Total Maximum Daily Loads of Phosphorus and Sediments to Johnson Pond in the Upper Wicomico Watershed Wicomico County, Maryland

Prepared by:

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

Submitted to:

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 Johnson Pond, the Upper Wicomico River watershed was identified on Maryland's 1996 list of WQLSs as being impaired by nutrients and sediments. This report proposes the establishment of two TMDLs for Johnson Pond: one for excess sedimentation and one for phosphorus.

Once the TMDLs are approved by the United States Environmental Protection Agency (EPA), they will be incorporated into the State's Continuing Planning Process. In the future, the established TMDLs will support restoration and control measures needed to restore water quality in Johnson Pond.

EXECUTIVE SUMMARY

On the basis of water quality problems associated with Johnson Pond, the Upper Wicomico River watershed (02-13-03-04) 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 Johnson Pond.

Johnson Pond is an impoundment at the outlet of the Upper Wicomico River, a tributary to Monie Bay. Monie Bay lies in the Lower Eastern Shore Tributary Strategy Basin as defined in Maryland's plans to achieve the nutrient goals of the Chesapeake Bay Agreement (MDE 1995). Johnson Pond is impacted by a high sediment load, which has resulted in excessive sedimentation of the reservoir. The pond also experiences occasional 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 pond's ecosystem balance and cause fish kills. Phosphorus is most likely the limiting nutrient for the production of algae in freshwater lake systems such as Johnson Pond. 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 Johnson Pond. This reduced loading rate is predicted to resolve excess algae problems and maintain dissolved oxygen concentration above the State water quality criteria. The TMDL for phosphorus was determined using empirical methods known as the Vollenweider Relationship and Carlson's Trophic State Index . Because the reduction of sediments is a component of controlling external phosphorus loads, a sediment loading rate consistent with narrative water quality criteria is predicted to be achieved.

The average annual TMDL for phosphorus is about 5,093 lb/yr. There are point sources in the Johnson Pond basin. Consequently, the allocation is partitioned between nonpoint sources, point 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. This loading rate is estimated to result in preserving about 74% of the reservoir's design volume over a period of 56 years.

Preliminary estimations of the phosphorus controls necessary to achieve the load reduction were conducted to provide a reasonable assurance that the TMDLs could be implemented. Because this lake has significant loading rates, it is estimated that 39% reduction (from total) and 49% (from non-point sources) in phosphorus loads would be necessary to meet the TMDL for phosphorus. This challenging goal can be put into perspective in two regards. First, the percentage of nutrient reduction associated with standard agricultural best management practices (BMPs) is greatest for easily erodible soils, which are present in the Johnson Pond drainage basin (Coastal Environmental Services, Inc, May 1990). 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.

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 the Section 303(d) list. A TMDL reflects the maximum pollutant loading of the impairing substance a water body can receive and still meet water quality standards. A TMDL can be expressed in mass per time, toxicity, or any other appropriate measure (40 CFR 130.2(i)). TMDLs must take into account seasonal variations and a margin of safety (MOS) to allow for uncertainty. Maryland’s 1996 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), lists the Upper Wicomico River watershed segment (02130304) for nutrients and sediments. That 1996 listing was prompted by quantitative data associated with Johnson Pond (MDE, 1995).

In 1990, Coastal Environmental Services, Inc. prepared a study of Johnson Pond for the City of Salisbury, Maryland. The goals of the study were “to identify the sources of nutrient and sediment loading to the pond, quantify the annual nutrient and sediment loads generated by all sources, prioritize each source based on the magnitude of the annual loads and prepare a restoration and management plan for the pond.” The results indicate excessive sedimentation and severe algal blooms as a result of high nonpoint source loading coming principally from agricultural land.

This document is not intended to replicate or update the 1990 study of Johnson Pond. The reader is referred to the study for a more in-depth discussion of the chronology of activities and studies relating to Johnson Pond. The limited purpose of this document is to establish TMDLs for phosphorus and sediments entering Johnson Pond, as required by Section 303(d) of the Clean Water Act.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Johnson Pond is a fairly large impoundment located at the outlet of the Upper Wicomico River in Wicomico County, Maryland (Figure 1). The Wicomico River is a tributary of Monie Bay, which lies in the Lower Eastern Shore Tributary Strategy Basin. Monie Bay drains to the Chesapeake Bay via Tangier Sound (MDE, May 1995). The impoundment, owned by the City of Salisbury, originally served as a mill pond but was significantly expanded following construction of a concrete dam in 1933 to its present dimension (Table 1) (Maryland Tidewater Administration, 1988). The dam at Johnson Pond is the designated dividing line between tidal and non-tidal waters in the Wicomico River.

Inflow to the pond is primarily via three major tributaries (Figure 1). Little Burnt Branch, Connelly Mill Branch, and Leonard's Pond Run merge to form the northernmost tributary while Middle Neck Branch and Peggy Branch merge to form the easternmost tributary. Brewington Branch enters the northeast arm of the pond between the other two main tributaries. Under base flow conditions, the tributaries are generally shallow (1-3 feet) at their point of discharge to the pond. Discharge from the pond is to the Wicomico River, which flows southwesterly to the Chesapeake Bay. Land use distribution in the watershed is approximately 41% agricultural, 42% forested, and 17% developed (Figure 2). Two significant point source discharges of nutrients are considered in the Johnson Pond

TMDL analysis. Delmar Wastewater Treatment Plant is permitted to discharge 0.650 million gallons per day (mgd) of treated domestic wastewater into Wood Creek, which empties into Leonard Pond Run. The Perdue Farms, Inc., Salisbury, Wastewater Treatment Plant is permitted to discharge 0.160 mgd of treated wastewater and 0.800 mgd of non-contact cooling water (drawn from wells under permit No. WI55G001) into Peggy Branch, which empties into Middle Neck Branch.

