Total Maximum Daily Loads of Phosphorus and Sediments for Lake Linganore, Frederick County, MD

FINAL

Prepared by:

Maryland Department of the Environment
Montgomery Park Business Center
1800 Washington Boulevard, Suite 540
Baltimore, MD 21230-1718

Submitted to:

U.S. Environmental Protection Agency, Region III
Water Protection Division
1650 Arch Street
Philadelphia, PA 19103-2029

December 2002

Submittal: December 30, 2002
Approval: May 13, 2003
Document version: December 24, 2002

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BMP	Best Management Practice
CBOD	Carbonaceous Biochemical Oxygen Demand
CBPO	EPA Chesapeake Bay Program Office
cfs	Cubic Feet per Second
Chl	Chlorophyll a
COMAR	Code of Maryland Regulation
CWA	Clean Water Act
CWAP	Clean Water Action Plan
DNR	Department of Natural Resources
DO	Dissolved Oxygen
D_s	Secchi Depth
EPA	Environmental Protection Agency
GPD	Gallons per day
g/yr	Gram per year
K_e	Extinction Coefficient
km	Kilometers
LA	Load Allocation
lbs/month	Pounds Per Month
lbs/yr	Pounds Per Year
LILAC	Low Income Loans for Agricultural Conservation
m	Meters
M/year	Meters Per Year
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
NMP	Nutrient Management Practice
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
SD	Secchi Depth
SCWQP	Soil Conservation Water Quality Plans
SOD	Sediment Oxygen Demand
T	Temperature
TMDL	Total Maximum Daily Load
TKN	Total Kjeldahl Nitrogen
TSI	Carlson's Trophic State Index

TSS	Total Suspended Solids
µg/l	Micrograms Per Liter
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
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

The Lower Monocacy River watershed (02-14-03-02) was identified on Maryland's 1996 list of water quality limited segments (WQLSs) as being impaired by nutrients and sediments. Recent data indicate that the Lake Linganore watershed, within this watershed, is impacted by nutrients and sediment. This document establishes Total Maximum Daily Loads (TMDLs) for the nutrient phosphorus and sediments entering Lake Linganore. The TMDLs described in this document were developed to address localized water quality impairments within the Lake Linganore watershed; the nutrient and sediment impairments within other parts of the Lower Monocacy River watershed will be addressed at a later date.

Lake Linganore is an impoundment located within Eagle Head development, near the city of Frederick in Frederick County, Maryland. The impoundment lies on Linganore Creek, a tributary of the Monocacy River. Linganore Creek lies in the Lower Monocacy River Drainage Basin. Lake Linganore was constructed for water supply and recreation.

Lake Linganore is impacted by a high sediment load. The lake also experiences frequent nuisance seasonal algal blooms, due to overenrichment by nutrients, which interfere with water supply and recreational uses. The death and decay of excessive algae can cause violations of the water quality standard for dissolved oxygen (DO), possibly resulting 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 Lake Linganore. 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 Lake Linganore. This reduced loading rate is predicted to resolve excess algal 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 5,288 lbs/yr. There is one point source in the Lake Linganore basin. Consequently, the allocation is partitioned between nonpoint sources, the point source and the margin of safety. For sediments, the TMDL is established to achieve a 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 48% - 79% of the lake's design volume over a period of 40 years.

Preliminary estimations of the phosphorus controls necessary to achieve the load reduction were conducted to provide reasonable assurance that the TMDL could be implemented. Based on an initial assessment of current loadings, which may be refined as better data become available, it is

estimated that a 90% reduction in phosphorus loads would be necessary to meet the TMDL for phosphorus.

1.0 INTRODUCTION

Section 303(d) of the federal Clean Water Act (CWA) and U.S. Environmental Protection Agency's (EPA) implementing regulations direct each State to develop Total Maximum Daily Loads (TMDLs) for all impaired waters on the State's 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. Pursuant to 40 CFR 130.2(i), a TMDL can be expressed in mass per time, toxicity, or any other appropriate measure. TMDLs must take into account seasonal variations and a margin of safety (MOS) to allow for uncertainty. Maryland's 1996 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), lists the Lower Monocacy River for nutrients and sediments. Recent data indicate that the Lake Linganore watershed, within this watershed, is impacted by nutrients and sediment. This document establishes TMDLs for the nutrient phosphorus and sediments entering Lake Linganore. The TMDLs described in this document were developed to address localized water quality impairments within the Lake Linganore watershed; the nutrient and sediment impairments within other parts of the Lower Monocacy River watershed will be addressed at a later date.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Lake Linganore is an impoundment located near Frederick in Frederick County, Maryland (Figure 1). The impoundment, which is owned by the Lake Linganore Association, lies on Linganore Creek, a tributary of the Monocacy River. An earthen dam was installed in 1972 to create the lake for the purpose of water supply and for recreational use.

Lake Linganore lies in the Piedmont physiographic province. The soils immediately surrounding the lake are the Manor-Linganore-Montalto association (USDA: Soil Conservation Service, 1960). The Montalto soils are deep, well drained, and fine textured while the Manor and Linganore are generally shallow to very shallow, excessively drained, immature, or skeletal. They form in material weathered from schistose, schist or phyllite and igneous rocks. The outer watershed area is comprised of soils of the Duffield-Hagerstown association. These soils are well drained soils developed from limestone.

Inflow to the lake is primarily via Bens Branch and Linganore Creek. Discharge from the lake is to Linganore Creek, which discharges to the Monocacy River. The watershed map (Figure 2) shows that land use in the watershed draining to Lake Linganore is predominantly agricultural. Land use distribution in the watershed is approximately 16% developed, 28% forested and other herbaceous, <1% open water, and 56% agricultural (Figure 3) (Maryland Department of Planning, 2000).

Frederick County, the City of Frederick and Lake Linganore Association, Inc. executed an agreement on December 14, 2000 approving the provision to authorize the release of up to 10.46

million gallons per day (MGD) from Lake Linganore for the purpose of drinking water supply (MDE, 2000).

Lake Linganore Association members have expressed concerns that the lake's watershed is not adequately protected. Meetings with plant operators and Lake Linganore Association officials were held to discuss concerns regarding the potential or known sources of contamination to the source water. Issues raised include sewer line placement, sedimentation, geese activities, nonpoint source pollution and development within the watershed. Full details are contained in the source water assessment report (MDE, 2000).

Chesapeake Bay Program data were used to estimate the current nonpoint source loads, 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 Libertytown Wastewater Treatment Plant (WWTP) is the only point source contribution within the watershed. This facility, National Pollutant Discharge Elimination System (NPDES) Permit MD0060577, is operated by Frederick County Division of Utilities and Solid Waste Management. Treated effluent is discharged into Town Branch, in the upper reaches of Linganore Creek. The Libertytown service area is approximately 0.5 square miles, encompassing the unincorporated community of Libertytown located at the intersection of Maryland Routes 26 and 75. The community has a current population of 526. The Libertytown WWTP was built by the County in 1986 with a capacity of 50,000 gallons per day (GPD). It treats an average flow of 30,000 GPD. The population of Libertytown is projected to be 1,050 by the year 2010. The wastewater plant will need to be expanded to 100,000 GPD to meet the projected population growth by 2010. The phosphorus load from the Libertytown WWTP is only about 0.5% that of the agricultural land in the watershed (see Appendix A).

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

Table 1: Current Physical Characteristics of Lake Linganore

Location:	Frederick County, MD lat. 39° 25' 10"N long. 77° 20' 20"W
Surface Area:	220 acres = (9,583,200 ft^2) = (890,308 m^2)
Average Lake Depth:	12.3 feet
Purpose	Recreation and Water Supply
Basin Code	02-14-03-02
Volume of Lake:	2,700 acre-feet
Drainage Area to Lake:	81.1 mi^2 (51,904 acres)
Average Discharge:	83.8 cfs

Source: Inventory of Maryland Dams and Hydropower Resources (DNR, 1999).

