Total Maximum Daily Loads of Phosphorus and Sediments to Tony Tank Lake, Wicomico County, MD

Prepared by:

Maryland Department of the Environment
2500 Broening Highway
Baltimore, MD 21224

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

1650 Arch Street
Philadelphia, PA 19103-2029

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PREFACE

Section 303(d) of the federal Clean Water Act directs States to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance, are inadequate to achieve water quality standards. For each WQLS, the State is to establish a Total Maximum Daily Load (TMDL) of the specified substance that the water can receive without violating water quality standards.

On the basis of water quality problems associated with Tony Tank Lake, the Wicomico River watershed was identified on Maryland's 1996 list of WQLSs as being impaired by nutrients and sediments. This report documents the proposed establishment of two TMDLs for Tony Tank Lake: one for excess sedimentation and one for phosphorus.

Once approved by the United States Environmental Protection Agency (EPA), the TMDLs will be documented through the State's Continuing Planning Process. In the future, the established TMDLs will support reservoir restoration and nonpoint source control measures needed to restore water quality in Tony Tank Lake.

EXECUTIVE SUMMARY

On the basis of water quality problems associated with Tony Tank Lake, the Wicomico River watershed (02060007) was identified on Maryland's 1996 list of WQLSs as being impaired by nutrients and sediments. This document establishes Total Maximum Daily Loads (TMDLs) for the nutrient phosphorus and sediments entering Tony Tank Lake.

Tony Tank Lake is an impoundment on Tony Tank Creek, a tributary of the Wicomico River. The Wicomico River is located in the Lower Eastern Shore Tributary Strategy Basin, which drains to the Chesapeake Bay. Tony Tank Lake is impacted by a high sediment load, which has resulted in excessive sedimentation. The lake also experiences regular nuisance seasonal algae blooms, excessive plant growth, and foul odors, which interfere with direct contact and recreational uses of the lake. 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 can cause fish kills. Phosphorus is most likely the limiting nutrient for the production of algae in freshwater lake systems such as Tony Tank 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 this TMDL is to reduce long-term phosphorus loads to a permissible enrichment level consistent with the physical characteristics of Tony Tank Lake. This reduced loading rate is predicted to resolve excess algae problems and maintain dissolved oxygen concentrations above the State 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 result from the reduction in sediment loading achieved through phosphorus controls.

The average annual TMDL for phosphorus is 736 lb/yr. There are no point sources in the Tony Tank basin that contribute phosphorus or sediment. 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 predicted to occur as a result of the proposed control of phosphorus. The sediment TMDL is 188.3 tons/yr.

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 the impairing substance a waterbody 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 1996 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), lists the Wicomico River watershed segment (02060007) as impaired by nutrients and sediments. That 1996 listing was prompted by quantitative data associated with Tony Tank Lake.

The purpose of this document is to meet the federal requirements under Section 303(d) of the Clean Water Act to establish TMDLs for impaired waters of Maryland. To that end, this document describes the development of TMDLs for phosphorus and sediments entering Tony Tank Lake.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Tony Tank Lake is a small, elongated impoundment located near the cities of Fruitland and Salisbury in Wicomico County, Maryland (Figure 1). The impoundment lies on Tony Tank Creek, a tributary of the Wicomico River. The Wicomico lies in the Lower Eastern Shore Tributary Strategy Basin, which drains to the Chesapeake Bay (MDE, May 1995). The impoundment, owned by Wicomico County and used for recreational purposes, was created in 1948 by the construction of the Shad Point Dam. The dam, which also functions as a base for MD Route 307, is the designated dividing line between tidal and non-tidal waters in Tony Tank Creek.

Inflow to the lake is primarily via discharge from Tony Tank Pond. Tony Tank Pond is fed in turn by discharges from Coulbourne (Fooks) and Morris Mill Ponds. Discharge from Tony Tank Lake is to the tidal portion of the Wicomico River. Land use in the watershed draining directly to Tony Tank Lake is mixed agricultural and urban. Land use distribution in the larger overall watershed (Figure 2), which drains through the other three impoundments before entering Tony Tank Lake, is approximately 20 % agricultural, 26% urban, and 54% is either forested or has other herbaceous cover (Figure 3).

Natural background sources of phosphorus and sediments are included in the assessment. The loads associated with each land use category include the naturally occurring as well as the human-induced contributions. The model uses Chesapeake Bay Program model loading rates, which account for the cumulative impact from all sources—naturally-occurring and human-induced. Direct atmospheric deposition of sediments and phosphorus to the lake, due to wind erosion, are considered insignificant because the ratio of the watershed area to the surface area of the lake is large (8700 acres/41.3 acres).

Soils in the watershed are primarily the Matawan loamy sand, the Downer loamy sand, and the Elkton sandy loam. These soils tend to be well drained and moderately erodible.

There are three permitted industrial point sources in the Tony Tank watershed; two are active and one is inactive as of 1997. A review of the permits for these sources reveals no mention of phosphorus or sediments, and they are assumed not to contribute either substance to the lake. Several relevant statistics for Tony Tank Lake are provided below in Table 1.

Table 1

Physical Characteristics of Tony Tank Lake

Location:	Wicomico County, MD (38 20.5 N, 75 37.6 W)
Surface Area:	41.3 acres (16.72 ha)
Length:	Approximately 0.8 mi
Maximum Width:	Approximately 0.2 mi
Average Lake Depth:	2.33 ft (0.71 m)
Drainage Area to Lake:	13.807 mi^2 (35.79 km^2)
Estimated Average Discharge:	16.07 cfs