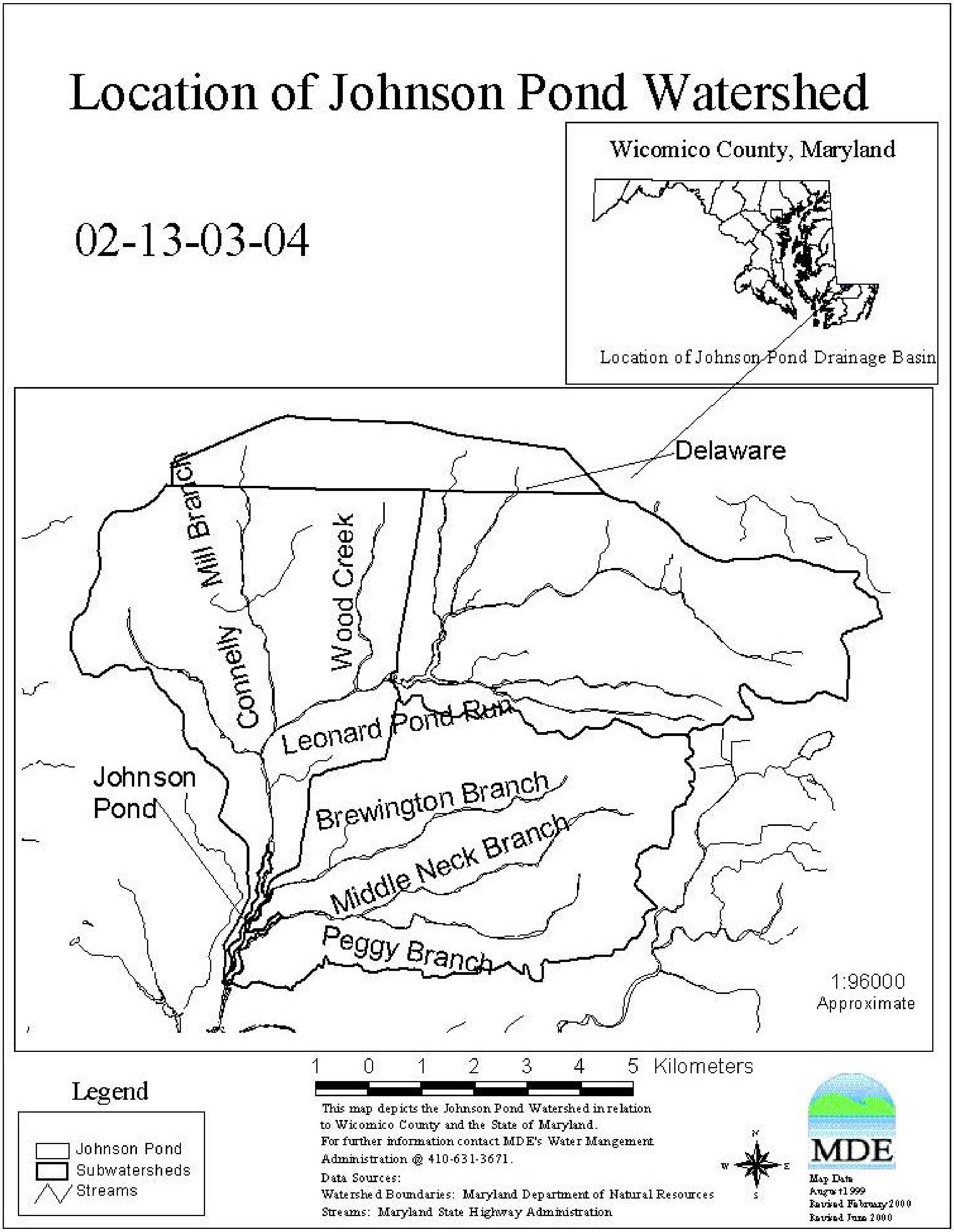
The model uses water quality data to estimate the current total phosphorus load to Johnson Pond. This estimate represents the cumulative impact from all sources—naturally-occurring and human-induced. The current sediment load was calculated using the Chesapeake Bay Program, Phase IV sediment loading rates in tons/acre/year for various land uses. Atmospheric sources (directly to the lake surface) of sediments and phosphorus due to wind erosion are considered insignificant because the ratio of the watershed area to the surface area of the Pond is large (184:1).

Johnson Pond lies in the Atlantic Coastal Plain physiographic province. The soils immediately surrounding the lake are the Evesboro-Klej association (Soil Conservation Service, 1970) and are easily erodible. These soils generally range from level to steep, excessively drained to somewhat poorly drained sands, and are characterized by loamy sands in upland areas. The outer watershed area is comprised of soils of the Matawan-Norfolk association. These soils are typically level to gently sloping, moderately well-drained and well-drained uplands soils that have a subsoil of friable or firm sandy clay loam. A portion of the extreme eastern section of the watershed contain soils of the Elkton-Matawan-Bayboro association. These are level to gently sloping, very poorly drained to moderately well-drained upland soils that have a subsoil of plastic silty clay, sandy clay loam, or sandy clay. Several relevant statistics for Johnson Pond are provided below in Table 1. Since a large volume of the lake has been lost to sedimentation, the TMDLs are developed under the assumption that the lake will be dredged to restore its approximate 1933 physical dimensions.

Table 1
Current Physical Characteristics of Johnson Pond

Location:	Wicomico County, MD lat. 38^{o} 22’ 40” long. 75^{o} 36’ 10” *
Surface Area:	55 ha (136 acres)
Length:	1.5 miles *
Maximum Width:	1500 feet *
Average Depth (Current)	7.0 feet*
Maximum Depth (Current)	20.3 feet *
Permanent Pool Elevation:	6.1 m (20 feet) above mean sea level *
Drainage Area to Lake:	10,114.4 ha (24,993 acres)
Average Discharge:	47.8 cfs
Current Volume (calculated):	41.4 Million ft^3 (1.17 Million m^3)
Original Volume (calculated):	62.1 Million ft^3 (1.76 Million m^3)

* Results of Survey by Coastal Environmental Services, Inc in August 1989

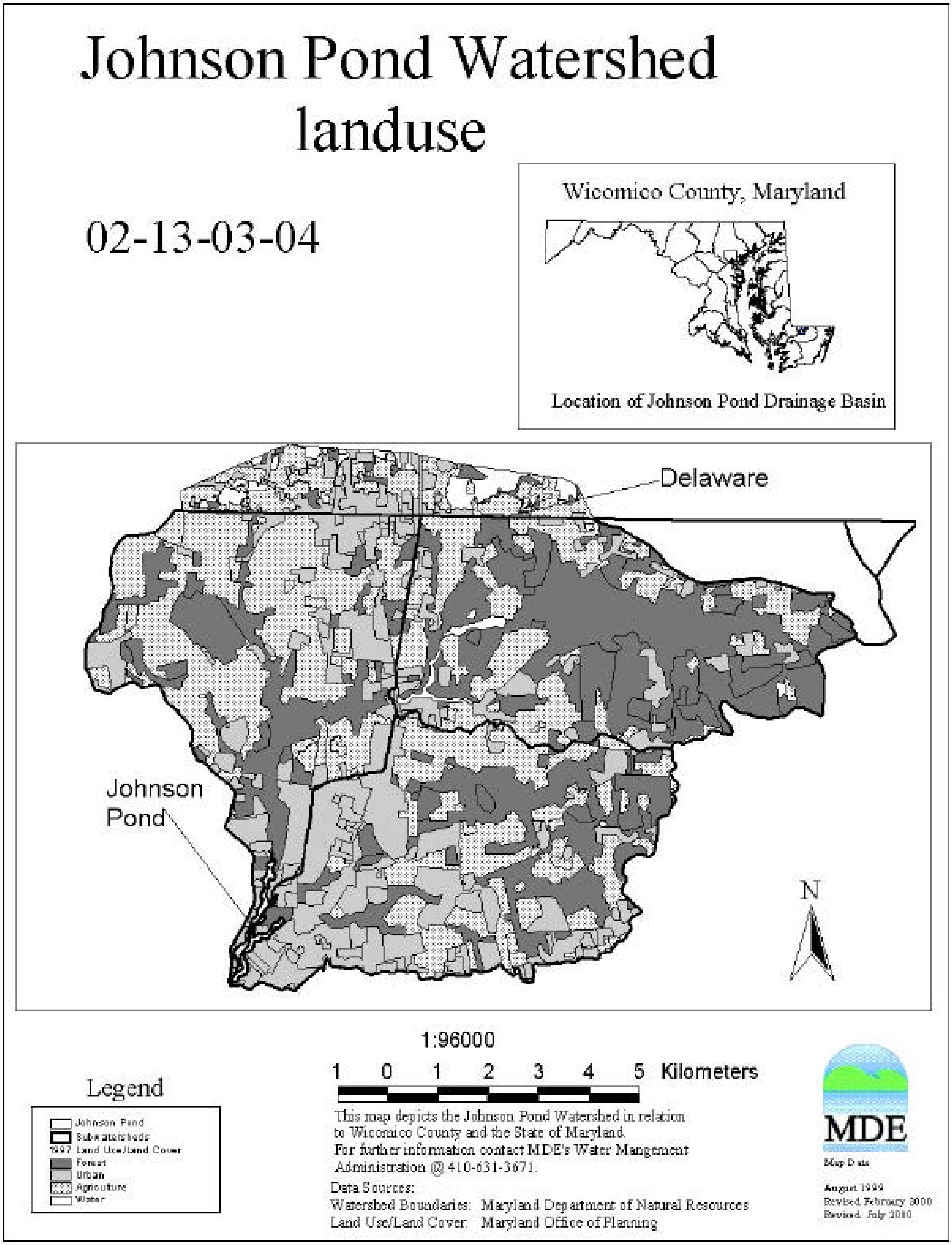


This map depicts the Johnson Pond Watershed in relation to Wicomico County and the State of Maryland.
For further information contact MDE's Water Mangement Administration @ 410-631-3671.

