Total Maximum Daily Loads of Phosphorus and Sediments for Liberty Reservoir, Baltimore and Carroll Counties, Maryland

FINAL

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

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List of Abbreviations

Acre-ft	Acre-feet
Acre-ft/yr	Acre-feet per year
AFO	Animal Feeding Operation
BCDPW	Baltimore City Department of Public Works
BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CAFO	Confined Animal Feeding Operation
CBLCD	Chesapeake Bay Watershed Land Cover Data
CBOD	Carbonaceous Biochemical Oxygen Demand
CBP	Chesapeake Bay Program
CBP P5.3.2	Chesapeake Bay Program Phase 5.3.2
CCAP	Coastal Change Analysis Program
Chla	Active Chlorophyll *a*
CNMP	Comprehensive Nutrient Management Plan
COMAR	Code of Maryland Regulations
CSO	Combined Sewer Overflow
CV	Coefficient of Variation
CWA	Clean Water Act
DO	Dissolved Oxygen
DS	Dissolved Solids
EOS	Edge-of-Stream
EPA	Environmental Protection Agency
ESD	Environmental Site Design
FIBI	Fish Index of Biotic Integrity
Ft^2	Square feet
Ft^3/s	Cubic Feet per second
GIS	Geographic Information System
HSPF	Hydrological Simulation Program Fortran
in/yr	inches per year
LA	Load Allocation
lbs/day	Pounds Per Day
lbs/yr	Pounds per Year
MAFO	Maryland Animal Feeding Operation
MD 8-Digit	Maryland 8-Digit Watershed
MDE	Maryland Department of the Environment
MDL	Maximum Daily Load
MDP	Maryland Department of Planning
mg/l	Milligrams per Liter
MGS	Maryland Geological Survey
Mi^2	Square miles
MOS	Margin of Safety
MRLC	Multi-Resolution Land Characteristics
MS4	Municipal Separate Storm Sewer System

n	Number
N:P	Nitrogen to Phosphorus Ratio
NH_3	Ammonia
NLCD	National Land Cover Data
NMP	Nutrient Management Plan
NO_{23}	Nitrite plus nitrate
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
POM	Particulate Organic Matter
SCS	Soil Conservation Service
SCWQP	Soil Conservation And Water Quality Plan
SOD	Sediment Oxygen Demand
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
tons/yr	Tons per year
TP	Total Phosphorus
TSD	Technical Support Document
TSI	Trophic State Index
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
W2	CE-QUAL-W2
WIP	Watershed Implementation Plan
WLA	Wasteload Allocation
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant
µg/l	Micrograms per Liter

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes Total Maximum Daily Loads (TMDLs) for phosphorus and sediments in Liberty Reservoir (basin number 02130907) (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-02130907_Liberty_Reservoir). Section 303(d) of the federal Clean Water Act (CWA) and EPA's implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is required to either establish a TMDL of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2012b).

The Maryland 8-Digit (MD 8-Digit) Liberty Reservoir watershed consists of:

1) The actual impoundment created behind the Liberty Dam, and
2) The nontidal tributaries within the watershed that drain to the impoundment.

The use of the term "Liberty Reservoir" throughout this report will refer to solely the impoundment created behind Liberty Dam. Use of the term "non-tidal portion of the Liberty Reservoir watershed" will refer to the non-tidal tributaries within the watershed draining to the Reservoir.

The Maryland Department of the Environment (MDE) has identified Liberty Reservoir on the State's 2010 Integrated Report as impaired by sediments - sedimentation/siltation (1996), nutrients - phosphorus (1996), mercury in fish tissue (2002), and metals – chromium and lead (1996) (MDE 2010a). The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Liberty Reservoir is Use I-P (*Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*) (COMAR 2012d). The non-tidal portion of the Liberty Reservoir watershed has been identified by MDE on the State's 2010 Integrated Report as impaired by bacteria – fecal coliform (mainstem only; 2002) and impacts to biological communities (2004) (MDE 2010a).

The TMDL established herein by MDE will address the 1996 nutrient and sediment listings for Liberty Reservoir, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. A water quality analysis (WQA) for chromium and lead in Liberty Reservoir was approved by the EPA in 2003, and a fecal coliform TMDL for the nontidal portion of the watershed was approved by the EPA in 2009. A TMDL for mercury in fish tissue is currently under development and is scheduled for submittal to EPA in 2012. In the draft 2012 Integrated Report, the listing for impacts to biological communities includes the results of a stressor identification analysis.

This document, upon approval by the EPA, establishes TMDLs for phosphorus and sediments in Liberty Reservoir. The water quality goal of the phosphorus TMDL is to decrease phosphorus inputs to the reservoir to levels that will 1) reduce high chlorophyll *a* (Chla) concentrations associated with excessive algal blooms, and 2) increase dissolved oxygen (DO) concentrations to levels that are supportive of the designated use for the reservoir. The water quality goal of the sediment TMDL for Liberty Reservoir is to increase the useful life of the reservoir for water supply purposes by preserving storage capacity.

The TMDL for total phosphorus (TP) was calculated using a time-variable, two-dimensional water quality eutrophication model, CE-QUAL-W2 (W2), to simulate the water quality response in Liberty Reservoir to various nutrient inputs. The TMDL is based on average annual TP loads for the model simulation period of 2000-2005, which includes both wet and dry years, and thus takes into account a variety of hydrological conditions. Elevated Chla concentrations reflective of eutrophic conditions can occur at any time of year and are resultant from the cumulative impact of phosphorus loadings over a prolonged period of time. Therefore, although daily loads were calculated for the analysis, average annual TP loads are the most appropriate measure for expressing the phosphorus TMDL for Liberty Reservoir. Similarly, the sediment TMDL for Liberty Reservoir, which is based on the calculated phosphorus TMDL and an estimation of how much phosphorus is bound to sediment (i.e., a phosphorus to sediment ratio), is expressed as an average annual load in keeping with the long-term water quality goal of preserving the storage capacity of the reservoir. The Maximum Daily Loads (MDLs) associated with the long-term average annual phosphorus and sediment TMDLs, which were calculated for the reservoir as part of this analysis, are provided in Appendix D.

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2012b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The phosphorus and sediment loading rates applied within the analysis are reflective of long term average annual loads, and the water quality response in the reservoir to various nutrient inputs was modeled using a continuous simulation model with a six year simulation period from 2000-2005. The six year simulation period encompasses seasonal variations and a range of hydrological and meteorological conditions, including a very dry year (2002) and very wet years (2003 and 2004). Thus, critical conditions and seasonality are implicitly addressed in the analysis.

EPA's regulations require TMDLs to be presented as a sum of waste load allocations (WLAs) for permitted point sources and load allocations (LAs) for nonpoint sources generated within the assessment unit accounting for natural background, tributary, and adjacent segment loads. Furthermore, all TMDLs must include a margin of safety (MOS) to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2012b). An explicit MOS set at 5% of the total assimilative loading capacity of the reservoir was applied for the phosphorus TMDL. The MOS for the sediment TMDL is implicit, since the sediment TMDL is based on: 1) a sediment-to-phosphorus reduction ratio of 0.5:1, rather than the 0.7:1 reduction ratio as recommended by EPA, and 2) the sediment TMDL is calculated using not only the conservative reduction ratio but also the individual phosphorus WLAs and LAs, rather than the total Phosphorus TMDL.

Baseline phosphorus and sediment loads for Liberty Reservoir are derived from the Chesapeake Bay Program's Phase 5.3.2 (CBP P5.3.2) Watershed Model 2009 Progress Scenario. The Liberty Reservoir Total Baseline Phosphorus Load is 75,977 pounds per year (lbs/yr). The total baseline phosphorus load is further subdivided into a nonpoint source baseline load (Nonpoint Source BL_{LR}) and three types of point source baseline loads: regulated Concentrated Animal Feeding Operations (CAFO BL_{LR}), National Pollutant Discharge Elimination System (NPDES) regulated stormwater (NPDES Stormwater BL_{LR}) and regulated process water (Process Water BL_{LR}) (see Table ES-1). The Liberty Reservoir Total Baseline Sediment Load is 20,767 tons per year (tons/yr), and is subdivided into the same source categories as the phosphorus baseline load (see Table ES-4). Phosphorus and sediment loads from septic systems are considered to be *de minimis* relative to the total watershed load.

The Liberty Reservoir Average Annual TMDL of Phosphorus is 41,009 lbs/yr. The average annual TMDL is further subdivided into point and nonpoint source allocations and is comprised of a Load Allocation (LA_{LR}) of 24,853 lbs/yr, a CAFO Wasteload Allocation (CAFO WLA_{LR}) of 430 lbs/yr, an NPDES Stormwater Wasteload Allocation (NPDES Stormwater WLA_{LR}) of 11,177 lbs/yr, and a Process Water Wasteload Allocation (Process Water WLA_{LR}) of 2,498 lbs/yr (see Table ES-2). The MOS for the Phosphorus TMDL is 2,050 lbs/yr (5% of the total TMDL). The Liberty Reservoir Average Annual TMDL of Sediment is 15,988 tons/yr, and is comprised of a Load Allocation (LA_{LR}) of 10,438 tons/yr, a CAFO Wasteload Allocation (CAFO WLA_{LR}) of 5 tons/yr, an NPDES Stormwater Wasteload Allocation (NPDES Stormwater WLA_{LR}) of 5,484 tons/yr, and a Process Water Wasteload Allocation (Process Water WLA_{LR}) of 61 tons/yr (see Table ES-5). The MOS for the Sediment TMDL is implicit.

Table ES-1:Liberty Reservoir Baseline Phosphorus Loads (lbs/yr)

Total Baseline Load (lbs/yr)	=	**Nonpoint Source BL_{LR}**	+	**CAFO BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**Process Water BL_{LR}**
75,977	=	51,421	+	1,060	+	20,088	+	3,409

Table ES-2:Average Annual Liberty Reservoir TMDL of Phosphorus (lbs/yr)

TMDL (lbs/yr)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**	+	**MOS**
41,009	=	24,853	+	430	+	11,177	+	2,498	+	2,050

Table ES-3: Liberty Reservoir Baseline Phosphorus Load, TMDL, and Total Reduction Percentage

Baseline Load (lbs/yr)	**TMDL** (lbs/yr)	**Total Reduction** (%)
75,977	41,099	46

Table ES-4: Liberty Reservoir Baseline Sediment Loads (tons/yr)

Total Baseline Load (tons/yr)	=	**Nonpoint Source BL_{LR}**	+	**CAFO BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**Process Water BL_{LR}**
20,767	=	12,720	+	11	+	8,021	+	15

Table ES-5: Average Annual Liberty Reservoir TMDL of Sediment (tons/yr)

TMDL (tons/yr)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**		**MOS**
15,988	=	10,438	+	5	+	5,484	+	61	+	Implicit

Table ES-6: Liberty Reservoir Baseline Sediment Load, TMDL, and Total Reduction Percentage

Baseline Load (tons/yr)	**TMDL** (tons/yr)	**Total Reduction** (%)
20,767	15,988	23

Once the EPA has approved this TMDL, and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. Section 303(d) of the CWA and current EPA regulations require reasonable assurance that the TMDL and WLAs can and will be implemented. Although the Liberty Reservoir watershed does not deliver significant phosphorus and sediment loads to the Chesapeake Bay, implementation of the Liberty Reservoir TMDLs should benefit from the programs Maryland has implemented to achieve the nitrogen and phosphorus load reductions as required by the EPA established Chesapeake Bay TMDLs (US EPA 2010a). The proposed approach for achieving the Liberty Reservoir reduction targets will be based on deployment of an appropriate selection of the comprehensive implementation strategies described in Maryland’s Phase I Watershed Implementation Plan (WIP) (MDE 2010b) and Phase II WIP (MDE 2012a), the centerpieces of the State’s “reasonable assurance” of implementation for the Chesapeake Bay TMDL. MDE is also planning on explicitly incorporating the phosphorus and sediment reduction goals for Liberty Reservoir and four other major drinking water reservoirs into the Phase III WIP, which will facilitate meeting the final Chesapeake Bay nutrient and sediment reduction goals by 2025. In addition, Baltimore City, Baltimore County and Carroll County have had in place a formal agreement to manage the reservoir watershed, and since 1984, these agreements have been accompanied by an action strategy with specific commitments from the signatories.

Relative to the required reduction in sediment loads from the NPDES Stormwater WLA, BMP implementation will primarily occur via the municipal separate storm sewer system (MS4) permitting process for medium and large municipalities. MDE intends for the required reduction to be implemented in an iterative process that first addresses those sources with the largest impact to water quality, with consideration given to cost of implementation.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes Total Maximum Daily Loads (TMDLs) for phosphorus and sediments in Liberty Reservoir (basin number 02130907) (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-02130907_Liberty_Reservoir). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each state to develop a TMDL for each impaired water quality limited segment (WQLS) on the State's Integrated Report, taking into account seasonal variations, critical conditions, and a protective margin of safety (MOS) to account for uncertainty (CFR 2012b). A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

TMDLs are established to determine the pollutant load reductions needed to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, protection of aquatic life, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

The Maryland 8-Digit (MD 8-Digit) Liberty Reservoir watershed consists of:

3) The actual impoundment created behind the Liberty Dam, and
4) The nontidal tributaries within the watershed that drain to the impoundment.

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The TMDL established herein by MDE will address the 1996 nutrient and sediment listings for Liberty Reservoir, for which a data solicitation was conducted, and all readily available data from the past five years have been considered. A water quality analysis (WQA) for chromium and lead in Liberty Reservoir was approved by the EPA in 2003, and a fecal coliform TMDL for the nontidal portion of the watershed was approved by the EPA in 2009. A mercury TMDL is currently under development and is scheduled for submittal to EPA in 2012. In the draft 2012 Integrated Report, the listing for impacts to biological communities includes the results of a stressor identification analysis.

Eutrophication is the over-enrichment of aquatic systems by excessive inputs of nutrients, particularly nitrogen and/or phosphorus. The nutrients act as a fertilizer, which cause the excessive growth of aquatic plants. These aquatic plants eventually die and decompose, leading to the bacterial consumption of dissolved oxygen (DO). Maryland's 2010 Integrated Report identified phosphorus, not nitrogen, as the specific impairing substance causing the nutrient impairment (i.e., eutrophic state) in the Liberty Reservoir.

This document, upon approval by the EPA, establishes TMDLs for phosphorus and sediments in the Liberty Reservoir. The water quality goal of the phosphorus TMDL is to decrease phosphorus inputs to the reservoir to levels that will 1) reduce high chlorophyll *a* (Chla) concentrations associated with excessive algal blooms, and 2) increase DO concentrations to levels that are supportive of the designated use for the reservoir. The water quality goal of the sediment TMDL for Liberty Reservoir is to increase the useful life of the reservoir for water supply purposes by preserving storage capacity.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Liberty Reservoir watershed is located within the Patapsco River sub-basin of the Chesapeake Bay watershed, within Maryland. The reservoir's watershed drains 104,800 acres of western Baltimore County and eastern Carroll County (see Figure 1) (majority of watershed is located in Carroll County). A dam was constructed on the North Branch Patapsco River in 1953, creating the Liberty Reservoir, which is owned by the Baltimore City Department of Public Works (BCDPW). Water supply intakes in the reservoir feed the BCDPW's Ashburton Water Filtration Plant, which provides drinking water to Baltimore City, Carroll County, and Baltimore County. The reservoir is primarily fed by the North Branch Patapsco River; other tributaries include Beaver Run, Keyer's Run, Prugh Run, Morgan Run, Middle Run, Locust Run, and Cooks Branch. There are several "high quality," or Tier II, stream segments (Benthic Index of Biotic Integrity (BIBI) and Fish Index of Biotic Integrity (FIBI) aquatic life assessment scores > 4 (scale 1-5)) located within the watershed requiring the implementation of Maryland's anti-degradation policy (COMAR 2012e). These include Keyser Run, Cooks Branch, an unnamed tributary to Morgan Run, an unnamed tributary to Little Morgan Run, and portions of Morgan Run, Joe Branch, Little Morgan Run, Middle Run, Beaver Run, the North Branch Patapsco River mainstem, and an unnamed tributary to the North Branch Patapsco River mainstem (MDE 2011). Approximately 1.9% percent of the watershed area is covered by water (i.e., streams, ponds, etc). The total population in the MD 8-digit Liberty Reservoir watershed is approximately 115,288 (US Census Bureau 2010).

Reservoir Characteristics

Several relevant statistics for Liberty Reservoir are provided below in Table 1.

Table 1: Current Physical Characteristics of Liberty Reservoir[1]

Location:	Baltimore County, MD Carroll County, MD Latitude 39˚ 22' 36" N – At Dam Longitude 76˚ 53' 30" W – At Dam
Surface Area:	3,106 acres (107,343,000 ft^2)[2]
Normal Reservoir Depth:	132.8 feet
Designated Use:	I-P (Water Supply/Recreation) (COMAR 2012d)
Volume:	132,000 acre-feet
Drainage Area to Reservoir:	164 mi^2 (104,800 acres)[3]
Average Discharge:[4]	20.0 ft^3/s (Discharge over the dam only)

Notes: [1] Sources: Weisberg et al. 1985 and James, Saffer, and Tallman 2001.
[2] ft^2: square feet.
[3] mi^2: square miles.
[4] ft^3/s: feet cubed per second.

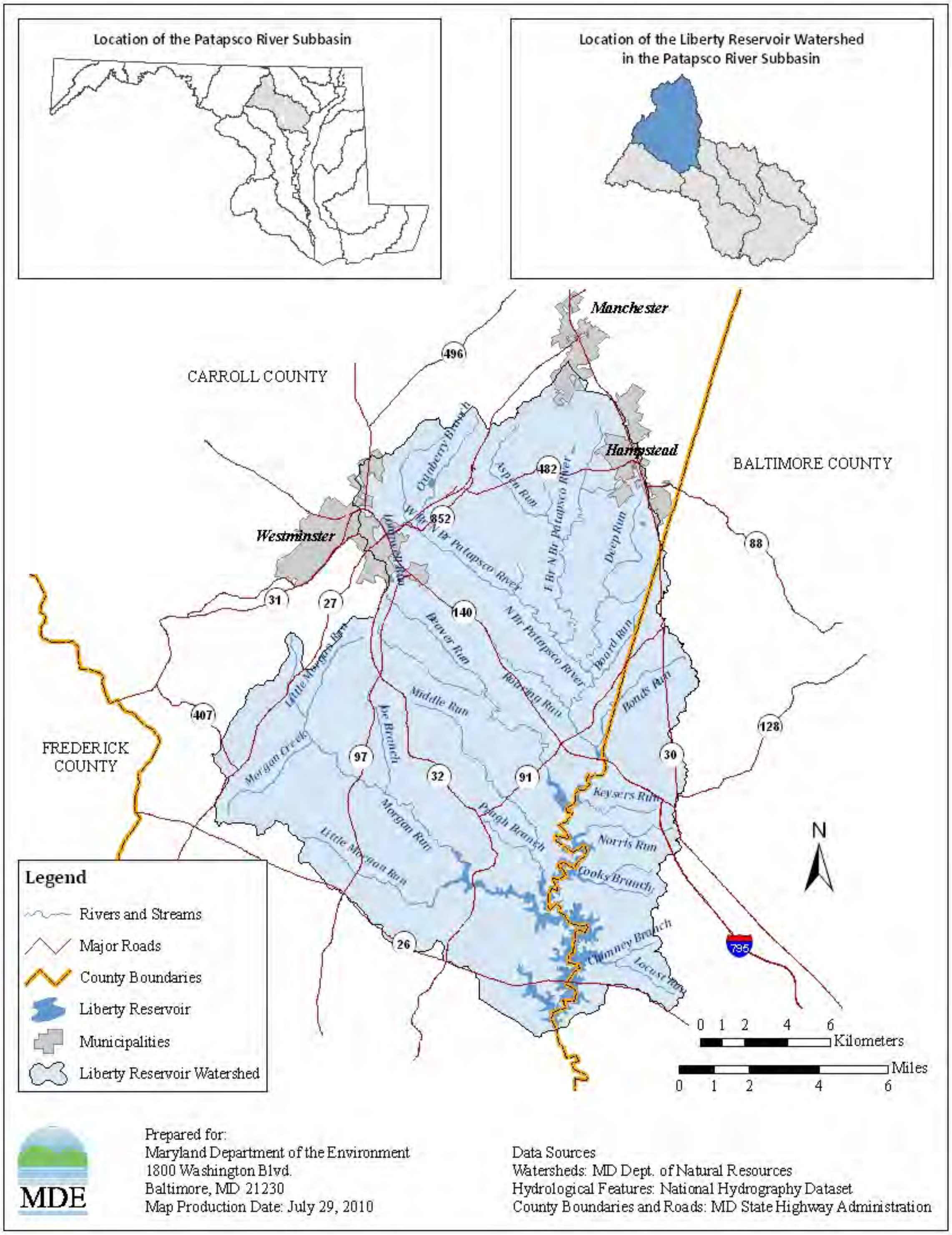

Figure 1: Location Map of the Liberty Reservoir Watershed

Geology/Soils

The Liberty Reservoir watershed lies within the north-central Piedmont Plateau physiographic province of Maryland, which is characterized by a gentle to steep rolling topography. The surficial geology of the watershed is composed of hard, crystalline igneous and metamorphic rocks of probable volcanic origin, which consist mainly of schist and gneiss, with smaller amounts of marble (Edwards 1981). The watershed drains in a northwest to southeasterly direction, following the dip of the underlying crystalline bedrock in the Piedmont physiographic province. Ground water is found primarily in the fractures and bedding-plane partings of rocks, but it may also be found in the solutional cavities of limestone and marble deposits (McCoy and Summers 1992).

The soils in the Liberty Reservoir watershed belong primarily to the Baile soil series (59%) and the Chester soil series (40%) (USDA 2006). The Baile soil series consists of soils that are very deep and poorly drained. These soils can be found on upland depressions and foot slopes and were formed in mica schist and granitized schist and gneiss. The Chester soil series consists of deep, well drained soils that are located on upland divides and upper slopes and were formed in materials weathered from micaceous schist (USDA 1976).

Soil type for the Liberty Reservoir watershed is also characterized by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) into four hydrologic soil groups: Group A soils have high infiltration rates and are typically deep well drained/excessively drained sands or gravels; Group B soils have moderate infiltration rates and consist of moderately deep-to-deep and moderately well-to-well drained soils, with moderately fine/coarse textures; Group C soils have slow infiltration rates with a layer that impedes downward water movement, and they primarily have moderately fine-to-fine textures; Group D soils have very slow infiltration rates consisting of clay soils with a permanently high water table that are often shallow over nearly impervious material. The Liberty Reservoir watershed is comprised primarily of Group B soils (81%) with smaller portions of Group C and Group D soils (13% and 6% respectively) (USDA 2006).

2.1.1 Land-Use

Land-Use Methodology

The land-use framework used to develop this TMDL was originally developed for the Chesapeake Bay Program Phase 5.3.2 (CBP P5.3.2) Watershed Model.[1] CBP P5.3.2 land-use was based on two distinct stages of development.

The first stage consists of the development of the Chesapeake Bay Watershed Land-Cover Data (CBLCD) series of Geographic Information System (GIS) datasets. These

[1] The EPA Chesapeake Bay Program developed the first watershed model in 1982. There have been many upgrades since the first phase of this model. The CBP P5.3.2 is the latest version and it was developed to estimate flow, nutrients, and sediment loads to the Bay.

datasets provide a 30 meter resolution raster representation of land-cover in the Chesapeake Bay watershed, based on sixteen Anderson Level two land-cover classes. The CBLCD basemap, representing 2001 conditions, was primarily derived from the Multi-Resolution Land Characteristics (MRLC) Consortium's National Land-Cover Data (NLCD) and the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program's (CCAP) Land-Cover Data. By applying Cross Correlation Analysis to Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper satellite imagery, the US Geological Survey's (USGS) contractor, MDA Federal, generated CBLCD datasets for 1984, 1992, and 2006 from the baseline 2001 dataset. The watershed model documentation, *Chesapeake Bay Phase 5.3 Community Watershed Model* (US EPA 2010b), describes the development of the CBLCD series in more detail. USGS and NOAA also developed an impervious cover dataset from Landsat satellite imagery for the CBLCD basemap, which was used to estimate the percent impervious cover associated with CBLCD developed land-cover classifications.

The second stage consists of using ancillary information for: 1) the creation of a modified 2006 CBLCD raster dataset, and 2) the subsequent development of the CBP P5.3.2 land-use framework in tabular format. Estimates of the urban footprint in the 2006 CBLCD were extensively modified using supplemental datasets. NAVTEQ street data (secondary and primary roads) and institutional delineations were overlayed with the 2006 CBLCD land-cover and used to reclassify underlying pixels. Certain areas adjacent to the secondary road network were also reclassified based on assumptions developed by USGS researchers, in order to capture residential development (*i.e.*, subdivisions not being picked up by the satellite in the CBLCD). In addition to spatially modifying the 2006 CBLCD, the following datasets were used to supplement the developed land cover data in the final CBP P5.3.2 land-use framework: US Census housing unit data, Maryland Department of Planning (MDP) Property View data, and estimates of impervious coefficients for rural residential properties (determined via a sampling of these properties using aerial photography). This additional information was used to estimate the extent of impervious area in roadways and residential lots. Acres of construction and extractive land-uses were determined independently (Claggett et al. 2012). Finally, in order to develop accurate agricultural land-use acreages, the CBP P5.3.2 incorporated county level US Agricultural Census data (USDA 1982, 1987, 1992, 1997, 2002). The watershed model documentation, *Chesapeake Bay Phase 5.3 Community Watershed Model* (US EPA 2010b), describes these modifications in more detail.

The result of these modifications is that CBP P5.3.2 land-use does not exist in a single GIS coverage; instead, it is only available in a tabular format. The CBP P5.3.2 watershed model is comprised of 30 land-uses. Within each generalized land-use classification, most of the sub-classifications are differentiated only by their nitrogen and phosphorus loading rates. Table 1 summarizes the CBP P5.3.2 land-use acres in the Liberty Reservoir watershed by generalized land-use sector. The land-use acres are based on the CBP P5.3.2 2009 Progress Scenario, which, for the CBP P5.3.2 model, represent current conditions.

<u>Liberty Reservoir Watershed Land-Use Distribution</u>

The land-use distribution in the Liberty Reservoir watershed consists primarily of forest (36.0%), crop land (27.2%), and urban land (31.6%). There are also smaller amounts of pasture (5.0%), animal feeding operations (AFOs) (0.1%), and nurseries (0.1%). A detailed summary of the watershed land-use areas is presented in Table 1, and a land-use map is provided in Figure 2.

Table 2: Land-Use Percentage Distribution for the Liberty Reservoir Watershed

General Land-Use	**Detailed Land-Use**	**Area** (acres)	**Percent** (%)	**Grouped Percent of Total** (%)
Forest	Forest	36,611	35.6	36.0
	Harvested Forest	369	0.4	
AFOs	Animal Feeding Operations	52	0.1	0.1
CAFOs	Concentrated Animal Feeding Operations	13	0.0	0.0
Pasture	Pasture	5,175	5.0	5.0
Crop	Crop	27,975	27.2	27.2
Nursery	Nursery	152	0.1	0.1
Urban	Construction	1,031	1.0	31.6
	Impervious	5,637	5.5	
	Pervious	25,796	25.1	
Extractive	Extractive	0	0.0	0.0
Total		**102,811**	**100.0**	**100.0**

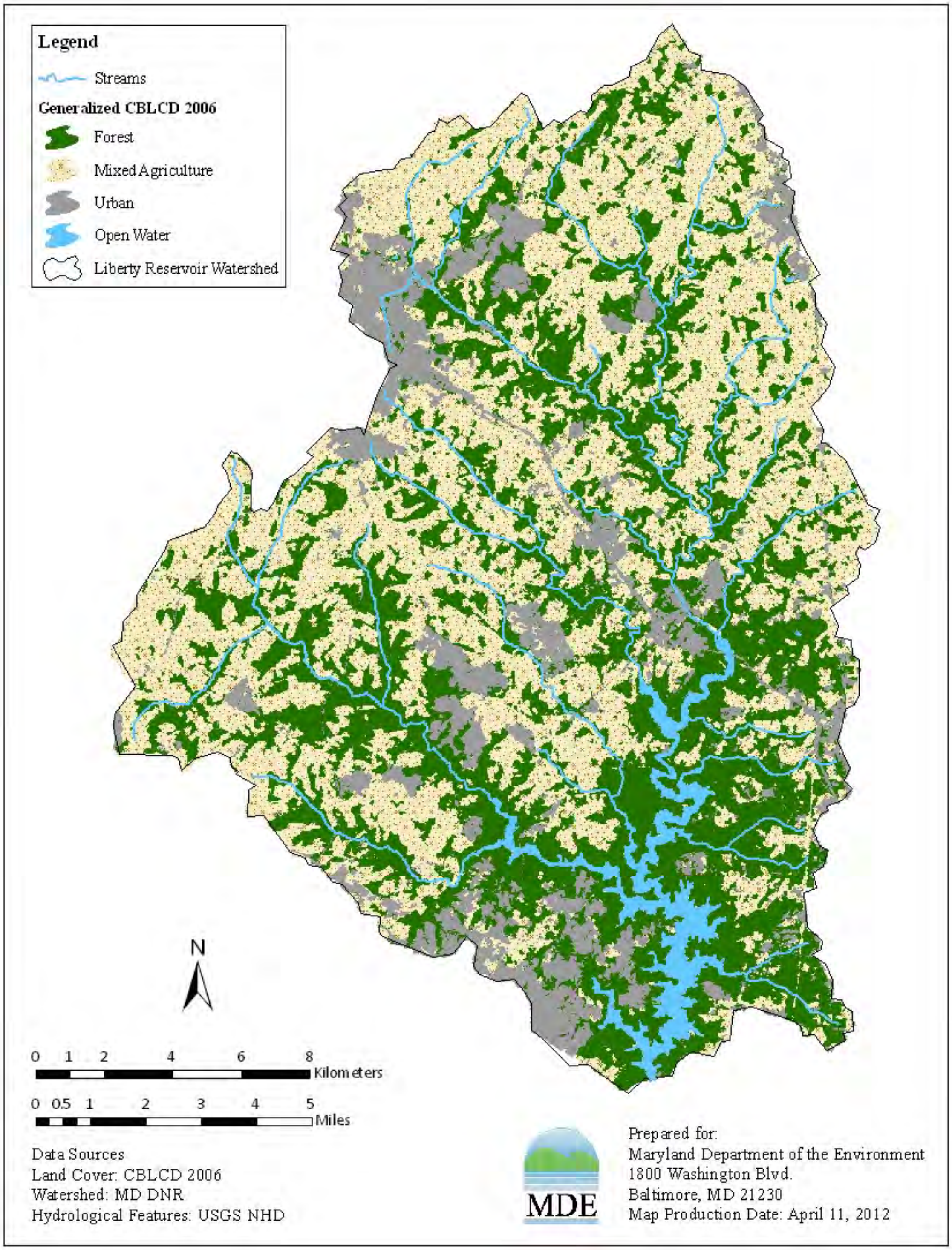

Figure 2: Land-Use Map for the Liberty Reservoir Watershed

2.2 Source Assessment

The Liberty Reservoir Watershed Total Baseline Phosphorus and Sediment Loads can be subdivided into nonpoint and point source loads. This section summarizes the methods used to derive each of these distinct source categories.

2.2.1 Nonpoint Sources Assessment

In this document, the nonpoint source loads account for phosphorus and sediment loads from unregulated stormwater runoff within the Liberty Reservoir watershed. This section provides the background and methods for determining the nonpoint source baseline loads generated within the Liberty Reservoir watershed (Nonpoint Source BL_{LR}).

General Load Estimation Methodology

Nonpoint source loads entering the Liberty Reservoir were estimated the CBP P5.3.2 Watershed Model. The CBP P53.2 model is a Hydrological Simulation Program Fortran (HSPF) model of Maryland, Virginia, the District of Columbia, and the portions of Pennsylvania, New York, Delaware, and West Virginia in the Chesapeake Bay watershed. Its primary purposes are (1) to determine the sources of nitrogen, phosphorus, and sediment to the Chesapeake Bay, (2) to calculate nutrient and sediment loads to the Chesapeake Bay for use in the Chesapeake Bay Program's (CBP) water quality model, and (3) to provide load allocations as part of nutrient and sediment TMDLs for impaired Chesapeake Bay segments. The HSPF model is described in greater detail in Bicknell et al. (2001), and further information on the development of the CBP P5.3.2 watershed model is included in the model documentation, *Chesapeake Bay Phase 5.3 Community Watershed Model* (US EPA 2010b).

Baseline non-point source phosphorus and sediment loads generated within the Liberty Reservoir watershed are estimated based on the edge-of-stream (EOS) loading rates from the 2009 Progress Scenario of the CBP P5.3.2 watershed model. The 2009 Progress Scenario represents current land-use, loading rates, and Best Management Practice (BMP) implementation within the Chesapeake Bay watershed, simulated using precipitation and other meteorological inputs from the time period of 1991-2000, in order to represent variable hydrological conditions. The 1991-2000 simulation period is used in all Chesapeake Bay TMDL scenarios to represent the impact of variable hydrology and meteorology. The 2009 Progress Scenario is applied as the baseline loading scenario for the Chesapeake Bay TMDLs and is considered to be the best available representation of current conditions.

Forest and Harvested Forest EOS phosphorus loads were revised to make them more compatible with the assumptions used in previous phosphorus TMDLs for the Gunpowder Reservoirs (MDE 2007; ICPRB 2006) and Patuxent Reservoirs (MDE 2008, ICPRB 2008). A separate modeling report, *Modeling Framework for Simulating Hydrodynamics and Water Quality in Liberty Reservoir* (ICPRB 2012), discusses the revision of forest EOS loads in more detail.

2.2.2 Point Source Assessment

A list of 36 active permitted point sources that contribute to the phosphorus and sediment loads in the Liberty Reservoir watershed was compiled using MDE's Permit database. The types of permits identified include individual industrial, individual municipal separate storm sewer systems (MS4s), general industrial stormwater, general MS4s, and general Concentrated Animal Feeding Operations (CAFOs). The technical memorandum to this document entitled *Significant Phosphorus and Sediment Point Sources in the Liberty Reservoir Watershed* lists all the permitted entities identified in the Liberty Reservoir watershed.

