Total Maximum Daily Loads of Phosphorus and Sediments for Loch Raven Reservoir And Total Maximum Daily Loads of Phosphorus for Prettyboy Reservoir, Baltimore, Carroll and Harford Counties, Maryland

FINAL

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List of Abbreviations

BMP	Best Management Practice
BOD	Biological Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CE-QUAL-W2	U.S. Army Corps of Engineers Water Quality and Hydrodynamic Model, Version 3
Chla	Active Chlorophyll *a*
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
CWAP	Clean Water Action Plan
DO	Dissolved Oxygen
DPW	Baltimore City Department of Public Works
EPA	Environmental Protection Agency
FSA	Farm Service Administration
HSPF	Hydrological Simulation Program Fortran
ICPRB	Interstate Commission on the Potomac River Basin
LA	Load Allocation
lbs/yr	Pounds per Year
MD	Maryland
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
MGS	Maryland Geological Survey
mg/l	Milligrams per Liter
MGD	Million Gallons per Day
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
NBOD	Nitrogenous Biochemical Oxygen Demand
NMP	Nutrient Management Plan
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System

NPS	Nonpoint Source
POM	Particulate Organic Matter
PO4	Phosphate
RTG	Reservoir Technical Group
SCWQP	Soil Conservation and Water Quality Plan
SOD	Sediment Oxygen Demand
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
W2	CE-QUAL-W2
WLA	Wasteload Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WRAS	Watershed Restoration Action Strategy
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 Loch Raven Reservoir (basin code 02-13-08-05) and for phosphorus in Prettyboy Reservoir (basin code 02-13-08-06).

Prettyboy Reservoir and Loch Raven Reservoir (referred to also as the Gunpowder Reservoirs), Use III-P waterbodies (COMAR 26.08.02.08J(4)), were identified on the 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE) as impaired by nutrients (1996), sediments (1996 – Loch Raven), metals (1996), bacteria (2002 – Prettyboy), mercury in fish tissue (2002), and impacts to biological communities (2002 & 2004). This document upon approval from EPA, establishes TMDLs for the nutrient and sediment impairments. TMDLs were completed in 2002 for both reservoirs for the mercury listings. Water Quality Analyses were completed for both reservoirs for the metals listings in 2003. Other impairments within these watersheds will be addressed separately at a future date.

The water quality goal of the nutrient TMDLs is to reduce high chlorophyll *a* (Chla) concentrations that reflect excessive algal blooms, and to maintain dissolved oxygen (DO) at a level supportive of the designated uses for Prettyboy and Loch Raven Reservoirs. The water quality goal of the sediment TMDL for Loch Raven Reservoir is to increase the useful life of the reservoir for water supply by preserving storage capacity.

The TMDLs for the nutrient total phosphorus (TP) were determined using a time-variable, two-dimensional water quality eutrophication model, CE-QUAL-W2 ("W2"), to simulate water quality in each reservoir. The TMDLs are based on average annual total phosphorus loads for the simulation period 1992-1997, which includes both wet and dry years, and thus takes into account a variety of hydrological conditions. Chla concentrations indicative of eutrophic conditions can occur at any time of year and are the cumulative result of phosphorus loadings that span seasons. Thus, average annual phosphorus total loads are the most appropriate measure for expressing the nutrient TMDLs for Prettyboy and Loch Raven Reservoirs. Similarly, the sediment TMDL for Loch Raven Reservoir, which is based on the water quality modeling performed for the nutrient TMDLs, 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 TMDLs include (1) a wasteload allocation (WLA) to municipal wastewater treatment plants and municipal storm sewer systems, (2) a load allocation (LA) to nonpoint sources, and (3) a 5% margin of safety (MOS) for the nutrient TMDLs and an implicit MOS for the sediment TMDL. The table below summarizes the nutrient and sediment TMDLs.

Summary of Nutrient and Sediment TMDLs for Prettyboy and Loch Raven Reservoirs

Waterbody	Constituent	TMDL	WLA	LA	MOS
Prettyboy Reservoir	TP (lbs/yr)	23,192	2,940	19,072	1,160
Loch Raven Reservoir	TP (lbs/yr)	54,941	22,010	30,184	2,747
Loch Raven Reservoir	Sediment (tons/yr)	28,925	1,210	27,715	Implicit

Numerous factors provide assurance that these TMDLs will be implemented. First, National Pollutant Discharge Elimination System (NPDES) permits for both wastewater treatment plants and urban stormwater systems will play important roles in assuring implementation. Second, Maryland has several well-established programs that may be drawn upon, including Maryland's Tributary Strategies for Nutrient Reductions developed in accordance with the Chesapeake Bay Agreement. Third, Maryland's Water Quality Improvement Act of 1998 requires that nutrient management plans be implemented for all agricultural lands throughout Maryland. Fourth, local jurisdictions, along with MDE and other stakeholders, have implemented a formal agreement, the Reservoir Watershed Management Agreement, to protect water quality in the reservoirs. Fifth, a Watershed Restoration Action Strategy (WRAS) is currently in development for the Prettyboy Reservoir. Sixth, Maryland has adopted a watershed cycling strategy, which will assure that routine future monitoring and TMDL evaluations are conducted. Additionally, the federal Safe Drinking Water Act requires states to develop and implement source water assessment programs to study the safety and evaluate the vulnerability of drinking water sources to contamination. The source water assessment for Loch Raven Reservoir Watershed (including Prettyboy Reservoir) is described fully in MDE, 2004.

1.0 INTRODUCTION

Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to develop a Total Maximum Daily Load (TMDL) for each water quality limited segment (WQLS) on the Section 303(d) List, taking into account seasonal variations and a protective margin of safety (MOS) to account for uncertainty. 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 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, 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.

Prettyboy Reservoir and Loch Raven Reservoir (also referred to as the Gunpowder Reservoirs), Use III-P waterbodies (COMAR 26.08.02.08J(4)), were identified on the 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE) as impaired by nutrients (1996) – due to signs of eutrophication, expressed as high chlorophyll *a* (Chla) levels, sediments (1996 – Loch Raven), metals (1996), bacteria (2002 – Prettyboy), mercury in fish tissue (2002), and impacts to biological communities (2002 and 2004). Eutrophication is the over-enrichment of aquatic systems by excessive inputs of nutrients, especially nitrogen and/or phosphorus. The nutrients act as a fertilizer leading to the excessive growth of aquatic plants, which eventually die and decompose, leading to bacterial consumption of dissolved oxygen (DO). Prettyboy Reservoir is also listed as impaired because of seasonal DO concentrations less than 5.0 mg/l in the hypolimnion. This document upon approval from EPA, establishes TMDLs for the nutrient and sediment impairments. TMDLs were completed in 2002 for both reservoirs for the mercury listings. Water Quality Analyses were completed for both reservoirs for the metals listings in 2003. Other impairments within these watersheds will be addressed separately at a future date.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Both Prettyboy and Loch Raven Reservoirs lie in the Gunpowder Falls watershed (Figure 1). Gunpowder Falls drains into Chesapeake Bay north of the City of Baltimore. The portion of the watershed draining to the reservoirs lies primarily in Baltimore and Carroll Counties, but also includes small portions of Harford County and York County, PA. Both reservoirs are part of the water supply system for Baltimore City and surrounding jurisdictions. Water supply intakes in Loch Raven Reservoir feed Baltimore City's

Montebello Water Treatment Plant. Prettyboy Reservoir, which is upstream of Loch Raven Reservoir, is used as a secondary reservoir to maintain capacity in Loch Raven Reservoir.

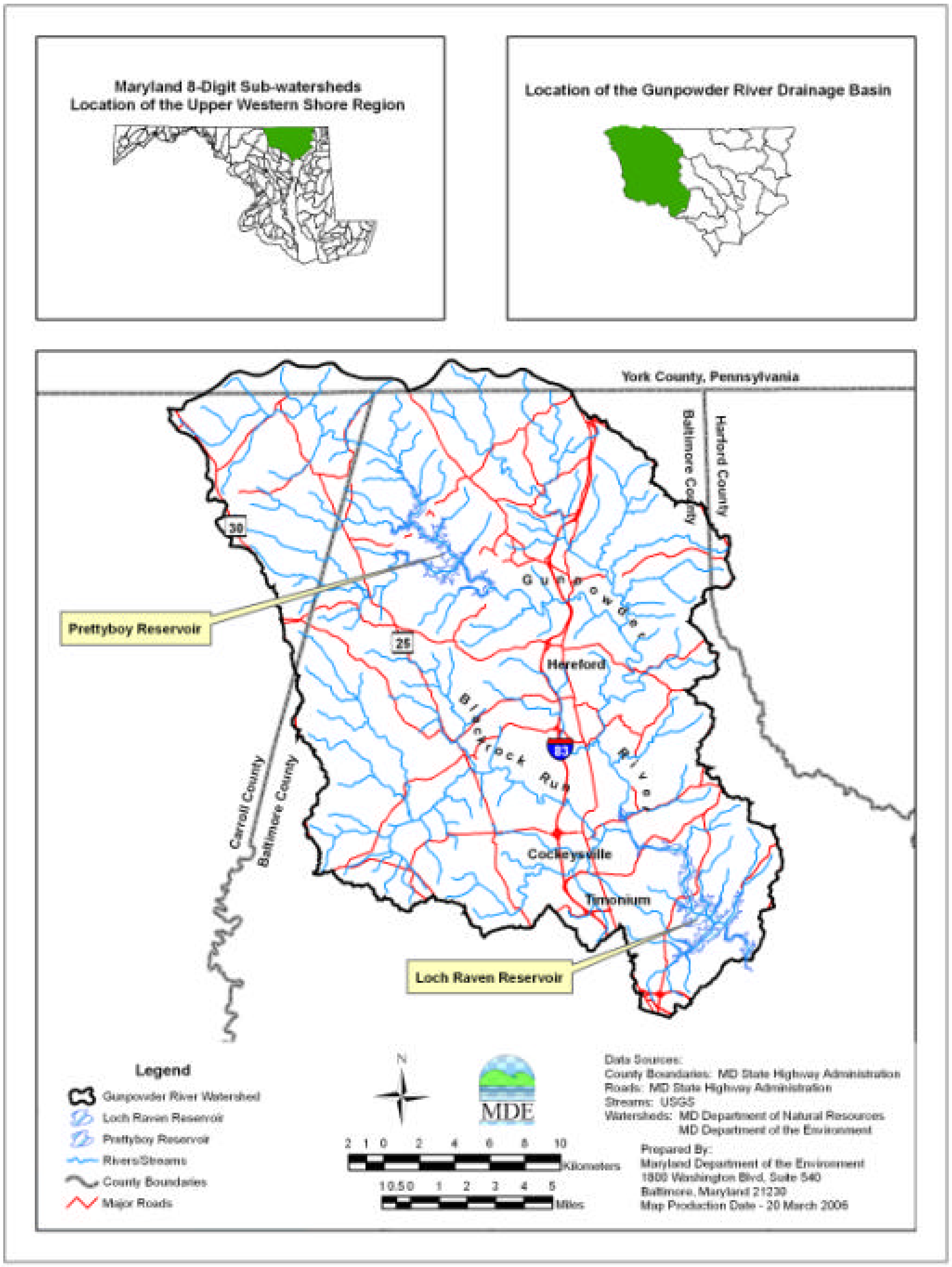

Figure 1: Location of Prettyboy and Loch Raven Reservoirs

Several relevant statistics for Prettyboy and Loch Raven Reservoirs are provided below in Table 1.

Table 1: Current Physical Characteristics of Prettyboy and Loch Raven Reservoirs

Characteristic	Prettyboy	Loch Raven
Location:	Baltimore County, MD Lat. 39° 37' 12" N Long. 76° 42' 36" W	Baltimore County, MD Lat. 39° 25' 48" N Long. 76° 32' 24" W
Surface Area:	1500 acres (65,340,000 ft^2)	2400 acres (104,544,000 ft^2)
Normal Reservoir Depth[1]:	98.5 feet	76.0 feet
Purpose:	Water Supply Recreation	Water Supply Recreation
Basin Code:	02-13-08-06	02-13-08-05
Volume:	60,100 acre-feet	72,700 acre-feet
Drainage Area to Reservoir:	80.0 mi^2 (51,200 acres)	303 mi^2 (193,920 acres)

Source: Inventory of Maryland Dams and Hydropower Resources (Weisberg *et al.*, 1985). [1]Measured from base of dam to spillway.