Data Sources:
Watershed Boundaries: Maryland Department of Natural Resources
Streams: Maryland State Highway Administration

Map Date
August 1999
Revised February 2000
Revised June 2000

Figure 1



This map depicts the Johnson Pond Watershed in relation to Wicomico County and the State of Maryland. For further information contact MDE's Water Mangement Administration @ 410-631-3671.

Data Sources:
Watershed Boundaries: Maryland Department of Natural Resources
Land Use/Land Cover: Maryland Office of Planning

Figure 2

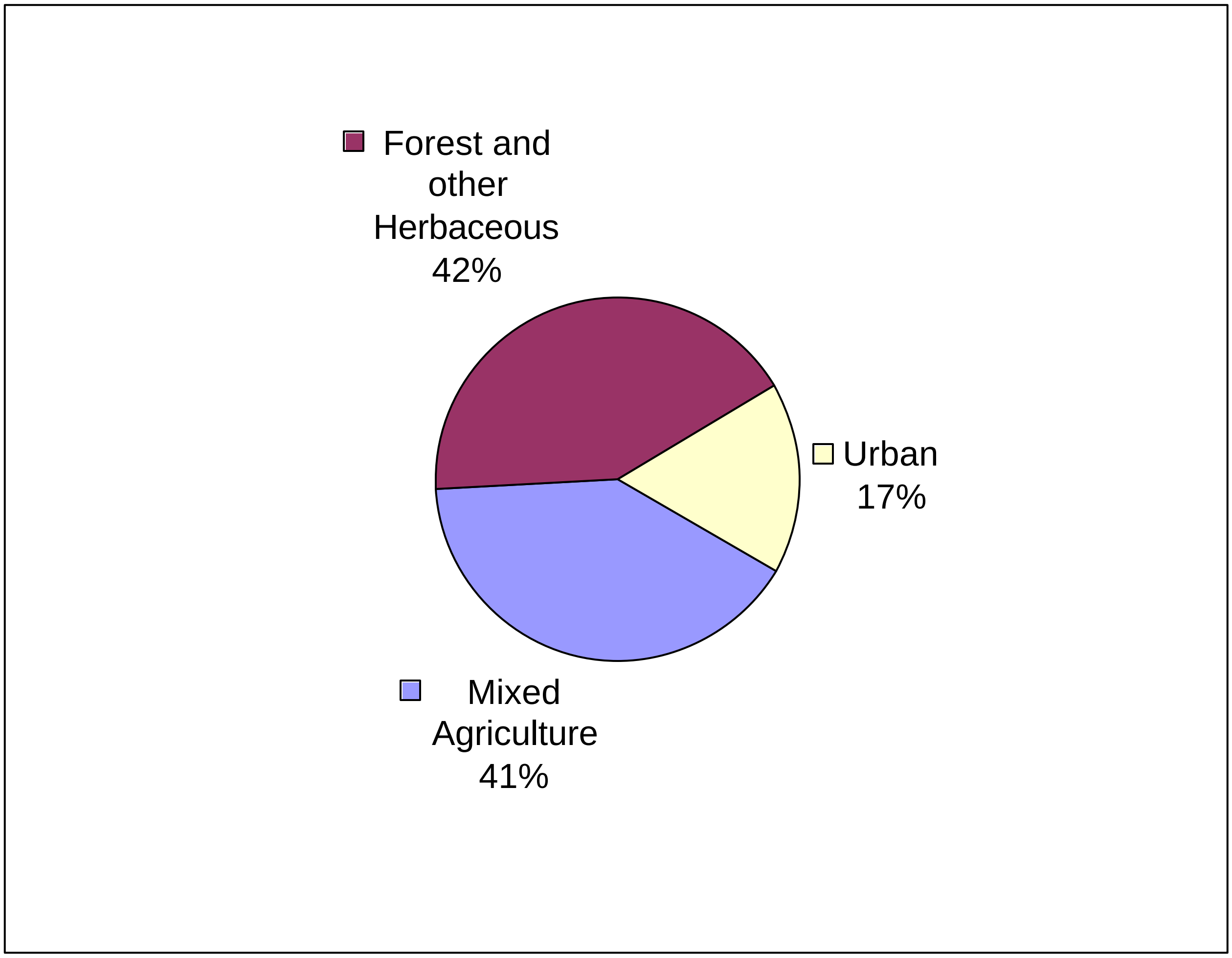


Figure 3. Land Use in Drainage Basin of Johnson Pond

2.2 Water Quality Characterization

Johnson Pond was identified as eutrophic and use-impaired, utilizing a trophic classification index and data from samples collected as part of the statewide lake assessment program in 1993. The pond suffers from algal blooms in the summer months, low levels of dissolved oxygen and an impaired fishery (Maryland Lake Water Quality Assessment Report , 1997, DNR, 1998); Maryland's 1994 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. Water quality sampling was conducted at Johnson Pond during 1990-93 by the Coastal Environmental Services, Inc. for the City of Salisbury (see Appendix A, Table A-1). Monitoring of Johnson Pond and tributaries was also conducted by MDE's field office during 1998. The first effort was made during high flow conditions

(2/18/98, 3/11/98 and 4/1/98) and low flow conditions(7/28/98, 8/24/98 and 9/22/98) to collect samples from the tributaries. Samples were analyzed by Chesapeake Biological Laboratory and the results were entered into the MDE's database. During this survey, input to and output from Johnson Pond were sampled, and no samples were collected from the pond itself. Total phosphorus input to the pond (Station WIW0241) ranged from 0.02780 mg/l to 0.0521 mg/l. Similarly, the output from the pond ranged from 0.04810 mg/l to 0.1018 mg/l (see Table-A2).

During the second effort (4/2/98-8/13/98), extensive sampling was done at the entry and exit locations for the pond, and the samples were analyzed by the Department of Health and Mental Hygiene (DHMH) laboratory (see Tables A-3 and A-4).

During the third effort (7/23/98-8/27/98), extensive sampling was done in the pond, and the samples were analyzed by DHMH laboratory (see Tables A -5 through A-7).

Dissolved oxygen concentrations ranged from 1.1 mg/l near the bottom of the pond to 14.9 mg/l near the surface (see Tables A-5 through A-7). Temperature ranged from 20°C near the bottom to 29°C near the top during July and August of 1998. Total phosphorus concentrations ranged from 0.02 mg/l to 0.11 mg/l (see Table A-1). Total nitrogen ranged from 2.6 to 3.7 mg/l. Nitrate and nitrite remained in the range of 1.9 to 3.1 mg/l (see Tables A-5 through 7). Ammonia was relatively low (<0.2 to 0.5 mg/l) in the pond's waters during July and August of 1998.

2.3 Water Quality Impairment

The Maryland water quality standards Surface Water Use Designation (COMAR 26.08.02.07) for Johnson Pond is Use I - *Water Contact Recreation, and Protection of Aquatic Life*. The water quality impairments of Johnson Pond consist of a violation of the numeric water quality for dissolved oxygen, and violations of general narrative criteria applicable to Use I waters. 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 how phosphorus was determined to be 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)). In lake environments, low levels of dissolved oxygen are expected in bottom waters even under optimal natural conditions. However, achievement of 5.0 mg/l is expected in the well-mixed surface waters.