The permits can be grouped into three categories: (1) process water, (2) stormwater, and (3) CAFOs. Process water permits can be divided into permits for municipal wastewater treatment plants (WWTPs) and permits for industrial facilities. There are no municipal WWTPs in the watershed; however, there are seven industrial facilities that discharge phosphorus and sediments. Baseline phosphorus and sediment loads (Process Water BL_{LR}) for these industrial facilities were calculated based on monitoring data collected as part of their permit requirements, or best professional judgment. Table 3 lists the current, active process water facilities represented in the CBP P5.3.2 watershed model within the Liberty Reservoir watershed and their estimated phosphorus and sediment loads in the 2009 Progress Scenario. The estimated process water total phosphorus (TP) load is 3,409 pounds per year (lbs/yr) and the process water sediment/total suspended solids (TSS) load is 15 tons per year (tons/yr).

Table 3: CBP P5.3.2 2009 Progress Scenario Phosphorus (lbs/yr) and Sediment Loads (tons/yr) for Process Water Point Source Facilities in the Liberty Reservoir Watershed

Facility Name[1,2]	NPDES #	Permit Type		Baseline Load Type	TP (lbs/yr)	TSS (tons/yr)
CONGOLEUM CORPORATION	MD0001384	Industrial	Individual	Individual	88	1
BTR HAMPSTEAD, LLC	MD0001881	Industrial	Individual	Aggregate	3,321	14
CITY OF WESTMINSTER KOONTZ WELL	MD0058556	Industrial	Individual	Aggregate		
S & G CONCRETE - FINKSBURG PLANT	MDG492472	Industrial	Individual	Aggregate		
CARROLL COUNTY FAMILY YMCA	MDG766057	Industrial	General	Aggregate		
THE BOSTON INN, INC.	MDG766199	Industrial	General	Aggregate		
FOUR SEASONS SPORTS COMPLEX	MDG766210	Industrial	General	Aggregate		
FREEDOM SWIM CLUB	MDG766371	Industrial	General	Aggregate		
GREEN VALLEY SWIM CLUB	MDG766379	Industrial	General	Aggregate		
MCDANIEL COLLEGE	MDG766048	Industrial	General	Aggregate		
GLYNDON TRACE CONDOMINIUMS	MDG766199	Industrial	General	Aggregate		
Total					**3,409**	**15**

Notes:
1 Two municipal Water Treatment Plants (WTPs) (Cranberry WTP, NPDES # MD0067644; and Freedom District WTP, NPDES# MD0067652) have been identified within the watershed, but are not included within the analysis, since they withdraw water from the watershed stream system. Therefore, any TP and TSS loads discharged from the plants are representative of a pass through condition.
2 Two hydrostatic testing permits (Maryland Military Facility – Camp Fretterd, NPDES# MDG675043; and Pearlstone Family Camp, NPDES# MDG675029) have also been identified within the watershed but are not included within the analysis, since they both discharge to groundwater rather than surface water, and therefore there are no potential TP or TSS loadings from the permits.

The stormwater category includes all National Pollutant Discharge Elimination System (NPDES) regulated stormwater discharges. The 25 NPDES Phase I or Phase II stormwater permits (see point source technical memorandum to this document entitled *Significant Phosphorus and Sediment Point Sources in the Liberty Reservoir Watershed*) identified throughout the Liberty Reservoir watershed are regulated based on BMPs and do not include nutrient or TSS limits. The Liberty Reservoir NPDES regulated stormwater loads (NPDES Stormwater BL_{LR}) are estimated using the CBP P5.3.2 Progress Scenario developed land-use acres, loading rates, and BMP implementation information. The total NPDES regulated stormwater TP load is 20,088 lbs/yr and the total sediment/TSS load is 8,021 tons/yr.

Starting in 2009, Maryland began the process of permitting CAFOs under the NPDES program. CAFOs are medium to large animal feeding operations that have some artificial conveyance like a swale or ditch to discharge runoff from feedlots to surface water. Recent EPA regulations require CAFOs to have a NPDES permit. Maryland also designates large animal feeding operations which do not discharge or propose to discharge as Maryland Animal Feeding Operations (MAFOs). It is anticipated that on review many MAFOs will require CAFO permits. Several operators in the Liberty

Reservoir watershed have filed notices of intent (NOI) to apply for permits under Maryland's CAFO or MAFO regulations. Based on the NOIs filed by the reporting deadline of February, 2009, the CBP P5.3.2 watershed model estimates that the current average annual TP load from CAFOs in the Liberty Reservoir watershed is 1,060 lbs/yr, and the average annual sediment/TSS load is 11 tons/yr.

2.2.3 Summary of Phosphorus Baseline Loads

Table 4 summarizes the Liberty Reservoir Baseline Phosphorus Loads, reported in lbs/yr and presented in terms of nonpoint and point source loadings.

Table 4: Liberty Reservoir Baseline Phosphorus Loads (lbs/yr)

Total Baseline Load (lbs/yr)	=	**Nonpoint Source BL_{LR}**	+	**CAFO BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**Process Water BL_{LR}**
75,977	=	51,421	+	1,060	+	20,088	+	3,409

Table 5 presents a breakdown of the Liberty Reservoir Total Baseline Phosphorus Load, detailing loads per land-use and specific source sectors. These loads are derived from the CBP P5.3.2 watershed model 2009 Progress Scenario for the Liberty Reservoir watershed. The largest source of phosphorus to the reservoir is from crop land (36.7%). Other phosphorus sources include urban land (26.4%), forest (9.4%), nurseries (13.4%), pasture (5.5%), process water point sources (4.5%), AFOs (1.1%), and CAFOs (1.4%). There are no combined sewer overflows (CSOs) in the Liberty Reservoir watershed, and phosphorus loads from septic systems are considered insignificant. Therefore, these source sectors are not presented in the breakdown.

Table 5: Liberty Reservoir Detailed Baseline Total Phosphorus Loads

General Land-Use/Source Sector	Detailed Land-Use/Source Sector	Load (lbs/yr)	Percent (%)	Grouped Percent of Total
Forest	Forest	6,885	9.1	9.4
	Harvested Forest	258	0.3	
AFOs	Animal Feeding Operations	831	1.1	1.1
CAFOs	Concentrated Animal Feeding Operations	1,060	1.4	1.4
Pasture	Pasture	4,216	5.5	5.5
Crop	Crop	27,853	36.7	36.7
Nursery	Nursery	10,149	13.4	13.4
Urban[1]	Construction	3,462	4.6	26.4
	Impervious	7,624	10.0	
	Pervious	9,002	11.8	
Extractive	Extractive	0	0.0	0.0
Process Water Point Sources	Industrial	3,409	4.5	4.5
	Municipal	0	0.0	
Atmospheric Deposition	Atmospheric Deposition	1,230	1.6	1.6
Total		**75,977**	**100.0**	**100.0**

Note: [1] The urban land-use load represents the permitted stormwater load.

2.2.4 Summary of Sediment Baseline Loads

Table 6 summarizes the Liberty Reservoir Baseline Sediment Loads, reported in ton/yr and presented in terms of nonpoint and point source loadings.

Table 6: Liberty Reservoir Baseline Sediment Loads (lbs/yr)

Total Baseline Load (tons/yr)	=	**Nonpoint Source BL_{LR}**	+	**CAFO BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**Process Water BL_{LR}**
20,767	=	12,720	+	11	+	8,021	+	15

Table 7 presents a breakdown of the Liberty Reservoir Total Baseline Sediment Load, detailing loads per land-use and specific source sectors. These loads are derived from the CBP P5.3.2 watershed model 2009 Progress Scenario for the Liberty Reservoir watershed. The largest source of sediment to the reservoir is from crop land (42.6%). Other sediment sources include urban land (38.6%), forest (15.5%), pasture (2.0%), nursery (0.9%), AFOs (0.2%), CAFOs (0.1%), and process water point sources (0.1 %). There are no CSOs in the Liberty Reservoir watershed, and there are no sediment loads from septic systems. Therefore, these source sectors are not presented in the breakdown.

Table 7: Liberty Reservoir Detailed Baseline Total Sediment Loads

General Land-Use/Source Sector	**Detailed Land-Use/Source Sector**	**Load** (tons/yr)	**Percent** (%)	**Grouped Percent of Total** (%)
Forest	Forest	3,019	14.5	15.5
	Harvested Forest	208	1.0	
AFOs	AFOs	45	0.2	0.2
CAFOs	CAFOs	11	0.1	0.1
Pasture	Pasture	423	2.0	2.0
Crop	Crop	8,842	42.6	42.6
Nursery	Nursery	182	0.9	0.9
Urban[1]	Construction	2,247	10.8	38.6
	Impervious	3,403	16.4	
	Pervious	2,371	11.4	
Extractive	Extractive	0	0.0	0.0
Process Water Point Sources	Industrial	15	0.1	0.1
	Municipal	0	0.0	
Atmospheric Deposition	Atmospheric Deposition	0	0.0	0.0
Total		**20,767**	**100.0**	**100.0**

Note: [1] The urban land-use load represents the permitted stormwater load.

2.3 Water Quality Characterization

2.3.1 Water Quality Monitoring Programs

The Liberty Reservoir watershed was originally listed on Maryland's 1996 303(d) List as impaired by nutrients and sediments from nonpoint sources, with supporting evidence cited in Maryland's 1996 305(b) report. The 1996 305(b) report did not directly state that elevated nutrients and sediments were a concern, and it has been determined that the sediment listing was based on best professional judgment (MDE 2004; DNR 1996). The BCDPW is currently the only entity that monitors water quality in the reservoir. Table 8 summarizes the characteristics of the monitoring programs. BCDPW samples four monitoring stations in the reservoir. Figure 3 shows the locations of these sampling stations.

Water column samples are analyzed for temperature, DO, TP, ammonia (NH_3), nitrate (NO_3), turbidity, and Secchi depth, among other constituents. Samples are not analyzed for phosphorus species and organic or total nitrogen. Starting at the surface, samples are taken every five feet until reaching sixty feet in depth; samples are taken at ten-foot intervals thereafter.

Not every sample is analyzed for the entire suite of parameters. Generally, only field measurements like temperature and DO are measured at every depth sampled. Lab analysis is performed for Chla for each sample collected at the surface and at ten-foot depth intervals down to 50 feet. Chemical analysis is performed on samples collected at the surface and at ten–foot depth intervals down to sixty feet.

Table 8: Summary of BCDPW Liberty Reservoir Monitoring Program

Water Quality Monitoring Characteristic	**Details**
Collection Period	3/98-11/04
Number of Monitoring Stations	4
Temperature and DO measurements/Monitoring Station	Samples taken at approximately 5-10 ft. intervals from surface to bottom
Water quality Samples/Monitoring Station	Samples taken at approximately 10 ft. intervals from surface to bottom
Water Quality Analysis Parameters	NH_3, NO_3, NO_{23}, TP, DS, Chla, Turbidity, Secchi depth[1]

Note: [1] NO_{23}: Nitrite plus Nitrate; DS: Dissolved Solids.

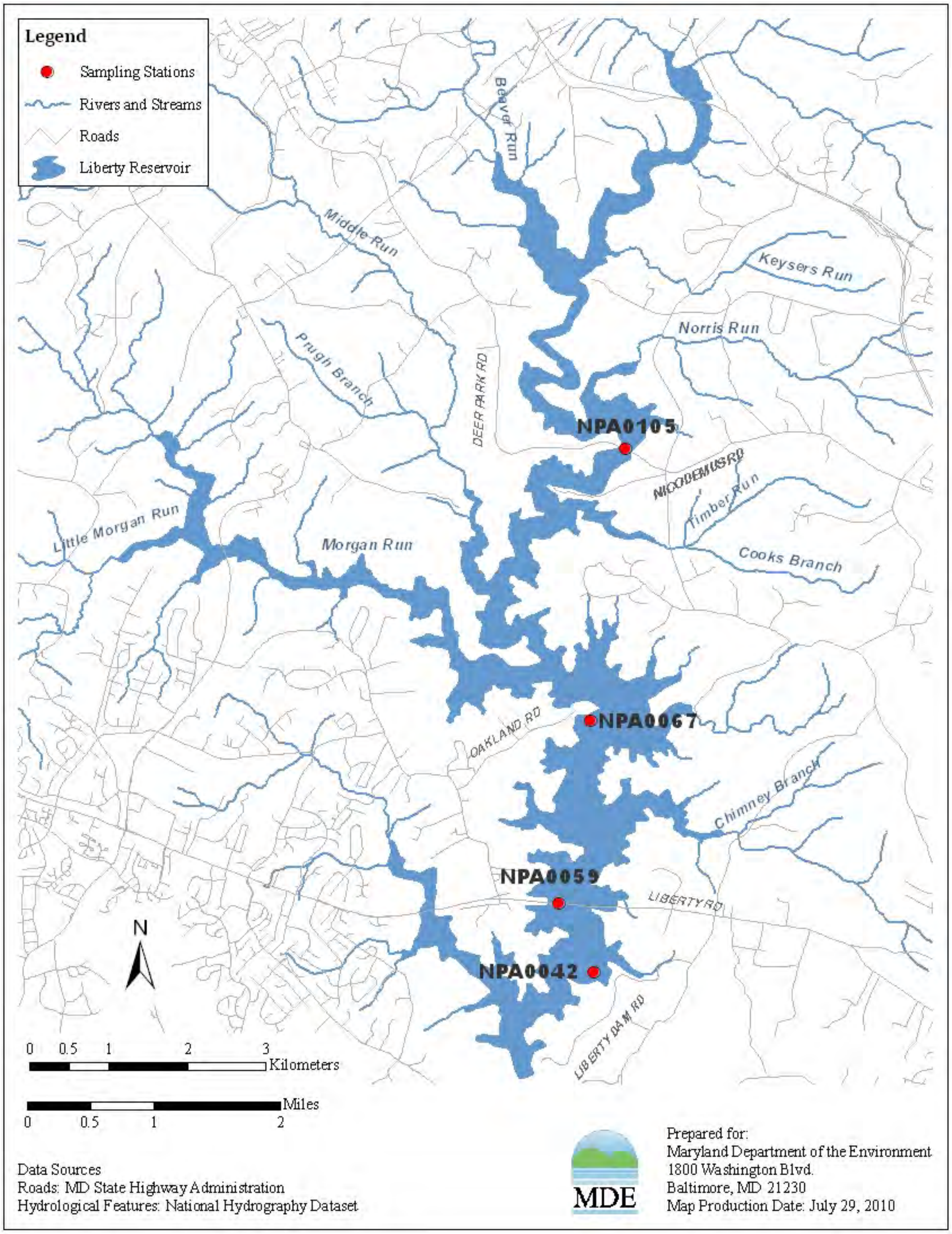

Figure 3: Liberty Reservoir BCDPW Monitoring Stations

2.3.2 Temperature Stratification

Liberty Reservoir regularly exhibits temperature stratification starting in April or May and lasting until November. Stratification sometimes occurs in winter but it does not have a significant effect on water quality at this time. Under stratified conditions during the summer and early fall, bottom waters in the reservoir can become hypoxic, or oxygen deficient, because stable density differences inhibit the turbulent mixing that usually transports oxygen from the surface. Under such conditions, the reservoirs can be divided vertically into a well-mixed surface layer, or epilimnion; a relatively homogeneous bottom layer or hypolimnion; and a transitional zone between them, the metalimnion, characterized by a sharp density gradient.

Contour plots of isotherms effectively illustrate the seasonal position of the well-mixed surface layer, or epilimnion. Figure 4 presents a contour plot of isothermals for BCDPW station NPA0042 in Liberty Reservoir. Contours are shown only for the first 30 feet from the surface. In the winter, isothermal lines are vertical, indicating that the reservoir has a fairly uniform temperature over the first 30 feet of depth. In spring, isothermal lines begin to shift from a vertical alignment to a horizontal alignment, and by May, at depths greater than approximately 15 to 20 feet, they are horizontally parallel to each other. At the surface, isothermal lines run vertically to a depth of 10 to 15 feet; this defines the epilimnion.

Figures A-1 through A-4 in Appendix A present contour plots for each BCDPW monitoring station from 2000 through 2005. Generally, the epilimnion is limited to a depth of 5 to 10 feet in the summer. For the purposes of this analysis, the surface layer is considered to be 10 feet deep, with the understanding that in the spring and fall the epilimnion can extend deeper than 10 feet, and in the summer, it is likely to be shallower. For screening purposes, samples taken at depths of 70 feet or greater are considered to be part of the bottom layer, or hypolimnion.

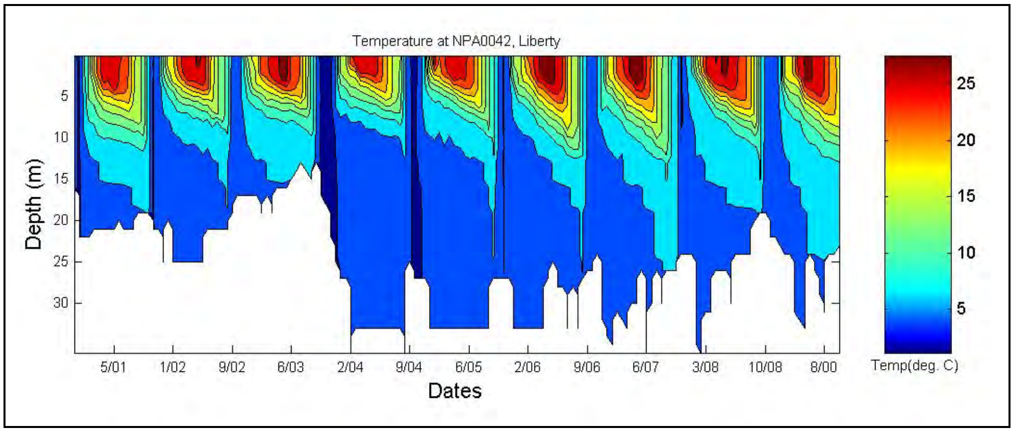

Figure 4: Liberty Reservoir BCDPW Station NPA0042 Isothermal Contours (2000-2008)

2.3.3 Dissolved Oxygen

Figures A-5 through A-8 in Appendix A show contour plots of DO concentrations at BCDPW stations NPA0042, NPA0059, NPA0067, and NPA0105 in Liberty Reservoir from 2000 through 2005. As demonstrated in these plots, low dissolved oxygen occurs in the Liberty Reservoir hypolimnion regularly (See Section 2.4).

Generally, the low DO concentrations in the hypolimnion are due to two related causes. First is temperature stratification, as explained above; second is the entrainment of low DO waters into the epilimnion. Entrainment refers to the process by which turbulent layers spread into a non-turbulent region (Ford and Johnson 1986). The onset of cool weather causes the epilimnion to increase in depth by entraining water from the metalimnion. This water can be low in oxygen and thereby reduce the DO concentrations in the epilimnion. This can occur any time under stratified conditions when the well-mixed surface layer deepens, often well before the fall overturn, when the surface and bottom layers displace one another, which is typical of many lakes and reservoirs (including Liberty).

Figure 5 shows the DO contours at station BCDPW NPA0042. Figure 4, in the previous section, showed the temperature contour. A comparison of the figures indicates that at the end of August at this particular location, the reservoir was highly stratified, with the well-mixed layer extending to about 10 feet deep. Throughout September, the surface waters cooled, and the epilimnion deepened. The layers with low oxygen concentrations in the summer were drawn into the epilimnion. By October, the epilimnion once again had fairly uniform DO concentrations, although the reservoir had not completely overturned.

Entrainment and the fall overturn account for the other low DO observations in the epilimnion of the Liberty Reservoir. In a typical reservoir system, there is also another factor that can influence entrainment, which is drawdown. Withdrawals from a reservoir can induce currents that enhance mixing. Figure 6 shows the surface elevation of Liberty Reservoir from 2000 through 2005. In 2002 (a drought year), withdrawals from Liberty Reservoir dropped the surface elevation by about ten feet. These drawdowns are more than likely contributing to the low DO concentrations in the well-mixed surface layer of the reservoir.

Figures A-9 through A-12 in Appendix A show time series of DO at the surface and at five-foot intervals up to 10 feet, the screening-level definition of the epilimnion. DO concentrations are above the 5.0 milligrams per liter (mg/l) criterion (See Section 2.4).

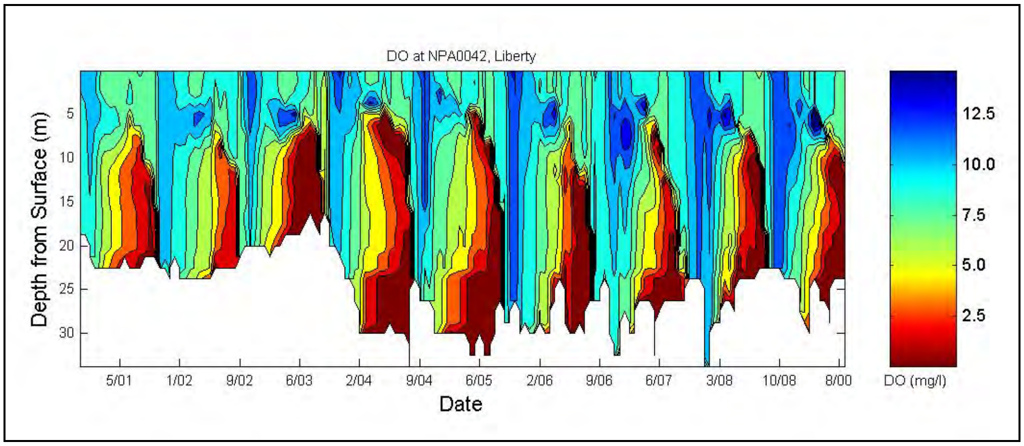

Figure 5: Liberty Reservoir BCDPW Station NPA0042 DO Contour (1998-2008)

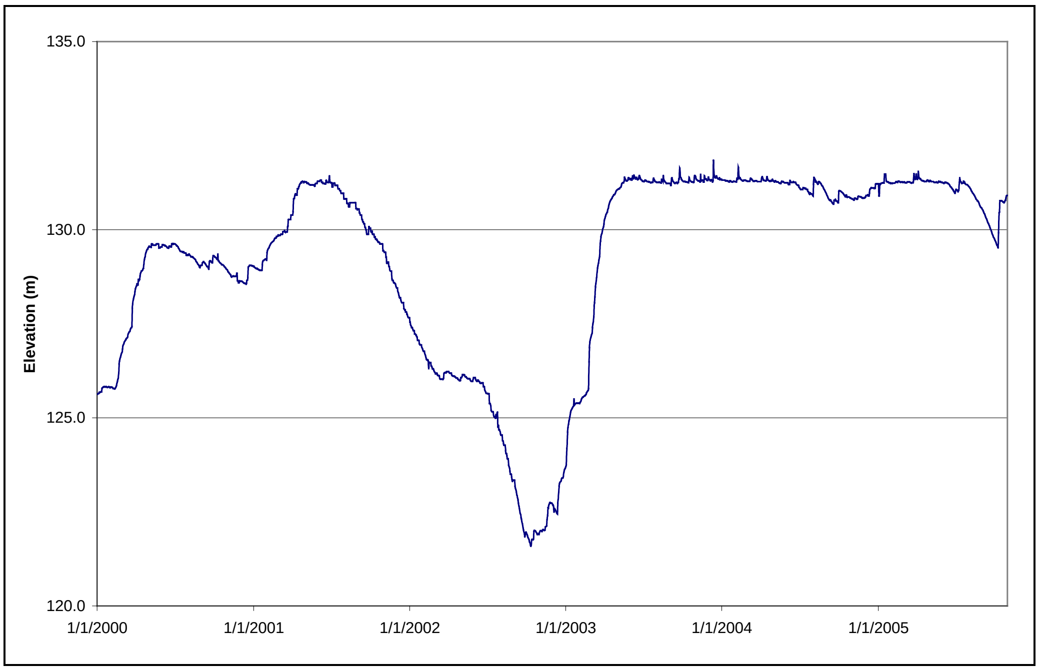

Figure 6: Liberty Reservoir Surface Water Elevation (2000-2005)

2.3.4 Phosphorus

Figures A-13 through A-16 in Appendix A show average TP concentrations at the surface and bottom sampling depths for each monitoring station in Liberty Reservoir from 2000 through 2008. Surface TP concentrations represent an average of the samples taken at depths less than 10-feet. Bottom concentrations represent an average of samples taken at depths of 70 feet or greater. Table 9 provides summary statistics for TP concentrations in Liberty Reservoir.

Table 9: Liberty Reservoir Total Phosphorus Summary Statistics (2000-2008)

Statistic	TP Concentrations (mg/L)						
	Surface Monitoring Stations				Bottom Monitoring Stations		
	NPA0042 (n = 96)[1]	NPA0059 (n = 53)	NPA0067 (n=53)	NPA0105 (n = 96)	NPA0042 (n = 91)	NPA0059 (n = 51)	NPA0067 (n = 45)
Mean	0.024	0.018	0.018	0.035	0.028	0.020	0.021
Standard Deviation	0.038	0.014	0.013	0.053	0.042	0.016	0.013
Minimum	0.005	0.005	0.005	0.004	0.002	0.005	0.005
1st Quartile	0.012	0.011	0.012	0.017	0.014	0.012	0.013
Median	0.015	0.015	0.015	0.022	0.018	0.016	0.017
3rd Quartile	0.023	0.022	0.023	0.031	0.028	0.021	0.023
Maximum	0.354	0.072	0.070	0.440	0.340	0.107	0.064

Note: [1] n: number of samples

2.3.5 Nitrogen

Figures A-17 through A-24 in Appendix A present the average surface and bottom ammonia and nitrate concentrations in Liberty Reservoir from 2000 through 2008. Since the surface layer of the reservoir is not nitrogen limited, bottom ammonia and nitrate concentrations are more relevant as a water quality indicator for two reasons. First, the time series graphs of ammonia concentrations indicate that there are significant releases of ammonia from the bottom sediments. This contributes to greater oxygen demand. Although observed ammonia concentrations were as high as 0.9 mg/l, Maryland's ammonia water quality criteria (COMAR 2012c) were never exceeded. Second, for the most part, nitrate concentrations remained above 0.5 mg/l. Nitrate is preferred to ferric iron (III) as an electron acceptor in diagenesis. The phosphate attached to the bottom sediments is bound to the sediment via ferric iron. It is not likely that phosphate will detach from sediment until ferric iron concentrations are reduced via diagenesis. Therefore, the phosphorus release rate from the sediments in the reservoir should remain low.

2.3.6 Nutrient Limitation

Nitrogen and phosphorus are essential nutrients for algal growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced, and it is said to be the "limiting nutrient". The amount of the nutrient in greater abundance does not matter because both nutrients are needed for algal growth. In general, a Total Nitrogen: Total Phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass indicates that plant growth is not limited by phosphorus or nitrogen concentrations. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the N:P ratio is less than 5:1, nitrogen tends to be limiting (Chiandani et al. 1974).

Since there are no data available for organic nitrogen concentrations in the reservoir, nitrate is substituted for total nitrogen (TN) in the TN:TP ratio assessment, and the TN:TP ratio is thereby inherently underestimated. In Liberty Reservoir, only about 7% of the samples taken at the 10- and 20-foot depths have NO_3:TP ratios less than 10:1, which is applied as the threshold for distinguishing nitrogen limitation from phosphorus limitation. The median NO_3:TP ratio in Liberty Reservoir is 38:1. Storm events are likely to have high concentrations of particulate nitrogen and phosphorus, but while particulate phosphorus is accounted for in NO_3:TP ratios, particulate organic nitrogen is not. Storm events therefore inflate TP concentrations and exacerbate the underestimation of TN, so the resultant ratios are considered anomalous. Based on the available monitoring data and high N:P ratios, it is clearly evident that Liberty Reservoir is phosphorus limited.

2.3.7 Algae and Chlorophyll α

Figures A-25 through A-28 in Appendix A present the time series graphs of maximum Chla concentrations in the surface layer at the four Liberty Reservoir BCDPW monitoring stations. Chla concentrations tend to be higher in the upstream portion of the reservoir, as represented by station NPA0105 in Figure A-28. Table A-1 in Appendix A presents the maximum Chla concentrations by month and year from 2000 through 2008. As the table indicates, Chla concentrations above 10 micrograms per liter (μg/l) occur regularly, and concentrations above 30 μg/l occur frequently. Concentrations above 10 μg/l occur in every season, but concentrations above 30 μg/l tend to occur more frequently in the summer months.

As per Table A-1, an algal bloom occurred in the winter of 2004 following the extremely wet conditions in 2003. Peak Chla concentrations reached 225 μg/l in the upper reaches of the reservoir at station NPA0105. An analysis of algal taxa performed at the Ashburn WTP showed that there was a significant blue-green algal component in the algal assemblage during the bloom, which is unusual for winter months. The bloom was localized to the upper reaches in the reservoir, as Chla concentrations observed during the bloom at station NPA0042, just upstream of the dam, were below10 μg/l. The magnitude of the bloom in the winter of 2004, the largest observed in the reservoir in the last twenty years, seems unique to the extreme hydrological conditions preceding the event, and it is not considered representative of long-term average conditions in the reservoir.

2.3.8 Sedimentation

The Maryland Geological Survey (MGS) developed new bathymetry for Liberty Reservoir in 2001 (Ortt and Wells 2001). Table 10 summarizes capacity loss and the average sediment accumulation rate for the reservoir.

Table 10: Liberty Reservoir Sedimentation Rates[1]

Capacity Prior to 1953 Construction (acre-ft)[2]	118,148
2001 Capacity (acre-ft)	115,617
Capacity Loss (acre-ft)	2,531
Average Annual Capacity Loss (acre-ft/yr)[3]	54
Sediment Accumulation Rate (in/yr)[4]	0.21

Note: [1]Source: Ortt and Wells 2001.
[2]acre-ft: acres by feet.
[3]acre-ft/yr: acre by feet per year.
[4]in/yr: inches per year.

2.4 Water Quality Impairments

The Maryland water quality standards surface water use designation in COMAR for the Liberty Reservoir is Use I-P (*Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply*) (COMAR 2012d). Maryland's general water quality criteria prohibit the pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 2012b). Excessive eutrophication, as indicated by elevated Chla concentrations, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. These algal blooms eventually die off and decompose, and as a result consume oxygen. Excessive eutrophication in Liberty Reservoir is caused by nutrient over enrichment. An analysis of the available water quality data presented in Section 2.3 has demonstrated that phosphorus is the limiting nutrient. In conjunction with excess nutrient inputs, sediment loadings in the watershed are also elevated, which has decreased the projected lifespan of the reservoir. The shortened lifespan of the reservoir violates Maryland's general water quality criteria that prohibits interference with a designated use, specifically, for Liberty Reservoir, the public water supply use.

As per Maryland's water quality criteria for specific water use designations, in Use I-P waters, DO is not allowed to fall below 5.0 mg/l at any time, unless natural conditions result in lower DO concentrations (COMAR 2012a). New DO standards for tidal waters of the Chesapeake Bay and its tributaries take into account stratification and its impact on deeper waters. MDE recognizes that stratified reservoirs and impoundments (there are no natural lakes in Maryland) have conditions similar to stratified tidal waters. Therefore, an interpretation of the existing use I-P standard, to allow for the impact of stratification on DO concentrations, is being applied within this analysis. This interpretation recognizes that low dissolved oxygen in the hypolimnion is due to natural conditions resultant from the morphology of the reservoir, the resulting degree of stratification, and the naturally occurring sources of organic material in the watershed. Therefore, the interpretation of the Use I-P DO standard for non-tidal waters, as applied to reservoirs, is as follows:

- A minimum DO concentration of 5.0 mg/l will be maintained throughout the water column during periods of complete and stable mixing;

- A minimum DO concentration of 5.0 mg/l will be maintained in the mixed surface layer at all times, even during stratified conditions, except during periods of overturn or other naturally-occurring disruptions to the stratification; and
- Hypolimnetic hypoxia will be addressed on a case-by-case basis, taking into account morphology, the degree of stratification, sources of diagenic organic material in reservoir sediments, and other such factors.

Hypoxia occurs when DO concentrations are below levels necessary to support aquatic life. DO concentrations below 2-3 mg/l are considered hypoxic (Committee on Environment and Natural Resources 2010). For the application of the DO standard to Liberty Reservoir, the hypolimnion will be considered hypoxic when DO concentrations are below 2 mg/l.

Analysis of the water quality data presented in Section 2.3 indicates that all observed DO concentrations below 5.0 mg/l in the surface layer of Liberty Reservoir are associated with stratification or the mixing of stratified waters into the surface layer during periods of reservoir overturn or drawdown. However, seasonal hypoxia occurs regularly in the hypolimnion of the reservoir.

3.0 TARGETED WATER QUALITY GOALS

The overall objective of the TMDLs proposed in this document is to reduce phosphorus and sediment loads to levels that support the Use I-P designation for Liberty Reservoir. Specifically, the TMDLs reflect phosphorus and sediment loadings to the reservoir that are in attainment of the applicable DO and Chla water quality criteria for Use I-P waters, appropriately modified based on the stratification of reservoirs and impoundments (See Section 2.4 for further details). The Chla endpoints selected for the reservoir are (1) a ninetieth percentile instantaneous chlorophyll concentration not to exceed 30 µg/l in the surface layer, and (2) a 30-day moving average concentration not to exceed 10 µg/l in the surface layer. A concentration of 10 µg/l corresponds to a score of approximately 53 on the Carlson Trophic State Index (TSI) (Carlson 1977). This is the approximate boundary between mesotrophic and eutrophic conditions, which is an appropriate trophic state at which to manage the reservoir. Mean Chla concentrations exceeding 10 µg/l are associated with Chla peaks exceeding 30 µg/l. These peaks are associated with a shift in algal composition to blue-green assemblages, which present taste, odor, and treatment problems (Walker 1984). Thus, the Chla endpoints should be reflective of conditions void of nuisance algal blooms. The decrease in phosphorus loads is expected to reduce excessive algal growth and therefore prevent violations of the narrative criteria associated with nuisances, such as taste and odor problems.

In summary, the TMDLs for phosphorus and sediment are intended to:

1. Resolve violations of the general, narrative water quality criteria, as it relates to excessive algal growth causing a nuisance, within the Liberty Reservoir, which is associated with the phosphorus enrichment of the reservoir;
2. Resolve violations of the general, narrative water quality criteria, as it relates to the preservation of a reservoir's life-span and the public water supply designated use, associated with excess sedimentation in Liberty Reservoir; and
3. Assure that DO levels in Liberty Reservoir are in attainment of the non-tidal Use I-P DO criteria, as appropriately modified for the reservoir.