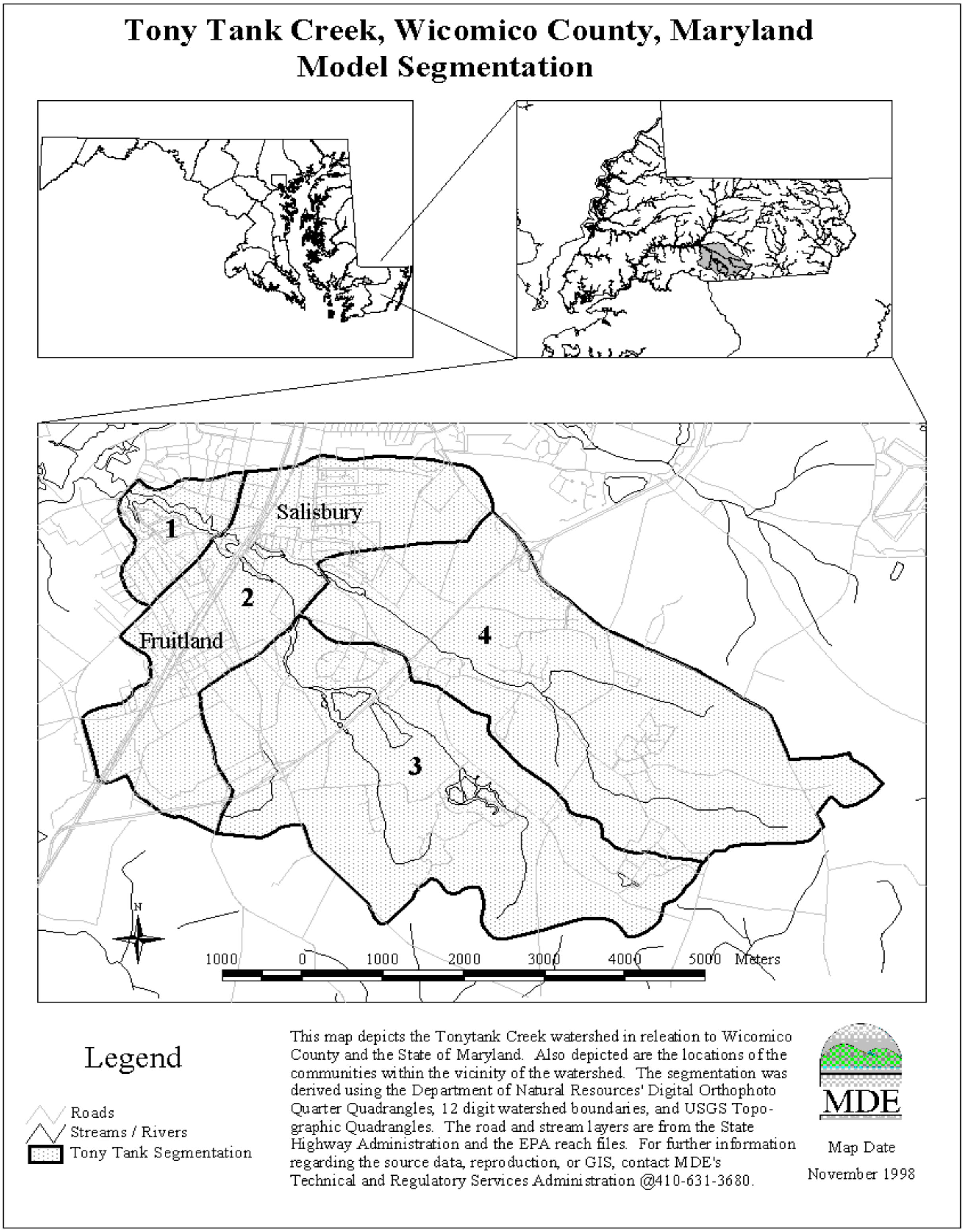

Figure 1. Location of Tony Tank Lake watershed, Wicomico County, MD

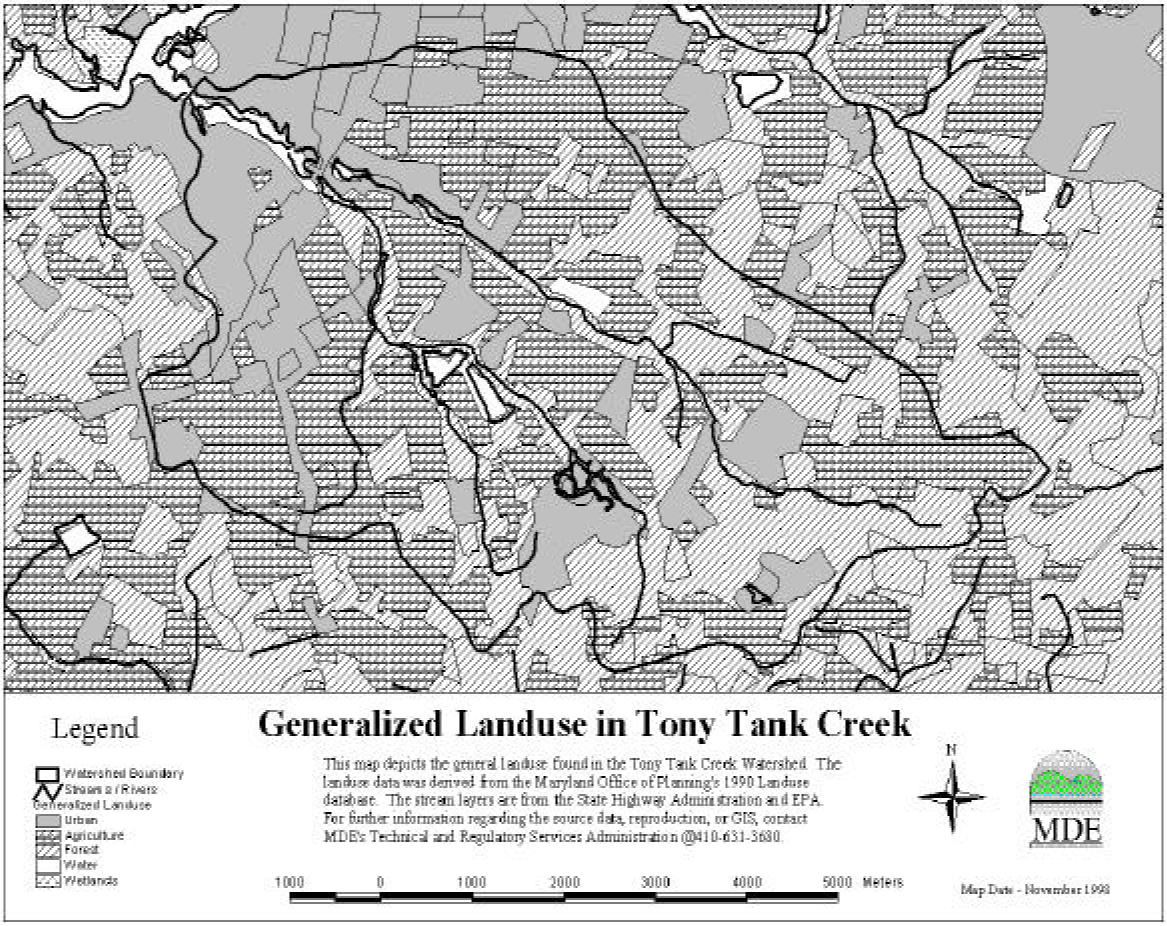

Figure 2. Land use map of Tony Tank Lake Watershed

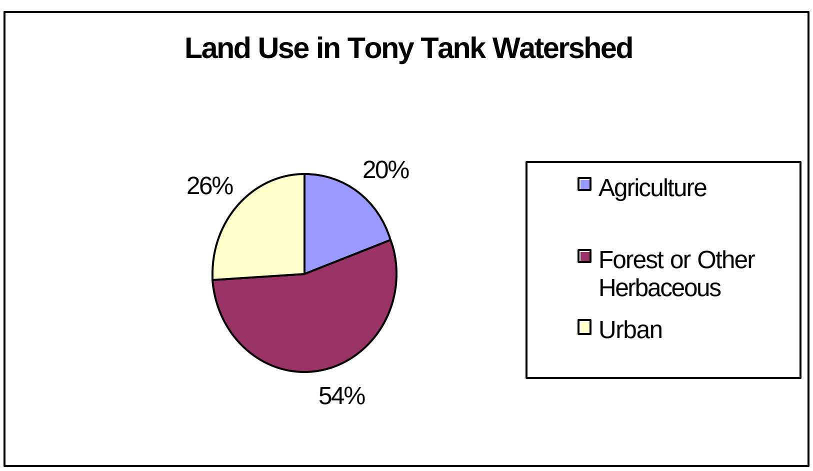

Figure 3. Land use by category in Tony Tank watershed

2.2 Water Quality Characterization

Tony Tank Lake was identified as eutrophic and use-impaired in Maryland's 1996 biennial state water quality report (Clean Water Act Section 305 (b) Report) to the U. S. Environmental Protection Agency (EPA). Impaired usage stemmed from sedimentation and nutrient enrichment, causing excessive aquatic plant and algae growth.