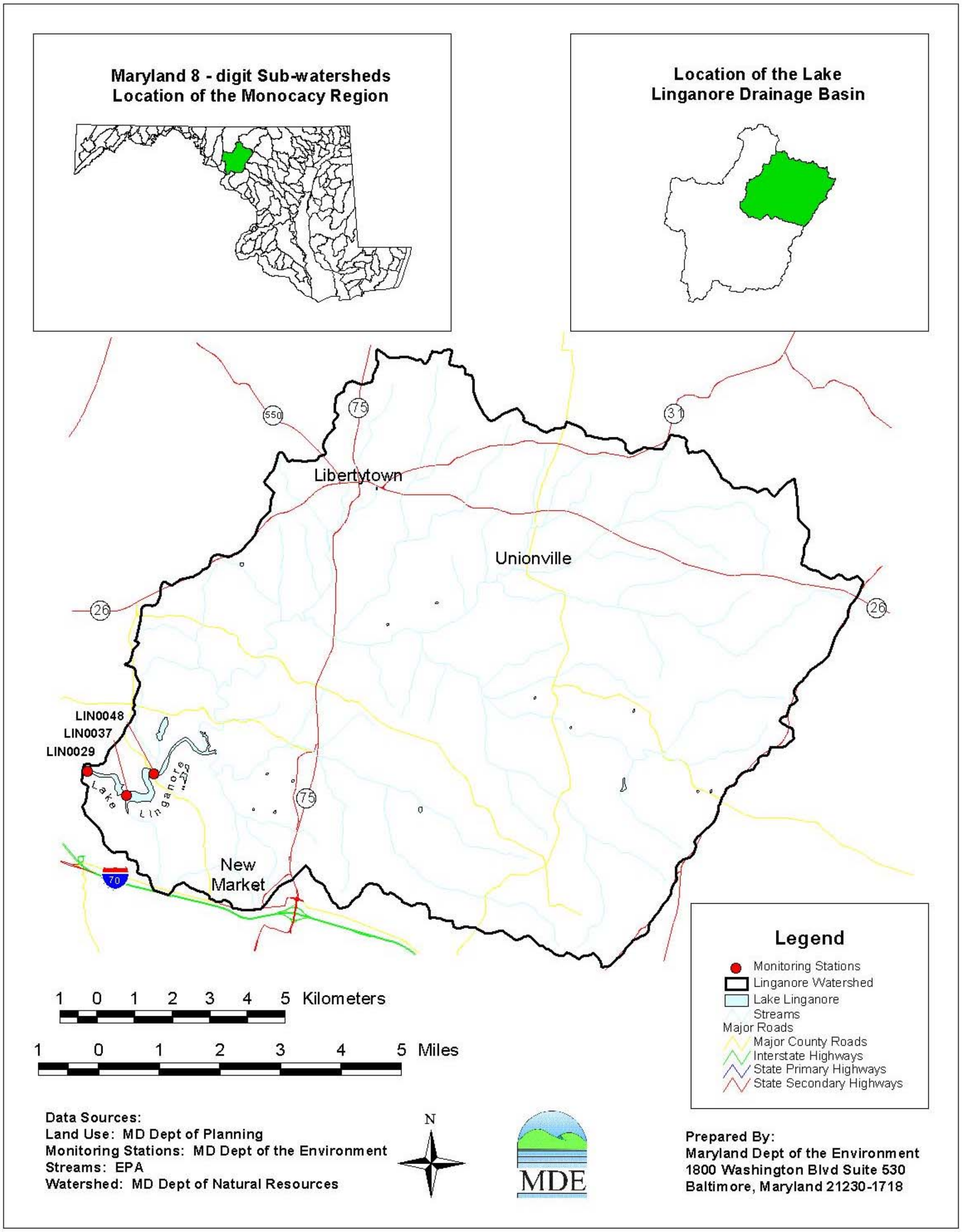
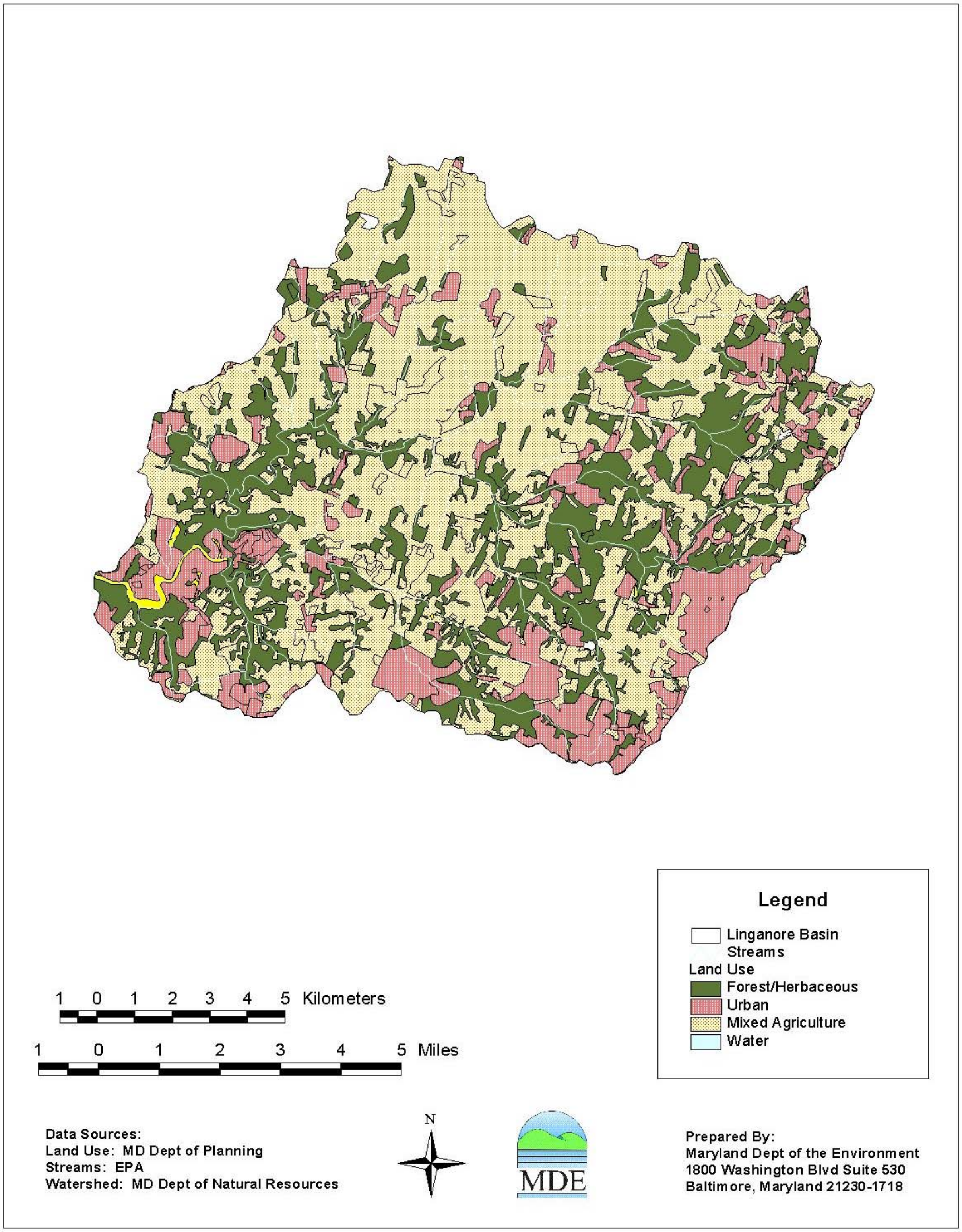


Figure 1: Location Map of Lake Linganore in Frederick County, MD



Data Sources:
Land Use: MD Dept of Planning
Streams: EPA
Watershed: MD Dept of Natural Resources

Prepared By:
Maryland Dept of the Environment
1800 Washington Blvd Suite 530
Baltimore, Maryland 21230-1718

Figure 2: Predominant Land Use in the Lake Linganore Watershed

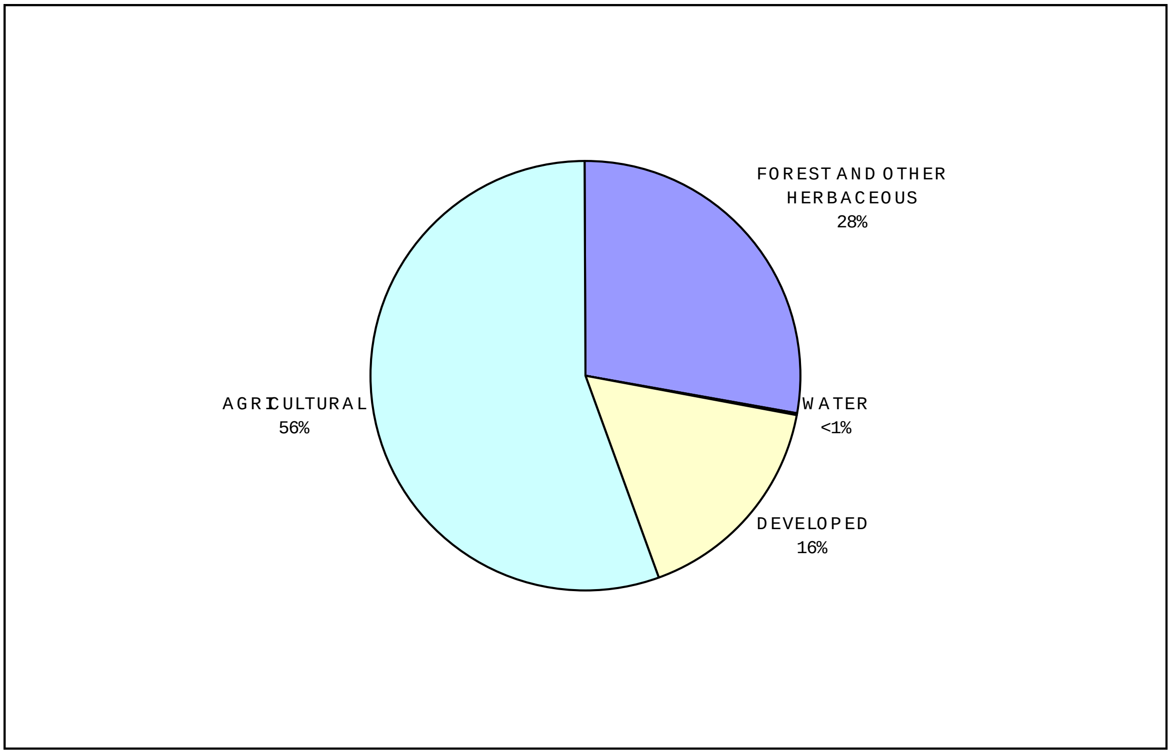


Figure 3: Land Use in Drainage Basin of Lake Linganore

2.2 Water Quality Characterization

Monitoring data collected on February 19, March 7, March 19, April 2, April 16 and April 30 of 2002 were used for this TMDL. Water samples were collected from a vertical profile of the water column. Samples were analyzed by the Chesapeake Biological Laboratory for total phosphorus, soluble orthophosphorus, nitrate and nitrite N, total Kjeldahl nitrogen (TKN), and total nitrogen. Maryland Department of Health and Mental Hygiene conducted analyses of chlorophyll *a*. Physical measurements of depths, water temperatures, pH, conductivity and dissolved oxygen (DO) 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.

A chlorophyll *a* concentration of 10 µg/l is typically associated with the boundary between eutrophic and mesotrophic states of a lake (Chapra, 1997). Instantaneous chlorophyll *a* concentrations ranging from 0.84 to 101.6 µg/l were observed in Lake Linganore during February – April sampling events. The maximum observed values in Lake Linganore, though associated with eutrophic conditions, are not extreme when compared to peak concentration of 275 µg/l in hyper-eutrophic lakes (Olem and Flock, 1990).