2.1.1 Land Use

Figure 2 shows the land use in the Prettyboy and Loch Raven watersheds. The land use is based on 1997 Maryland Department of Planning Land Use/Land Cover data. The Prettyboy Reservoir watershed (excluding the reservoir surface area) covers approximately 49,000 acres or 77 square miles. About half of the watershed is in crops or pasture, 39% in forest, and 12% in residential, commercial, or industrial land uses (Figure 3). The Loch Raven Reservoir watershed, excluding the drainage to Prettyboy Reservoir and the reservoir surface areas, covers approximately 140,000 acres or about 218 square miles. Approximately 21% of the watershed is developed and 38% is forest, with the remainder in crops, pasture or "mixed open" land uses (Figure 4). Mixed open land uses represent a mixture of several categories of anthropogenically modified open land, including low-density urban cover, horse pasture, fallow cropland or transitional agricultural land.

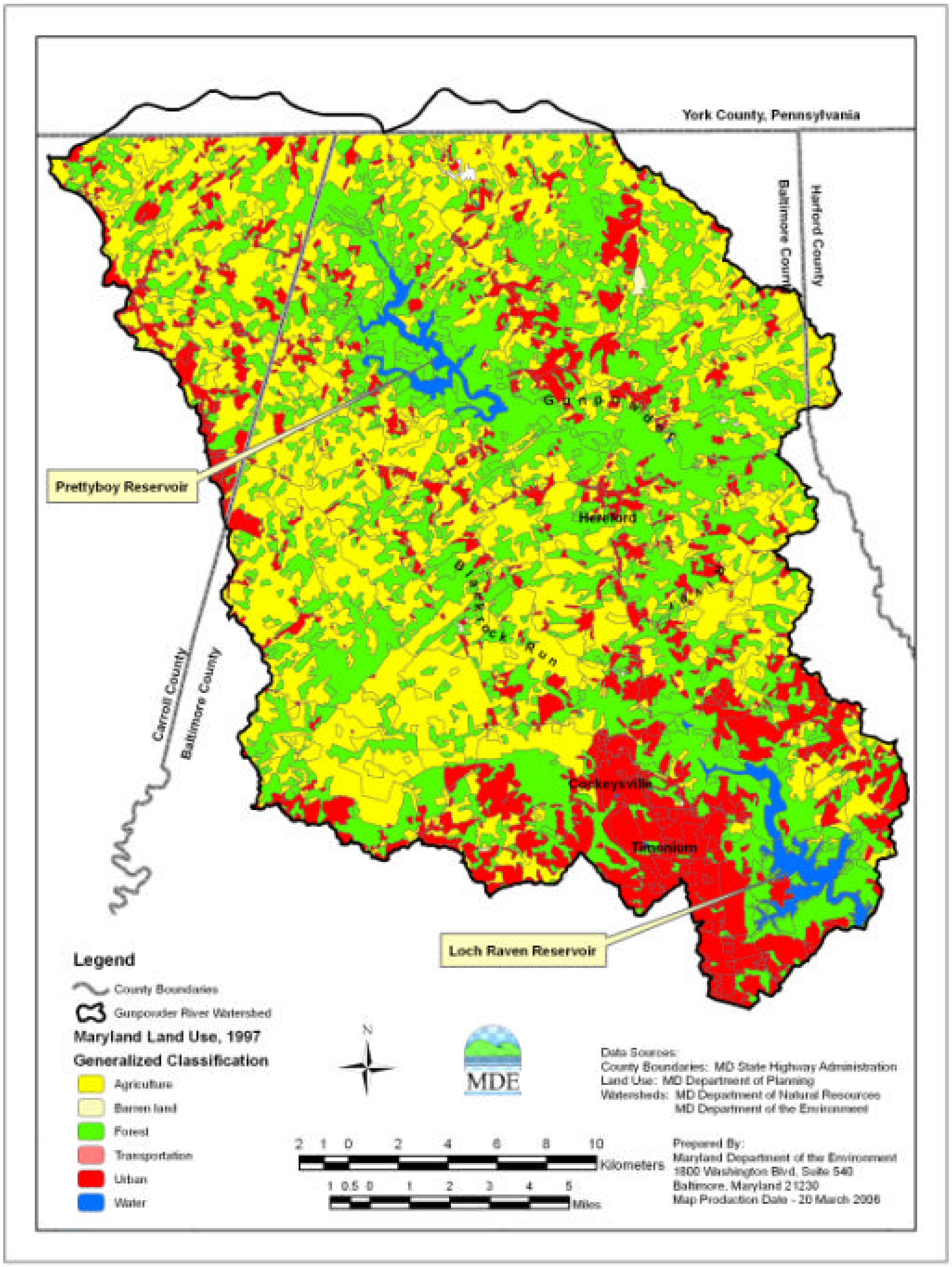

Figure 2: Land Use in Gunpowder Falls Watershed

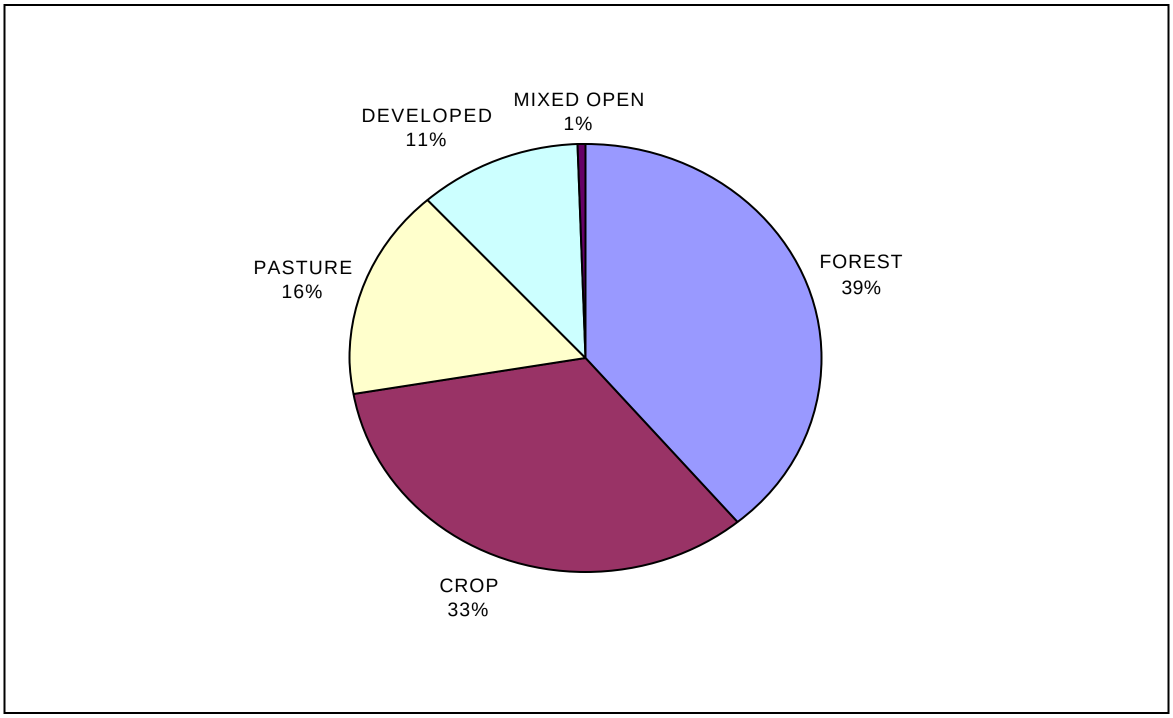

Figure 3: Proportion of Land Use in the Prettyboy Reservoir Watershed

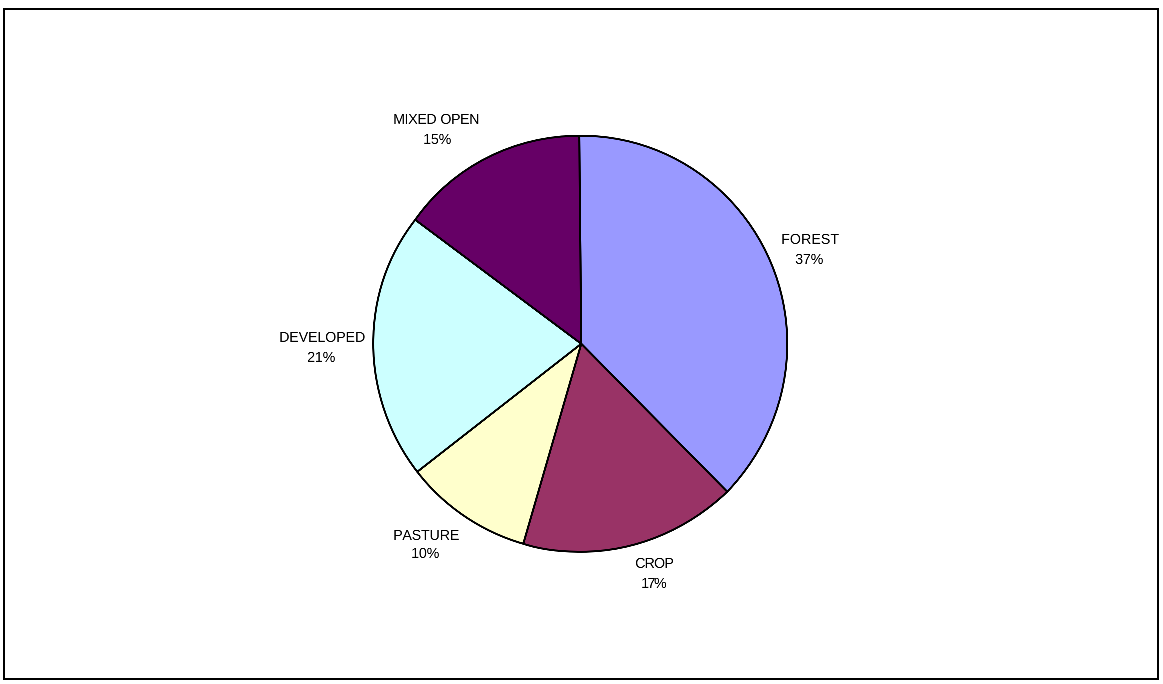

Figure 4: Proportion of Land Use in the Loch Raven Reservoir Watershed

2.1.2 Geology and Soils

The watersheds of Prettyboy and Loch Raven Reservoirs lie in the Piedmont physiographic province. The surficial geology is characterized by metamorphic rock of Precambrian and Cambrian age. Prettyboy schist is the underlying bedrock of the Prettyboy Reservoir watershed (MDE, 2004). The underlying metamorphic rock complex of the Loch Raven watershed downstream of Prettyboy consists mainly of crystalline schists and gneiss with smaller areas of marble. The underlying marble formations, Cockeysville Marble and the Patuxent Formation, are less resistant to weathering than the schists and gneiss and consequently occur mainly in valleys.

The primary soil associations in the watershed are the Manor-Glenelg, Chester-Glenelg, Baltimore-Conestoga-Hagerstown, Beltsville-Chillum-Sassafras, Glenelg-Chester-Manor, and Mt. Airy-Linganore associations. These soils are mainly deep and well-drained to moderately well-drained (Reybold and Matthews, 1976; Matthews, 1969). Within the stream floodplains, alluvial, Codorus and Hatboro soil series predominate. Nearly 85% of the soils in the watershed below Prettyboy Reservoir are classified as Hydrologic Group B, which means that they have low to moderate surface runoff potential, moderate infiltration rates, and moderately fine to moderately coarse soil texture (Tetra Tech, 1997).

2.1.3 Point Sources and Wastewater Treatment Plant Loads

The development of nutrient TMDLs for Prettyboy and Loch Raven Reservoirs was based on computer simulation modeling of water quality conditions from 1992 to 1997. During that time, the Manchester municipal wastewater treatment plant (WWTP) discharged within the Prettyboy Reservoir watershed, and the Hampstead municipal WWTP, along with ten small industrial sources, discharged within the Loch Raven Reservoir watershed. Table 2 shows the annual phosphorus and sediment loads from the municipal WWTPs during the simulation period, 1992-1997.