Tony Tank Lake was sampled as part of the Maryland Lake Water Quality Assessment program in June and August of 1993. The lake was characterized as eutrophic, with high total phosphorus concentrations (0.08-0.12 mg/L), occasional algal blooms, and low Secchi depth (0.4-0.6 m). Although dissolved oxygen (DO) concentrations measured during daytime were high at the surface, the observation of dead algal mats along the shoreline and high chlorophyll-a concentrations indicate a probable diurnal swing in DO, with hypoxia likely early in the morning.

2.3 Water Quality Impairment

The Maryland water quality standards Surface Water Use Designation (COMAR 26.08.02.07) for Tony Tank Lake is Use I - *Water Contact Recreation, and Protection of Aquatic Life.* The water quality impairments of Tony Tank Lake consist of violations of general narrative criteria. The substances causing these water quality violations are phosphorus and sediments (see the discussion of the nitrogen/phosphorus ratio, under Section 4.2 "Analysis Framework," for an explanation of why phosphorus is suspected as the limiting nutrient associated with the eutrophication problems).

According to the numeric criteria for dissolved oxygen (DO), concentrations may not be less than 5.0 mg/l at any time (COMAR 26.08.02.03-3A(2)) unless resulting from naturally occurring conditions (COMAR 26.08.02.03.A(2)). It is the judgement of MDE that narrative criteria for meeting the Use I designation are violated. Specifically, excessive nutrient enrichment of Tony Tank Lake results in excessive plant and algae growth, which causes odors and physically impedes direct contact use, fishing, and boating. Finally, in conjunction with excessive nutrients, Tony Tank Lake has experienced excessive sediment loads. In addition to carrying nutrients, sediment loads are filling the impoundment at a high rate.

3.0 TARGETED WATER QUALITY GOALS

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 change the trophic status of Tony Tank Lake by reducing the phosphorus load. This is predicted in turn to reduce excessive plant and algae growth, which leads to violations of the numeric DO criteria, associated fish kills, and the violation of various narrative criteria associated with nuisances cited above (odors and physical impedance of direct contact use).

Since phosphorus binds to sediments, sedimentation rates will be reduced as a component of reducing phosphorus loads. It is expected that this reduction will be sufficient to prevent violations of narrative sediment criteria.

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

1. Assure that a minimum dissolved oxygen concentration of 5 mg/l is maintained in the well-mixed surface waters of Tony Tank Lake;

2. Resolve violations of narrative criteria associated with excess phosphorus enrichment of Tony Tank Lake; and

3. Resolve violations of narrative criteria associated with excess sedimentation of Tony Tank Lake by reducing sedimentation to a reasonable rate.

4.0 TOTAL MAXIMUM DAILY LOADS AND ALLOCATION

4.1 Overview

This section describes how the nutrient TMDLs and loading allocations were developed for Tony Tank Lake. The second subsection describes the analysis for determining that phosphorus is likely to be the limiting nutrient in Tony Tank 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 Total Maximum Daily Loads and allocations. The seventh subsection describes the margin of safety. The last section summarizes the TMDL, and allocations to nonpoint sources and the margin of safety.

4.2 Analytical Framework

Tony Tank Lake suffers from excessive sediment loads and associated nutrient enrichment. Predicting algal blooms using a mechanistic approach can be a very complex problem, and such methods require extensive data and the investment of substantial resources to develop a model to simulate the relationships regarding algal production and water quality response. Given the monumental task of developing numerous TMDLs for the entire State of Maryland, MDE must make judicious use of limited water quality management resources. One opportunity is to apply less complex methods when appropriate. To that end MDE is compelled to consider the applicability of well-established empirical approaches for determining the permissible nutrient loading to over-enriched lakes. Empirical methods typically consist of a formula derived from analysis of experiments or observations. Such an approach has been investigated and adopted for developing the Tony Tank Lake TMDL for phosphorus.

The TMDL for phosphorus is based on an empirical method known as the Vollenweider Relationship. The relationship predicts the degree of a lake's eutrophication as a function of the areal phosphorus loading. The relationship was developed by R.A. Vollenweider by assessing a large number of lakes (Vollenweider 1968). 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 ($\bar{z}$) to hydraulic residence time (τ_w) (Figure 4).

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, a nitrogen to phosphorus (N:P) ratio in the range of 5 to 10 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P ratio is greater than 10, phosphorus tends to be limiting, and if the N:P ratio is less than 5, nitrogen tends to be limiting (Chiandani and Vighi, 1974). An N:P ratio of approximately 14 was estimated using EPA/CBP nutrient loading coefficients for the various land uses in the watershed. This ratio facilitates the use of the Vollenweider Relationship. Supporting data and calculations are provided in Appendix A.

The dynamics of phosphorus loadings to Tony Tank Lake are somewhat complex in that the vast majority of flow to the lake has passed through one or two other impoundments—Tony Tank Pond, and either Morris Mill Pond or Coulbourne (Fooks) Pond (see Figure 1). Sediment-bound phosphorus is subject to settling in these impoundments before reaching Tony Tank Lake. Since 70% to 90% (Illinois EPA 1986) of phosphorus is typically bound to sediment, this component of the phosphorus load to Tony Tank Lake is subject to a degree of removal via such settling. This phenomenon is taken into consideration in the design of the TMDL, and is explained more fully in Section 4.3.

4.3 Vollenweider Relationship Analysis

The Vollenweider Relationship (Figure 4) 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 ($\bar{z}$) 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 ($\bar{z}$), 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.

<u>Tony Tank Lake Mean Depth ($\bar{z}$):</u>

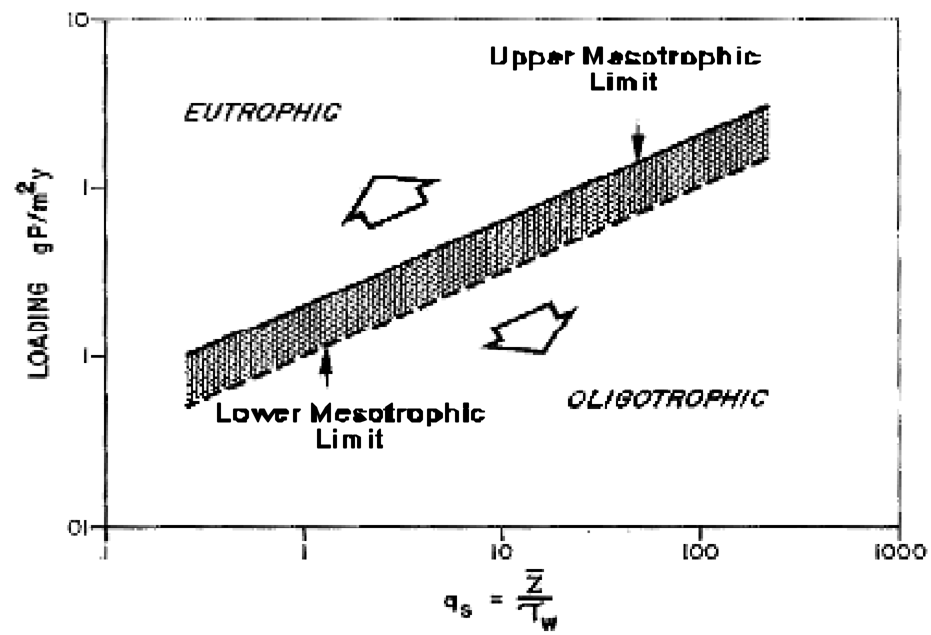

Figure 4. Vollenweider Relationship.