In addition to the violation of the numeric criteria for DO, certain narrative criteria for meeting the Use I designation (COMAR 26.08.02.03B) are violated. Specifically, excessive nutrient enrichment of Johnson Pond 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, Johnson Pond has experienced excessive sediment loads. In addition to carrying nutrients, the excessive sediment loads are filling in the reservoir at a high rate. Since 1933, sedimentation has reduced the lake’s volume from 62.1 to 41.4 million cu. ft. The reduction in fish habitat and impediment to recreational use (e.g., fishing and boating) violate narrative water quality criteria.

3.0 TARGETED WATER QUALITY GOALS

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

Raschke (1994, *in* EPA 1999) reports that a mean growing season chlorophyll *a* concentration of <25 μg /L is recommended to maintain a minimal aesthetic environment for viewing pleasure, safe swimming, and good fishing and boating. Hendricks, Maceina and Reeves (1995) analyzed black bass (*Micropterus* spp.) tournament catch data from 27 Alabama reservoirs over a five-year period from 1986-1991. Among many parameters, concentrations of chlorophyll *a* were positively correlated both with average weight of the bass caught, and with frequency of 'memorable size' (≥ 2.27 kg) catches.

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

Johnson Pond lies in the Mid-Atlantic Coastal Plain (MACP) ecoregion, which extends from central New Jersey to northern Georgia. Topography is low and flat, soils are sandy, the dominant land use is agricultural, and there are few natural lakes (none in Maryland). Impoundments tend to be shallow with large watershed/surface area ratios, resulting in a relatively high degree of allochthonous nutrient loading. Morphometry thus favors eutrophy. The MACP ecoregion is topographically and functionally similar to the two agricultural ecoregions Heiskary describes in Minnesota.

Johnson Pond is used as a recreational warm-water (bass) fishery. Moderate degrees of eutrophication are compatible with sustenance and enhancement of such warm water fisheries. An appropriate management goal, therefore, is to enhance or maintain support of this fishery. An endpoint, seeking to maintain the productive fishery while avoiding nuisance algal blooms, is a maximum permissible chlorophyll *a* level of 20 μg/l. This corresponds approximately to a Carlson's TSI of 60.

The overall objective of the TMDLs established in this document is to reduce phosphorus and sediment loads to levels that are expected to result in meeting all water quality criteria that support the Use I designation. Specifically, one goal is to improve the trophic status of Johnson Pond by reducing the total phosphorus loads. This is predicted in turn to reduce excessive plant and algae growth, which leads to violations of the numeric DO criteria, 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 Johnson Pond;

2. Resolve violations of narrative criteria associated with excess phosphorus enrichment of Johnson Pond; and

3. Resolve violations of narrative criteria associated with excess sedimentation of Johnson Pond 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 Johnson Pond. The second subsection describes the analysis for determining that phosphorus is likely to be the limiting nutrient in Johnson Pond, 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

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

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

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

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

When considering the results of TSI calculations, one should recall the assumptions on which the carbon formulae are based: 1) Secchi transparency is a function of phytoplankton biomass: 2) phosphorus is the factor limiting algal growth; and 3) total phosphorus concentration directly correlates with algal biomass.

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

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

In general, an N:P ratio in the range of 5 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 et al., 1974). An N:P ratio of well over 10 was computed, which supports the use of the Vollenweider Relationship. Supporting data are provided in Appendix A.

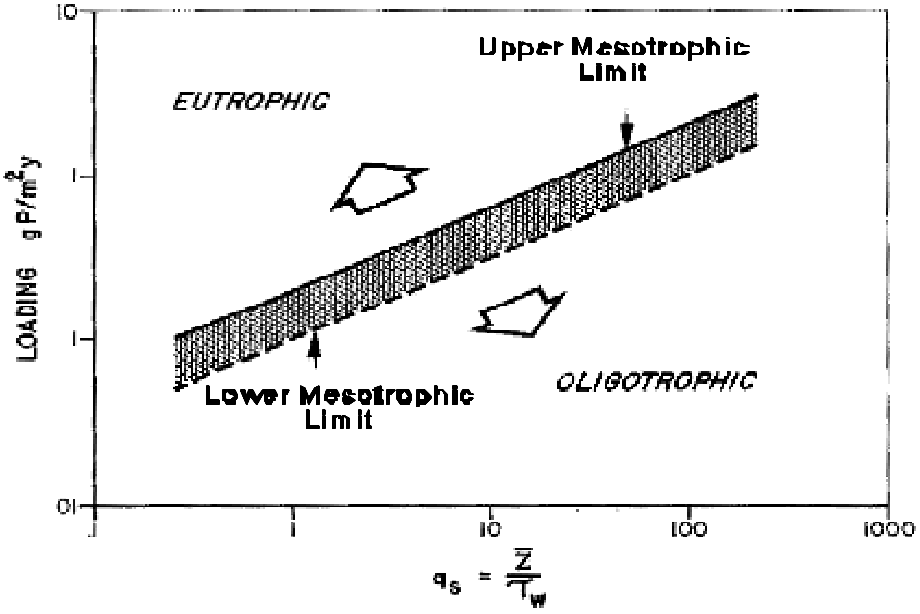


Figure 4. Vollenweider Relationship

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 (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.

Johnson Pond Mean Depth ($\bar{Z}$):

The application of the Vollenweider assumes the lake's physical dimensions to include the volume lost to sediments which was measured during the 1989 field survey and the volume determined by measuring water depths during the 1988 Statewide Fisheries Survey (Maryland Tidewater Administration ,1988)[1]. A survey of in-lake sediment accumulation was conducted in August 1989 as a part of the field study program. Six sampling transects were established so as to adequately reflect and represent the major morphometric features of Johnson Pond. At least one transect was located in each arm of the pond and in the pond's main body. At about 15-foot intervals along each transect, a

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[1] This assumption is in recognition that the natural tendency is for reservoirs to accumulate sediments, which eventually must be removed if the lake is to persist. Thus, the original design capacity is the most logical baseline upon which to establish the TMDLs .

calibrated rod was hand-driven through the loose sediments to the point of first refusal. The depth of penetration was recorded and then mapped. An average of these depths of accumulated sediment was calculated and was used to determine the volume of accumulated sediment. The mean lake depth was computed by adding these two volumes and then dividing it by the surface area of the lake. The surface area of Johnson Pond during the 1988 survey was 55 hectares or 136 acres (550,000 m^2).

Johnson Pond Volume: 1,758,672 m^3 (1933 conditions, from Appendix A, Page A-10)

Johnson Pond Surface Area: 55 hectares or 550,000 m^2

Johnson Pond Mean Depth($\bar{z}$): (Volume)/(Surface Area) = 3.20 m (1933 conditions, from Appendix A, Page A-10)

Phosphorus Loading to Johnson Pond (Lp):

The total phosphorus loading is cited as 3.418 tons per year based on the 1998 Water Quality Data. (Appendix A, Page A-11). Expressing this value as a loading per surface area of the lake gives:

Annual Phosphorus Load (L_p) is: 6.2 g/m^2 yr. Details are provided in Appendix A, Page A-11.

Maximum Allowable Phosphorus Load (L_p) is 4.2 g/m^2yr Details are provided in Appendix A, Page A-13.

Johnson Pond Hydraulic Residence Time (τ_w)

The hydraulic residence time is computed as volume/outflow; the time it would take to drain the lake. Assuming a volume of 1,758,672 m^3, and a discharge rate of 42,378,631 m^3/yr (Water Quality Data 1998) the hydraulic residence time would be 1,758,672 m^3/42,378,631 m^3/yr = 0.0415 yr.