4.0 TOTAL MAXIMUM DAILY LOADS (TMDLs) AND ALLOCATIONS

4.1 Overview

This section describes how the phosphorus and sediment TMDLs and the corresponding allocations were developed for the Liberty Reservoir watershed. Section 4.2 describes the modeling framework for simulating hydrodynamics, nutrient and sediment loads, and water quality responses and resultant assimilative capacity in Liberty Reservoir. Section 4.3 describes the scenarios developed on the basis of modeling results. Section 4.4 explains how the modeling framework satisfies the requirements that TMDLs take into account critical conditions and seasonality. Section 4.5 explains the calculation of the TMDL loading caps. Section 4.6 details the load allocations, and Section 4.7 explains the rationale for the margin of safety. Finally, Section 4.8 summarizes the phosphorus and sediment TMDLs for Liberty Reservoir.

4.2 Computer Modeling Framework

To develop a TMDL, a linkage must be made between the water quality endpoints (e.g., targets or goals) and the identified sources of phosphorus and sediments. This linkage establishes the cause-and-effect relationship between the pollutant loads to/concentrations in the reservoir and their sources. This relationship can vary seasonally, particularly for nonpoint sources, due to factors such as precipitation. Once this link is established, it provides the estimate of the total loading capacity, or TMDL, of the reservoir (US EPA 1999).

Computer simulation models are often used to provide the linkage between the sources of pollutants and targeted water quality goals. The computer modeling framework used to develop the Liberty Reservoir TMDLs has two elements: (1) a refined version of the CBP P5.3.2 watershed model was used to determine the rate and timing of phosphorus and sediment loads to Liberty Reservoir; and (2) a CE-QUAL-W2 (W2) model of the Liberty Reservoir itself, to simulate the impact of those loads on water quality.

The CBP P5.3.2 watershed model was refined for the Liberty Reservoir watershed. One of the refinements that was made to the model involves the CBP P5.3.2 forest EOS loads. Forest EOS phosphorus loads were refined to make them more compatible with the assumptions used in previous phosphorus TMDLs for the Gunpowder Reservoirs (MDE 2007; ICPRB 2006) and Patuxent Reservoirs (MDE 2008, ICPRB 2008). Furthermore, the CBP P5.3.2 representation of the Liberty Reservoir watershed, represented by a single reach, was refined by subdividing the watershed into 12 sub-basins, each with their own modeled reach. Monitoring data collected by the BCDPW was used to simulate the nutrient and sediment loads in the model's sub-basins. The refined CBP P5.3.2 Liberty Reservoir watershed model is used to estimate flows as well as total suspended solid and nutrient loads from the watershed's sub-basins, which are linked to the two-dimensional W2 model of the reservoir. Further details regarding the development of the refined CBP P5.3.2 Liberty Reservoir watershed model can be found in the modeling report for this

TMDL, *Modeling Framework for Simulating Hydrodynamics and Water Quality in Liberty Reservoir* (ICPRB 2012).

W2 is a laterally averaged, two-dimensional computer simulation model, capable in its most recent formulations of representing the hydrodynamics and water quality of rivers, lakes, and estuaries. It is particularly well-suited for representing the temperature stratification that occurs in reservoirs such as Liberty. The W2 reservoir model was used to simulate not only hydrodynamics and temperature but also eutrophic dynamics as well. The reservoir model uses version 3.2 of W2. Cole and Wells (2003) give a general description of the W2 model.

Liberty Reservoir was represented by 48 active, longitudinal segments in five branches in the W2 model. The segments contain anywhere between two to 45 one-meter thick layers. The simulation period for the model is 2000 to 2005. These six years provide a range of hydrological conditions, including wet years (2003 and 2004), a dry year (2002), and average years (2001 and 2005), thus fulfilling the requirement that TMDLs take into account a variety of hydrological conditions.

State variables in the W2 model include dissolved oxygen, ammonia, nitrate, dissolved inorganic phosphorus, and both dissolved and particulate organic matter (POM) in labile and refractory forms. In addition, a number of inorganic solids, carbonaceous biochemical oxygen demand (CBOD) variables, and algal species can be represented in the model. Organic nitrogen and phosphorus, however, are only implicitly represented through CBOD, organic matter, and algal biomass state variables. In order to preserve a mass balance of all species of phosphorus, the state variables in the W2 models were configured as follows:

1. Inorganic phosphorus attached to silt and clay was modeled as distinct inorganic solids. Sorption between sediment and the water column was not simulated in the model.
2. Three biochemical oxygen demand (BOD) variables were used to represent allochthonous organic matter inputs to the reservoir: (1) labile dissolved BOD, (2) labile particulate CBOD, and (3) refractory particulate CBOD. The concentration of these CBOD inputs was calculated based on the concentration of organic phosphorus in the HSPF model, using the stoichiometric ratio between phosphorus and oxygen demand in the reservoir model.
3. The organic matter state variables were reserved to represent the recycling of nutrients within the reservoir between algal biomass and reservoir nutrient pools. No organic matter, as represented by these variables, was input into the reservoir. They were used to track nutrients released from algal decomposition.

To use the W2 model in this configuration, several minor changes had to be made to the W2 version 3.2 code. Inorganic solids contribute to light extinction, but inorganic solids representing solid-phase phosphorus do not contribute to light extinction over and above the sediment to which they are attached. The W2 code was altered so solid-phase phosphorus would not contribute to light extinction. Second, in the W2 model, sediment oxygen demand (SOD) can be represented as a first-order reaction based on the quantity of labile organic matter that has settled to the bottom of a segment. In the original version 3.2 code, the CBOD variables do not settle and do not contribute to the pool of organic material in the sediments. The code was altered so that (1) CBOD species could be assigned a settling velocity, and (2) labile particulate CBOD contributed to sediment organic matter. Further details regarding the development of the Liberty Reservoir W2 model are discussed in the modeling report for this TMDL, *Modeling Framework for Simulating Hydrodynamics and Water Quality in Liberty Reservoir* (ICPRB 2012.

4.3 Scenario Descriptions and Results

4.3.1 Scenario Descriptions

TMDL development for the Liberty Reservoir consisted of the following four scenarios:

1. **Baseline Scenario**: The Baseline Scenario models the current phosphorus and sediment loads in the Liberty Reservoir watershed. These loads are shown in Tables 5 and 7 for phosphorus and sediments, respectively. The phosphorus and sediment loads from the CBP P5.3.2 2009 Progress Scenario were applied as the Baseline Scenario for the TMDLs. The 2009 Progress Scenario represents current land-use, loading rates, and BMP implementation within the Liberty Reservoir watershed. The scenario is simulated within the CBP P5.3.2 model using precipitation and other meteorological inputs from the time period of 1991 to 2000, in order to represent variable hydrological conditions. The 1991 to 2000 simulation period is used in all Chesapeake Bay TMDL scenarios to represent the impact of variable hydrology and meteorology. The 2009 Progress Scenario is used as the baseline scenario for the Chesapeake Bay TMDL, and it provides the best available representation of current conditions.

2. **Calibration Scenario**: The Calibration Scenario represents the actual phosphorus and sediment loads over the model simulation period of 2000 to 2005. The phosphorus and sediment loads in this scenario were used to calibrate the Liberty Reservoir W2 model. Loads from WWTPs and other point source discharges are based on reported flows and concentrations for the model simulation period. Loads from NPDES regulated urban land, as well as nonpoint source loads from forest and agricultural land, were estimated based on the calibration of the refined CBP P5.3.2 Liberty Reservoir watershed model.

3. **TMDL Scenario**: The TMDL Scenario represents the maximum allowable phosphorus and sediment loads the Liberty Reservoir can receive and still meet water quality standards, as predicted by the reservoir water quality model. Phosphorus and sediment loads from NPDES regulated urban stormwater and forested/agricultural nonpoint sources are reduced in the watershed model until the W2 reservoir model indicates that the relevant water quality conditions are in attainment with their criteria. Loads from process water point sources in the

TMDL Scenario are set based on their Wasteload Allocations (WLAs) specified within the Chesapeake Bay TMDL (EPA 2010a) and Maryland's Phase I and II Watershed Implementation Plans (MDE 2010b, 2012).

4. **All-Forest Scenario**: The All-Forest Scenario simulates the response of the reservoir to phosphorus, sediment, nitrogen, and BOD loads that would occur if all of the land in the reservoir's watersheds were forested (i.e., natural conditions). The All-Forest Scenario is used to determine the extent to which hypoxic conditions in the hypolimnion are a function of current watershed pollutant loadings or reservoir morphology. The All-Forest Scenario constitutes an estimate of hypolimnetic DO concentrations under natural conditions. Flows and temperature were taken from the Calibration Scenario, while constituent loads were taken from the HSPF model simulation, wherein all land in the watershed was converted to forest.

4.3.2 Calibration Scenario Results

The primary function of the Liberty Reservoir W2 model is to link algae biomass, as represented by Chla concentrations, to total phosphorus loads. The models were calibrated conservatively, so as to ensure that simulated Chla concentrations were at least as high as observed concentrations, even if maximum seasonal concentrations were shifted upstream or downstream in simulation, or if they occurred a month earlier or later than the corresponding observed concentrations. The unprecedented 2004 winter bloom, which is unrepresentative of long-term conditions in the reservoir, was not simulated in the W2 model. Figure B-1 in Appendix B compares the observed and simulated maximum Chla concentrations by season at station NPA042. The W2 model captures the maximum seasonal Chla concentrations except during the winters of 2003, 2004, and 2005. The model generally captures the observed peak seasonal average Chla concentrations, though sometimes they are shifted spatially or temporally. Figure B-2 in Appendix B compares the simulated and observed cumulative distributions of Chla concentrations at station NPA042 in Liberty Reservoir.

Figure B-3 compares simulated and observed average surface DO concentrations at station NPA042 in Liberty Reservoir. Figure B-4 shows the simulated and observed average bottom DO concentrations. The figure indicates that the model accurately captures the seasonal trend in bottom DO. The coefficients of determination between the observed and simulated DO concentrations are 0.49 and 0.75 in the surface and bottom layers of the reservoir, respectively.

Appendix C contains time series plots comparing simulated and observed concentrations of phosphate, total phosphorus, nitrate, ammonia, and total nitrogen at all four BCDPW monitoring stations.

4.3.3 TMDL Scenario Results

The Liberty Reservoir W2 model was used to calculate the maximum total phosphorus load the reservoir can assimilate and still meet water quality standards. Simulated phosphorus and sediment loads were reduced until two conditions were met: (1) the ninetieth percentile of simulated Chla concentrations in any W2 model cell did not exceed 30 µg/l, and (2) the 30-day moving average Chla concentration of each W2 model cell within approximately 50 feet of the surface was not greater than 10 µg/l. Figure B-5 in Appendix B compares maximum surface layer Chla concentrations from the Calibration and TMDL Scenarios to the observed maximum surface layer concentrations by date at BCDPW monitoring station NPA042.

The TMDL Scenario was also used to evaluate whether the reservoir would meet the DO criteria for Use I-P waters at the scenario's calculated phosphorus and sediment loadings. Figure B-6 shows the average surface DO concentrations at station NPA042 in Liberty Reservoir, based on a screening depth of ten feet. To more accurately screen for potential violations, the position of the well-mixed surface layer was estimated on a daily basis, thereby providing for a more precise evaluation (daily comparison) in the surface layer of DO concentrations versus the Use I-P DO criterion. Instantaneous DO concentrations were output from all cells in the surface layer at half-day intervals. In the TMDL scenario, there is no cell in the surface layer of the reservoir with an instantaneous DO concentration less than 5.0 mg/l except during periods such as the fall overturn, when the surface layer deepens and entrains water with low DO concentrations from the metalimnion.

Even in the TMDL Scenario, seasonal hypoxia persists in the hypolimnion of Liberty Reservoir. Figure B-7 in Appendix B shows the average bottom DO concentrations at the downstream BCDPW monitoring stations in the reservoir. As the figure indicates, although the average DO concentration in the bottom layer increases in the TMDL Scenario, the reservoir still does not maintain a DO concentration greater than 5.0 mg/l in the hypolimnion throughout the simulation period.

4.3.4 All-Forest Scenario Results

As explained previously in Section 4.3, the purpose of the All-Forest Scenario is to aid in assessing whether hypoxic conditions in the bottom layers of Liberty Reservoir are primarily due to 1) the stratification of the reservoir caused by its morphology, or 2) current nutrient inputs from the reservoir watershed. If hypoxia occurs even under all-forested watershed conditions and associated nutrient loadings, then reservoir stratification is the primary cause of hypoxia in the hypolimnion. Consequently, the reservoir would be meeting the applicable water quality standards for DO in Use I-P waters, as interpreted for reservoirs and impoundment (see Section 2.3 for further details).

Average annual TP loads in the Liberty Reservoir All-Forest Scenario are 24% of the TP loads in the Calibration Scenario. The reduction in average annual loads of POM, the precursor to sediment oxygen demand, is less; average annual POM loads in the Liberty Reservoir All-Forest Scenario are 33% of the load in the Calibration Scenario.

Figure 7 below shows the average bottom DO concentrations in the All-Forest Scenario at one of the downstream monitoring stations in the reservoir. The minimum DO concentration at the monitoring station is also shown. Average DO in the bottom layer of the reservoir improves considerably under the All-Forest Scenario. The minimum DO concentration, however, frequently drops below 5.0 mg/l. Even under the All-Forest Scenario, the hypolimnion remains hypoxic in many (but not all) years of the simulation.

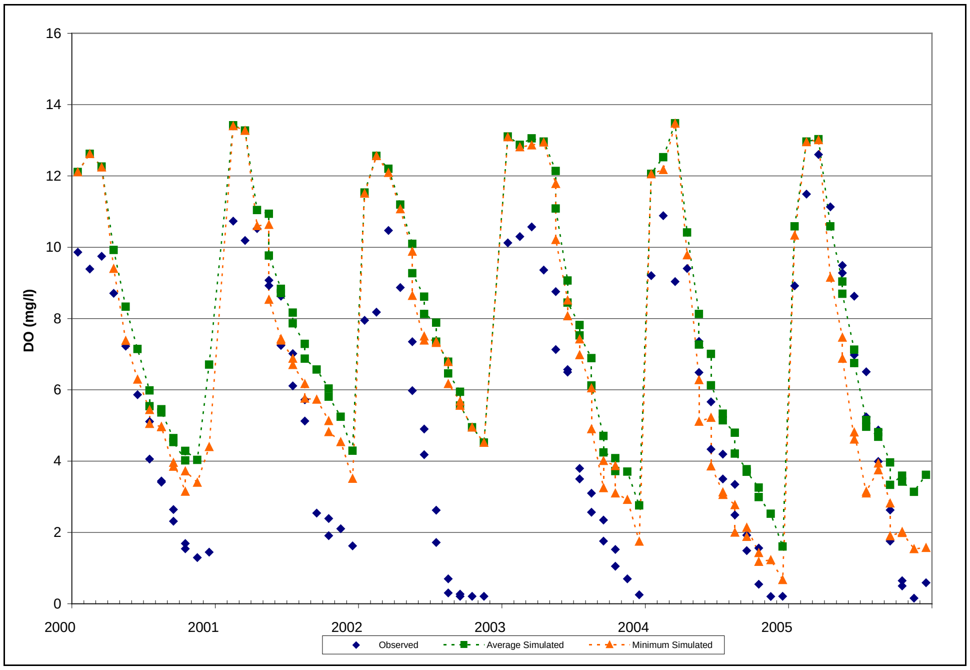

Figure 7: Liberty Reservoir BCDPW Station NPA0042 Observed and Simulated (All-Forest Scenario) Bottom DO Concentrations on Sampling Dates

A sensitivity analysis was performed to better determine how phosphorus and organic matter loading rates impact hypoxia in the hypolimnion. External loading rates of particulate organic matter were reduced to 50%, 20% and 10% of the loads of the All-Forest Scenario, and the percent of sampling dates where DO < 2.0 mg/l at the sampling locations was calculated. Figure 8 shows the results. Hypoxia persists even when loads are reduced to only 20% of the All-Forest Scenario. Although hypoxia disappears when loading rates are 10% of the All-Forest Scenario, 17% of sampling dates under those loading conditions still have DO concentrations less than 5 mg/l in the hypolimnion. The sensitivity analysis shows that low DO in the bottom layers of the reservoirs is relatively insensitive to the particular assumptions used to determine organic matter loads in the models, and demonstrates that hypolimnetic hypoxia is primarily driven by stratification and reservoir morphology, rather than by external loads.

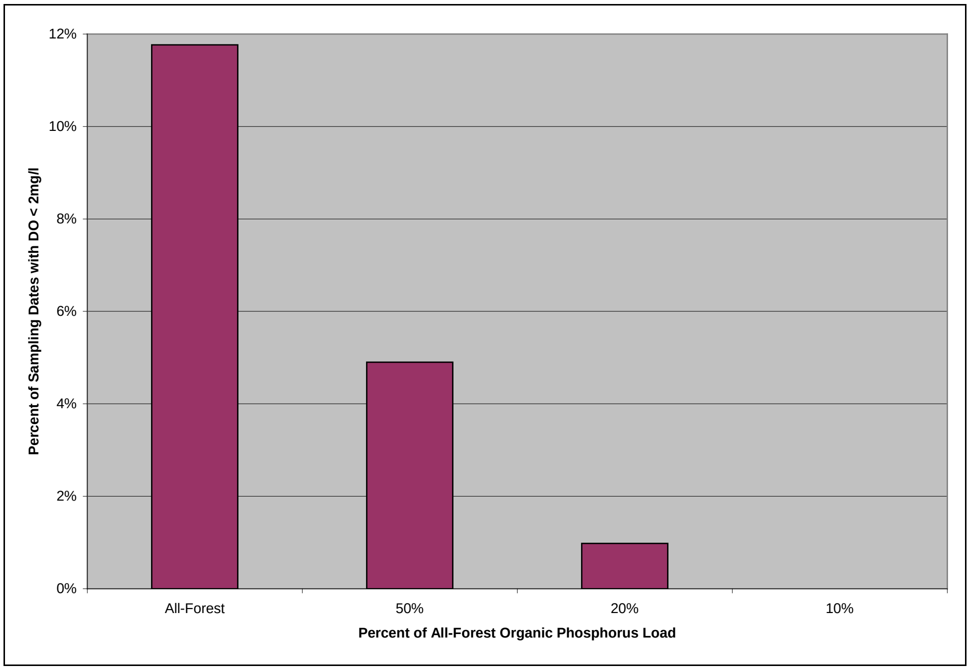

Figure 8: Liberty Reservoir Percent of Sampling Dates on which DO < 2mg/l, as a Function of Percent Particulate Organic Phosphorus

The All-Forest Scenario demonstrates that current phosphorus and sediment loads, and the loads simulated in the TMDL Scenario, do not result in hypoxic conditions that significantly exceed those associated with the natural conditions in the watershed. To an extent, low DO concentrations in the bottom layer of the reservoir are a naturally occurring condition, as described by the interpretation of Maryland's water quality standards for DO in Use I-P waters for reservoirs and impoundments. The TMDL Scenario thus meets water quality standards for DO as per this interpretation.

4.4 Critical Conditions and Seasonality

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2012b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable.

The phosphorus and sediment loading rates applied within the analysis are reflective of long term average annual loads, and the water quality response in the reservoir to various nutrient inputs was modeled using a continuous simulation model with a six year simulation period from 2000-2005. The six year simulation period encompasses seasonal variations and a range of hydrological and meteorological conditions, including a very dry year (2002) and very wet years (2003 and 2004). Thus, critical conditions and seasonality are implicitly addressed in the analysis.

4.5 TMDL Loading Caps

4.5.1 Phosphorus TMDL Loading Cap

This section presents the average annual phosphorus TMDL for Liberty Reservoir. The TMDL was established based on the modeled phosphorus loadings within the TMDL Scenario, as described in Section 4.3, and the resulting water quality response in the reservoir for the simulated years of 2000 to 2005, which demonstrated achievement of the applicable Chla and DO water quality standards for Use I-P waters. This model simulation time period was used to estimate the TMDL because it is suitable for calculating long-term average loading rates. It includes a dry year as well as very wet years and therefore takes into account a variety of hydrological conditions. Chla concentrations indicative of eutrophic conditions can occur at any time of year, and the model simulation time period encompasses the complete spectrum of observed, seasonal concentrations (see Tables B-1 and B-5 in Appendix B). Low DO concentrations in the hypolimnion that occur seasonally each year are also captured in the model.

In order to attain the phosphorus TMDL loading cap calculated for the reservoir, reductions will be applied to the controllable sources in the watershed. The controllable sources include: (1) NPDES regulated urban land; (2) high till crops, low till crops, hay, and pasture; (3) harvested forest; (4) unregulated AFOs and regulated CAFOS; and (5) industrial process water discharges. If the TMDL loading cap can not be achieved by applying reductions to solely the controllable sources, additional sources might need to be identified and controlled in order to ensure that the water quality standards are attained.

The Liberty Reservoir Total Phosphorus Baseline Load, TMDL, and reduction percentage are presented in Table 11. An overall phosphorus reduction of 46% from current estimated loads will be required to meet the TMDL and attain Maryland's applicable water quality standards for Use I-P waters.

Table 11: Liberty Reservoir Phosphorus TMDL

Baseline Load (lbs/yr)	**TMDL** (lbs/yr)	**Reduction** (%)
75,977	41,009	46

4.5.2 Sediment TMDL Loading Cap

Excess sedimentation reduces a reservoir's storage capacity and therefore negatively impacts its ability to function as a water supply reservoir. Since Liberty Reservoir is a Use I-P waterbody, designated as a public water supply reservoir, this excess sedimentation interferes with the designated use of the waterbody and therefore violates the general, narrative water quality standard applicable to the reservoir. Additionally, excessive sedimentation can also negatively impact a reservoir's fishery and interfere with its recreational uses. Although the maximum sedimentation rates occur during wet weather events, it is the cumulative effect of sedimentation that impacts the reservoir. No single, critical time period can be defined relative to the impact that sedimentation has on water quality in the reservoir. An excessive sedimentation rate negatively impacts a reservoir, regardless of when it occurs. Therefore, efforts to reduce sediment loadings to the reservoir should focus on achieving effective, long-term sediment control. Since measures to control phosphorus can also effectively reduce sedimentation, the expected sediment reduction can be estimated based on the degree of phosphorus control needed to achieve water quality standards in the reservoir.

To quantify the sediment reduction associated with the total required phosphorus reduction for the reservoir, modeling assumptions applied within the CBP P5.3.2 watershed model were applied. For agricultural BMPs that control both phosphorus and sediments, EPA's CBP estimates a 1:1 reduction in sediments, as a result of controlling phosphorus (US EPA 1998). This ratio, however, does not account for phosphorus controls that do not remove sediments.

To estimate the applicable ratio between phosphorus and sediment reductions, it is necessary to estimate the proportion of the phosphorus reduction controls that remove sediments versus those that do not. In general, soil conservation and water quality plans (SCWQPs) remove sediments as well as phosphorus, while nutrient management plans (NMPs) do not. It is assumed that 50% of the phosphorus reduction in the Liberty Reservoir watershed will come from SCWQPs and 50% will come from NMPs. This results in a 0.5:1 ratio of sediment reduction to phosphorus reduction. The net sediment reduction associated with a 46% phosphorus reduction from nonpoint sources is about 23% (0.46 * 0.5 = 0.23).

It is assumed that a reduced sediment loading rate would result in a similar reduction in the sediment accumulation rate in the reservoir. The sediment accumulation rate estimated to result from this reduced loading rate would allow for the retention of 99% of the reservoir's overall, original volume after 40 years.

MDE contends that this volumetric retention will support the Use I-P designated use of Liberty Reservoir: water contact recreation, protection of aquatic life, and public water supply. This estimate is reasonably consistent with technical guidance provided by EPA Region III, which estimates a 0.7:1.0 reduction in sediment relative to phosphorus reductions (US EPA 1998). This rule-of-thumb would yield a 32 % estimated reduction in sediment [100*(0.46 * 0.70) = 32%]

The Liberty Reservoir Sediment TMDL assumes that a 46% reduction in total phosphorus load results in a 23% reduction in sediment load. The Liberty Reservoir Total Sediment Baseline Load, TMDL, and reduction percentage are presented in Table 12.

Table 12: Liberty Reservoir Sediment TMDL

Baseline Load (tons/yr)	**TMDL** (tons/yr)	**Reduction** (%)
20,767	15,988	23%

In order to attain the sediment TMDL loading cap calculated for the reservoir, reductions will be applied to the controllable sources in the watershed. The controllable sources include: (1) NPDES regulated urban land; (2) high till crops, low till crops, hay, and pasture; (3) harvested forest; (4) unregulated AFOS and regulated CAFOS; and (5) industrial process water discharges. If the TMDL loading cap can not be achieved by applying reductions to solely the controllable sources, additional sources might need to be identified and controlled in order to ensure that the water quality standards are attained.

4.6 Load Allocations Between Point and Nonpoint Sources

Per EPA regulation, all TMDLs need to be presented as a sum of WLAs for point sources and Load Allocations (LAs) for nonpoint source loads generated within the assessment unit, as accounting for natural background, tributary, and adjacent segment loads (CFR 2012a). Consequently, the Liberty Reservoir watershed TMDL allocations are presented in terms of WLAs (i.e., point source loads identified within the watershed) and LAs (i.e., the nonpoint source loads within the watershed). The State reserves the right to allocate the TMDL among different sources in any manner that is reasonably calculated to protect the designated use of the reservoir from nutrient and sediment related impacts.

Table 13 summarizes the TMDL Scenario results for phosphorus, and Table 14 summarizes the TMDL Scenario results for sediment. The source categories are based on multiple sources (e.g., high till, low till, and hay are all considered crop sources). In this watershed, crops, pasture, nurseries, NPDES regulated urban land, AFOs, CAFOs, and industrial process water facilities were identified as the predominant controllable sources. Forest is the primary non-controllable source, as it represents the most natural condition in the watershed. Direct atmospheric deposition on water is a minor source that primarily originates outside of the watershed. Atmospheric deposition will be reduced by existing state and federal programs and therefore is not addressed in this TMDL. There are no CSOs in the Liberty Reservoir watershed, and phosphorus and sediment loads from septic systems are considered insignificant.

Table 13: Liberty Reservoir Phosphorus TMDL Reductions by Source Category

Baseline Load Source Categories		Baseline Load (lbs/yr)	TMDL Components	TMDL (lbs/yr)	Reduction (%)
Nonpoint Source	Forest	7,143	**LA**	6,898	3
	AFOs	831		42	95
	Pasture	4,216		518	88
	Crop	27,853		8,689	69
	Nursery	10,149		7,477	26
	Atmospheric Deposition	1,230		1,230	0
	Extractive	0		0	0
	Subtotal	**51,421**		**24,853**	**52**
Point Source	CAFOs	1,060	**WLA**	430	59
	Regulated Urban	20,088		11,177	44
	Process Water	3,409		2,498	27
	Subtotal	**24,556**		**14,105**	**43**
MOS[1]				2,050	
Total		**75,977**		**41,009**	**46**

Note: [1] See Section 4.7 for further details regarding the MOS.

Table 14: Liberty Reservoir Sediment TMDL Reductions by Source Category

Baseline Load Source Categories		Baseline Load (lbs/yr)	TMDL Components	TMDL (lbs/yr)	Reduction (%)
Nonpoint Source	Forest	3,228	**LA**	3,153	2
	AFOs	45		43	5
	Pasture	423		307	27
	Crop	8,842		6,774	23
	Nursery	182		161	12
	Atmospheric Deposition	0		0	0
	Extractive	0		0	0
	Subtotal	**12,720**		**10,438**	**18**
Point Source	CAFOs	11	**WLA**	5	50
	Regulated Urban	8,021		5,484	32
	Process Water	15		61	0
	Subtotal	**8,047**		**5,550**	**31**
MOS[1]				Implicit	
Total		**20,767**		**15,988**	**23**

Note: [1] See Section 4.7 for further details regarding the MOS.

The Liberty Reservoir TMDLs require a 52% reduction in phosphorus loads and a 18% reduction in sediment loads from nonpoint sources, primarily agricultural land-uses (See Tables 13 and 14). Equal percent reductions were applied to the current controllable loads from nonpoint sources. Current controllable loads were determined as the difference between the CBP P5.3.2 2009 Progress Scenario and the "E3" Scenario, where the E3 Scenario represents the application of all possible BMPs and control technologies to current land-uses and point sources. All of the urban stormwater nutrient and sediment loads within the watershed are regulated via NPDES stormwater permits, and therefore they included in the WLA. For more detailed information regarding the Liberty Reservoir TMDL nonpoint source allocations, please see the technical memorandum to this document entitled "*Significant Phosphorus and Sediment Nonpoint Sources in the Liberty Reservoir Watershed*".

The WLA of the Liberty Reservoir watershed is allocated to three permitted source categories: Process Water WLA, Stormwater WLA, and CAFO WLA. The categories are described below.

Process Water WLA

Process Water permits capable of discharging TP and TSS are assigned to the WLA. There are no municipal WWTPs in the Liberty Reservoir watershed; however, there are eleven industrial process water sources in the watershed that are capable of discharging TP and TSS (four major facilities and seven minor facilities). Within the Chesapeake Bay TMDL, industrial facilities capable of discharging phosphorus or sediment in their process water were assigned a WLA based on monitoring data collected as part of their permit requirements or best professional judgment. These WLAs were adopted for the Liberty Reservoir Phosphorus and Sediment TMDLs.

The Liberty Reservoir Phosphorus TMDL requires a 27% reduction in phosphorus loads from process water sources (See Table 13). No reduction is required in sediment loads from process water sources (See Table 14). Allocations for minor industrial facilities are presented in the Chesapeake Bay TMDL as a watershed-wide aggregate WLA. A similar approach was adopted for the Liberty Reservoir TMDL, and all minor industrial process water facility allocations are represented as a watershed-wide WLA. A list of the industrial process water facilities within the watershed, information pertaining to these permits, information regarding the individual allocations to the major facilities, and information related to the minor facilities included in the aggregate WLA are provided in the technical memorandum to this document entitled "*Significant Phosphorus and Sediment Point Sources in the Liberty Reservoir Watershed*".

Stormwater WLA

Per EPA requirements, "stormwater discharges that are regulated under Phase I or Phase II of the NPDES stormwater program are point sources that must be included in the WLA portion of a TMDL" (US EPA 2002). Phase I and II permits can include the following types of discharges:

- small, medium, and large MS4s – these can be owned by local jurisdictions, municipalities, and state and federal entities (i.e., departments of transportation, hospitals, military bases, etc.),
- industrial facilities permitted for stormwater discharges, and
- small and large construction sites

EPA recognizes that available data and information are usually not detailed enough to determine WLAs for NPDES regulated stormwater discharges on an outfall-specific basis (US EPA 2002). Therefore, NPDES regulated stormwater loads within the Liberty Reservoir watershed TMDL will be expressed as a single NPDES stormwater WLA. Upon approval of the TMDL, "NPDES-regulated municipal stormwater and small construction storm water discharges effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002).

The Liberty Reservoir NPDES Stormwater WLAs are based on reductions applied to the current controllable phosphorus and sediment loads from the urban land-use in the watershed and may include legacy or other sources. Some of these sources may also be subject to controls from other management programs. An equal percent reduction was applied to the controllable loads amongst the predominant, controllable nonpoint sources, as described previously in this section; however, the reduction for the NPDES regulated stormwater source sector was not allowed to exceed 75% of the controllable load, since this has been defined by MDE as the maximum feasible reduction for the individual source sector. The Liberty Reservoir NPDES stormwater WLA requires an overall reduction of 44% for phosphorus (See Table 13) and 32 % for sediment (See Table 14). As stormwater assessment and/or other program monitoring efforts result in a more refined source assessment, MDE reserves the right to revise the current NPDES stormwater WLAs provided the revisions are reasonably calculated to protect the designated use of the reservoir from nutrient and sediment related impacts.

For a detailed list of all NPDES regulated stormwater discharges within the watershed and further information regarding the distribution of NPDES stormwater WLAs among these discharges, please see the technical memorandum to this document entitled "*Significant Phosphorus and Sediment Point Sources in the Liberty Reservoir Watershed*".

CAFO WLA

As per the CWA all CAFOs are required to obtain NPDES permits for their discharges or potential discharges (CFR 2012c). In January, 2009, Maryland implemented new regulations governing CAFOs (COMAR 2012f,g), which were approved by the EPA in January, 2010. Under these regulations, CAFOs are required to fulfill the conditions of a general permit. These conditions include instituting a Comprehensive Nutrient Management Plan (CNMP) that meets the Nine Minimum Standards to Protect Water Quality. The general permit also prohibits the discharge of pollutants, including nutrients, from CAFO production areas except as the result of an event greater than the

25-year, 24-hour storm. For phosphorus, a maximum 75% percent reduction was applied to current controllable loads from CAFOs, and for sediment, an equal percent reduction of current controllable loads was taken from CAFOs as well as from nonpoint sources and regulated stormwater. Overall, a 59% reduction in phosphorus loads and 50% reduction on sediment loads are required from CAFOs in the Liberty Reservoir TMDLs.

4.7 Margins of Safety

All TMDLs must include a margin of safety to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2012b). The MOS shall also account for any rounding errors generated in the various calculations used in the development of the TMDL. The MOS is intended to account for such uncertainties between pollutant loads and water quality response in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through two approaches (US EPA 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = LA + WLA + MOS). The second approach is to incorporate the MOS as conservative assumptions used in the TMDL analysis. Maryland has adopted a MOS for nutrient TMDLs using the first approach. The reserved load allocated to the MOS was computed as 5% of the total phosphorus load. The explicit phosphorus MOS for Liberty Reservoir is 2,050 lbs/yr.

In establishing a MOS for sediments, Maryland has adopted an implicit approach by incorporating conservative assumptions. First, because phosphorus binds to sediments, sediment loads will be controlled as a result of controlling phosphorus loads. This estimate of sediment reduction is based on the phosphorus LAs and WLAs, rather than the entire phosphorus TMDL including the MOS. Thus, the explicit 5% MOS for phosphorus will result in an implicit MOS for sediments. This conservative assumption results in a difference of about 280tons/yr (see Section 4.5 above for a discussion of the relationship between the reductions in phosphorus and sediments). Secondly, as described in Section 4.4.2, MDE conservatively assumes a sediment-to-phosphorus reduction ratio of 0.5:1, rather than 0.7:1 estimated in the technical guidance provided by EPA Region III. Table 15 compares the volumetric preservation of the Liberty Reservoir as per the TMDL Scenario with the volumetric preservation of several other approved TMDLs.