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 Tony Tank Lake are 41.3 acres (1,799,028 ft^2) and 96 acre feet (4,181,760 ft^3), respectively. Mean depth was thus calculated as follows:

- Tony Tank Lake Mean Depth ($\bar{z}$) = (Volume)/(Surface Area) = 2.32 ft (0.71 m)

<u>Phosphorus Loading to Tony Tank Lake (Lp):</u>

Phosphorus loading to Tony Tank Lake is estimated as the load from combined direct runoff to the lake, plus the loadings from Tony Tank Pond, which include drainage from Coulbourne and Morris Mill Ponds. The load estimate is based on EPA/Chesapeake Bay Program model Phase

IV land use phosphorus loading coefficients for the Lower Eastern Shore region (CBPO 1997). This estimate necessitates the use of several assumptions, as described below:

1. The portion of phosphorus associated with sediment is assumed as **85%** throughout the watershed. The remaining phosphorus is assumed to be in dissolved form. This assumption is based on a range of 70-90% of phosphorus bound to sediments (Illinois EPA 1986).

2. Phosphorus transported in association with sediment is subject to removal as that sediment settles out. For the three upper impoundments, sediment trapping efficiency was estimated using the method of Brune (1953). This method estimates trapping efficiencies for impoundments as a function of the ratio of impoundment volume (acre feet) to inflow (acre feet/yr). Volume data were available from DNR (1985). Inflow was assumed to be equivalent to discharge. Since discharge data are unavailable, this parameter was estimated by examining a number of watersheds of various sizes on the Lower Eastern Shore for which long-term flow data were readily available from the U.S. Geological Survey. Average daily flow from each of these stations was plotted against watershed area. Linear regression was used to estimate flow. Estimated sediment trapping efficiencies for the three upper impoundments are presented in Appendix A.

3. All dissolved phosphorus is assumed to pass through the upper impoundments into Tony Tank Lake. In reality, a portion of the dissolved component will be sequestered through biological uptake in the upper impoundments. This may thus be an overestimate of the phosphorus load to Tony Tank Lake.

Accounting for phosphorus removed in conjunction with sedimentation in the upper impoundments, the current total phosphorus loading to Tony Tank Lake is estimated to be 1812 lbs/yr (823.7 kg/yr). Using the lake surface area of 1,799,028 ft^2 (167,195.9 m^2) this value, converted to grams per m^2 year, is:

- Annual Phosphorus Load (L_p) = 4.9 g/m^2 yr. Details are provided in Appendix A.

Tony Tank Lake Hydraulic Residence Time (t_w)

Residence time (t_w) is computed by dividing volume by annual discharge. For Tony Tank Lake, average discharge data are unavailable. Since the spillway is crumbling and irregular in shape, with an unquantifiable cross-sectional area, discharge cannot be estimated mathematically. Discharge was thus estimated using linear regression as described above. Flow from Tony Tank Lake is estimated as follows (details are shown in Appendix A):

- **Flow (Q) = watershed area (13.6 mi^2) x 1.1821 = 16.07 cfs = 11,641.75 acre feet/year**

Lake volume is cited as 96 acre feet (DNR 1985). Hydraulic residence time is thus calculated as follows:

- **Hydraulic Residence Time (t_w) = 96 acre feet/ 11,641.75 acre feet/year = 0.008 years**

The mean depth of the lake (0.71 m) is then divided by hydraulic residence time (0.008 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 Tony Tank Lake, **Q_s = 88.75**.

4.4 Vollenweider Relationship Results

The basic elements of the Vollenweider Relationship, established above, were combined to estimate both the current trophic status of Tony Tank Lake, and the maximum allowable unit loading. The current phosphorus loading of 4.9 g/m^2/yr falls into the eutrophic range, as indicated on Figure 5 below by a diamond "♦". The maximum allowable unit loading of 2.0 g/m^2/yr for a lake with mean depth of 0.71 m and a hydraulic residence time of 0.008 years is indicated by the intersection of two segments. The TMDL implications are presented below in Section 4.5.

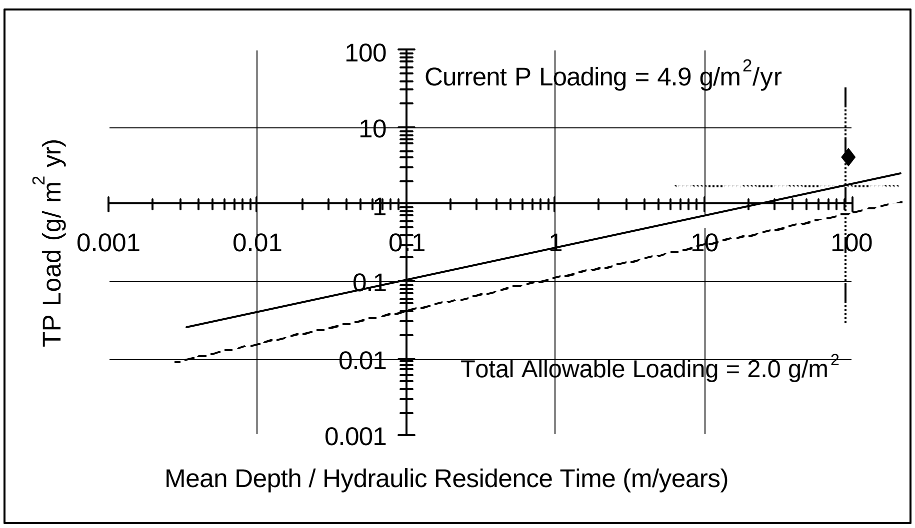

Figure 5. Vollenweider Relationship for Tony Tank Lake

4.5 Total Maximum Daily Loads

The resultant TMDL for phosphorus is based on the unit allowable loading indicated by the results of the Vollenweider Relationship. That is, the unit loading per square meter (2.0 g/m^2 per year) times the total surface area of the lake (167,196 m^2) or 334,392 g/yr. Incorporating a 10%

margin of safety (see section 4.7 for discussion), this TMDL represents a 63.5% reduction from the current phosphorus loading.