DO concentrations ranged from 0.4 to over 13.1 mg/l along the vertical profile. Oxygen depletion occurs discontinuously, beginning at a depth of about 4 m during the April 30 sampling event. Total phosphorus concentrations ranged from 0.025 mg/l to 0.14 mg/l. Total nitrogen ranged from 1.7 to 3.4 mg/l in Lake Linganore.

Water temperatures taken during the February – April 2002 sampling periods ranged from 1.4°C to 20.5°C. Thermal stratification is expected to become apparent when the results of subsequent sampling cruises become available.

2.3 Water Quality Impairment

Lake Linganore, an impoundment on a tributary of the Linganore Creek near Frederick, has been designated a Use IV-P water body, pursuant to which it is protected for recreational trout and public water supply. See Code of Maryland Regulations (COMAR) 26.08.02.02B(7). Use IV waters are subject to a DO criterion of not less than 5.0 mg/l at any time (COMAR 26.08.02.03-3G(1)) unless natural conditions result in lower levels of DO (COMAR 26.08.02.03G(1)). The DO concentration in Lake Linganore occasionally falls below 5.0 mg/l in the deeper portion of the lake.

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 26.08.02.03G(1). 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. The excess algal blooms eventually die off and decompose, consuming oxygen, resulting in violations of the DO and general water quality standards in Lake Linganore. Excessive eutrophication in Lake Linganore is ultimately caused by nutrient overenrichment, most likely phosphorus. Finally, in conjunction with excessive nutrients, Lake Linganore has experienced excessive sediment loads, resulting in a significantly shortened projected lifespan of the lake.

The water quality impairments of Lake Linganore addressed by these TMDLs consist of violations of the applicable numeric DO criterion and general water quality criteria. DO violations are observed only in the hypolimnion.

During the April 30, 2002 sampling event, DO concentrations as high as 9.7 mg/l were observed at the surface (1 meter depth) of Lake Linganore, with DO values as low as 0.4 mg/l at a depth of 7 m. This depth/DO profile indicates that hypolimnetic hypoxia begins as early as April. A chlorophyll *a* concentration of 101.6 μg/l was observed in the lake on April 2, 2002, with numerous measurements in excess of 10 μg/l observed during the 2002 sampling events.

3.0 TARGETED WATER QUALITY GOALS

Lake Linganore is classified as Use IV-P— *recreational trout water and public water supply*. The chlorophyll *a* endpoint selected for Lake Linganore is a maximum concentration of 10 μg/l, or approximately 53 on the Carlson's Trophic State Index (TSI). This is at the boundary of mesotrophy and eutrophy, which is an appropriate trophic state at which to manage this impoundment, and should avoid nuisance algal blooms and excessive aquatic macrophyte growth.

Lake Linganore 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).

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 IV-P designation. Reduction of the phosphorus load is predicted to reduce excessive algal growth, preventing violations of the numeric DO criteria and the violation of various narrative criteria associated with nuisances (*i.e.*, taste, odors and physical impedance of direct contact use). In summary, the TMDLs for phosphorus and sediment are intended to:

1. Assure that the following DO concentrations are maintained in the epilimnion and the deeper waters of Lake Linganore:

   (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 Lake Linganore, leading to excessive algal growth;

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

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 Lake Linganore. The second subsection describes the analysis for determining that phosphorus is likely to be the limiting nutrient in Lake Linganore, 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

Lake Linganore 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 relationship between a lake's phosphorus loading and the ratio of the lake's mean depth to hydraulic residence time (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 was developed by Carlson (1977). Carlson's 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):

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

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 TSI constitute sufficient, readily available tools.

Nitrogen and phosphorus are essential nutrients for algal 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, 2002), which supports the use of the Vollenweider Relationship. Supporting data are provided in Appendix A.

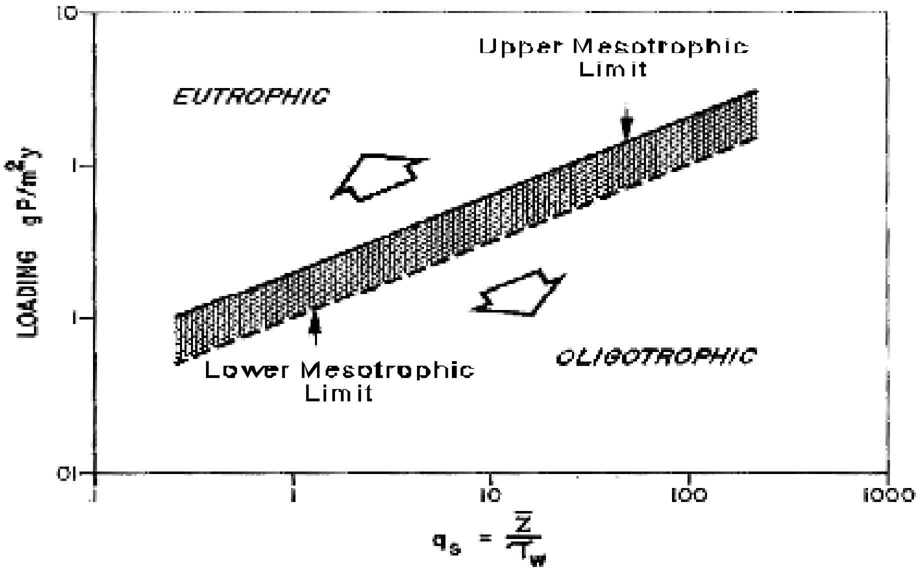


Figure 4. Vollenweider Relationship

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.

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

The application of the Vollenweider Relationship assumes the lake's physical dimensions when the lake and dam were constructed in 1972. The mean lake depth was calculated using lake volume and surface area given in the Inventory of Maryland Dams [Department of Natural Resources (DNR), 1999]. The cited surface area and volume of Lake Linganore are 220 acres (9,583,200 ft^2) and 2,700 acre feet (117,612,000 ft^3), respectively.

The mean depth was thus calculated as follows:

- ***Lake Linganore Mean Depth ($\overline{Z}$): (Volume)/(Surface Area) = 12.3 ft or 3.7 m***

Phosphorus Loading to Lake Linganore (Lp):

The current estimated total phosphorus loading is 51,129 lbs/year (or 23,192,265 g/year) based on loading coefficients from the Chesapeake Bay Program (Phase 4.3 Watershed Model, Segment 210, for agricultural, urban and forested areas) and permitted point source contributions. Expressing this value as a loading per surface area of the lake gives:

- ***Annual Phosphorus Load (L_p) is: 26.0g/m^2 yr***. Details are provided in Appendix A.

Lake Linganore Hydraulic Residence Time (τ_W)

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

- **Flow (Q) = 83.8 cfs = 60,668 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 2,700 acre feet from above, and a discharge rate of 61,537 acre-feet per year (DNR, 1999) the hydraulic residence time is calculated as follows:

- **2,700 acre feet ÷ 60,668 acre feet/year = 0.04 years**

- ***Lake Linganore Hydraulic Residence Time (τ_w): 0.04 years = 14.6 days***

The mean depth of the lake (3.7 m) is then divided by hydraulic residence time (0.04 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 Lake Linganore, **q_s = 92.5 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 Lake Linganore, and the maximum allowable unit loading. The current trophic status associated with a loading of 26.0 g/m^{2}yr falls into the eutrophic range, as indicated on Figure 5 by a circle "●". The maximum allowable unit loading of 2.7 g/m^2 yr corresponds to an estimated chlorophyll *a* level of 10 µg/l associated with a TSI of 53 for a lake with mean depth of 3.7 m and hydraulic residence time of 0.04 years is indicated by "♦". The TMDL implications are presented below in Section 4.5.

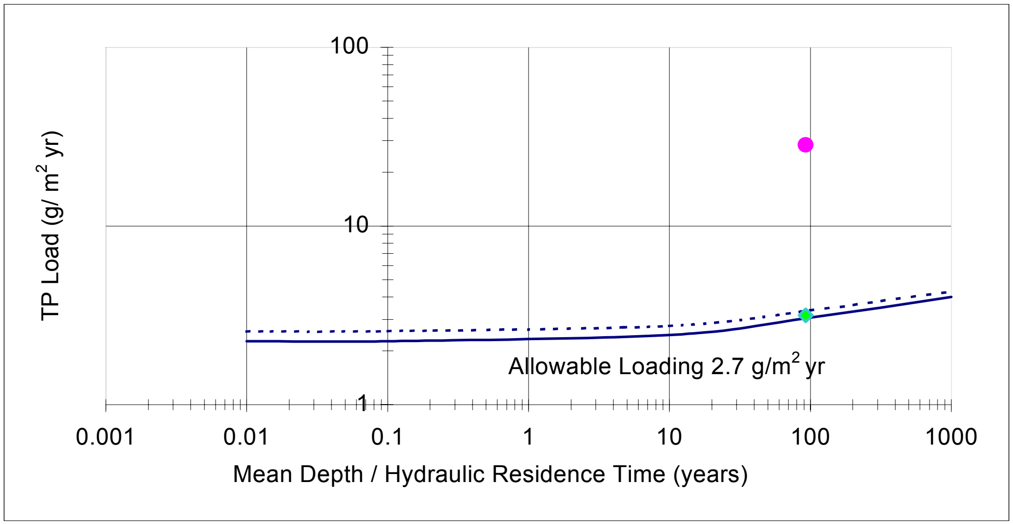


Figure 5: Vollenweider Results for Lake Linganore

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 drinking water and recreational uses and avoid nuisance algal blooms, is a maximum TSI of 53, which is approximately at the boundary between mesotrophy and eutrophy. A TSI of 53 corresponds to a maximum chlorophyll *a* concentration of 10 µg/l and a loading rate of 5,288 lbs/yr. Based on an assessment of current loadings, which may be refined as better data become available, this represents a 90% 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 Lake Linganore is currently within State standards (see Tables A1 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).