Johnson Pond Hydraulic Residence Time (t_w): 0.0415 years

4.4 Vollenweider Relationship Results

The basic elements of the Vollenweider Relationship, established above, were combined to estimate the current trophic status of Johnson Pond. The maximum allowable unit loading was estimated using both Vollenweider Relationship and Carlson's trophic status index. The current trophic status associated with a loading of 6.2 g/m^2 yr falls well into the eutrophic range, as indicated on figure 5 by a diamond “♦”. The maximum allowable unit loading of 4.2 g/m^2 yr for a lake with mean depth of 3.20 m and hydraulic residence time of 0.0415 year is indicated by a circle " ● " . This loading of 4.2 g/m^2 yr corresponds to an estimated chlorophyll level of 20 µg/l associated with a TSI of 60. The TMDL implications are presented in Section 4.5.

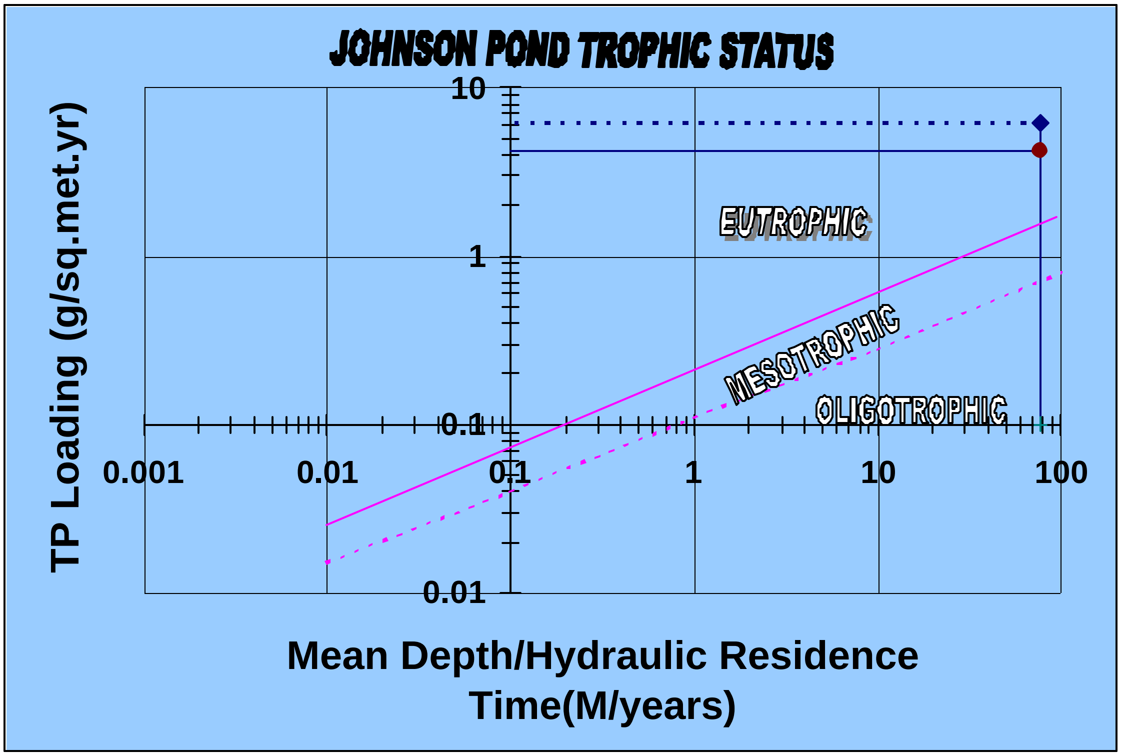

Figure 5. Vollenweider Results for Johnson Pond

4.5 Total Maximum Daily Loads

This TMDL appropriately 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 current in pond TSI of 67.5 corresponds to a chlorophyll concentration of 43 µg/l and a loading rate of 3,418,166 g/yr. The TMDL water quality endpoint, which will maintain the warm water fishery and avoid nuisance algal blooms, is a maximum TSI of 60, which is associated with the lower range of eutrophic conditions. A TSI of 60 results in a chlorophyll concentration of 20 µg/l and a loading rate of 2,310,000 g/yr. This represents a 39% 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 over enrichment causes excess algal blooms, which eventually die off and decompose, consuming DO. Several computations are provided to account for the key processes that determine DO concentration in the well-mixed surface layer of a lake (see Appendix A). These processes, as they apply to Johnson Pond, are outlined below. This assessment is based on critical conditions and uses conservative assumptions:

- Dissolved oxygen saturation capacity as a function of water temperature.
- The diurnal variation in DO resulting from the shift between daytime photosynthetic activity and nighttime respiration of algae. This is calculated as a function of the concentration of active Chlorophyll-*a*, which is inputed from the lake's targeted slightly eutrophic status (defined by the Vollenweider Relationship) to range from 10 to 20 µg/l (Chapra 1997).
- Sediment Oxygen Demand (SOD).
- Carbonaceous Biochemical Oxygen Demand (CBOD).
- Water reaeration.

According to calculations presented in Appendix A, it is expected that an areal phosphorus load of 4.2 g/m^2 will result in a minimum surface DO concentration of about 5.109 mg/l.

No single critical period can be defined for the water quality impact of sedimentation. Sedimentation negatively impacts the lake regardless of when it occurs. In terms of sediment loading, the critical conditions occur during wet-weather events when the greatest amount of sediment is delivered to the lake. 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, 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 49% NPS phosphorus reduction is about 24.5% (0.49 * 0.5 = 0.245). 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 74% of the impoundment's volume after 56 years. MDE believes that this volumetric retention will support the designated use of Johnson Pond (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 34.3% estimated reduction in sediment [100*(0.7 * 0.49) = 34.3%]

PHOSPHORUS TMDL	2,310,000 g/*yr* = 5,093 lbs/yr
SEDIMENT TMDL	2,008 Tons/yr

4.6 TMDL Allocation

The watershed that drains to Johnson Pond contains two permitted surface water discharges. The model uses water quality data to estimate the non-point source loading rates, which represent the cumulative impact from all sources—naturally-occurring and human-induced. Atmospheric sources of sediments and phosphorus due to wind erosion are considered insignificant because the ratio of the watershed area to the surface area of the lake is large (184:1). All significant point and non-point sources are included in the allocation and are described further in the technical memorandum entitled *Significant Point and Non-point Phosphorus and Sediment Sources in the Johnson Pond Watershed, Wicomico County, Maryland.* Because the loading estimates are based on total annual load estimated from monitored data, rather than a loading model, the allocation of the nonpoint source load is not attributed to specific land uses. Given the small size of the watershed, the assignment of load reductions to specific subwatersheds is considered to be an implementation planning element, which is beyond the scope of this TMDL.

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 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 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; the highest temperature observed during monitoring was 29^o C.

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 (4,584 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 93 tons/yr (see Appendix)

4.8 Summary of Total Maximum Daily Loads

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

TMDL	=	**WLA**	+	**LA**	+	**MOS**
5,093	=	**1135**	+	**3,449**	+	**509**

On average, this TMDL represents a daily phosphorus load of 14 lbs/day.

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

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

TMDL	=	**WLA**	+	**LA**	+	**MOS**
2,008	=	**34**	+	**1974**	+	**Implicit**

On average, this TMDL represents a daily sediment load of 12,877 lbs/day.

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the nitrogen and phosphorus TMDLs will be achieved and maintained. For both TMDLs, Maryland has several well-established programs that will be drawn upon: the Water Quality Improvement Act of 1998 (WQIA), the Clean Water Action Plan (CWAP) framework, and the State's Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction. Also, Maryland has adopted procedures to assure that future evaluations are conducted for all TMDLs that are established.

Maryland’s WQIA requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout Maryland. This act specifically requires that nutrient management plans for nitrogen be developed and implemented by 2002, and plans for phosphorus to be done by 2005. Maryland’s CWAP has been developed in a coordinated manner with the State's 303(d) process. All Category I watersheds identified in Maryland's Unified Watershed Assessment process are totally coincident with the impaired waters list for 1996 and 1998 approved by EPA. The State is giving a high priority for funding assessment and restoration activities to these watersheds.