EPA Chesapeake Bay Program Phase IV model loading coefficients were used for sediments. Current sediment load to Tony Tank Lake is estimated at 275.7 tons/yr. To quantify the sediment reduction associated with a 63.5% reduction in phosphorus loading, the EPA Chesapeake Bay Program watershed modeling assumptions were consulted. For the agricultural Best Management Practices (BMPs) that affect both phosphorus and sediments, EPA estimates a 1-to-1 reduction in sediments as a result of controlling phosphorus (EPA, CBPO 1998). However, this ratio does not account for phosphorus controls that do not remove sediments.

To estimate the applicable ratio, and hence the sediment load reduction, it is necessary to estimate the proportion of the phosphorus reductions 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 63.5% phosphorus reduction is about 31.8% (0.635 * 0.50 = 0.3175).

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 44.5% estimated reduction in sediment [100*(0.7 * 0.635) = 44.5].

It is assumed that this reduced sediment loading rate would result in a similar reduction in the sediment accumulation rate. Assuming a sediment volume-weight ranging from 10 lb/ft^3 to 25 lb/ft^3, this would result in an estimated preservation of 64% to 85% of the lake's volume after 40 years. See Appendix A for further details concerning this estimate.

TMDLs for Tony Tank Lake are as follows:

PHOSPHORUS TMDL: 735.7 lb/yr = 333,714 g/yr

SEDIMENT TMDL: 188.3 tons/yr = 171,182 kg/yr

4.6 TMDL Allocation

The Clean Water Act and EPA regulations provide for flexibility in implementation of TMDLs, as long as the overall load is not exceeded. In the present case, the watershed that drains to Tony Tank Lake contains two permitted surface water discharges. A review of the permits of these point sources indicates that neither source discharges either phosphorus or sediment; thus they need not be considered in allocating either TMDL. Rather, only nonpoint sources (and a margin of safety) need be considered in determining how to allocate these TMDLs. Details are described in the technical memorandum entitled "Significant Phosphorus and Sediment Nonpoint Sources in the Tony Tank Lake Watershed." Maryland expressly reserves the right to allocate these TMDLs among different sources in any manner that is reasonably calculated to achieve water quality standards.

4.7 Margin of Safety

A margin of safety (MOS) is required as part of a TMDL to account for uncertainties in data and the ability to predict the properties of water quality in natural systems. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = 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 adopted an explicit margin of safety for phosphorus. Following the first approach, the load allocated to the MOS was computed as 10% of the total allowable load. This value is considered reasonable in that it implies an additional 10% reduction in nonpoint source phosphorus loading beyond what would be expected to meet the goal.

Maryland has also incorporated conservative assumptions that effectively constitute an additional, implicit, margin of safety. In calculating minimum DO levels, MDE assumes a water temperature of 30^{o} C. Similarly, an active chlorophyll *a* concentration of 10 μg/l was assumed in calculating the diurnal DO fluctuation. This is at the upper limit of the mesotrophic range (Thomann and Mueller 1987) as predicted using the Vollenweider Relationship. Furthermore, the estimated average solar radiation (500 ly/day) used in calculating diurnal DO fluctuation may be a slight overestimate.

In establishing a margin of safety 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 (662 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 (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.

4.8 Summary of Total Maximum Daily Loads

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

TMDL	=	**WLA**	+	**LA**	+	**MOS**
735.7	=	**0**	+	**662.1**	+	**73.6**

On average, this TMDL represents a daily phosphorus load of 2.02 lbs/day.

Where: LA = Nonpoint Source
WLA = Point Source
MOS = Margin of Safety

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

TMDL	**=**	**WLA**	**+**	**LA**	**+**	**MOS**
188.3 T/yr	**=**	**0**	**+**	**188.3 T/yr**	**+**	**Built-in**

5.0 ASSURANCE OF IMPLEMENTATION

Tony Tank Lake is located in a watershed in which the impairment is dominated by nonpoint source contributions. As such, the implementation provisions will need to be more 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 three specific programs: the Water Quality Improvement Act of 1998 (WQIA), the EPA-sponsored Clean Water Action Plan of 1998 (CWAP), and the State's Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction.

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 these phosphorus nutrient management plans be developed and implemented by 2004. Thus, a specific milestone and benchmark, including a final expected attainment date, has been established for this TMDL against which the adequacy of the initial load allocation and implementation plan can be measured. The water quality response accomplished by the date of this benchmark can be the basis for triggering appropriate load allocation revisions (higher or lower). Additionally, 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.

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 63.5 % reduction of external phosphorus loadings. Taking actions to meet this reduction is estimated to result in a 31.8% reduction in sediment loads.

Because the watershed is 20% agricultural land, meeting these reductions will entail the implementation of agricultural best management practices (BMPs). Table 3 shows estimated reduction efficiencies for individual BMPs based on the "Technical Appendix for Maryland's Tributary Strategy" (Maryland, 1996). These efficiencies, when applied in combination, can be expected to have an ultimate nutrient reduction efficiency that is greater than any single BMP, but less than the sum of the BMPs. Furthermore, agricultural land, though comprising only 20% of the land use in the watershed (Figure 3), contributes 55% of the phosphorus load to Tony Tank Lake. Additionally, due to the sequestration of some loads originating in the portions of the watershed draining initially to the upper impoundments, P loads originating in the lower portion of the watershed have a relatively greater contribution. These factors will need to be considered in the implementation planning phase, which is beyond the scope of the present document.

Table 3

Phosphorus Removal Efficiencies of Various Agricultural BMPs

Best Management Practice	Estimated Range of Phosphorus Removal
Soil Conservation & Water Quality Plan (SCWQP)	11% - 35%
Treatment of Highly Erodible Land	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)

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. Such buffer strips could be established along tributaries draining to Tony Tank Lake, Tony Tank Pond, Coulbourne Pond and Morris Mill Pond. 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).

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Appendix A: Technical Appendix

Assessment of the N:P Ratio for Tony Tank 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 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, phosphorus tends to be limiting, and if the N:P ratio is less than 5, nitrogen tends to be limiting (Chiandani, et al., 1974).

For Tony Tank Lake, the N:P ratio was estimated using EPA/CBPO Phase IV loading coefficients for land use in the Tony Tank basin. Estimated nitrogen loads were summed for the whole watershed and then divided by summed, estimated phosphorus loads. The resulting N:P ratio is 14.1:1, suggesting phosphorus limitation in Tony Tank Lake. It should be noted that this approach assumes that all N and P loads ultimately arrive in Tony Tank Lake. In reality, some of each is removed from the system by sedimentation and biological uptake. Since a far greater proportion of P than of N is bound to sediment and deposited, the true N:P ratio is likely to be higher than 14.1:1.

Supporting Calculations for the Vollenweider Analysis

<u>Tony Tank Lake Mean Depth ($\bar{z}$):</u>

The lake’s design volume and surface area were used to compute mean depth:

Capacity = 96 acre feet = 118,416 m^3

Surface Area = 41.3 acres = 167,195.9 m^2

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

118,416m^3 ÷ 167,195.9 m^2 = **0.71 m**

<u>Phosphorus Loading to Tony Tank Lake (Lp):</u>

Deposition of Sediment-bound Phosphorus:

In order to accurately estimate the amount of phosphorus loading to Tony Tank Lake, an estimate must be made of the amount of sediment-bound phosphorus deposited in the upper impoundments, prior to reaching Tony Tank Lake. The Illinois EPA (1986) reports a range of 70-95% of total phosphorus as bound to sediment. For the Tony Tank Lake analysis, a figure of **85%** was used.