According to calculations presented in Appendix A, it is expected that an areal phosphorus load of 2.7 g/m^2 yr will result in an increase of minimum hypolimnetic DO from the observed levels to concentrations of about 0.5 – 0.7 mg/l at a minimum. 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.

No single critical period can be defined for the water quality impact of sedimentation. An excessive sedimentation rate negatively impacts a lake regardless of when it occurs. The maximum sediment loading rate occurs during wet-weather events. 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 (Ag. 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 (CBPO), 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 reductions 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 90% NPS phosphorus reduction is about 45% (0.90 * 0.5 = 0.45). 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 35% - 74% of the impoundment's volume after 50 years. MDE believes that this volumetric retention will support the designated use of Lake Linganore (Use IV-P) for which it is protected for recreational trout and public water supply. (See Appendix A for further details concerning this estimate). 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. This rule-of-thumb would yield a 63% estimated reduction in sediment [100*(0.7 * 0.90) = 63%]

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

PHOSPHORUS TMDL **2,403,832 g/yr = 5,288 lbs/yr**

SEDIMENT TMDL **7,073 tons/yr**

4.6 TMDL Allocation

The watershed that drains to Lake Linganore contains one permitted point source discharge with a negligible phosphorus contribution compared with nonpoint loads (about 0.5%); thus, no reduction is required of the point source. The model uses Chesapeake Bay Program, Phase 4.3 phosphorus loading coefficients to estimate the loading rates from agricultural, developed and forested areas, which represent the cumulative impact from all sources—naturally-occurring and human-induced. The allocations described in this section demonstrate how the TMDL can be implemented to achieve water quality standards in Lake Linganore. Specifically, these allocations show the sum of phosphorus loadings to Lake Linganore from existing point and nonpoint sources can be maintained safely within the TMDL established here. These allocations demonstrate how this TMDL could be implemented to achieve water quality standards; however, the State reserves the right to revise these allocations provided the allocations are consistant with the achievement of the water quality standard. Details are described in the attached technical memorandum entitled “Significant Phosphorus Point and Nonpoint Sources in the Lake Linganore Watershed”. The nonpoint source and point source phosphorus allocations for average annual conditions are shown in Table 2.

Table 2: Average Annual Phosphorus Allocations

	Total Phosphorus (lbs/yr)
Nonpoint Source	4,150
Point Source	609

Under TMDL conditions, the point source will contribute a negligible amount of TSS—about 4.5 tons/yr, which is approximately 0.04% of the nonpoint contribution. This is believed to be insignificant; nevertheless, a nominal allocation of 1% (about 707 tons/yr) has been made to the point source.

Table 3: Average Annual Sediment Allocations

	Total Solids (tons/yr)
Nonpoint Source	6,346
Point Source[1]	707

---

[1] MDE recognizes that this nominal allocation exceeds the likely solids discharge of this facility at any time in the future. The allocation does not imply a future permitting allowance. Permitting decisions will consider the impact of discharge to the local portion of Linganore Creek as well as to Lake Linganore.

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 = waste load allocation (WLA) + load allocation (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 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 10% 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, MDE conservatively assumes a sediment-to-phosphorus reduction ratio of 0.5:1, rather than 0.7:1. Table 4 (below) compares the volumetric preservation under TMDL conditions in Lake Linganore with that of several other approved TMDLs.

Table 4: 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)	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%

4.8 Summary of Total Maximum Daily Loads

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

TMDL	=	**WLA**	+	**LA**	+	**MOS**
5,288	=	**609**	+	**4,150**	+	**529**

On average, this TMDL represents a daily phosphorus load of 13 lbs/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**
7,073	=	**707**	+	**6,346**	+	**Implicit**

On average, this TMDL represents a daily sediment load of 19 tons/day.

5.0 ASSURANCE OF IMPLEMENTATION

Lake Linganore is located in a watershed in which the impairment is due largely 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. This section provides the basis for reasonable assurances that the phosphorus TMDL will be achieved and maintained. Maryland has several well-established programs to draw upon: the Water Quality Improvement Act of 1998 (WQIA), the Clean Water Action Plan (CWAP), and the State's Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction. Also, Maryland has adopted procedures to ensure that future evaluations are conducted for all TMDLs that are established.

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 phosphorus management plans be developed by December 2001 and be implemented by December 2002 if chemical fertilizer is used, and by 2004-2005 for those who use manure or organic sources (COMAR Title 15 Maryland Department of Agriculture Subtitle 20 Soil and Water Conservation: 15.20.07.04). In addition to nutrient management plans, Maryland’s Agricultural Cost Share Program (MACS) has been developed to address potential pollution problems from agriculture and is available to fund Best Management Practices (BMPs) in this watershed; and Low Income Loans for Agricultural Conservation (LILAC) program provides loans for projects.

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.

Maryland’s Tributary Strategies have already established a voluntary program and an institutional framework in which to advance the goals of this TMDL. The findings of the TMDL analysis indicate that the implementation of the TMDL on the basis of external loading controls would require a 90% reduction of external phosphorus loadings. This challenging goal can be put into perspective in two regards. First, the percentage of nutrient reduction associated with standard agricultural BMPs is greatest for easily erodible soils present in the Lake Linganore drainage basin. Second, if this goal is an overestimation of the necessary load reductions, it can be refined using better data and analysis tools, while initial steps are taken to reduce the loads (See Table A8).

A watershed plan entitled “Watershed Plan-Environmental Assessment for Linganore Creek” was developed in August 1989 by the U.S. Department of Agriculture Soil Conservation Service to address water quality, sediment damage reduction and soil resource protection. The recommendations presented in that report provide an additional foundation upon which to implement this TMDL.

The sedimentation reduction goal is reasonable and implementable. A number of best management practices—both structural and non-structural—can significantly reduce sediment loads. For instance, maintained vegetated buffer strips along stream channels have been shown to capture a significant amount of sediment and dissipate the energy of the surface runoff during storm events. The vegetation also helps to reduce stream bank erosion. Recent estimates of the trap efficiency of buffer strips range from 70% to 90% (Qui and Prato, 1998).

Finally 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.

REFERENCES

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

Carlson, R.E., and J. Simpson. 1996. A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society and the Educational Foundation of America.

Chapra, Steven C. Surface Water Quality Modeling. McGraw – Hill, 1997.

Chianudani, G. and M. Vighi, "The N:P Ratio and Tests with Selanastrum to Predict Eutrophication in Lakes," Water Research, Vol. 8, pp 1063-1069. 1974.

Code of Federal Regulations, 40 CFR 130.7(c)(1), 40 CFR 132.2(1).

Code of Maryland Regulations, 26.08.02, 26.08.03.

Maryland State, "Technical Appendix for Maryland's Tributary Strategies," National Atmospheric Deposition Program (IR-7) National Trends Network. (1989) NAPD/NTN Coordination Office, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO., March 12, 1996.

Maryland Department of the Environment, Maryland Lake Water Quality Assessment, 1991 Final Report, 1995.

Maryland Department of the Environment, Source Water Assessment Report, 2000.

Maryland Department of the Environment, Maryland Department of Natural Resources, Maryland Department of Agriculture, Maryland Office of State Planning, Maryland's Governor's Office, University of Maryland, "Tributary Strategy for Nutrient Reduction in Maryland's Upper Eastern Shore Watershed," May, 1995.

Maryland Department of Natural Resources, Inventory of Dams and Hydropower Resources, 1999.

Maryland Department of Natural Resources, Maryland Lake Water Assessment Report, March 1998.

Maryland Department of Planning, 2000 Land Use Data.

Moore, I. and K. Thornton, (Ed.) Lake and Reservoir Restoration Guidance Manual USEPA, EPA 440/5-88-002, 1988.

Olem, H. and G. Flock. Editors. Lake and Reservoir Restoration Guidance Manual. 2nd Edition. EPA 440/4-90-006. Prepared by N. Am. Lake Management Society for U.S. Environmental Protection Agency, Washington, D.C. 1990.

Qui, Z. and T. Prato, "Economic Evaluation of Riparian Buffers in an Agricultural Watershed," Journal of the American Water Resources Association, 34:4, pp. 877-890, 1998.

Thomann, R. V. and J. A. Mueller. Principles of Surface Water Quality Modeling and Control. Harper Collins, Inc., New York, 1987.

U.S. Department of Agriculture, Soil Conservation Service, Soil Survey of Frederick County, Maryland, September, 1960.

U.S. Department of Agriculture, Soil Conservation Service, Watershed Plan-Environmental Assessment for Linganore Creek, August 1989.

U.S. EPA, "Water Quality Assessment: A Screening Method for Nondesignated 208 Areas," Office of Research and Development, Athens Georgia, EPA/600/9-77-023, August 1977.

U.S. EPA, "Technical Support Document for Water Quality-based toxics Control," OW/OWEP and OWRS, Washington, D.C., April 23, 1991.

U.S. EPA, Chesapeake Bay Program Office, Table H.2.2, Chesapeake Bay Watershed Model BMP Matrix with Associated Nutrient Reduction Efficiencies, provided by Bill Brown, CBPO, Oct. 1998.

Vollenweider, R.A., "Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication," Technical Report to OECD, Paris, France, 1968.

Zison, S. W., K. F. Haven, W. B. Mills, and Tetra Tech Inc. "Water Quality Assessment, A Screening Method for Nondesignated 208 Area", Environmental Research Laboratory, Grant identification number. EPA-600, pp.340-42, 1977.

Appendix A

Lake Linganore Water Quality

Data collected from February 19 through April 30, 2002 were used in this TMDL analysis. A summary of the water quality data was provided in the main body of this report. Table A1 through Table A3 provide data available as of August 2002, from which the summaries were derived.