Table 2: Annual Municipal Wastewater Treatment Plant Loads 1992-1997

	Manchester (MD0022446)			Hampstead (MD0022578)		
Year	PO_4 (lbs/yr)	Organic P (lbs/yr)	TSS (tons/yr)	PO_4 (lbs/yr)	Organic P (lbs/yr)	TSS (tons/yr)
1992	192.33	177.84	2.77	276.41	173.39	0.27
1993	300.08	275.61	4.15	489.03	291.04	0.35
1994	382.14	370.30	7.06	254.56	195.37	0.39
1995	195.65	37.44	0.89	139.16	146.87	0.40
1996	90.65	80.92	0.83	168.81	107.44	0.85
1997	126.78	114.59	3.30	207.61	88.88	0.39
Average	214.60	176.11	3.16	255.93	167.16	0.44

Currently, the Manchester WWTP discharges through spray irrigation from April 1 through November 30, and in March if weather permits. Its current design flow is 0.5 million gallons per day (MGD). The Hampstead WWTP's current design flow is 0.9 MGD.

There are no industrial sources permitted for discharging phosphorus. Three facilities are permitted to discharge total suspended solids. Only one of them, a limestone quarry and concrete production facility owned by co-permittees Lafarge Mid-Atlantic and Imerys, has the potential to discharge solids in significant quantities.

2.1.4 Nonpoint Source Loads and Urban Stormwater Loads

Nonpoint source loads and urban stormwater loads entering the Prettyboy and Loch Raven Reservoirs were estimated using the Hydrologic Simulation Program-Fortran (HSPF) model. The HSPF model is used to estimate flows, suspended solids and nutrient loads from the watershed's sub-basins, which are linked to two-dimensional CE-QUAL-W2 models of each reservoir. These are used to determine the maximum loads of total phosphorus (TP) that can enter each reservoir while maintaining the water quality criteria associated with their designated uses. The water quality modeling framework is addressed in more detail in Section 4.2.

The simulation of the Loch Raven and Prettyboy Reservoir watersheds used the following assumptions: (1) variability in patterns of precipitation were estimated from existing National Oceanic and Atmospheric Administration (NOAA) meteorological stations; (2) hydrologic response of land areas were estimated for a simplified set of land uses in the basin; and (3) agricultural information was estimated from the Maryland Department of Planning (MDP) land use data, the 1997 Agricultural Census Data (U. S. Department of Commerce, 1997), and the Farm Service Agency (FSA). The HSPF simulates nonpoint source and urban stormwater loads and integrates all natural and human induced sources, including direct atmospheric deposition, and loads from septic tanks, which are associated with river base flow during low flow conditions. Details of the HSPF watershed model developed to estimate these urban and non-urban loads can be found in *Modeling Framework for Simulating Hydrodynamics and Water Quality in Prettyboy and Loch Raven Reservoirs* (ICPRB and MDE, 2006).

Figures 5 and 6 show the relative size of the contribution of point and nonpoint sources of total phosphorus to Prettyboy and Loch Raven Reservoirs, respectively, 1992-1997. Figure 7 shows the relative size of the contribution of sediment sources to Loch Raven Reservoir over the same period.

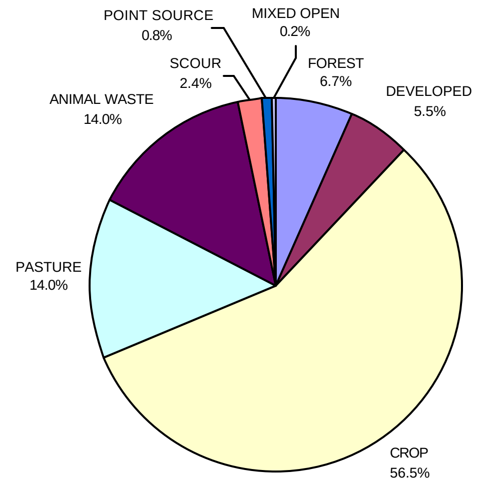

Figure 5: Percent Contribution of Sources to Total Phosphorus Loads to Prettyboy Reservoir

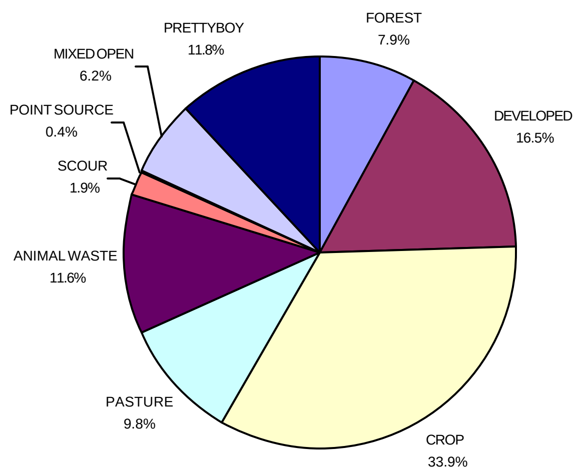

Figure 6: Percent Contribution of Sources to Total Phosphorus Loads to Loch Raven Reservoir

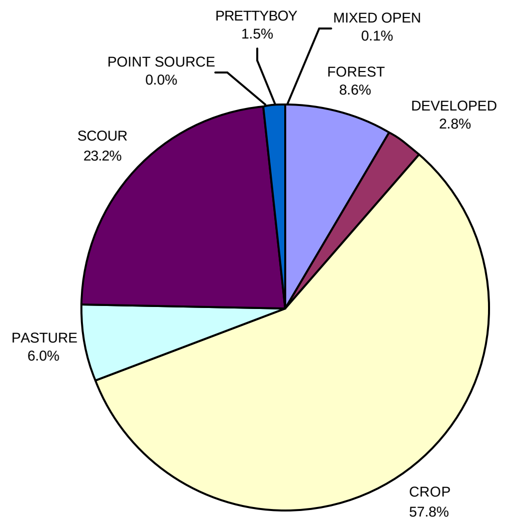

Figure 7: Percent Contribution of Sources to Sediment Loads to Loch Raven Reservoir

2.2 Water Quality Characterization

2.2.1 Baltimore City Department of Public Works Monitoring Program

Baltimore City Department of Public Works (DPW) is the only agency that monitors water quality in the reservoirs. DPW samples at three locations in Prettyboy Reservoir, and at five locations in Loch Raven Reservoir. Figures 8 and 9 show the sites of these sampling locations. Not all locations are sampled at the same time. Sampling is performed by boat at locations GUN0401, GUN0171, and GUN0190 weather permitting; otherwise, in the winter months, sampling is at fixed locations GUN0399, GUN0156, and GUN0174. Sampling at GUN0142 and GUN0437 can occur either by boat or from a fixed platform.

Samples are analyzed for water temperature, dissolved oxygen, total phosphorus, ammonia, nitrate, turbidity, and Secchi depth, among other constituents. Samples are not analyzed for phosphorus species, organic or total nitrogen, or suspended sediment. Starting at the surface, samples are taken every five feet up to sixty feet; samples are taken at ten-foot intervals thereafter.

Not every sample is analyzed for the entire suite of constituents. Generally, only field measurements like temperature and dissolved oxygen are measured at every depth sampled. Lab analysis is performed for Chla for each sample collected at the surface and at ten-foot depths down to 50 feet. In Loch Raven, chemical analysis is performed on samples collected at the surface and every ten feet down to sixty feet. In Prettyboy, chemical analysis is performed on samples taken at the surface and at 10, 20, and 40 feet below the surface, with an additional sample taken at either 60 feet below the surface, in the case of GUN0437, or 80 feet below in the case of the other two stations.

For the purpose of data analysis and the presentation of results, the locations in Loch Raven sampled by boat and the locations with fixed sampling positions have been paired to yield an annual representation of the middle and upper portion of the reservoir. Stations GUN0399 and GUN401 in Prettyboy have been paired to represent the lower portion of the reservoir. GUN0437 by itself represents the middle portion of Prettyboy. There are no sampling locations in the upper portion of Prettyboy reservoir. Table 3 summarizes how the sampling locations are grouped together in this report.

Table 3: Characterization of Reservoir Monitoring Locations

Station	Reservoir	Location	Classification
GUN0142	Loch Raven	Gatehouse	Lower
GUN0156	Loch Raven	Loch Raven Drive bridge	Middle
GUN0171	Loch Raven	Between picnic area and golf course	Middle
GUN0174	Loch Raven	Dulaney Valley Road bridge	Upper
GUN0190	Loch Raven	At the power lines	Upper
GUN0399	Prettyboy	Gatehouse	Lower
GUN0401	Prettyboy	1000 ft. upstream of dam	Lower
GUN0437	Prettyboy	Beckleysville Road Bridge	Middle

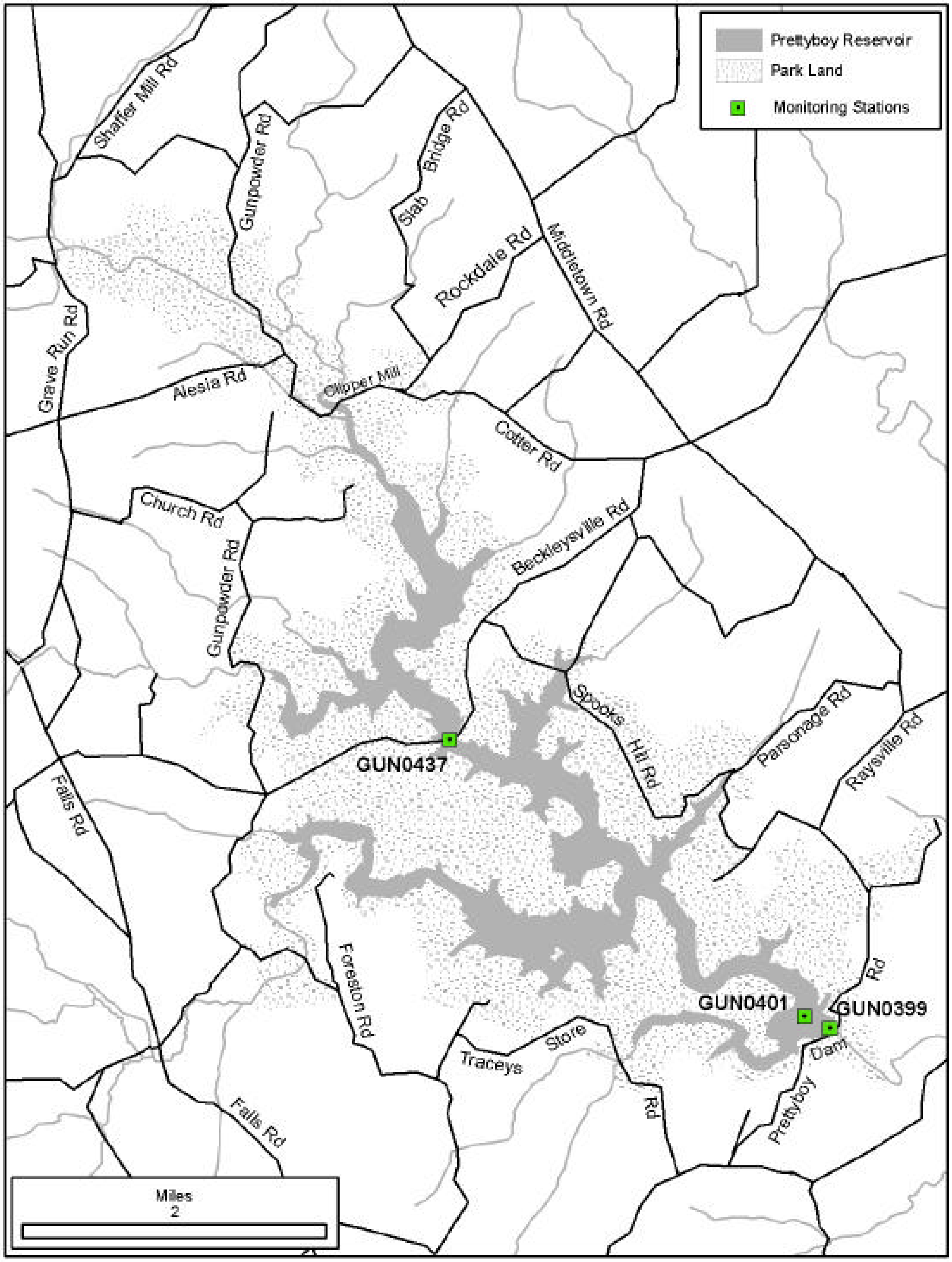

Figure 8: Sampling Locations in Prettyboy Reservoir (from DPW)