Table 15: Sediment TMDL Volumetric Preservation of Impoundments

TMDL	State	VOLUMETRIC PRESERVATION (TMDL time-span)	VOLUMETRIC PRESERVATION (100 year time span)
Urieville Community Lake	Maryland	76% after 40 years	40%
Tony Tank Lake	Maryland	64% – 85% after 40 years	10% to 62.5%
Hurricane Lake	West Virginia	70% after 40 yrs	25%
Tomlinson Run Lake	West Virginia	30% after 40 yrs	Silted in
Clopper Lake	Maryland	98% - 99% after 40 years	96% to 98%
Centennial Lake	Maryland	68% - 87% after 40 years	20% to 69%
Lake Linganore	Maryland	52% - 80% after 40 years	Silted in to 52%
Loch Raven Reservoir	Maryland	85% after 50 years	80%
Triadelphia Reservoir	Maryland	95% after 40 years	87%
Liberty Reservoir	Maryland	99% after 40 years	96%

4.8 Summary of Total Maximum Daily Loads

The Average Annual Liberty Reservoir Phosphorus TMDL is summarized in Table 16. The TMDL is the sum of the LA, NPDES Stormwater WLA, Process Water WLA, CAFO WLA, and MOS. The Maximum Daily Load (MDL) is summarized in Table 17 (See Appendix D for more details).

Table 16: Average Annual Liberty Reservoir Phosphorus TMDL (lbs/yr)

TMDL (lbs/yr)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**	+	**MOS**
41,009	=	24,853	+	430	+	11,177	+	2,498	+	2,050

Table 17: Liberty Reservoir Phosphorus MDL (lbs/day)[1]

MDL (lbs/day)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**	+	**MOS**
300.3	=	180.0	+	3.1	+	80.9	+	21.2	+	15.0

Note: [1]lbs/day: pounds per day.

The Average Annual Liberty Reservoir Sediment TMDL is summarized in Table 18. The TMDL is the sum of the LA, NPDES Stormwater WLA, Process Water WLA, CAFO WLA, and MOS. The MDL is summarized in Table 19 (See Appendix D for more details).

Table 18: Average Annual Liberty Reservoir Sediment TMDL (tons/yr)

TMDL (tons/yr)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**		**MOS**
15,988	=	10,438	+	5	+	5,484	+	61	+	Implicit

Table 19: Liberty Reservoir Sediment MDL (tons/day)

MDL (tons/day)	=	**LA_{LR}**	+	**CAFO WLA_{LR}**	+	**NPDES Stormwater WLA_{LR}**	+	**Process Water WLA_{LR}**		**MOS**
51.6	=	33.5	+	0.02	+	17.6	+	0.5	+	Implicit

5.0 ASSURANCE OF IMPLEMENTATION

Section 303(d) of the CWA and current EPA regulations require reasonable assurance that the TMDL LAs and WLAs can and will be implemented. This section provides the basis for reasonable assurances that the Liberty Reservoir Phosphorus and Sediment TMDLs will be achieved and maintained.

Since 1979, Baltimore City, Baltimore County, and Carroll County have had in place a formal agreement to manage the Liberty Reservoir watershed, and, since 1984, these agreements have been accompanied by an action strategy with specific commitments from the signatories. A revised Reservoir Watershed Management Agreement was signed in 2005, accompanied by a revised Action Strategy. Table 20 lists the parties to the 2005 agreement and some of their major commitments made in the Action Strategy.

Table 20: Signatories to the 2005 Reservoir Management Agreement and the Major Commitments of the 2005 Action Strategy[1]

Maryland Department of the Environment	1. Use NPDES program to discourage significant phosphorus discharges in reservoir watersheds from package plants and new industrial dischargers.
Maryland Department of Agriculture	1. Enforce the provisions of Maryland Water Quality Improvement Act of 1998. 2. Offer assistance through the Maryland Agriculture Cost-Share Program. 3. Target assistance to farm operations having problems with the potential to cause water pollution.
Baltimore City	1. Continue water quality monitoring of reservoirs.
Baltimore County	1. Continued water quality monitoring of tributaries. 2. Maintain Resource Conservation zoning in the reservoir watersheds and maintain insofar as possible the Urban-Rural Demarcation Line. 3. Conduct programs of street-sweeping, storm drain-inlet cleaning, and storm pipe cleaning in urban areas.
Carroll County	1. Require enhanced stormwater management practices for all new development in reservoir watersheds. 2. Use master land-use plans to support Reservoir Management Agreement. 3. Limit insofar as possible additional urban development zoning with the reservoir watersheds.
Baltimore County Soil Conservation District Carroll County Soil Conservation District	1. Encourage farmers to participate in federal and state assistance programs that promote soil conservation and the protection of water quality. 2. Prepare Soil Conservation and Water Quality Plans for each farm in the reservoir watersheds, update plans where necessary, and assist operators in implementing them. 3. Encourage and assist operators to comply with nutrient management plans mandated under the Maryland Water Quality Improvement Act.
Baltimore Metropolitan Council	1. Provide staff for coordination and administration of the Reservoir Technical Program through the financial support of its member jurisdictions.

Note: [1]Source: (RTG 2005)

<u>Maryland Legislative Actions and Funding Programs to Support TMDL Implementation</u>

Maryland recently enacted significant new legislation that requires Phase I MS4 jurisdictions to establish, by July 1, 2013, an annual stormwater remediation fee and a local watershed protection and restoration fund to support implementation of local stormwater management plans. Maryland has made a commitment to include provisions in Phase I and II MS4 permits, due for issuance in 2012, to reduce nutrient and sediment loads from urban stormwater sources.

MD's Water Quality Improvement Act of 1998 (WQIA) requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout MD. This act specifically required such plans for nitrogen be developed and implemented by 2002, and plans for phosphorus be completed by 2005.

Additional potential funding sources for implementation include Maryland's Agricultural Cost Share Program (MACS), which provides grants to farmers to help protect natural resources, and the Environmental Quality and Incentives Program, which focuses on implementing conservation practices and BMPs on land involved with livestock and production.

Maryland is also working to adopt a revised Phosphorus Site Index (PSI) and incorporate the new PSI into nutrient management plans in preparation for the 2013 crop season (winter 2012-2013).

To enhance Urban Nutrient Management as a nutrient reduction strategy, the State is working to develop regulations to implement the Fertilizer Use Act. This will: limit nitrogen & phosphorus content in fertilizer content and use on non-agricultural land; require certification and training for non-agricultural applicators; require certain fertilizer product labeling; and require outreach and education programs for homeowner fertilizer use.

Liberty Reservoir Phosphorus and Sediment TMDLs and the Chesapeake Bay TMDL and WIPs

Although the Liberty Reservoir watershed does not deliver significant phosphorus and sediment loads to the Chesapeake Bay, implementation of the Liberty Reservoir TMDLs is expected to benefit from the programs Maryland has put in place to implement the nitrogen and phosphorus load reductions that will be required to meet the Chesapeake Bay TMDL recently established by EPA (US EPA 2010a), as well as Maryland's Phase I and II Watershed Implementation Plans (WIPs), which were developed to provide implementation strategies to achieve the Chesapeake Bay TMDL required nutrient and sediment reductions (MDE 2010b, 2012a).

Maryland had been working with key local partners, including county and municipal staff, soil conservation managers, and a variety of stakeholder organizations and business interests, to help them develop local implementation plans at the county scale. During these interactions, MDE had been emphasizing to the local jurisdictions to focus their efforts on improving water quality in their local rivers, streams, and impoundments. These local plans have been incorporated into the basin-scale implementation plans in the Phase II WIP, which was finalized in July 2012.

Accounting, tracking, and reporting are an important part of the overall WIP strategy, and progress will be closely monitored by tracking both implementation and water quality. This framework of accounting, tracking, and reporting also applies to the Liberty Reservoir phosphorus and sediment TMDLs. This approach provides further assurance that the implementation of the Liberty Reservoir phosphorus TMDL will be achieved through increased accountability and verification of water quality improvements over time.

Certain legislation and funding programs, in addition to those identified previously, have been specifically created relative to the Chesapeake Bay TMDL (US EPA 2010a) and Maryland’s Phase I and II WIPs (MDE 2010b,2012a). These pieces of legislation and funding programs are as follows:

Maryland has enacted significant new legislation to increase the Bay Restoration Fund to provide financing for wastewater treatment plant upgrades and on-site septic system improvements, as well as legislation to guide growth of central sewer and septic systems and the application of cover crops by individual farmers. These new laws will support local efforts to reduce nutrient loads in both non-tidal watersheds and in downstream tidal waters of the Chesapeake Bay. In the Liberty Reservoir MD 8-Digit watershed, only the cove crop portion of these funds are applicable, since there are no wastewater treatment plants in the watershed and septic systems have no associated phosphorus loadings, only nitrogen.

In response to the WIPs and the increased burden on local governments to achieve nutrient reduction goals, Maryland has continued to increase funding in the Chesapeake and Atlantic Coastal Bays Trust Fund. For Fiscal Year 2013, in addition to $25 million (pending) for the Trust Fund, $38 million in general obligation bonds were made available to local communities for implementation of stormwater capital improvements. These funds will not only kick start restoration at the local level, but also create and retain green jobs in Maryland's economy. Funding was also increased to support implementation of natural filters on public lands ($9 million), and funding for Soil Conservation Districts from 16 to 39 positions ($2.2 million). In addition, funding for the cover crop program is at $12 million – a record level.

For the 2012-2013 milestone period for the Chesapeake Bay TMDL, Maryland is working to: restrict fall fertilization of small grain crops on soil testing above a given nitrate level thresholds; require incorporation of organic nutrient sources (with some exceptions); limit fall applications of organic nutrient sources; and, require a cover crop following fall applications of organic nutrient sources. Future changes: nutrient application setbacks of 10-35 feet (depending upon application methods) will be required (2014); best management practices will be required for streams with adjacent livestock (2014); winter application of all organic nutrient sources will be prohibited (2016-2020).

NPDES Regulated Stormwater WLA Implementation

Implementation of the required urban sediment and phosphorus load reductions is expected to occur primarily via the Phase I MS4 permitting process for medium and large municipalities, specifically, in this watershed, the Carroll and Baltimore County Phase I MS4 permits, which require the jurisdictions to retrofit 10% of their existing impervious area where there is failing, minimal, or no stormwater management (estimated to be areas developed prior to 1985) every permit cycle, or five years. These Phase I MS4 jurisdictions should work with other regulated stormwater entities in the watershed (please see the technical memorandum to this document entitled "*Significant Point Sources in the Liberty Reservoir Watershed*") during the implementation process to achieve the necessary reductions.

It has been estimated that the average removal efficiencies for BMPs installed between the years of 1985-2002 and post 2002, respectively, which are reflective of the stormwater management regulations in place during these time periods, are 30% and 40% for TP and 50% and 80% for TSS (Claytor and Schueler 1997; Baldwin et al. 2007; Baish and Caliri 2009). Based on these average TP and TSS reduction efficiencies, BMP specific reduction efficiencies as estimated by CBP, and best professional judgment, MDE estimates that future stormwater retrofits, which are expected to be implemented as part of the retrofit requirement to existing impervious land every five years (MDE 2012b), will have approximately a 35% reduction efficiency for TP and a 65% reduction efficiency for TSS. These estimated reduction efficiencies are subject to change over time as technology improves and the amount of data gathered from monitoring these retrofits increases. Additionally, any new development in the watershed will be subject to Maryland's Stormwater Management Act of 2007 and will be required to use environmental site design (ESD) to the maximum extent practicable.

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Appendix A

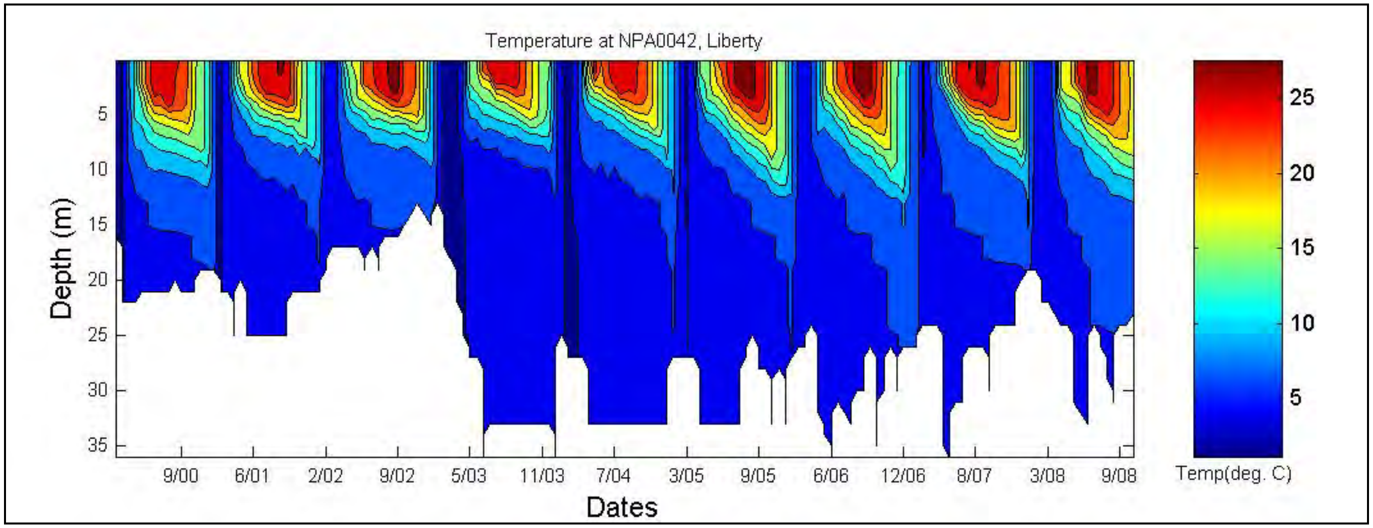

Figure A-1: Liberty Reservoir BCDPW Station NPA0042 Isothermal Contours (2000–2008)

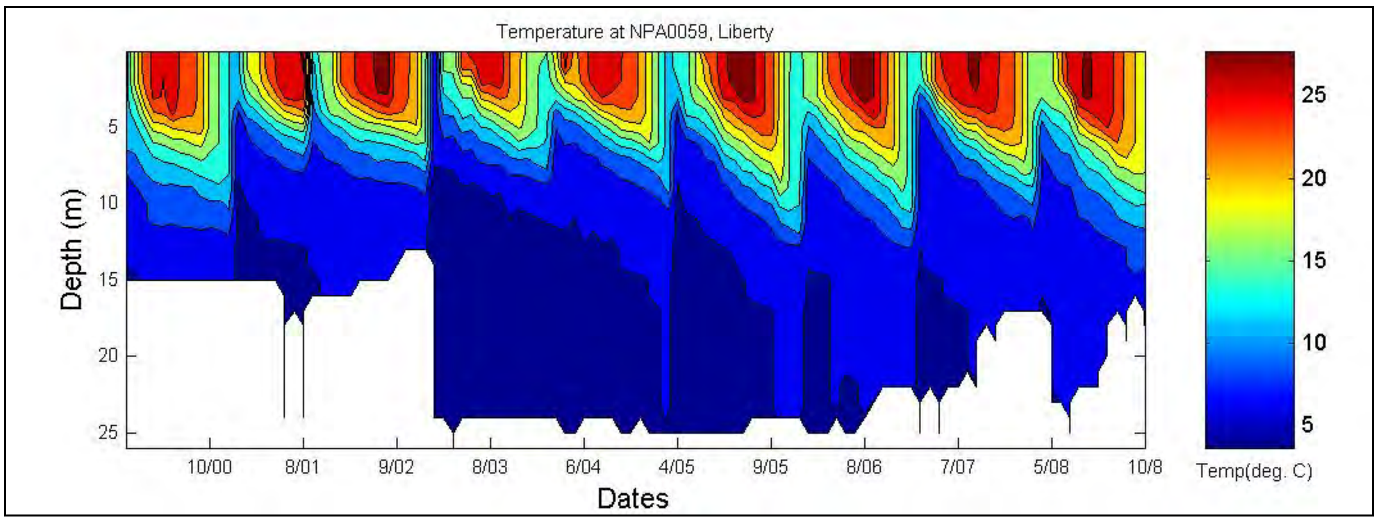

Figure A-2: Liberty Reservoir BCDPW Station NPA0059 Isothermal Contours (2000–2008)

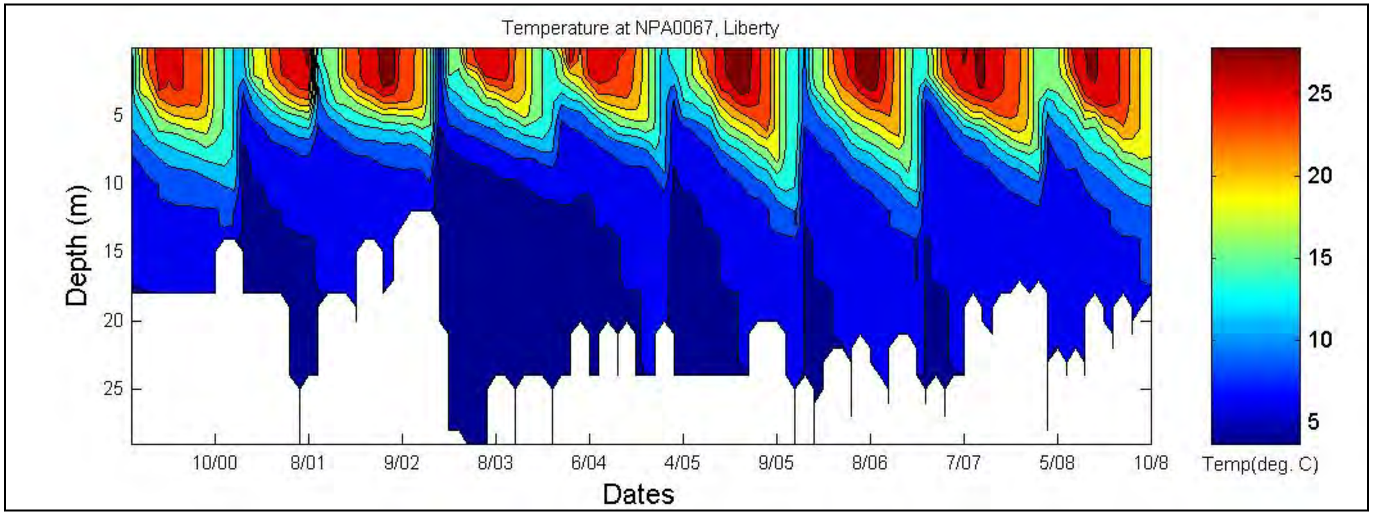

Figure A-3: Liberty Reservoir BCDPW Station NPA0067 Isothermal Contours (2000-2008)

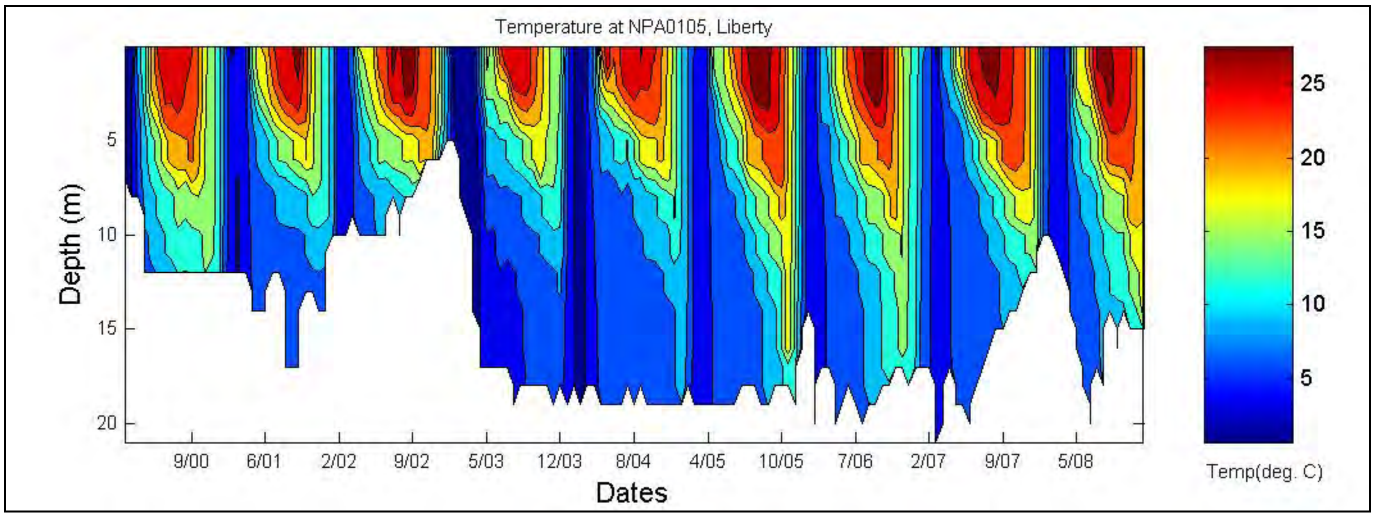

Figure A-4: Liberty Reservoir BCDPW Station NPA0105 Isothermal Contours (2000-2008)

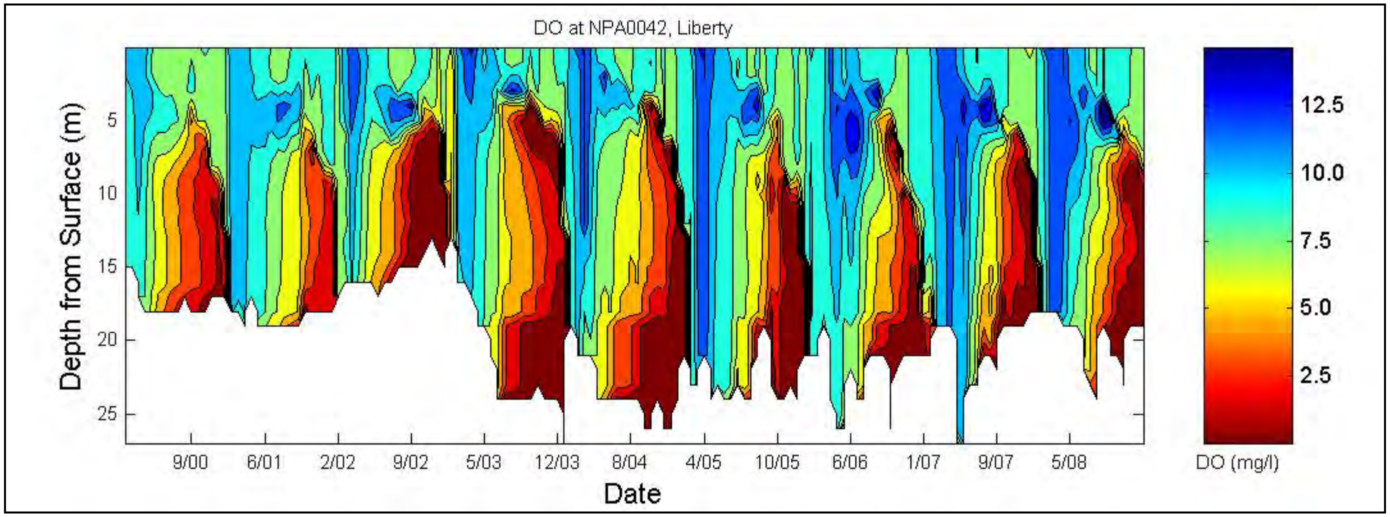

Figure A-5: Liberty Reservoir BCDPW Station NPA0042 DO Contours (2000-2008)

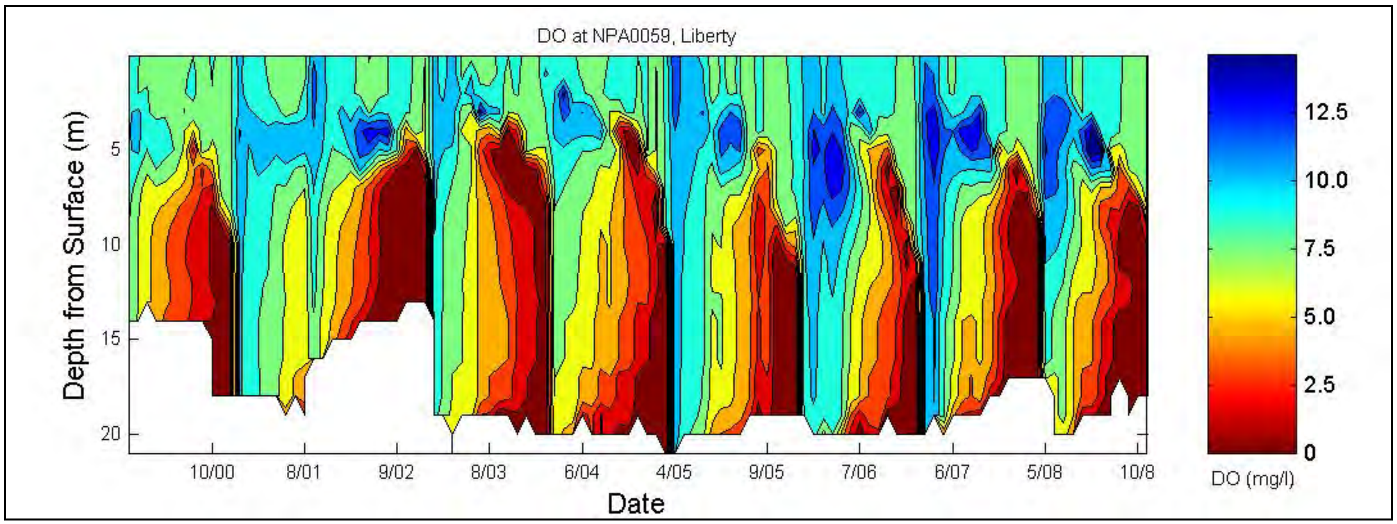

Figure A-6: Liberty Reservoir BCDPW Station NPA0059 DO Contours (2000-2008)

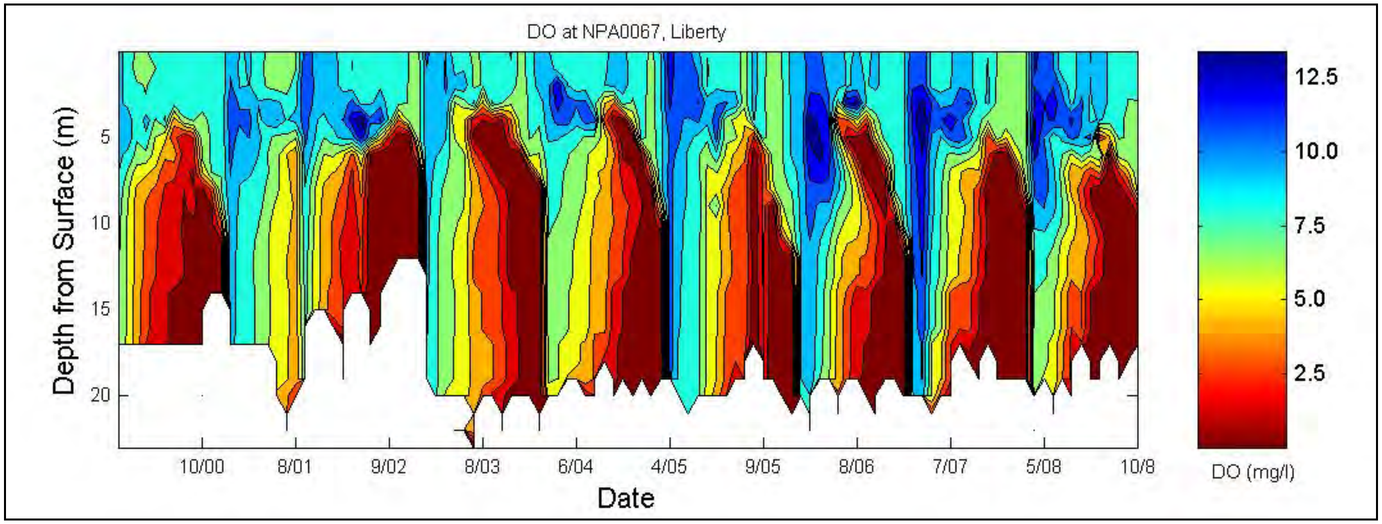

Figure A-7: Liberty Reservoir BCDPW Station NPA0067 DO Contours (2000-2008)

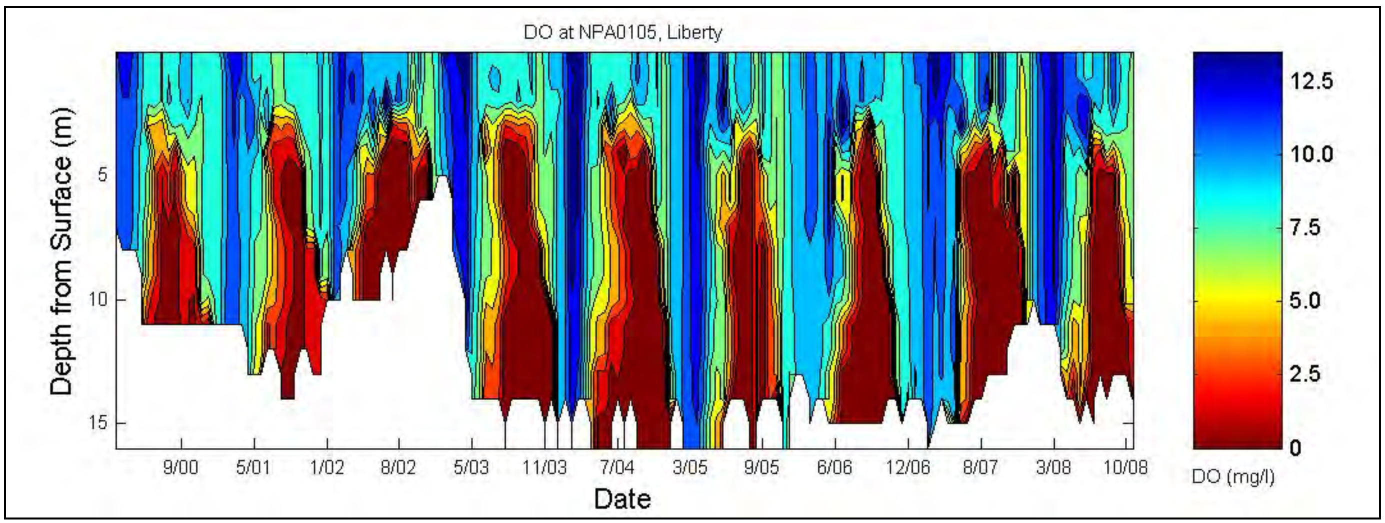

Figure A-8: Liberty Reservoir BCDPW Station NPA0105 DO Contours (2000-2008)

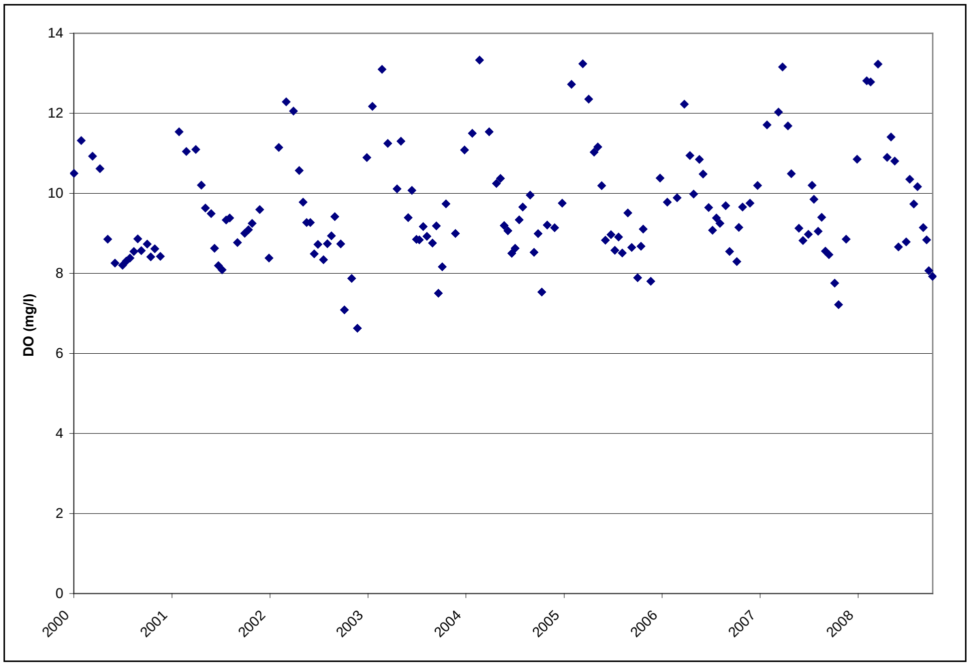

Figure A-9: Liberty Reservoir BCDPW Station NPA0042 Average Surface Dissolved Oxygen (2000-2008)

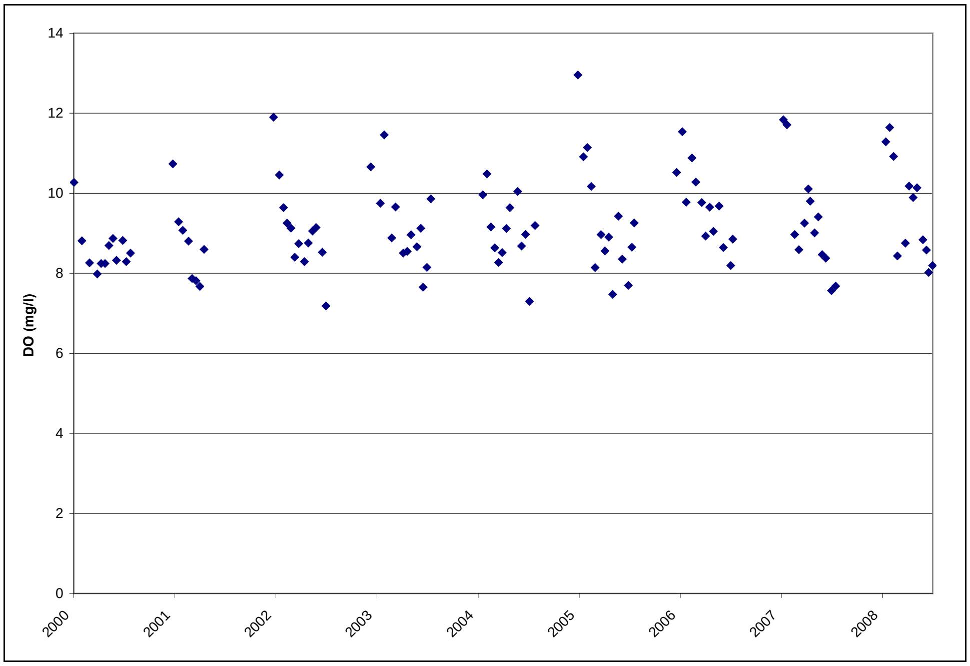

Figure A-10: Liberty Reservoir BCDPW Station NPA0059 Average Surface Dissolved Oxygen (2000-2008)

