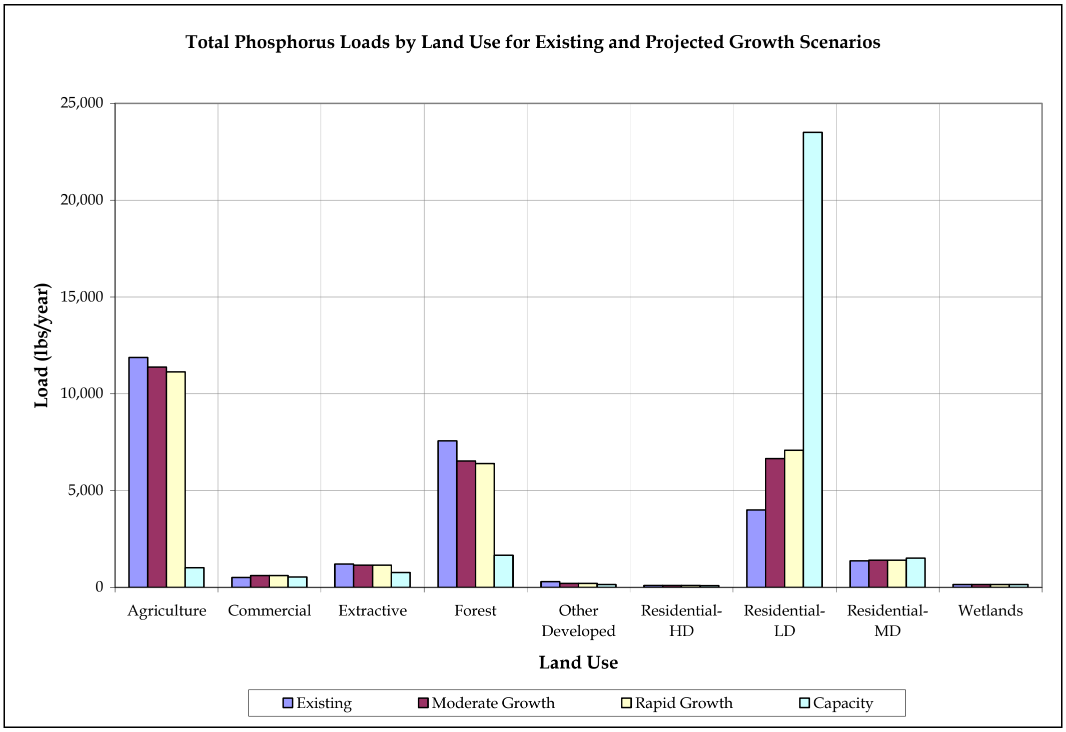

Figure 2-7 Existing and projected total phosphorus NPS loads for Deep Creek Lake

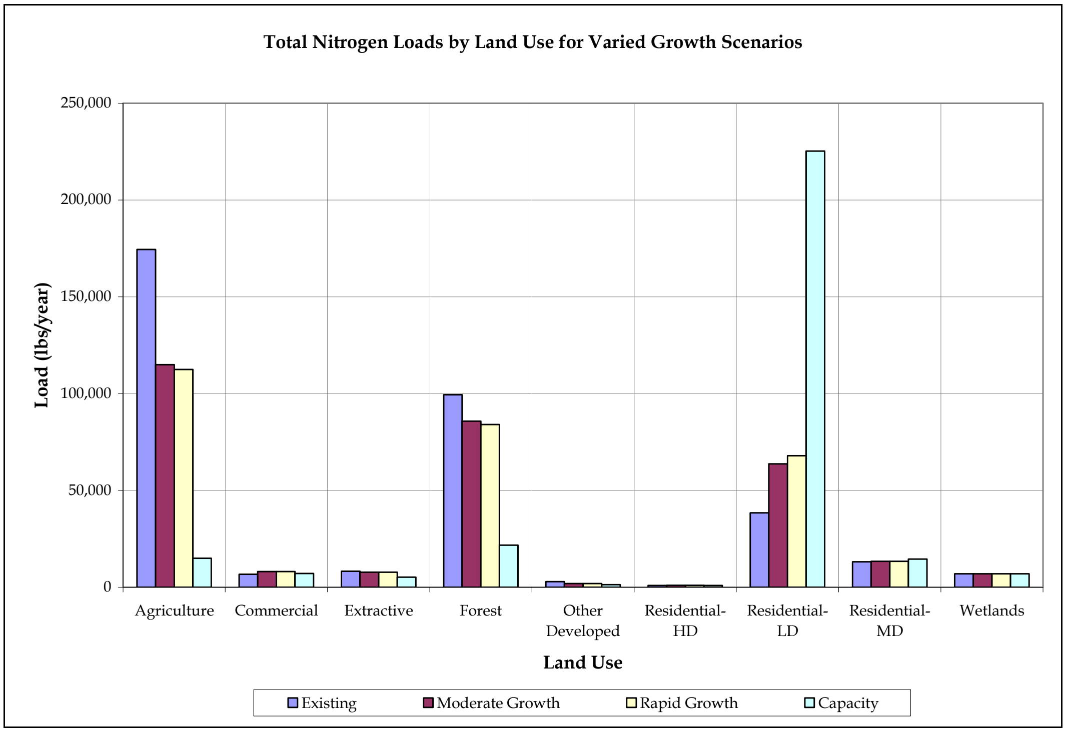

Figure 2-8 Existing and projected total nitrogen NPS loads for Deep Creek Lake

Atmospheric loads were provided by the ICPRB in terms of daily loads of nitrogen and phosphorus applied directly upon the surface area of the lake. Nitrate and ammonia nitrogen were the only forms of nitrogen available; these were combined to estimate the total atmospheric nitrogen load. Both orthophosphate and total phosphorus were available from the ICPRB. The latest values available (December 31, 2004) were applied to the model (Table 2-17). These values were assumed constant in the projected development scenarios.

Table 2-17 Annual atmospheric nutrient load deposition rates

TP (lbs/acre-yr)	TN (lbs/acre-yr)	PO_4 (lbs/acre-yr)	Inorg-N (lbs/acre-yr)
0.0016	0.0172	0.0004	0.0172

Estimates of Deep Creek Lake's septic loads were available from the ICPRB for total nitrogen. For projected development scenarios, the loads were adjusted in direct proportion to changes in the low-density residential areas (Table 2-18).

Table 2-18 Annual septic total nitrogen load rates

Scenario	LD-Residential (acres)	Septic TN Load (lbs/d)	Septic TN Load (lbs/year)
Existing	4824	55.8	20,367
Moderate	8018	92.7	33,853
Rapid	8538	98.8	36,052
Capacity	28327	327.7	119,605

Though the nonpoint source nitrogen loads decrease with each scenario, the effect of the septic loads result in a net increase in total nitrogen from the existing case to the capacity scenario (Table 2-19).

Table 2-19 Total nitrogen load summary

Scenario	Septic TN Load (lbs/year)	Atmospheric TN Load (lbs/year)	Runoff TN Load (lbs/year)	Total TN Load (lbs/year)
Existing	20,367	62	350,852	371,281
Moderate	33,853	62	303,526	337,441
Rapid	36,052	62	303,484	339,598
Capacity	119,605	62	297,861	417,528

3. *VOLLENWEIDER ANALYSIS*

The trophic state of Deep Creek Lake was examined using three different methods: the Vollenweider analysis discussed in this section, examination of field data using Carlson's TSI scores (Section 4) and the BATHTUB model (Section 5).

Eutrophication is a complex term that may be best defined as a state in which a waterbody exhibits excessive growth of aquatic plants with an undesirable increase in frequency and severity of phytoplankton blooms and / or growth of aquatic weeds (Thomann and Mueller, 1987). The eutrophic process is also described as the acceleration of the natural aging of a waterbody through excess nutrients and human activities. The trophic state of a lake is commonly described in terms of four designations: oligotrophic (clear, low productivity), mesotrophic (intermediate productivity), eutrophic (nutrient rich and productive in terms of aquatic plant or animal life), and hypereutrophic (extremely high productivity) (classifications based on EPA's Terminology Reference System at www.epa.gov). Deep Creek Lake has previously been assessed as mesotrophic-oligotrophic based on a 1993 Statewide Trophic Lake Assessment Study (Herb, 1993).

Designating a lake as eutrophic has been difficult scientifically since the classification system can be subjective and depends on the perspective of the observer. A eutrophic system need not be persistently dense with algae, nor aesthetically unpleasing, nor a source of unpleasant odors. Algal blooms may come and go with varying degrees of undesirable attributes. Classification methods have been published over the past three decades to aid in understanding the health of a waterbody. A simple method to estimate the trophic state of a lake is the Vollenweider analysis, based on the work of Richard A. Vollenweider (Vollenweider, 1968, 1975) who pioneered trophic quantification methods relating excess lake phosphorus loading to depth and residence time. The mean depth of Deep Creek Lake is 8 m. Residence time can be estimated as the quotient of average lake volume (115.8×10^6 m^3) and the average flow (4.05 cms January 2001 through January 2006) which equals 331 days.

Note well that these values are subject to revision since the phosphorus loading was derived from the preliminary results of the CBP model. The residence time is a simplified estimate; a more sophisticated estimate requiring field surveys is recommended in the conclusion of this report.

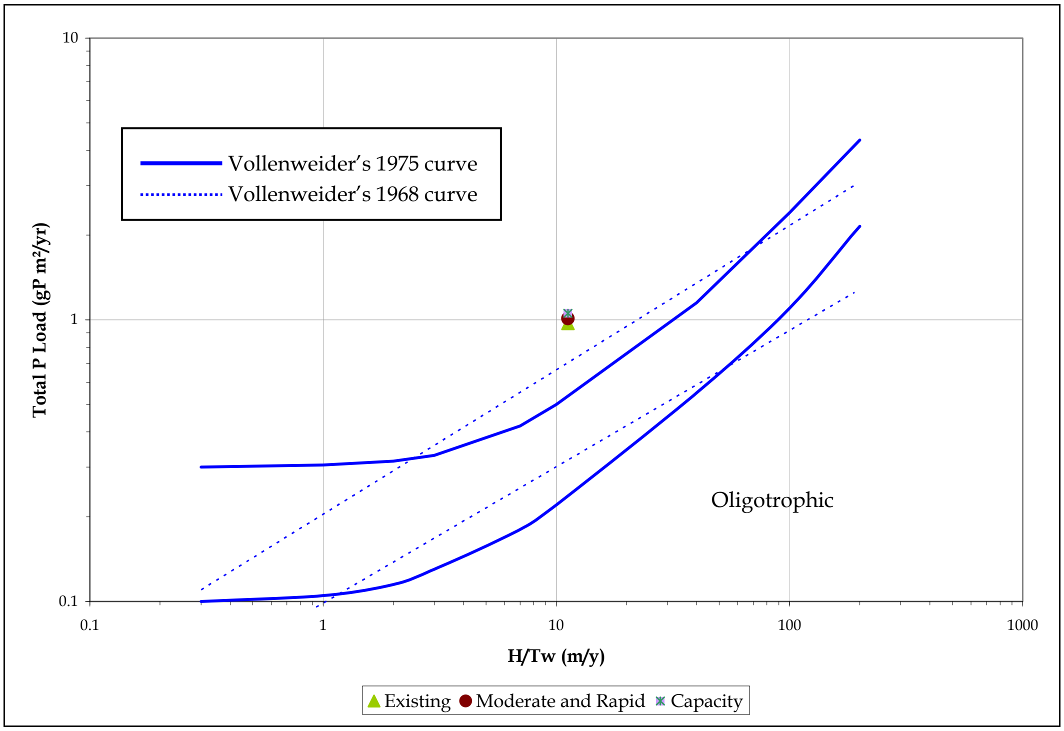

Figure 3-1 Vollenweider analysis for each scenario (source: Vollenweider, 1975)

The Vollenweider analysis shown in Figure 3-1 was performed using the phosphorus load rates for each scenario. Lake-wide total phosphorus load rates (Table 2-12 to Table 2-15) were plotted against the depth to residence time ratio. These points were compared against curves designating the boundaries between trophic states. Vollenweider updated these boundaries from straight lines (Vollenweider, 1968) to curves (Vollenweider, 1975). The results of this analysis indicate that the lake is currently in a eutrophic state and will likely become slightly more eutrophic in the development scenarios. Designation of the lake as eutrophic is counter to published observations (MDE, 1993) and is likely the result of an overestimate of existing nonpoint source nutrient loads. In the following section, the eutrophic designation is examined again through analysis of recent field observations.

4. ANALYSIS OF FIELD DATA

Field data was examined in terms of eutrophication potential as determined by the Carlson TSI Score (Section 4.1) and in an evaluation of the nutrient limiting the growth of algae (Section 4.2).

4.1. CARLSON'S TSI SCORES

Calculating Carlson's Trophic State Index (TSI) scores is another method to quantify the trophic status of a lake (Carlson, 1977). Developed by Dr. Robert Carlson of Kent State University, these scores provide a measure of algal biomass using values easily comparable between waterbodies or between present and projected conditions. TSI scores provide a standardized numerical relationship between total phosphorus, chlorophyll *a* (an indicator of the presence of phytoplankton), and secchi depth. Total phosphorus and chlorophyll *a* concentrations and secchi depth are chemically and biologically related in lakes but are not easily compared using their typical units of measurement. In general, higher phosphorus concentrations provide more food for algae (indicated by chlorophyll *a*) to reproduce and, thus, decrease the depth of light penetration (measured via secchi depth). For each of the three parameters, a TSI value can be calculated using the following equations:

$$TSI(SD) = 60 - 14.41 \times \ln(SD) \qquad \text{(Eq. 4-1)}$$

$$TSI(CHL) = 9.81 \times \ln(CHL) + 30.6 \qquad \text{(Eq. 4-2)}$$

$$TSI(TP) = 14.42 \times \ln(TP) + 4.15 \qquad \text{(Eq. 4-3)}$$

where *SD* is secchi depth in m, *CHL* is chlorophyll *a* concentration in μg/L, and *TP* is total phosphorus concentration in μg/L.

Typical TSI values range from 0 to 110 where smaller numbers represent clearer lakes with less biomass production and larger numbers indicate higher turbidity and more biomass production. In theory, if chlorophyll *a*, total phosphorus, and secchi depth are measured at the same place and time in a lake, then the TSI values calculated for all three parameters should be equal. The index is based on observations and the above formulas are calibrated to numerically standardize the lake's trophic state. For this reason, the index is sometimes used to predict total phosphorus or chlorophyll *a* concentrations when only secchi depth measurements are available. However, it should be noted that the three TSI values represent specific biological or chemical processes which influence the trophic state of a lake and should not be averaged.

Table 4-1 relates TSI value ranges to their respective trophic status and includes attributes of the various trophic states.

Table 4-1 TSI Values and corresponding trophic status in freshwater lakes

TSI Value	Trophic Status	Attributes	Aquatic Life
Less than 30	Oligotrophic	Clear water, low production, oxygenated hypolimnion.	Trout possible in deep lakes.
30 – 50	Mesotrophic	Moderately clear water, possible anoxia in summer.	Warm water fishery
50 – 70	Eutrophic	Low transparency, anoxic hypolimnion in summer.	Warm water fishery
Greater than 70	Hypereutrophic	Dense algae and macrophytes, noticeable odor, fish kills possible.	

USEPA, 1992

Water quality measurements provided by the MDE (Appendix C) were examined for an indication of the trophic status. Chlorophyll *a* measurements in Deep Creek Lake (Figure 4-1) show typical concentrations between 1 and 10 μg/L. According to USEPA (1974), describing a simple relationship between chlorophyll *a* concentrations and trophic state, this range would classify the lake between oligotrophic (<4 μg/L) and mesotrophic (4 to 10 μg/L).

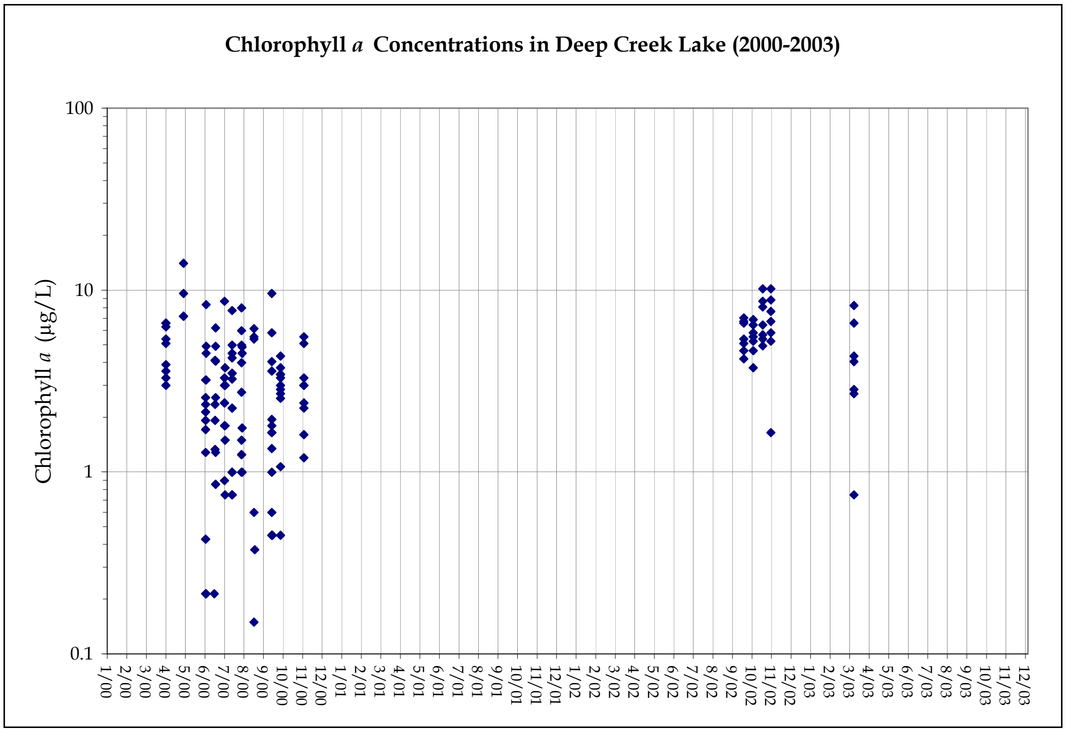

Figure 4-1 Deep Creek Lake chlorophyll *a* concentrations (source: MDE)

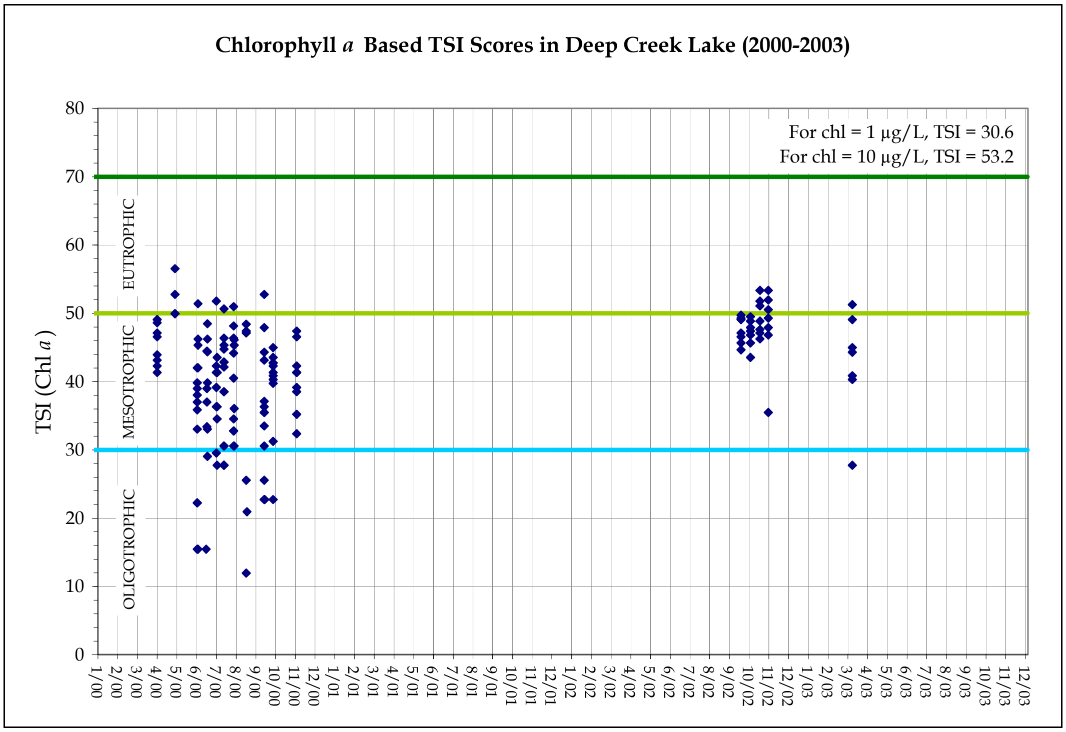

Figure 4-2 TSI scores based on 2000-2003 chlorophyll *a* values (source: MDE)

Converting the chlorophyll *a* values in Figure 4-1 into TSI scores using Equation 4-2 (Figure 4-2) shows TSI scores for Deep Creek Lake predominantly in the mesotrophic range, though some values also scored in the lower eutrophic and upper oligotrophic ranges.