Estimates of the sediment-trapping efficiency of the three upper impoundments were obtained by using the method of Brune (1953). This method estimates trapping efficiencies for impoundments as a function of the ratio of impoundment volume (acre feet) to inflow (acre feet/yr). Impoundment volume was obtained from DNR (1985), while inflow was estimated from watershed size using linear regression as described elsewhere in this document. The median curve for normal ponded reservoirs (Figure A-1) was used to assign the sediment-trapping efficiencies presented in Table A-1.

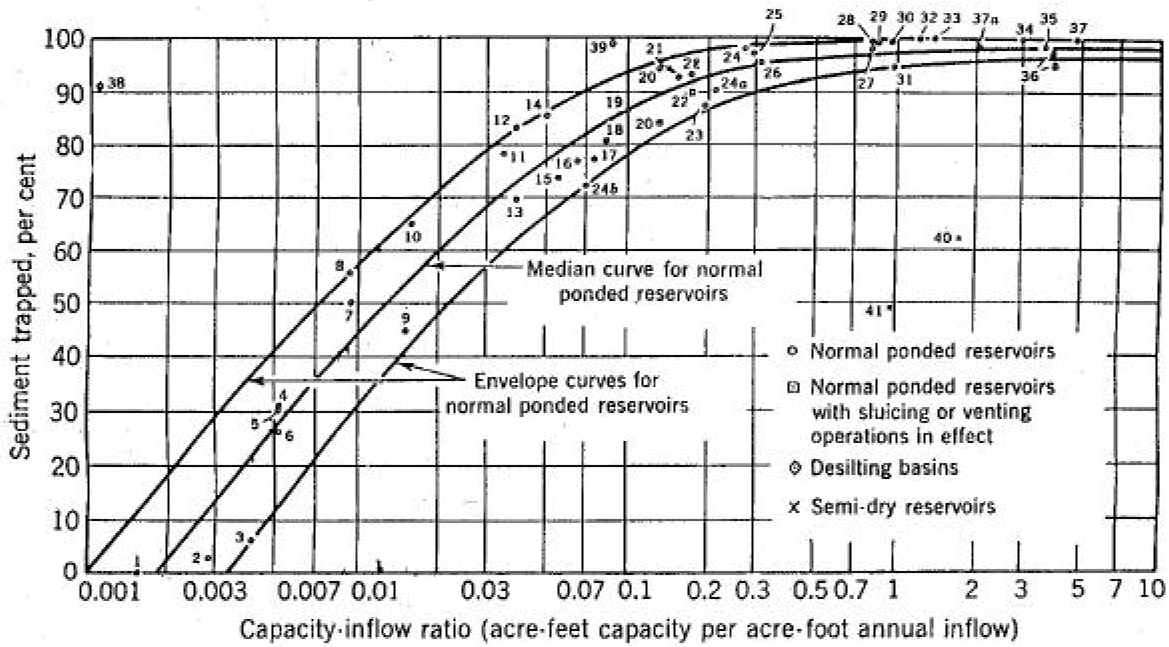

Figure A-1. Brune method for estimating sediment trapping efficiency of impoundments

Table A-1

Sediment-Trapping Efficiencies in Upper Impoundments of Tony Tank Lake System

IMPOUNDMENT	VOLUME (acre feet)	ANNUAL INFLOW (acre feet)	VOLUME/ INFLOW	SEDIMENT TRAPPED (%)
Tony Tank Pond	100	9,845	0.010	45
Morris Mill Pond	19	4,368	0.004	23
Coulbourne (Fooks) Pond	21	4,709	0.004	23

These estimated sediment-trapping efficiencies were applied to the estimated sediment-bound component of the phosphorus loads entering these three water bodies. Phosphorus loads are summarized (Table A-2) below. The **initial load** is the load resulting from modeled direct runoff into the impoundment. The **sediment-bound load** is estimated to be 85% of the initial load, with the remainder being the dissolved fraction (Illinois EPA 1986). **Primary deposition** is defined as the particulate phosphorus component removed via sedimentation in the impoundment receiving the initial load. The initial direct load to Tony Tank *Lake* is not considered subject to removal via sedimentation, since the Vollenweider Relationship equation accounts for settling. **Secondary deposition** represents removal via further sedimentary deposition—in Tony Tank *Pond*—of the particulate phosphorus load originating in runoff to Coulbourne and Morris Mill Ponds. The initial load to Tony Tank Pond is thus considered subject to *primary*, but not *secondary*, deposition. All remaining sediment-bound phosphorus, combined with the dissolved component, constitutes the **final load**.

Table A-2

Summary of Phosphorus Loadings to Tony Tank Lake System

IMPOUNDMENT	INITIAL LOAD	SEDIMENT-BOUND LOAD	PRIMARY DEPOSITION	SECONDARY DEPOSITION	FINAL LOAD
Coulbourne Pond	968.0	822.8	189.2	285.1	493.7
Morris Mill Pond	1077.6	915.9	210.7	317.4	549.5
Tony Tank Pond	913.9	776.8	349.6	0	564.3
Tony Tank Lake	204.6	173.9	0	0	204.6
SUM	3164.1	2689.5	749.5	602.5	1812.1

Values are in pounds per year. Source: U.S. EPA Chesapeake Bay Program, 1997.

The current total phosphorus loading to Tony Tank Lake was estimated to be 1,812.1 pounds per year.

1812.1 lbs/yr x 453.6 g/lb = 821,968.6 g/yr

Using the lake surface area of 167,196 m^2, this value can be converted to grams per square meter per year as follows: 821,968.6 ÷ 167,196 m^2 = **4.9 g/m^2 yr**.

<u>Tony Tank Lake Hydraulic Residence Time (t_w)</u>

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 regressing watershed size versus all discharge data on record for nine watersheds of varying size on the lower Eastern Shore region of Maryland, and adjacent Sussex County, Delaware. Linear regression provided a correlation coefficient (R^2) of 0.9957, and 0.9938 when the Y-intercept was forced to zero. The high R^2 shows a very strong positive correlation between area and resulting flow for a given watershed on the lower Eastern Shore. The insignificant change when the Y-intercept was forced to zero suggests that flow is not significantly affected by sources not proportional to direct runoff—for example, a spring-fed stream. This strengthens the case for estimating discharge of the lake as a function of watershed area. The regression line and equation are shown in Figure A-2 below. The overall Tony Tank Lake watershed measures 13.6 mi^2; the estimated discharge is thus 16.07 cfs (11,641.75 acre feet per year).