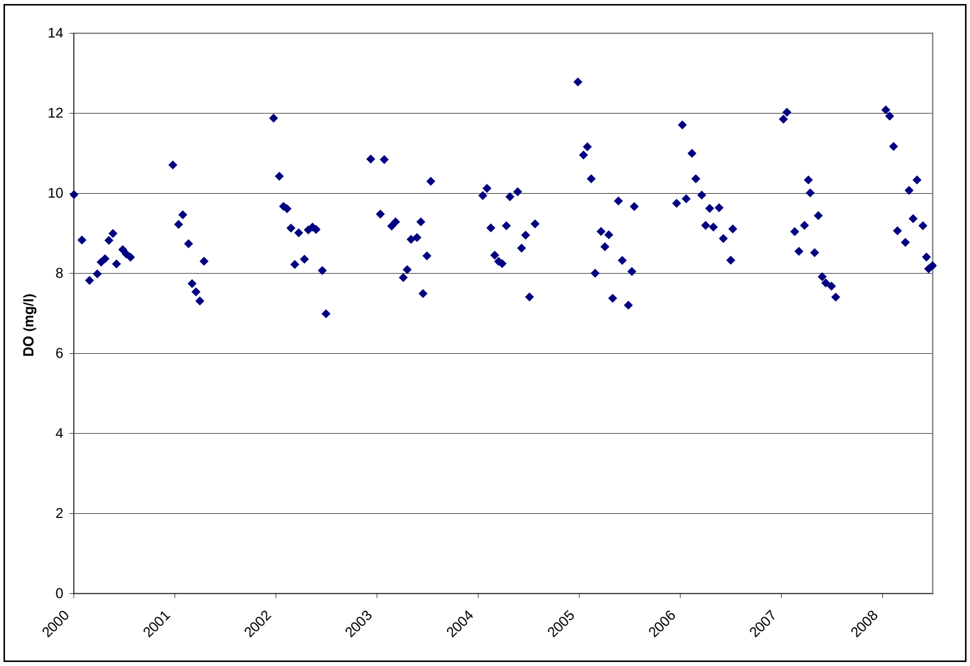

Figure A-11: Liberty Reservoir BCDPW Station NPA0067 Average Surface Dissolved Oxygen (2000-2008)

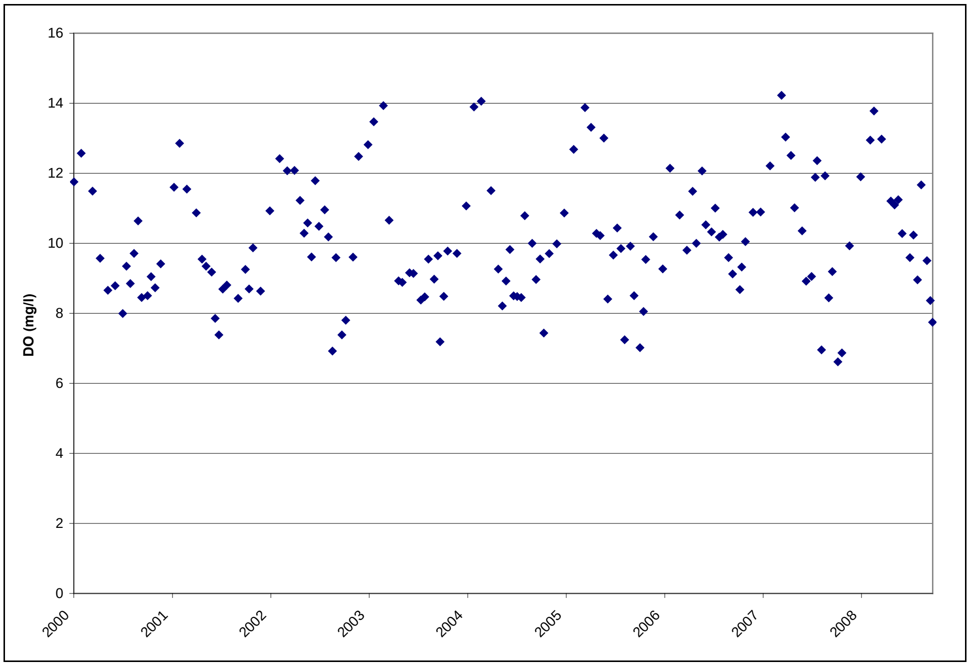

Figure A-12: Liberty Reservoir BCDPW Station NPA0105 Average Surface Dissolved Oxygen (2000-2008)

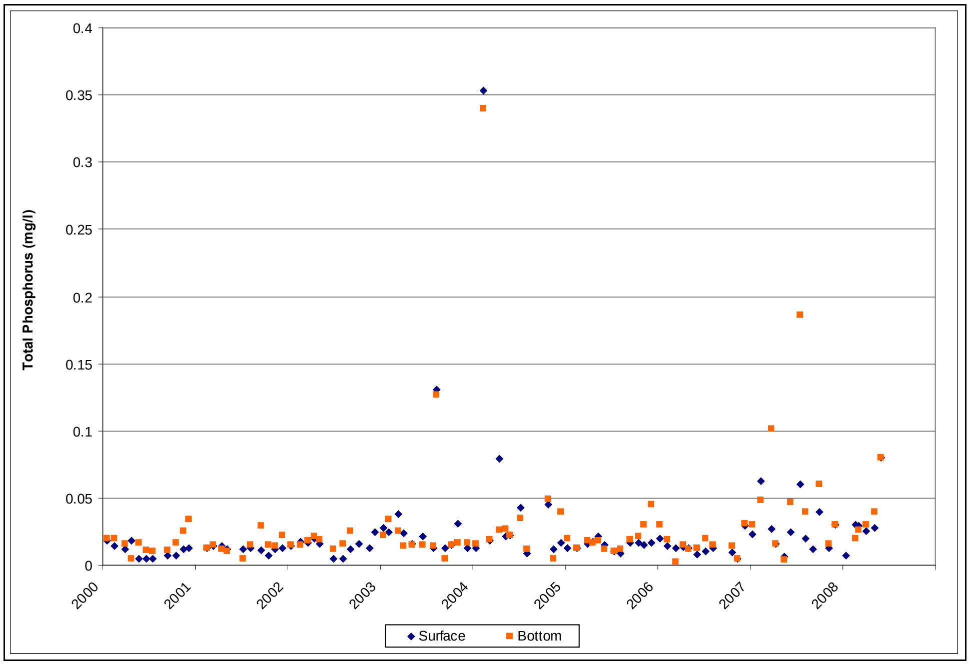

Figure A-13: Liberty Reservoir BCDPW Station NPA 0042 Average Total Phosphorus (2000-2008)

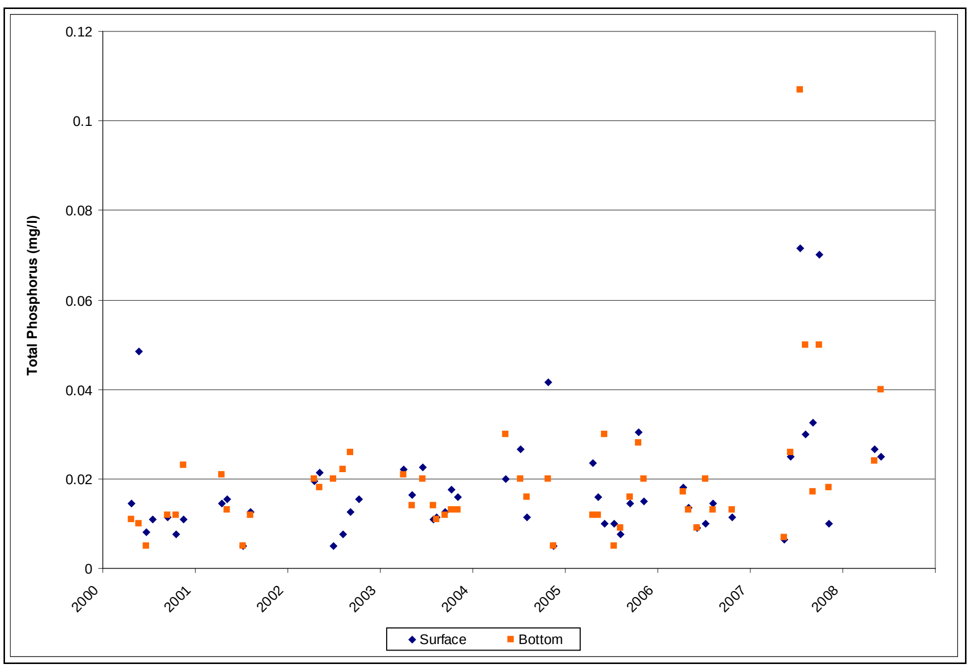

Figure A-14: Liberty Reservoir BCDPW Station NPA0059 Average Total Phosphorus (2000-2008)

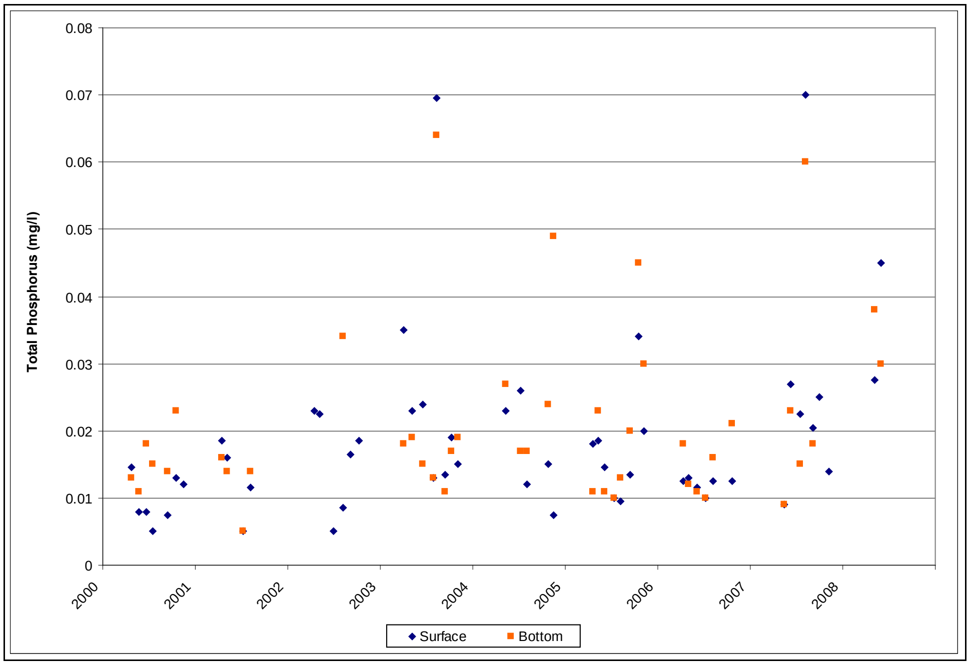

Figure A-15: Liberty Reservoir BCDPW Station NPA0067 Average Total Phosphorus (2000-2008)

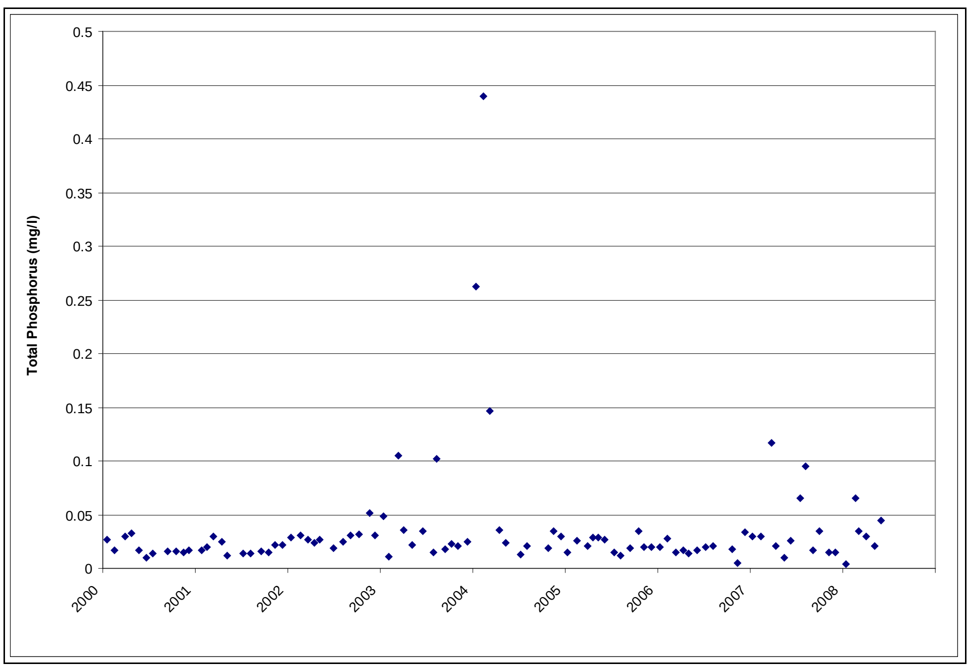

Figure A-16: Liberty Reservoir BCDPW Station NPA0105 Average Total Phosphorus (2000-2008)

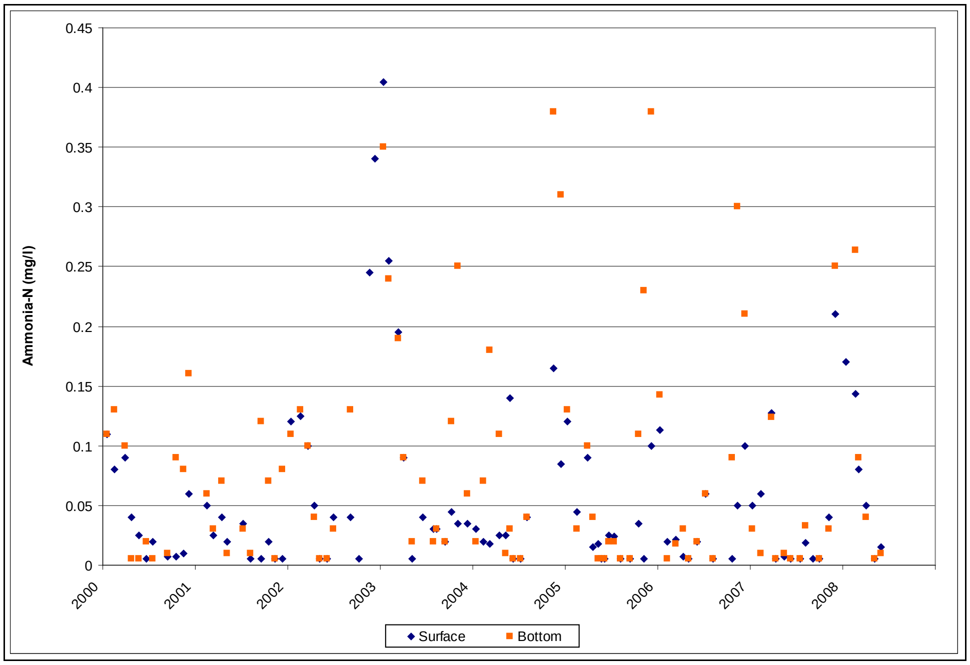

Figure A-17: Liberty Reservoir BCDPW Station NPA0042 Average Ammonia (2000-2008)

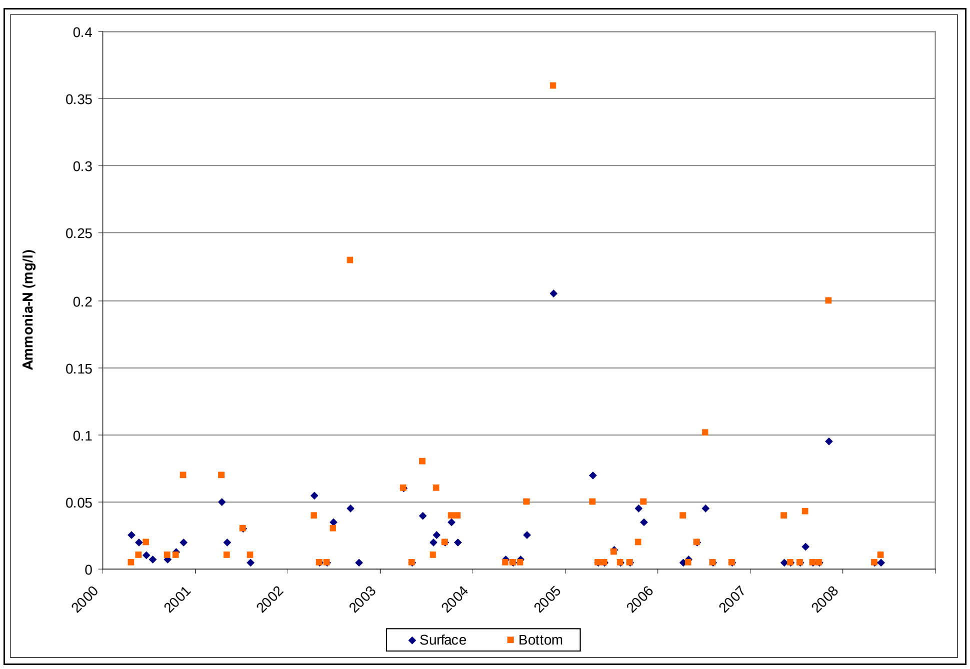

Figure A-18: Liberty Reservoir BCDPW Station NPA0059 Average Ammonia (2000-2008)

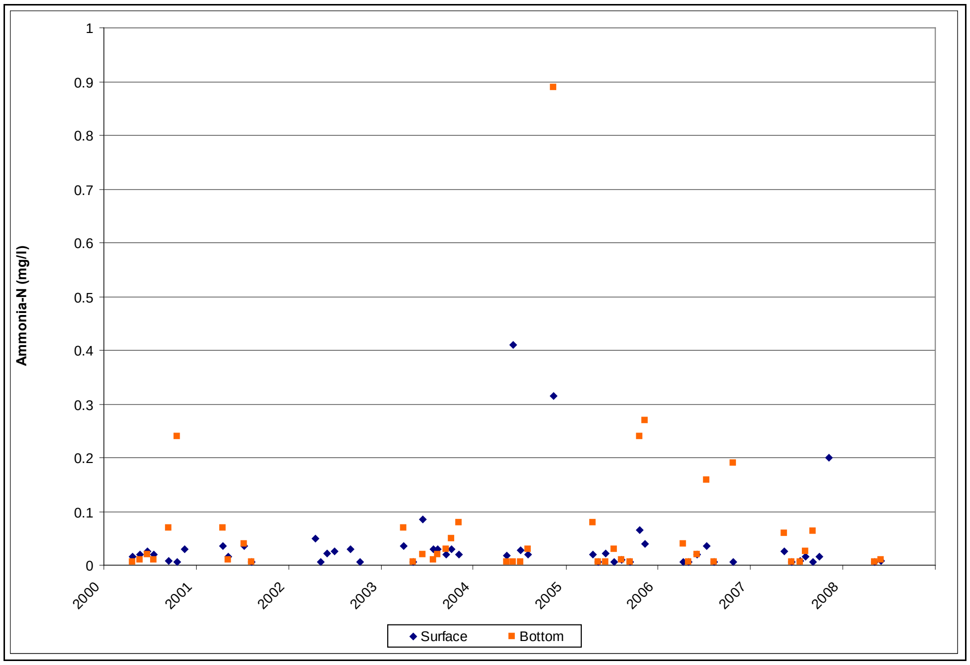

Figure A-19: Liberty Reservoir BCDPW Station NPA0067 Average Ammonia (2000-2008)

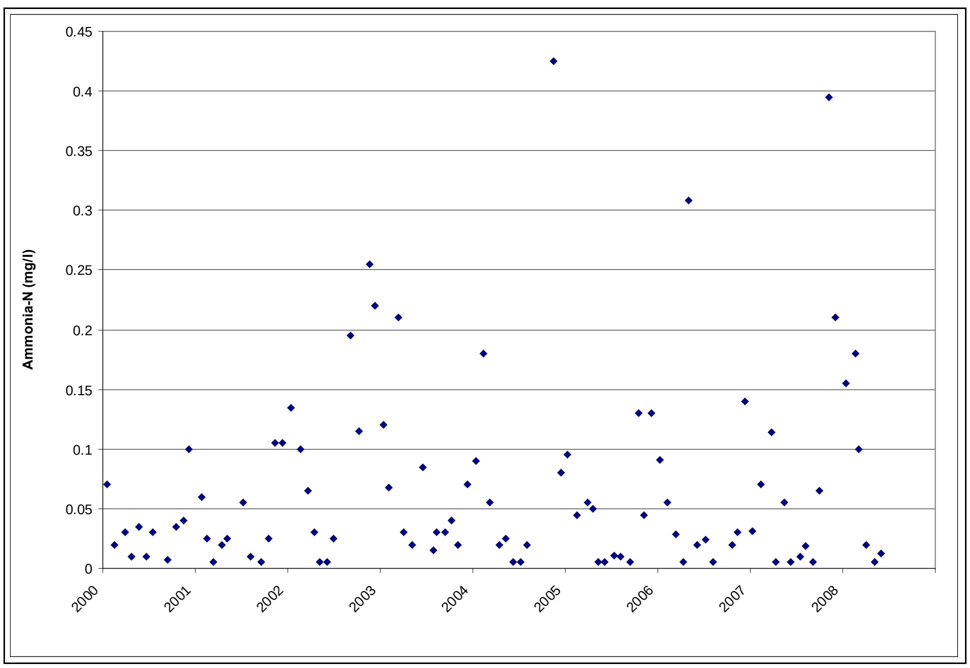

Figure A-20: Liberty Reservoir BCDPW Station NPA0105 Average Ammonia (2000-2008)

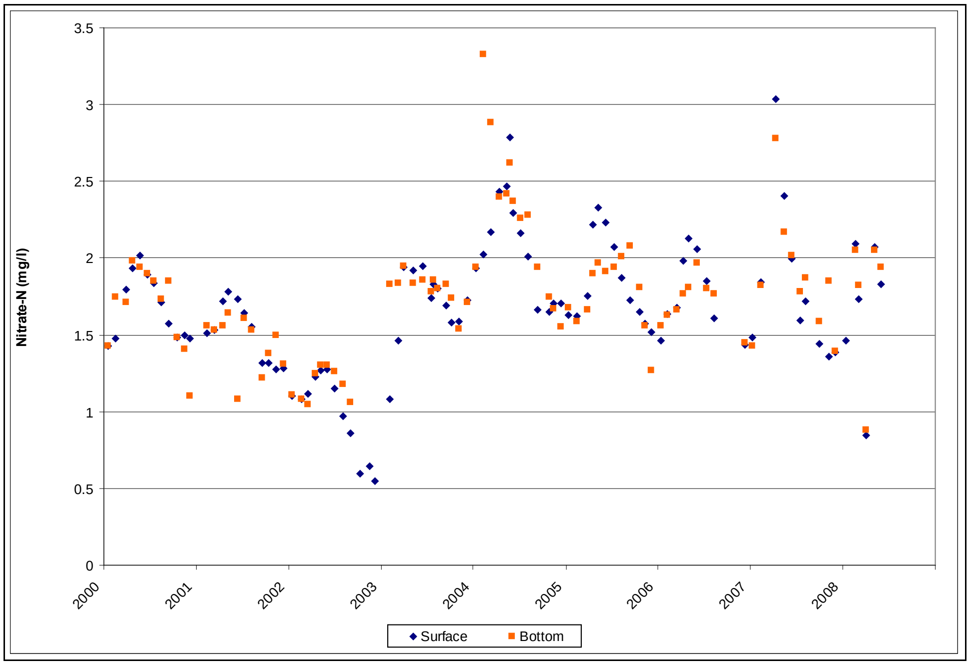

Figure A-21: Liberty Reservoir BCDPW Station NPA0042 Average Nitrate (2000-2008)

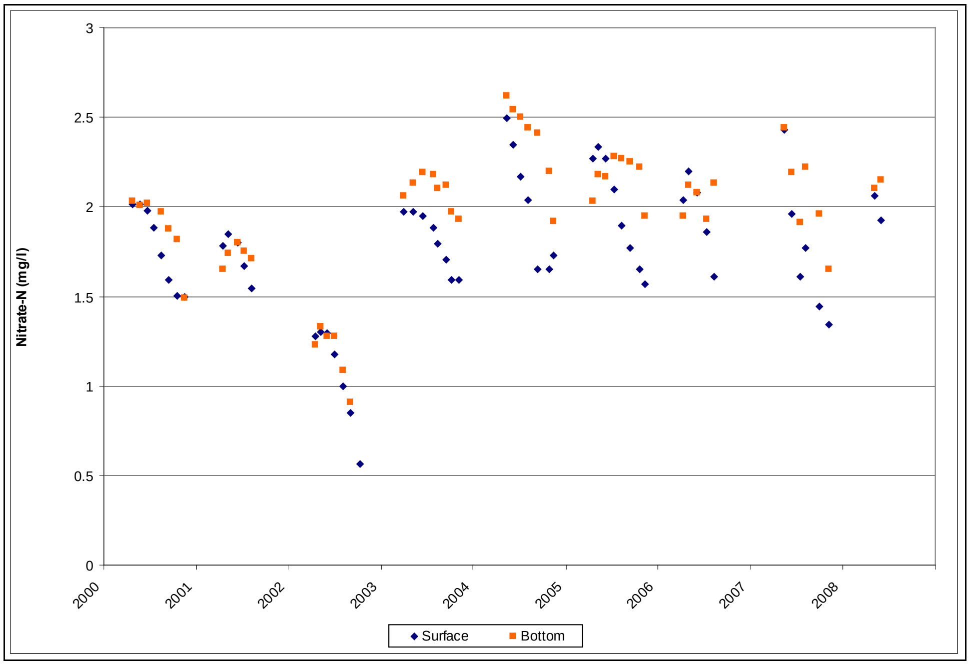

Figure A-22: Liberty Reservoir BCDPW Station NPA0059 Average Nitrate (2000-2008)

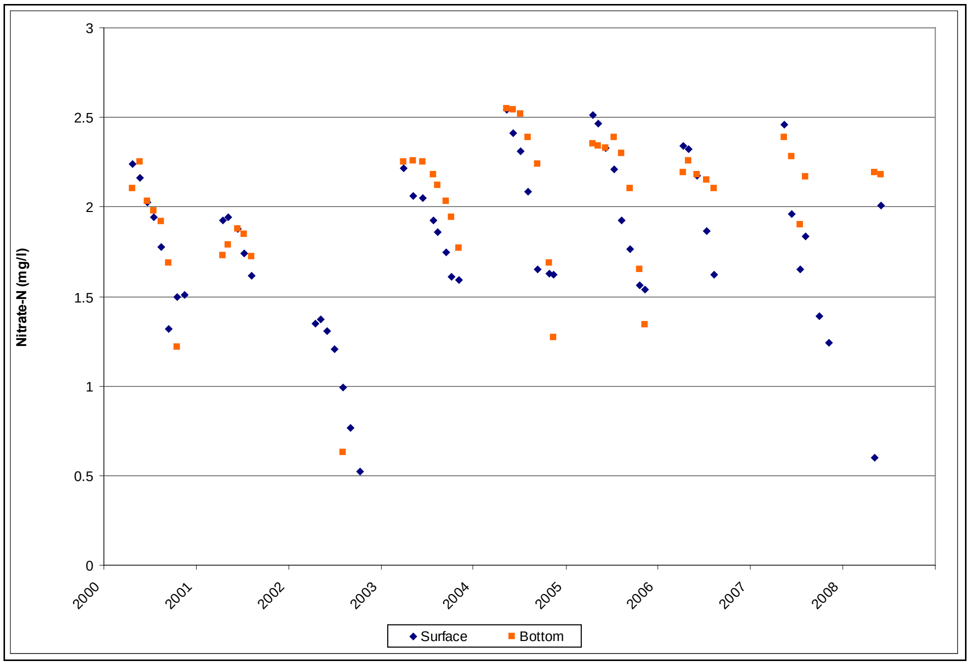

Figure A-23: Liberty Reservoir BCDPW Station NPA0067 Average Nitrate (2000-2008)

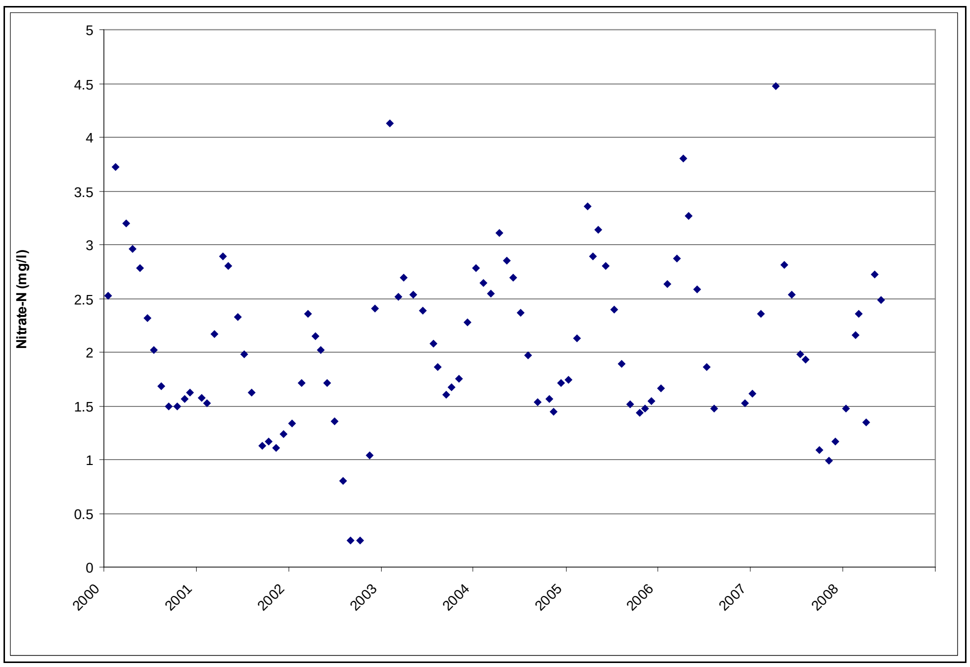

Figure A-24: Liberty Reservoir BCDPW Station NPA0105 Average Nitrate (2000-2008)

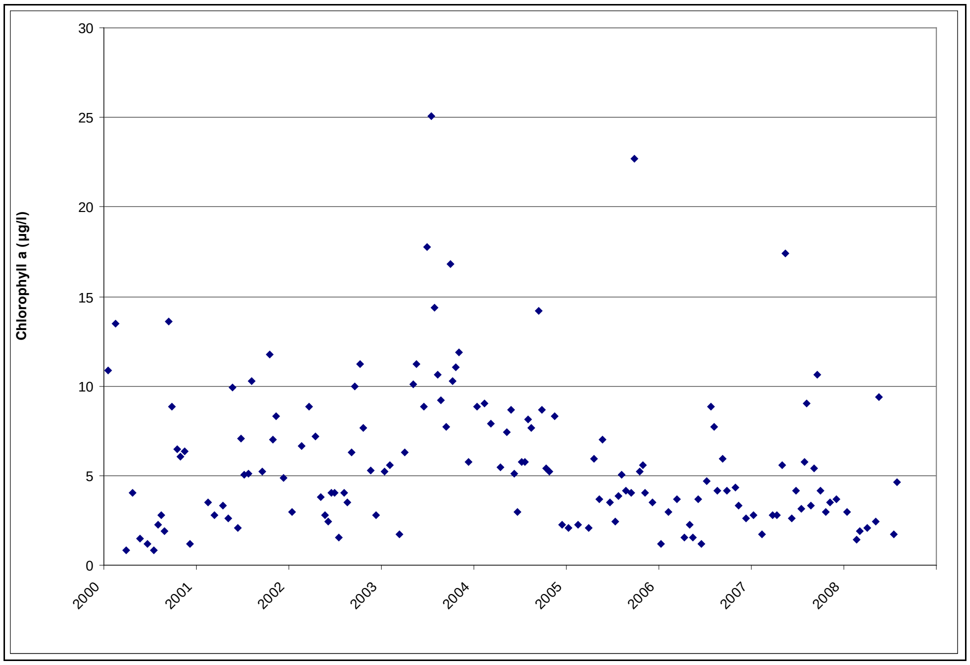

Figure A-25: Liberty Reservoir BCDPW Station NPA0042 Maximum Surface Chlorophyll a (2000-2008)

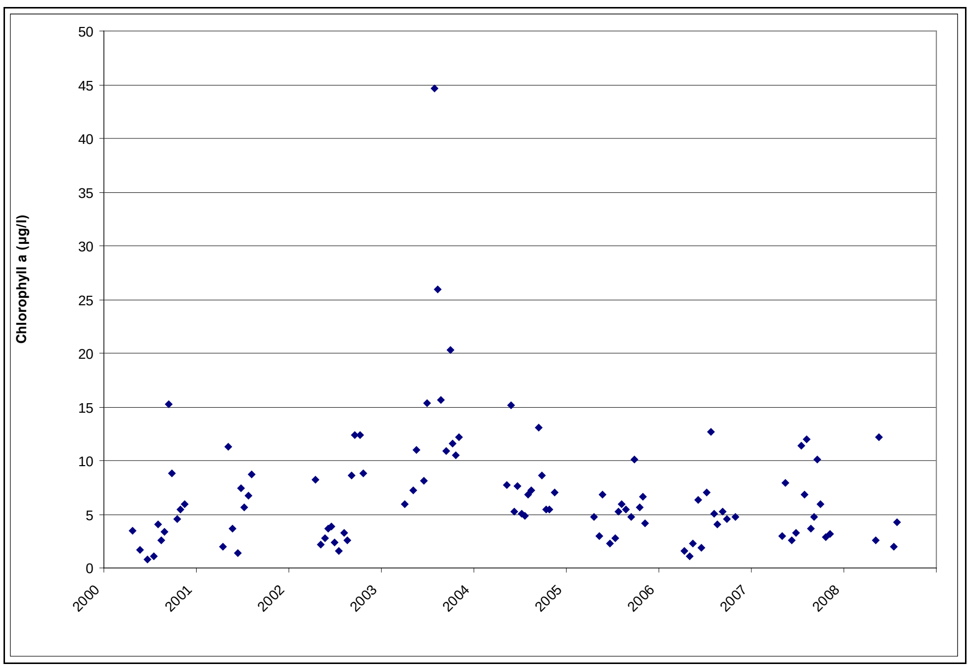

Figure A-26: Liberty Reservoir BCDPW Station NPA0059 Maximum Surface Chlorophyll a (2000-2008)

