Total Maximum Daily Loads of Phosphorus and Sediments for Clopper Lake, Montgomery County, MD

FINAL

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List of Abbreviations

7Q10	7-day consecutive lowest flow expected to occur every 10 years
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CAFOs	Confined Animal Feeding Operations
CBOD	Carbonaceous Biochemical Oxygen Demand
CEAM	Center for Exposure Assessment Modeling
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
COMAR	Code of Maryland Regulation
CWAP	Clean Water Action Plan
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DNR	Department of Natural Resources
DO	Dissolved Oxygen
D_s	Secchi Depth
EPA	Environmental Protection Agency
EUTRO5.1	Eutrophication Module of WASP5.1
FNH_4	Ammonia Sediment Flux
FPO_4	Phosphate Sediment Flux
g O_2/m^2	Grams of Oxygen Per Square Meter
g/yr	Gram per year
K_e	Extinction Coefficient
Km	Kilometers
LA	Load Allocation
lb/month	Pounds Per Month
lb/yr	Pounds Per Year
m	Meters
MACS	Maryland's Agricultural Cost Share Program
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
mg/l	Milligrams Per Liter
mi^2	Square miles
MOS	Margin of Safety
NBOD	Nitrogenous Biochemical Oxygen Demand
NH_3	Ammonia
NMP	Nutrient Management Practice
NO_{23}	Nitrate + Nitrite

NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
ON	Organic Nitrogen
OP	Organic Phosphorus
PO_4	Ortho-Phosphate
SOD	Sediment Oxygen Demand
T	Temperature
TMDL	Total Maximum Daily Load
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
USGS	United States Geological Survey
WASP5.1	Water Quality Analysis Simulation Program 5.1
WLA	Waste Load Allocation
WQLS	Water Quality Limited Segment
WQIA	Water Quality Improvement Act
WRAS	Watershed Restoration Action Strategy
*u*g/l	Micrograms Per Liter

EXECUTIVE SUMMARY

On the basis of water quality problems associated with nutrients and sediments, Clopper Lake in the Seneca Creek watershed (02-14-02-08) was identified on Maryland's 1998 list of WQLSs as being impaired. This document establishes Total Maximum Daily Loads (TMDLs) for the nutrient phosphorus and sediments entering Clopper Lake.

Clopper Lake is an impoundment located within Seneca Creek State Park, near Gaithersburg in Montgomery County, Maryland. The impoundment lies on Long Draught Branch, a tributary of the Seneca Creek. The Seneca Creek lies in the Potomac River Drainage Basin. Clopper Lake was constructed for flood control and recreation.

Clopper Lake has been previously impacted by a high sediment load. The lake also experiences occasional nuisance seasonal algae blooms, due to overenrichment by nutrients, which interfere with recreational uses. The death and decay of excessive algae can cause violations of the water quality standard for dissolved oxygen (DO), which can result in a disruption of the lake's ecosystem balance and cause fish kills. Analysis suggests that phosphorus is the limiting nutrient for the production of algae in Clopper Lake. Due to the propensity of phosphorus to bind to sediments, the overall strategy is to simultaneously address the water quality problems associated with phosphorus and sediments.

The water quality goal of these TMDLs is to reduce long-term phosphorus and sediment loads to acceptable levels consistent with the physical characteristics of Clopper Lake. This reduced loading rate is predicted to resolve excess algae problems and maintain a dissolved oxygen concentration above the State's water quality standard. The TMDL for phosphorus was determined using an empirical method known as the Vollenweider Relationship. Because the reduction of sediments is a component of controlling external phosphorus loads, a sediment loading rate consistent with narrative water quality criteria is predicted to be achieved.

The average annual TMDL for phosphorus is about 555 lb/yr. There are no point sources in the Clopper basin. Consequently, the allocation is partitioned between nonpoint sources and the margin of safety. For sediments, the TMDL is established to achieve a reasonable loading rate, consistent with the uses of the lake, as a result of the proposed control of phosphorus. This loading rate is estimated to result in preserving about 97 - 99% of the lake's design volume over a period of 50 years.

Preliminary estimations of the phosphorus controls necessary to achieve the load reduction were conducted to provide a reasonable assurance that the TMDL could be implemented. It is estimated that a 45% reduction in phosphorus loads would be necessary to meet the TMDL for phosphorus.

1.0 INTRODUCTION

The Clean Water Act Section 303(d)(1)(C) and federal regulation 40 CFR 130.7(c)(1) direct each state to develop a Total Maximum Daily Load (TMDL) for all impaired waters on their Section 303(d) list. A TMDL reflects the maximum pollutant loading of an impairing substance a water body can receive and still meet water quality standards. A TMDL can be expressed in mass per time, toxicity, or any other appropriate measure (40 CFR 130.2(i)). TMDLs must take into account seasonal variations and a margin of safety (MOS) to allow for uncertainty. Maryland's 1998 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), lists Clopper Lake for nutrients and sediments. The 1998 listing was prompted by an assessment of data associated with Clopper Lake (Maryland Department of Natural Resources [DNR], 1998).

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Clopper Lake is an impoundment located near Gaithersburg in Montgomery County, Maryland (Figure 1). The impoundment, which is owned by the Maryland Department of Natural Resources, lies on Long Draught Branch, a tributary of the Seneca Creek. An earthen dam was installed in 1975 for the purpose of flood control and creating the lake for recreational uses.

Clopper Lake lies in the Piedmont physiographic province. The soils immediately surrounding the lake are the Glenelg-Gaila-Occoquan association (Soil Conservation Service, 1994). These soils generally range from fine-loamy, mixed, mesic Ochreptic Hapludults to mesic Typic Hapludults. They are very deep and well drained. They form in material weathered from quartz muscovite schist, schist and gneiss. The outer watershed area is comprised of soils of the Urban Land-Wheaton-Glenelg association. These soils are very deep and well drained (Soil survey of Montgomery County, Maryland, USDA, 1988).

Inflow to the lake is primarily via Long Draught Branch and one unnamed tributary. Discharge from the lake is to the Great Seneca Creek, which discharges to the Seneca Creek. The watershed map (Figure 2) shows that land use in the watershed draining to Clopper Lake is predominantly developed. Land use distribution in the watershed is approximately 77% developed, 17% forested/herbaceous, 6% open water, and less than 1% agricultural (Figure 3) (Maryland Office of Planning, 1994).

The load reduction assessment uses Chesapeake Bay Program data to estimate the nonpoint source loading rates, which represent the cumulative impact from all sources—naturally-occurring and human-induced. Natural background sources of phosphorus are included in the assessment including direct atmospheric deposition to the water surface. The loads associated with each land use category include the naturally occurring as well as the human-induced contributions. No point source discharge permits for nutrients have been issued in the Clopper Lake Watershed.

Several relevant statistics for Clopper Lake are provided below in Table 1.

Table 1

Current Physical Characteristics of Clopper Lake

Location:	Montgomery County, MD lat. 39° 06' 37" long. 77° 15' 27"
Surface Area:	90 acres = (3,920,400 ft^2) = (360,677 m^2)
Length:	1.24 mi
Maximum Width:	1200 feet
Average Lake Depth:	17.7 feet
Maximum Depth:	28.5 feet
Purpose	Recreation and Flood Control
Basin Code	02-14-02-08
Volume of Lake:	1,592 acre-feet (1,963,732 m^3)
Drainage Area to Lake:	2.86 mi^2
Average Discharge:	5.9 cfs