Assessment of the N:P Ratio for Lake Linganore

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 2002 samples (MDE, 2002). The concentrations of Total Nitrogen and Total Phosphorus of both samples were used to calculate the N:P ratio. The TN:TP ratio ranged from 18:1 to over 40:1.

Table A1: Physical Water Quality Data—Lake Linganore, 2002

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	FIELD PH	SAMPLE DEPTH FROM SURFACE METERS	DISSOLVED OXYGEN FIELD VALUE MG/L	WATER TEMPERATURE °C	CONDUCTIVITY FIELD VALUE µMHOS/CM
LIN0023	02/19/2002	8	0	12.7	3.9	242
LIN0072	02/19/2002	7.7	0	13	1.4	230
LIN0005	03/07/2002	7.6	0	12.6	4.1	265
LIN0023	03/07/2002	7.9	0	12	5.2	235
LIN0029	03/07/2002	9	0.5	12.8	5.6	234
LIN0029	03/07/2002	9	1	12.7	5.3	234
LIN0029	03/07/2002	9	3	12.6	5.3	234
LIN0029	03/07/2002	9	5	12.4	5.2	234
LIN0029	03/07/2002	9.1	7	12.3	5.1	235
LIN0029	03/07/2002	9.2	9.5	12.2	5.1	235
LIN0037	03/07/2002	8.7	0.5	13.1	5.8	231
LIN0037	03/07/2002	8.7	1	13.1	5.5	230
LIN0037	03/07/2002	8.7	3	13	5.1	230
LIN0037	03/07/2002	8.6	5	12.7	5	230
LIN0037	03/07/2002	8.4	6.2	12.6	5	230
LIN0048	03/07/2002	8.1	0.5	12.8	4.9	220
LIN0048	03/07/2002	8.1	1	12.8	4.9	220
LIN0048	03/07/2002	8.1	2.1	12.6	4.6	220
LIN0058	03/07/2002	8.1	0.5	12.7	4.2	227
LIN0072	03/07/2002	7.5	0	12.3	3.2	215
LIN0023	03/19/2002	8.8	0	11.2	9.4	231
LIN0072	03/19/2002	7.6	0	11.3	7.7	219
LIN0005	04/02/2002	8.1	0	11.4	11.1	250
LIN0023	04/02/2002	8.7	0	10.8	11.9	229
LIN0029	04/02/2002	9	0.5	14.1	10.6	230
LIN0029	04/02/2002	8.9	1	13.8	10.2	230
LIN0029	04/02/2002	8.8	3	13.3	9.9	230
LIN0029	04/02/2002	8.3	5	12	9.3	231
LIN0029	04/02/2002	7.6	7.6	10.4	8.3	230
LIN0037	04/02/2002	9.2	0.5	15.1	11.5	230
LIN0037	04/02/2002	9.2	1	14.8	11.5	230
LIN0037	04/02/2002	9.1	2	13.9	11	230
LIN0037	04/02/2002	7.9	3	10.9	9.3	230
LIN0037	04/02/2002	7.7	4	9.9	8.7	230
LIN0037	04/02/2002	7.6	5.4	9.9	8.2	230
LIN0048	04/02/2002	7.8	0.5	10	12.3	240
LIN0048	04/02/2002	7.8	1	10.4	12.2	240

LIN0048	04/02/2002	8.2	1.7	11.8	11.1	240
LIN0058	04/02/2002	7.7	0.5	9.1	11.4	240
LIN0072	04/02/2002	8	0	10.8	11	230
LIN0023	04/16/2002	9.1	0	9.7	18.3	225
LIN0072	04/16/2002	7.7	0	8.4	20.5	241
LIN0005	04/30/2002	7.3	0	9.1	12.5	245
LIN0023	04/30/2002	7.8	0	9	13.9	225
LIN0029	04/30/2002	8.1	0.5	5.6	15.3	227
LIN0029	04/30/2002	8.1	1	5.4	15	227
LIN0029	04/30/2002	8	2	5.2	14.6	227
LIN0029	04/30/2002	7.9	3	5	14.6	227
LIN0029	04/30/2002	7.6	4	4.3	14.3	228
LIN0029	04/30/2002	7	5	1.2	10.7	251
LIN0029	04/30/2002	7	6	0.5	9.5	246
LIN0029	04/30/2002	7.2	7.4	0.4	9.3	246
LIN0037	04/30/2002	9	0.5	7.9	15.6	219
LIN0037	04/30/2002	8.9	1	7.5	15.4	220
LIN0037	04/30/2002	8.8	2	6.9	15.3	221
LIN0037	04/30/2002	8.6	3	5.9	15.1	223
LIN0037	04/30/2002	7.4	4	3.2	13.7	236
LIN0037	04/30/2002	7.2	5.4	0.8	10.4	265
LIN0048	04/30/2002	8.3	0.5	8	15.2	222
LIN0048	04/30/2002	7.6	1	7.5	14	220
LIN0048	04/30/2002	7.4	2.1	7.3	13.3	215
LIN0058	04/30/2002	7.4	0.5	8.6	12	221
LIN0072	04/30/2002	7.4	0	9.7	11	217

Subsequent data to be included upon availability

Table A2: Water Quality (Nutrient) Data Lake Linganore

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TOTAL DEPTH THIS STATION METERS	SAMPLE DEPTH FROM SURFACE METERS	TOTAL NITROGEN, MG/L	TOTAL PHOSPHORUS, MG/L	TN:TP
LIN0023	02/19/2002		0			
LIN0072	02/19/2002		0			
LIN0005	03/07/2002		0	2.456	0.0271	90.62731
LIN0023	03/07/2002		0	2.483	0.0358	69.35754
LIN0029	03/07/2002	10.5	0.5	2.462	0.0251	98.08765
LIN0029	03/07/2002	10.5	1			
LIN0029	03/07/2002	10.5	3			
LIN0029	03/07/2002	10.5	5			
LIN0029	03/07/2002	10.5	7			
LIN0029	03/07/2002	10.5	9.5			
LIN0037	03/07/2002	7.2	0.5	2.552	0.032	79.75
LIN0037	03/07/2002	7.2	1			
LIN0037	03/07/2002	7.2	3			
LIN0037	03/07/2002	7.2	5			
LIN0037	03/07/2002	7.2	6.2			
LIN0048	03/07/2002	3.1	0.5	3.135	0.0625	50.16
LIN0048	03/07/2002	3.1	1			
LIN0048	03/07/2002	3.1	2.1			
LIN0058	03/07/2002	1.6	0.5	3.1008	0.0313	99.06709
LIN0072	03/07/2002		0	3.4466	0.0334	103.1916
LIN0023	03/19/2002		0			
LIN0072	03/19/2002		0			
LIN0005	04/02/2002		0	2.24	0.0307	72.96417
LIN0023	04/02/2002		0	2.434	0.0566	43.00353
LIN0029	04/02/2002	8.6	0.5	2.75	0.0608	45.23026
LIN0029	04/02/2002	8.6	1			
LIN0029	04/02/2002	8.6	3			
LIN0029	04/02/2002	8.6	5			
LIN0029	04/02/2002	8.6	7.6			
LIN0037	04/02/2002	6.4	0.5	2.973	0.0832	35.73317
LIN0037	04/02/2002	6.4	1			
LIN0037	04/02/2002	6.4	2			
LIN0037	04/02/2002	6.4	3			
LIN0037	04/02/2002	6.4	4			
LIN0037	04/02/2002	6.4	5.4			

Table A2: Water Quality (Nutrient) Data Lake Linganore (cont'd)

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TOTAL DEPTH THIS STATION METERS	SAMPLE DEPTH FROM SURFACE METERS	TOTAL NITROGEN, MG/L	TOTAL PHOSPHORUS, MG/L	TN:TP
LIN0048	04/02/2002	2.7	0.5	2.926	0.0818	35.77017
LIN0048	04/02/2002	2.7	1			
LIN0048	04/02/2002	2.7	1.7			
LIN0058	04/02/2002	1.5	0.5	2.766	0.0865	31.97688
LIN0072	04/02/2002		0	2.817	0.0651	43.27189
LIN0023	04/16/2002		0			
LIN0072	04/16/2002		0			
LIN0005	04/30/2002		0	1.78	0.0574	31.01045
LIN0023	04/30/2002		0	1.69	0.0559	30.23256
LIN0029	04/30/2002	8.4	0.5	1.658	0.0491	33.76782
LIN0029	04/30/2002	8.4	1			
LIN0029	04/30/2002	8.4	2			
LIN0029	04/30/2002	8.4	3			
LIN0029	04/30/2002	8.4	4			
LIN0029	04/30/2002	8.4	5			
LIN0029	04/30/2002	8.4	6			
LIN0029	04/30/2002	8.4	7.4			
LIN0037	04/30/2002	6.4	0.5	1.672	0.064	26.125
LIN0037	04/30/2002	6.4	1			
LIN0037	04/30/2002	6.4	2			
LIN0037	04/30/2002	6.4	3			
LIN0037	04/30/2002	6.4	4			
LIN0037	04/30/2002	6.4	5.4			
LIN0048	04/30/2002	3.1	0.5	2.352	0.1225	19.2
LIN0048	04/30/2002	3.1	1			
LIN0048	04/30/2002	3.1	2.1			
LIN0058	04/30/2002	0.7	0.5	2.267	0.0859	26.39115
LIN0072	04/30/2002		0	2.477	0.1364	18.15982
LIN0023	05/14/2002		0		0.053	0
LIN0072	05/14/2002		0	2.14335	0.0873	24.55155
LIN0023	06/10/2002		0			
LIN0072	06/10/2002		0			
LIN0005	06/25/2002		0	1.4806	0.0621	23.84219
LIN0029	06/25/2002		0.5	0.897	0.0287	31.25436
LIN0037	06/25/2002		0.5	1.007	0.0385	26.15584
LIN0048	06/25/2002		0.5	1.052	0.0742	14.1779
LIN0058	06/25/2002		0.5	2.31	0.2825	8.176991
LIN0072	06/25/2002		0	2.193	0.1109	19.77457
LIN0005	07/09/2002		0	1.1358	0.0674	16.85163