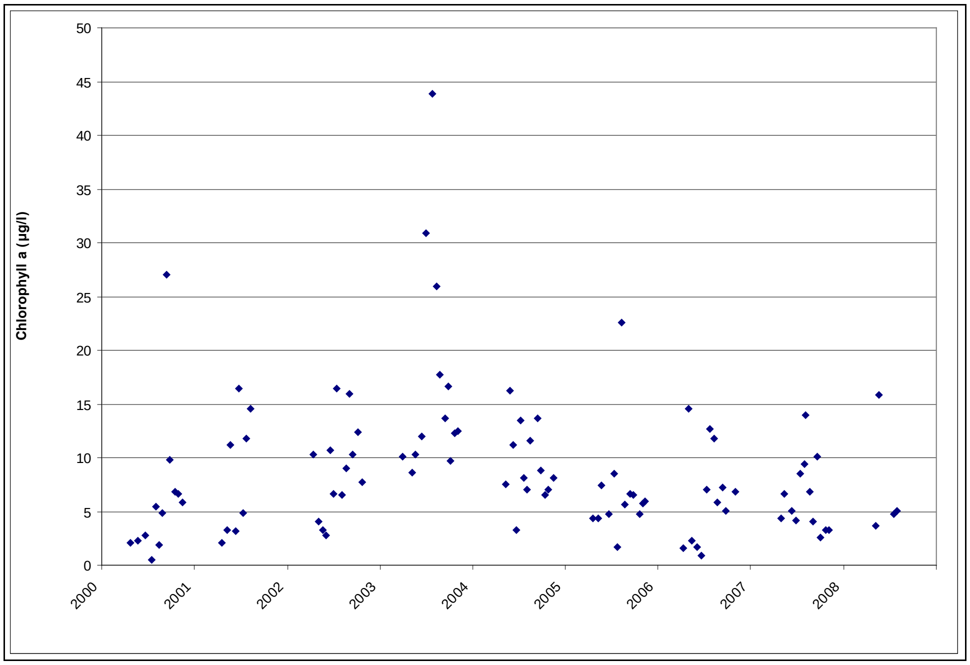

Figure A-27: Liberty Reservoir BCDPW Station NPA0067 Maximum Surface Chlorophyll a- (2000-2008)

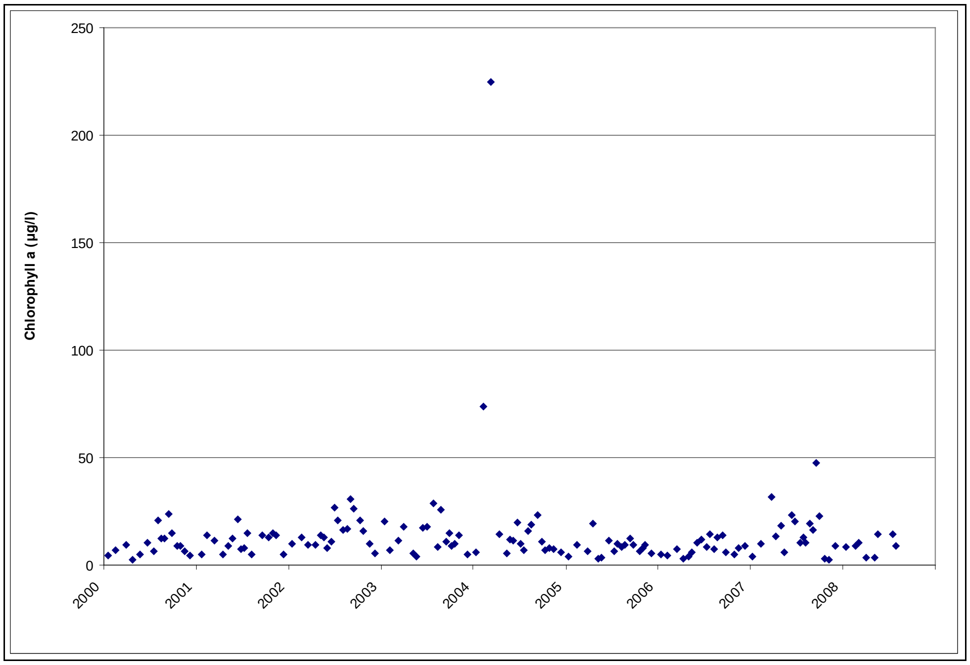

Figure A-28: Liberty Reservoir BCDPW Station NPA0105 Maximum Surface Chlorophyll a- (2000-2008)

Table A-1: Liberty Reservoir Maximum Chla Concentrations by Month and Year

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	10.85	13.47	9.38	4.02	5.07	10.29	20.66	13.74	27.05	9.03	6.49	5.42
2001	13.06	13.99	11.26	4.94	12.45	21.26	17.79	14.55	13.85	14.74	13.65	4.89
2002	10.12	13.43	9.57	10.29	13.62	15.54	26.81	24.39	30.65	20.7	10.12	5.6
2003	20.29	7.03	11.58	17.58	11.21	30.86	44.63	25.98	20.27	12.32	13.65	5.78
2004	8.85	73.95	224.87	14.21	16.19	19.92	13.44	18.83	23.2	7.75	8.31	5.78
2005	4.18	9.2	6.67	19.11	7.39	11.39	10.66	22.61	22.69	7.84	9.38	5.44
2006	4.72	5.96	7.21	3.13	17.39	11.76	14.18	13.06	13.83	6.85	7.93	9.02
2007	4.01	9.93	31.68	13.24	18.34	23.05	16.47	19.5	75.56	26.18	3.66	9.02
2008	8.43	9	10.2	3.66	15.87		14.38					

Appendix B

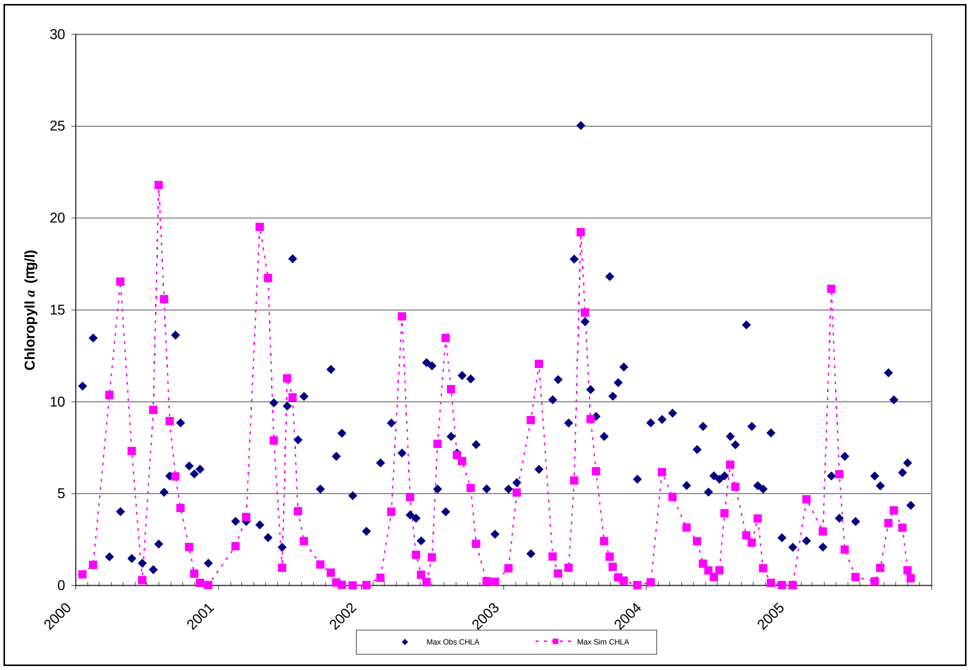

Figure B-1: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration Scenario) Maximum Chla Concentrations on Sampling Dates

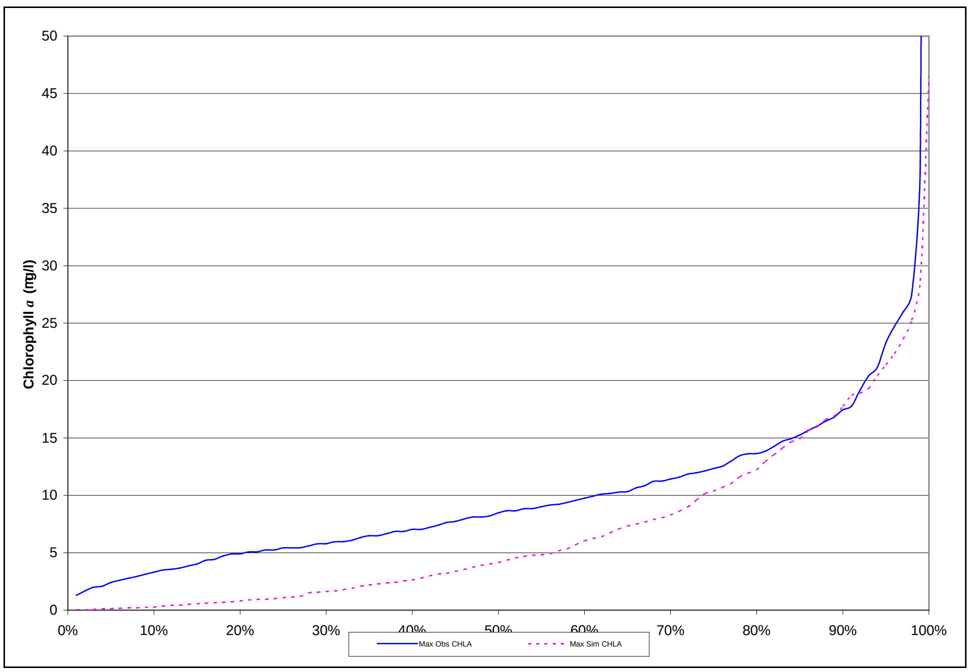

Figure B-2: Liberty Reservoir Observed and Simulated (Calibration Scenario) Cumulative Distribution of Chla Concentrations on Sampling Dates

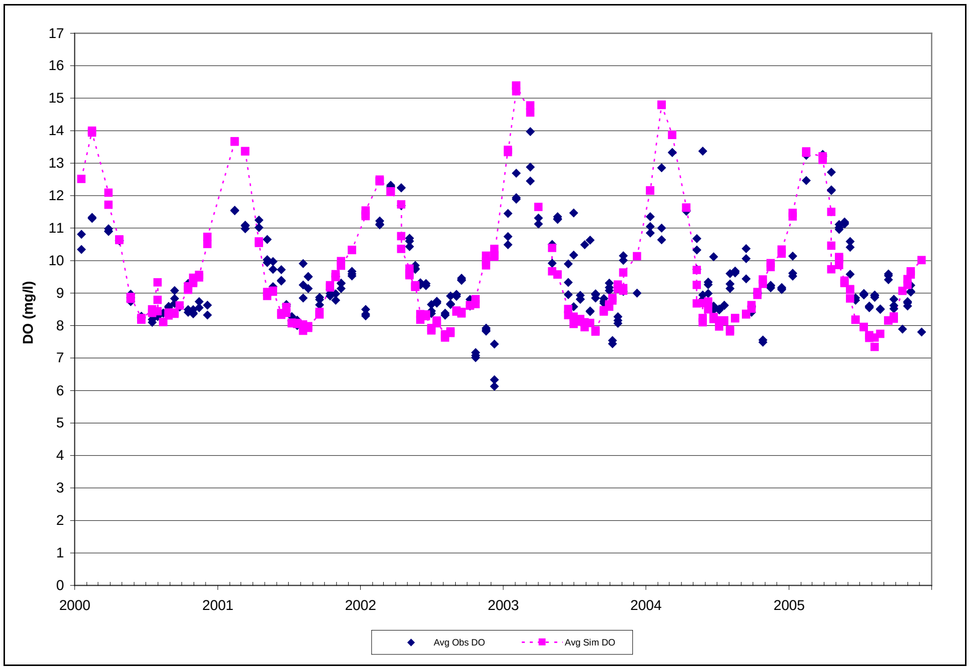

Figure B-3: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration Scenario) Average Surface DO Concentrations on Sampling Dates

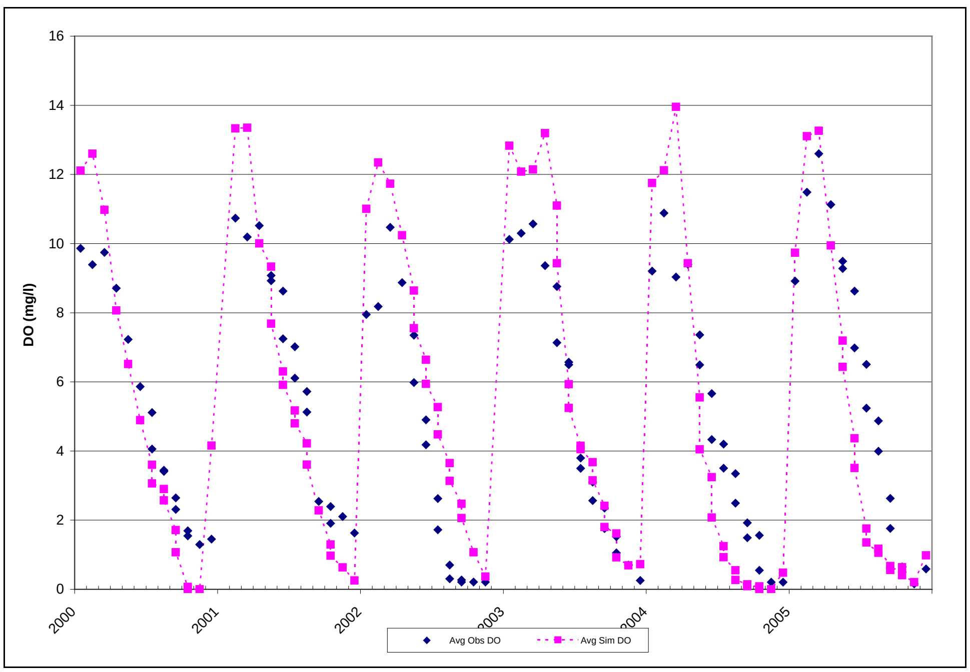

Figure B-4: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration Scenario) Average Bottom DO Concentrations on Sampling Dates

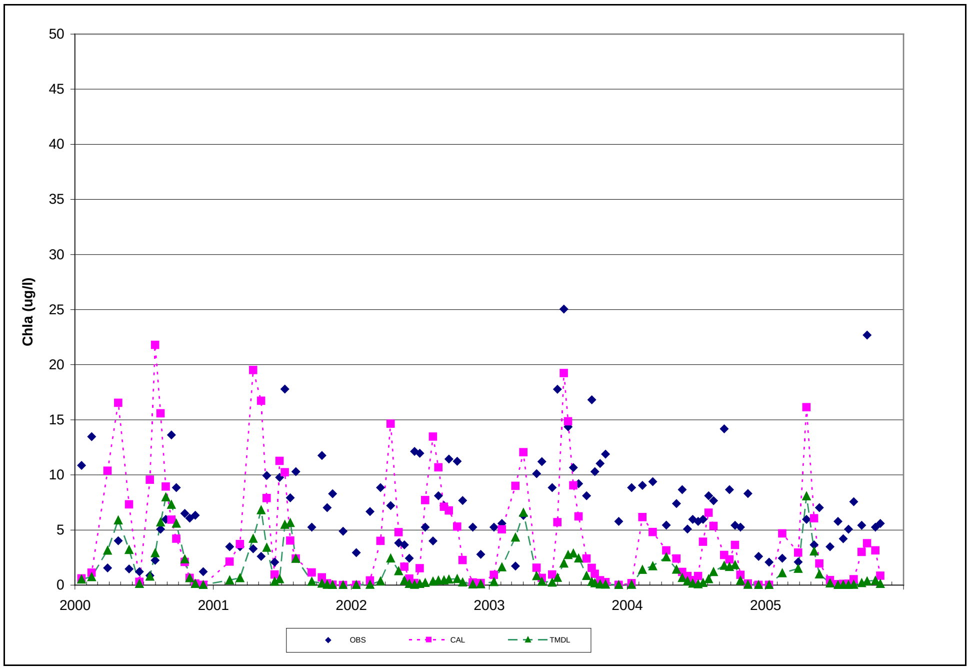

Figure B-5: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration and TMDL Scenarios) Maximum Chla Concentrations on Sampling Dates

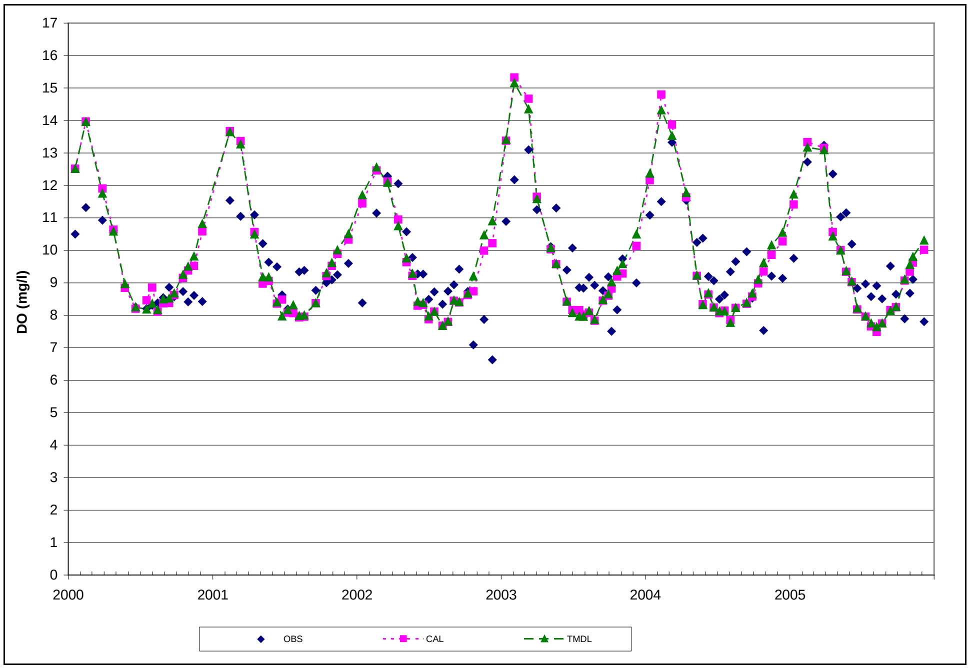

Figure B-6: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration and TMDL Scenarios) Average Surface DO Concentrations on Sampling Dates

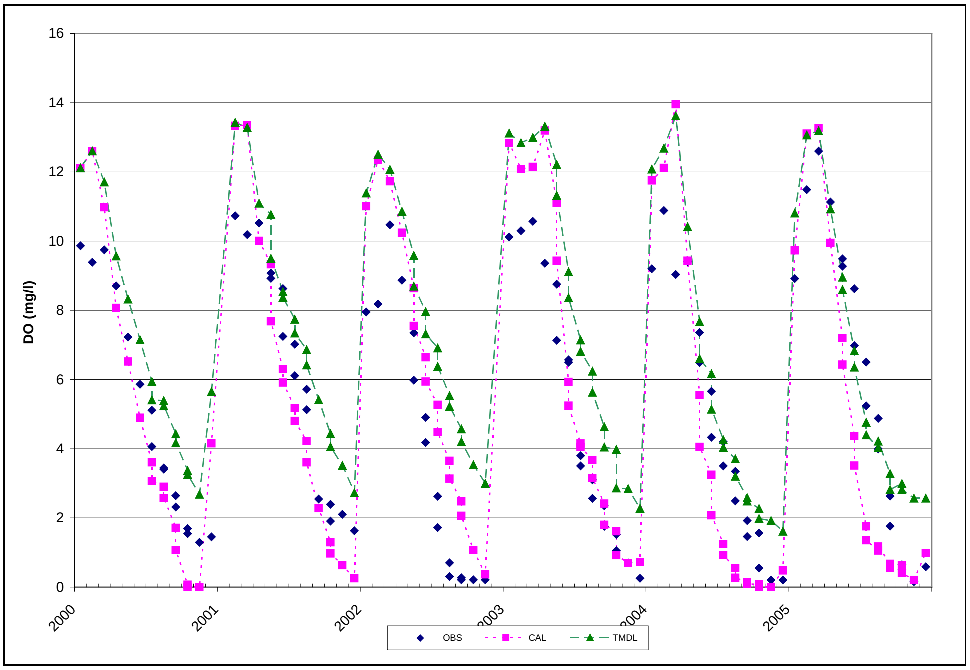

Figure B-7: Liberty Reservoir BCDPW Station NPA042 Observed and Simulated (Calibration and TMDL Scenarios) Average Bottom DO Concentrations on Sampling Dates

Appendix C

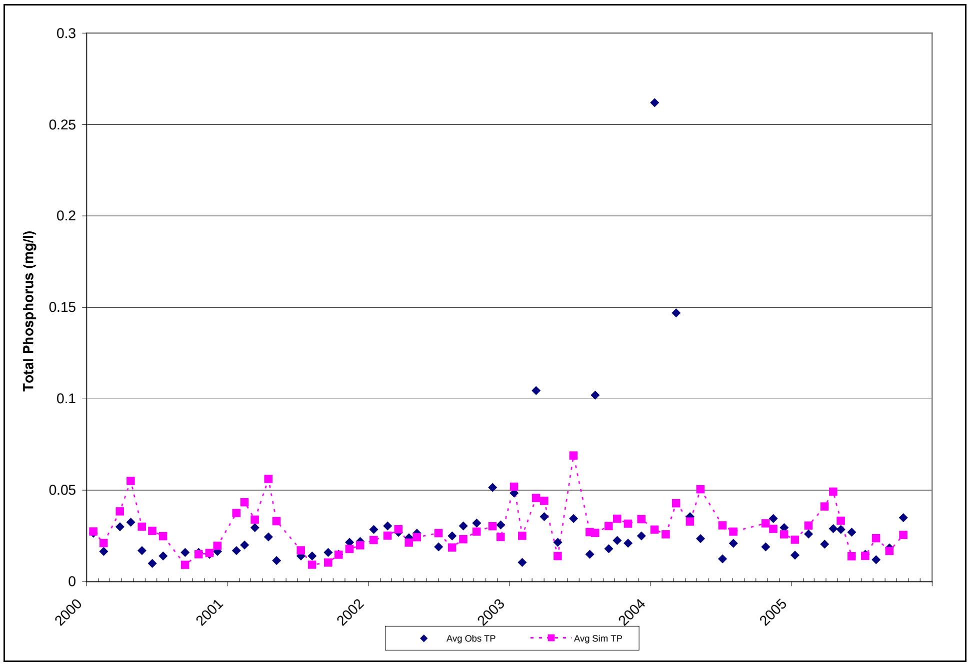

Figure C-1: Liberty Reservoir BCDPW Station NPA0105 Surface Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

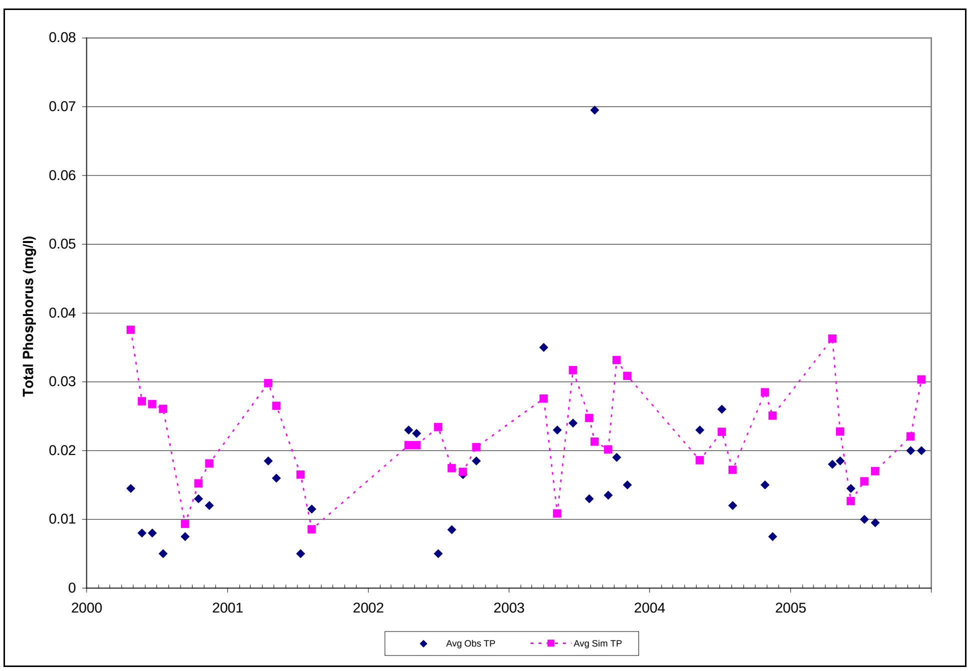

Figure C-2: Liberty Reservoir BCDPW Station NPA0067 Surface Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

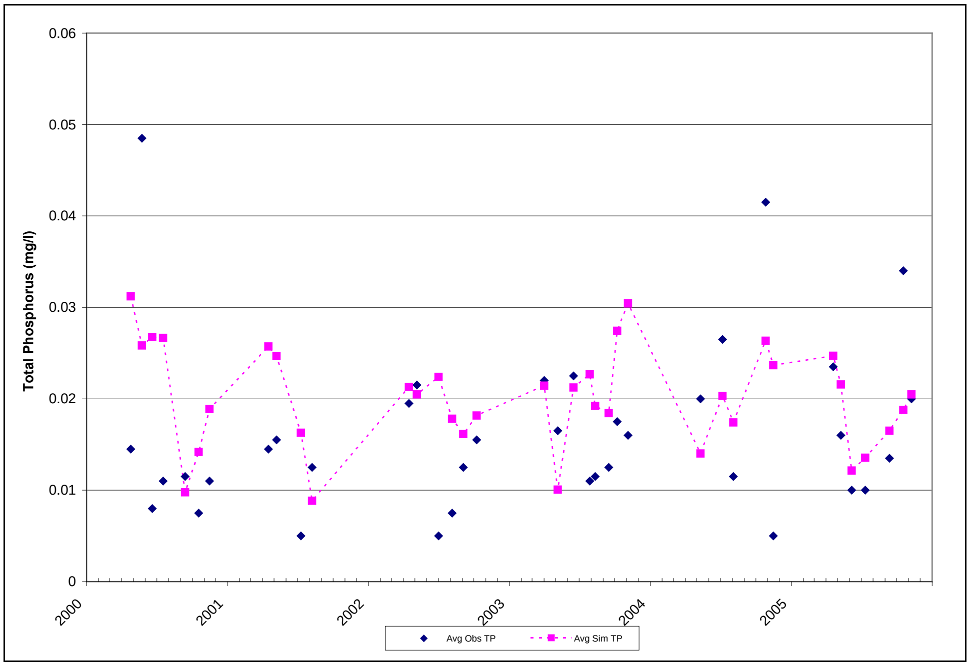

Figure C-3: Liberty Reservoir BCDPW Station NPA0059 Surface Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

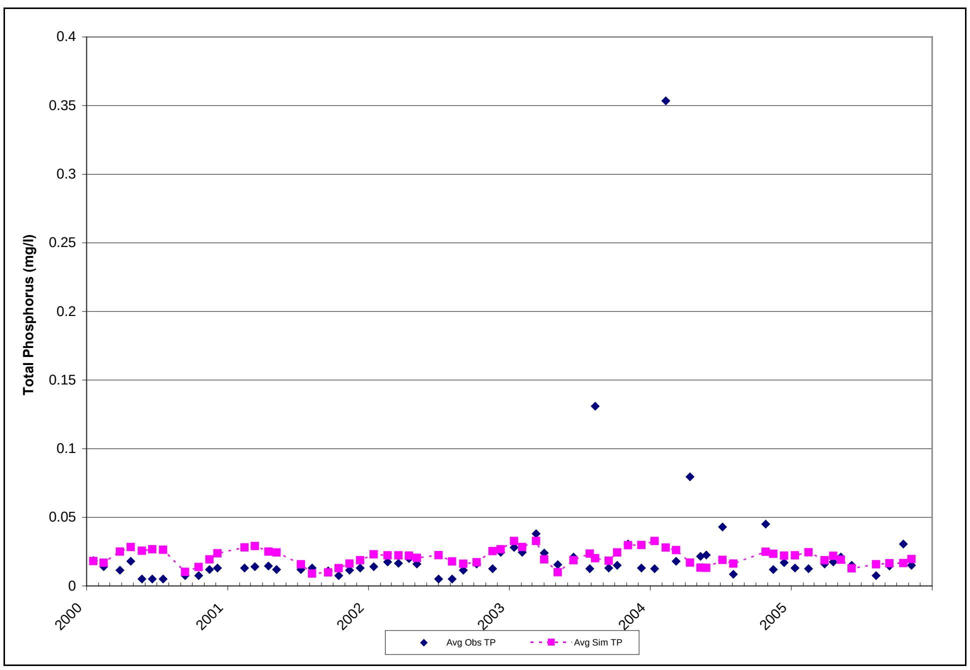

Figure C-4: Liberty Reservoir BCDPW Station NPA0042 Surface Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

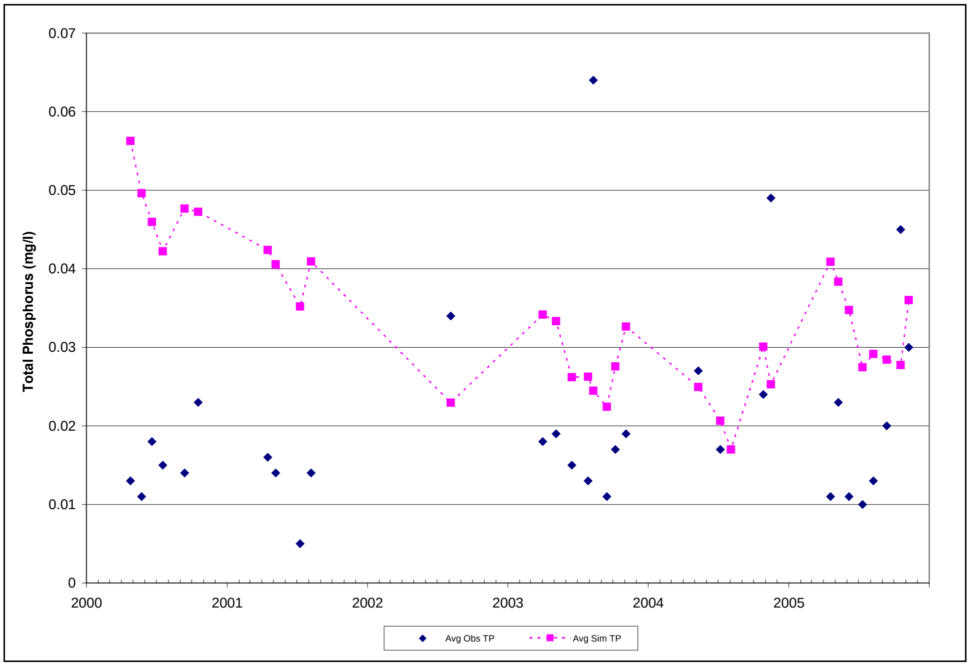

Figure C-5: Liberty Reservoir BCDPW Station NPA0067 Bottom Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

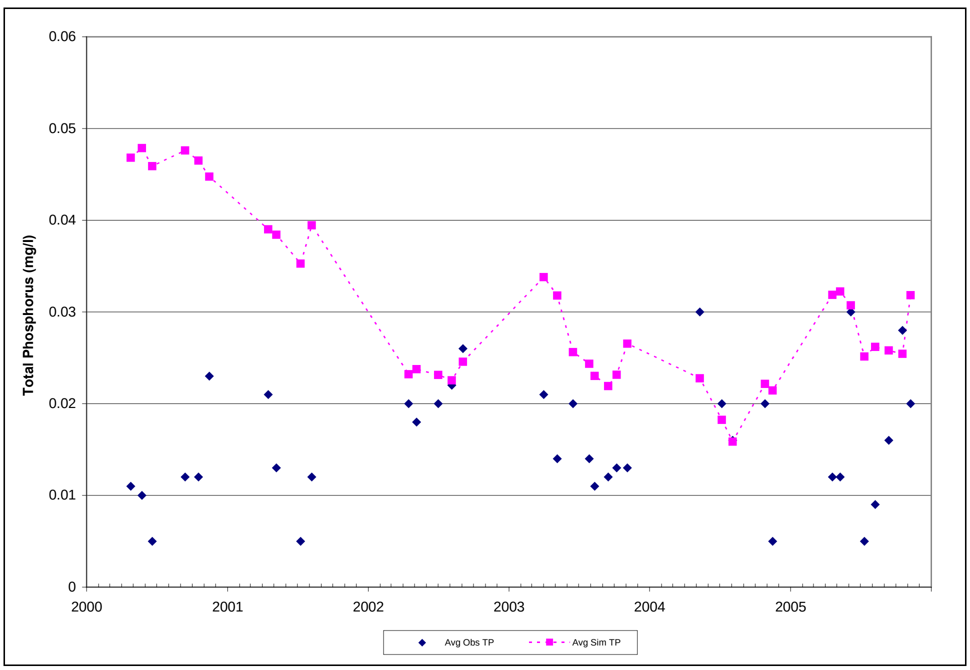

Figure C-6: Liberty Reservoir BCDPW Station NPA0059 Bottom Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

FINAL

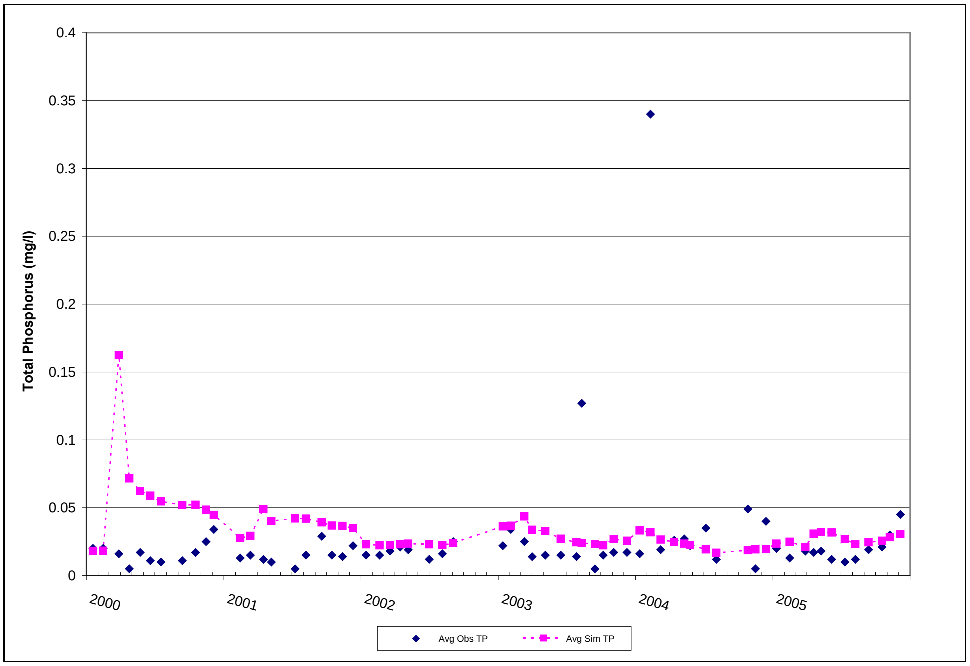

Figure C-7: Liberty Reservoir BCDPW Station NPA0042 Bottom Observed and Simulated (Calibration) TP Concentrations on Sampling Dates