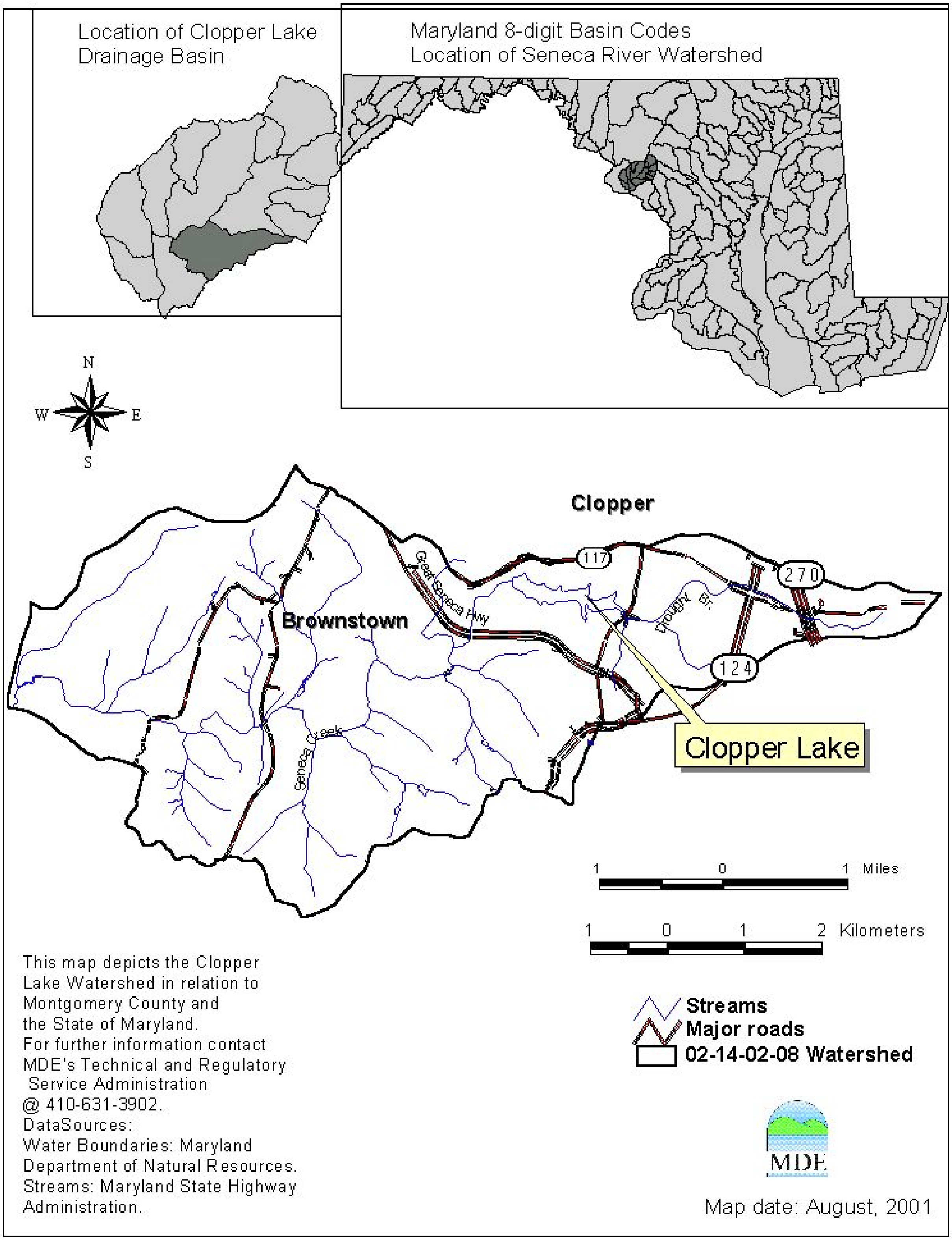

Figure 1 – Location Map of Clopper Lake in Montgomery County, MD

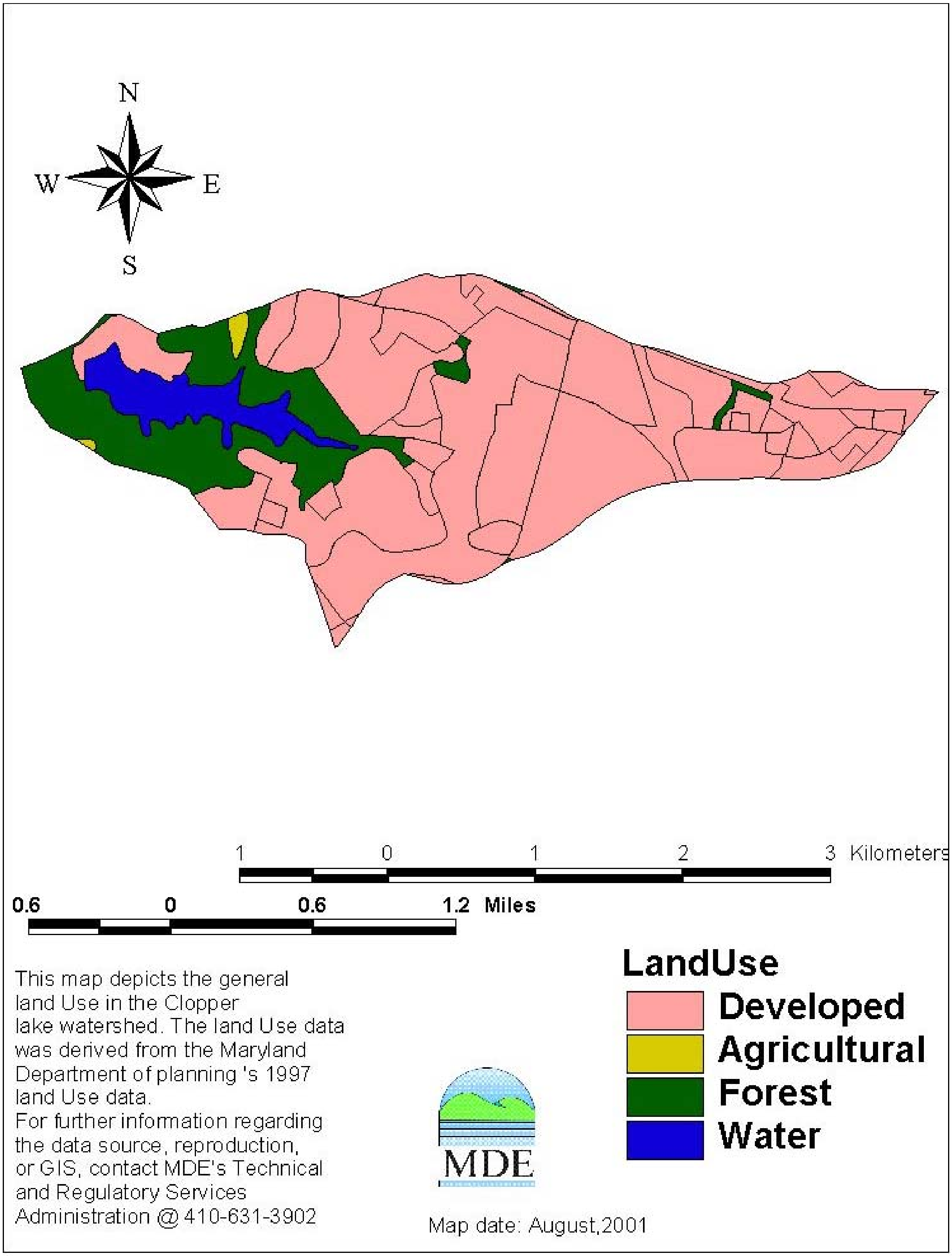

Figure 2 – Predominant Land Use in the Clopper Lake Watershed

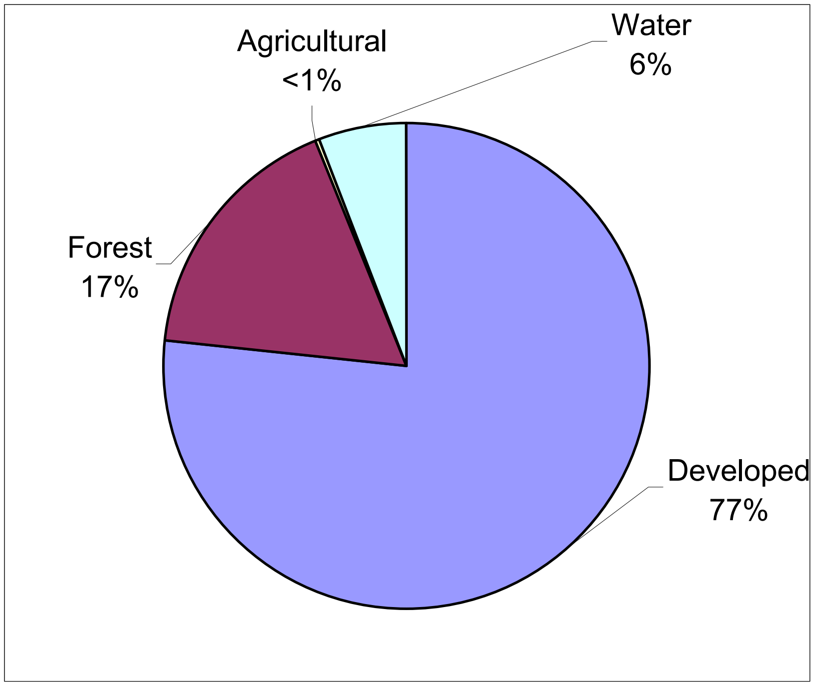

Figure 3. Land Use in Drainage Basin of Clopper Lake

2.2 Water Quality Characterization

Clopper Lake was identified as having low dissolved oxygen levels and nuisance levels of algae in the *Maryland Lake Water Assessment Report* (March 1998). As a result of this evaluation, Clopper Lake was added to Maryland's 1998 303(d) list.

Clopper Lake was monitored in July and August of 1991 (MDE, 1995), and again in 2000 (October, November and December) and 2001 (January through August). Water samples were collected from a vertical profile of the water column. Samples were analyzed by the Maryland Department of Health and Mental Hygiene for total phosphorus, soluble orthophosphorus, nitrate and nitrite N, total Kjeldahl nitrogen, total organic solvents and chlorophyll *a*. Physical measurements of depths, water temperatures, pH, conductivity and dissolved oxygen were recorded in the field from the surface, middle and lower portion of the water column. Detailed water quality data are presented in Appendix A.

Instantaneous chlorophyll *a* concentrations ranging from 1.4 to 22 µg/l were observed in Clopper Lake. While not extreme when compared to peak concentrations (10 to 275 µg/l) in eutrophic lakes (Olem and Flock 1990), chlorophyll *a* levels above 10 µg/l are associated with eutrophic conditions in lakes (Chapra, 1997).

Dissolved oxygen (DO) concentrations ranged from 0.1 to over 10 mg/l along the vertical profile. Oxygen depletion occurs discontinuously, coincident with the depth at which thermal stratification was observed (*i.e.* about 3-5 m) during the two sampling events. Total phosphorus concentrations ranged from 0.01 mg/l to 0.03 mg/l. Total Kjeldahl nitrogen ranged from 0.45 to 0.65 mg/l in Clopper Lake.

Water temperatures taken during the sampling period ranged from 27.8°C to 28.9°C in the surface water depth (0.3-1 meter column); 25.7°C to 28°C in the 2-4 meter water column; and 13.1°C to 21.4°C in the 5-7 meter water column. This wide range of water temperatures, with an abrupt discontinuity at about 5 m, indicates that Clopper Lake is thermally stratified and not well mixed.