Similarly, TSI scores using total phosphorus and secchi depth have been calculated and also show TSI scores predominantly in the mesotrophic range (Figure 4-3 through Figure 4-6).

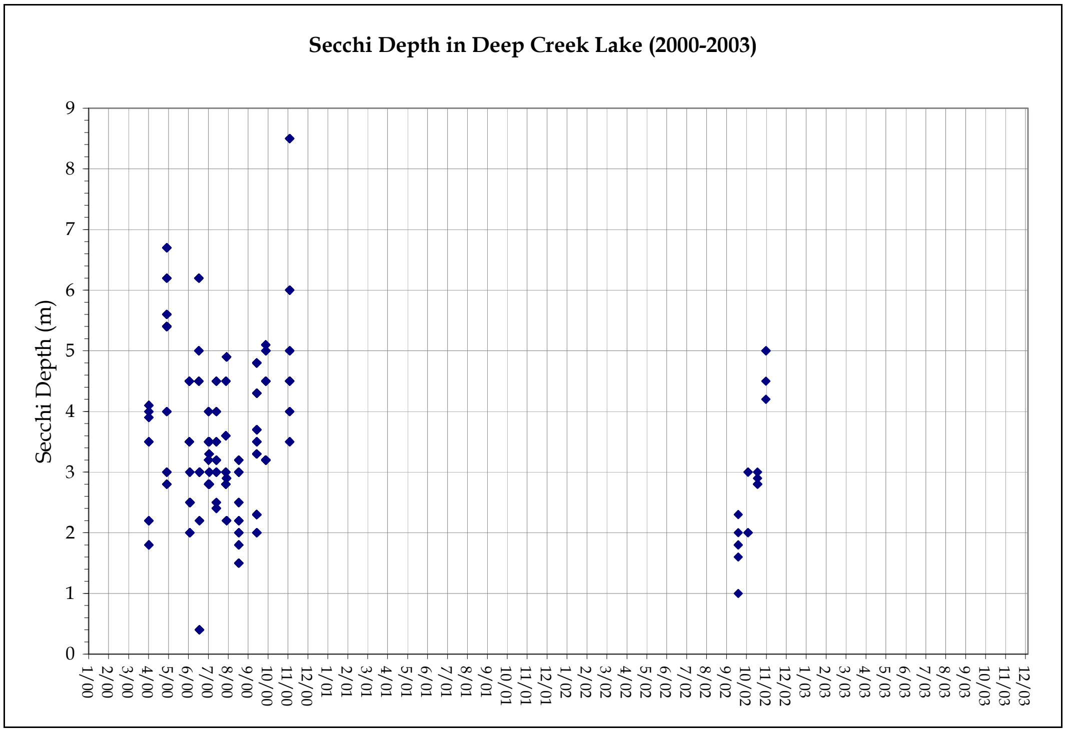

Figure 4-3 Deep Creek Lake secchi depth measurements (source: MDE)

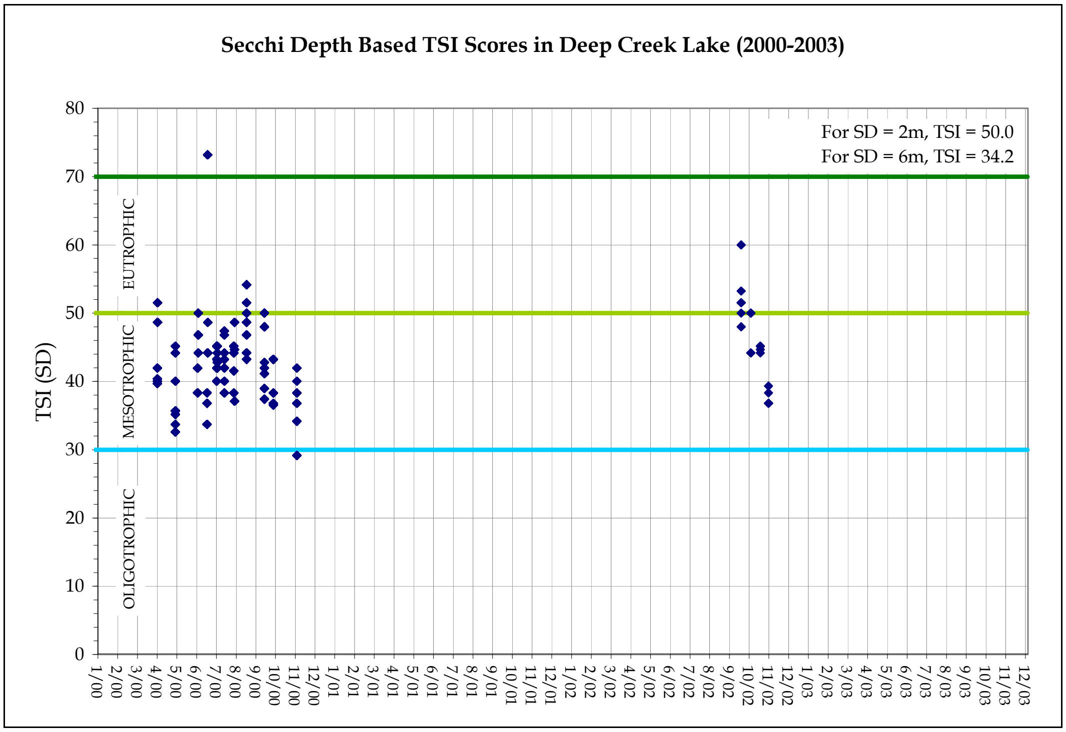

Figure 4-4 TSI scores based on 2000-2003 secchi depth values (source: MDE)

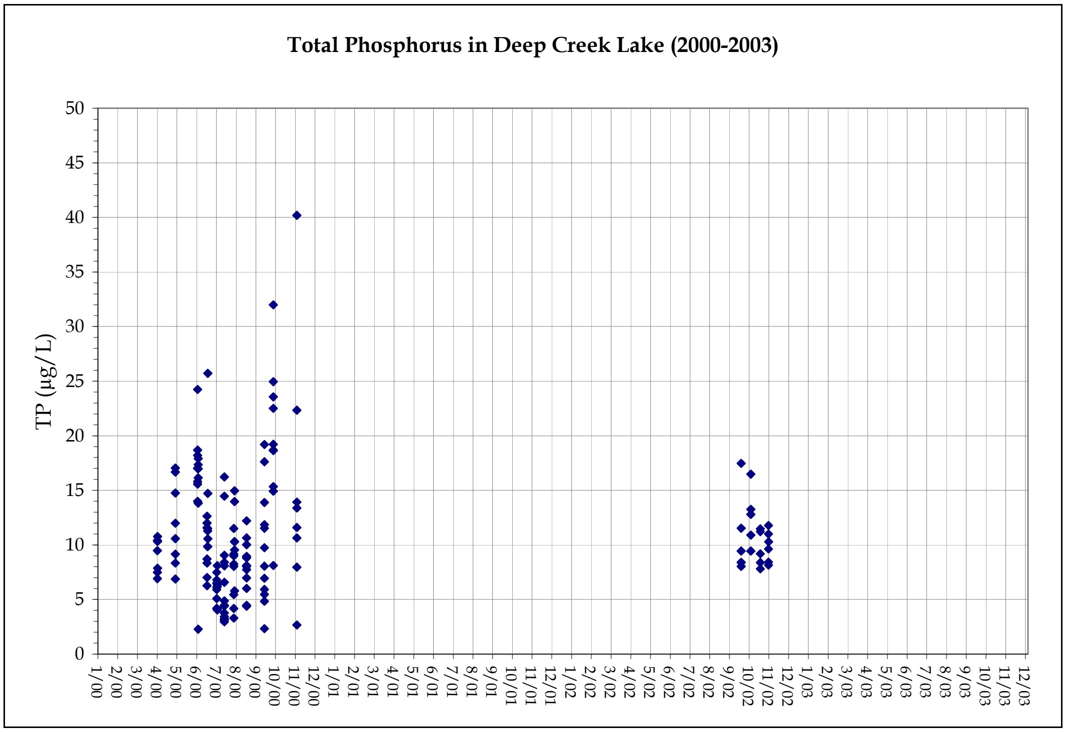

Figure 4-5 Deep Creek Lake total phosphorus concentrations (source: MDE)

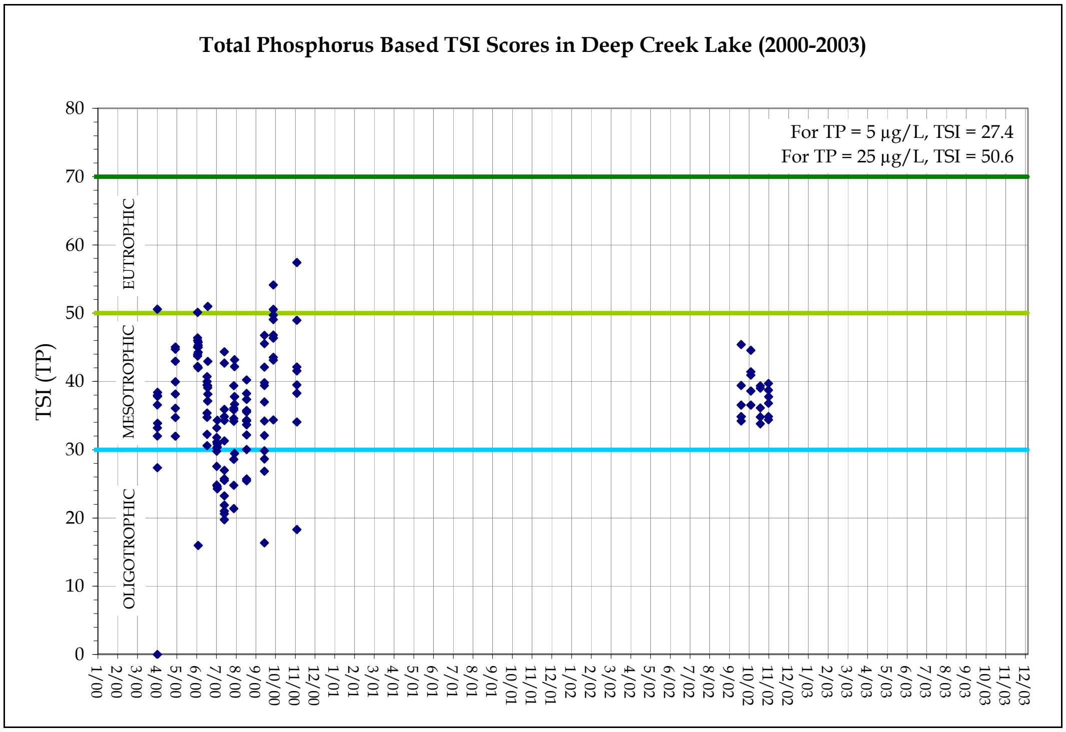

Figure 4-6 TSI scores based on 2000-2003 total phosphorus values (source: MDE)

4.2. THE NITROGEN TO PHOSPHORUS RATIO

The growth of aquatic plants is dependent on both nitrogen and phosphorus; when one nutrient is in relative abundance, the other nutrient is said to be the "limiting nutrient", as the stoichiometric relationship is limited by that nutrient's concentration. The determination of a limiting nutrient is commonly made by calculating the nitrogen to phosphorus ratio (N:P). As the N:P in biomass is approximately 7.2, ratios typically greater than 10 indicates phosphorus is limiting, while less than 10 indicates nitrogen is limiting. Examining the Maryland DNR water quality data, the nitrogen to phosphorus ratio exceeded 10 for over 93% of the recorded values during the 1999-2000 time period when the majority of the measurements were made (Figure 4-7) indicating phosphorus is predominantly limiting. To illustrate more clearly the relationship between TN to TP, a frequency histogram was made showing the range of N:P ratio values.

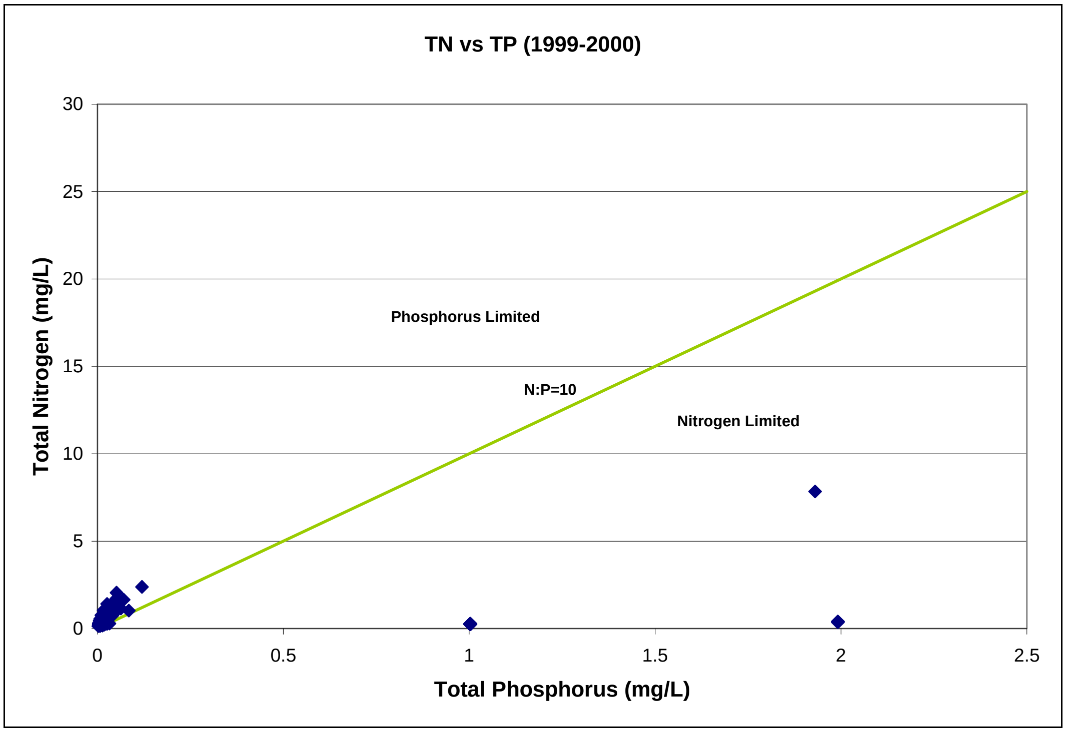

Figure 4-7 Total nitrogen vs. total phosphorus – Deep Creek Lake (1999 to 2000)

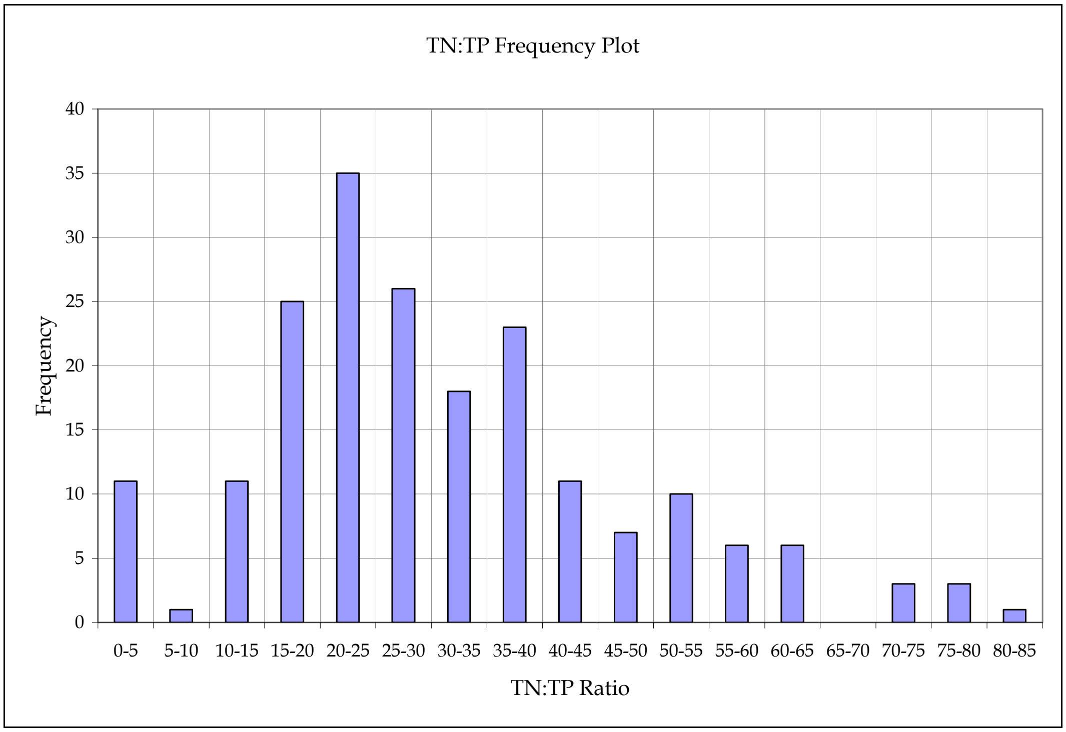

Figure 4-8 Total nitrogen to total phosphorus ratio frequency histogram

5. BATHTUB MODEL APPLICATION AND RESULTS

The BATHTUB model was utilized for a steady-state assessment of the trophic status of Deep Creek Lake using TSI scores. The software, a product of the U.S. Army Corps of Engineers, Waterways Experiment Station, applies empirical eutrophication algorithms to make lake-wide water quality predictions of total phosphorus, total nitrogen, chlorophyll *a*, and transparency (i.e. secchi depth) using nutrient load estimates. (Walker, 1985; 1986).