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TOTAL DEPTH THIS STATION METERS	SAMPLE DEPTH FROM SURFACE METERS	TOTAL NITROGEN, MG/L	TOTAL PHOSPHORUS, MG/L	TN:TP
LIN0023	07/09/2002		0	1.394	0.1287	10.83139
LIN0029	07/09/2002		0.5	0.808	0.0338	23.90533
LIN0037	07/09/2002		0.5	0.747	0.036	20.75
LIN0048	07/09/2002		0.5	0.781	0.0535	14.59813
LIN0058	07/09/2002		0.5	2.12	0.23	9.217391
LIN0072	07/09/2002		0	1.4977	0.1028	14.56907

Table A3: Water Quality (Chlorophyll) Data Lake Linganore

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TIME START SAMPLING	SAMPLE DEPTH FROM SURFACE METERS	TOTAL CHLOROPHYLL µG/L	FLOW /cfs	PHEOPHYTIN A µG/L
LIN0023	02/19/2002	11:05	0	17.304	7.68	1.734432
LIN0072	02/19/2002	10:40	0	0.84	13.47	0.687792
LIN0005	03/07/2002	8:55	0	16.66		2.54184
LIN0023	03/07/2002	9:10	0	28.84	16.01	2.89072
LIN0029	03/07/2002	10:15	0.5	16.38		1.76932
LIN0029	03/07/2002	10:15	1			
LIN0029	03/07/2002	10:15	3			
LIN0029	03/07/2002	10:15	5			
LIN0029	03/07/2002	10:15	7			
LIN0029	03/07/2002	10:15	9.5			
LIN0037	03/07/2002	10:35	0.5	27.16		2.66644
LIN0037	03/07/2002	10:35	1			
LIN0037	03/07/2002	10:35	3			
LIN0037	03/07/2002	10:35	5			
LIN0037	03/07/2002	10:35	6.2			
LIN0048	03/07/2002	10:45	0.5	7.84		1.04664
LIN0048	03/07/2002	10:45	1			
LIN0048	03/07/2002	10:45	2.1			
LIN0058	03/07/2002	11:00	0.5	1.4		0.22428
LIN0072	03/07/2002	9:35	0	1.4	17.15	0.47348
LIN0023	03/19/2002	12:00	0	47.628	26.44	5.607
LIN0072	03/19/2002	11:35	0	4.452	29.24	1.839096
LIN0005	04/02/2002	12:05	0	10.5		1.22108
LIN0023	04/02/2002	11:40	0	33.46	39.9	2.1182
LIN0029	04/02/2002	9:25	0.5	53.62		1.04664
LIN0029	04/02/2002	9:25	1			
LIN0029	04/02/2002	9:25	3			
LIN0029	04/02/2002	9:25	5			
LIN0029	04/02/2002	9:25	7.6			
LIN0037	04/02/2002	9:40	0.5	101.64		1.04664
LIN0037	04/02/2002	9:40	1			
LIN0037	04/02/2002	9:40	2			
LIN0037	04/02/2002	9:40	3			
LIN0037	04/02/2002	9:40	4			
LIN0037	04/02/2002	9:40	5.4			

Table A3: Water Quality (Chlorophyll) Data Lake Linganore (cont'd)

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TIME START SAMPLING	SAMPLE DEPTH FROM SURFACE METERS	TOTAL CHLOROPHYLL µG/L	FLOW /cfs	PHEOPHYTIN A µG/L
LIN0048	04/02/2002	9:55	0.5	19.88		2.7412
LIN0048	04/02/2002	9:55	1			
LIN0048	04/02/2002	9:55	1.7			
LIN0058	04/02/2002	10:10	0.5	6.16		2.59168
LIN0072	04/02/2002	11:20	0	2.94	26.68	1.29584
LIN0023	04/16/2002	12:15	0	26.292	28.53	4.739784
LIN0072	04/16/2002	12:00	0	14.28	20.68	7.02744
LIN0005	04/30/2002	9:00	0	7.42		6.45428
LIN0023	04/30/2002	9:10	0	6.44		6.08048
LIN0029	04/30/2002	10:55	0.5	4.34		3.04024
LIN0029	04/30/2002	10:55	1			
LIN0029	04/30/2002	10:55	2			
LIN0029	04/30/2002	10:55	3			
LIN0029	04/30/2002	10:55	4			
LIN0029	04/30/2002	10:55	5			
LIN0029	04/30/2002	10:55	6			
LIN0029	04/30/2002	10:55	7.4			
LIN0037	04/30/2002	10:40	0.5	43.54		10.86512
LIN0037	04/30/2002	10:40	1			
LIN0037	04/30/2002	10:40	2			
LIN0037	04/30/2002	10:40	3			
LIN0037	04/30/2002	10:40	4			
LIN0037	04/30/2002	10:40	5.4			
LIN0048	04/30/2002	10:25	0.5	47.32		8.62232
LIN0048	04/30/2002	10:25	1			
LIN0048	04/30/2002	10:25	2.1			
LIN0058	04/30/2002	10:05	0.5	10.64		3.76292
LIN0072	04/30/2002	9:20	0	3.64	34.05	1.7444
LIN0072	05/14/2002	11:50	0	7.476		3.678192
LIN0023	05/14/2002	12:10	0	11.34		3.81276
LIN0072	06/10/2002	12:00	0	5.376		2.885736
LIN0023	06/10/2002	12:10	0	37.044		7.670376
LIN0005	06/25/2002	9:15	0	3.5		2.41724
LIN0072	06/25/2002	9:45	0	3.92		2.09328
LIN0037	06/25/2002	10:30	0.5	18.9		2.57922
LIN0029	06/25/2002	10:50	0.5	12.81		0.71022
LIN0048	06/25/2002	11:20	0.5	43.05		4.70988
LIN0058	06/25/2002	11:35	0.5	138.18		17.86764
LIN0072	05/14/2002	11:50	0	7.476		3.678192

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	TIME START SAMPLING	SAMPLE DEPTH FROM SURFACE METERS	TOTAL CHLOROPHYLL µG/L	FLOW /cfs	PHEOPHYTIN A µG/L
LIN0023	05/14/2002	12:10	0	11.34		3.81276
LIN0072	06/10/2002	12:00	0	5.376		2.885736
LIN0023	06/10/2002	12:10	0	37.044		7.670376
LIN0005	06/25/2002	9:15	0	3.5		2.41724
LIN0072	06/25/2002	9:45	0	3.92		2.09328
LIN0037	06/25/2002	10:30	0.5	18.9		2.57922

Table A4: Point Source Data (MD0060577)

NPDES	YEAR	MONTH	FLOW/MGD	TSS	TP/mg/l
MD0060577	1992	1	0.015	24	2.89
MD0060577	1992	2	0.02	10	2.89
MD0060577	1992	3	0.023	21	2.89
MD0060577	1992	4	0.02	15	2.89
MD0060577	1992	5	0.019	15	2.89
MD0060577	1992	6	0.02	17	2.89
MD0060577	1992	7	0.019	23	2.89
MD0060577	1992	8	0.019	19	2.89
MD0060577	1992	9	0.022	17	2.89
MD0060577	1992	10	0.02	8	2.89
MD0060577	1992	11	0.023	50	2.89
MD0060577	1992	12	0.027	9	2.89
MD0060577	1993	1	0.027	11	2.89
MD0060577	1993	2	0.022	14	2.89
MD0060577	1993	3	0.056	8	2.89
MD0060577	1993	4	0.054	5	2.89
MD0060577	1993	5	0.031	12	2.89
MD0060577	1993	6	0.027	12	2.89
MD0060577	1993	7	0.021	17	2.89
MD0060577	1993	8	0.024	8	2.89
MD0060577	1993	9	0.023	12	2.89
MD0060577	1993	10	0.022	26	2.89
MD0060577	1993	11	0.026	9	2.89
MD0060577	1993	12	0.028	8	2.89
MD0060577	1994	1	0.022	23	2.89
MD0060577	1994	2	0.036	15	2.89
MD0060577	1994	3	0.055	12	2.89
MD0060577	1994	4	0.036	12	2.89
MD0060577	1994	5	0.025	8	2.89
MD0060577	1994	6	0.023	13	2.89
MD0060577	1994	7	0.023	8	2.89
MD0060577	1994	8	0.022	15	2.89
MD0060577	1994	9	0.024	10	2.89
MD0060577	1994	10	0.022	65	2.89
MD0060577	1994	11	0.024	26	2.89
MD0060577	1994	12	0.026	7	2.89
MD0060577	1994	1	0.022	23	2.89
MD0060577	1994	2	0.036	15	2.89
MD0060577	1994	3	0.055	12	2.89
MD0060577	1994	4	0.036	12	2.89
MD0060577	1994	5	0.025	8	2.89
MD0060577	1994	6	0.023	13	2.89