2.3 Water Quality Impairment

The water quality impairments of Clopper Lake addressed by these TMDLs consist of violations of the applicable numeric dissolved oxygen (DO) criterion and general water quality criteria. DO violations occur only in the hypolimnion.

Clopper Lake, an impoundment on a tributary of the Seneca Creek near Gaithersburg, has been designated a Use I water body, pursuant to which it is protected for water contact recreation, fishing, aquatic life and wildlife. See COMAR 26.08.02.07. Use I waters are subject to a DO criterion of not less than 5.0 mg/l at any time (COMAR 26.08.02.03-3A(2)) unless natural conditions result in lower levels of dissolved oxygen (COMAR 26.08.02.03A(2)). The dissolved oxygen concentration in Clopper Lake occasionally falls below the standard of 5.0 mg/l.

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. See COMAR 26.08.02.03B(2). Excessive eutrophication, indicated by elevated levels of chlorophyll *a*, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. Violations of the dissolved oxygen and general water quality standards in Clopper Lake are the result of overenrichment by the nutrient phosphorus. Finally, in conjunction with excessive nutrients, Clopper Lake has experienced excessive sediment loads.

Clopper Lake water temperatures taken during the sampling period indicate the lake is thermally stratified and not well mixed. During the 1991 sampling period (July and August), DO concentrations as high as 10.1 mg/l were observed at the surface (1 meter depth) of Clopper Lake, with DO values as low as 0.1 mg/l at a depth of 5-7 meter. The July 2001 samples showed similar stratification. Average DO at the surface was 8.7 mg/l, and less than 1.0 mg/l at the range of 4 -7 meter depth. The observed numeric values fall short of the applicable numeric criterion in the deeper parts of the lake.

3.0 TARGETED WATER QUALITY GOALS

Clopper Lake is classified as Use I—*Water Contact Recreation, and Protection of Aquatic Life*. The chlorophyll *a* endpoint selected for Clopper Lake is a maximum concentration of 20 µg /l, or approximately 60 on the Carlson's Trophic State Index (TSI). This is in the lower range of eutrophy, which is an appropriate trophic state at which to manage this impoundment.

Other states have adjusted their trophic-state expectation for lakes or impoundments with differing uses. Minnesota, for example, uses an ecoregion-based approach. Heiskary (2000) reports that individuals utilizing lakes for recreational purposes (water contact, fishing) demanded relatively clear, less enriched lakes in the Northern Lakes and Forest (NLF) and North Central Hardwood Forest (NCHF) ecoregions. In the Western Corn Belt Plains (WCBP) and Northern Glaciated Plains (NGP) ecoregions, however, users accepted relatively greater enrichment and less clarity. Under Minnesota's classification system, lakes in the NLF and NCHF ecoregions are considered to fully meet use support with TSIs of about 53 and 57, respectively. Lakes in the other two ecoregions, both of which are largely agricultural, are considered to fully support use with TSIs of about 60 (Heiskary 2000).

Clopper Lake lies in the Piedmont ecoregion, which occurs between the Appalachian Mountains and the Atlantic Coastal Plain on the East Coast. Topography is rolling to moderately hilly, soils are varied, the land use is a mixture of forest, agricultural and developed, and there are few natural lakes (none in Maryland).

Clopper Lake is used for recreational purposes, *e.g*. fishing and boating. Moderate degrees of eutrophication are compatible with these uses. An appropriate management goal, therefore, is to enhance or maintain support of these recreational uses. An endpoint, seeking to avoid nuisance algal blooms and excessive aquatic macrophyte growth, is a maximum permissible chlorophyll *a* level of 20 μg/l. This corresponds approximately to a Carlson's TSI of 60.

The overall objective of the TMDLs established in this document is to reduce phosphorus and sediment loads to levels that are expected to result in meeting all water quality criteria that support the Use I designation. Specifically, one goal is to reduce the phosphorus load. This is predicted to reduce excessive algae growth, which leads to violations of the numeric DO criteria and the violation of various narrative criteria associated with nuisances (*i.e*., odors and physical impedance of direct contact use). In summary, the TMDLs for phosphorus and sediment are intended to:

1. Assure that minimum dissolved oxygen criteria are maintained both in the epilimnion and the deeper waters of Clopper Lake:

   (a) 5 mg/l in the surface layer (epilimnion);
   (b) A minimum DO saturation of 10% and associated temperature-dependent DO concentration below the epilimnion (See Appendix A);

2. Resolve violations of narrative criteria associated with phosphorus enrichment of Clopper Lake, leading to excessive algal growth;

3. Resolve violations of narrative criteria associated with excess sedimentation of Clopper Lake.

4.0 TOTAL MAXIMUM DAILY LOADS AND ALLOCATIONS

4.1 Overview

This subsection describes how the nutrient and sediment TMDLs and loading allocations were developed for Clopper Lake. The second subsection describes the analysis for determining that phosphorus is likely to be the limiting nutrient in Clopper Lake, and the methodological framework for estimating a permissible phosphorus load. The third subsection summarizes the analysis used to establish the maximum allowable phosphorus load. The fourth subsection provides a discussion of the analytical results. The fifth and sixth subsections describe the translation of these results into statements of a Total Maximum Daily Load and allocations for both phosphorus and sediments. The seventh subsection describes the margin of safety. The last subsection summarizes the TMDLs and allocations to nonpoint sources and the margin of safety.

4.2 Analytical Framework

Clopper Lake suffers from excessive nutrient enrichment and sedimentation. The TMDL for phosphorus is based on widely accepted empirical methods known as the Vollenweider Relationship and Carlson's Trophic State Index.
The Vollenweider Relationship predicts the degree of a lake's trophic status as a function of the areal phosphorus loading. R. A. Vollenweider (1968) developed the relationship by assessing a large number of lakes. He established a linear relationship between the log of the phosphorus loading (L_p) and the log of the ratio of the lake's mean depth ($\overline{Z}$) to hydraulic residence time (τ_w) (Figure 4). This method is advantageous for a number of reasons: It is based on observed data collected from a wide range of lakes; its application is conceptually simple and does not require the assumptions of many unknown parameters; and it is recognized by the scientific community as a reasonable method of predicting the trophic status of lakes.

A frequently used biomass-related trophic state index is that developed by Carlson (1977). Carlson's trophic status index (TSI) uses Secchi depth (SD), chlorophyll *a* (Chl), and total phosphorus (TP), with each producing an independent measure of trophic state. Index values range from 0 (ultraoligotrophic) to 100 (hypereutrophic). The index is scaled so that TSI=0 represents a Secchi transparency of 64 meters (m). Each halving of transparency represents an increase of 10 TSI units. For example, a TSI of 50 represents a transparency of 2 m, the approximate division between oligotrophic and eutrophic lakes. A TSI can be calculated from Secchi depth, chlorophyll *a* concentration and phosphorus concentration as stated below (Carlson, 1977: Carlson and Simpson, 1996):

$$TSI\ (Chl) = 30.6 + 9.81 \ln (Chl)$$
$$TSI\ (TP) = 4.15 + 14.42 \ln (TP)$$
$$TSI\ (SD) = 60 - 14.41 \ln (SD)$$

Trophic state indices can be used to infer trophic state of a lake and whether algal growth is nutrient or light limited. The following classification can be used to interpret the TSI (Moore and Thornton, 1988);

TSI < 35	most oligotrophic lakes
35 < TSI < 55	mesotrophic lakes
TSI > 55	eutrophic lakes
TSI > 70	hypertrophic lakes

There are other more complex approaches (*i.e.*, water quality models that simulate eutrophication processes) that can also yield acceptable results. However, such methods require extensive data and the investment of substantial resources to develop. In light of the data available for this TMDL and the small size of the watershed, the Vollenweider Relationship and Carlson's trophic status index constitute sufficient, readily available tools.

Nitrogen and phosphorus are essential nutrients for algae growth. However, common types of algae require different amounts of these two nutrients. If one nutrient is available in great abundance relative to the other nutrient, then the nutrient that is less available restricts the amount of plant matter that can be produced, regardless of the amount of the other nutrient that is available. This latter nutrient is called the "limiting nutrient." Applying the Vollenweider Relationship necessitates that phosphorus be the limiting nutrient. Thus, before considering the application of the Vollenweider Relationship, it is necessary to examine the ratio of nitrogen to phosphorus to establish whether phosphorus is the limiting nutrient.

In general, an 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, and if the N:P ratio is less than 5:1, nitrogen tends to be limiting (Chianudani *et al*., 1974). An N:P ratio of greater than 20:1 was computed using best readily available data (MDE Lake Water Quality Assessment Project, 1991), which supports the use of the Vollenweider Relationship. Supporting data are provided in Appendix A.