5.1. MODEL INPUTS AND ASSUMPTIONS

BATHTUB is a model that can be used to assess trophic status of a waterbody. Like all models, BATHTUB is based on a number of assumptions. As used for Deep Creek Lake, BATHTUB is a single cell, fully mixed model. The combination of river inputs and nonpoint source (NPS) loads resulting from direct runoff into the lake are treated as a single flow with aggregate nutrient concentrations. Phosphorus and nitrogen are each modeled using two state variables: total and ortho phosphorus and total and inorganic nitrogen. BATHTUB includes internal phosphorus loads that account for the transfer of nutrients from the sediment bed to the water column. Atmospheric and septic loads are also considered. The model time scale is yearly and all inputs, calculations, and results are treated as such. BATHTUB is simpler in structure than other eutrophication models that have three-dimensional capabilities with more state variables, complex inputs to describe rate constants, and time-varying computations. However, BATHTUB is an appropriate model for estimating the trophic status of a lake when the extensive datasets required for the more complex models are not available, which is the case for Deep Creek Lake.

5.1.1. Parameters and Constants

Over 22 parameters and constants were required by BATHTUB to describe the global, atmospheric, morphological (shape-related), internal load, and NPS characteristics of Deep Creek Lake. Table 5-1 and Table 5-2 present the parameters and constants used as inputs for the BATHTUB model. The chemical parameters were gathered from various sources. Evaporation rates were obtained from published National Oceanic and Atmospheric Administration (NOAA) long term yearly averages (United States Department of Commerce, 1974). Internal loads were determined from studies of the nearby Susquehanna and Potomac Rivers (Susquehanna River Basin Commission, 1997) and published limnological data (Wetzel, 1975). The nonpoint source, atmospheric, and septic loads were derived from the CBP model (Mandel, 2006) described in Section

2.2.2. The morphological parameters were estimated using GIS datasets developed for the Comprehensive Plan.

Table 5-1 Parameters and constants used in the Deep Creek Lake BATHTUB model

Parameter/Constant	Units	Value
Global Variables		
Averaging Period	years	1
Precipitation[1]	meters	1.35
Evaporation[2]	meters	0.9
Increase in Storage	meters	0
Atmospheric Loads		
Total P[3]	mg/m^2-yr	63.4
Ortho P[3]	mg/m^2-yr	16
Total N[3]	mg/m^2-yr	705.3
Inorganic N[3]	mg/m^2-yr	705.3
Morphological Variables		
Total Watershed Area	km^2	151
Surface Area	km^2	14.6
Mean Depth	meters	8.0
Length	km	17
Mixed Layer Depth	meters	7
Estimated Mixed Depth	meters	6
Hypolimnetic Depth	meters	8
Internal Loads		
Total Phosphorus[4]	mg/m^2-yr	0.2
Total Nitrogen[5]	mg/m^2-yr	2.0
Septic Loads		
Total Nitrogen3 (Base)	mg/m2-yr	1.7
NPS Loads (Base)		
Runoff[6]	m/yr	0.9
Total P Conc[3]	mg/m^3	106
Ortho P Conc[7]	mg/m^3	5.83
Total N Conc[3]	mg/m^3	1345
Inorganic N Conc[3]	mg/m^3	941.5

Notes:
1 NCDC, Oakland 1 SE, Oakland, Maryland
2 United States Department of Commerce, 1974
3 Mandel, Nov 2006
4 Assume TP:TN Ratio of 1:10
5 Wetzel, 1975
6 Runoff according to area weighted flow estimates based on USGS Station 3076500
7 Concentrations in NPS determined from Susquehanna River Basin Commission, 1997

Table 5-2 Projected load rates for BATHTUB model

Scenario	Septic TN mg/m2-yr	Runoff TP mg/m3	Runoff PO4 mg/m3	Runoff TN mg/m3	Runoff Inorg-TN mg/m3
Moderate	2.9	111.6	6.14	1377.2	964

Scenario	Septic TN mg/m2-yr	Runoff TP mg/m3	Runoff PO4 mg/m3	Runoff TN mg/m3	Runoff Inorg-TN mg/m3
Rapid	3.1	112.3	6.18	1377	963.9
Capacity	10.2	132.0	7.26	1330	931

5.1.2. Precipitation Data

Rainfall data were obtained from the National Climatic Data Center (NCDC) station at Oakland, Maryland (Oakland 1 SE). These NCDC rain data were averaged yearly and used for all model runs and sensitivity analyses. For the precipitation sensitivity analysis, average yearly NCDC rain data were used for the "slightly wet" case and the "average" case was determined based on published NOAA data (United States Department of Commerce, 1974). Figure 5-1 and Figure 5-2 present the precipitation record at NCDC station Oakland 1 SE from 2002 to 2005.

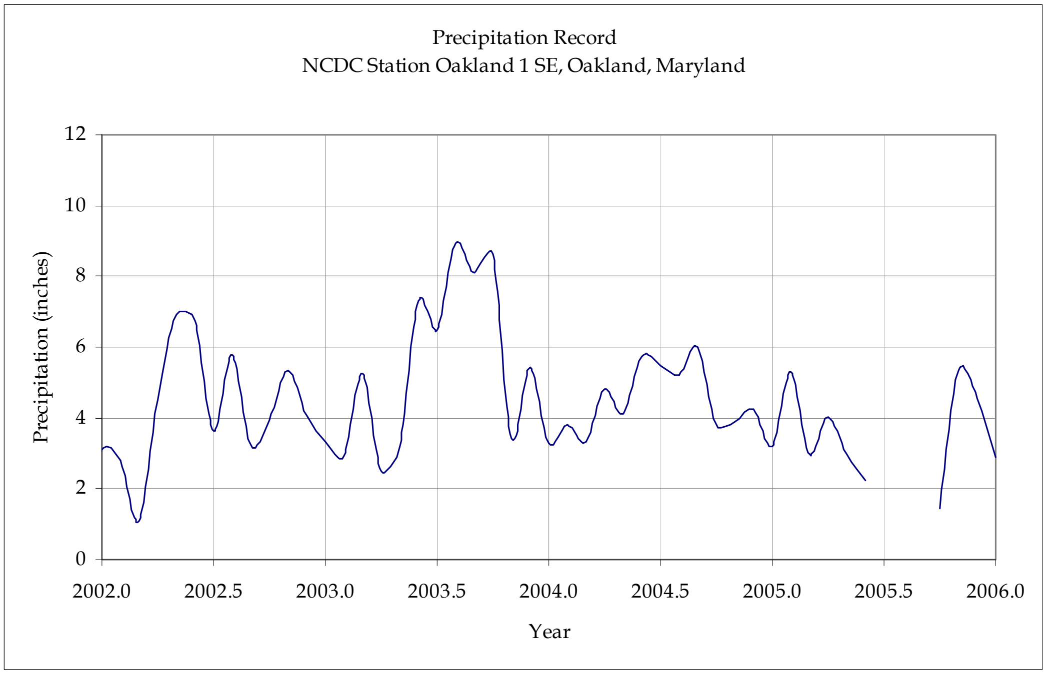

Figure 5-1 Precipitation record (2002-2005) at NCDC Station Oakland 1 SE, Oakland, Maryland

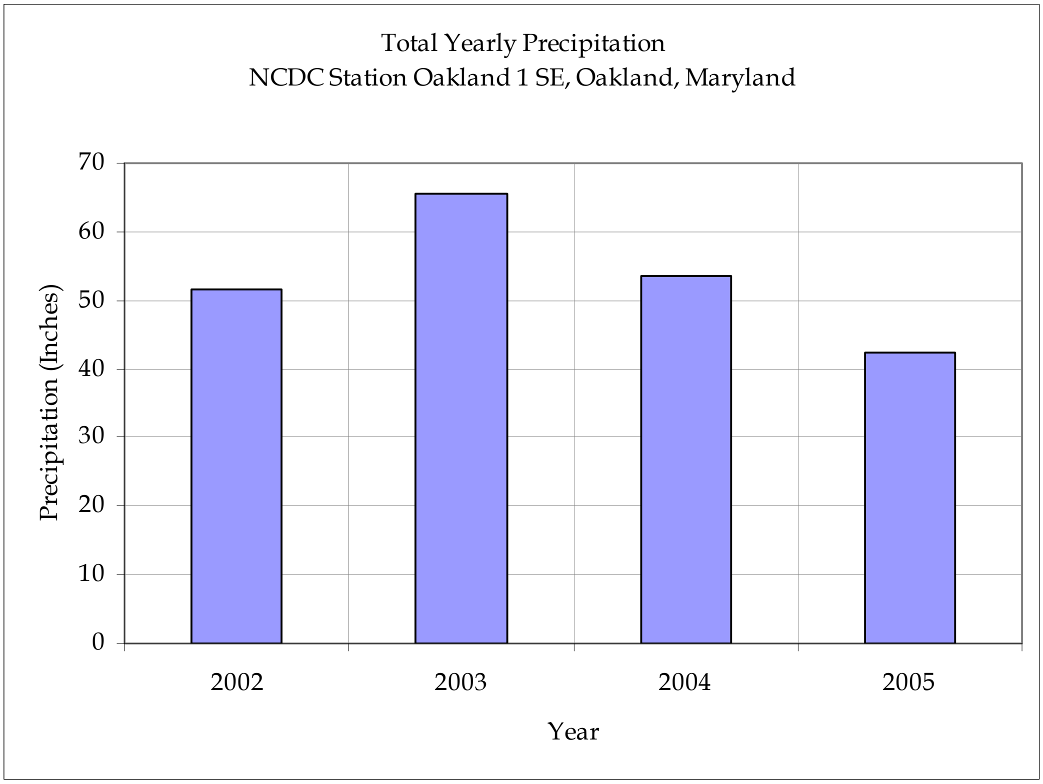

Figure 5-2 Total yearly precipitation (2002-2005) at NCDC Station Oakland 1 SE, Oakland, Maryland

5.1.3. Land Use and NPS Data

The BATHTUB model utilized the flows and loads as described in Section 2. BATHTUB required the loads be converted into concentration units. Estimates of an annual average concentration was made by dividing the annual nutrient loads by an annual average runoff flow rate for the Deep Creek Lake watershed (3.2 cms). NPS runoff resulting from potential development conditions could not be input directly, but rather was obtained by calibrating the model's runoff coefficient, precipitation, and runoff value (in m/year). The runoff rate was estimated by calculating aggregate runoff coefficients for all four conditions and then applying scalar multiplication factors to the existing runoff value. Average yearly runoff for Deep Creek Lake for existing and potential development conditions is shown in Table 5-3.

Table 5-3 Existing and projected average annual NPS runoff for Deep Creek Lake

Case	Average Yearly Runoff m/year
Existing	0.70
Moderate Development	0.71
Rapid Development	0.71
Capacity	0.72

5.1.4. *Algorithm Selection*

BATHTUB contains multiple algorithms for computing chemical and biological parameters. As stated in Section 4.2, the ratio of total nitrogen to total phosphorus in Deep Creek Lake is greater than 10:1 and, therefore, phosphorus is considered to be the limiting nutrient for algal growth. For all parameters except phosphorus, BATHTUB's default algorithm was assumed. A sensitivity analysis was performed to determine the effects of the choice of the phosphorus algorithm. Table 5-5 presents the results for all seven phosphorus algorithms. The sensitivity analysis was completed using the average 2002-2005 precipitation data and existing land use conditions. As shown in Table 5-5, the choice of the phosphorus algorithm had an effect on the computed nutrient levels, as well as a smaller effect on the trophic status. The default phosphorus algorithm, "2nd Order Available Phosphorus" was selected. Table 5-4 shows the complete list of algorithms selected in the final Deep Creek Lake BATHTUB model.

Table 5-4 Computational algorithms used in the Deep Creek Lake BATHTUB model

Parameter	Algorithm
Total Phosphorus	2nd Order, Avail P
Total Nitrogen	2nd Order, Avail N
Chlorophyll *a*	P, Light T
Transparency	vs. Chla & Turbidity
Longitudinal Dispersion	Fischer-Numberic
Phosphorus Calibration	Decay Rates
Nitrogen Calibration	Decay Rates

Table 5-5 Phosphorus algorithm sensitivity analysis

Phosphorus Algorithm	Total P mg/m3	Total N mg/m3	chl-a mg/m3	Secchi m	Organic N mg/m3	TP-ortho-P mg/m3	Inorg N:P	Turbidity 1/m	chl-a *secchi	chl-a :Total P	Carlson TSI-P	Carlson TSI-chl-a	Carlson TSI-secchi
2nd Order Available P*	35.3	588.2	10.4	1.9	413.9	20.6	11.9	0.3	20.0	0.3	55.5	53.6	50.6
2nd Order Decay	16.1	588.2	5.2	2.6	294.8	11.3	61.2	0.3	13.3	0.3	44.2	46.7	46.4
2nd Order, Fixed	28.7	588.2	8.9	2.1	379.6	17.9	19.3	0.3	18.5	0.3	52.6	52.1	49.5
Canf & Bach, Reserv	39.5	588.2	11.3	1.8	433.3	22.1	8.9	0.3	20.8	0.3	57.2	54.4	51.2
Vollenweider	56.3	588.2	13.8	1.7	491.8	26.7	3.2	0.3	22.8	0.2	62.3	56.4	52.8
First Order	56.0	588.2	13.8	1.7	490.8	26.6	3.3	0.3	22.8	0.2	62.2	56.4	52.7
Settling Velocity	100.0	588.2	17.2	1.4	569.8	32.8	0.3	0.3	25.0	0.2	70.6	58.5	54.7
Canf & Bach, Lakes	46.6	588.2	12.5	1.7	461.0	24.3	5.7	0.3	21.8	0.3	59.5	55.4	51.9
Canf & Bach, General	41.2	588.2	11.6	1.8	440.3	22.7	8.0	0.3	21.1	0.3	57.8	54.6	51.4

Note:
* Selected Algorithm

5.2. MODEL RESULTS AND EUTROPHICATION ASSESSMENT

A sensitivity analysis was performed to assess the effects of wet and dry weather conditions on the water quality of Deep Creek Lake. Cases included annual precipitation described as dry, slightly dry, average, slightly wet, and wet conditions. All cases were completed with the 2nd Order Available Phosphorus algorithm. The slightly wet condition represents the 2002-2005 average annual rainfall measured at the National Climatic Data Center (NCDC) station at Oakland, Maryland (Oakland 1 SE). The average precipitation condition used in the precipitation sensitivity analysis was determined based on historical data presented in the *Climatic Atlas of the United States* (United States Department of Commerce, 1974). Table 5-6 presents the results of the precipitation sensitivity analysis. For the four wettest conditions, TSI scores varied by less than 1%. However, for the dry case, phosphorus levels in Deep Creek Lake rose from 36.1 to 38.9 mg/l, secchi depth decreased from 1.9 to 1.8 m, and all three TSI scores rose by approximately 1. This analysis indicates that the effect of variations in precipitation in general has little impact on the trophic state unless there is a significantly dry year.

The Deep Creek Lake BATHTUB model was run using the 2002-2005 precipitation data from Oakland, Maryland, the 2nd Order Available Phosphorus algorithm, and existing land use conditions. The results of the BATHTUB model run produced TSI scores of 56.9, 54.2, and 51.1 for phosphorus, chlorophyll *a*, and secchi depth, respectively, indicating the system is currently in the mildly eutrophic condition (see Table 4-1 for an overview of the TSI value and trophic status relationship). As for the case of the Vollenweider analysis, this result is dependant upon the nutrient loads from the CBP model results, which is likely to be high for both nitrogen and phosphorus.

Next, the existing conditions Deep Creek Lake BATHTUB model was used as a basis for the three development scenarios considering three different development scenarios. All parameters, constants, and assumptions developed in the calibration of the base conditions scenario were kept the same except the NPS flow and nutrients inputs. Using potential land use data, NPS flow and nutrients loads were recalculated. Figure 2-5 summarizes the land use characteristics of the existing and three potential cases. While all land uses categories are affected, the development cases indicate that the largest impact on land use in the Deep Creek Lake watershed will be agricultural and forest land uses converted into low density residential.

Table 5-6 Precipitation sensitivity analysis for Deep Creek Lake BATHTUB model

Case	Yearly Precipitation m	Yearly Runoff m	Total P mg/m3	Total N mg/m3	Chl *a* mg/m3	Secchi m	Organic N mg/m3	TP-ortho-P mg/m3
Dry	0.535	0.277	38.9	614.9	11.3	1.8	433.3	22.1
Slightly Dry	0.803	0.416	36.1	584.2	10.7	1.9	419.4	21.0
Average	1.070	0.555	35.3	581.7	10.5	1.9	415.0	20.7
Slightly Wet (2002-2005 average)	1.350	0.700	35.3	588.2	10.4	1.9	413.9	20.6
Wet	1.605	0.835	35.5	597.5	10.4	1.9	414.4	20.6

Case	Inorg N:P	Turbidity 1/m	Chl *a* *Secchi	Chl *a* :Total P	Carlson TSI-TP	Carlson TSI-Chl *a*	Carlson TSI-Secchi
Dry	10.8	0.3	20.8	0.3	56.9	54.4	51.2
Slightly Dry	11.0	0.3	20.2	0.3	55.8	53.8	50.7
Average	11.4	0.3	20.1	0.3	55.5	53.6	50.6
Slightly Wet (2002-2005 average)	11.9	0.3	20.0	0.3	55.5	53.6	50.6
Wet	12.3	0.3	20.0	0.3	55.6	53.6	50.6

As previously stated, these land use changes increase NPS total phosphorus loads for all three potential conditions while NPS total nitrogen loads decrease due to the conversion of agricultural land to low density residential land. Septic nitrogen loads increase as low density residential area increases.

BATHTUB results for the three development conditions are presented in Table 5-7. For moderate and rapid development, there was only a small degradation in water quality. TSI values for phosphorus increased from 56.9 to 57.0 for both moderate and rapid development suggesting only small increases in the phosphorus concentrations and trophic status of the lake. Likewise, the chlorophyll *a* TSI only changed one tenth of a TSI score, while there was no change in the secchi depth TSI values for moderate and rapid growth. For the Capacity Analysis Scenario, TSI values increased by 0.4, 0.2, and 0.1 for phosphorus, chlorophyll *a*, and secchi depth, respectively. Overall, the BATHTUB model results for the moderate development, rapid development, and capacity scenarios suggest only minimal increases in the TSI scores when compared to modeled existing conditions. While the model appears to be overly conservative in assessing that the trophic status of Deep Creek Lake is mildly eutrophic, this projected trophic status will not change significantly for any of the scenarios.