NPDES	YEAR	MONTH	FLOW/MGD	TSS	TP/mg/l
MD0060577	1994	7	0.023	8	2.89
MD0060577	1994	8	0.022	15	2.89
MD0060577	1994	9	0.024	10	2.89
MD0060577	1994	10	0.022	65	2.89
MD0060577	1994	11	0.024	26	2.89
MD0060577	1994	12	0.026	7	2.89
MD0060577	1995	1	0.031	8.8	3
MD0060577	1995	2	0.022	21	3
MD0060577	1995	3	0.027	13	3
MD0060577	1995	4	0.022	13	3
MD0060577	1995	5	0.022	17	3
MD0060577	1995	6	0.023	23	3
MD0060577	1995	7	0.023	10	3
MD0060577	1995	8	0.022	11	3
MD0060577	1995	9	0.023	19	3
MD0060577	1995	10	0.024	12	3
MD0060577	1995	11	0.027	13	3
MD0060577	1995	12	0.024	22	3
MD0060577	1996	1	0.043	27	2.89
MD0060577	1996	2	0.034	8	2.89
MD0060577	1996	3	0.034	10	2.89
MD0060577	1996	4	0.038	19	2.89
MD0060577	1996	5	0.031	17	2.89
MD0060577	1996	6	0.032	21	2.89
MD0060577	1996	7	0.048	21	2.89
MD0060577	1996	8	0.04	16	2.89
MD0060577	1996	9	0.044	14	2.89
MD0060577	1996	10	0.046	17	2.89
MD0060577	1996	11	0.045	15	2.89
MD0060577	1996	12	0.063	22	2.89
MD0060577	1997	1	0.033	18	2.89
MD0060577	1997	2	0.041	14	2.89
MD0060577	1997	3	0.048	21	2.89
MD0060577	1997	4	0.036	13	2.89
MD0060577	1997	5	0.029	15	2.89
MD0060577	1997	6	0.027	13	2.89
MD0060577	1997	7	0.03	17	2.89
MD0060577	1997	8	0.023	20	2.89
MD0060577	1997	9	0.02	15	2.89
MD0060577	1997	10	0.025	15	2.89
MD0060577	1997	11	0.028	21	2.89
MD0060577	1997	12	0.023	22	2.89
MD0060577	1998	1	0.047	22	2.89
MD0060577	1998	2	0.058	19	2.89
MD0060577	1998	3	0.052	9	2.89

NPDES	YEAR	MONTH	FLOW/MGD	TSS	TP/mg/l
MD0060577	1998	4	0.034	12	2.89
MD0060577	1998	5	0.029	9	2.89
MD0060577	1998	6	0.024	13	2.89
MD0060577	1998	7	0.014	17	2.89
MD0060577	1998	8	0.015	20	2.89
MD0060577	1998	9	0.014	14	2.89
MD0060577	1998	10	0.016	7	2.89
MD0060577	1998	11	0.015	13	2.89
MD0060577	1998	12	0.015	17	2.89
MD0060577	1999	1	0.02	24	2.89
MD0060577	1999	2	0.019	15	2.89
MD0060577	1999	3	0.02	14	2.89
MD0060577	1999	4	0.02	13	2.89
MD0060577	1999	5	0.015	15	2.89
MD0060577	1999	6	0.015	18	2.89
MD0060577	1999	7	0.013	17	2.89
MD0060577	1999	8	0.014	21	2.89
MD0060577	1999	9	0.024	30	2.89
MD0060577	1999	10	0.025	22	2.89
MD0060577	1999	11	0.02	10	2.89
MD0060577	1999	12	0.022	21	2.89
MD0060577	2000	1	0.022	13	2.89
MD0060577	2000	2	0.034	5	2.89
MD0060577	2000	3	0.033	13	2.89
MD0060577	2000	4	0.033	8	2.89
MD0060577	2000	5	0.026	17	2.89
MD0060577	2000	6	0.02	14	2.89
MD0060577	2000	7	0.019	13	2.89
MD0060577	2000	8	0.018	11	2.89
MD0060577	2000	9	0.024	8	2.89
MD0060577	2000	10	0.023	8	2.89
MD0060577	2000	11	0.023	13	2.89
MD0060577	2000	12	0.026	11	2.89

There is no monitoring for phosphorus for this plant and that the concentrations listed are default values from the Chesapeake Bay program and MDE's Water Management section. The average annual load based on these values is 223 lbs, which is about 0.5% of the agricultural land contribution and 0.4% of total nonpoint source contribution. Based on a projected increase to 100,000 GPD by 2010, and an assumed TP permit of 2.0 mg/l, a reasonable annual load under TMDL conditions is about 609 lbs/yr of phosphorus.

At this projected flow, with a permitted TSS limit of 30 mg/l, an annual contribution of 9,130 lbs (about 4.5 tons) per year would result. This is less than 0.04% the contribution from nonpoint sources (see p. A19), and is considered insignificant. A nominal allocation of 1% of the TMDL—which works out to about 707 tons per year—is made to this point source.[2]

Supporting Calculations for the Vollenweider Analysis

Lake Linganore 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, 1999). The cited surface area and volume of Lake Linganore are 220 acres (9,583,200ft^2) and 2700-acre feet (117,612,000ft^3), respectively.

Convert feet^2 to m^2: 9,583,200ft^2 x 0.0929 m^2/ft^2 = 890,308 m^2

Convert acre feet to m^3: 2,700 acre feet x 1,233.5 m^3/ acre feet = 3,330,401 m^3

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

2,700 acre-ft ÷ 220acre = **12.3 ft or 3.7 m**

Current Phosphorus Loading to Lake Linganore (Lp):

The point source load to Lake Linganore is 223.3 lbs/yr. The total phosphorus loading from nonpoint source is 50,906.0 lbs/year (23,090,976 g/yr), based on loading rates for agricultural and forested areas from the Chesapeake Bay Program Phase 4.3 Model, segment 210, calculated as follows:

Table A5

SCENARIO	PERIOD	B.SEGMENT	MAJOR_LAND_USE	LOAD_TYPE	SED (TONS/YR)	ACRES	TP (LBS/YR)
s19prog00	10 year	210	AGRICULTURE	eos	75297.15	216726.8	316381.2
s19prog00	10 year	210	FOREST	eos	4486.32	184019.8	4760.26
s19prog00	10 year	210	URBAN	eos	5752.45	39794.7	39514.59

Source: Chesapeake Bay Program Phase 4.3 Model

Land use: *16%* developed land*, 56%* agriculture, *28%* forested land
Developed land P loading rate = 0.99 lbs/acre-yr
Agriculture P loading rate = 1.46 lbs/acre-yr
Forested land P loading rate = 0.026 lbs/acre-yr
Watershed area = 81.1 mile^2 = 51,907.3 acres
P loading from developed land = 0.99 lbs/acre-yr x 51,907.3 acres x *16% = 8,352.1 lbs/yr*
P loading from agriculture source = 1.46 lbs/acre-yr x 51,907.3 acres *x 56%= 42,180.6 lbs/yr*
P loading from forested land = 0.026 lbs/acre-yr x 51,907.3 acres x *28%= 373.3 lbs/yr*

---

[2] MDE recognizes that this nominal allocation exceeds the likely solids discharge of this facility at any time in the future. The allocation does not imply a future permitting allowance. Permitting decisions will consider the impact of discharge to the local portion of Linganore Creek as well as to Lake Linganore.

Total P loading from nonpoint sources = *8,352.1+ 42,180.6 + 373.3 = 50,906.03 lbs/yr = 23,090,976 g/yr*

The Total P loading from nonpoint sources and point sources = *50,906.03 + 223.3 = 51,129.33 lbs/yr = 23,192,265 g/yr*

Using the estimated 1980 lake surface area (890,308 m^2), this value can be converted to grams per square meter per year as follows: 23,192,265 g/yr ÷ 890,308 m^2 = 26.04 g/m^2 yr.

Lake Linganore 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. Direct discharge from the lake unavailable; however, USGS gauge 01642500 lies only a short distance downstream, with the cited drainage area of 82.3 mi^2 being only slightly greater than that of Lake Linganore. This gauge represents an accurate measurement of the flow through the lake. The overall Lake Linganore watershed measures 81.1 mi^2. The is the average of the mean of daily mean values for the period of 49 years from the USGS gauge at Linganore creek near Frederick, Frederick County, Maryland (USGS 01642500) is 85 cfs. The average discharge from Lake Linganore is computed as the areally-adjusted proportion of this amount, or 83.8 cfs, or 60,668.1 acre-feet/yr. See table A6 below for more information about this gauging station.

Hydrologic Unit Code 02070009
Latitude 39°24'55", Longitude 77°20'00" NAD27
Drainage area 82.30 square miles
Gage datum 270 feet above sea level NGVD29

Table A6

Day of month	Mean of daily mean values for this day for 49 years of record[1], in ft^3/s											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	145	98.1	133	147	105	113	53.4	58.7	62.2	101	45.3	72.5
2	120	114	118	157	99.5	134	49.5	41.4	38.6	52.8	49.4	79.6
3	127	133	144	134	108	83.3	56.3	52.4	32.6	50.9	54.7	59.2
4	119	121	131	131	108	91	68.9	66.1	36.8	37.4	47	87.6
5	108	98.1	160	175	101	84.5	60.1	55.7	69	36.3	54	67
6	97.1	117	152	150	92.4	80.8	56.3	36.2	84.9	38.1	47	77.9
7	93.4	161	160	128	105	65	43.4	38.9	35.2	34.5	55.7	92.4
8	86.7	135	120	138	91.1	69.8	54.2	37.7	35.3	36.3	64.9	78.2
9	133	108	111	137	93.5	63.7	55.3	57.2	28.3	75.3	54.2	79
10	100	119	100	136	82.4	69.7	52.6	40.3	34.7	67.6	43.7	74.8
11	83.1	119	128	112	77.3	64.2	54	41.4	40.5	42.5	45.9	81.4
12	85.9	109	155	112	83.1	66.3	50.7	58.7	48.3	39.3	48.3	72.8
13	85.4	150	151	156	84.8	108	54.8	106	47.1	39	72	69.1
14	119	139	162	160	87.8	85.9	43	78.3	84	63.2	54.3	79.3
15	99.1	126	150	133	90.9	67.6	58.1	45	42.6	46.7	57.8	70.7
16	79.4	122	136	116	94.5	62.7	63.3	37	32.3	67.8	44.5	80.4
17	71.5	126	149	123	86.1	76.6	46.2	43.1	36.2	41.8	42.8	68.2
18	75.5	113	129	111	80.2	66.5	52.5	48.4	41.6	36.9	51	84.3
19	74.5	139	141	112	75.2	72.4	44.8	40.2	30.8	48	45.6	68.5
20	87.5	121	137	125	89	67.8	57.4	39.9	31.2	51.6	49.3	89.8
21	128	124	139	109	89.7	74.4	86.7	39.3	41.6	45.7	58.3	90.3
22	110	125	167	107	111	303	64.8	44.8	47.7	39.5	64.6	79.2
23	93.2	130	174	101	82.7	130	62	42.5	38.4	58.7	46.7	75.2
24	131	133	142	99.7	86.2	90.7	57.9	38.5	44.9	39.9	48.2	74.3
25	144	163	135	108	102	62.4	37.1	40.4	98.8	64.9	82.9	80
26	174	194	139	151	104	57.8	63.7	42.6	124	64.8	53.6	100
27	127	148	137	185	80.3	70.8	40.6	59.1	56.7	53.7	56.6	95.4
28	116	139	122	162	94.4	61.6	63.9	38.4	38.2	53.8	72.3	80.6
29	101	129	117	122	81.3	62.7	49.1	32.1	38.1	46	86.5	98.4
30	115		118	110	82.8	81	59.2	33	34.1	44.8	76	132
31	98.3		121		93.1		40.9	48.1		46.8		108

1 -- Available period of record may be less than value shown for certain days of the year.