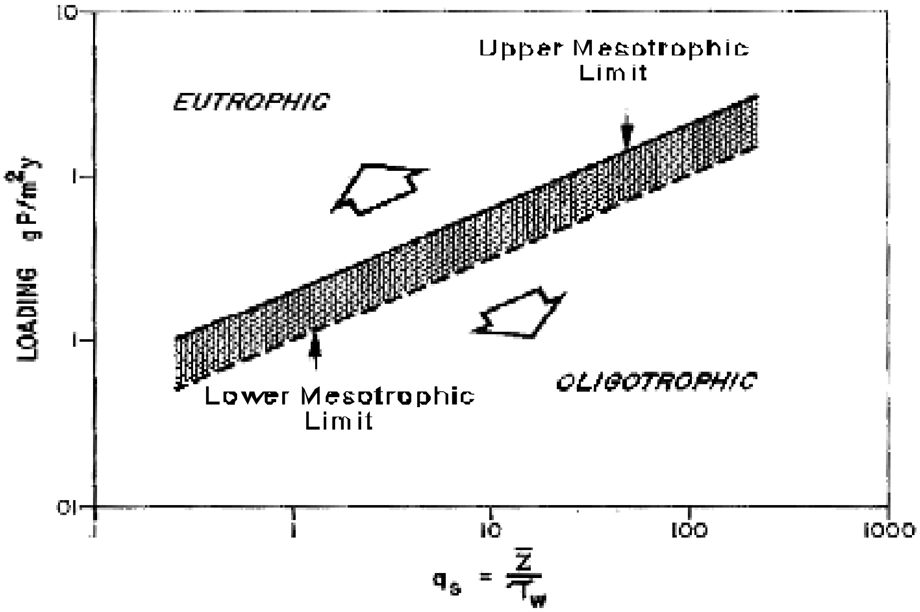

Figure 4. Vollenweider Relationship

4.3 Vollenweider Relationship Analysis

The Vollenweider Relationship establishes a linear relationship between the log of the phosphorus loading (L_p) and the log of the ratio of the lake's mean depth ($\overline{Z}$) to hydraulic residence time (τ_w). Thus, the Vollenweider Relationship requires the computation of three key values: (1) the average annual phosphorus loading (L_p), (2) the lake's mean depth ($\overline{Z}$), and (3) the hydraulic residence time (τ_w). The computations and results of the Vollenweider Relationship are summarized below. See Appendix A for details of the computations and supporting data.

Clopper Lake Mean Depth ($\overline{Z}$):

The application of the Vollenweider Relationship assumes the lake's physical dimensions when the lake and dam were constructed in 1975. The mean lake depth was calculated using lake volume and surface area given in the Inventory of Maryland Dams and Hydropower Resources (DNR 1985). The cited surface area and volume of Clopper Lake are 90 acres (3,920,400 ft^2) and 1592 acre feet (69,347,520 ft^3), respectively.

The mean depth was thus calculated as follows:

- ***Clopper Lake Mean Depth ($\overline{Z}$): (Volume)/(Surface Area) = 17.7 ft or 5.4 m***

Phosphorus Loading to Clopper Lake (Lp):

The current estimated total phosphorus loading is 915 lb/year (or 414,495 g/year) based on loading coefficients from the Chesapeake Bay Program, segment 220, Phase 4.3 Watershed Model for agricultural and forested areas; urban developed area loading rate based on NPDES data for Montgomery County provided by Montgomery County (personal communication). Expressing this value as a loading per surface area of the lake gives:

- ***Annual Phosphorus Load (L_p) is: 1.14 g/m² yr***. Details are provided in Appendix A.

Clopper Lake Hydraulic Residence Time (τ_w)

Residence time (τ_w) is computed by dividing the lake volume by annual discharge. For Clopper Lake, average discharge data are unavailable. Since discharge data are unavailable, flow from Clopper Lake is estimated as follows (details are shown in Appendix A):

- **Flow (Q) = 5.9 cfs = 4,272 acre feet/year**

The hydraulic residence time is computed as volume/outflow; it is the time it would take to drain the lake. Assuming a volume of 1,592 acre feet (DNR, 1985), from above, and a discharge rate of 4,272 acre per year (DNR, 1985) the hydraulic residence time is calculated as follows:

- **1,592 acre feet ÷ 4,272 acre feet/year = 0.37 years**

- ***Clopper Lake Hydraulic Residence Time (τ_w): 0.37 years = 135 days***

The mean depth of the lake (5.4 m) is then divided by hydraulic residence time (0.37 years) to yield q_s, the parameter with which to compare phosphorus loading using the Vollenweider Relationship to assess the lake's trophic status. For Clopper Lake, **q_s = 14.6 m/yr**.

4.4 Vollenweider Relationship Results

The basic elements of the Vollenweider Relationship, established above, were combined to estimate both the current trophic status of Clopper Lake, and the maximum allowable unit loading. The current trophic status associated with a loading of 1.14 g/m^{2}yr falls into the eutrophic range, as indicated on figure 5 by a circle "●". The maximum allowable unit loading of 0.7 g/m^2 yr corresponds to an estimated chlorophyll level of 20 µg/l associated with a TSI of 60 for a lake with mean depth of 5.4 m and hydraulic residence time of 0.37 years is indicated by "♦". The TMDL implications are presented below in Section 4.5.

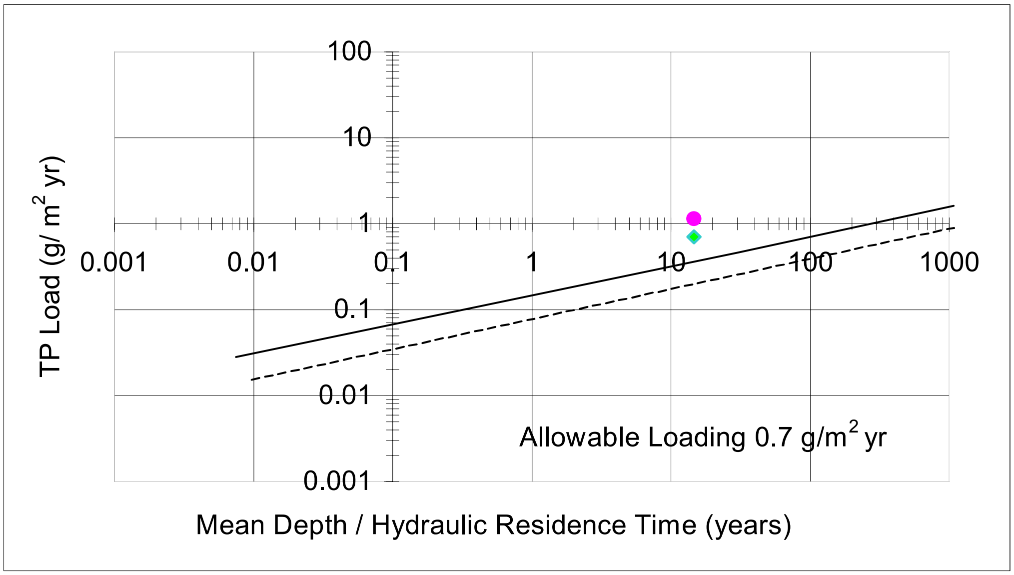

Figure 5. Vollenweider Results for Clopper Lake

4.5 Total Maximum Daily Loads

This TMDL considers seasonal variations by estimating loading rates over the entire year. This captures the dry weather loading rates, which generally occur during the warmer months when algae production is most prevalent. It also captures the wet-weather loading rates, which contribute significant sediment-bound sources of phosphorus. The Vollenweider Relationship specifically uses long-term loading estimates to avoid adopting a single transient loading pulse, which would yield erroneous results.

The TMDL water quality endpoint, which will maintain recreational use and avoid nuisance algal blooms, is a maximum TSI of 60, which is associated with the lower range of eutrophic conditions. A TSI of 60 corresponds to a maximum chlorophyll *a* concentration of 20 µg/l and a loading rate of 500 lb /yr. This represents a 45% reduction in phosphorus loading.

The link between DO concentration and the lake's trophic status (as defined by the Vollenweider Relationship) is indirect, but may be inferred as described below. Nutrient overenrichment causes excess algal blooms, which eventually die off and decompose, consuming DO.
The DO in the surface layer of Clopper Lake is currently within State standards (see Tables A-1 and A4, Appendix A). An assessment is made of the processes that determine DO concentration in the sub-epilimnetic portion of this lake (see Appendix A). These processes, as they apply to Clopper Lake, are outlined below. This assessment is based on critical conditions and uses conservative assumptions.

- Dissolved oxygen saturation capacity as a function of trophic status and water temperature.
- Sediment Oxygen Demand (SOD).
- Carbonaceous Biochemical Oxygen Demand (CBOD).

According to calculations presented in Appendix A, it is expected that an areal phosphorus load of 0.7 g/m^2 will result in an increase of minimum hypolimnetic DO from the observed 0.2 mg/l to DO concentrations of about 0.5 – 0.7 mg/l. This would be consistent with Maryland's interim interpretation of the dissolved oxygen criterion as it applies to stratified lakes, which is discussed in detail in Appendix A.

Excessive sedimentation negatively impacts a lake by reducing the lake's capacity to support fishery and recreational uses. Although the maximum sedimentation rates occur during wet weather events, it is the cumulative effects of sedimentation that impacts the lake. Therefore, the efforts to reduce sediment loading to the lake should focus on achieving effective, long term sediment control.

The remaining agricultural land in the Clopper Lake watershed is negligible; hence, any reduction in sedimentation from agricultural land will have a minimal impact on the lake. Sediment loading coefficients for developed land suggest that current sedimentation to the lake is minimal. The construction phase in the Clopper Lake watershed is largely complete (K. van Ness, Montgomery County DEP, pers. comm., 2001). Thus, sedimentation in the lake is currently not a problem, with the volumetric loss caused by sedimentation having occurred largely during the construction phase.