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

The implementation of point source nutrient controls will be executed through the use of NPDES permits. The NPDES permits for the Delmar WWTP and Perdue Farms, Inc WWTP, which are the only plants discharging to the Johnson Pond drainage basin, will require implementation of Chemical Phosphorus Removal (CPR) . The NPDES permits for these two WWTPs will have compliance provisions, which provide a reasonable assurance of implementation.

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

The findings of the TMDL analysis indicate that the implementation of the TMDL on the basis of external loading controls can be achieved through a 53% reduction in point source and 49% reduction in non-point source loadings. Point source reduction can be achieved by lowering the total phosphorus limit for Delmar Wastewater Treatment Plant from 1.0 mg/l to 0.5 mg/l and for Perdue Farms, Inc from 0.5 mg/l to 0.3 mg/l. While it is recognized that a 49% reduction in non-point source phosphorus load may be difficult to achieve, any major reduction reduction in NPS phosphorus will have a significant effect in improving the trophic state of Johnson Pond, improving it from highly eutrophic to only somewhat eutrophic. Taking actions to meet this reduction is estimated to result in a 24.5% reduction in sediment loads.

Because the watershed is 41% agricultural land, meeting these reductions will entail the implementation of agricultural best management practices (BMPs). Table 2 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. However, because the soils in the Johnson Pond watershed are easily erodible (Coastal Environmental Services, Inc. May 1990), the efficiency of the soil conservation BMPs are expected to be toward the high end of the range.

Table 2

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[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 Johnson Pond watershed are considered easily erodible (DNR, Oct. 1996).

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 (in this case, tributaries draining to Johnson Pond) 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).

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Appendix - A

Johnson Pond Water Quality

A number of studies of Johnson Pond have been conducted over the years in which water quality data have been collected (Coastal Environmental Services, Inc., 1992-93 and Maryland Department of the Environment, 1998). A summary of the water quality data was provided in the main body of this report. Tables A1 through A7 provide the underlying data from which the summaries were derived.

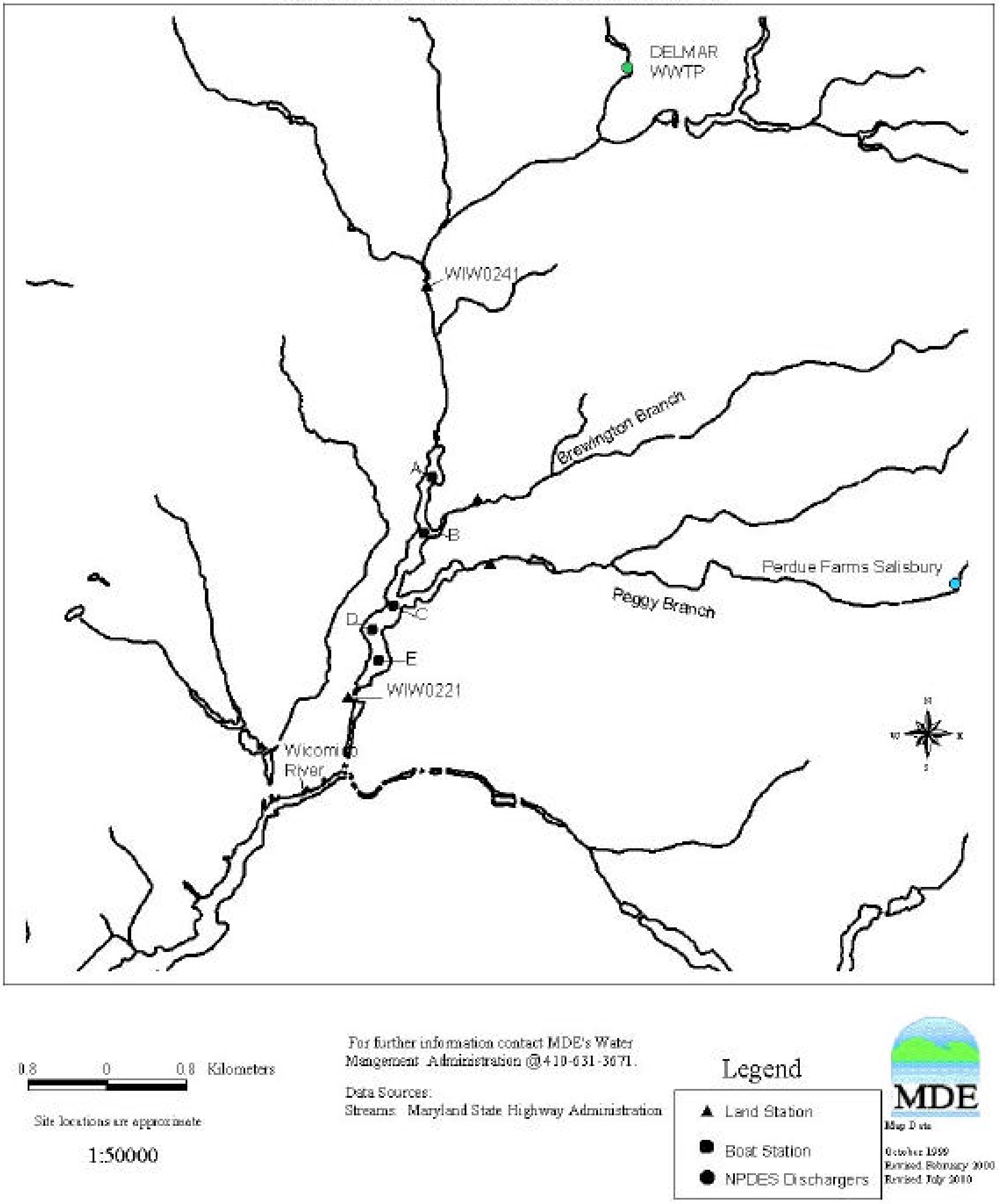
Assessment of the N:P Ratio for Johnson Pond

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 10:1, phosphorus tends to be limiting, and if the N:P ratio is less than 5:1, nitrogen tends to be limiting (Chiandani, et al., 1974).

The N:P ratio of above10:1 cited in the body of this report was drawn directly from the 1998 Water Quality study by Maryland Department of the Environment. This assessment was based on data from the streams entering Johnson Pond .

Johnson Pond is fed by three major tributaries. Little Burnt Branch, Connelly Mill Branch, and Leonard's Pond Run merge to form the northernmost tributary while Middle Neck Branch and Peggy Branch merge to form the easternmost tributary. Brewington Branch enters the northeast arm of the pond between the other two main tributaries. The exact computation used to arrive at the N:P ratio of above 10:1 is documented in Tables A-1 and A-2. The data in Table A-1 was collected by Coastal Environmental Services, Inc. in 1992 and 1993 as a part of the Phase II Implementation of Restoration and Management Recommendations contained in Coastal's Phase I Diagnostic / Feasibility Study Reports(1990). Table A-2 shows the results of the samples collected by the Maryland Department of the Environment during high and low flow conditions. The samples were analyzed by the Chesapeake Biological Laboratory. Tables A-3 through A-7 show the results of the extensive sampling work done by Maryland Department of the Environment. These samples were analyzed using Department of Health and Mental Hygiene (DHMH) protocol and unfortunately the detection limit used for total phosphorus and Ammonia-Nitrogen was 0.2 mg/l. This data was not used to determine N:P ratio and to calculate total phosphorus loading to the pond.

Johnson Pond
Land and Boat Stations



Site locations are approximate

1:50000

For further information contact MDE's Water Mangement Administration @410-631-3671.