Table 5-7 Deep Creek Lake BATHTUB model results – existing and projections

Development Scenario	Total P mg/m3	Total N mg/m³	Chl *a* mg/m³	Secchi m	Organic N mg/m³	TP-ortho-P mg/m³	Inorg N:P	Turbidity 1/m	Chl *a* *Secchi	Chl *a* :Total P	Carlson TSI-TP	Carlson TSI-Chl *a*	Carlson TSI-Secchi
Existing	38.7	649.8	11.1	1.9	430.0	21.8	14.8	0.3	20.7	0.3	56.9	54.2	51.1
Moderate	39.0	635.6	11.1	1.9	430.8	21.9	12.0	0.3	20.7	0.3	57.0	54.3	51.1
Rapid	39.0	637.9	11.2	1.9	430.9	21.9	12.1	0.3	20.7	0.3	57.0	54.3	51.1
Capacity	39.9	710.9	11.3	1.8	434.6	22.2	15.7	0.3	20.8	0.3	57.3	54.4	51.2

The value provided by the ICPRB for the phosphorous load rate for the Forest land use category, 0.4 lbs/acre-year (Table 2-7), is larger than rates found in the literature and used in similar studies. ICPRB staff noted the atypical value computed by their model for this region, and suggested examining 0.1 lbs/acre-year or 0.01 lbs/acre-year to test the sensitivity of the computed trophic state index to these lower rates.

The BATHTUB model was re-run using these lower rates. The resulting TSI scores are provided in Table 5-8. The difference between these scores and those obtained with the adopted phosphorous load rate of 0.4 lbs/acre-year are summarized in Table 5-9.

Table 5-8 Carlson TSI scores for various Forest land use phosphorous load rates

Phosphorous load rate	0.01 lbs/acre-year			0.1 lbs/acre-year			0.4 lbs/acre-year		
Development Scenario	**TP**	**Chl *a***	**Secchi**	**TP**	**Chl a**	**Secchi**	**TP**	**Chl *a***	**Secchi**
Existing	54.6	53.1	50.3	55.2	53.4	50.5	56.9	54.2	51.1
Moderate	55.1	53.4	50.4	55.6	53.6	50.6	57	54.3	51.1
Rapid	55.2	53.4	50.5	55.7	53.6	50.6	57	54.3	51.1
Capacity	56.9	54.2	51.1	57	54.3	51.1	57.3	54.4	51.2

Table 5-9 Change in Carlson TSI scores relative to the adopted Forest land use phosphorous load rate of 0.4 lbs/acre-year

Phosphorous load rate	0.01 lbs/acre-year			0.1 lbs/acre-year		
Development Scenario	**TP**	**Chl *a***	**Secchi**	**TP**	**Chl a**	**Secchi**
Existing	4.0%	2.0%	1.6%	3.0%	1.5%	1.2%
Moderate	3.3%	1.7%	1.4%	2.5%	1.3%	1.0%
Rapid	3.2%	1.7%	1.2%	2.3%	1.3%	1.0%
Capacity	0.7%	0.4%	0.2%	0.5%	0.2%	0.2%

The resulting increases in the TSI score range from 0.2% to 4.0%. If lower TP load rates were applied, the biggest difference would be observed in the Existing Case since that scenario contains the most amount of forested land. As residential or commercial development replaces forest, the impact of TP load reductions decreases.

6. CE-QUAL-W2 MODEL APPLICATION AND RESULTS

The third and most sophisticated level of analysis used in this study used the U. S. Army Corps of Engineers' standard reservoir water quality model, CE-QUAL-W2. This model is a longitudinal-vertical hydrodynamic and transport model designed for long-term, time-varying water quality simulations of long and relatively narrow lakes, reservoirs, and estuaries. CE-QUAL-W2 can accurately reproduce vertical and longitudinal water quality gradients when complete boundary condition data are available. The model runtime per year of simulation, though dependent on grid size and other factors, is usually short enough to allow multi-decade simulations in a few hours.

An application of CE-QUAL-W2 to a lake first establishes a grid that represents the dimensions of the main branch of the lake and any adjoining branches. The grid consists of longitudinal segments with length and vertical layers with thickness. The intersections of the segments and layers are called cells; the width of each cell provides the third dimension for the grid. Typical grid dimensions feature segment lengths of 1 km, layer thickness of 1 m, and cell widths one-half or less of the segment length. Depth is represented in the model by extending the cells to the local lake bottom. The model is laterally averaged, i.e., there is no variation across the width. However, since most lakes experience stronger longitudinal gradients and vertical gradients, than lateral gradients the laterally averaged assumption is general valid. W2 allows the creation of multiple branches, in which longitudinal-vertical detail is provided for each branch and which gives the grid a quasi-three-dimensional structure.

The model runs in deterministic mode in which meteorological data for surface heat exchange and wind shear, inflow and outflow rates, inflow temperatures and nutrient loads, are supplied as individual files, each record of which is time- and date-stamped. An overall control file directs the length of the simulation and allows for the input of the many parameters required to define the water quality algorithms, the types of output, and initial conditions. Output from the model consists of two basic types: (1) "snapshots" in which a particular parameter (e.g., water temperature) is presented at every location in the grid at the same instant in time and, (2) "time-series" in which parameters are presented at a specific location through time. There are many variants on these two types of output, including contour plots, animations and vertical profiles.

CE-QUAL-W2 has been under development for the Corps of Engineers since 1974. The model is described in Buchak and Edinger (1984) and Cole and Buchak (1995), which present formulations of the fundamental equations, the structure of the computations, and summaries of applications. Verified applications of LARM and GLVHT (earlier versions of the code), and CE-QUAL-W2 have been presented by Gordon (1980, 1981) and Gordon and Lane (1983); Edinger et al. (1983); Kim, et al. (1983); Johnson, et al. (1981); and Martin (1988). Many additional applications of the model have been verified since these earlier studies. In addition, Maryland MDE has used the model for TMDL studies of Pretty Boy and Loch Raven Reservoirs and intends to use CE-QUAL-W2 for a TMDL for Deep Creek Lake, Triadelphia, and Rocky Gorge reservoirs.

Source code, user manuals and documentation for CE-QUAL-W2, Versions 3.2 (used in this study) are available at http://www.ce.pdx.edu/w2/. Inasmuch as CE-QUAL-W2 has limited field data capabilities with respect to storage, display, and comparison to model output, the pre- and post-processing capabilities of GEMSS® (Generalized Environmental Modeling System for Surfacewaters) were used to provide these functions.

Because the model is deterministic, i.e., because it simulates historical time periods, it requires that all required forcing function data be available for the selected simulation period. As with the other analyses and models used in this study, the year 2005 was chosen for simulation. For calibration, CE-QUAL-W2's rigorous water quality algorithms require a considerable amount of systematic, in-lake water quality observations as well as measured inflow rates, temperatures, and nutrient concentrations. Section 2 discusses the existing datasets and points out that these do not support a W2 calibration.

However, the application of the model to Deep Creek Lake does provide information on the lake's characteristics that is useful for planning activities. The simulations that show these characteristics are discussed below. Furthermore, the model application developed for this study can be used to plan a robust water quality monitoring program and could provide Maryland MDE with a starting point for its planned Deep Creek Lake TMDL.

6.1. BATHYMETRY, GRID AND ENGINEERING FEATURES

In general, bathymetric data describes the lake bottom and consists of soundings, cross-sections, or contours. Supporting information in the form of the location of the lake shoreline is also required. All this information is normally provided in geo-referenced, GIS format but is unavailable for Deep Creek Lake (Figure 6-1). The limited bathymetric information that is available consists of the project elevation-volume table, provided by Brookfield Power (Table 6-1); the normal pool elevation of 2462 ft published by the USGS; and the shoreline polygon digitized by Garrett County.

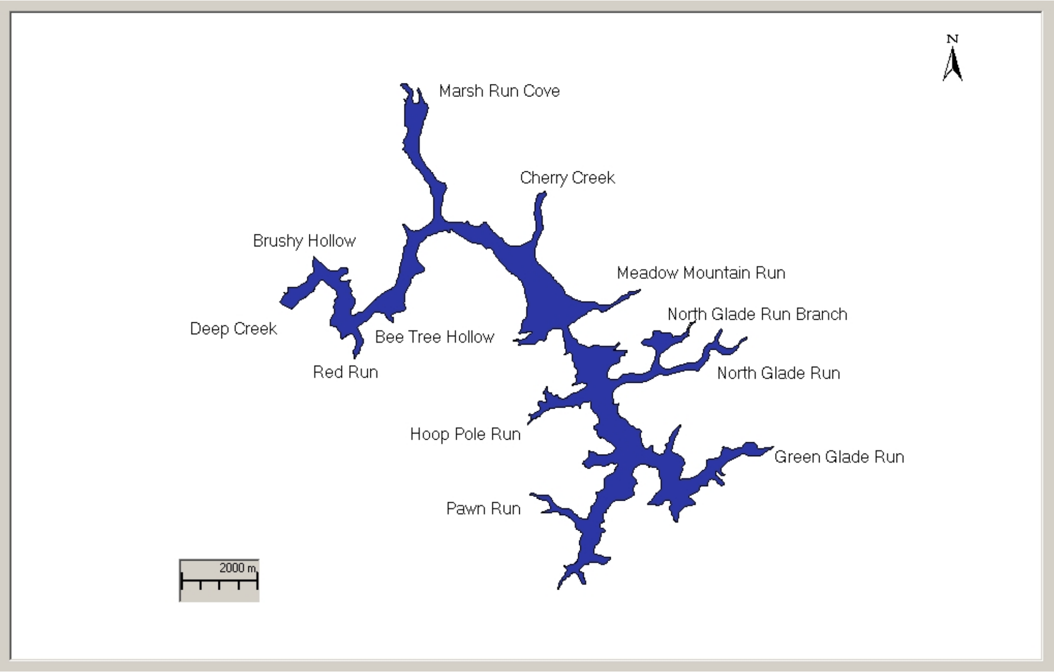

Figure 6-1 Deep Creek Lake and tributaries

Table 6-1 Deep Creek Lake elevation and cumulative volume (source: Brookfield Power, 2005)

Elevation (ft)	Cumulative volume (million ft^3)
2443	1404.0
2444	1515.0
2445	1630.0
2446	1747.0
2447	1868.0
2448	1992.0
2449	2119.0
2450	2250.0
2451	2383.0
2452	2520.0
2453	2660.0
2454	2803.0
2455	2950.0
2456	3099.0
2457	3252.0
2458	3407.0
2459	3566.0
2460	3726.0
2461	3888.0
2462	4050.0

To construct CE-QUAL-W2's grid with the existing bathymetric data, the following procedure was used. First, the water depth and bottom elevation at the dam was established from the USGS topographic quadrangle. The streambed elevation below the dam is 2380 ft, indicating a maximum water depth of 82 ft. Next, the bottom slope along the streambed was estimated by using the downstream elevation of 2380 ft and an upstream elevation at the intersection of the shoreline and the 2462 ft normal pool elevation contour. For each of the eight side branches in the model, a similar procedure was adopted. For each branch, the downstream bottom elevation was taken from the main branch at its intersection with the side branch.

The width of each cell in the grid was also assumed to vary linearly with depth from the measured width at the normal pool elevation to the bottom. Adjustments to the widths were then made by comparing the computed and observed elevation and volume tables until satisfactory agreement was obtained.

Figure 6-2 shows a plan view of the Deep Creek Lake grid. The grid includes nine branches: the main branch (Deep Creek), Pawn Run Branch, Green Glade Run Branch, Hoop Pole Run Branch, North Glade Run Branch, North Glade Run Sub-Branch, Meadow Mountain Run Branch, Cherry Creek Branch, and Marsh Run Branch. Each of these branches has a separate inflow which enters the branch at the head. In addition, the model setup includes eight tributaries: Blakeslee, Roman Nose Hill, Thayerville, Bee Tree Hollow, Red Run, Smith Run, Lower Deep Creek, and Shingle Camp Hollow. Because of the close proximity of some of these tributaries and the approximate 0.5 km resolution of the segments, these eight tributaries were amalgamated into four tributaries. Tributaries can enter model branches at any segment along the length of the branch.

The grid includes a total of 91 segments of which 33 are in the main branch. Segment lengths are shown in Table 6-2. The layer thickness throughout the grid is 1 m.

Table 6-2 CE-QUAL-W2 Segment lengths by branch

Branch Number	Branch Name	Minimum segment length, m	Maximum segment length, m
1	Deep Creek	353	800
2	Pawn Run	250	460
3	Green Glade Run	442	818
4	Hoop Pole Run	423	460
5	North Glade Run	270	548
6	North Glade Run Sub-Branch	370	599
7	Meadow Mountain	423	516
8	Cherry Creek	321	423
9	Marsh Run Cove	600	725

The only engineering structure of importance is the elevation of the release structure at the dam, which is 2415 ft (Charles B. Hawley & Co. Inc., 1924).

Table 6-3 shows the elevation and volume table between 2382 ft to 2463 ft. The last column of Table 6-3 is the ratio of the computed volume to the Brookfield Power observed volume and shows satisfactory agreement.

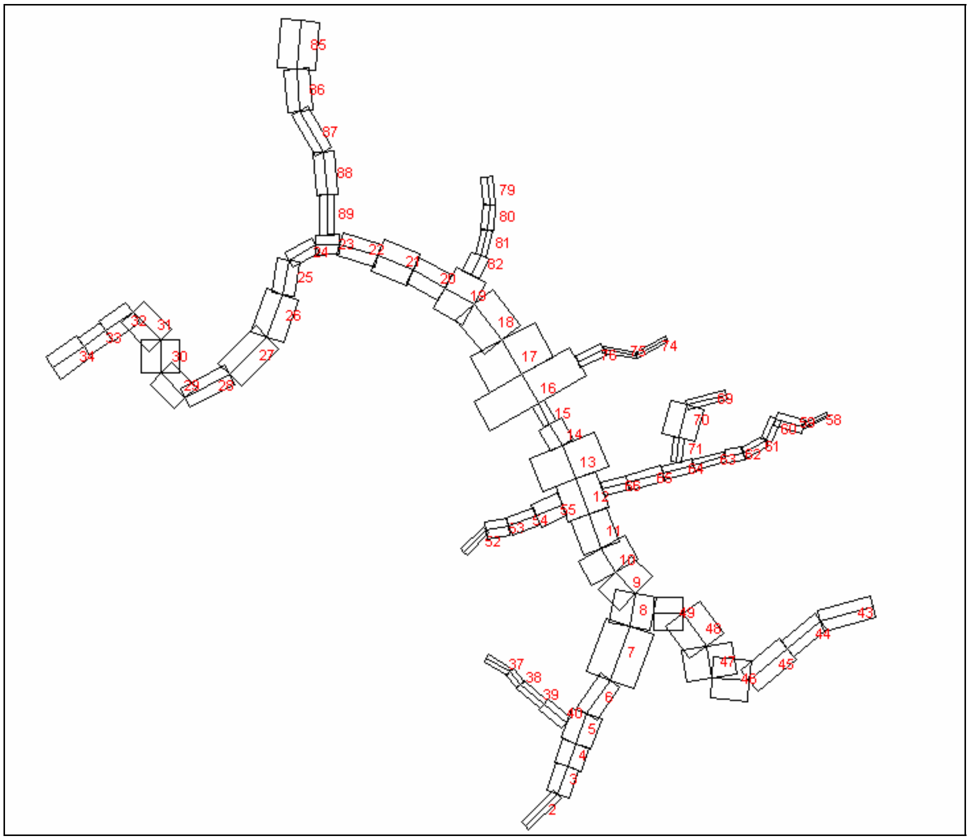

Figure 6-2 Deep Creek Lake CE-QUAL-W2 grid showing longitudinal segments

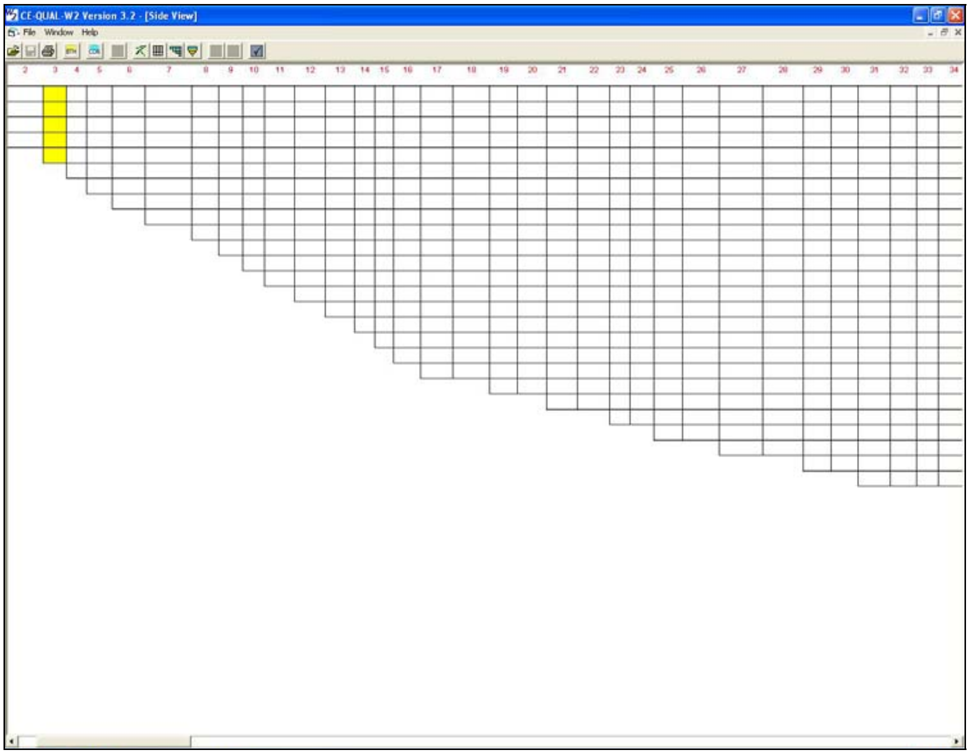

Figure 6-3 Side view of the grid representing the main branch of Deep Creek Lake

Table 6-3 Elevation-area-volume for Deep Creek Lake

Elevation (ft)	Computed area (m^2)	Computed volume (million ft^3)	Observed volume (million ft^3)	Ratio of computed to observed volume
2463	15251788	4175	4214	0.99
2461	13873966	3814	3823	1.00
2457	12632389	3324	3300	1.01
2454	11454363	2878	2810	1.02
2451	10185001	2473	2350	1.05
2447	8897546	2114	1930	1.10
2444	7749733	1800	1538	1.17
2441	6721411	1526	**	**
2438	5774111	1289	**	**
2434	5015666	1085	**	**
2431	4369624	908	**	**
2428	3825257	753	**	**
2425	3327351	618	**	**
2421	2851122	501	**	**
2418	2454903	400	**	**
2415	2108389	313	**	**
2411	1781218	239	**	**
2408	1467006	176	**	**
2405	1094658	124	**	**
2402	830773	85	**	**
2398	627673	56	**	**
2395	452968	34	**	**
2392	289000	18	**	**
2388	146167	8	**	**
2385	58926	3	**	**
2382	12690	0	**	**

** Data unavailable.

6.2. TIME VARYING BOUNDARY CONDITION DATA

Time-varying datasets quantify the forcing functions for the lake, including meteorological data for surface heat exchange and wind shear, inflow and outflow rates, inflow temperatures and nutrient loads. Each of these datasets was formatted for input to CE-QUAL-W2 by providing a standard date- and time-stamp.