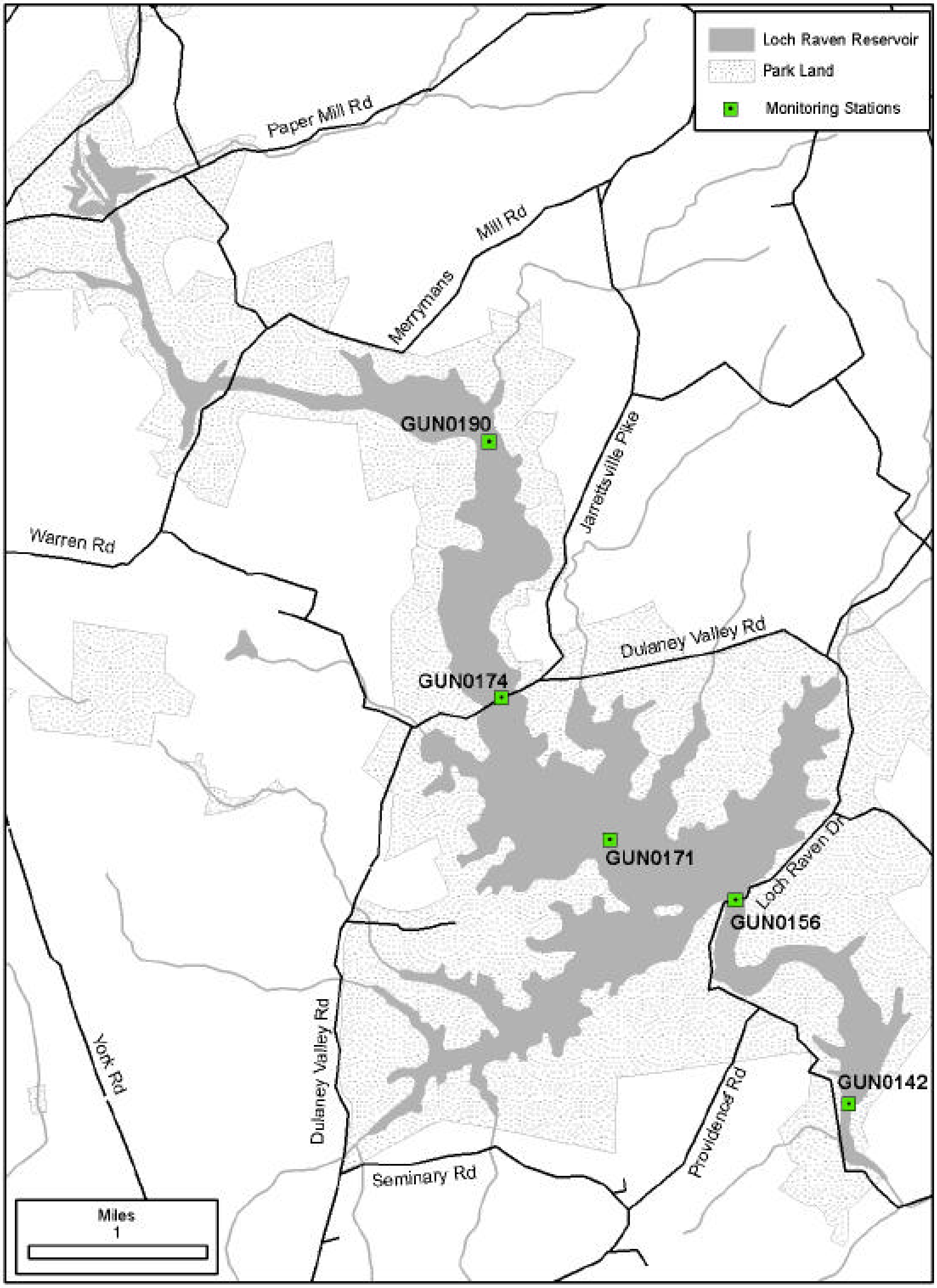

Figure 9: Sampling Locations in Loch Raven Reservoir (from DPW)

2.2.2 Temperature Stratification

Prettyboy and Loch Raven Reservoirs both regularly exhibit temperature stratification starting in April or May and lasting until November. Stratification sometimes occurs in winter but without significant consequences for water quality. Under stratified conditions during the summer and early fall, bottom waters in both reservoirs can become hypoxic, because stable density differences inhibit the turbulent mixing that 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 seasonal position of the well-mixed surface layer or epilimnion. Figure 10 presents a contour plot of isothermals for GUN0142 in Loch Raven Reservoir for 1993, a representative year. Contours are shown only for the first 30 feet from the surface. In the winter, isothermal lines are vertical, showing that the reservoir has fairly uniform temperature over the first 30 feet of depth. In spring, isothermal lines begin to tilt away from the vertical, until by May, at depths greater than 15 to 20 feet, they are parallel to each other horizontally. At the surface, isothermal lines run vertically to a depth of 10 to 15 feet; this defines the epilimnion.

Figures A1 - A20 in Appendix A present contour plots for each monitoring location (lower, middle and upper) over the period 1992-2004. Generally, in both reservoirs, the epilimnion is limited to a depth of 10 to 15 feet in the summer. For the purposes of data analysis, the surface layer is considered to be 20 feet deep, with the understanding that in spring and fall the epilimnion can extend deeper than 20 feet, and in the summer it is likely to be shallower. For screening purposes, samples taken at depths of 40 feet or greater are considered in the bottom layer or hypolimnion.

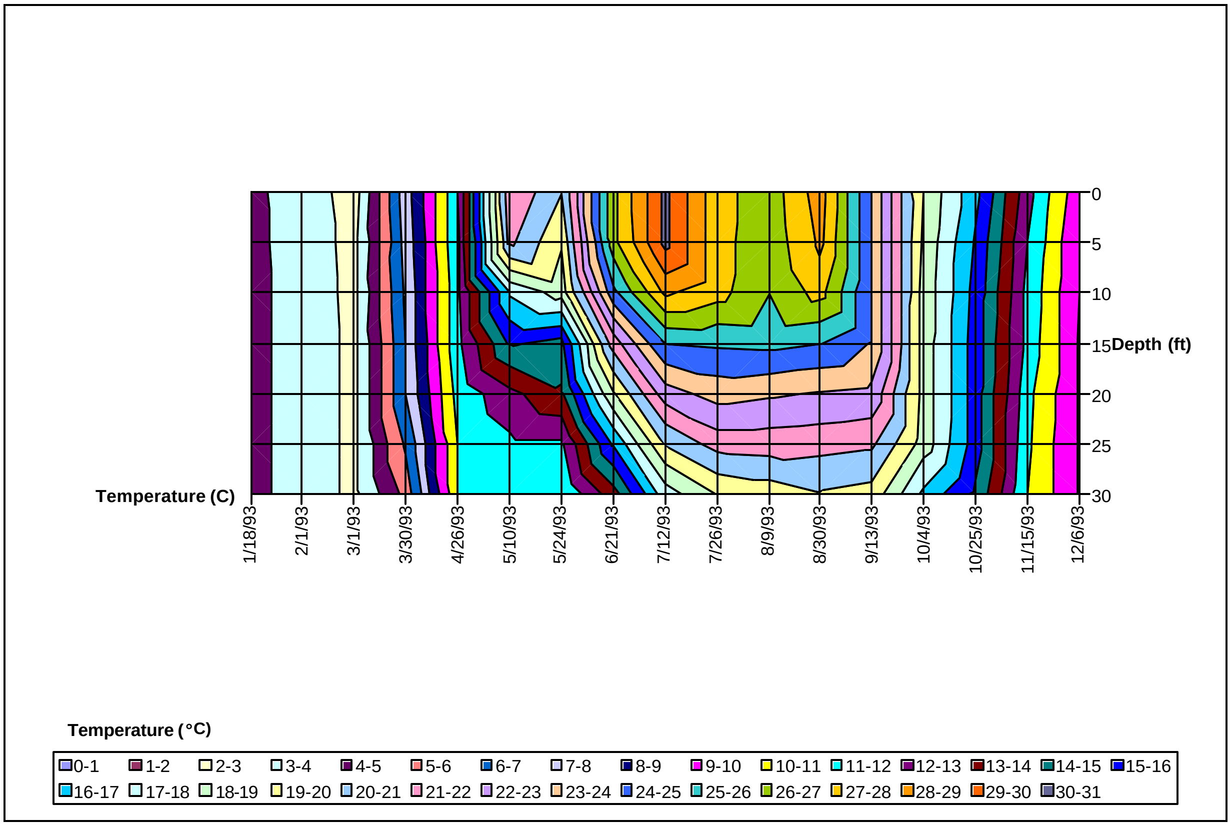

Figure 10: Isothermal Contours, Loch Raven Reservoir, Middle Stations, 1993

2.2.3 Dissolved Oxygen

Figures A21 - A25 in Appendix A show time series of average bottom DO concentrations at all monitoring locations in Prettyboy and Loch Raven Reservoirs. Quite clearly, hypoxia occurs in the hypolimnion of both Prettyboy and Loch Raven Reservoirs with regularity.

Figures A26-30 in Appendix A also show time series of DO at the surface and at five-foot intervals up to 20 feet, the screening-level definition of the epilimnion. For the most part, DO concentrations are above the 5.0 mg/l criterion, but there are periodic excursions below 5.0 mg/l at the 15- and 20-foot depths. In the majority of cases in which apparent hypoxia is observed in the epilimnion, the 20-foot screening depth has over-estimated the depth of the well-mixed layer, as shown by the temperature observations. As noted in the previous section, the depth of the epilimnion ranges between 10 and 15 feet in the summer months. See Tables B1 and B2 in Appendix B for a listing of all dates when DO concentrations were below 5.0 mg/l at either 15- or 20-foot sampling depth in Loch Raven and Prettyboy Reservoirs, respectively.

There are two related causes of these low DO concentrations. The first is temperature stratification, as explained above; the 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 reduce the DO concentration in the well-mixed layer. This can occur any time under stratified conditions when the surface mixed-layer deepens, often well before the fall overturn typical of many lakes and reservoirs (including Prettyboy and Loch Raven), when the surface and bottom layers displace one another. All nineteen dates on which low DO occurred in Loch Raven without an approximately 2ºC difference in temperature between the 5- and 20-foot depths occurred in September, October or November, and all but five occurred in September alone.

This is illustrated by the low DO reading recorded on September 13, 1993, in GUN0171, the middle of Loch Raven Reservoir. Figure 11 shows the DO contour at this location. Figure 10 in the previous section, shows the temperature contour. A comparison of the figures indicates that at the end of August the reservoir at this location was highly stratified, with the well-mixed layer extending to about 15 feet. 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 overturning account for the other low DO oxygen observations in Loch Raven and Prettyboy as well. In Prettyboy, another factor also can influence entrainment: drawdown. Withdrawals from a reservoir can induce currents that enhance mixing. Figure 12 shows the surface elevation of Prettyboy Reservoir from 1994 through 2004. In 1999 and 2002 (drought years), releases from Prettyboy to fill Loch Raven dropped the surface elevation by 30 feet or more. These drawdowns are probably a contributing factor in mixing low DO concentrations into the surface levels of the reservoir.