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

From the computations above the mean depth of Lake Linganore ($\overline{Z}$) is 12.3 ft (3.7 m), and the hydraulic residence time (τ_w) is 0.04 yr. The ratio was computed as:

3.7 m / 0.04 yr = **92.5 m/yr**

Graphing of Trophic Status of Lake Linganore using the Vollenweider Relationship

The intersection of the phosphorus loading rate (L_p) = 26.0 g/m^{2}yr and the ratio ($\overline{Z}$ /τ_w) = 92.5 m/yr was plotted on log log paper to establish the trophic status of Lake Linganore (See Figure 5 in the main report and Figure A-1 below).

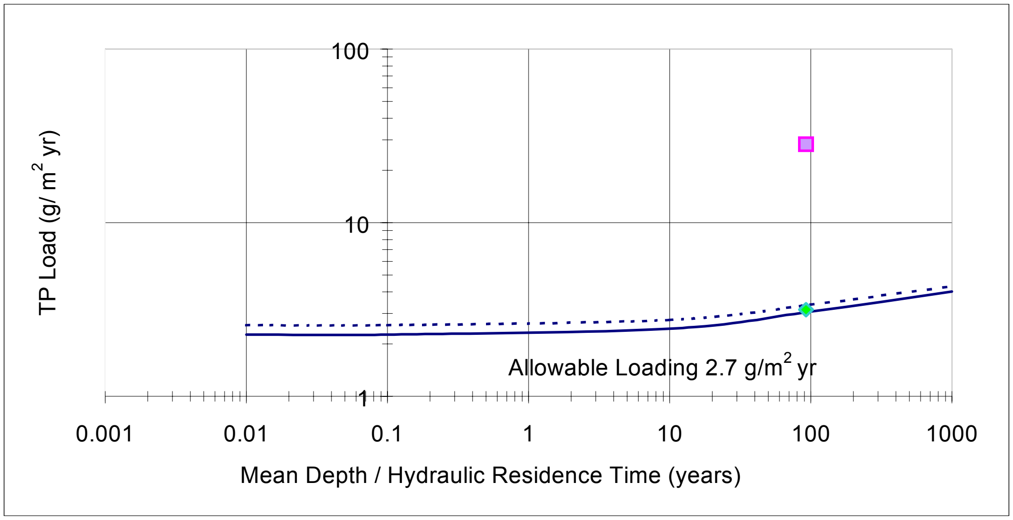


Figure A-1: Vollenweider Results for Lake Linganore

Supporting Calculations for the TMDL Analysis

Graphing of Maximum Allowable Unit Phosphorus loading of Lake Linganore 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 (2.7g/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
(2.7 g/m^2yr) x (890,308 m^2) = 2,403,832g/yr

Converted to pounds per year:
(2,403,832g/yr) x (0.0022 lbs/g) = 5,288 lbs/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 (5,288 lbs/yr) = 528.8 lbs/yr

Computing the Percentage Phosphorus Reduction

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

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

$$\frac{(51{,}129.3\text{ lbs/yr}) - (5{,}288\text{ lbs/yr})}{(51{,}129.3\text{ lbs/yr})} = 90\%\text{ reduction}$$

* 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, but can be determined graphically by reading the expected DO concentration at a specified percent saturation from a published nomogram or comparable calculation method.

Chapra (1997) presents ranges of hypolimnetic DO saturation as a function of trophic status in eutrophic, mesotrophic and oligotrophic lakes (Table A7). 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 A8).

Table A7

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 A8

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 Lake Linganore at a meso-eutrophic status. Current phosphorus loading estimates place Lake Linganore in the eutrophic status. 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 A7. 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, Equation 1 below (Benson and Krause 1980; *in* Mortimer 1981) 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 typically observed in the deeper waters of Maryland lakes during critical summertime conditions (18 – 25 °C).

$$\begin{aligned} \ln C^* &= -139.34410 + (1.575701x10^5/T) - \\ &(6.642308x10^7/T^2) + (1.243800x10^{10}/T^3) \\ &- (8.621949x10^{11}/T^4) \end{aligned} \qquad (1)$$

This represents an expected minimum hypolimnetic DO concentration ranging from about 0.8 – 0.9 mg/l. This range reflects an increase over the lowest DO concentration (0.4 mg/l) observed on April 30, 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).

Estimating the Sediment TMDL

The EPA Chesapeake Bay Program watershed modeling assumptions were adopted to quantify the sediment reduction associated with this phosphorus reduction. 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, CBPO 1998). The primary BMP in this category are the various land management practices that fall under Soil Conservation and Water Quality Plans (SCWQPs). The other broad category of phosphorus controls is nutrient management plans (NMPs), which manage fertilizer application, including animal waste. Thus, if nutrient management plans make up part of the control strategy, the ratio will be less than 1-to-1.

To estimate this ratio, hence the sediment load reduction, it is necessary to estimate the proportion of the phosphorus reduction that is anticipated to result from SCWQPs versus NMPs. Table 2 of the report, which shows estimated ranges of phosphorus reduction, is reproduced below for convenience. Note that the range in reduction of phosphorus is about the same for NMPs and SCWQPs. Since these BMPs are applied on a per-acre basis, an initial assumption might be that half the reduction would come from NMPs and half from SCWQPs, making the ratio about 0.5-to-1. This ratio has been adopted for estimating the reduction in sediment loads.

This ratio is conservative (gives a low estimate of sediment reductions) for two reasons. First, because soils are easily erodible in the Lake Linganore watershed, the NMP removal efficiency should be compared to the "treatment of highly erodible land," which is another term for a SCWQP in areas where soils are highly erodible. This interpretation of the BMPs gives a ratio of 1-to-0.75 or better. Second, the sediment reduction effects of conservation tillage have not been counted.

Table A9: Phosphorus Removal Efficiencies of Various Agricultural BMPs

Best Management Practice	Estimated Range of Phosphorus Reduction
Soil Conservation & Water Quality Plan (SCWQP)	11% - 35%
Treatment of Highly Erodible Land[1]	3 x the result of SCWQP on typical soil
Conservation Tillage	13% - 50%
Nutrient Management Plans	9% - 30%

Source: "Technical Appendix for Maryland's Tributary Strategy" (Maryland, 1995)
Notes:
1. The soils in the Lake Linganore watershed are considered easily erodible (DNR, Oct. 1996).

To estimate the net sediment reduction associated with the 90 percent phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:

100* (0.5 * 0.90) = **45 percent reduction in sediment loads**

The existing sediment loads for Lake Linganore from the Chesapeake Bay Program Phase 4.3 Model, segment 210 (see Table A5) are:

Sediment loading from developed land = 0.144 tons/acre-yr x 51,907.3 acres x *16%* = *1215 tons/yr*

Sediment loading from agriculture source = 0.347 tons/acre-yr x 51,907.3 acres *x 56%*=

10,025 tons /yr

Sediment loading from forested land = 0.024 tons/acre-yr x 51,907.3 acres x *28%=*
345 ton /yr

Total Sediment loading from nonpoint sources = *1,215 + 10,025+ 345= 11,585 tons/yr*

Applying this reduction to the current estimation of *10,025* tons of sediments (agricultural sources) per year results in the estimated reduction, the converse of which is the estimated allowable load:

(0.45 * 10,025) = 4,511.3 tons/year reduction

Total sediment load = developed land source + forest source + agricultural source

= 1,215 + 10,025+ 345= 11,585 tons/yr

11,585 - (0.45 * 10,025) = **7,073 tons/year allowable sediment load**

Estimation of Volumetric Preservation of Lake Linganore

No bathymetric studies have been performed to establish volume loss due to sedimentation in Lake Linganore. 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 lbs/ft^3 to 59.9 lbs/ft^3. Lake Linganore is smaller and shallower than many impoundments typically used for public water supply (such as 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 Lake Linganore 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 lbs/ft^3) is used. With an annual allowable sediment load of 7,073 tons, this range results in an annual volume loss of 13 acre-feet (@ 25 lbs/ft^3) to 32 acre-feet (@ 10 lbs/ft^3). Table A10 below expresses these annual losses in terms of preservation of the lake's volume (2,700 acre-ft) over time. The time to infill under current conditions is estimated to fall between 10.6yrs (10 lbs/ft^3) and 26.6yrs (25 lbs/ft^3).

Table A10: Expected preserved volume for Lake Linganore, assuming a sediment volume-weight ranging from 10.0 to 25.0 lbs/ft^3.

Time Period	**Range Of Volumetric Preservation**
50 Years	41% to 76%
100 Years	Silted in to 52%
200 Years	Silted in to 4%