6.2.1. Meteorological data

Meteorological data for input to CE-QUAL-W2 was taken from hourly National Weather Service observations of air temperature, dew point temperature, wind speed and direction, and cloud cover at Morgantown Municipal AP - Hart Field (WBAN 13736). Morgantown, approximately 30 miles west northwest of Deep Creek Lake, is the closest station that electronically records all the required data. Solar radiation, an important component of the heat budget, is not directly observed but instead computed from cloud cover observations.

6.2.2. *Inflow and outflow rates and the water surface elevation*

Inflow rates for Deep Creek Lake were developed for each branch and tributary at the same time that the nutrient loads were developed and are discussed in Section 2. Brookfield Power provided estimates of the outflow rates. The total inflow and outflow rates for the 2005 simulation year are shown in Figure 6-4 and Figure 6-5, respectively. To close the water balance, computed and observed water surface elevations were compared during the initial CE-QUAL-W2 simulations. It was necessary to introduce a flow adjustment to obtain close agreement of the computed and observed water surface elevations (Figure 6-6). This adjustment procedure is commonly done in CE-QUAL-W2 applications where inflow rates are not measured or a detailed hydrologic model has been applied to the watershed. This adjustment could also represent groundwater inflows. When it is necessary to add or subtract a small flow to close the water balance, the flow is added as a distributed tributary, i.e., along the entire length of the main branch so as to diminish the impact on local flow fields.

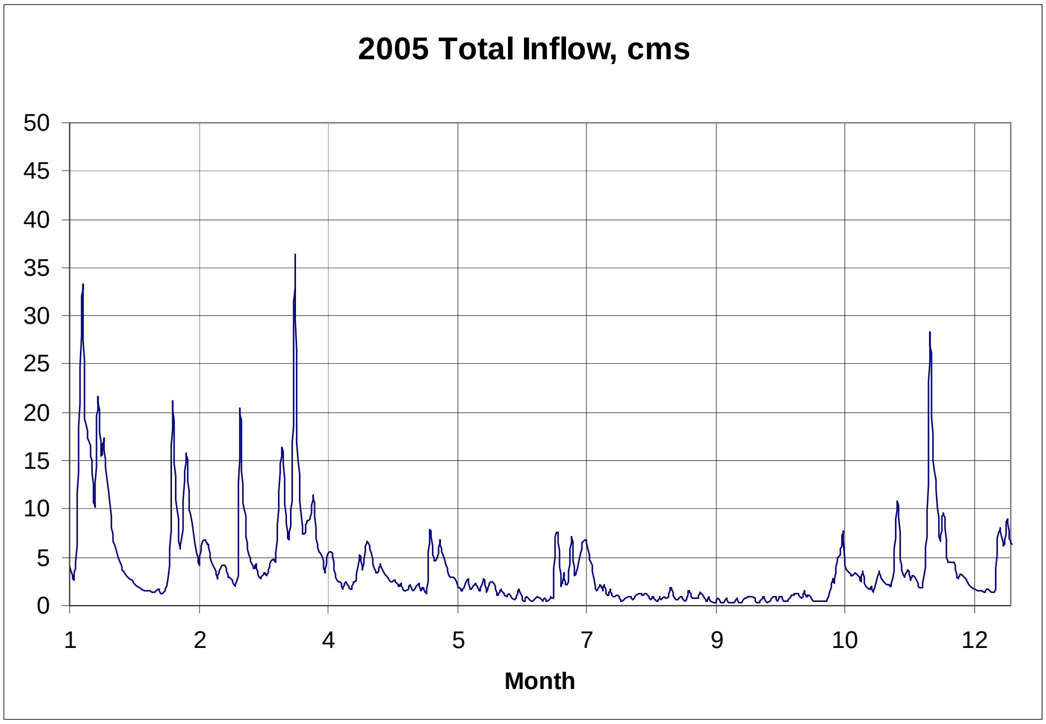

Figure 6-4 Summary of total inflow (cms) to Deep Creek Lake for 2005

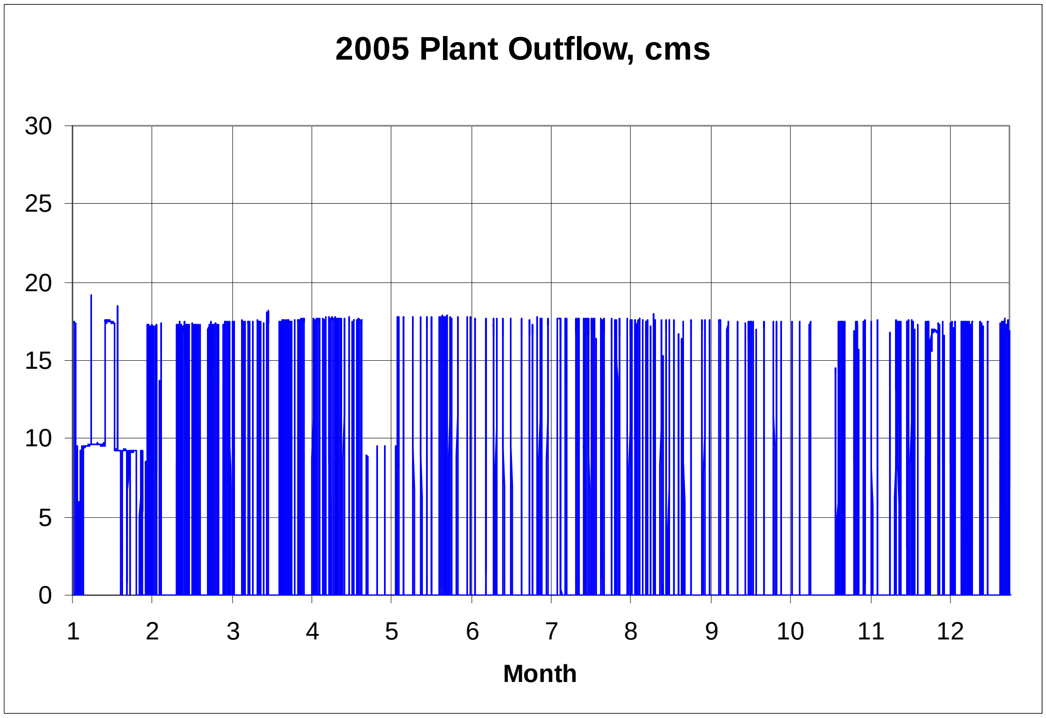

Figure 6-5 Hydropower outflows (cms) from Deep Creek Lake for 2005

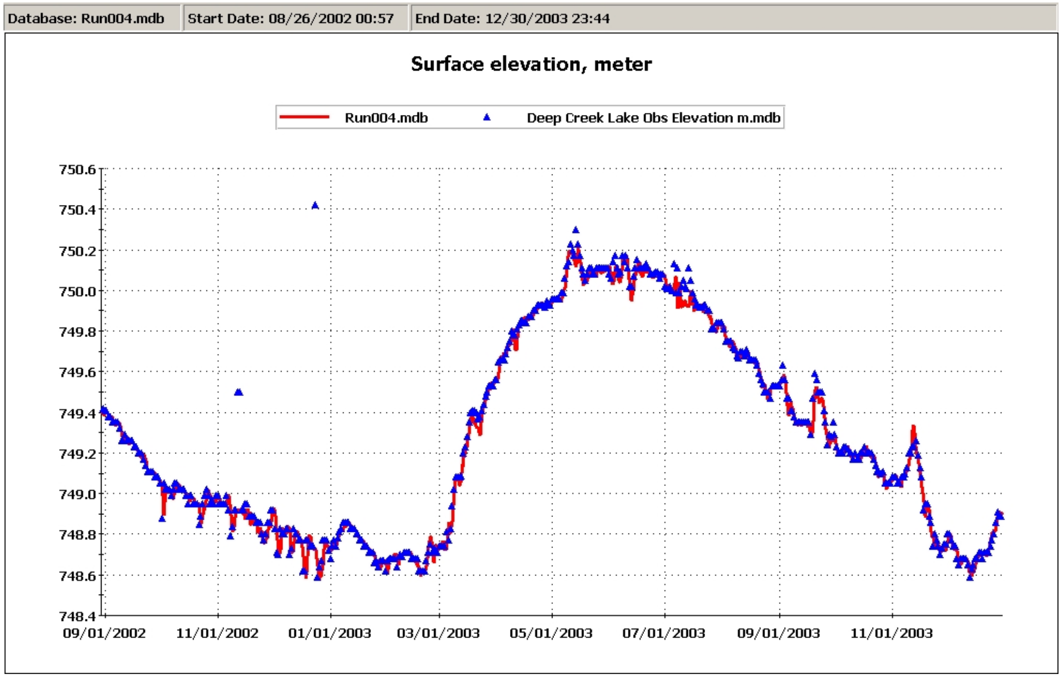

Figure 6-6 Observed (blue) and computed (red) water surface elevation

6.2.3. Inflow temperatures

Temperatures of the inflows to Deep Creek Lake are required for the heat balance in the model. Since very little tributary temperature data has been collected, inflow temperatures were computed from the meteorological data using the response temperatures approach, then calibrated to the few observations that are available in 2003 from STORET Station GEO0009 (Figure 6-7). After calibration for 2003, identical parameters (mostly the assumed tributary depth) were used to compute inflow temperatures for the 2005 study period.

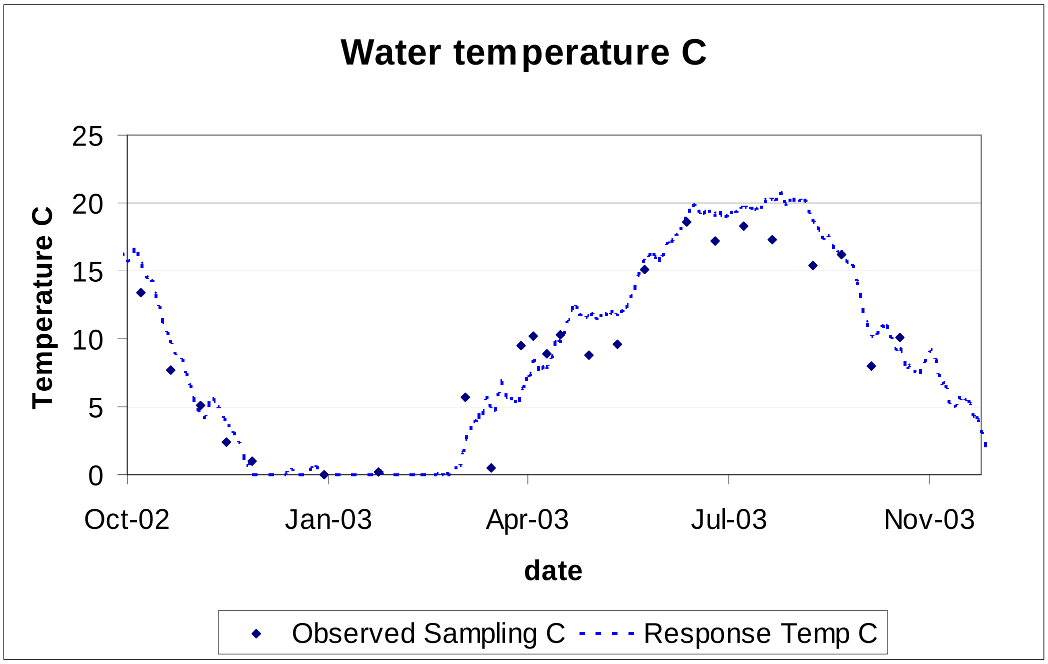

Figure 6-7 Observed and computed tributary temperatures.

6.3. CE-QUAL-W2 SIMULATIONS AND RESULTS

As noted earlier, CE-QUAL-W2's rigorous water quality algorithms require coincident measured inflow rates, temperatures, and nutrient concentrations and in-lake water quality observations. These datasets are not available for Deep Creek Lake. However, applying CE-QUAL-W2 for Deep Creek Lake using the datasets that do exist or were developed for this study does provide information on the lake's characteristics that are not available with either the Vollenweider analysis or the BATHTUB model. Simulations that show the circulation, degree of stratification, water age, and total suspended solids at various locations in Deep Creek Lake are discussed below.

6.3.1. Circulation patterns and stratification

Circulation patterns for Deep Creek Lake are typical of long residence time reservoirs. Velocities near the dam are dominated by the outflow rate, the location of the outlet structure in the vertical, and by the varying temperature profile adjacent to the dam. During periods of vertical homogeneity, the outlet draws from nearly the entire depth near the dam. When the lake is stratified, as is the case in Deep Creek Lake, the withdrawal envelope is confined because warmer, more buoyant water near the surface cannot be drawn to the depth of the outlet. The same is true at depth: colder, denser water cannot be drawn to the depth of the outlet.

At the upstream end of Deep Creek Lake and of each branch, the inflow rates and temperatures vary widely with season. Inflows develop either as an overflow, interflow, or underflow as the inflow seeks its corresponding density in the lake.

The lake density structure is primarily a function of temperature, although elevated total suspended solids concentrations can modify the density. Seasonal temperature patterns in the main branch of Deep Creek Lake as computed by CE-QUAL-W2 are shown in Figure 6-8 through Figure 6-11. It should be noted that the most basic calibration parameter for these simulations, i.e., seasonal vertical temperature profiles, were not available and that the degree of stratification as well as times of onset and turnover are dependent on confirmation of the model's performance against observed profiles.

Deep Creek Lake begins the year in a near-isothermal state (uniform temperatures) in which wind- and inflow-induced mixing is effective throughout its depth (Figure 6-8). As daily solar radiation increases into the spring and early summer, temperatures at the surface increase because solar radiation only penetrates to a limited depth. In the absence of wind, this effect would lead immediately to thermal stratification, which would be continually reinforced by the buoyancy of the warmer water. However, wind events act to mix the lake before the establishment of a stable and buoyant surface layer.

At some point in the spring a period of relative calm allows the permanent establishment of a warm upper layer, known as the epilimnion (Figure 6-9). From this point on, the warm upper layer grows in depth and intensity as solar radiation increases the surface temperature and its buoyancy, and wind mixing acts to accentuate the homogeneity of the epilimnion.

By the end of summer, the hypolimnion is isolated from the epilimnion by a region of rapid temperature change with depth called the thermocline. The implications for water quality are that, while the epilimnion is exposed to surface aeration, the hypolimnion can only obtain oxygen across the barrier of the thermocline. Furthermore, the hypolimnion is subject to sediment oxygen demand which, if present, can further deplete oxygen such that anoxia develops.

In late fall, the intensity of solar radiation decreases along with the temperature of the epilimnion. At some point in this cooling process, the density of the epilimnion increases and becomes identical to that of the hypolimnion. When this occurs, the lake is subject to vertical mixing during wind events.

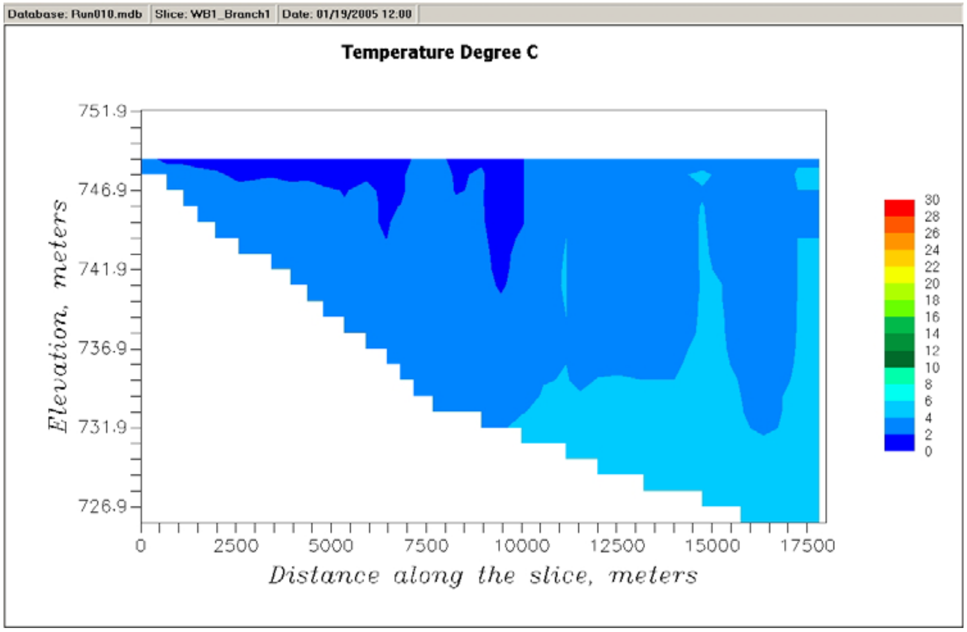

Figure 6-8 Typical winter temperatures in Deep Creek Lake (19 Jan 2005)

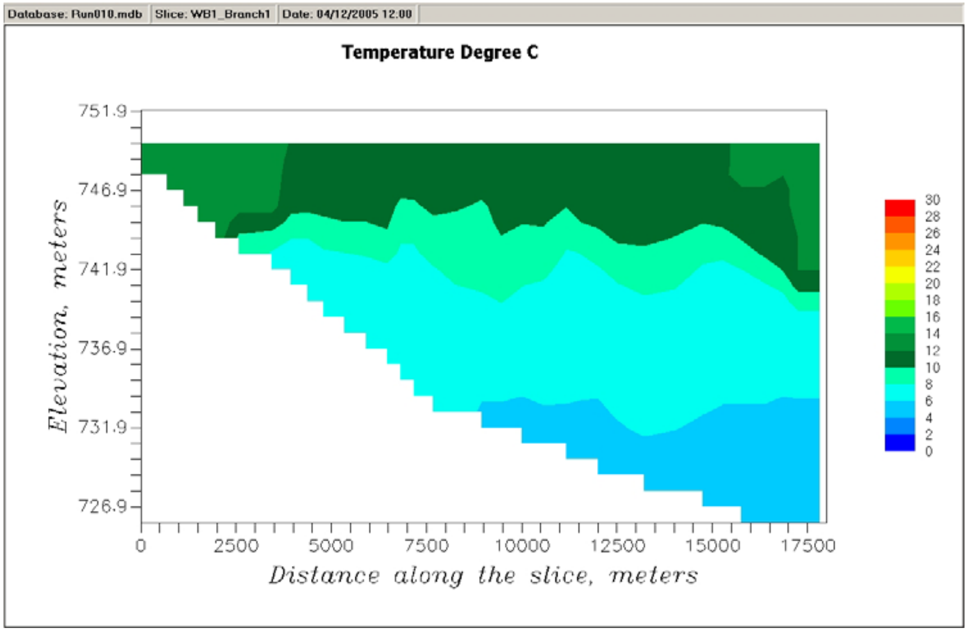

Figure 6-9 Typical early spring temperatures in Deep Creek Lake (12 April 2005)