Data Sources:
Streams: Maryland State Highway Administration

Figure 6

Table A-1
Data Collected by Coastal Environmental Services, Inc. in 1992-93

Station	Date	Nitrate-N (mg/l)	Total-P (mg/l)	TSS (mg/l)	Chl-a mg/l
In Lake	7/22/93	1.80	0.42	11.0	67.7-75.5
	8/27/93	2.00	0.02	4.0	12.5
	6/18/92	1.48	0.06	6.0	23.0
	8/20/92	0.94	0.11	2.0	5.0
Middle Neck Branch	6/17/93	5.0	0.05	5.0	
	7/22/93	2.70	0.155	5.0	
	8/27/93	4.20	0.08	6.0	
	6/18/92	1.94	0.15	6.0	
	7/24/92	1.62	0.19	8.0	
	8/20/92	1.28	0.32	2.0	
Naylor Mill Branch	6/17/93	6.90	0.05	2.5	
	7/22/93	5.80	0.040	1.5	
	8/27/93	6.10	0.04	1.5	
	6/18/92	4.15	0.05	1.0	
	7/24/92	4.27	0.04	2.0	
	8/20/92	1.58	0.05	5.0	

Table A-2
Stream Inflow and Water Quality Data for Johnson Pond - 1998 (First Effort by MDE)

Station	DATE	DO (mg/l)	TSS (mg/l)	NH4 (mg/l)	NO3 (mg/l)	TN (mg/l)	NO23 (mg/l)	NO2 (mg/l)	PO4 (mg/l)	TP (mg/l)	TN/TP Ratio	DN/DP Ratio
WIW0241	2/18/98	8.7	4.4	0.052	3.9010	4.33	3.91	0.0090	0.0156	0.0347	127	254
WIW0241	3/11/98	9.8	5.20	0.027	2.221		2.23	0.0090	0.0193	0.0521		117
WIW0241	4/1/98	8.8	1.70	0.018	4.4017	5.189	4.410	0.0083	0.0123	0.0278	186	360
WIW0241	7/28/98	7.9	2.2	0.0410	4.5821	5.548	4.59	0.0079	0.0201	0.0349	159	230
WIW0241	8/24/98	7.5	1.50	0.0240	5.634	5.9949	5.640	0.0060	0.0205	0.0314	190	276
WIW0241	9/22/98	8.2	3.5	0.020	4.7718	4.957	4.78	0.0082	0.0214	0.0288	172	224
WIW0221	2/18/98	10.3	2.25	0.066	3.5096	3.7985	3.520	0.0104	0.0280	0.0481	79	128
WIW0221	3/11/98	11.8	7.90	0.-058	2.4873	3.2425	2.5	0.0127	0.0496	0.1018	32	52
WIW0221	4/1/98	8.6	5.50	0.017	3.1930	3.8	3.205	0.0121	0.0178	0.0513	74	181
WIW0221	7/28/98	8.8	18	0.0740	2.1628	3.65	2.1850	0.0220	0.0042	0.0549	66	538
WIW0221	8/24/98	10.5	16.30	0.037	2.1913	3.334	2.2150	0.0238	0.0055	0.0550	60	409
WIW0221	9/22/98	9.6	10.35	0.0285	2.6513	3.661	2.675	0.0237	0.0489	0.0520	61	55

Table A-3
Loads Entering Johnson Pond (Naylor Mill Road) using DHMH Protocols
Second Effort by MDE

Date	DO mg/l	BOD mg/l	SS mg/l	T.Solids mg/l	NH3 mg/l	TKN mg/l	NO2/NO3 mg/l	Op mg/l	TP mg/l
4/2/98	12.9	4.1	**6**	90	0.20	0.9	2.3	<0.2	<0.2
4/9/98	11.6	<2.0	2	91		0.8	3.8	<0.2	<0.2
4/16/98	11.4	<2.0	2	104	<0.20	0.6	4.8	<0.2	<0.2
4/23/98	12.5	2.8	3	105	<0.20	0.9	3.7	<0.2	<0.2
4/30/98	12.6	<2.0	4	112	<0.20	0.5	5.3	<0.2	<0.2
5/7/98	8.7	<2.0	6	90	0.20	0.6	3.8	<0.2	<0.2
5/14/98	8.6	2.1	4	86	0.30	1.2	2.4	<0.2	<0.2
5/21/98	8.3	<2.0	8	100	<0.20	0.7	3.3	<0.2	<0.2
5/28/98	8.5	3.7	1	103	<0.20	0.7	4.7	<0.2	<0.2
6/4/98	8.2	<2.0	5	81	<0.20	0.7	3.3	<0.2	<0.2
6/11/98	8.7	<2.0	2		<0.20	0.5	5.2	<0.2	<0.2
6/18/98	8.5	<2.0			0.30	0.90	1.8	<0.2	<0.2
6/25/98	8.1	2.8	4	93	0.30	1.1	1.9	<0.2	<0.2
7/1/98	8.2	<2.0	7	115	<0.20	0.6	4.2	<0.2	<0.2
7/9/98	11.0	<2.0	10	116	<0.20	0.7	2.5	<0.2	<0.2
7/16/98	8.6	2.0	3	93	0.30	0.8	3.5	<0.2	<0.2
7/23/98	9.1	2.4	1	104	<0.20	1.0	5.4	<0.2	<0.2
7/30/98	11.4	2.0	3	117	<0.20	0.6	5.3	<0.2	<0.2
8/6/98	8.7	<2.0	<1	113	<0.20	0.3	4.9	<0.2	<0.2
8/13/98	8.2	<2.0	1	111	<0.20	0.3	5.3	<0.2	<0.2

Table A-4
Loads Exiting Johnson Pond (Isabella Street) using DHMH Protocols
Second Effort by MDE

Date	DO mg/l	BOD mg/l	SS mg/l	Turbid mg/l	NH3 mg/l	TKN mg/l	NO2/NO3 mg/l	OP mg/l	TP mg/l
4/2/98	12.0	<2.0	8	4.4	0.2	1.0	3.5	<0.2	0.2
4/9/98	12.4	<2.0	3	3.9	<0.2	0.9	2.6	<0.2	<0.2
4/16/98	12.2	2.4	2	3.3	0.2	0.9	3.3	<0.2	<0.2
4/23/98	26.0	2.3	7	3.9	<0.2	0.8	3.2	<0.2	<0.2
4/30/98	14.8	3.2	6	3.1	<0.2	0.7	3.5	<0.2	<0.2
5/7/98	10.2	4.9	7	4.5	0.2	0.7	3.3	<0.2	<0.2
5/14/98	9.2	<2.0	4	6.2	0.3	0.9	2.3	<0.2	<0.2
5/21/98	9.3	3.2	9	3.3	<0.2	1.0	2.9	<0.2	<0.2
5/28/98	8.9	3.1	3	2.7	<0.2	0.6	3.3	<0.2	<0.2
6/4/98	9.6	3.9	14	5.7	0.3	1.0	2.8	<0.2	<0.2
6/11/98	9.3	2.9	13	5.7	<0.2	0.8	2.8	<0.2	<0.2
6/18/98	9.8	3.4		4.7	0.2	0.9	1.9	<0.2	<0.2
6/25/98	8.8	3.0	4	3.6	0.3	1.0	2.2	<0.2	<0.2
7/1/98	8.5	3.4	12	4.5	<0.2	1.5	1.5		<0.2
7/9/98	9.5	2.3	10	3.7	0.2	0.9	4.9	<0.2	<0.2
7/16/98	10.6	4.0	7	3.8	<0.2	0.8	2.4	<0.2	<0.2
7/23/98	12.3	6.4	23	7.8	<0.2	1.0	2.9	<0.2	<0.2
7/30/98	12.5	6.9	12	5.3	0.2	1.0	2.2	<0.2	<0.2
8/6/98	9.2	3.8	6.5	4.3	0.2	0.9	2.0	<0.2	<0.2
8/13/98	8.2	2.9	9	3.7	<0.2	0.6	2.4	<0.2	<0.2