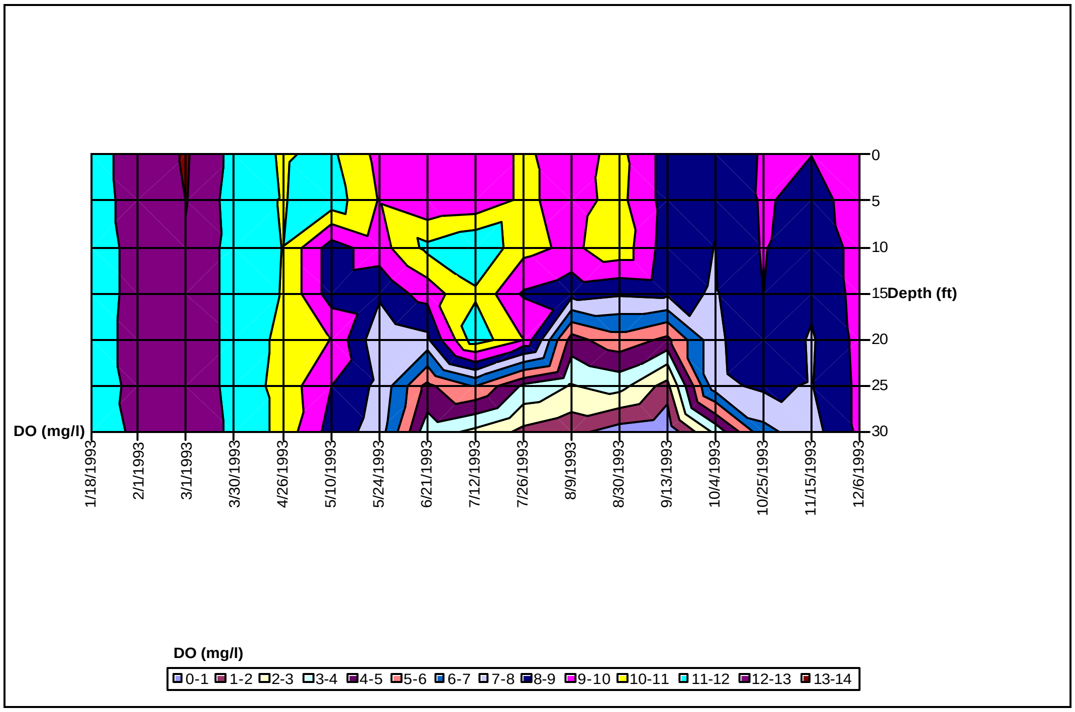

Figure 11: DO Contour, Loch Raven Reservoir, Middle Locations, 1993

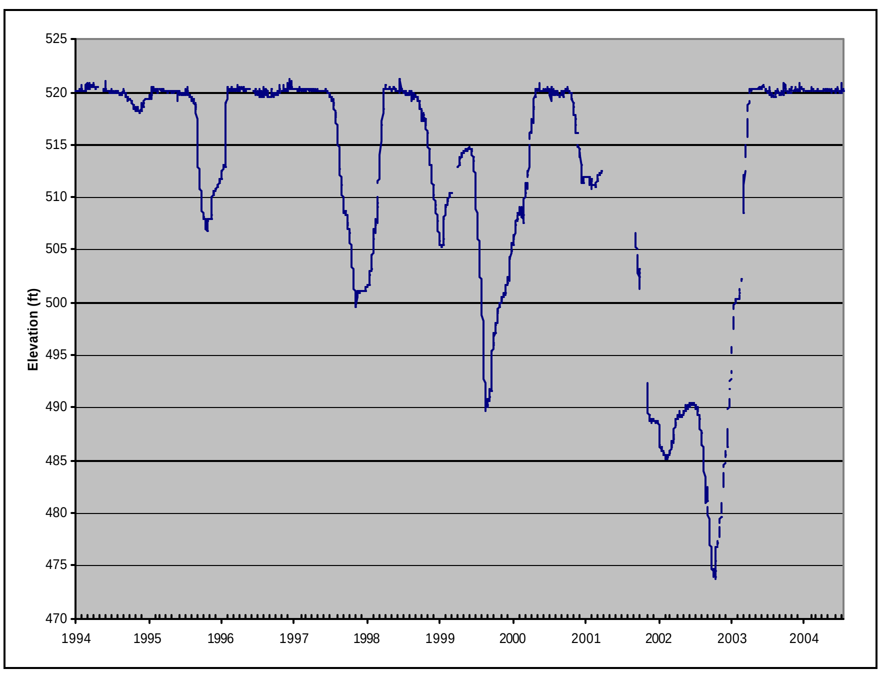

Figure 12: Surface Water Elevations in Prettyboy Reservoir, 1994-2004

2.2.4 Total Phosphorus

Figures A31 - A35 in Appendix A show average total phosphorus concentrations in the top and bottom sampling depths at each monitoring location in Prettyboy and Loch Raven Reservoirs. Surface layer concentrations are an average of the 10- and 20-foot depth samples. Bottom concentrations are averages of samples taken at 40-foot depths or greater. Tables 4 and 5 give summary statistics for TP concentrations (mg/l) in Prettyboy and Loch Raven Reservoirs, respectively. As the tables show, there is a longitudinal gradient to TP concentrations, with concentrations generally decreasing downstream. This is thought to reflect the fact that much of the phosphorus entering the reservoir is bound to sediment, and thus settles out before reaching the dams.

Table 4: Summary Statistics: TP Concentrations (mg/l) in Prettyboy Reservoir, 1992-2004

	Surface		Bottom	
Statistic	Middle	Lower	Middle	Lower
Mean	0.079	0.058	0.075	0.067
Standard deviation	0.112	0.082	0.106	0.110
Minimum	0.002	0.003	0.002	0.002
1st Quartile	0.021	0.019	0.025	0.018
Median	0.045	0.035	0.041	0.040
3rd Quartile	0.078	0.065	0.073	0.066
Maximum	0.675	0.552	0.825	0.970
Count	127	127	127	127

Table 5: Summary Statistics: TP Concentrations (mg/l) in Loch Raven Reservoir, 1992-2004

	Surface			Bottom		
Statistic	Upper	Middle	Lower	Upper	Middle	Lower
Mean	0.078	0.066	0.054	0.084	0.082	0.062
Standard Deviation	0.108	0.102	0.092	0.092	0.148	0.109
Minimum	0.005	0.003	0.002	0.005	0.003	0.003
1st Quartile	0.027	0.023	0.019	0.033	0.026	0.022
Median	0.053	0.042	0.036	0.058	0.045	0.033
3rd Quartile	0.085	0.071	0.060	0.100	0.081	0.078
Maximum	1.010	0.835	1.040	0.580	1.313	1.260
Count	136	139	205	90	138	205

The surface sample itself was excluded from the analysis because samples periodically have concentrations as high as 1.0 mg/l. Some of these high concentrations are confined to the surface layer and are suspected to be surface films. For this reason DPW also excludes surface layer concentrations (Baltimore City DPW, 1996).

2.2.5 Nutrient Limitation

Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the "limiting nutrient." The amount of the abundant nutrient does not matter because both nutrients are needed for algae growth. In general, a Nitrogen:Phosphorus (N:P) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P 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 on 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 underestimated. In both reservoirs, only about 7% of the samples taken at the 10- and 20-foot depths have nitrate:TP ratios less than 10:1, which can be taken as a cutoff for distinguishing nitrogen limitation from phosphorus limitation. The median nitrate:TP ratio in Loch Raven is 38:1 and the median in Prettyboy is 47:1. About half the samples from Loch Raven with nitrate:TP ratios less than 10:1 occur on five dates, all of which appear to be associated with storm events. Storm events are likely to have high concentrations of particulate nitrogen and phosphorus, but while particulate phosphorus is accounted for in nitrate: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 prevalent high N:P ratios, the evidence is conclusive that both Prettyboy and Loch Raven Reservoirs are strongly phosphorus limited.

2.2.6 Ammonia and Nitrogen

Figures A36 - A45 in Appendix A show the average surface and bottom concentrations of ammonia and nitrate in Prettyboy and Loch Raven Reservoirs. Since the surface layers of the reservoirs are not nitrogen limited, bottom concentrations of ammonia and nitrate are more important from the water quality standpoint for two reasons.

First, the time series graphs of ammonia show that, particularly for Loch Raven, there are significant releases of ammonia from the sediments. This contributes to oxygen demand. Although observed ammonia concentrations range as high as 4.0 mg/l, Maryland's ammonia water quality criteria (COMAR 26.08.02.03-2H(1)) were not exceeded. Second, nitrate concentrations for the most part remain above 0.5 mg/l. Nitrate is preferred to ferric iron (III) as an electron acceptor in diagenesis. Phosphate in the sediments is bound through ferric iron. It is less likely that phosphate will be released from sediments until ferric iron is reduced in diagenesis. Thus it can be anticipated that the phosphorus release rate from the sediments will remain low.

2.2.7 Algae and Chlorophyll *a*

Figures A46 – A50 in Appendix A show the time series of maximum Chla concentrations in the surface layer at the sampling locations in Prettyboy and Loch Raven Reservoirs. The same information is presented in a different format in Tables B3 and B4 in Appendix B, showing maximum Chla concentrations by month and year, 1992-2004. As these tables indicate, Chla concentrations above 10 µg/l (the approximate threshold of eutrophy) occur frequently but not regularly. Concentrations above 30 µg/l are infrequent.

In Loch Raven Reservoir, the largest concentrations tend to occur in early spring or in October. Concentrations are most consistently above 10 µg/l in the summer months, and most consistently below 10 µg/l in the winter months. In Prettyboy Reservoir, in contrast, surface Chla concentrations are most consistently above 10 µg/l in late winter and early spring. Concentrations above 30 µg/l are most frequently found in March or secondarily in September and October. Surface Chla concentrations tend to be below 10 µg/l from May through July, as well as in November and December.

2.2.8 Sedimentation

The Maryland Geological Survey (MGS) performed a new bathymetry survey of Loch Raven Reservoir in 1998 (Ortt *et al.*, 2000). In conjunction with the survey, MGS also estimated sedimentation rates. Average annual sedimentation rates can be described in many ways: percent loss of capacity, inches of sediment accumulation per year, or tons/mi^2/yr. The latter measure was estimated by the Reservoir Technical Group (RTG) (2004), based on the new survey. Table 6 summarizes the average sediment accumulation rate for Loch Raven Reservoir.

The annual percent capacity loss (volumetric reduction) rate in Loch Raven Reservoir, 0.13%, compares favorably with the national averages. The mean average capacity loss rate for comparably sized reservoirs is 0.43%; the median is 0.27% *(*Ortt *et al., 2000)*. However, sediment accumulation varies spatially within the reservoir. MGS estimated that the Dulaney Branch of Loch Raven has lost 8% of its capacity, the Long Quarter Branch 13% of its capacity, and the upper reservoir 19% of its capacity. Sediment deposits in the former stream channel were greater than 10 feet thick and ran as high as 59 feet thick. The survey was not able to proceed above Warren and Merryman's Mill Road bridge because the reservoir became unnavigable.

Table 6: Sedimentation Rates in Loch Raven Reservoir

Sedimentation Rates	Loch Raven (built 1923)
Total Capacity Lost Since Construction	10.8%
Annual Average Capacity Lost	0.13%
Sediment Accumulation Rate (in/yr)	0.6
Sediment Deposition Rate (tons/mi^2/year)	0.49

2.3 Water Quality Impairments

The Maryland Water Quality Standards Stream Segment Designations for Prettyboy and Loch Raven Reservoirs are Use III-P: Nontidal Cold Water and Public Water Supply (COMAR 26.08.02.08J(4)). Designated Uses present in the Prettyboy and Loch Raven Reservoirs are: 1) growth and propagation of trout; and 2) public water supply.

Maryland's General Water Quality Criteria prohibit pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 26.08.02.03B(2)). Excessive eutrophication, indicated by elevated levels of Chla, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. The excess algal blooms eventually die off and decompose, consuming oxygen. Excessive eutrophication in Prettyboy and Loch Raven Reservoirs is ultimately caused by nutrient overenrichment. An analysis of the available water quality data presented in Section 2.2 has demonstrated that phosphorus is the limiting nutrient. In conjunction with excessive nutrients, Loch Raven Reservoir has experienced excessive sediment loads, resulting in a shortened projected lifespan of the reservoir.

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

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

The analysis of water quality data in Section 2.2 has shown that all observed DO concentrations below 5.0 mg/l in the surface layers of Prettyboy and Loch Raven Reservoirs are associated with stratification or the mixing of stratified waters into the surface layers during periods of reservoir overturn or drawdown. On the other hand, seasonal hypoxia occurs regularly in both reservoirs in the hypolimnion.