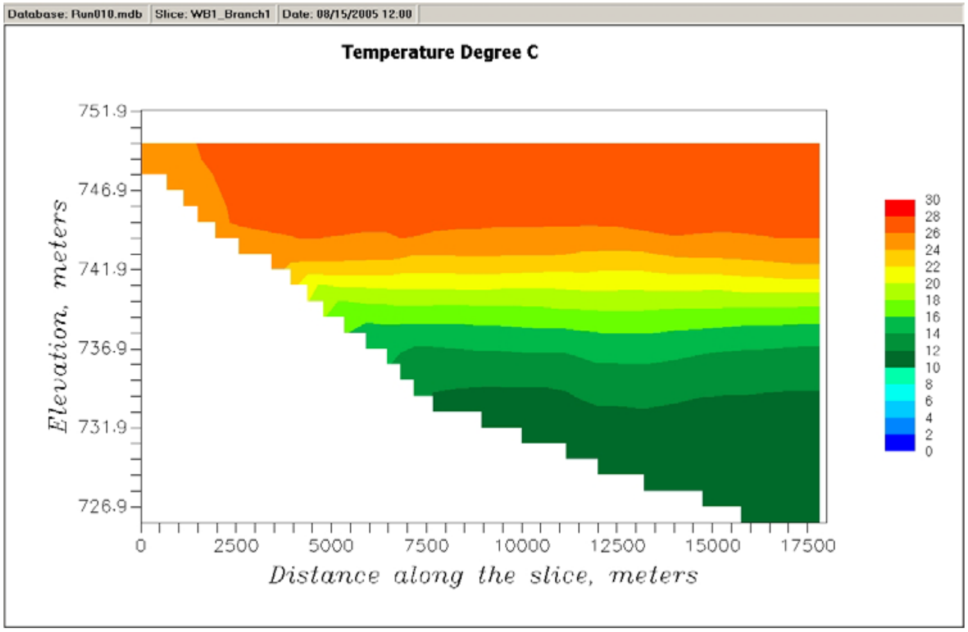

Figure 6-10 Typical, stratified, mid-summer temperatures in Deep Creek Lake (15 August 2005)

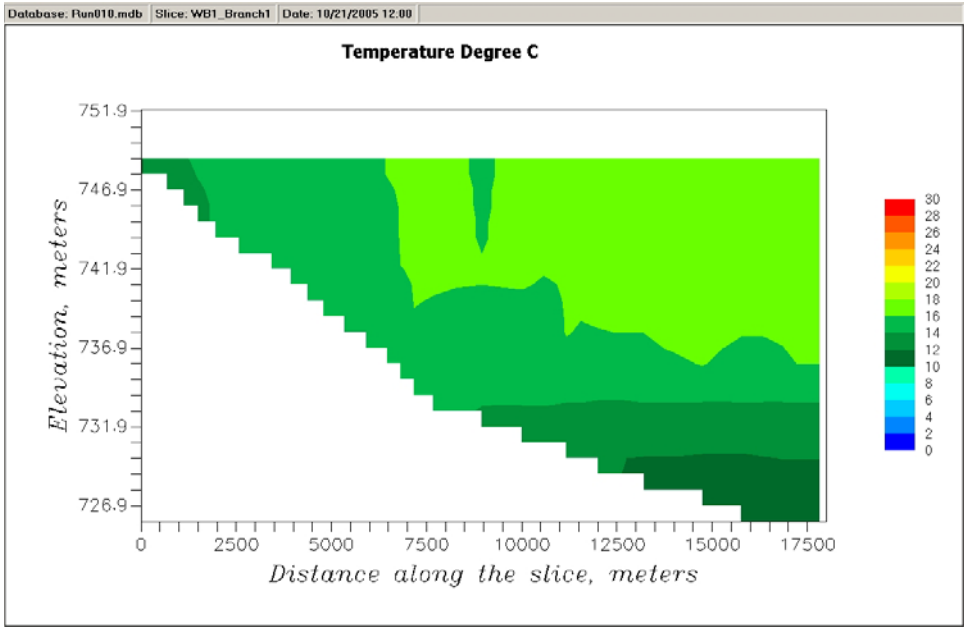

Figure 6-11 Typical late fall (near-overturn) temperatures in Deep Creek Lake (21 Oct 2005)

6.3.2. Residence Time and Water Age

Residence time is generally computed as the lake volume divided by the average flow through the lake. For Deep Creek Lake, the residence time is about 300 days. This number indicates that inflows remain in Deep Creek Lake for nearly a year. CE-QUAL-W2 can compute a more spatially detailed value for residence time, called water age, which has the same units as residence time (days), but varies longitudinally and vertically.

Water age is computed by setting a decay rate for a numerical dye equal to -1 per day. Its initial value is zero and, if no water entered or left the lake during the first day of simulation, water age would have the value of one day. If the no flow condition continued for an entire year, the water age throughout the lake would have a value of 365 days. But because new water is introduced daily as inflows, "old" water leaves at the dam, and water circulates from one location to another (or remains relatively stationary), the water age variable shows locations that are susceptible to stagnation. Water age responds to changes in the inflow rate and degree of stratification. For example, Figure 6-12 shows the age of the water for 31 Mar 2005, a period of high inflow rate (see Figure 6-4). Since this is a period of vertical temperature homogeneity, water age values are also nearly vertically mixed and nearly equal to the length of the simulation to that point (about 90 days). Figure 6-13 shows the water age during a period of low inflow and stratification. Note the age of the hypolimnetic water relative to the epilimnetic water.

Since inflow rates vary insignificantly for each of the development scenarios, these circulation and water age properties are invariant from the Base Case to any of the potential land development cases.

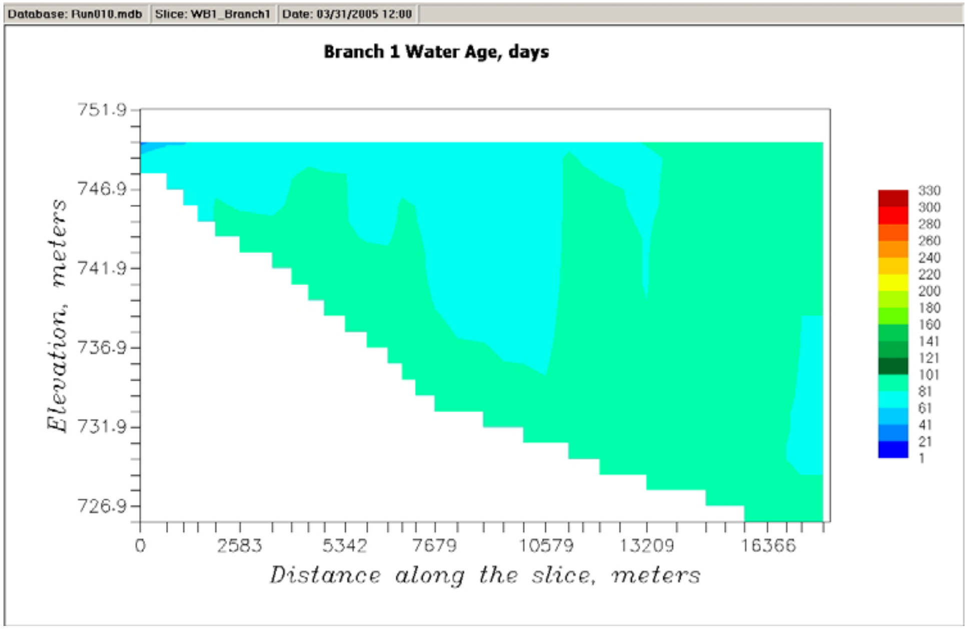

Figure 6-12 Water age during a period of high inflow

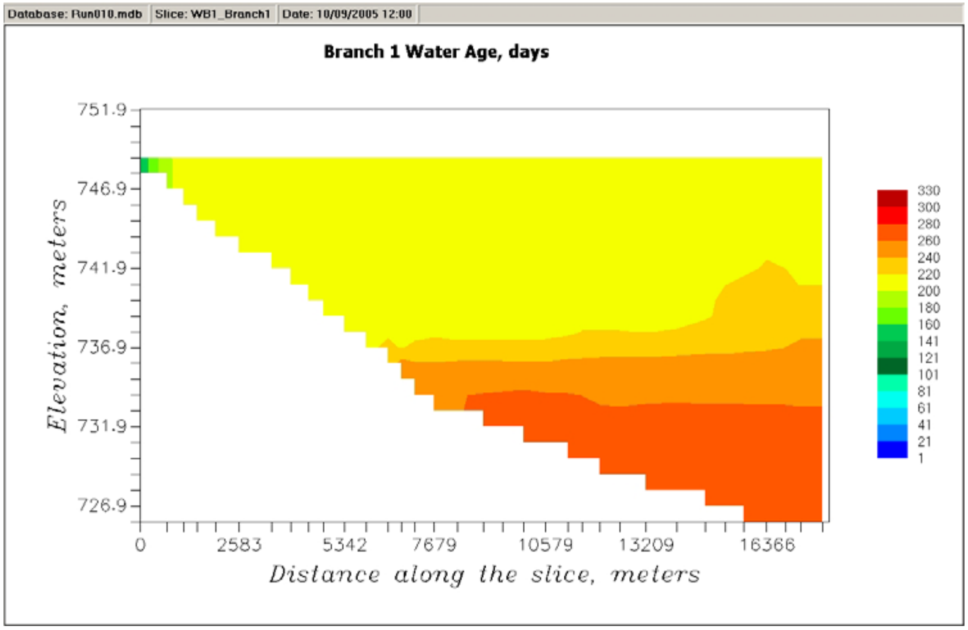

Figure 6-13 Water age during a period of low inflow and stratification

6.3.3. *Total suspended solids*

Using the total suspended solids (TSS) concentrations developed from the nutrient load estimations (Section 2.2.2), simulations were made for the Base Case and for each development case (Table 6-4). These loads may be conservatively high, and may be revised in subsequent revisions published by the CBP. Loads were proportioned throughout the year as a function of the total tributary flows entering the lake, such that larger flow events carried higher mass loadings to Deep Creek Lake. Low, medium, and high TSS concentrations were assumed for each sub-watershed and development case corresponding to flows less than 200 cfs (80% of flow events), less than 800 cfs (99% of flow events) and greater than 800 cfs (1% of flow events). Concentration values were proportioned as a function of drainage area size and sub-watershed specific load contributions.

Table 6-4 TSS loads by branch and development case for W2

TSS LOADS (lbs/acre-year)				
W2 Branch	**Base**	**Moderate**	**Rapid**	**Capacity**
Deep Creek	978,708	1,005,910	1,008,994	1,444,105
Pawn Run	1,133,228	1,149,774	1,154,516	1,517,857
Green Glade Run	1,058,403	1,426,914	1,443,414	2,138,638
Hoop Pole Run	521,042	556,166	563,197	573,455
North Glade Run	1,825,545	1,922,920	1,928,808	2,381,800
Meadow Mountain	1,227,485	1,262,049	1,268,077	2,117,004
Cherry Creek	2,796,890	2,791,930	2,800,191	4,819,181
Marsh Run Cove	1,228,829	1,368,306	1,387,030	1,672,400
Blakeslee	265,576	272,974	276,695	270,352
Thayerville	649,508	765,389	813,191	973,508
Red Run	707,112	861,481	911,556	1,534,322
Lower Deep Creek	583,943	1,132,479	1,144,825	1,531,827

For the low flow and medium flow conditions, the Base Case concentrations for the Deep Creek Branch was arbitrarily assumed to be 10 mg/L and 50 mg/L respectively representing typical expected concentrations. Each other branch used concentrations scaled in proportion to the relative differences between their annual TSS loads and Deep Creek Branch's annual TSS load. The high flow (storm event) concentration was adjusted for each branch such that the sum total load at the end of the year was equivalent to the total load predicted in the CBP model. As a result of this method, the TSS inflows spike during infrequent storm events typically between 300 to 600 mg/L for each given sub-watershed input. These concentrations and flows were used as inputs into W2 to simulate the TSS concentrations over the year 2005.

The results showed lake water column concentrations rise and fall in concert with the tributaries' concentrations at the upstream end of the lake. At the downstream end by the dam concentrations were greatly reduced to values less than 10 mg/L. Though in reality there are likely a range of particle sizes and associated settling velocities, a moderately slow rate of 1 m d^{-1} was assumed. Given the long residence time (approximately 300 days) of the lake, TSS is quick to settle out from the water column. As such, the spikes in the input loads do not cause a lingering elevated TSS concentration in the water column. The Moderate and Rapid development scenarios differ only slightly from the Base Case, while the development Capacity Case shows brief periods with brief large spikes approximately double in size to the Base Case in the upstream end of the lake. Output is provided for both the upstream and downstream ends, comparing each development case to the Base Case (Figure 6-14 through Figure 6-19).

Table 6-5 Lake input tributary TSS concentrations (mg/L)

Scenario	Concentration range	Deep Creek	Pawn Run	Green Glade Run	Hoop Pole Run	North Glade Run	Meadow Mountain	Cherry Creek	Marsh Run Cove	Blakeslee	Thayerville	Red Run	Lower Deep Creek
Base	High	394.5	449.0	265.8	490.0	424.2	316.3	381.5	456.1	549.8	457.9	226.1	188.7
	Medium	50.0	56.9	33.7	62.1	53.8	40.1	48.4	57.8	69.7	58.0	28.7	23.9
	Low	10.0	11.4	6.7	12.4	10.8	8.0	9.7	11.6	13.9	11.6	5.7	4.8
Moderate	High	391.1	439.5	345.7	504.5	431.1	313.7	367.4	489.9	545.1	520.6	265.7	353.1
	Medium	51.4	57.7	45.4	66.3	56.6	41.2	48.3	64.4	71.6	68.4	34.9	46.4
	Low	10.3	11.5	9.1	13.3	11.3	8.2	9.7	12.9	14.3	13.7	7.0	9.3
Rapid	High	391.4	440.3	348.9	509.7	431.4	314.5	367.6	495.5	551.3	551.8	280.5	356.1
	Medium	51.5	58.0	45.9	67.1	56.8	41.4	48.4	65.2	72.6	72.7	36.9	46.9
	Low	10.3	11.6	9.2	13.4	11.4	8.3	9.7	13.0	14.5	14.5	7.4	9.4
Capacity	High	524.4	541.8	483.9	485.8	498.6	491.5	592.2	559.2	504.2	618.4	441.9	446.0
	Medium	73.8	76.2	68.1	68.3	70.1	69.1	83.3	78.7	70.9	87.0	62.2	62.7
	Low	14.8	15.2	13.6	13.7	14.0	13.8	16.7	15.7	14.2	17.4	12.4	12.5

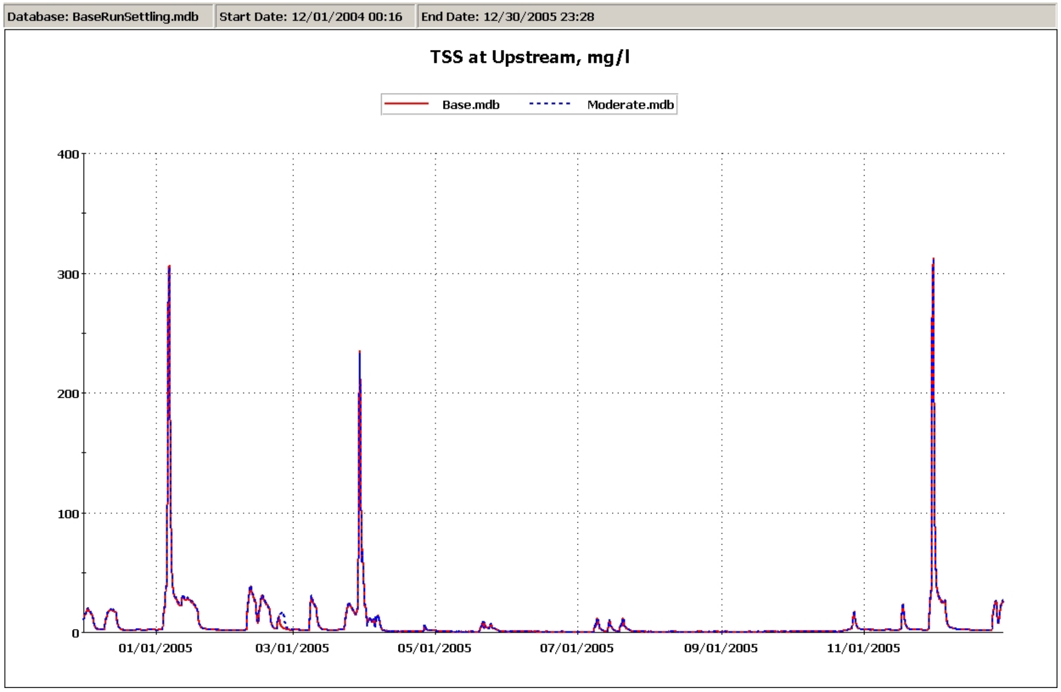

Figure 6-14 Upstream TSS concentrations – Base and Moderate Development Scenarios

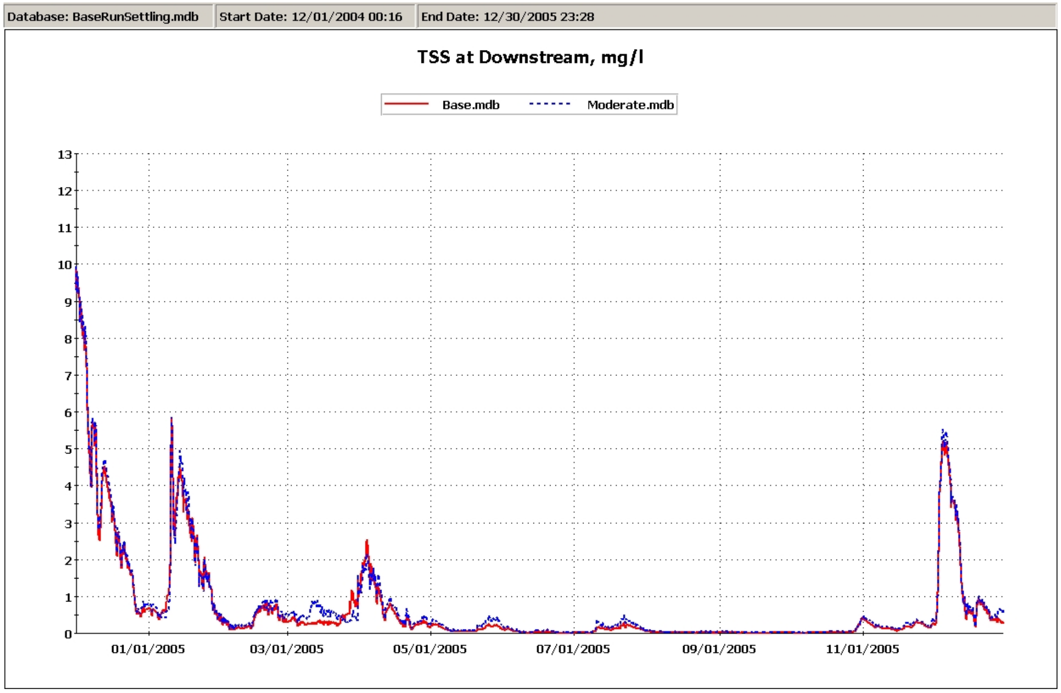

Figure 6-15 Downstream TSS concentrations – Base and Moderate Development Scenarios