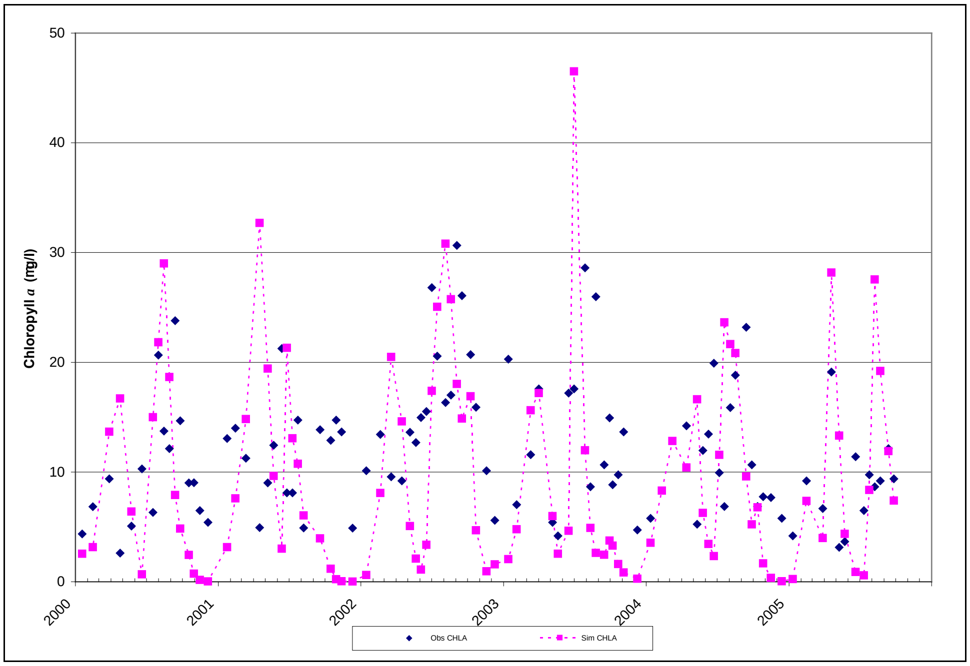

Figure C-8: Liberty Reservoir BCDPW Station NPA0105 Surface Observed and Simulated (Calibration) Chla Concentrations on Sampling Dates

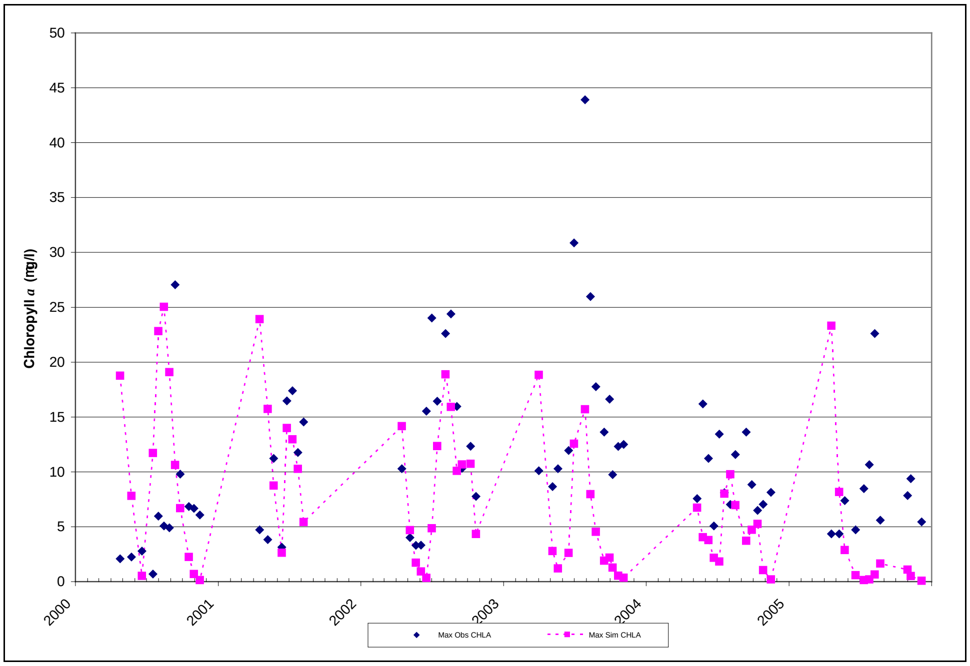

Figure C-9: Liberty Reservoir BCDPW Station NPA0067 Surface Observed and Simulated (Calibration) Chla Concentrations on Sampling Dates

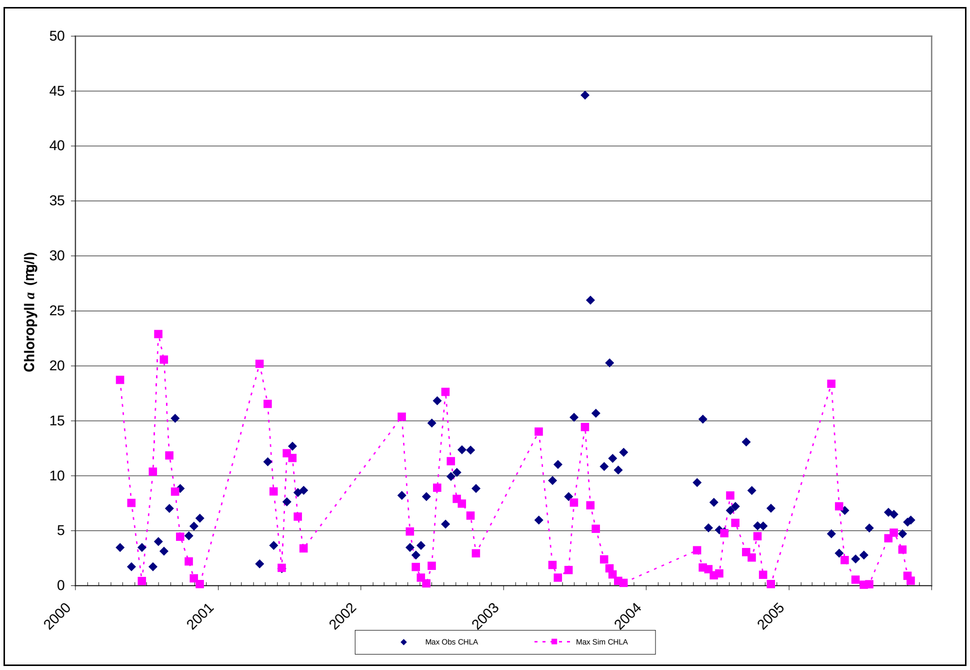

Figure C-10: Liberty Reservoir BCDPW Station NPA0059 Surface Observed and Simulated (Calibration) Chla Concentrations on Sampling Dates

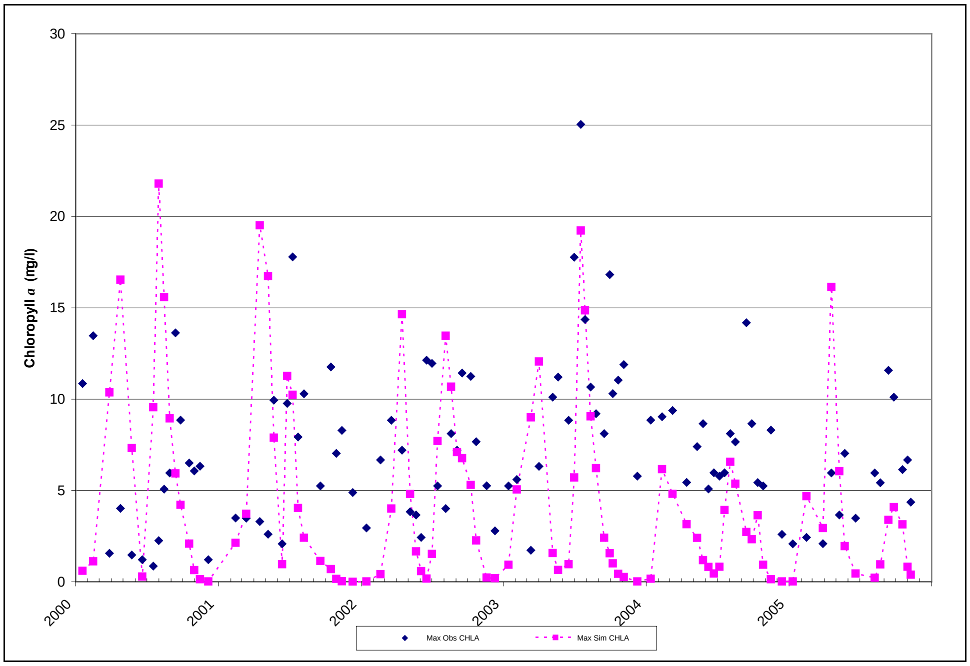

Figure C-11: Liberty Reservoir BCDPW Station NPA0042 Surface Observed and Simulated (Calibration) Chla Concentrations on Sampling Dates

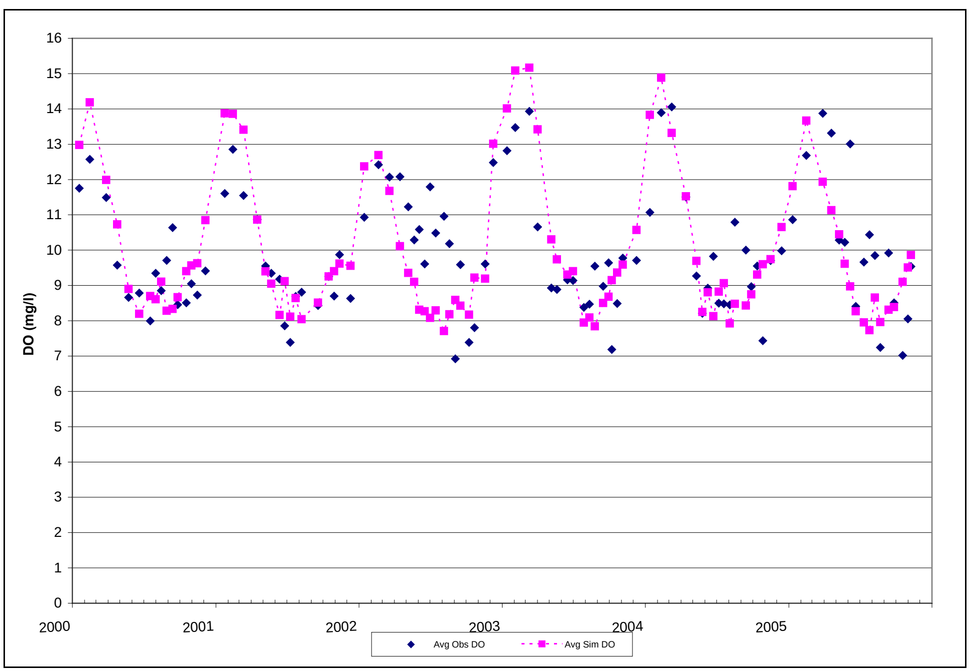

Figure C-12: Liberty Reservoir BCDPW Station NPA0105 Surface Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

Figure C-13: Liberty Reservoir BCDPW Station NPA0067 Surface Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

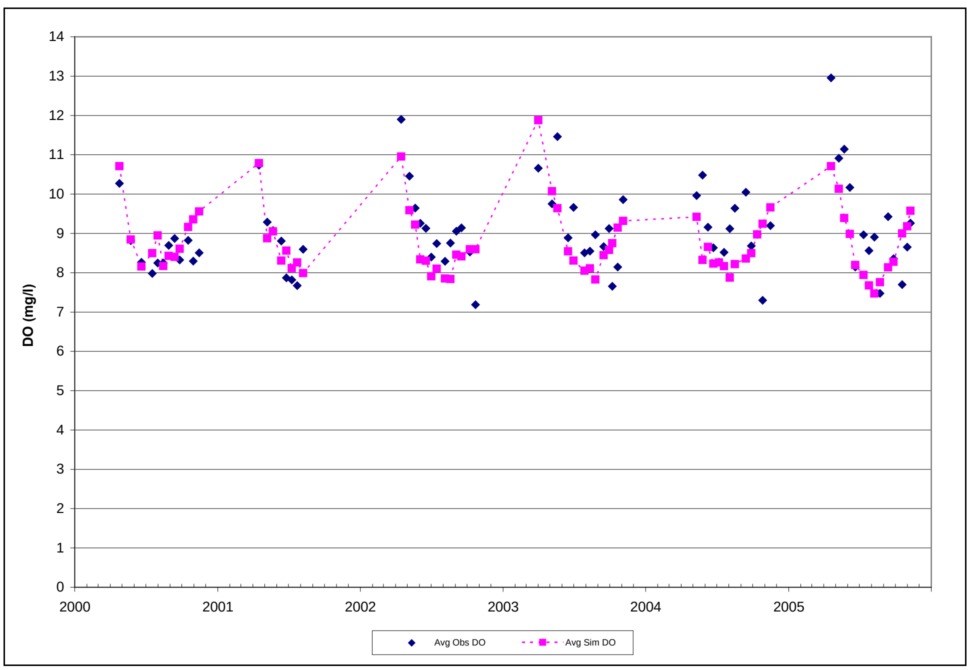

Figure C-14: Liberty Reservoir BCDPW Station NPA0059 Surface Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

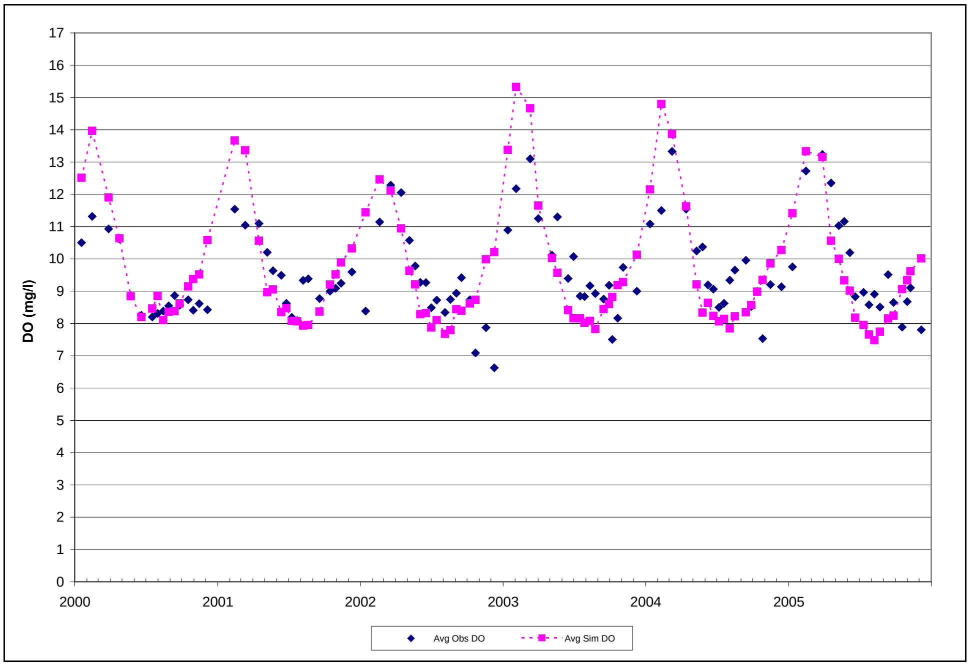

Figure C-15: Liberty Reservoir BCDPW Station NPA0042 Surface Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

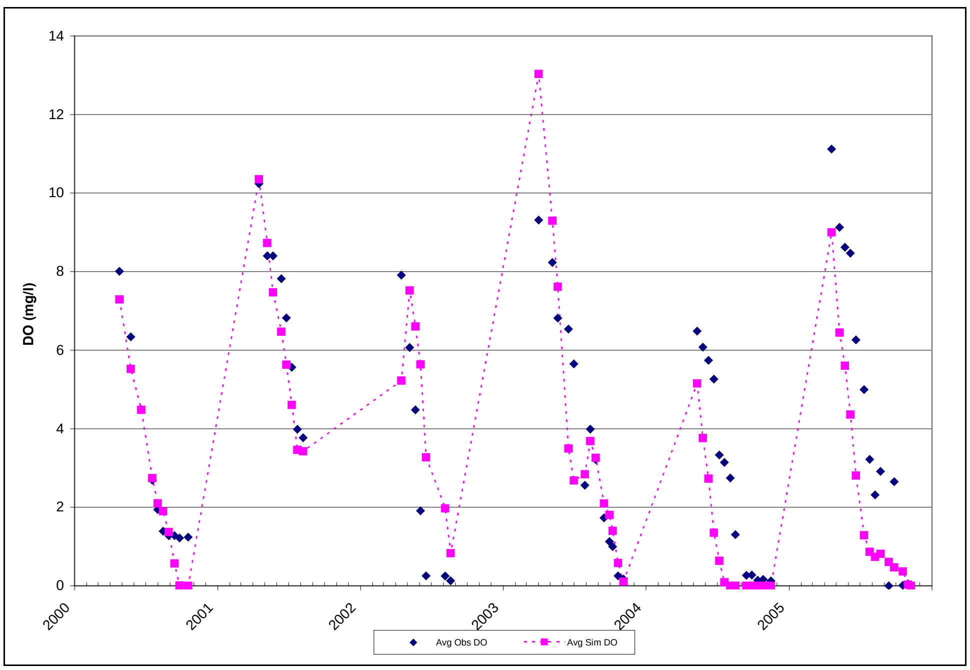

Figure C-16: Liberty Reservoir BCDPW Station NPA0067 Bottom Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

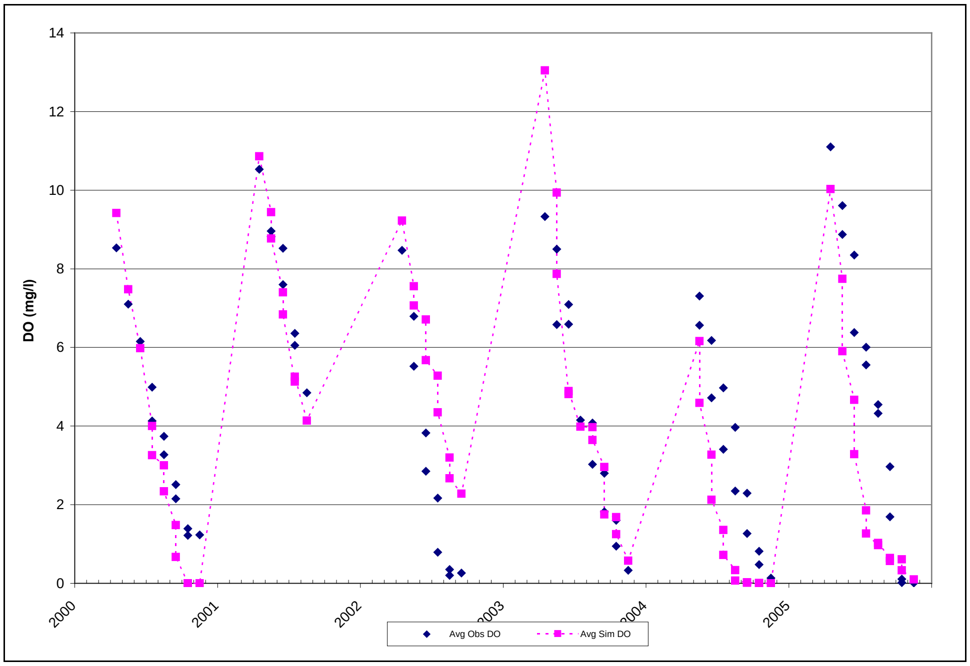

Figure C-17: Liberty Reservoir BCDPW Station NPA0059 Bottom Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

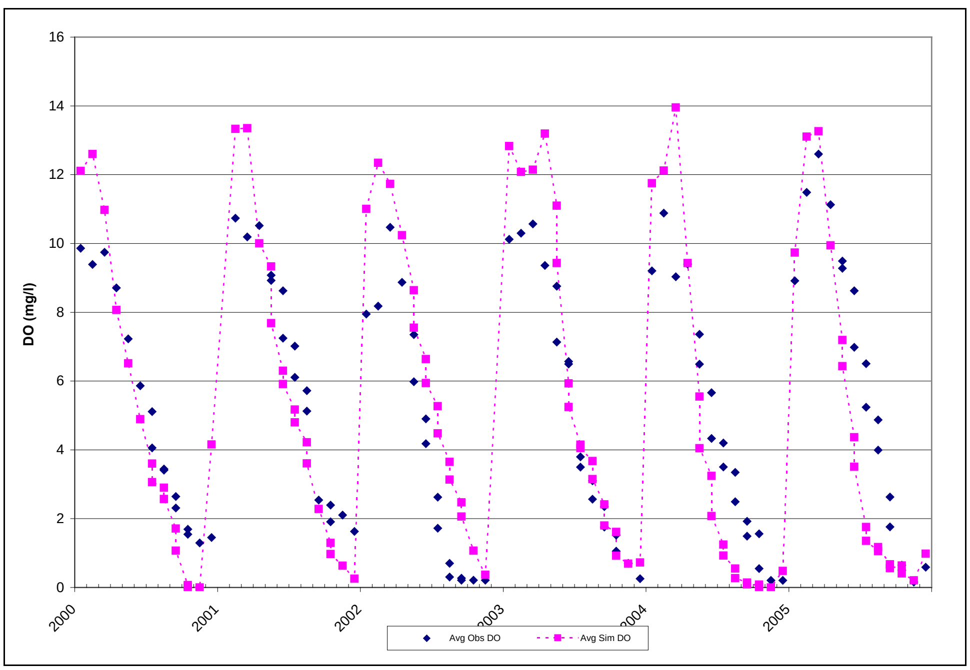

Figure C-18: Liberty Reservoir BCDPW Station NPA0042 Bottom Observed and Simulated (Calibration) DO Concentrations on Sampling Dates

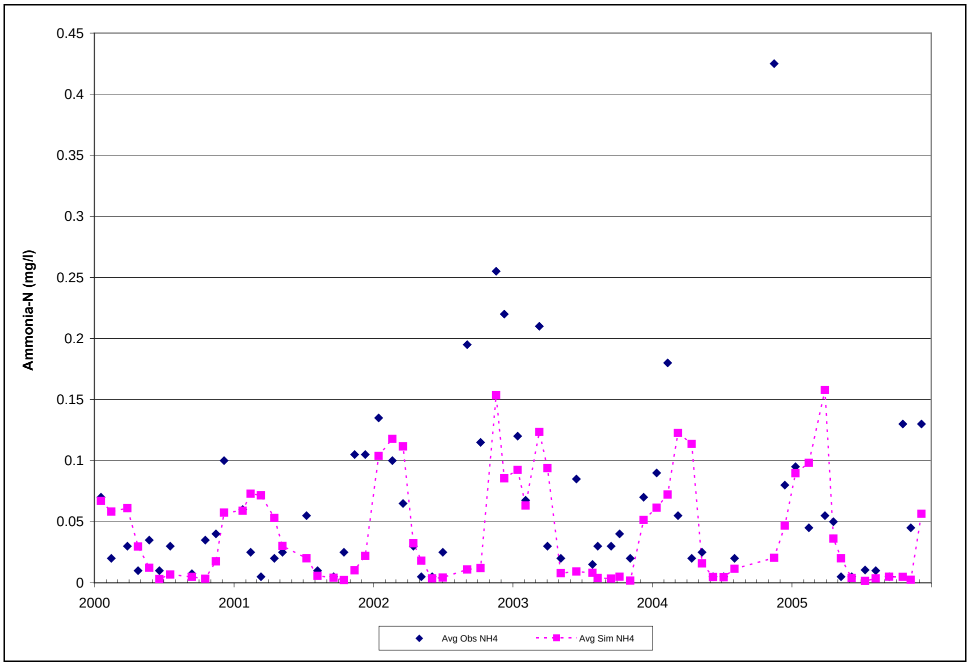

Figure C-19: Liberty Reservoir BCDPW Station NPA0105 Surface Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

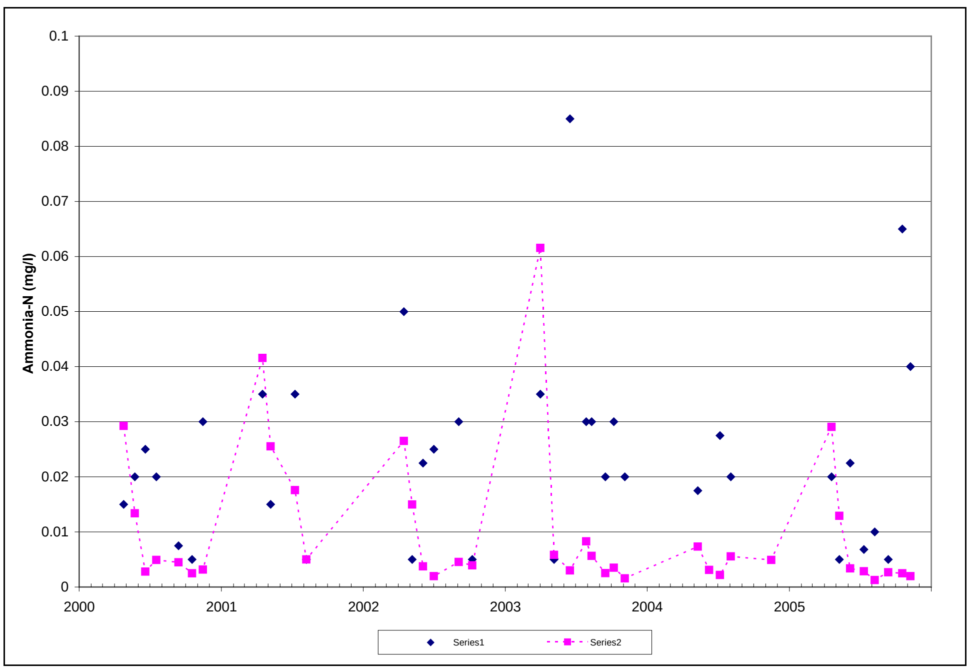

Figure C-20: Liberty Reservoir BCDPW Station NPA0067 Surface Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

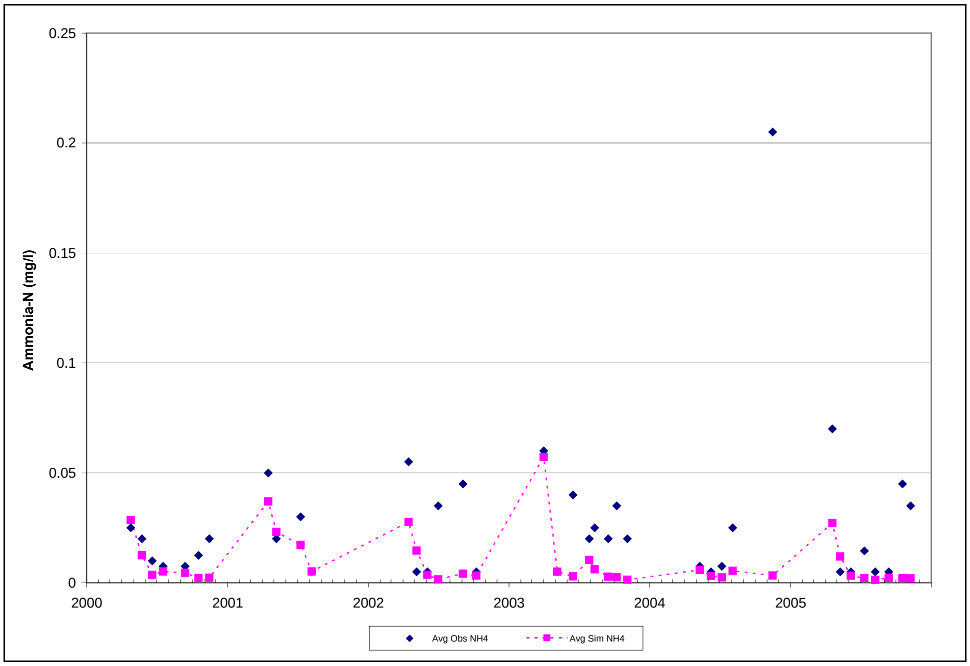

Figure C-21: Liberty Reservoir BCDPW Station NPA0059 Surface Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

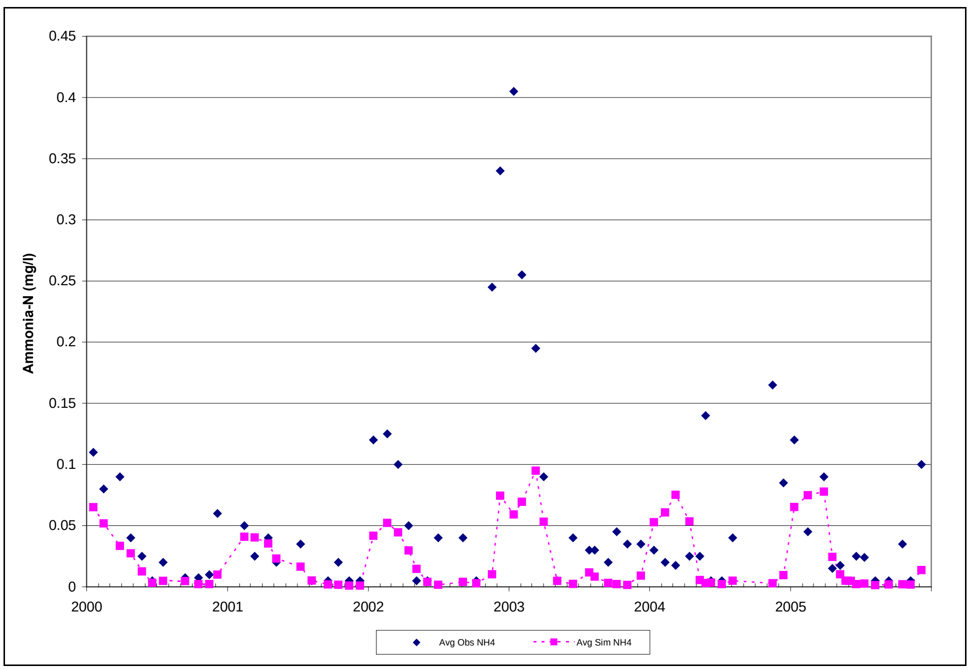

Figure C-22: Liberty Reservoir BCDPW Station NPA0042 Surface Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

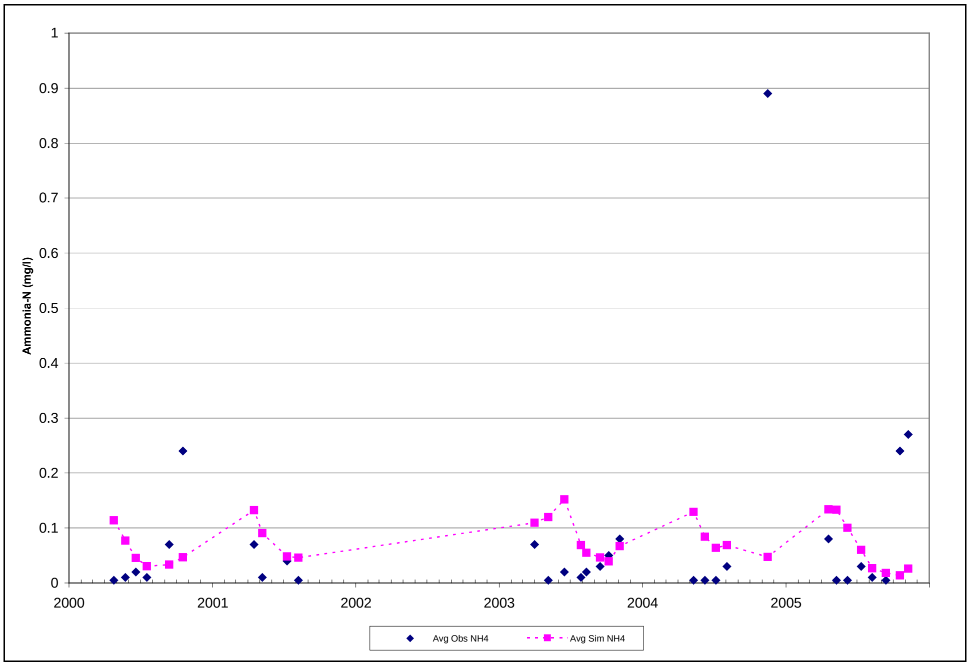

Figure C-23: Liberty Reservoir BCDPW Station NPA0067 Bottom Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

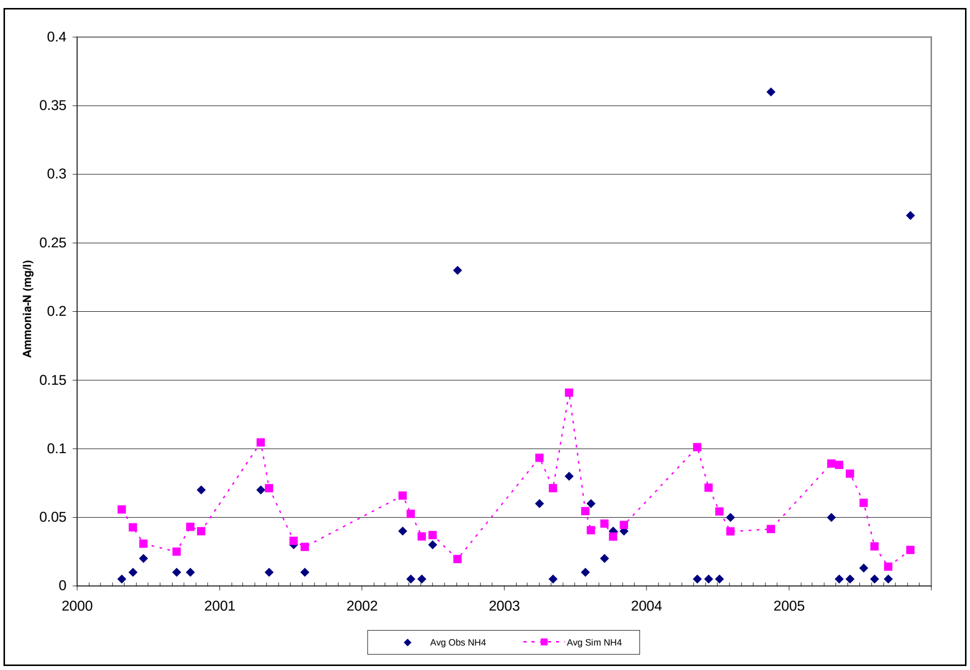

Figure C-24: Liberty Reservoir BCDPW Station NPA0059 Bottom Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