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 are expected to result in the attainment of the water quality criteria that support the Use III-P designation for Loch Raven and Prettyboy Reservoirs. The Chla endpoints selected for the reservoirs are (1) a maximum permissible instantaneous chlorophyll concentration of 30 µg/l in the surface layers and (2) a 30-day moving average concentration not to exceed 10 µg/l in the surface layers. A concentration of 10 µg/l corresponds to a score of approximately 53 on the Carlson Trophic State Index (TSI). This is the approximate boundary between mesotrophic and eutrophic conditions, which is an appropriate trophic state at which to manage these reservoirs. Mean Chla concentrations exceeding 10 ug/l are associated with peaks exceeding 30 ug/l, which in turn are associated with a shift to blue-green assemblages, which present taste, odor and treatment problems (Walker 1984). These Chla endpoints should thus avoid nuisance algal blooms. Reduction of the phosphorus loads is predicted to reduce excessive algal growth and therefore prevent violations of 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 narrative criteria resulting in excessive algal growth in Prettyboy and Loch Raven Reservoirs;
2. Resolve violations of narrative criteria associated with excess sedimentation of Loch Raven Reservoir; and
3. Assure both Prettyboy and Loch Raven Reservoirs provide dissolved oxygen levels sufficient to support aquatic life.

4.0 TOTAL MAXIMUM DAILY LOADS (TMDLs) AND ALLOCATIONS

4.1 Overview

Section 4.2 describes the modeling framework for simulating hydrodynamics, nutrient and sediment loads, and water quality responses in Prettyboy and Loch Raven Reservoirs. Section 4.3 describes the baseline scenario developed on the basis of modeling results. Section 4.4 explains how the nutrient TMDLs and load allocations for point sources and nonpoint sources were developed for the reservoirs, based on computer modeling of the water quality response to reduced nutrient and sediment loads. Section 4.5 presents the modeling results in the proper format for TMDLs and allocates the TMDLs between point sources and nonpoint sources. Section 4.6 explains the rationale for the margin of safety. Finally, the elements of the equations are combined in a summary of TMDLs for total phosphorus for both Prettyboy and Loch Raven Reservoirs, as well as a TMDL for sediments for Loch Raven Reservoir.

4.2 Computer Modeling Framework

To develop a TMDL, a linkage must be defined between the selected targets or goals and the identified sources. This linkage establishes the cause-and-effect relationship between the pollutant of concern and the pollutant sources. The relationship can vary seasonally, particularly for nonpoint sources, with factors such as precipitation. Once defined, the linkage yields the estimate of total loading capacity or TMDL (U.S. EPA, 1999).

CE-QUAL-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 temperature stratification that occurs in reservoirs like Prettyboy and Loch Raven. The W2 reservoir models were used to simulate not only hydrodynamics and temperature but dissolved oxygen and eutrophication dynamics as well. The reservoir models use version

3.2 of CE-QUAL-W2. Cole and Wells (2003) give a general description of the CE-QUAL-W2 model.

Prettyboy Reservoir was represented by eighteen active longitudinal segments in two branches. Each segment contains from four to thirty one-meter thick layers. Loch Raven Reservoir is represented by a single branch of sixteen segments, each with four to sixteen one-meter thick layers. The simulation period was set to 1992-1997 to coincide with the Gunpowder HSPF Model. These six years provide a range of hydrological conditions, including wet years (1993, 1996), dry years (1992, 1997), and average years (1994, 1995), thus fulfilling the requirement that TMDLs take into account a variety of hydrological conditions. Each year was simulated separately, and observed data, where available, were used to set the initial conditions for the simulation.

State variables in the CE-QUAL-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, any number of inorganic solids, carbonaceous biochemical oxygen demand (CBOD) variables or 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 reservoirs: (1) labile dissolved BOD, labile particulate CBOD, and refractory particulate CBOD. The concentration of these CBOD inputs were calculated based on the concentration of organic phosphorus determined by the HSPF model, using the stoichiometric ratio between phosphorus and oxygen demand in the reservoir models.
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 reservoirs. 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 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 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. Each year's simulation was initialized with the final concentrations of sediment organic matter from the previous year's simulation, because no observations of sediment organic matter were available.

4.3 Scenario Descriptions and Results

4.3.1 Scenario Descriptions

TMDL development for the Gunpowder reservoirs involved the following four scenarios:

1. **Calibration Scenario**: The Calibration Scenario represents actual loads over the simulation period 1992-1997. As the name suggests, the loads in this scenario were used to calibrate the CE-QUAL-W2 models of Prettyboy and Loch Raven Reservoirs. Loads from wastewater treatment plants and other point source dischargers are based on reported flows and concentrations for the period. Loads from developed land falling under the National Pollutant Discharge Elimination System (NPDES) permit for stormwater discharge, as well as nonpoint source loads from forests and agricultural land, were determined through the calibration of the Gunpowder Falls HSPF Model.

2. **Baseline Scenario**: The Baseline Scenario differs from the Calibration Scenario only in that design flows and concentrations at the permitted limits are used to determine loads from wastewater treatment plants and other point source dischargers. Loads from developed land under Municipal Separate Storm Sewer System (MS4) permits and nonpoint source loads are the same as in the Calibration Scenario.

3. **TMDL Scenario**: The TMDL Scenario represents the maximum allowable loads from developed land falling under NPDES stormwater permits and the maximum allowable loads from nonpoint sources such that computer simulation predicts water quality standards will be met in Prettyboy and Loch Raven Reservoirs. Loads from permitted dischargers are calculated based on the design flow of the permit and the maximum permitted concentration.

4. **All-Forest Scenario**: The All-Forest Scenario simulates the response of the reservoirs to the phosphorus, sediment, nitrogen, and BOD loading rates that would occur if all of the land in the reservoirs' watersheds were forested. The All-Forest Scenario is used to determine to what extent hypoxic conditions in the hypolimnion are a function of external loading rates 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 whereby all land in the watershed was forested.

4.3.2 Calibration Scenario Results

The primary function of the CE-QUAL-W2 models of Prettyboy and Loch Raven Reservoirs is to link algae biomass concentrations, as represented by Chla concentrations, to total phosphorus loads. The models were calibrated conservatively, 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 occurred a month earlier or later than the corresponding observed concentrations.

Figures B1 and B2 in Appendix B compare simulated and observed maximum Chla concentrations in the surface layers of Prettyboy and Loch Raven Reservoirs, respectively, by sampling date. The models capture the observed peak seasonal average Chla concentrations, though sometimes shifted spatially or temporally. Similarly, Figures B3 and B4 show the cumulative distribution of simulated and observed maximum Chla concentrations. In both reservoirs, simulated concentrations are higher than observed concentrations above the 10 µg/l level, demonstrating further the conservative character of the calibration.

Figures B5 and B6 in Appendix B compare simulated and observed average surface DO concentrations at the lower sampling locations in Prettyboy and Loch Raven Reservoir, respectively. The models follow the seasonal trend in DO but tend to over-simulate DO in winter and under-simulate DO in summer. Figures B7 and B8 show the simulated and observed average bottom DO concentrations. The models capture the seasonal trend in bottom DO. The coefficients of determination between observed and simulated values are 0.80 and 0.81 for Prettyboy and Loch Raven Reservoirs, respectively.

Appendix C contains time series plots comparing simulated and observed concentrations at other locations. It also shows time series plots for total phosphorus, nitrate, and ammonia.

4.3.3 Baseline Scenario Results

Wastewater treatment plants and other permitted point sources (excluding MS4 discharges) contribute less than 1% of the total phosphorus load to Prettyboy and Loch Raven Reservoirs, and an insignificant amount to the sediment load to Loch Raven Reservoir. The results of the Baseline Scenario are indistinguishable from the Calibration Scenario. Baseline loads are broken out by land use and jurisdiction in Appendix D.

4.3.4 TMDL Scenario Results

The CE-QUAL-W2 models of Prettyboy and Loch Raven Reservoirs were used to determine the maximum total phosphorus loads compatible with water quality standards. Simulated loads were reduced until two conditions were met: (1) no simulated Chla concentration in any cell was above 30 µg/l, and (2) the 30-day moving average Chla concentration of each modeling cell within 15 meters of the surface was not greater than 10 µg/l. Figures B9 and B10 in Appendix B compare maximum Chla concentrations by date under the Calibration and TMDL Scenarios to observed concentrations in the surface layer of Prettyboy and Loch Raven Reservoirs, respectively.

The TMDL Scenario was also analyzed to determine whether the reservoirs would meet the DO criteria for Use III-P waters under TMDL loading rates. Figures B11 and B12 show the average surface DO concentrations at the lower sampling locations in Prettyboy and Loch Raven Reservoirs, based on a screening depth of 20 feet. To more accurately screen for potential violations, the position of the well-mixed surface layer was more precisely determined on a daily basis. Instantaneous DO concentrations were output from all cells in the surface layer at 0.1-day intervals; the daily average DO concentration was also calculated for each cell in the surface layer. Under the TMDL scenario, there is no cell in the surface layer of either reservoir with an instantaneous DO concentration less than 5.0 mg/l, or a daily average DO concentration of less than 6.0 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.

Seasonal hypoxia persists in the hypolimnion in both reservoirs even under the TMDL Scenario. Figures B13 and B14 in Appendix B show the average bottom DO concentrations at the lower sampling locations in Prettyboy and Loch Raven Reservoirs. As the figures indicate, although the average DO in the bottom layers improves under the TMDL Scenario, neither reservoir maintains a DO concentration of 5.0 mg/l in the hypolimnion throughout the simulation period.

4.3.5 All-Forest Scenario Results

As explained earlier, the purpose of the All-Forest Scenario is to help determine whether hypoxia in the bottom layers of Prettyboy and Loch Raven Reservoirs is primarily due to the stratification induced by reservoir morphology, or to input loads. If hypoxia occurs even under all-forested loading rates, then reservoir stratification is the primary cause of hypoxia and it can be concluded that the reservoir meets the water quality standards for DO as described in Section 2.3.

Average annual TP loads in the All-Forest Scenario are 20% of the load in the Calibration Scenario in Prettyboy Reservoir, and 28% of the load in the Calibration Scenario in Loch Raven Reservoir. The reduction in average annual loads of POM, the precursor to sediment oxygen demand, is not as large. Average annual POM loads in the All-Forest Scenario are 29% of the load in Calibration Scenario in Prettyboy and 41% of the load in Calibration Scenario in Loch Raven. The load decrease is less in the Loch Raven watershed because of the high percentage of forested and developed land.

Figures 13 and 14 below show the average bottom DO concentrations at lower sampling locations in the reservoirs under the All-Forest Scenario. Minimum concentrations at the sampling locations are also shown.

Average DO in the bottom layers of both reservoirs 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. The hypoxia tends to be worse in the lower stations of the reservoirs where the depths are greatest.