The estimated TMDLs for phosphorus and sediment are as follows (see Appendix for detailed calculations):

PHOSPHORUS TMDL **252,474 g*/yr* =555 lb/yr**

SEDIMENT TMDL **129 tons/yr**

4.6 TMDL Allocation

The watershed that drains to Clopper Lake contains no permitted point source discharges. Hence, the entire allocation will be made to nonpoint sources. The model uses Chesapeake Bay Program, Phase 4.3 phosphorus loading coefficients to estimate the loading rates from agricultural and forested areas, which represent the cumulative impact from all sources—naturally-occurring and human-induced. The loading rate for developed area was provided by Montgomery County (M. Curtis, personal communication, 2001). Details are described in the technical memorandum entitled "Significant Phosphorus Nonpoint Sources in the Clopper Lake Watershed".

4.7 Margin of Safety

A margin of safety (MOS) is required as part of a TMDL in recognition of the fact that there are many uncertainties in scientific and technical understanding of water quality in natural systems. Specifically, 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 water bodies. 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 one of 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 = WLA + LA + MOS). The second approach is to incorporate the MOS as part of the design conditions for the WLA and the LA computations.

Maryland has elected to incorporate an explicit margin of safety into this phosphorus TMDL. Following the first approach, the load allocated to the MOS was computed as 10% of the total allowable load.

In establishing a margin of safety for sediments, Maryland has adopted an implicit approach by selecting a conservative endpoint. This is also to compensate for the lack of accurate data regarding the physical dimensions of the lake. The sediment TMDL is predicted to result in a volumetric preservation of 97% - 99% over a period of 50 years. This preservation compares favorably with several other approved sediment TMDLs in Maryland and elsewhere (see Table 2 below). Because the area is largely built out, land use in the watershed is not likely to change, nor will additional disturbance from construction-related activities likely pose a sedimentation problem.

Table 2.

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% – 62.5%
Hurricane Lake (WV)	70% after 40 yrs	25%
Tomlinson Run Lake (WV)	30% after 40 yrs	Silted in
Clopper Lake (MD)	97% - 99% after 50 years	95% - 98%

4.8 Summary of Total Maximum Daily Loads

The annual TMDL **for Phosphorus (lb/yr):**

TMDL	=	WLA	+	LA	+	MOS
555	=	**0**	+	**500**	+	**55**

On average, this TMDL represents a daily phosphorus load of 1.37lb/day.

Where:

WLA = Waste Load Allocation (Point Source)
LA = Load Allocation (Nonpoint Source)
MOS = Margin of Safety

The Annual **TMDL for Sediments (tons/yr):**

TMDL	=	WLA	+	LA	+	MOS
129	=	**0**	+	**129**	+	**Implicit**

5.0 ASSURANCE OF IMPLEMENTATION

Clopper Lake is located in a watershed in which the impairment is due to nonpoint source contributions. As such, the implementation provisions will need to be rigorous and iterative. Significant phosphorus reductions are required to meet the load allocation of this TMDL. The certainty of implementation of the phosphorus reduction plan in this watershed will be enhanced by two specific programs: the Watershed Restoration Action Strategies (WRASs) associated with the EPA-sponsored Clean Water Action Plan of 1998 (CWAP), and the Maryland Tributary Strategies for implementing the Chesapeake Bay Agreement.

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 1996 and 1998 approved by EPA. The State has given a high priority for funding assessment and restoration activities to these watersheds.

As part of Maryland's Watershed Cycling Strategy, follow-up monitoring and assessments will be conducted to (1) determine the effect of the practices on water quality and related conditions, (2) determine the degree to which the selected practices are implemented, and (3) to the extent possible, determine the efficacy and impacts of the practices chosen. Based on this monitoring and assessment program, the TMDL will be evaluated as to whether additional practices must be employed in order to eliminate any remaining impairment.

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Appendix A

Clopper Lake Water Quality

A study of Clopper Lake was conducted in 1991 MDE Lake Water Quality Assessment Project. MDE also collected water data in March and July 2001. A summary of the water quality data was provided in the main body of this report. Tables A1 through A4 provide the underlying data from which the summaries were derived.

Assessment of the N:P Ratio for Clopper Lake

Before considering the application of the Vollenweider Relationship, it is necessary to examine the ratio of nitrogen (N) to phosphorus (P) to establish whether phosphorus is the limiting nutrient. In general, an N:P ratio in the range of 5:1 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, and if the N:P ratio is less than 5:1, nitrogen tends to be limiting (Chianudani, *et al*., 1974).

The N:P ratio was estimated using data from the two August 1991 samples (MDE Lake Water Quality Assessment Project). The concentrations of Total Kjeldahl Nitrogen (TKN) and Total Phosphorus of both samples were used to calculate the N:P ratio. The TKN:P ratio ranged from 20:1 to over 40:1. The best available data were used to calculate the N:P ratio. TKN does not include all nitrogen; therefore, the estimated N:P ratio (as calculated from TKN:P ratio) is a conservative estimate of the true value of this parameter.

Table A1
Physical Water Quality Data—Clopper Lake, 1991

STATION	DATE	TIME	DEPTH (m)	WATER TEMP (°C)	pH FIELD	DO (mg/l)	COND (µmhos/cm)
LDR0009	07/01/1991	1252	0.3	28.6	8.5	9.5	221
LDR0009	07/01/1991	1252	1.0	28.7	8.4	9.5	221
LDR0009	07/01/1991	1252	2.0	28.6	8.2	9.5	221
LDR0009	07/01/1991	1252	3.0	26.5	7.6	8.8	219
LDR0009	07/01/1991	1252	4.0	24.6	7.7	8.8	213
LDR0009	07/01/1991	1252	5.0	21.4	6.5	4.2	227
LDR0009	07/01/1991	1252	6.0	15.7	6.8	0.7	231
LDR0009	07/01/1991	1252	7.0	13.1	6.9	0.1	228
LDR0009	07/01/1991	1252	8.0	11.4	7.0	0.1	226
LDR0009	07/01/1991	1252	9.0	10.1	7.0	0.1	235
LDR0009	07/01/1991	1252	10.0	9.5	7.0	0.1	255
LDR0009	07/01/1991	1252	10.6	9.4	7.1	0.1	270
LDR0015	07/01/1991	1326	1.0	28.7	8.5	10.1	221
LDR0015	07/01/1991	1326	2.0	28.4	7.9	10.4	220
LDR0015	07/01/1991	1326	3.0	28.7	8.6	10.1	221
LDR0015	07/01/1991	1326	3.0	27.1	7.1	9.9	220
LDR0015	07/01/1991	1326	4.0	24.7	6.8	8.5	217
LDR0015	07/01/1991	1326	4.5	21.2	7.0	2.6	218
LDR0009	08/22/1991	1335	0.3	28.7	7.5	7.2	211
LDR0009	08/22/1991	1335	1.0	27.5	7.4	7.3	210
LDR0009	08/22/1991	1335	2.0	27.0	7.4	7.3	211
LDR0009	08/22/1991	1335	3.0	26.6	7.1	7.2	210
LDR0009	08/22/1991	1335	4.0	25.4	6.9	0.8	206
LDR0009	08/22/1991	1335	5.0	24.2	7.0	0.2	212
LDR0009	08/22/1991	1335	6.0	20.4	6.8	0.1	240
LDR0009	08/22/1991	1335	7.0	17.5	6.8	0.1	246
LDR0009	08/22/1991	1335	8.0	14.0	6.9	0.1	244
LDR0009	08/22/1991	1335	9.0	12.0	7.0	0.1	252
LDR0009	08/22/1991	1335	10.0	10.5	7.0	0.1	269
LDR0009	08/22/1991	1335	11.0	10.1	7.0	0.1	290
LDR0009	08/22/1991	1335	12.0	9.9	7.0	0.2	314
LDR0015	08/22/1991	1358	0.3	28.9	7.7	7.4	208
LDR0015	08/22/1991	1358	1.0	27.6	7.7	7.9	207
LDR0015	08/22/1991	1358	2.0	27.1	7.4	8.0	208
LDR0015	08/22/1991	1358	3.0	26.7	6.8	3.4	196
LDR0015	08/22/1991	1358	4.0	25.7	6.8	1.6	180
LDR0015	08/22/1991	1358	5.0	23.8	6.8	0.1	175
LDR0015	08/22/1991	1358	5.3	23.3	6.8	0.1	195

Table A2
Water Quality (Nutrient) Data Clopper Lake

STATION	DATE	TIME	DEPTH (m)	TN (mg/l)	TKN (mg/l)	TP (mg/l)
LDR0009	08/22/1991	1335	0.3	-	0.65	0.03
LDR0015	08/22/1991	1358	0.3	-	0.45	0.01
LDR0022	10/18/2000	9:35	0	2.6197	-	0.0357
LDR0008	10/18/2000	10:00	0	5.4449	-	0.0154
LDR0022	11/16/2000	8:30	0	1.1761	-	0.0198
LDR0008	11/16/2000	9:00	0	1.8018	-	0.0089
LDR0022	12/06/2000	8:40	0	2.6219	-	0.0148
LDR0008	12/06/2000	9:00	0	3.3298	-	0.0067
LDR0022	01/10/2001	10:00	0	3.5196	-	0.0119
LDR0008	01/10/2001	10:30	0	0.9709	-	0.005
LDR0022	02/07/2001	11:10	0	2.1541	-	0.0933
LDR0008	02/07/2001	11:35	0	0.9473	-	0.008
LDR0022	03/21/2001	11:05	0	1.13	-	0.0398
LDR0008	03/21/2001	10:55	0	0.8288	-	0.0077
LDR0022	04/18/2001	9:07	0	1.5399	-	0.0191
LDR0008	04/18/2001	9:20	0	1.0642	-	0.0078
LDR0022	05/16/2001	9:20	0	2.1015	-	0.0102
LDR0008	05/16/2001	9:40	0	2.9757	-	0.0099
LDR0022	06/20/2001	8:45	0	1.4911	-	0.0227
LDR0008	06/20/2001	9:20	0	0.9591	-	0.0107
LDR0022	07/25/2001	9:15	0	1.8751	-	0.0198
LDR0008	07/25/2001	9:50	0	4.0023	-	0.0057
LDR0022	08/08/2001	9:00	0	1.642	-	0.0349
LDR0008	08/08/2001	9:23	0	4.5732	-	0.0047