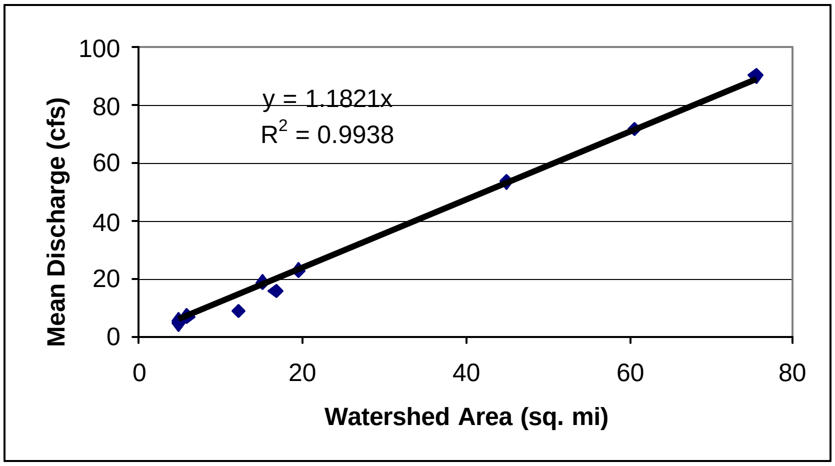

Figure A-2. Discharge as function of watershed area, lower Eastern Shore region of Maryland and Delaware.

Hydraulic residence time (t_w) is calculated as follows:

t_w = (96 acre feet) ÷ (11,641.75 acre feet per year) = **0.008 yr**.

<u>Ratio of Mean Depth to Hydraulic Residence Time ($\bar{z}/t_w$)</u>

From the computations above the mean depth of Tony Tank Lake ($\bar{z}$) is 0.71 m, and the hydraulic residence time (τ_w) is 0.008 yr. The ratio was computed as:

0.71m / 0.008 yr = 88.75 m/yr

Graphing of Trophic Status of Tony Tank Lake using the Vollenweider Relationship

The intersection of the phosphorus loading rate (L_p) = 4.9 g/m^2yr and the ratio ($\bar{z}/\tau_w$) = 88.75 m/yr was plotted on a double-log scale to establish the trophic status of Tony Tank Lake (See Figure 5 in text).

Supporting Calculations for the TMDL Analysis

<u>Graphing of Maximum Allowable Unit Phosphorus loading of Tony Tank Lake using the Vollenweider Relationship</u>

Figure 5 shows how the maximum allowable unit phosphorus loading can be read off of the graph. The intersection of the upper diagonal line with the vertical line at **$\bar{z}/t_w$ = 88.75 m/yr** represents the maximum allowable load, which includes the load allocation and the margin of safety (2.0 g/m^2yr).

Computing the Phosphorus TMDL

The TMDL is computed from the maximum unit load read at the intersection of the upper diagonal line with the vertical line at **$\bar{z}/t_w$ = 88.75 m/yr** on Figure 5 in the text:

(Unit loading) x (Lake Surface Area) = Annual Loading
(2.0 g/m^2 yr) x (167,195.9 m^2) = **334,392 g/*yr***

Converted to pounds per year:
(334,392 g/yr) x (0.0022 lb/g) = **735.7 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) = Annual Loading
(0.10) x (334,392) = **33,439 g/*yr***

Converted to pounds per year:
33,439 g/*yr* x (0.0022 lb/g) **= 73.6 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:

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

$$\frac{(821{,}968.6 \text{ g/yr}) - (300{,}953 \text{ g/yr})}{(821{,}968.6 \text{ g/yr})} = 63.38\ \%\ \text{reduction}$$

* Note that the allowable load does not include the margin of safety.

Supporting Calculations of Expected Minimum DO in Mixed Surface Layer

The dissolved oxygen concentration in the mixed surface waters is a balance between oxygen sources (ambient DO levels in water flowing into the lake, photosynthesis, reaeration) and oxygen sinks (cellular respiration, sediment oxygen demand, and biochemical oxygen demand). Saturation DO concentration is a function of temperature. Conceptually, this balance is represented by the following equation:

$$DO = f(T)\left[\left(DO_{AMBIENT} + DO_{PSN} + \mathrm{Re}\,aeration\right) - \left(Metabolic\,Demands + SOD + CBOD\right)\right]$$

Where:

f(T) = Function of temperature on the following term;
$DO_{AMBIENT}$ = [DO] in water entering the lake;
DO_{PSN} = Photosynthetic DO contribution;
Reaeration = Diffusion of atmospheric O_2 into the water;
Metabolic demands = Metabolic oxygen consumption, including cellular respiration;
SOD = Sediment Oxygen Demand;
CBOD = Carbonaceous Biochemical Oxygen Demand.

Since we are especially concerned with minimum DO levels, a modification of this conceptual equation may be represented as:

$$DO_{MIN} = f(T)\left[(DO_{AMBIENT}) - (Max.Metabolic\,Depletion) - (SOD + CBOD)\right]$$

Where *Max. Metabolic Depletion* represents the maximum diurnal depletion of DO resulting from the calculated photosynthetic and respiratory fluctuation.

Following are two sets of computations. The first estimates the diurnal DO fluctuation resulting from photosynthesis and respiration, while the second addresses the effects of SOD and CBOD. Temperature and reaeration are implicit or explicit terms in both calculations.

Calculations of Dissolved Oxygen Diurnal Fluctuation:

Because the photosynthetic process is dependent on solar radiant energy, the production of oxygen proceeds only during daylight hours. Concurrently with this production, however, the algae (and other aquatic biota) require oxygen for respiration, which can be considered to proceed continuously. Minimum values of dissolved oxygen usually occur in the early morning predawn when the algae have been without light for the longest period of time. Maximum values of dissolved oxygen usually occur in the early afternoon. The diurnal range (maximum minus minimum) may be large, and if the daily mean level of dissolved oxygen is low, minimum values of dissolved oxygen during a day may approach zero and hence create a potential for fish kill. The diurnal dissolved oxygen variation due to photosynthesis and respiration can be estimated based on the amount of chlorophyll *a* in the water. The equations used to calculate the diurnal dissolved oxygen are shown below:

Diurnal Dissolved Oxygen Calculations

$$p_{av} = p_s G(I_a) \qquad \text{where}: p_s = 0.25P$$

$$\frac{\Delta}{P_{av}} = \frac{\left(1-e^{-K_a f T}\right)\left(1-e^{-K_a T(1-f)}\right)}{f\,K_a\left(1-e^{-K_a T}\right)} \qquad \text{where}: a_1 = \frac{I_a}{I_s}e^{-K_e z} \quad , \quad a_o = \frac{I_a}{I_s}$$

Where:

p_{av} = average gross photosynthetic production of dissolved oxygen (*mg* O_2*/l day*)
p_s = light saturated rate of oxygen production (*mg* O_2*/l day*)
P = phytoplankton chlorophyll *a (mg/l*)
$G(I_a)$ = light attenuation factor

$$G(I_a) = \frac{2.718 f}{K_e H}\left[e^{-a_1} - e^{-a_0}\right]$$

f = photoperiod (fraction of a day)
H = the maximum depth (*m*)
K_e = the light extinction coefficient (m^{-1})
I_s = saturation light intensity for phytoplankton (*langley/day*)
I_a = average solar radiation during the day (*langley/day*)
z = depth at which photosynthetic activity is calculated (*m*)
Δ = dissolved oxygen variation due to phytoplankton
K_a = reaeration coefficient (day^{-1})
T = period (Thomann and Mueller 1987)