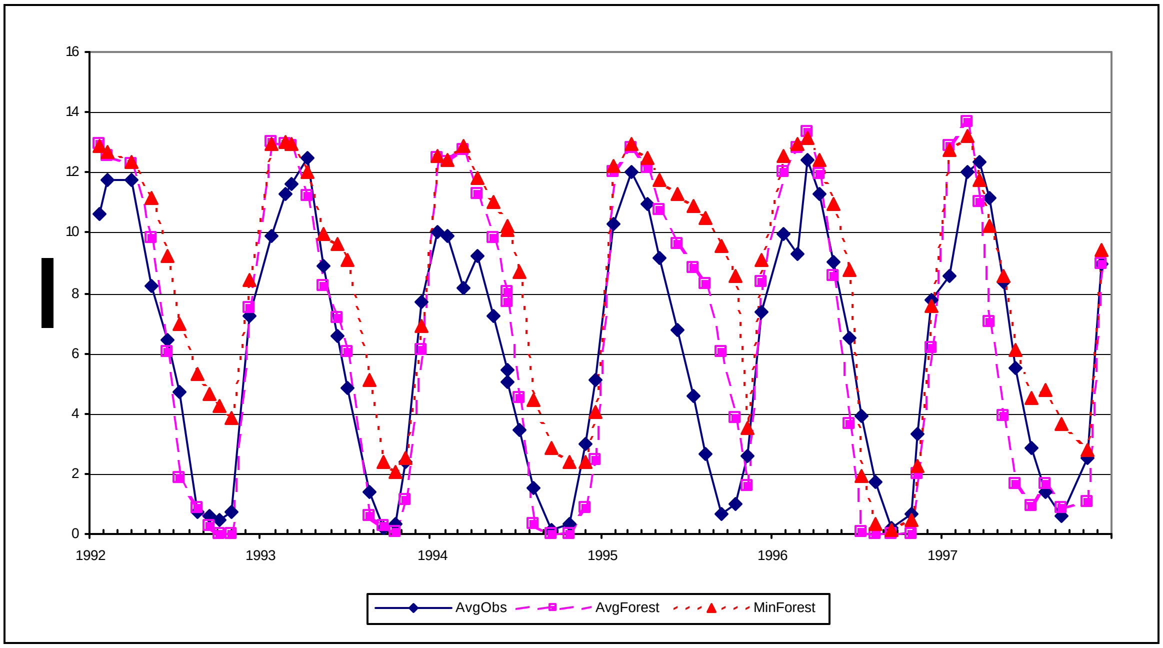

Figure 13: Observed and Simulated Average Bottom DO Concentrations, Lower Stations, All-Forest Scenario, Prettyboy Reservoir

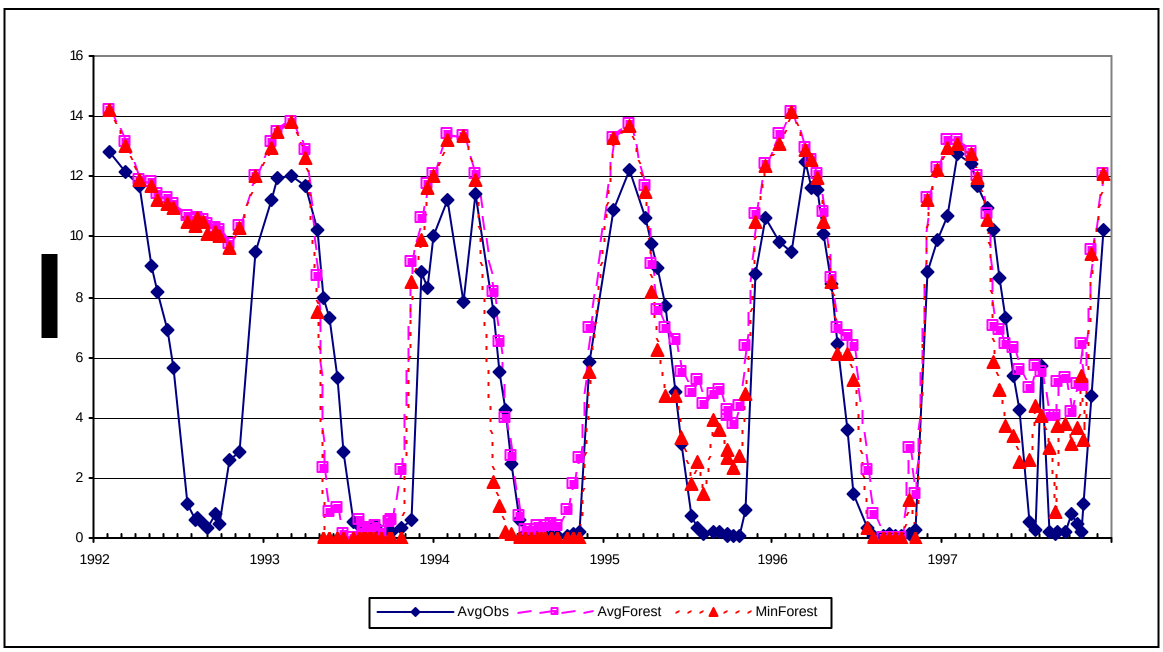

Figure 14: Observed and Simulated Average Bottom DO Concentrations, Lower Stations, All-Forest Scenario, Loch Raven Reservoir

A sensitivity analysis was performed to better determine how phosphorus and organic matter loading rates impact hypoxia in the hypolimnion. POM and TP loading rates 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 15 shows the results. Significant hypoxia persists even when loads are reduced to only 10% of the All-Forest Scenario, particularly in Prettyboy Reservoir, which is deeper than Loch Raven even though it has less volume. 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. The All-Forest Scenario demonstrates that current loads, and loads simulated under the TMDL Scenario, do not result in hypoxia that significantly exceeds that associated with natural conditions in the watershed. Low DO concentrations in the bottom layers of the reservoirs are therefore a naturally occurring condition, as described by the interim interpretation of Maryland's water quality standards. The TMDL Scenario thus meets water quality standards for DO under the interim interpretation.

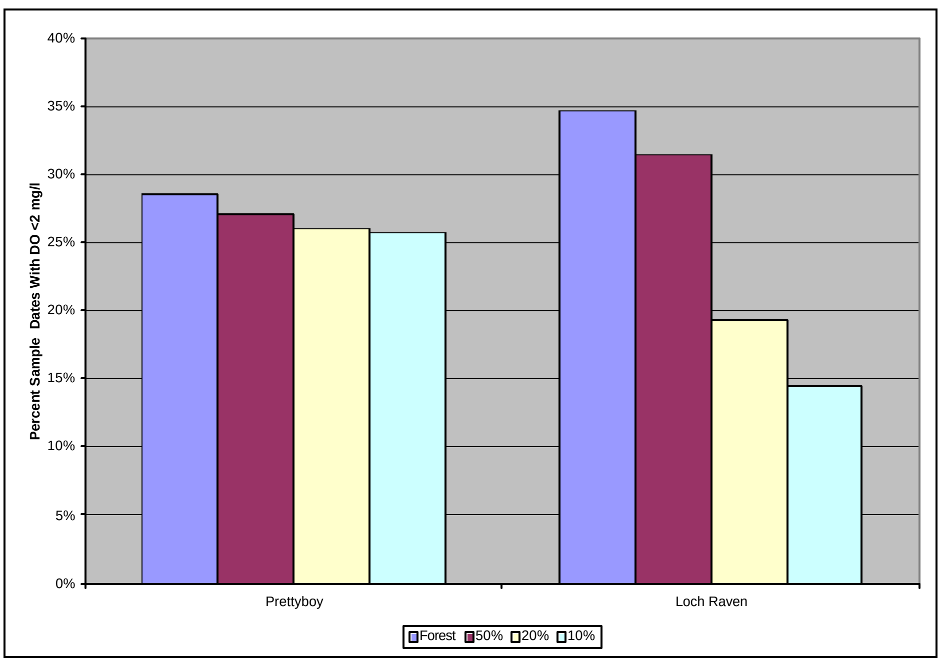

Figure 15: Percent of Sampling Dates on which DO < 2.0 mg/l as a function of proportion of All-Forest Scenario

4.4 TMDL Loading Caps

4.4.1 Phosphorus TMDL Loading Caps for Prettyboy and Loch Raven Reservoirs

This section presents the TMDLs for phosphorus for Prettyboy and Loch Raven Reservoirs. The TMDLs were estimated based on the phosphorus loadings as explained in Section 4.3 and the resulting water quality in the reservoirs for the simulated years 1992-1997. This period was selected to estimate the TMDLs because it covers a period that includes dry years as well as very wet years and thus takes into account a variety of hydrological conditions. Chla concentrations indicative of eutrophic conditions can occur at any time of year, and the simulation period encompasses the spectrum of observed seasonal concentrations (see Tables B3 and B4, Appendix B). Seasonal low DO concentrations in the hypolimnia that occur regularly each year are also represented in the simulation models.

TMDL loads were calculated on an average annual basis. The average residence time of Loch Raven Reservoir is approximately three to four months while the residence time of Prettyboy is approximately one year. Water quality conditions in both reservoirs are the cumulative result of loadings that span seasons, or even, in the case of hypolimnetic hypoxia, years. Average annual TP loads are therefore the appropriate measure in which to express nutrient TMDLs for Prettyboy and Loch Raven Reservoirs.

For Prettyboy Reservoir:

Total Phosphorus TMDL 23,192 lbs/year

For Loch Raven Reservoir:

Total Phosphorus TMDL 54,941 lbs/year

The TMDLs reflect a reduction of 54% from baseline TP loads in Prettyboy Reservoir and 50% from baseline loads in Loch Raven Reservoir. Load reductions are broken out by land use and jurisdiction in Appendix D.

Average Daily Loads:

In Prettyboy Reservoir, the average annual TMDL for TP will result in average daily TP loads of approximately 63.54 lbs/day. In Loch Raven Reservoir, the average annual TMDL for TP will result in average daily TP loads of approximately 150.95 lbs/day.

4.4.2 Sediment TMDL Loading Caps for Loch Raven Reservoir

Excessive sedimentation reduces a reservoir's storage capacity and therefore negatively impacts its ability to function as a water supply reservoir. 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 period can be defined for the water quality impact of sedimentation. An excessive sedimentation rate negatively impacts a reservoir regardless of when it occurs. Therefore, the efforts to reduce sediment loading to the lake should focus on achieving effective, long-term sediment control. Since some measures to control phosphorus from agriculture sources can also effectively reduce sedimentation, the expected sediment reduction can be estimated based on the degree of phosphorus control needed to improve the water quality of the reservoir.

To quantify the sediment reduction associated with this phosphorus reduction, the EPA Chesapeake Bay Program watershed modeling assumptions were consulted. For the agricultural best management practices (BMPs) that affect both phosphorus and sediments, EPA estimates a 1-to-1 reduction in sediments as a result of controlling phosphorus (EPA, Chesapeake Bay Program Office, 1998). However, this ratio does not account for phosphorus controls that do not remove sediments.

To estimate the applicable ratio, hence the sediment load reduction, 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 along with the phosphorus removal, while nutrient management plans (NMPs) do not. It has been assumed that 50% of the phosphorus reduction will come from SCWQPs and 50% from NMPs. This results in a 0.5-to-1 ratio of sediment reduction to phosphorus reduction. The net sediment reduction associated with a 50% NPS phosphorus reduction is about 25% (0.50 * 0.5 = 0.25).

It is assumed that this reduced sediment loading rate would result in a similar reduction in the sediment accumulation rate. The sediment accumulation rate predicted to result from this reduced loading rate would allow for the retention of 85% of the overall impoundment's original volume after 50 years. More important, it will reduce loss of volume in the upper reservoir, which otherwise would have less than 70% of its original capacity after 50 years. Under the TMDL loading cap, the upper reservoir may retain as much as 80% of its original capacity if the reduction in loading rates reduces volumetric loss at a rate proportionate to current capacity loss.

MDE believes that this volumetric retention will support the designated uses of Loch Raven Reservoir (Use III-P) for which it is protected: naturally-breeding trout and public water supply. This estimate is reasonably consistent with technical guidance provided by EPA Region III of a 0.7-to-1.0 reduction in sediment in relation to the reduction in phosphorus. (EPA, 1998) This rule-of-thumb would yield a 35% estimated reduction in sediment [100*(0.7 * 0.50) = 35%]

Assuming that a 50% reduction in total phosphorus load results in a 25% reduction in sediment load, the sediment loading cap for Loch Raven Reservoir is as follows:

For Loch Raven Reservoir:

Sediment TMDL 28,925 tons/year

Average Daily Loads:

In Loch Raven Reservoir, the average annual TMDL for sediment will result in average daily sediment loads of approximately 79.25 tons/day.

4.5 Total Load Allocations Between Point Sources and Nonpoint Sources

The allocations described in this section demonstrate how the TMDLs can be implemented to achieve water quality standards in Prettyboy and Loch Raven Reservoirs. Specifically, these allocations show that the sum of phosphorus loadings to the reservoirs from existing point and nonpoint sources can be maintained safely within the TMDLs established herein. The State reserves the right to revise these allocations provided such revisions are consistent with the achievement of water quality standards.

Phosphorus TMDL Allocations

- Nonpoint Source (NPS) Loads

  Nonpoint source loads including agricultural and forest loads are assigned to the TMDL as the Load Allocation (LA). The Calibration and Baseline Scenario loads were based on the HSPF model of the Gunpowder Falls Watershed. The modeling of the watershed accounted for both natural and human-induced components, including atmospheric deposition and septic loadings. Details on the HSPF model can be found in *Modeling Framework for Simulating Hydrodynamics and Water Quality in Prettyboy and Loch Raven Reservoirs* (ICPRB and MDE, 2006).

- Stormwater Loads

  In November 2002, EPA advised states that NPDES-regulated storm water discharges must be addressed by the wasteload allocation (WLA) component of a TMDL. See 40 C.F.R. § 130.2(h). NPDES-regulated storm water discharges may not be addressed by the load allocation (LA) component of a TMDL. EPA also provided guidance on ways to reflect the TMDL stormwater wasteload allocation (WLA). The stormwater phosphorus loads simulated in the TMDL scenario represent a 15% reduction in TP from baseline urban stormwater loads. Urban stormwater loads are now part of the WLA.