Table A3
Water Quality (Chlorophyll) Data Clopper Lake

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TIME START SAMPLING	DEPTH	CHLOROPHYLL A µg/L	PHEOPHYTIN A µg/L
LDR0009	07/01/1991	1252	0.3	1.4	-0.1
LDR0009	07/01/1991	1252	0.3	1.6	-0.3
LDR0015	07/01/1991	1:26	0.3	2.2	0
LDR0015	07/01/1991	1:26	0.3	2.5	-0.3
LDR0009	08/22/1991	1:35	0.3	6.6	0.1
LDR0009	08/22/1991	1:35	0.3	6.8	1.9
LDR0015	08/22/1991	1:58	0.3	6.2	0.2
LDR0015	08/22/1991	1:58	0.3	8.4	0.5
LDR0022	10/18/2000	9:35	0	2.2428	1.106448
LDR0008	10/18/2000	10:00	0	2.6166	2.6166
LDR0022	11/16/2000	8:30	0	0.9612	0.01068
LDR0008	11/16/2000	9:00	0	1.869	2.31756
LDR0022	12/06/2000	8:40	0	1.94376	0
LDR0008	12/06/2000	9:00	0	0	0
LDR0022	01/10/2001	10:00	0		
LDR0008	01/10/2001	10:30	0	5.83128	0.343896
LDR0022	02/07/2001	11:10	0	4.63512	0
LDR0008	02/07/2001	11:35	0	7.92456	0.657888
LDR0022	03/21/2001	11:05	0	9.56928	3.409056
LDR0008	03/21/2001	10:55	0	22.6149	0.01869
LDR0022	04/18/2001	9:07	0	5.83128	0.44856
LDR0008	04/18/2001	9:20	0	2.84088	1.136352
LDR0022	05/16/2001	9:20	0	7.62552	2.212896
LDR0008	05/16/2001	9:40	0		
LDR0022	06/20/2001	8:45	0	0.623	0.59808
LDR0008	06/20/2001	9:20	0	3.738	0
LDR0022	07/25/2001	9:15	0	1.04664	0.313992
LDR0008	07/25/2001	9:50	0	1.869	3.10254
LDR0022	08/08/2001	9:00	0	1.34568	0.7476
LDR0008	08/08/2001	9:23	0	1.869	1.27092

Table A4
Physical Water Quality Data—Clopper Lake, 2000/2001

STATION	DATE	SAT. %	DEPTH (m)	WATER TEMP (°C)	pH FIELD	DO (mg/l)	COND (µmhos/cm)
LDR0022	10/18/2000	-	0	14.8	7	8	662
LDR0008	10/18/2000	-	0	9.6	6.8	7.5	920
LDR0022	11/16/2000	-	0	3.4	7	11.3	422
LDR0008	11/16/2000	-	0	9.8	7.3	9.8	410
LDR0022	12/06/2000	-	0	0.2	7.7	14	560
LDR0008	12/06/2000	-	0	5.8	7.3	10.1	520
LS-5	07/18/2001	103	0.5	27.3	8.2	8.2	297
LS-5	07/18/2001	100	1	27.4	8.1	8	297
LS-5	07/18/2001	96	3	25.6	7.3	7.9	306
LS-5	07/18/2001	9	5	13.9	6.7	0.9	499
LS-5	07/18/2001	5	7	8.9	6.8	0.6	533
LS-5	07/18/2001	5	9	7.7	7	0.6	627
LS-5	07/18/2001	11	11.5	6.8	7.1	0.9	1393
LS-6	07/18/2001	105	0.5	27.5	8.3	8.4	298
LS-6	07/18/2001	105	1	27.5	8.3	8.4	298
LS-6	07/18/2001	103	2	27.4	8.1	8.2	298
LS-6	07/18/2001	88	3	26.2	7.4	7.1	303
LS-6	07/18/2001	129	4	20.6	7.5	11.5	414
LS-6	07/18/2001	7	5.1	13.5	7	0.7	534
LSP-16	07/18/2001	115	0.5	27.5	8.7	9	299
LSP-16	07/18/2001	115	1	27.5	8.7	9	298
LSP-16	07/18/2001	111	1.9	27.5	8.6	8.7	298
LS-17	07/18/2001	106	0.5	27.5	8.3	8.3	297
LS-17	07/18/2001	106	1	27.5	8.3	8.3	297
LS-17	07/18/2001	104	2	27.2	8.2	8.3	297
LS-17	07/18/2001	99	3	25.8	7.8	8	302
LS-17	07/18/2001	129	4	18.3	7.7	12	427
LS-17	07/18/2001	3	5	12.8	6.8	0.3	520
LS-17	07/18/2001	4	6	10.4	6.8	0.4	531
LS-17	07/18/2001	4	7	9	6.8	0.5	545
LS-17	07/18/2001	4	8	8.3	6.9	0.5	575
LS-17	07/18/2001	7	9.7	7.7	7	0.8	664
LS-5	07/25/2001	117	0.5	28.7	8.8	9	308
LS-5	07/25/2001	118	1	28.5	8.8	9.1	308
LS-5	07/25/2001	118	2	28.5	8.8	9.1	307
LS-5	07/25/2001	105	3	27.1	8	8.4	309
LS-5	07/25/2001	135	4	22	7.8	11.8	421

LS-5	07/25/2001	15	5	15.6	6.7	1.5	508
LS-5	07/25/2001	2	6	11.3	6.7	0.2	530
LS-6	07/25/2001	2	7	9.4	6.8	0.2	541
LS-6	07/25/2001	3	8	8.6	6.9	0.3	562
LS-6	07/25/2001	3	9	8	7	0.3	601
LS-6	07/25/2001	2	10	7.4	7	0.3	689
LS-6	07/25/2001	4	11.2	7	6.9	0.5	1146
LS-6	07/25/2001	116	0.5	28.9	8.8	8.9	308
LSP-16	07/25/2001	114	1	28.9	8.8	8.8	308
LSP-16	07/25/2001	118	2	27.1	8.8	9.4	305
LSP-16	07/25/2001	99	3	26.9.	7.5	7.9	311
LS-17	07/25/2001	100	4	21.4	7.2	8.9	402
LS-17	07/25/2001	2	5	14.7	6.8	0.2	531
LS-17	07/25/2001	2	5.4	11.4	6.9	0.3	551
LS-17	07/25/2001	115	0.5	29	8.9	9.3	309
LS-17	07/25/2001	131	1	28.9	9	10.1	309
LS-17	07/25/2001	140	1.7	28.8	9.2	10.8	309
LS-17	07/25/2001	114	0.5	28.8	8.8	8.8	308
LS-17	07/25/2001	116	1	28.7	8.8	8.9	308
LS-17	07/25/2001	119	2	28.3	8.8	9.3	306
LS-17	07/25/2001	110	3	27.5	8.2	8.6	308
LS-5	07/31/2001	143	4	22.7	8.3	12.3	408
LS-5	07/31/2001	3	5	16.9	6.7	0.3	476
LS-5	07/31/2001	3	6	11	6.8	0.3	536
LS-5	07/31/2001	3	7	9.4	6.8	0.4	557
LS-5	07/31/2001	5	8	8.5	6.9	0.6	581
LS-5	07/31/2001	15	8.6	8.1	6.9	1.8	603
LS-5	07/31/2001	110	0.5	25.7	8.5	8.9	316
LS-6	07/31/2001	106	1	25.6	8.5	8.6	314
LS-6	07/31/2001	86	3	25.5	8	7.1	314
LS-6	07/31/2001	8	5	14.4	6.5	0.8	494
LS-6	07/31/2001	10	7	8.6	6.7	1.2	566
LS-6	07/31/2001	22	9	7.8	6.7	2.6	634
LS-6	07/31/2001	17	10.5	7.4	6.7	2.1	758
LSP-16	07/31/2001	105	0.5	25.6	8.4	8.5	316
LSP-16	07/31/2001	104	1	25.6	8.4	8.4	316
LSP-16	07/31/2001	95	2	25.5	8.3	7.7	315
LS-17	07/31/2001	80	3	25.4	7.9	6.6	316
LS-17	07/31/2001	47	4	22.8	7.1	4	317
LS-17	07/31/2001	10	5	12.7	6.9	1.1	565
LS-17	07/31/2001	105	0.5	25.6	8.4	8.5	316
LS-17	07/31/2001	104	1	25.6	8.5	8.4	315
LS-17	07/31/2001	101	2	25.6	8.3	8.2	315
LS-17	07/31/2001	105	0.5	25.6	8.5	8.5	316
LS-17	07/31/2001	102	1	25.6	8.4	8.3	315
LS-17	07/31/2001	101	2	25.6	8.3	8.2	314
LS-17	07/31/2001	75	3	24.2	8.1	6.3	315