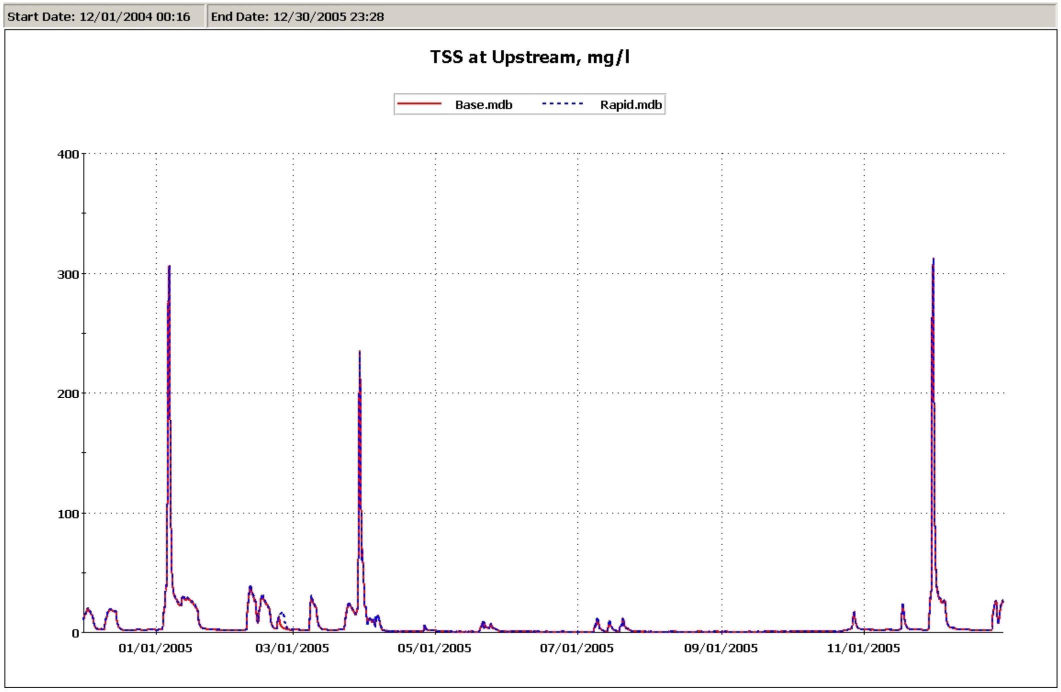

Figure 6-16 Upstream TSS concentrations – Base and Rapid Development Scenarios

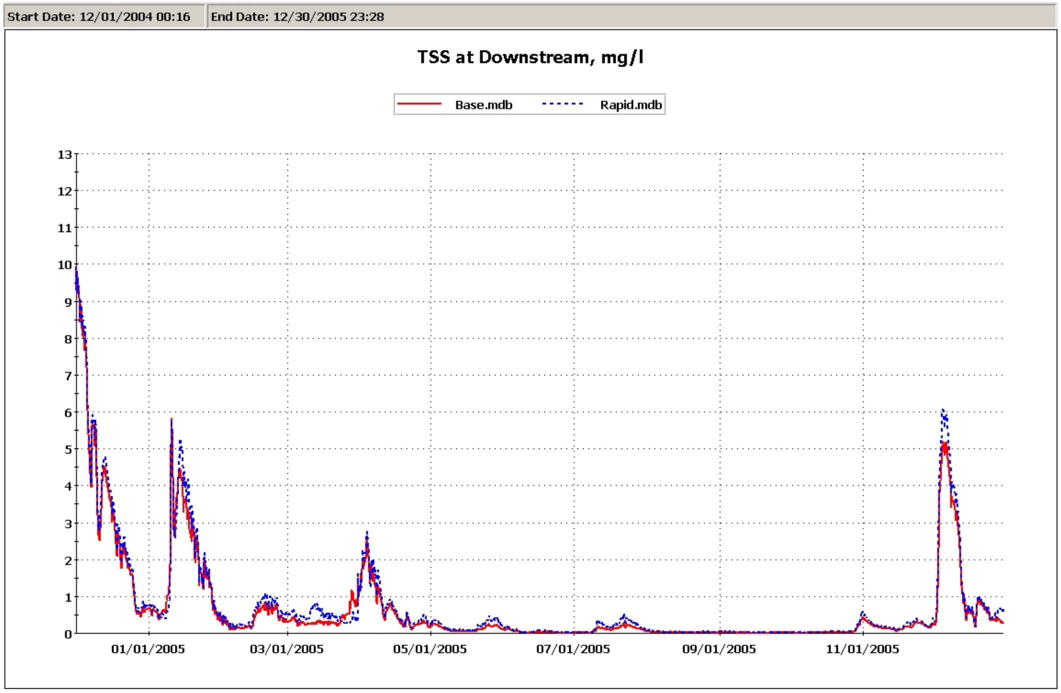

Figure 6-17 Downstream TSS concentrations – Base and Rapid Development Scenarios

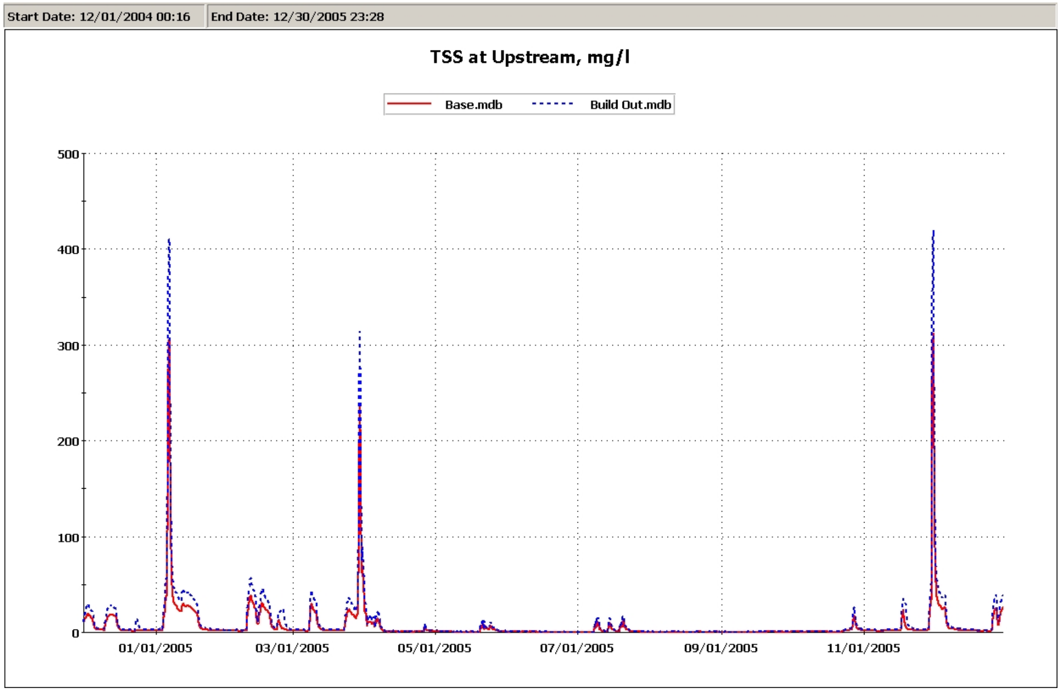

Figure 6-18 Upstream TSS concentrations – Base and Capacity Cases

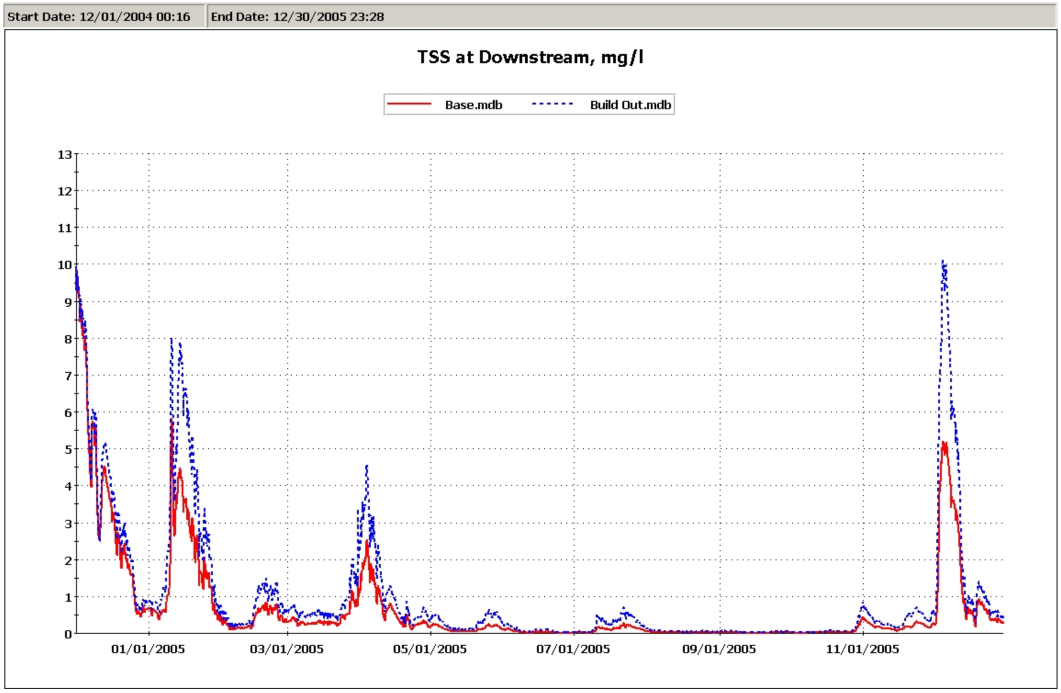

Figure 6-19 Upstream TSS concentrations – Base and Capacity Cases

7. CONCLUSIONS AND RECOMMENDATIONS

Examination of field data, a Vollenweider analysis, and modeling using BATHTUB and CE-QUAL-W2 were performed. Field data analysis and historical reports indicate that the lake is currently in a mesotrophic state. The Vollenweider analysis and BATHTUB modeling indicate the lake is currently eutrophic, but both are dependant on the CBP Phase V HSPF modeling, which is likely to have overestimated nutrient runoff, especially in the forest areas. BATHTUB was used to examine the trophic state resulting from changes in nutrient loads for potential development scenarios. CE-QUAL-W2 modeling examined hydraulic conditions of the lake, the tendency for vertical stratification, and changes in TSS concentrations between existing conditions and the potential development scenarios.

The potential development in the Deep Creek Lake watershed is likely to have only a minor impact on the lake in terms of degraded trophic status. Changes in secchi depth and TSI score were the primary indicators of the trophic status of the lake used in this study. The Moderate and Rapid Growth development scenarios are predicted to produce a negligible change in secchi depth readings (and therefore water clarity), and a slight increase in TSI scores indicating a tendency towards eutrophication. The Capacity Analysis scenario is predicted to show a slight decrease in secchi depth (0.1 m) and a minor increase in the TSI score of, at most, 0.4 (whereas divisions between major trophic status categories are represented every 20 TSI units).

As agricultural lands are converted into residential lands, nonpoint source nitrogen loads may decrease; however, septic sources of nitrogen in low density residential areas will likely increase significantly. Phosphorus appears to be the limiting factor in algal growth, such that the large addition of nitrogen, the more abundant nutrient, will likely have little effect. Though septic sources of nitrogen are likely to undergo nitrification converting ammonia into nitrite and nitrate, it is possible that water quality criteria for ammonia nitrogen may be exceeded if the increased total nitrogen loads are not managed. Since phosphorus is likely dictating the growth of algae, and there is evidence of potential for overstimulation of algal growth, the current and projected increased phosphorus loads should be addressed and reduced by implementation of best management practices.

Predictions indicate a potentially significant short-duration increase in suspended solids loads to the lake which may exceed water quality criteria. Due to the long residence time within Deep Creek Lake, suspended solids loads are likely have time to settle rather than to remain suspended. A grain size analysis should also be performed to understand the solids loads better, and to provide an accurate estimate of TSS settling rate, build up of the sediment layer, and predicted lake turbidity. When more accurate loads and sediment data are available, these models should be rerun.

Currently there are several significant sources of uncertainty in estimating water quality impacts due to potential development in the watershed. Firstly, the available datasets do not support the application of an elaborate water quality model. Secondly, the conclusions regarding nutrients and solids are dependent on the Chesapeake Bay Program's nonpoint source runoff model's results. These results are preliminary and likely to have over-estimated nutrient loads.

Deep Creek Lake has been identified on the state 303(d) list as impaired for nutrients and the available data indicate that the lake is moderately stressed (i.e. mesotrophic) by nutrients, though not in a critical (i.e. eutrophic) state. As such, it is likely that forthcoming TMDL analyses will recommend management plans to reduce nutrient loads to the watershed. Utilizing the limited data available and modeling described in this report, our best professional judgment is that plans for development under the Moderate Growth and Rapid Growth scenarios need not be primarily driven by concerns over water quality impacts. It is realistic to assume that the Moderate Growth, the Rapid Growth, and the Capacity Analysis Scenarios can be implemented as long as the increased water quality stress caused by development is addressed under the load restrictions that may be defined by the TMDL program. Nonetheless, in light of the uncertainty, caution and prudence dictate obtaining additional field observations and performing additional analyses before significant development proceeds (i.e., the Capacity Analysis scenario).

It is recommended that additional measurements be performed in Deep Creek Lake to better understand existing water quality and to provide the basis for accurate estimates of the trophic state for various development scenarios. A thorough bathymetric survey should be performed as well as a comprehensive water quality measurement program including all forms of nitrogen and phosphorus, chlorophyll *a*, total dissolved and suspended solids, dissolved oxygen, biological oxygen demand, sediment nutrient fluxes, and sediment oxygen demand. These measurements should be taken with lake-wide spatial coverage and depth. Bacteria measurements are currently limited and should be expanded to quantify year round loads, lake-wide values, and to quantify sources of bacteria (septic, avian, wildlife). Seasonal analyses should be performed along with monthly algal profiles to determine the species of algae present and their temperature sensitivities.

After further water quality studies are performed, it is recommended that CE-QUAL-W2 be calibrated to the observed datasets and used to provide more spatially-detailed estimates of the water quality impacts of potential development in the watershed.

8. REFERENCES

Brookfield Power. 2002. Hydro Plant Operating Instructions Station: Deep Creek / Section: F8. Flow Data. Internal documentation.

Buchak, E. M. and J. E. Edinger. 1984. Generalized, Longitudinal-Vertical Hydrodynamics and Transport: Development, Programming and Applications. Prepared for U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. Contract No. DACW39-84-M-1636. Prepared by J. E. Edinger Associates, Wayne, Pennsylvania 19087-3226. Document No. 84-18-R. June.

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society.

Charles B. Hawley & Co. Inc., "Deep Creek Development- Plan and Profile of Tunnel." Drawing 1676-23H. 15 Apr 1924.

Cole, T. M. and Buchak, E. M. 1995. CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 2.0. Instruction Report EL-95-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Edinger, J. E., E. M. Buchak and D. H. Merritt. 1983. "Longitudinal-Vertical Hydrodynamics and Transport with Chemical Equilibria for Lake Powell and Lake Mead", in Salinity in Watercourses and Reservoirs, (R. H. French, ed.). Butterworth Publishers, Stoneham, Massachusetts, pp. 213-222.

Gordon, J. A. 1980. "An Evaluation of the LARM Two-Dimensional Model for Water Quality Management Purposes". Proceedings of the Symposium on Surface-Water Impoundments, (H. G. Stefan, ed.), Minneapolis, Minnesota, June 2-5, 1980, Vol. 1, Paper 4-34, pp. 518-527. American Society of Civil Engineers, New York, New York. June.

Gordon, J. A. 1981. "LARM Two-Dimensional Model: An Evaluation". Journal of the Environmental Engineering Division, Vol. 107, No. EE5, pp. 877-886. Proceedings of the American Society of Civil Engineers, New York, New York. October.

Gordon, J. A. and J. S. Lane. 1983. "Short-Term Hydrodynamics in a Stratified Reservoir". Proceedings of the 1983 National Conference on Environmental Engineering, (A. Medine and M. Anderson, eds.), Boulder, Colorado, July 6-8, 1983, pp. 524-531. American Society of Civil Engineers, New York, New York.

Herb, T. H. 1993. Maryland Lake Water Quality Assessment 1993 Final Report.

Johnson, B. H. 1981. A Review of Numerical Reservoir Hydrodynamic Modeling. Technical Report E-81-2, Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. February.

Kim, B. R., J. M. Higgins and D. J. Bruggink. 1983. "Reservoir Circulation Patterns and Water Quality" in the Journal of Environmental Engineering, Proceedings of the American Society of Civil Engineers, Vol. 109, No. 6, pp. 1284-1294. December.

Mandel, Ross. Interstate Commission on the Potomac River Basin (ICPRB). Personal Correspondence in November 2006.

Martin, J. L. 1988. "Application of Two-Dimensional Water Quality Model" in the Journal of Environmental Engineering, Proceedings of the American Society of Civil Engineers, Vol. 114, No. 2, pp. 317-336. April.

Maryland Department of Natural Resources (MDDNR). 2007. Webpage: http://www.dnr.state.md.us/publiclands/dcreport.html

Maryland Department of the Environment. 2002. *Total Maximum Daily Load of Mercury for Deep Creek Lake Garrett County, Maryland.*

Susquehanna River Basin Commission. *Summary of Nutrient and Suspended-Sediment Loads in the Susquehanna River Basin, 1994-95*. Publication 187. Harrisburg: June 1997.

Susquehanna River Basin Commission. *Water Quality of Interstate Streams in the Susquehanna River Basin*. Publication 185. Harrisburg: June 1997.

Thomann, Robert V. and John A. Mueller. Principles of Surface Water Quality Modeling and Control. Harper and Row Publishers, New York. 1987.

U.S. Environmental Agency, Region III Watershed Protection Division.

U.S. Environmental Protection Agency (USEPA). 1974. The Relationships of Phosphorus and Nitrogen to Trophic State of Northeast and North-Central Lakes and Reservoirs. National Eutrophication Survey Working Paper No. 23.