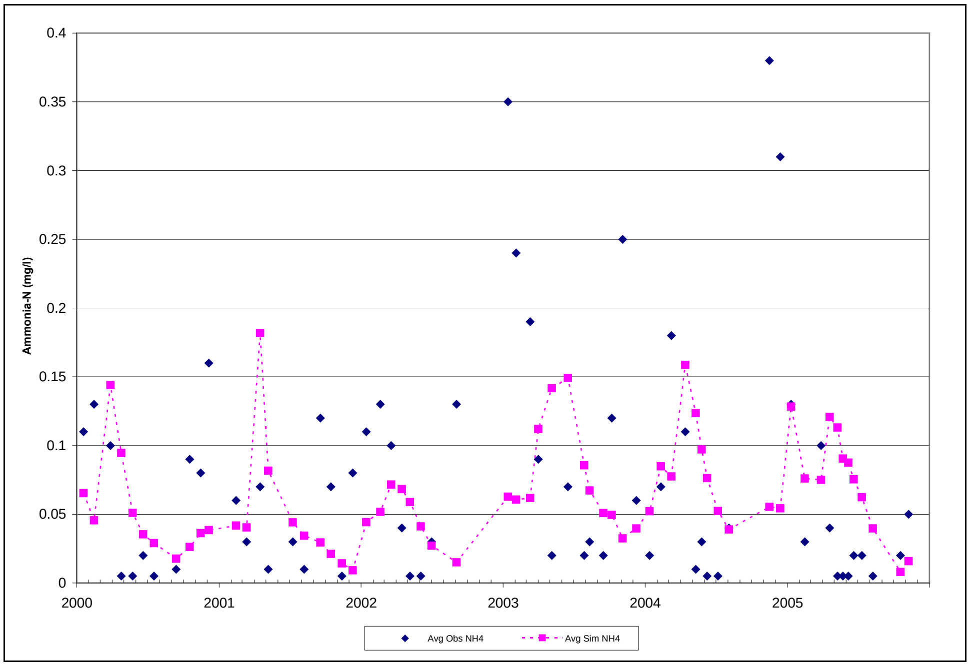

Figure C-25: Liberty Reservoir BCDPW Station NPA0042 Bottom Observed and Simulated (Calibration) NH4 Concentrations on Sampling Dates

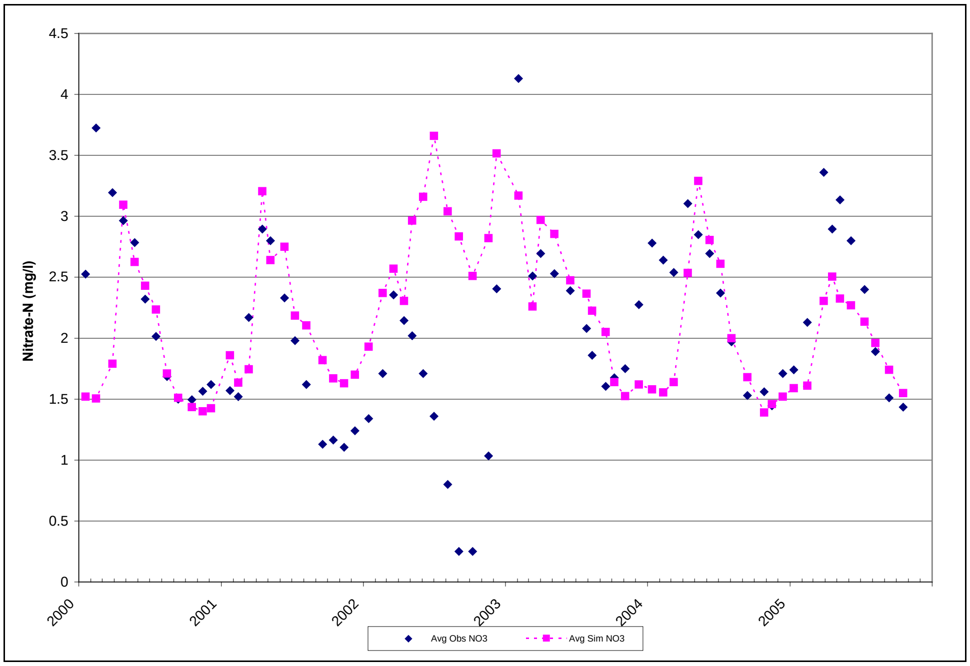

Figure C-26: Liberty Reservoir BCDPW Station NPA0105 Surface Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

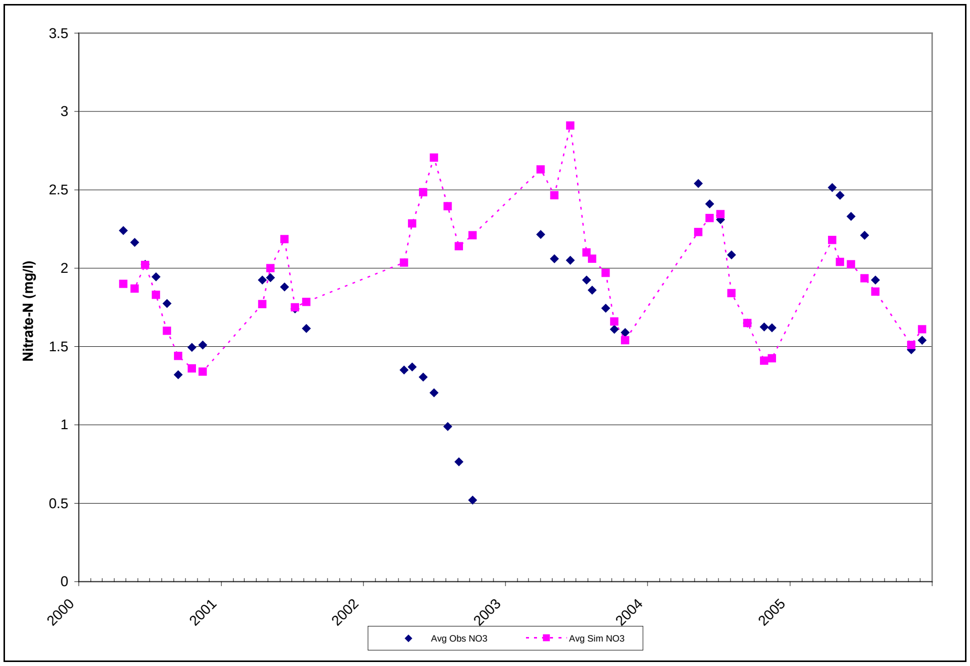

Figure C-27: Liberty Reservoir BCDPW Station NPA0067 Surface Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

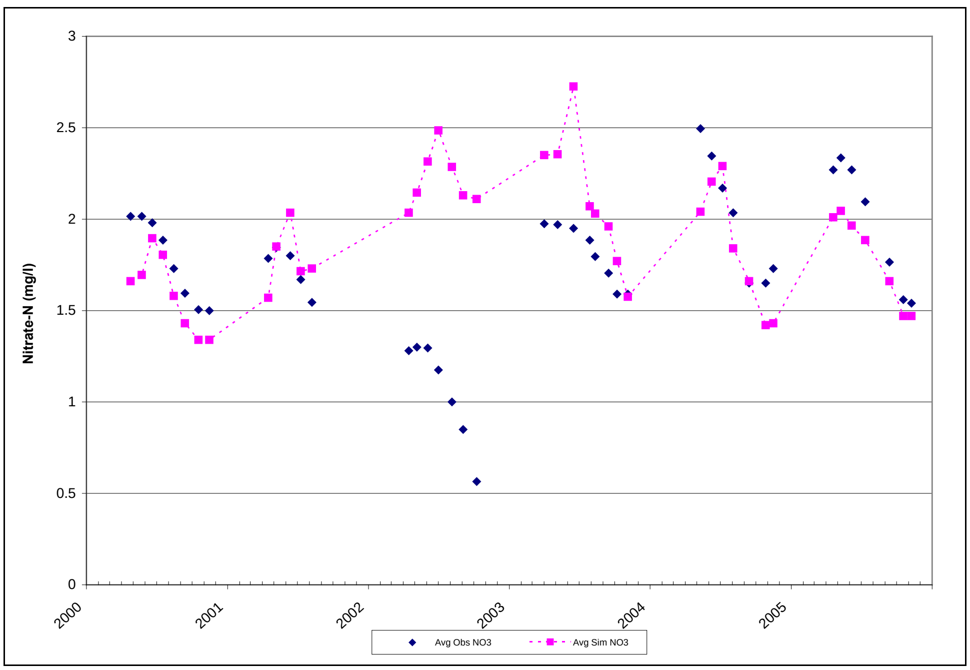

Figure C-28: Liberty Reservoir BCDPW Station NPA0059 Surface Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

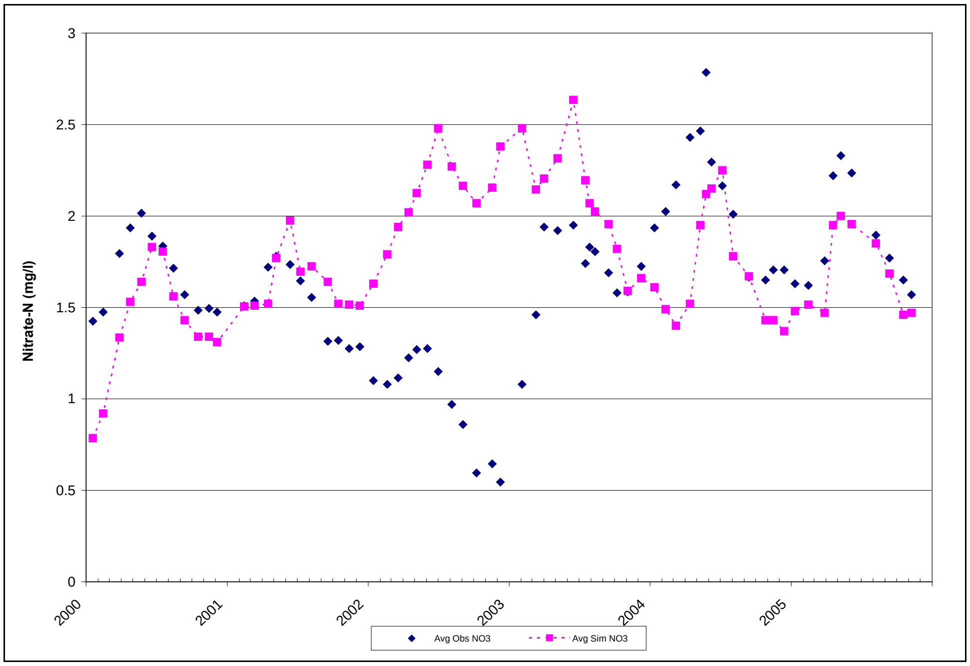

Figure C-29: Liberty Reservoir BCDPW Station NPA0042 Surface Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

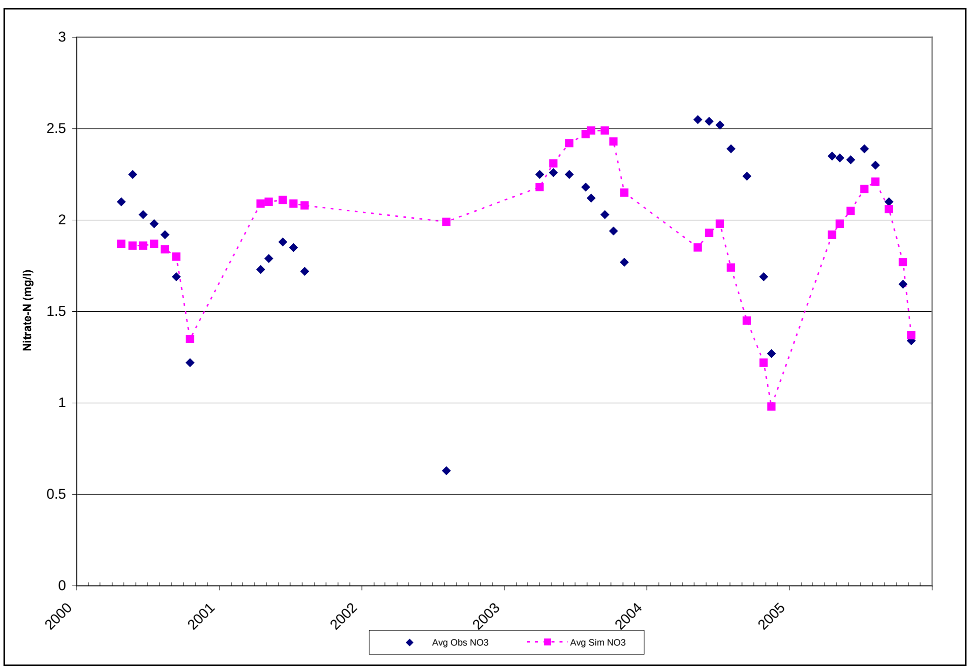

Figure C-30: Liberty Reservoir BCDPW Station NPA0067 Bottom Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

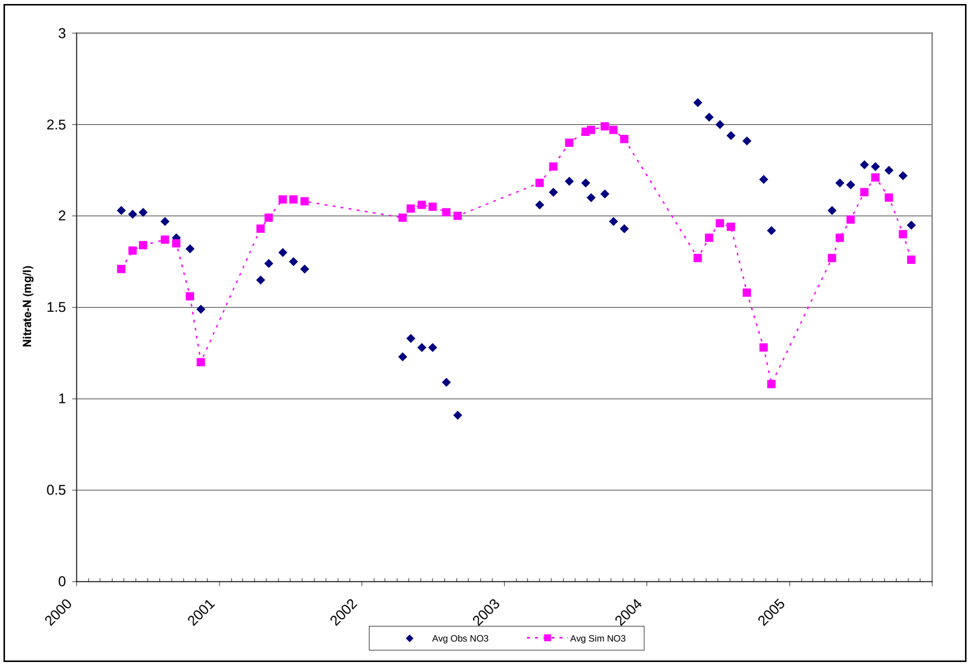

Figure C-31: Liberty Reservoir BCDPW Station NPA0059 Bottom Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

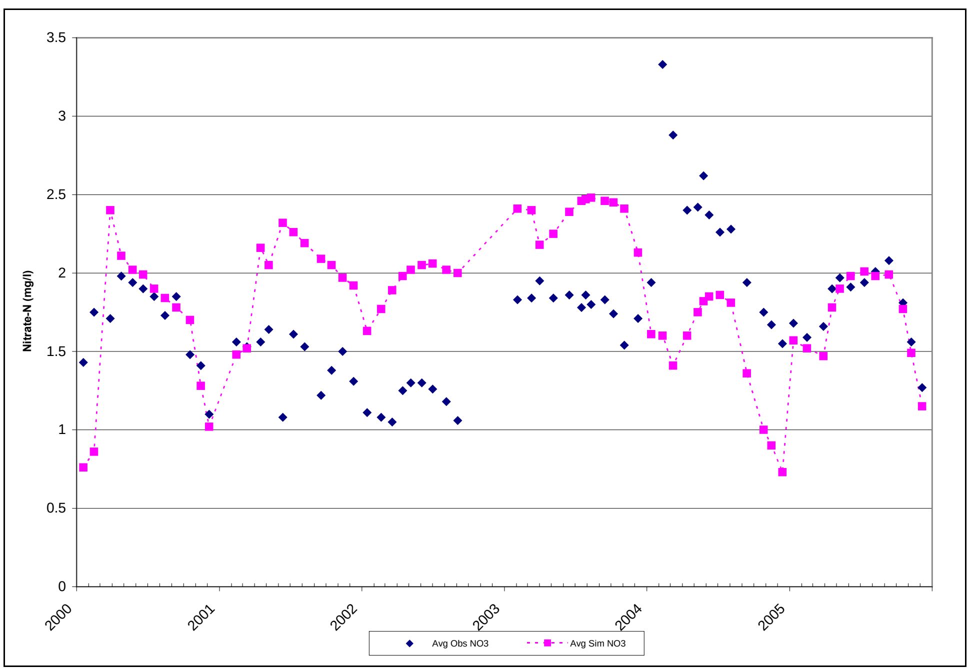

Figure C-32: Liberty Reservoir BCDPW Station NPA0042 Bottom Observed and Simulated (Calibration) NO3 Concentrations on Sampling Dates

Appendix D

Technical Approach Used to Generate Maximum Daily Loads

Summary

This appendix documents the technical approach used to define MDLs of phosphorus and sediment consistent with the average annual TMDLs, which are protective of water quality standards in Liberty Reservoir. The approach builds upon the modeling analysis that was conducted to determine the loadings of phosphorus and sediment, and can be summarized as follows.

- The approach defines MDLs for each of the source categories.
- The approach builds upon the TMDL modeling analysis that was conducted to ensure that average annual loading targets result in the achievement of water quality standards.
- The approach converts daily time-series loadings into TMDL values in a manner that is consistent with available EPA guidance on generating daily loads for TMDLs.
- The approach considers a daily load level of a resolution based on the specific data that exists for each source category.

Introduction

This appendix documents the development and application of the approach used to define total maximum daily loads on a daily basis. It is divided into sections discussing:

- Basis for approach
- Options considered
- Selected approach
- Results of approach

Basis for approach

The overall approach for the development of daily loads was based upon the following factors:

- **Average Annual TMDLs:** The basis of the average annual phosphorus TMDL is that cumulative high nutrient loading rates lead to eutrophication. Thus, the average annual phosphorus loads were calculated to be protective of the aquatic life designated use of Liberty Reservoir. Similarly, high sediment loading rates lead to a loss of reservoir storage capacity, and average annual sediment loads were calculated to protective of the public water supply designated use of the reservoir.

- **The CBP P5.3.2 Liberty Reservoir Watershed Model Phosphorus and Sediment Loads:** As described in Section 2.2.1, the phosphorus and sediment loads from the Liberty Reservoir watershed model are based on EOS loads from the CBP P5.3.2 watershed model, refined for these TMDLs via statistical analysis of monitoring data collected by BCDPW in the Liberty Reservoir watershed.
- **Draft EPA guidance document entitled "Developing Daily Loads for Load-based TMDLs"**: This guidance document provides options for defining MDLs when using TMDL approaches that generate daily output (US EPA 2007).

The rationale for developing TMDLs expressed as *daily* loads was to accept the existing average annual TMDLs, but then develop a method for converting these numbers to a MDL – in a manner consistent with EPA guidance and available information.

Options Considered

The draft EPA guidance document for developing daily loads does not specify a single approach that must be adhered to, but rather it contains a range of acceptable options for calculating MDLs. The selection of a specific method for translating a time-series of allowable loads into the expression of a TMDL requires decisions regarding both the level of resolution (e.g., single daily load for all conditions vs. loads that vary with environmental conditions) and level of probability associated with the TMDL.

This section describes the range of options that were considered when developing MDLs for the Liberty Reservoir.

<u>Level of Resolution</u>

The level of resolution pertains to the amount of detail used in specifying the MDL. The draft EPA guidance on daily loads provides three categories of options for level of resolution, all of which are potentially applicable for the Liberty Reservoir phosphorus and sediment TMDLs:

1. **Representative daily load:** In this option, a single daily load (or multiple representative daily loads) is specified that covers all time periods and environmental conditions.
2. **Flow-variable daily load:** This option allows the MDL to vary based upon the observed flow condition.
3. **Temporally-variable daily load:** This option allows the MDL to vary based upon seasons or times of varying source or water body behavior.

<u>Probability Level</u>

All TMDLs have some probability of being exceeded, with the specific probability being explicitly specified or implicitly assumed. This level of probability directly or indirectly reflects two separate phenomena:

1. Water quality criteria consist of components describing acceptable magnitude, duration, and frequency. The frequency component addresses how often

conditions can allowably surpass the combined magnitude and duration components.

2. Pollutant loads, especially from wet weather sources, typically exhibit a large degree of variability over time. It is rarely practical to specify a "never to be exceeded value" for a daily load, as essentially any loading value has some finite probability of being exceeded.

The draft daily load guidance document states that the probability component of the MDL should be "based on a representative statistical measure" that is dependent upon the specific TMDL and best professional judgment of the developers. This statistical measure represents how often the MDL is expected/allowed to be exceeded. The primary options for selecting this level of protection would be:

1. **The MDL reflects some central tendency:** In this option, the MDL is based upon the mean or median value of the range of loads expected to occur. The variability in the actual loads is not addressed.
2. **The MDL reflects a level of protection implicitly provided by the selection of some "critical" period**: In this option, the MDL is based upon the allowable load that is predicted to occur during some critical period examined during the analysis. The developer does not explicitly specify the probability of occurrence.
3. **The MDL is a value that will be exceeded with a pre-defined probability:** In this option, a "reasonable" upper bound percentile is selected for the MDL based upon a characterization of the variability of daily loads. For example, selection of the 95th percentile value would result in a MDL that would be exceeded 5% of the time.

Selected Approach

The approach selected for defining MDLs for Liberty Reservoir was based upon the specific data that exists for each source category. The approach consists of unique methods for each of the following categories of sources:

- Approach for Nonpoint Sources, CAFOs, and Stormwater Point Sources
- Approach for Process Water Point Sources

<u>Approach for Nonpoint Sources, CAFOs, and Stormwater Point Sources</u>

The level of resolution selected for defining daily MDLs for Liberty Reservoir was a representative daily load, expressed as a single daily load for each loading source. This approach was chosen based upon the specific data that exists for nonpoint sources, CAFOs, and stormwater point sources.

Currently, the best available data is the Liberty Reservoir W2 model input loads, which are calculated from the refined CBP P5.3.2 Liberty Reservoir watershed model daily time series, calibrated to long-term average annual loads. It was concluded that it would not be appropriate to apply the absolute values of the Liberty Reservoir W2 model inputs to the TMDL. Rather, it was decided that best approach would be to adopt the methodology applied within Maryland's non-tidal sediment and nutrient TMDLs, which is a statistically-based estimate using the annual loads and the distribution of simulated daily loads. Since the TMDL loads and simulated daily loads are based on the same model hydrology, this approach assumes that the distribution of the daily simulated river reach loads represents the distribution of delivered EOS loads used in the TMDL, and therefore they could be used to calculate a normalized statistical parameter to estimate the MDLs.

The MDL was estimated based on three factors: a specified probability level, the average annual phosphorus or sediment TMDL, and the coefficient of variation (CV) of the total simulated daily loads entering Liberty Reservoir. The probability level (or exceedance frequency) is based upon guidance from EPA (US EPA 1991) where examples suggest that when converting from a long-term average to a daily value, the z-score corresponding to the 99th percentile of the log-normal probability distribution should be used.

CBP P5.3.2 Liberty Reservoir watershed model reach simulations consisted of a daily time series beginning in 2000 and extending to the year 2005. The CV was estimated by first converting the daily phosphorus or sediment load values to a log distribution and then verifying that the results approximated a normal distribution (see Figures D-1 and D-2 for total phosphorus and sediment, respectively). Next, the CV for this distribution was calculated using the arithmetic mean and standard deviation results from the log transformation. The log-transformed values were used to reduce the possible influence of outliers. The resulting CVs (0.490 for phosphorus and 0.069 for sediment) were calculated using the following equation:

$$CV = \frac{\beta}{\alpha} \qquad \text{(Equation D-1)}$$

Where:

CV = coefficient of variation

$\beta = \alpha\sqrt{e^{\sigma^2} - 1}$

$\alpha = e^{(\mu + 0.5*\sigma^2)}$

α = mean (arithmetic)

β = standard deviation (arithmetic)

μ= mean of logarithms

σ=standard deviation of logarithms

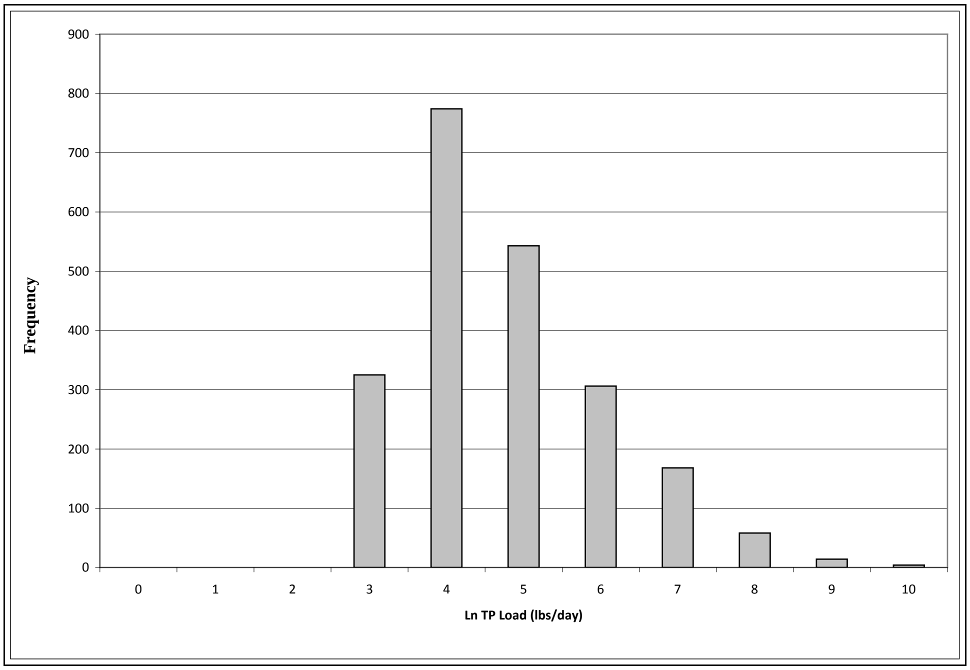

Figure D-1: Histogram of CBP River Segment Daily Phosphorus Simulation Results for Liberty Reservoir

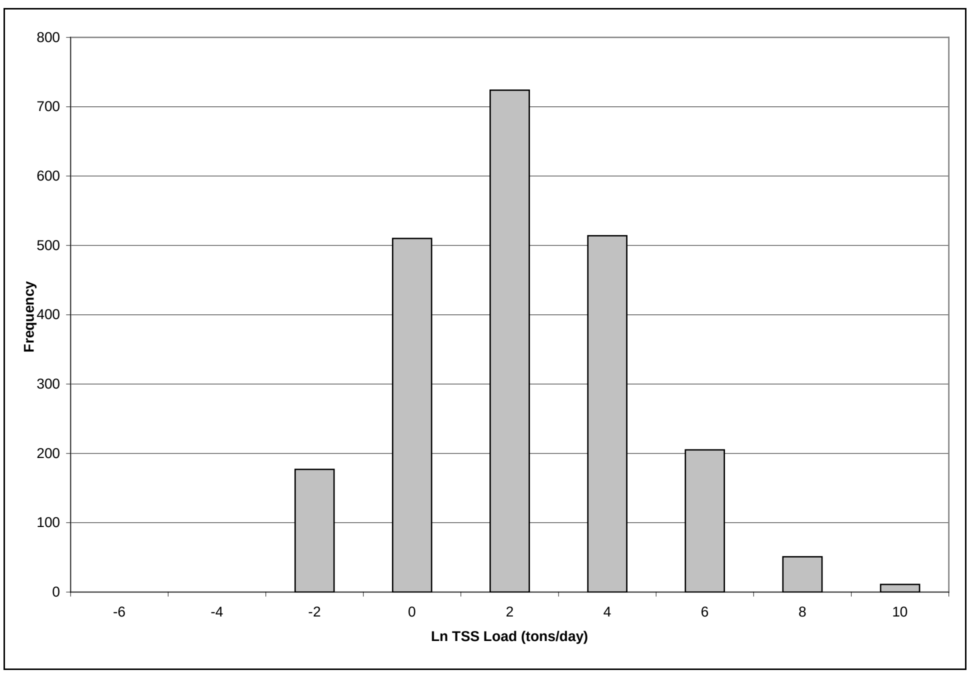

Figure D-2: Histogram of CBP River Segment Daily Sediment Simulation Results for Liberty Reservoir

The MDL for each contributing source is estimated as the long-term average annual load multiplied by a factor that accounts for expected variability of daily loading values. The equation is as follows:

$$MDL = LTA * e^{(z\sigma - 0.5\sigma^2)} \qquad \text{(Equation D-2)}$$

Where:

MDL = Maximum daily load
LTA = Long-term average (average annual load)
Z = z-score associated with target probability level
$\sigma^2 = \ln(CV^2+1)$
CV = Coefficient of variation based on arithmetic mean and standard deviation

Using a z-score associated with the 99^{th} percent probability, the CVs of 0.490 and 0.069 for phosphorus and sediment, respectively, and consistent units, the resulting dimensionless conversion factor from long-term average loads to a maximum daily value is 2.64 and 1.17 for phosphorus and sediment, respectively. The average annual Liberty Reservoir phosphorus TMDL is reported in lbs/yr, and the conversion from lbs/yr to a MDL in lbs/day is 0.0072 (e.g. 2.64/365). The average annual Liberty Reservoir sediment TMDL is reported in tons/yr, and the conversion from tons/yr to a MDL in tons/day is 0.0032 (e.g. 1.17/365).

Approach for Process Water Point Sources

The TMDL also considers contributions from other point sources (*i.e.*, sources other than stormwater point sources) in the watershed that have NPDES permits with phosphorus or sediment limits. As these sources are generally minor contributors to overall nutrient or sediment loads, the TMDL analysis that defined the average annual TMDL did not propose any reductions for these sources and held each of them constant at their existing technology-based NPDES permit monthly (or daily if monthly was not specified) limit for the entire year.

The approach used to determine MDLs for these sources was dependent upon whether a MDL was specified within the permit. If a maximum daily limit was specified, then the reported average flow was multiplied by the daily maximum limit to obtain a MDL. If a maximum daily limit was not specified, the MDLs were calculated based on the guidance provided in the Technical Support Document (TSD) for Water Quality-based Toxics Control (US EPA 1991). The long-term average annual TMDL was converted to maximum daily limits using Table 5-2 of the TSD assuming a coefficient of variation of 0.6 and a 99^{th} percentile probability. This results in a dimensionless multiplication factor of 3.11. The average annual Liberty Reservoir phosphorus TMDL is reported in lbs/yr, and the conversion from lbs/yr to a MDL in lbs/day is 0.0072 (e.g. 2.64/365). The average annual Liberty Reservoir sediment TMDL is reported in tons/yr, and the conversion from tons/yr to a MDL in tons/day is 0.0032 (e.g. 1.17/365).

None of the permitted process water point sources in the Liberty Reservoir watershed have daily maximum phosphorus or sediment concentrations, so the MDL was calculated based on the TSD guidance.

Margin of Safety
The MOS for the Liberty Reservoir phosphorus TMDL was set equal to 5% of the total TMDL (including the MOS), or 5.26% of the total WLAs and LAs. The MOS for the Liberty Reservoir sediment TMDL is implicit.

Results of Approach

This section lists the results of the selected approach to define MDLs for the Liberty Reservoir.

- Calculation Approach for Nonpoint Sources, CAFOs, and Stormwater Point Sources

For Phosphorus:

LA_{LR} (lbs/day) = Average Annual TMDL LA_{LR} (lbs/yr) * 0.0072

NPDES Stormwater WLA_{LR} (lbs/day) = Average Annual TMDL NPDES Stormwater WLA_{LR} (lbs/yr) * 0.0072

CAFO WLA_{LR} (lbs/day) = Average Annual TMDL NPDES Stormwater WLA_{LR} (lbs/yr) * 0.0072

For Sediment:

LA_{LR} (tons/day) = Average Annual TMDL LALR (tons/yr) * 0.0032

Stormwater WLALR (tons/day) = Average Annual TMDL Stormwater WLA_{LR} (tons/yr) * 0.0032

CAFO WLA_{LR} (tons/day) = Average Annual TMDL Stormwater WLA_{LR} (tons/yr) * 0.0032

- Calculation Approach for Process Water Point Sources
    - For permits with a daily maximum limit:

Process Water WLA_{LR} (lbs/day; tons/day) = Permit flow (millions of gallons per day (mgd)) * Daily maximum permit limit (mg/l) * 0.0042

- For permits without a daily maximum limit:

Process Water WLA_{LR} (lbs/day; tons/day) = Process Water WLA (lbs/yr)* 0.0072 (phosphorus)/0.0032 (sediments)

Table D-1: Summary of Liberty Reservoir Total Phosphorus MDLs (lbs/day)

MDL (lbs/day)	=	LA_{LR}	+	**CAFO** WLA_{LR}	+	**NPDES Stormwater** WLA_{LR}	+	**Process Water** WLA_{LR}	+	**MOS**
300.3	=	180.0	+	3.1	+	80.9	+	21.2	+	15.0

Table D-2: Summary of Liberty Reservoir Sediment MDLs (tons/day)

MDL (tons/day)	=	LA_{LR}	+	**CAFO** WLA_{LR}	+	**NPDES Stormwater** WLA_{LR}	+	**Process Water** WLA_{LR}		**MOS**
51.6	=	33.5	+	0.02	+	17.6	+	0.5	+	Implicit