LS-17	07/31/2001	21	4	20.8	6.9	1.9	349
LS-17	07/31/2001	5	5	14.4	6.7	0.5	516
LS-17	07/31/2001	6	6	11.5	6.7	0.7	545
LS-17	07/31/2001	12	7.2	9.6	6.8	1.3	565
LDR0022	01/10/2001	-	0	0	7.2	13.2	3060
LDR0008	01/10/2001	-	0	3.8	7.4	11.9	460
LDR0022	02/07/2001	-	0	3.9	7.1	13.2	1637
LDR0008	02/07/2001	-	0	4.6	7.5	12.3	450
LDR0022	03/21/2001	-	0	7.3	7.6	11.1	561
LDR0008	03/21/2001	-	0	7.6	7.9	11.5	528
LDR0022	04/18/2001	-	0	7.7	7.1	10.5	400
LDR0008	04/18/2001	-	0	11	7.1	8.8	500
LDR0022	05/16/2001	-	0	12.5	7.5	11.4	1048
LDR0008	05/16/2001	-	0	7.4	7.1	7.9	1840
LDR0022	06/20/2001	-	0	20.7	7.4	8.2	525
LDR0008	06/20/2001	-	0	25.3	7.2	7.4	466
LDR0022	07/25/2001	-	0	23.2	7.5	7.9	705
LDR0008	07/25/2001	-	0	14.8	7.1	7	1149
LDR0022	08/08/2001	-	0	22.4	7.4	7.3	694
LDR0008	08/08/2001	-	0	13.1	7.2	7.1	1150

Supporting Calculations for the Vollenweider Analysis

Clopper Lake Mean Depth ($\overline{Z}$):

The mean lake depth was calculated using lake volume and surface area given in the Inventory of Maryland Dams and Hydropower Resources (DNR, 1985). The cited surface area and volume of Clopper Lake are 90 acres (3,920,400 ft^2) and 1592-acre feet (69,347,520 ft^3), respectively.

Convert $feet^2$ to m^2 : 3,920,400 ft^2 x 0.0929 m^2/ft^2 = 364,217 m^2

Convert acre feet to m^3 : 1592 acre feet x 1,233.5 m^3/ acre feet = 1,963,732 m^3

The mean depth of Clopper Lake is (Volume)/(Surface Area) is computed as:

1,592 acre-ft ÷ 90acre = **17.7 ft or 5.4 m**

Current Phosphorus Loading to Clopper Lake (Lp):

The total phosphorus loading from land is 915 lb/year (414,495 g/yr), based on loading rates for agricultural and forested areas from the Chesapeake Bay Program Phase 4.3 Model, segment 220, and developed area from Montgomery County NPDES Program, calculated as follows:

Land use: *77%* developed land, *0%* agriculture, *17%* forested land
Developed land P loading rate = 0.643 lb/acre-yr
Agriculture P loading rate = 1.24 lb/acre-yr
Forested land P loading rate = 0.029 lb/acre-yr
Watershed area = 2.86 $mile^2$ = 1830 acres
P loading from developed land = 0.643 lb/acre-yr x 1830 acres x *77% = 906 lb/yr*
P loading from agriculture source = 1.24 lb/acre-yr x 1830 acres *x 0% = 0 lb/yr*
P loading from forested land = 0.029 lb/acre-yr x 1830 acres x *17% = 9 lb/yr*
Total P loading from nonpoint sources *= 906+ 0 + 9 = 915 lb/yr = 414,495 g/yr*

Using the estimated 1975 lake surface area (360,677 m^2), this value can be converted to grams per square meter per year as follows: 414,495 g/yr ÷ 364,217 m^2 = 1.14 g/m^2 yr.

Clopper Lake Hydraulic Residence Time (τ_w):

The hydraulic residence time is computed as volume/outflow; it is the time it would take to drain the lake. Hydraulic residence time is calculated based on the lake volume and discharge rate. Since discharge data are unavailable, discharge was estimated by using the equation below. The overall Clopper Lake watershed measures 2.86 mi^2; the estimated discharge is thus 5.9 cfs (4,272 acre feet/year).

FLOW ESTIMATION

To conduct a Vollenweider analysis, the discharge (Q) of a lake is needed to calculate the hydraulic residence time. In the absence of accurate discharge data from lakes, it becomes necessary to estimate this parameter.

In a homogeneous area for which ample long-term USGS gages are available, linear regression has been used to estimate an annual average daily flow. In the case of smaller or more heterogeneous areas, this may not be possible. An alternate method requiring fewer observed data is to base an estimated flow on observed data from a watershed with as similar characteristics as possible. The equation below is used:

$$Q_{sim} = Q_{obs}\left(\frac{A_{sim}}{A_{obs}}\right)^{\exp} \quad \textbf{(1)}$$

where:

Q = discharge;
A = area
obs = observed
sim = simulated
exp = exponent

For Clopper Lake, gage 01591400 (in the Patuxent) was used as the basis. This gage, located on Cattail Creek near Glenwood, MD, drains an area of 22.9 mi^2. The gage was selected on the following bases:

- The drainage area is relatively small;
- Map observation suggests a mixture of primarily agricultural, suburban and forest land, similar to the drainage of Clopper Lake;
- The period of record is current and complete.

An average annual daily discharge (Q) was computed for a twenty-year period, October 1, 1980 through September 30, 2000 (water years 1981 through 2000). An exponent of 0.7 was used. Results appear in the table below.

SITE	**AREA (mi^2)**	**Q obs (cfs)**	**Q sim (cfs)**
01591400	22.9	25.3	NA
Clopper Lake	2.86	NA	5.9
Exponent			0.7

The average discharge rate for Clopper Lake = 5.9 cfs = 4,272 acre-ft/yr
Hydraulic residence time (τ_w) is calculated as follows:

(1592 acre-feet) ÷ (4272 acre-feet per year) **= 0.37 yr.**

Ratio of Mean Depth to Hydraulic Residence Time ($\overline{Z}$ / τ_w)

From the computations above the mean depth of Clopper Lake ($\overline{Z}$) is 17.7 ft (5.4 m), and the hydraulic residence time (τ_w) is 0.37 yr. The ratio was computed as:

5.4 m / 0.37 yr = **14.6 m/yr**

Graphing of Trophic Status of Clopper Lake using the Vollenweider Relationship

The intersection of the phosphorus loading rate (L_p) = 1.14 g/m^{2}yr and the ratio ($\overline{Z}$ /τ_w) = 14.6 m/yr was plotted on log log paper to establish the trophic status of Clopper Lake (See Figure 5 in the main report and Figure A-1 below).

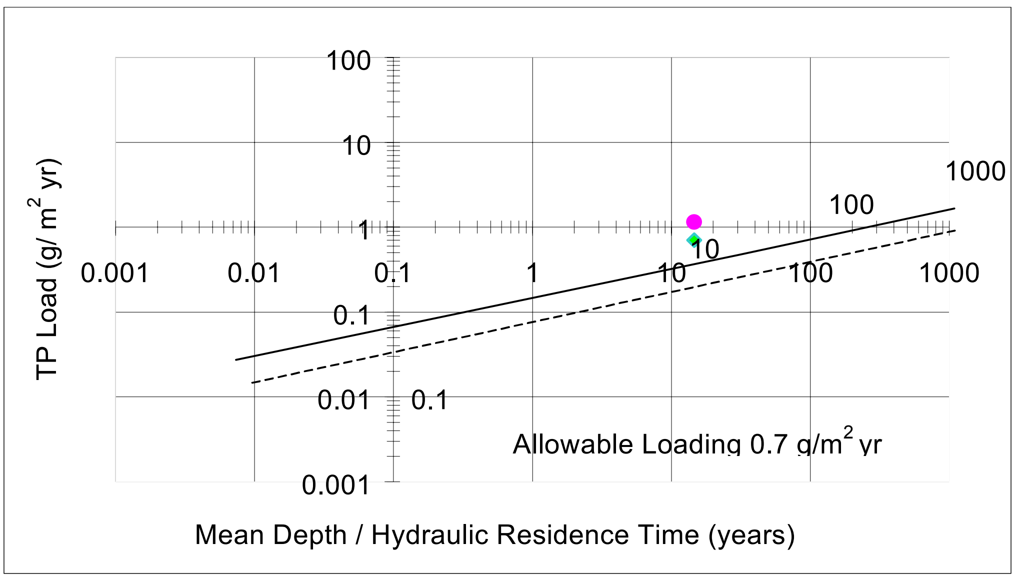


Figure A-1. Vollenweider Results for Clopper Lake

Supporting Calculations for the TMDL Analysis

Graphing of Maximum Allowable Unit Phosphorus loading of Clopper Lake using the Vollenweider Relationship

Figure 5 of the report (reproduced here as Figure A-1) shows how the maximum allowable unit phosphorus loading can be read off of the log log paper. A point represented by a diamond "♦" represents the maximum allowable load, which includes the load allocation and the margin of safety (0.7g/m^2yr).

Computing the Phosphorus TMDL

The TMDL is computed from the maximum unit load read from "♦" on Figure 5:

(Unit loading) x (Lake Surface Area) = Annual Loading
(0.7 g/m^2yr) x (360,677 m^2) = 252,474 g/*yr*

Converted to pounds per year:
(252,474 g/yr) x (0.0022 lb/g) = 555 lb/yr

Computing the Phosphorus Margin of Safety

The Margin of Safety is computed as 10% of the total allowable unit loading:

0.10 x (Total allowable loading) = (0.10) x (555 lb/yr) = 55.5 lb/yr

Computing the Percentage Phosphorus Reduction

The necessary reduction in phosphorus loads, as a percentage of the current estimated load was computed as follows:

$$\frac{\text{(current load)} - \text{(allowable load*)}}{\text{(current load)}} =$$

$$\frac{(915 \text{ lb/yr}) - (499.5 \text{ lb/yr})}{(915 \text{ lb/yr})} = 45\ \%\ \text{reduction}$$

* The allowable load does not include the margin of safety.