U.S. Environmental Protection Agency (USEPA). 1999. *Total Maximum Daily Loads for Bear Lake, West Virginia*. Region 3. September.

United States Department of Commerce. *Climatic Atlas of the United States.* Printed by National Oceanic and Atmospheric Administration. 1974.

Vollenwieder, R.A. 1968. "The Scientific Basis of Lake and Stream Eutrophication with Particular Reference to Phosphorus and Nitrogen as Eutrophication Factors." Technical Report DAS/DSI/68.27, Organization for Economic Cooperation and Development, Paris.

Vollenwieder, R.A. 1975. "Input-Output Models with Special Reference to Phosphorus Loading Concept in Limnology." *Schweiz. Z. Hydrol.* 37:53-84

Walker, W. W., 1985. *Empirical Methods for Predicting Eutrophication in Impoundments; Report 3, Phase III: Model Refinements*. Technical Report E-81-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wetzel, Robert G. *Limnology*. W. B. Saunders Company, Philadelphia: 1975. Page 212.

APPENDIX A: GLOSSARY

Term	**Meaning**
Algorithms	Step by step procedures for solving a (mathematical) problem
Anoxia	Region of depleted dissolved oxygen, often occurring in the hypolimnion
CBP	Chesapeake Bay Program
cfs	cubic feet per second
cms	cubic meter per second
Epilimnion	The warm, upper layer of a lake ("surface layer")
Eutrophic	A trophic state of nutrient rich water and high productivity in terms of aquatic plant or animal life ("well fed")
GIS	Geographic Information System – Electronic mapping with associated information and databases.
Hypereutrophic	A trophic state indicating extremely high productivity
Hypolimnion	The isolated, cold bottom water of a lake ("deep layer")
ICPRB	Interstate Commission on the Potomac River Basin
L	Liter
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
Mesotrophic	An intermediate trophic state (between oligotrophic and eutrophic)
mg	Milligram
NPS	Nonpoint Source
Oligotrophic	A trophic state of clear water and low productivity ("insufficient food")
pH	Measure of acidity and alkalinity
Residence time	The flushing time of a lake, usually computed as the volume divided by the annual inflow rate
Secchi depth	A saucer-sized disc placed in the water used to measure transparency (the depth of visibility)?
Stoichiometric	Proportion of chemical elements
Thermocline	The region of rapid temperature change separating the epilimnion from the hypolimnion
Trophic state	A general measure of a lake's biological productivity
Trophic State Index (TSI)	A quantitative measure of a lake's biological productivity
TSS	Total Suspended Solids

APPENDIX B: METHODOLOGY FOR DEVELOPING LAND USE ACREAGES

Memorandum

Environmental
Resources
Management
200 Harry S. Truman Pkwy,
Suite 400
Annapolis, MD 21401-7351
(410) 266-0006
(410) 266- 8912 (Fax)

To: Edward M. Buchak, Michael Fichera, Surfacewater Modeling Group

From: Clive Graham, Ben Sussman

Date: February 14, 2007

Subject: Methodology for developing land use acreages for Deep Creek Lake Water Quality Assessment

This memo summarizes the methodology used to develop the land use information (Existing, Moderate Growth Scenario, Rapid Growth Scenario, Capacity Case) for the Deep Creek Lake Water Quality Assessment.

Existing (2005)

The acreages shown in Table 2-8 of the Assessment (Existing Case) reflect a modified version of the Maryland Department of Planning's (MDP) 2002 Land Use/Land Cover (LULC) GIS shapefile.[1] This shapefile was modified to reflect large new residential developments between 2002 and 2005. These were mapped on top of underlying 2002 LULC designations using GIS. The Land Use category for these subdivisions was determined based on each subdivision's residential density (number of units divided by the acreage of the property), compared against the densities used in the MDP LULC data: (< 2 units/acre is "Low Density"; 2-8 units/acre is "Medium Density"; > 8 units/acre is "High Density").

Moderate and Rapid Growth Scenarios

The acreages shown in Table 2-10 (Moderate Growth Scenario) and Table 2-11 (Rapid Growth Scenario) of the Assessment are based on the Existing Case data (described above), modified in the following ways:

- All subdivisions, Planned Residential Developments, and condominium projects identified by the Garrett County Planning and Land Development Office as being either Pipeline (approved site plan) or Planned (proposed, but not yet approved) were mapped on top of the Existing Case layer using GIS. Table 1 of this memorandum shows the number of new Pipeline, Planned, and

---

[1] The shapefile is available at http://www.mdp.state.md.us/download_LULC/garrlu02.zip

Scattered units in each subwatershed.[2] The Land Use category for these developments was determined based on each one's residential density (number of units divided by the acreage of the property), compared against the densities used in the MDP LULC data: (< 2 units/acre is "Low Density"; 2-8 units/acre is "Medium Density"; > 8 units/acre is "High Density").

- Acreage related to scattered residential development (future development not associated with an approved or planned subdivision, PRD, or condo), was divided between infill (new development on lots within areas with residential land use designations), forest, and agriculture according to the existing share of those land use types already within each watershed.

  For example, assume that Existing development within a given subwatershed was 50% residential, 40% forest, and 10% agriculture, and that the Growth exercise identified 20 units of "scattered" development for that subwatershed. In that case, 10 (or 50%) of the scattered units would be assigned as infill within the existing residential areas; no net change in land use acreages would be associated with such an assignment. Another eight units (or 40%) would be replace forest acreage, and two units (or 10%) would replace agriculture acreage.

  The assumed density of these scattered units was 0.87 units per acre (which corresponds to "Low Density Residential"), the same density that MDP used for the Lake Residential zoning district in its Development Capacity Analysis. Thus, in this example, the eight units of new residential development in area currently designated Forest would replace 9.2 acres of Forest (8 units/0.87 units/acre).

---

[2] More information on Pipeline, Planned, and Scattered development can be found in ERM's February 1, 2007 memo to Garrett County Planning and Land Development Office entitled "Comprehensive Plan 2030 Growth Scenarios and Non-Residential Development Estimates."

Table 1: Garrett County Comprehensive Plan Growth Scenarios Through 2030 (Housing Units)

		Capacity (Current	2030 Scenarios											Share of		Share of Growth: 1990-2005[4]	
	2005		Moderate Growth				Rapid Growth				Share of	1990	Change	County Units		Entire	Units not in Deep
Countywide Analysis	**Existing[1]**	**Regulations)[3]**	Pipeline[2]	Planned[2]	Scattered[2]	Total	Pipeline	Planned	Scattered	Total	**Capacity**	**Existing[1]**	**1990-2005**	**1990**	**2005**	**County**	**Creek or Towns**
Watersheds																	
Youghiogheny River																	
Deep Creek Lake Influence Area[5, 6]	124	1,076	252	996	25	1,273	252	1,121	50	1,423	132%	87	37	1%	1%	1%	
Bear Creek							-	-							0%		
Accident	168	166	-	-	25	25	-	-	25	25	15%	149	19	1%	0%	0%	
Remainder of Bear Creek	822	7,933	78	-	149	227	78	-	216	294	4%	595	227	4%	5%	5%	11%
Southern Youghiogheny	386	5,008	7	-	40	47	7	-	54	61	1%	339	47	2%	1%	1%	2%
Friendsville	281	61	-	-	25	25	-	-	50	50	82%	246	35	2%	1%	1%	
Remainder of Youghiogheny	2,680	28,723	94	18	551	663	94	18	747	859	3%	2,017	663	15%	15%	15%	33%
Little Youghiogheny River							-	-									
Oakland	961	537	-	-	250	250	-	-	300	300	56%	745	216	5%	5%	5%	
Loch Lynn Heights	210	108	-	-	25	25	-	-	50	50	46%	185	25	1%	1%	1%	
Mountain Lake Park	1,017	377	-	-	150	150	-	-	175	175	46%	810	207	6%	5%	5%	
Deer Park	181	1,088	-	-	75	75	-	-	100	100	9%	162	19	1%	0%	0%	
Remainder of Little Youghiogheny	1,306	8,188	16	17	179	212	16	17	242	275	3%	1,094	212	8%	5%	5%	10%
Deep Creek Lake[7]	5,559	23,084	735	1,342	700	2,777	735	1,842	1,250	3,827	17%	3,700	1,859	27%	41%	41%	
Casselman River							-	-									
Grantsville	305	528	-	-	100	100	-	-	150	150	28%	237	68	2%	2%	2%	
Remainder of Casselman	1,955	16,201	24	-	408	432	24	-	536	560	3%	1,523	432	11%	10%	10%	21%
Savage River	1,093	10,947	-	-	262	262	-	-	339	339	3%	831	262	6%	6%	6%	13%
North Branch Potomac River							-	-							0%		
Kitzmiller	164	115	-	-	25	25	-	-	25	25	22%	154	10	1%	0%	0%	
Remainder of North Branch	1,048	19,995	23	-	152	175	23	-	204	227	1%	873	175	6%	4%	4%	9%
Georges Creek	66	2,246	-	-	8	8	-	-	10	10	0%	58	8	0%	0%	0%	0%
Summary																	
Towns (10% of Total New Units)	3,287	2,980				675				875	29%	2,688	599	19%	18%	13%	
Deep Creek Lake Area (60% of Total)	5,683	24,160				4,050				5,250	22%	3,787	1,896	27%	31%	42%	
Rest of County (30% of Total)	9,356	99,241				2,025				2,625	3%	7,330	2,026	53%	51%	45%	100%
County Total	**18,326**	**126,381**	**1,229**	**2,373**	**3,148**	**6,750**	**1,229**	**2,998**	**4,523**	**8,750**	7%	**13,805**	**4,521**	**100%**	**100%**	**100%**	

			Capacity (Current	Moderate Growth				Rapid Growth				Share of	1990	Change: 1990-2005	Share of DCL Area		Share of DCL Area Growth: 1990-2005
Deep Creek Lake Influence Area[7]																	
Deep Creek Lake Watershed			**Regulations)**	Pipeline	Planned	Scattered	Total	Pipeline	Planned	Scattered	Total	**Capacity**	**Existing**	**Units**	**1990**	**2005**	
1	Cherry Creek	128	3,237	13	-	20	33	13	-	20	33	1%	92	36	2%	2%	2%
2	Meadow Mountain		1,709	-	-	15	15	-	-	20	20	1%		-	0%	0%	0%
3	Marsh Run	1,294	1,804	80	348	50	478	80	348	100	528	29%	883	411	23%	23%	22%
4	Lower Deep Creek	335	1,615	-	673	20	693	-	948	40	988	61%	242	93	6%	6%	5%
5	Shingle Camp Hollow	129	184	126	-	5	131	126	-	15	141	77%	42	87	1%	2%	5%
6	Cherry Creek Cove	212	543	-	-	25	25	-	-	40	40	7%	123	89	3%	4%	5%
7	Meadown Mountain Run	204	1,166	12	-	25	37	12	-	40	52	4%	135	69	4%	4%	4%
8	Roman Nose Hill	386	203	-	-	20	20	-	-	40	40	20%	215	171	6%	7%	9%
9	Smith Run	79	238	96	-	25	121	96	-	50	146	61%	23	56	1%	1%	3%
10	Bee Tree Hollow	82	258	32	40	50	122	32	40	100	172	67%	49	33	1%	1%	2%
11	Red Run	231	1,053	-	-	25	25	-	-	50	50	5%	165	66	4%	4%	3%
12	Thayerville	250	1,596	117	-	85	202	117	-	200	317	20%	179	71	5%	4%	4%
13	North Glade Run	734	2,773	155	99	50	304	155	174	75	404	15%	457	277	12%	13%	15%
14	Green Glade Run	641	2,456	40	150	60	250	40	300	100	440	18%	510	131	13%	11%	7%
15	Hoop Pole Run	314	462	-	26	50	76	-	26	100	126	27%	228	86	6%	6%	5%
16	Blakeslee	99	245	31	-	75	106	31	-	125	156	64%	53	46	1%	2%	2%
17	Pawn Run	243	1,898	2	-	50	52	2	-	75	77	4%	176	67	5%	4%	4%
18	Upper Deep Creek	198	1,644	31	6	50	87	31	6	60	97	6%	128	70	3%	3%	4%
Deep Creek Lake Watershed Total		5,559	23,084	735	1,342	700	2,777	735	1,842	1,250	3,827	17%	3,700	1,859	98%	98%	98%
Youghiogheny River Watershed		124	1,076	252	996	25	1,273	252	1,121	50	1,423	132%	87	37	2%	2%	2%
DCL Influence Area Total		**5,683**	**24,160**	**987**	**2,338**	**725**	**4,050**	**987**	**2,963**	**1,300**	**5,250**	**22%**	**3,787**	**1,896**	**100%**	**100%**	**100%**

- Commercial acreage was added to the Moderate/Rapid layers based on parcels that had been identified (by the Planning and Land Development Office) for approved or planned commercial development. Specifically, four such known developments were considered: Sand Flats Road plaza, a hotel/water theme park in McHenry, the Exhibition Hall at the fairgrounds, and the Keystone Lime property (minus the original Exhibition Hall). Tables 2-10 and 2-11 of the Assessment reflect approximately 66 acres of new commercial land compared to the Existing Case.

Capacity Case

Data for Table 2-12 (Capacity Case) ignored all Pipeline, Planned, and Scattered development, and instead evaluated all possible development in each subwatershed, based on the capacity that MDP identified in its Development Capacity Analysis report (November 1, 2006).

As part of that analysis, MDP assigned capacity (a number of possible new units) to each parcel in the Deep Creek Lake Watershed. ERM summed these capacities for each existing land use type (per the Existing Case), for each subwatershed. The location of each parcel’s centroid (unique identifier) on the parcel in the GIS file determined its Existing Case land use. For example, in the Blakeslee subwatershed, there is capacity for a total of 245 new units (see Table 1). Based on the location of the centroids, of the total of 245 units 217 new units would be built on 253 acres of land designated Agriculture (taking the agriculture total from 255 acres in Table 2-8 to 2 acres in Table 2-12).

Based on the summation, ERM determined what type of residential land (Low, Medium, or High Density) would result from maximization of capacity. In the example above, 217 units on 253 acres is a density of 0.86 units/acre, which corresponds to Low Density Residential. Thus, the Capacity Case reflects a conversion of 253 acres of Agriculture to Low Density Residential in the Blakeslee subwatershed.

Commercial acreage under the Capacity Case is lower than under the Moderate and Rapid Growth Scenarios because the Development Capacity Analysis was residential only. Much of the commercial land in the Deep Creek Lake watershed has zoning that permits both commercial and residential uses. MDP's model assigned residential capacity to this land. In the Capacity Case, ERM did account for land use change associated with land zoned solely for commercial uses, by identifying parcels in the watershed with Commercial-only zoning (CR1 and GC), and with LULC designations of Forest or Agriculture. Table 2-12 reflects approximately 18 acres of new commercial land compared to the Existing Case.

APPENDIX C: WATER QUALITY DATA

The following is an inventory of files containing water quality measurements provided electronically (CD-ROM) with this report.

Garrett County Health Department – 1988-2003

- Beach2001.XLS
- Beach2002.XLS
- Beach2003.XLS
- Beach94-95.XLS
- Beach97.XLS
- Beach98.XLS
- Beach99.XLS
- Lake2000.doc
- Lake2001.doc
- Lake2002.doc
- Lake2003.doc
- Lake93.doc
- Lake94.doc
- Lake95.DOC
- Lake96.dot
- Lake97.dot
- lake98.doc
- Lake99.doc
- LakepH Summary.xls
- LakepH1988.XLS
- LakepH1989.XLS
- LakepH1990.XLS
- LakepH1991.XLS
- LakepH1992.XLS
- LakepH1993.XLS
- LakepH1994.XLS
- LakepH1995.XLS
- LakepH1996.XLS
- LakepH1997.XLS
- LakepH1999.XLS
- LakepH2000.XLS
- LakepH2001.XLS
- LakepH2002.XLS
- LakepH98.XLS
- LalepH2003.XLS

Maryland Department of the Environment - Basin Code 05020203 1998-2005

- MDE-WQdata.xls

APPENDIX D: COMMENTS RECEIVED AND RESPONSES

The following is a summary of comments received on the draft report dated February 21, 2007 and in response to a presentation of the draft report given at Garrett College on February 27, 2007. Comments were received through March 27, 2007. ERM responses to the comments are provided.

Comment	**Response**
"The study seems to differ to some extent with the power point presentation of this evening. The Summary of the power point stated (basically) there would be no difference in the water quality of the Lake whether there was a sewer system of septic systems. However, the Summary at the beginning of the study says, "The moderate and rapid development scenarios are predicted to produce a minor degradation in water clarity (secchi depth) and a slight shift toward eutrophic conditions. Projections for the capacity analysis indicate an even greater shift towards eutrophic conditions. The large nitrogen increase from septic sources does little to stimulate algal growth when there is not a similar increase in phosphorus; both nutrients are needed because phosphorus concentration appears to be the limiting nutrient. Predictions indicate a potentially significant but brief increase in suspended solids loads to the lake during storm events. However, the likely effect will be little or no long term turbidity increase. '*Though septic sources of nitrogen are likely to undergo nitrification converting ammonia into nitrite and nitrate, it is possible that water quality criteria for ammonia nitrogen may be exceeded if the increased total nitrogen loads are not managed."* "And the conclusions contained at page 69 state, 'Though septic sources of nitrogen are likely to undergo nitrification converting ammonia into nitrite and nitrate, it is possible that water quality criteria for ammonia nitrogen may be exceeded if the increased total nitrogen loads are not managed.'" While these statements don't actually contradict the power point presentation, they seem to be somewhat more limiting. "Would you please forward this to ERM for clarification?"	The report includes the definitive discussion of the impacts of growth in the watershed, including impacts from increased use of septic systems on Deep Creek Lake. The presentation emphasized the impacts on the trophic status, which is the most important measure of the lake's water quality. Time limitations allowed only limited presentation of the impacts of nitrogen from septic systems and of suspended sediment from changes in runoff. Any perceived inconsistencies between the report and the presentation should be resolved by referring to the report.
(summary) Mercury has been observed in Deep Creek Lake and nearby waterbodies. The study did not address this important issue.	Our assessment was limited to aspects of watershed development that can be controlled at the county level. There are no direct mercury sources in the watershed, consequently mercury control is being addressed at the state, regional, and primarily national levels.

Comment	**Response**
Sediment and erosion control enforcement	(see letter from John E. Nelson, Planning and Land Development Director, Garrett County to Dr. Charles Hoffeditz of March 12, 2007)
Public sewers and trophic status	(see letter from John E. Nelson, Planning and Land Development Director, Garrett County to Dr. Charles Hoffeditz of March 12, 2007)
Maryland Department of the Environment (MDE). Comments from this organization were taken at the beginning of the study, after the completion of critical milestones during the study, and after issuance of the draft report.	An recurring comment throughout the study was MDE's emphasis on the sparse datasets available to support the assessment. While recognizing the necessity of this assessment, MDE recommended that the uncertainty related to the sparse datasets be highlighted. This recommendation was implemented in the report and in the presentation. All other technical comments received from MDE were addressed in the draft report.