Current stormwater Phase I individual permits and new stormwater Phase II permits are considered point sources subject to WLA assignment in the TMDL, instead of LA assignment as in the past. EPA recognizes that limitations in the available data and information usually preclude stormwater allocations to specific outfalls. Therefore, EPA's guidance allows this stormwater WLA to be expressed as a gross allotment, rather than individual allocations for separate pipes, ditches, construction sites, etc. Available information for the Gunpowder Falls watershed allows the stormwater WLA for this analysis to be defined separately for Carroll, Baltimore and Harford Counties; however, these WLAs aggregate municipal and industrial stormwater, including the loads from construction activity.

Waste load allocations from point source dischargers are usually based on the relative contribution of pollutant load to the waterbody. Estimating a load contribution to a particular waterbody from the stormwater Phase I and II sources is imprecise, given the variability in sources, runoff volumes, and pollutant loads over time. Therefore, any stormwater WLA portion of the TMDL is based on a rough estimate.

- Wastewater Treatment Plant Loads

  In addition to nonpoint source loads and stormwater point sources, waste load allocations to the Hampstead and Manchester WWTP plus a 5% MOS, estimated as explained in the next section, make up the balance of the total allowable load. The Hampstead WWTP maximum allowable design flow of 0.9 MGD is used for this scenario. The total phosphorus limit at Hampstead is 0.3 mg/l year round. The Manchester WWTP maximum allowable current permit flow of 0.5 MGD is used for this scenario; discharges to surface water occur only from December through March. The total phosphorus limit at Manchester is 1.0 mg/l *when discharges occur*. All significant point sources are addressed by this allocation and are described further in the technical memorandum entitled "*Significant Nutrient and Sediment Point Sources in the Prettyboy and Loch Raven Reservoir Watersheds.*"

The TMDL, including loads from stormwater discharges, is now expressed as:

TMDL = WLA [non-stormwater point sources + regulated stormwater point source] + LA + MOS

The phosphorus allocations for Prettyboy and Loch Raven Reservoirs are presented in Table 7.

Table 7: Total Phosphorus Allocations (lbs/yr) for Prettyboy and Loch Raven Reservoirs

	Prettyboy Reservoir	Loch Raven Reservoir
Nonpoint Source[1]	19,092	30,184
Point Source[2]	2,940	22,010
Margin of Safety[3]	1,160	2,747
Total Maximum Daily Load	23,192	54,941

[1] Excludng urban stormwater loads.
[2] Including urban stormwater loads.
[3] Representing 5% of baseline nonpoint source and urban stormwater loads.

4.5.1 Sediment Load Allocations for Loch Raven Reservoir

- Nonpoint Source (NPS) Loads

  Nonpoint source loads including agricultural and forest loads are assigned to the TMDL as LA. The Calibration and Baseline Scenario loads were based on the HSPF model of the Gunpowder Falls Watershed. The modeling of the watershed accounted for both natural and human-induced components. The LA to nonpoint sources below the Prettyboy Dam represents a decrease of approximately 25% from baseline loads. Sediment loads from Prettyboy Reservoir are less than 2% of total sediment load. Details on the HSPF model can be found in *Modeling Framework for Simulating Hydrodynamics and Water Quality in Prettyboy and Loch Raven Reservoirs* (ICPRB and MDE, 2006).

- Stormwater Loads

  The reduction in total phosphorus loads from stormwater discharges will result in a reduction in sediment loads, but because of the uncertainty in BMP efficiencies for developed land, no reduction is assumed for sediment loads from stormwater discharges, and their share of the WLA is set equal to baseline conditions.

- Wastewater Treatment Plant Loads

  The waste load allocation to the Hampstead WWTP makes up the balance of the total allowable load. The Hampstead WWTP maximum allowable current permit flow of 0.9 MGD is used for this scenario. The total suspended solids limit is 30.0 mg/l year round. All significant point sources are addressed by this allocation and are described further in the technical memorandum entitled *"Significant Nutrient and Sediment Point Sources in the Prettyboy and Loch Raven Reservoir Watersheds."*

- Permitted Industrial Facilities

  There are three industrial facilities with permits regulating the discharge of total suspended solids in the Loch Raven Reservoir watershed. Only one of them, the Lafarge Mid-Atlantic and Imerys facility, has even the potential to discharge significant sediment loads. The waste load allocation for the quarry was set as the product of maximum recorded average discharge at each of the two permitted outfalls and a suspended solids limit of 15 mg/l and 17 mg/l for the respective outfalls. The waste load allocation for the two other industrial facilities was also set as a product of the maximum recorded average flow and the permitted suspended solids concentration. All significant industrial point sources are addressed by this allocation and are described further in the technical memorandum entitled *"Significant Nutrient and Sediment Point Sources in the Prettyboy and Loch Raven Reservoir Watersheds."* Load reductions are broken out by land use and jurisdiction in Appendix D.

The TMDL for Suspended Sediment in Loch Raven Reservoir is as follows:

TMDL (tons/yr)	=	LA	+	WLA	+	MOS
28,925	**=**	**27,715**		**1,210**		**implicit**

4.6 Margins of Safety

A MOS is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (*i.e.*, TMDL = Load Allocation (LA) + Waste Load Allocation (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 loads for phosphorus. These explicit phosphorus margins of safety are **1,160 lbs/yr** for Prettyboy Reservoir, and **2,747 lbs/yr** for Loch Raven Reservoir.

In establishing a MOS for sediments, Maryland has adopted an implicit approach by incorporating conservative assumptions. First, because phosphorus binds to sediments, sediments will be controlled as a result of controlling phosphorus. This estimate of sediment reduction is based on the load allocation of phosphorus (4,150 lbs/yr), 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 5,099 tons/yr (see Section 4.5 above for a discussion of the relationship between 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 sediment-to-phosphorus reduction ratio given in the technical guidance provided by EPA Region III. Table 8 compares the volumetric preservation under TMDL conditions in Loch Raven Reservoir with that of several other approved TMDLs.

Table 8: Volumetric Preservation of Various Impoundments Under Sediment TMDL Conditions

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

4.7 Summary of Total Maximum Daily Loads

The following equations summarize the nutrient TMDLs for Prettyboy and Loch Raven Reservoirs, and the sediment TMDL for Loch Raven Reservoir:

For Total Phosphorus in Prettyboy Reservoir:

TMDL (lbs/yr)	**=**	**LA +**	**WLA +**	**MOS**
23,192	**=**	**19,092**	**2,940**	**1,160**

For Total Phosphorus in Loch Raven Reservoir:

TMDL (lbs/yr)	**=**	**LA +**	**WLA +**	**MOS**
54,941	**=**	**30,184**	**22,010**	**2,747**

For Suspended Sediment in Loch Raven Reservoir:

TMDL (tons/yr)	**=**	**LA**	**+**	**WLA +**	**MOS**
28,925	**=**	**27,715**		**1,210**	**implicit**

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the phosphorus and sediment TMDLs will be achieved and maintained. For both TMDLs, Maryland has numerous well-established programs that may be drawn upon: the Water Quality Improvement Act of 1998 (WQIA); the Clean Water Action Plan (CWAP) framework; the Maryland Agricultural Water Quality Cost-Share (MACS) Program; the Low Interest Loans for Agricultural Conservation (LILAC) Program; the Maryland Agricultural Land Preservation Easement (MALPE) Program, and the Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction. Also, Maryland has adopted procedures to assure that future evaluations are conducted for all TMDLs that are established. Additionally, the federal Safe Drinking Water Act requires states to develop and implement source water assessment programs (SWAPs) to study the safety and evaluate the vulnerability of drinking water sources to contamination.

The Hampstead WWTP will continue to meet the requirements of its NPDES discharge permit, which since 1997 requires an effluent phosphorus concentration below 0.3 mg/l and a total suspended solids concentration less than 30 mg/l. The Manchester WWTP will continue to meet the requirements of its NPDES discharge permit, which requires it to use spray irrigation to dispose of its wastewater discharge April through November, and to meet an effluent concentration limit of 1.0 mg/l TP and 30 mg/l TSS when discharging to surface water December through March.

Maryland's WQIA requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout Maryland. This act specifically requires that nutrient management plans for nitrogen be developed and implemented by 2002, and plans for phosphorus be completed by 2005. Maryland's CWAP has been developed in a coordinated manner with the State's 303(d) process. All Category I watersheds identified in Maryland's Unified Watershed Assessment process are totally coincident with the impaired waters list for 2002 approved by EPA. The State is giving a high priority for funding assessment and restoration activities to these watersheds.

In 1983, the States of Maryland, Pennsylvania, and Virginia, the District of Columbia, the Chesapeake Bay Commission, and the U.S. EPA joined in a partnership to restore the Chesapeake Bay. In 1987, through the Chesapeake Bay Agreement, Maryland made a commitment to reduce nutrient loads to the Chesapeake Bay. In 1992, the Chesapeake Bay Agreement was amended to include the development and implementation of plans to achieve these nutrient reduction goals. Maryland's resultant Tributary Strategies for Nutrient Reduction provide a framework supporting the implementation of nonpoint source controls in the Upper Western Shore Tributary Strategy Basin, which includes the Gunpowder Falls watershed. Maryland is in the forefront of implementing quantifiable nonpoint source controls through the Tributary Strategy efforts. This will help to ensure that nutrient control activities are targeted to areas in which nutrient TMDLs have been established.

In November 1990, EPA required jurisdictions with a population greater than 100,000 to apply for NPDES permits for stormwater discharges. In 1983, the EPA Nationwide Urban Runoff Program found that stormwater runoff from urban areas contains the same general types of pollutants found in wastewater, and that 30% of identified cases of water quality impairment were attributable to stormwater discharges. The two Maryland jurisdictions where the majority of the Loch Raven and Prettyboy watersheds are located, Carroll County and Baltimore County, are required to participate in the stormwater NPDES program, and have to comply with the NPDES permit regulations for stormwater discharges. Several management programs have been implemented in different areas served by the counties. These jurisdiction-wide programs are designed to control stormwater discharges to the maximum extent practicable.

Since 1979, Baltimore City, Baltimore County and Carroll County have had in place a formal agreement to manage the reservoir watersheds 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 9 lists the parties to the 2005 agreement and some of their major commitments made in the Action Strategy.

In June 2005, the Baltimore County Department of Environmental Protection and Resource Management, in cooperation with MDE and other stakeholders in the region, began to develop a Watershed Restoration Action Strategy (WRAS) document for Prettyboy Reservoir. The purpose of the document is to present a strategy to reduce NPS pollution that contribute to impairments in the watershed, while at the same time conserving the unique, high quality natural resources. The strategy is developed through the combined efforts of the general public, watershed stakeholders, local and county governments, non-profit organizations, and state and federal agencies. The document outlines the conditions in the watershed, the potential sources of pollution and impairments, and actions that can be taken to address these issues. It is anticipated that this strategy, scheduled for completion in late 2006, will assure TMDL implementation for nonpoint sources.

Additionally, Maryland uses a five-year watershed cycling strategy to manage its waters. Pursuant to this strategy, the State is divided into five regions and management activities will cycle through those regions over a five-year period. The cycle begins with intensive monitoring, followed by computer modeling, TMDL development, implementation activities, and follow-up evaluation. The choice of a five-year cycle is motivated by the five-year federal NPDES permit cycle. This continuing cycle ensures that every five years intensive follow-up monitoring will be performed. Thus, the watershed cycling strategy establishes a TMDL evaluation process that assures accountability.

Finally, it is noted that the baseline calibration scenarios inherently include the effects of some BMPs as of the time period affixed in the scenarios (*i.e.*, 1992 – 1997). Additional land use changes and BMP implementation efforts, potentially resulting in water quality changes of as-of-yet unknown type and magnitude, have occurred since then. It is likely that initial phases of the implementation process may include an assessment of these practices and their potential benefits (or detriments) to water quality.

Table 9: Signatories to the 2005 Reservoir Management Agreement and Their Major Commitments under the 2005 Action Strategy (RTG, 2005)

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.

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