Supporting Determination of the Expected Minimum DO Below Epilimnion

As noted in the main body of this document, DO concentration in the surface waters currently meets State standards. The following analysis provides a linkage between the maximum allowable phosphorus load, as specified by the Vollenweider Relationship, and the assurance of meeting DO criteria in the lake's sub-epilimnetic waters.

During periods of thermal stratification in a lake, DO concentration below the epilimnion is largely determined by the relationship between trophic status and the saturation potential of oxygen. Because DO concentration is a function of temperature, the minimum allowable DO concentration cannot be specified *per se*, but can be determined graphically by reading the expected DO concentration at a specified percent saturation from a published nomogram.

Chapra (1997) presents ranges of hypolimnetic DO saturation as a function of trophic status in eutrophic, mesotrophic and oligotrophic lakes (Table A-5). MDE (1999) has adapted and extended this methodology to apply to the two additional trophic categories—oligo-mesotrophic and meso-eutrophic—used to classify Maryland's lakes (Table A-6).

Table A-5

Relationship between Lake Trophic Status and Dissolved Oxygen Saturation in the Hypolimnion of a Thermally Stratified Lake

Trophic Status	Hypolimnetic Dissolved Oxygen Saturation
Eutrophic	0% - 10%
Mesotrophic	10% - 80%
Oligotrophic	80% - 100%

Adapted from Chapra (1997)

Table A-6

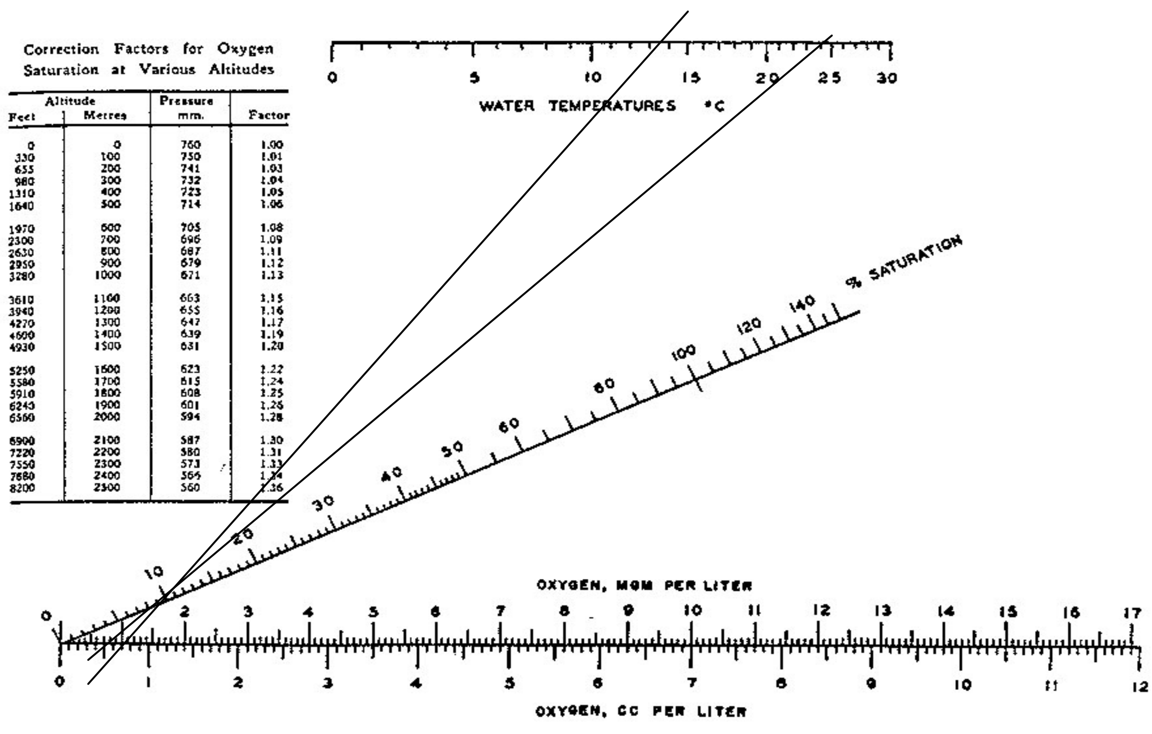
Extended Relationship between Lake Trophic Status and Dissolved Oxygen Saturation in the Sub-Epilimnetic Waters of a Thermally Stratified Lake

Trophic Status	Minimum Hypolimnetic Dissolved Oxygen Saturation
Eutrophic	0%
Meso-eutrophic	10%
Mesotrophic	33%
Oligo-mesotrophic	56%
Oligotrophic	80%

MDE is establishing a phosphorus TMDL to manage the Clopper Lake at a meso-eutrophic status. Current phosphorus loading estimates place Clopper Lake slightly in the eutrophic status category. As phosphorus reductions result in a shift to a meso-eutrophic status, it is predicted that the DO saturation will increase to 10% in the waters below the epilimnion, as indicated in Table A-5. This increased saturation is consistent with interim interpretation of Maryland's water quality criterion for dissolved oxygen in thermally stratified lakes (MDE, 1999).

Because DO concentration is a function of water temperature, a single expected DO concentration cannot be predicted. However, the nomogram in Figure A-2 may be used to determine a range of dissolved oxygen concentrations expected to result as phosphorus loads are reduced. This is demonstrated below using temperatures observed in the deeper waters of Clopper Lake during critical summertime conditions.

Specifically, two line segments have been drawn from the ends of the observed range of temperatures (13– 25 °C), through the point at 10% on the diagonal scale for DO saturation. These two line segments intersect the lower horizontal scale indicating an expected DO concentration ranging from 0.5 – 0.7 mg/l. This range reflects an increase over the current minimum observed DO concentration of 0.1 mg/l, and reflects the DO endpoint expected to result from the TMDL. This increased sub-epilimnetic DO concentration is consistent with the interim interpretation of Maryland's water quality criterion for dissolved oxygen in thermally stratified lakes (MDE, 1999).



Correction Factors for Oxygen Saturation at Various Altitudes

Altitude Feet	Altitude Metres	Pressure mm.	Factor
0	0	760	1.00
330	100	750	1.01
655	200	741	1.03
980	300	732	1.04
1310	400	723	1.05
1640	500	714	1.06
1970	600	705	1.08
2300	700	696	1.09
2630	800	687	1.11
2950	900	679	1.12
3280	1000	671	1.13
3610	1100	663	1.15
3940	1200	655	1.16
4270	1300	647	1.17
4600	1400	639	1.19
4930	1500	631	1.20
5250	1600	623	1.22
5580	1700	615	1.24
5910	1800	608	1.25
6240	1900	601	1.26
6560	2000	594	1.28
6900	2100	587	1.30
7220	2200	580	1.31
7550	2300	573	1.33
7880	2400	565	1.34
8200	2300	560	1.36

Figure A-2. Nomogram (adapted from Reid 1961) showing expected sub-epilimnetic DO concentrations at ambient temperatures in Clopper Lake during periods of stratification.

Estimating the Sediment TMDL

Sediment loading coefficients for developed land suggest that current sedimentation to the lake is minimal. The construction phase in the Clopper Lake watershed is largely complete (K. van Ness, Montgomery County DEP, pers. comm., 2001). Thus, sedimentation in the lake is currently not a problem, with the volumetric loss caused by sedimentation having occurred largely during the construction phase.

The existing sediment loads for Clopper Lake are: Forest= 12 tons/yr; Developed land = 117 tons/yr; and Agricultural source = 0 tons/yr.

Total sediment load = forest source + developed land source + agricultural source
= 12 + 117 + 0 = 129 tons/yr

TMDL for sediments = Total sediment load – sediment load reduction
= 129 – 0 = 129 tons/year allowable sediment load

Estimation of Volumetric Preservation of Clopper Lake

No bathymetric studies have been performed to establish volume loss due to sedimentation in Clopper Lake. Since sedimentation rates (based on land use coefficients) are available, these were used to derive a range of probable volume losses due to sedimentation.

The literature was consulted to examine volume-weight measurements obtained from impoundments throughout the U.S. (USDA/SCS 1978). The cited volume-weights (for continually submerged sediments) range from 31.6 lb/ft^3 to 59.9 lb/ft^3. Clopper Lake is smaller and shallower than impoundments typically used for public water supply (as are those cited), with presumably stiller waters and greater settling of fine particles. For this reason, it is likely that the volume-weight of sediments in Clopper Lake is toward the lower end of the range.

Lower volume-weights result in a greater loss in impoundment volume from a sediment load of a specified weight. To ensure an environmentally conservative estimate, a range of low volume-weights (10 to 25 lb/ft^3) is used. With an annual allowable sediment load of 129 tons, this range results in an annual volume loss of 0.26 acre-feet (@ 25 lb/ft^3) to 0.65 acre-feet (@ 10 lb/ft^3). Table A8 below expresses these annual losses in terms of preservation of the lake’s volume (1592 acre-ft) over time.

Table A8

Expected preserved volume for Clopper Lake, assuming a sediment volume-weight ranging from 10.0 to 25.0 lb/ft^3.

Time Period	Range Of Volumetric Preservation
50 Years	98% to 99%
100 Years	96% to 98%
200 Years	92% to 97%