Input variables for Tony Tank Lake diurnal DO swing calculations are shown below:

p_s = 0.25 P
P = 10.0 *mg/l*
f = 0.6 day
H = 1.83 m
K_e = 1.04 m^{-1}
I_s = 350 langley/day
I_a = 500 langley/day
z = 0.71 m
K_a = 0.5 day^{-1}
T = 1 d

Using these input parameters, a step-by-step breakdown of the diurnal DO variation computation is provided below:

1. Determination of the average gross photosynthetic production of dissolved oxygen (p_a)

   a. $G(I_a)$ (light attenuation factor):

$$G(I_a) = \frac{2.718\ (0.6\,d)}{1.04\ m\ (1.83\ m)}\left[e^{-0.68} - e^{-1.43}\right]$$

$$G(I_a) = 0.228$$

b. $\boldsymbol{p}_{av}$ (light saturated D.O. production rate):

$$p_{av} = p_s G(I_a)$$

$\boldsymbol{p}_{av}$ = 0.57 mg O_2 /l-day

2. Estimate of the diurnal dissolved oxygen range:

$$\frac{\Delta}{P_{av}} = \frac{\left(1-e^{-(0.5/d)(0.6d)(1d)}\right)\left(1-e^{--(0.5d)(1d)(0.4d)}\right)}{0.6d(0.5d)\left(1-e^{-(0.5d)(1d)}\right)}$$

$$\frac{\Delta}{0.57\ mg\ 0_2\ /\ l - d} = 0.398$$

$$\Delta = 0.226\ mg\ 0_2\ /\ l - d$$

For Tony Tank Lake, the diurnal variation in DO is calculated as a range of **0.452** mg/l—i.e., **0.226** mg/l in either direction from the average daily DO concentration.

Calculations incorporating the effects of Sediment Oxygen Demand (SOD) and Carbonaceous Biochemical Oxygen Demand (CBOD):

Sediment oxygen demand and biochemical oxygen demand are included as components of the overall DO concentration in the equation below (Thomann and Mueller 1987):

$$c = \left(\frac{Q}{Q + K_L A}\right)c_{in} + \left(\frac{K_L A}{Q + K_L A}\right)c_s - \left(\frac{VK_d}{Q + K_L A}\right)L - \left(\frac{S_B A}{Q + K_L A}\right)$$

where:

c = lakewide DO accounting for SOD and CBOD
Q = lake discharge = 39,916 m^3/d
K_L = DO transfer rate = 0.87 m/d
K_d = effective deoxygenation rate = 0.2/d*
L = ambient lake CBOD 2.0 mg/l (common value for Maryland waters)
A = area = 167,200 m^2
V = volume = 118,712 m^3
S_B = SOD rate = 0.5 g/m^2/d** (Ambrose *et al*. 1988)
c_s = ambient lake saturation DO level at T = 30^o C = 7.559 mg/l (Thomann and Mueller 1987)
c_{in} = DO in incoming flow to the lake = assumed as 5.0 mg/l***

* K_d is 0.2/d at 20^o C. To account for the assumed critical ambient temperature of 30^o C, the formula below was used to calculate K_d:

$$(K_d)_T = (K_d)_{20} 1.047^{T-20}$$

where $(K_d)_T$ and $(K_d)_{20}$ are deoxygenation rates at water temperature T(^{o}C) and 20^o C, respectively (Thomann and Mueller 1987). Thus,

$$(k_d)_{30} = (0.2/d)1.047^{30-20}$$
$$(k_d)_{30} = 0.3/d$$

** S_B is 0.5 g/m^2/d at 20^o C. To account for the assumed critical ambient temperature of 30^o C, the formula below was used to calculate S_B:

$$(S_B)_T = (S_B)_{20}(1.65)^{T-20}$$

where $(S_B)_T$ and $(S_B)_{20}$ are SOD rates at water temperature T(^{o}C) and 20^o C, respectively (Thomann and Mueller 1987). Thus,

$$(S_B)_T = 0.5 \text{ g } O_2/m^2/\text{day} * 1.065^{10}$$
$$(S_B)_T = 0.92 \text{ g } O_2/m^2/\text{day}$$

*** No data for this parameter are available. Surface DO concentrations in both Tony Tank Lake and Tony Tank Pond exceeded 8.0 mg/l during 1993 sampling events. Any value of c_{in} greater than 2.5 mg/l will result in a theoretical minimum DO concentration in excess of 5.0 mg/l. Since observed data do not suggest low DO in surface waters, a value of 5.0 mg/l is assumed.

Using these input parameters, a step-by-step breakdown of the in-lake DO computation (including SOD) is provided below:

$$c = \left(\frac{39916 \; m^3/d}{39916 \; m^3/d + (0.87 \; m/d)(167200 \; m^2)} \right) 5.0 \, mgO_2/l +$$

$$\left(\frac{(0.87 \; m/d)(167200 \; m^2)}{39916 \; m^3/d + (0.87 \; m/d)(167200 \; m^2)} \right) 7.559 \; mgO_2/l -$$

$$\left(\frac{35614 \; m^3}{39916 \; m^3/d + (0.87 \; m/d)(167200 \; m^2)} \right) 2.0 \, mgO_2/l -$$

$$\left(\frac{0.92 \; g/m^2/d \, (167200 \; m^2)}{39916 \; m^3/d + (0.87 \; m/d)(167200 \; m^2)} \right)$$

Thus, ***c*** = 5.794 mgO_2/l.

Final Estimate of Minimum DO under Critical Conditions:

Including SOD, an adjusted lakewide DO of **5.794 mg/l** is estimated for Tony Tank Lake. Incorporating the DO depletion estimated to result from diurnal variation (0.226 mg/l), the predicted theoretical minimum DO concentration under the assumed conditions is **5.570 mg/l.**

<u>Estimating the Sediment TMDL</u>

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 are 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, and 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 3 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) since the sediment reduction effects of conservation tillage have not been counted.

Table 3

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	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)

To estimate the net sediment reduction associated with the 58 percent phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:

100* (0.5 * 0.634) = **31.8 percent reduction in sediment loads**

Applying this reduction to the current estimation of 275.7 tons of sediments per year results in the estimated reduction, the converse of which is the estimated allowable load:

(0.317 * 275.7) = 87.2 tons/year reduction
275.7 - (0.317 * 275.7) = **188.5 tons/year allowable sediment load**

Estimation of Volumetric Preservation of Tony Tank Lake

No bathymetric studies have been performed to establish volume loss due to sedimentation in Tony Tank 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 lbs/ft^3 to 59.9 lbs/ft^3. Tony Tank 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. Furthermore, the bulk of inflow to the lake passes through one or more impoundments, with preferential settling of larger particles in the upper impoundments, and greater passage of fine particles on to Tony Tank Lake. For these reasons, it is likely that the volume-weight of sediments in Tony Tank 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 lbs/ft^3) is used. With an annual load of 188 tons, this range results in an annual volume loss of 0.35 acre-feet (25 lbs/ft^3) to 0.86 acre-feet (10 lbs/ft^3). Table 4 (below) expresses these annual losses in terms of preservation of the lake's volume over time.

Table 4

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

Time Period	**Range Of Volumetric Preservation**
40 Years	64% to 85%
70 Years	37% to 74%
100 Years	10% to 64%