Table A-5

Land Team Data for Johnson Pond, Using DHMH Protocol, Third Effort by MDE

Entry to Johnson Pond, Land Stations

Date	**Flow cfs**	**DO mg/l**	**BOD mg/l**	**SS mg/l**	**TSS mg/l**	**NH3 mg/l**	**TKN mg/l**	**NO2,3 mg/l**	**Op mg/l**	**TP mg/l**	**Chl-a mg/l**
7/23/98	33.70	7.4	1.2	3	ND	<0.2	0.9	5.4	<0.2	<0.2	
7/29/98	33.70	7.5	2.3	1	110	<0.2	0.7	4.3	<0.2	<0.2	0.9
8/20/98	20.30	8.3	<2.0	<1.0	119	<0.2	<0.2	5.7	<0.2	<0.2	0.3
8/27/98	33.70	7.8	2.9	<1.0	ND	<0.2	<0.2	5.2	<0.2	<0.2	0.4

Exit from Johnson Pond, Land Stations

7/23/98	32.0	9.4	8.7	22	ND	<0.2	1.3	2.9	<0.2	<0.2	
7/29/98	35.20	9.6	5.6	20	108	<0.2	1.3	2..3	<0.2	<0.2	65.4
8/20/98	22.60	10.1	3.7	11	96	<0.2	0.8	2.2	<0.2	<0.2	38.9
8/27/98	23.50	8.9	5.0	3	ND	<0.2	1.0	2.1	<0.2	<0.2	27.8

In Johnson Pond, Boat Stations, STATION "A"

Date	Secchi	Depth	DO	BOD	SS	NH3	TKN	NO23	OP	TP	Chl-a
7/23/98	0.7	0.3	10.8	3.3	2.0	<0.2	0.8	2.8	<0.2	<0.2	
		0.9	10.3								
7/29/98	0.6	0.3	11.0	4.7	9	<0.2	0.8	2.2	<0.2	<0.2	35.6
		0.9	10.6								
8/20/98	1.4	0.3	7.2	<0.2	3	<0.2	0.4	3.1	<0.2	<0.2	4.5
		0.9	6.6								
8/27/98	0.8	0.3	7.0	3.1	1	<0.2	0.7	2.6	<0.2	<0.2	17.2
		0.9	3.1								

Table A-6
Land Team Data for Johnson Pond Using DHMH Protocol, Third Effort by MDE

In Johnson Pond, Boat Stations, STATION "B"

Date	Secchi met	Depth met	DO mg/l	BOD mg/l	SS mg/l	NH3 mg/l	TKN mg/l	NO23 mg/l	Op mg/l	TP mg/l	Chl-a mg/l
7/23/98	0.7	0.5	10.7	4.7	4.0	<0.2	1.1	2.5	<0.2	<0.2	
		1.0	10.2								
		2.0	4.1								
7/29/98	0.6	0.3	12.2	3.6	13	<0.2	0.7	2.1	<0.2	<0.2	32.6
		1.0	11.4								
		2.0	8.1								
8/20/98	0.8	0.5	7.2	2.4	9	<0.2	0.8	2.5	<0.2	<0.2	32.9
		1.0	10.7								
		1.5	10.7								
8/27/98	0.6	0.3	8.1	2.7	7	<0.2	0.7	2.4	<0.2	<0.2	17.2
		1.0	5.2								
		2.0	1.6								

In Johnson Pond, Boat Stations, STATION "C"

Date	Secchi met	Depth met	DO mg/l	BOD mg/l	SS mg/l	NH3 mg/l	TKN mg/l	NO23 mg/l	Op mg/l	TP mg/l	Chl-a mg/l
723/98	0.6	0.5	12.2	4.3	13	<0.2	1.0	2.4	<0.2	>0.2	
		1.0	10.5								
		1.5	6.8								
		2.0	2.2								
7/29/98	0.6	0.1	14.4	4.2	13	<0.2	0.9	1.9	<0.2	<0.2	69.1
		1.0	9.8								
		2.0	6.1								
8/20/98	0.8	0.1	12.7	3.5	1	<0.2	0.8	2.1	<0.2	<0.2	41.9
		1.0	12.5								
		2.0	11.1								
8/27/98	0.6	0.1	10.7	3.2	8	<0.2	0.8	2.1	<0.2	<0.2	38.9
		1.0	4.8								
		2.0	1.1								

Table A-7
Land Team data for Johnson Pond Using DHMH Protocol , Third Effort By MDE

In Johnson Pond, Boat Stations, STATION "D"

Date	**Secchi met**	**Depth met**	**DO mg/l**	**BOD mg/l**	**SS mg/l**	**NH3 mg/l**	**TKN mg/l**	**NO23 mg/l**	**Op mg/l**	**TP mg/l**	**Chl-a mg/l**
7/23/98	0.6	0.5	13.2	4.2	9.5	<0.2	1.0	2.4	<0.2	<0.2	
		1.0	9.5								
		2.0	3.5	3.3	14	0.2	1.0	3.0	<0.2	>0.2	
7/29/98	0.8	0.1	14.6	3.2	9	<0.2	0.6	2.0	<0.2	<0.2	40.1
		1.0	13.0								
		2.0	3.0	2.8	12	<0.2	0.6	3.1	<0.2	<0.2	45.5
8/20/98	0.8	0.1	12.4	3.4	13	<0.2	0.8	2.1	<0.2	<0.2	42.5
		1.0	12.1								
		2.0	11.3	2.4	12	<0.2	1.2	2.1	<0.2	<0.2	41.0
8/27/98	0.6	0.1	10.6	3.0	2	<0.2	0.8	2.1	<0.2	<0.2	31.0
		1.0	3.7								
		2.0	1.1	3.0	3	<0.2	0.7	2.1	<0.2	<0.2	34

In Johnson Pond, Boat Stations, STATION "E"

Date	Secchi	Depth	DO	BOD	SS	NH3	TKN	NO23	OP	TP	Chl-a
7/23/98	0.6	0.5	14.9	4.7	12	<0.2	1.2	2.5	<0.2	<0.2	
		1.0	11.3								
		2.4	2.2	3.5	23	0.5	1.1	2.4	<0.2	<0.2	
7/29/98	0.8	0.3	14.6	3.4	12	<0.2	0.8	2.1	<0.2	<0.2	40.4
		1.0	8.6								
		2.0	3.0								
		2.4	0.6	3.9	18	0.3	1	2.2	<0.2	<0.2	60.4
8/20/98	0.8	0.3	12.2	2.3	12	<0.2	0.8	2.1	<0.2	<0.2	52.9
		1.0	12.4								
		2.0	11.7								
		2.4	11.1	3.9	13	<0.2	0.9	2.0	<0.2	<0.2	52.0
8/27/98	0.6	0.3	11.1	2.9	1	<0.2	0.8	2.1	<0.2	<0.2	29.5
		1.0	8.0								
		2.0	3.1								
		2.4	1.3	3.1	7	<0.2	0.7	2.1	<0.2	<0.2	73.3

TABLE A-8
Land Team Data for Tributaries of Johnson Pond Using DHMH Protocol, Third Effort

Brewington Branch

Date	Flow (cfs)	DO (mg/l)	BOD (mg/l)	SS (mg/l)	NH3 (mg/l)	TKN (mg/l)	NO2,3 (mg/l)	OP (mg/l)	TP (mg/l)
7/23/98	0.48	4.5	4.9	10	< 0.2	1.0	1.1	< 0.2 < 0.2	< 0.2
7/29/98	0.60	3.8	< 2.0	4	< 0.2	0.8	1.0	< 0.2	< 0.2
8/20/98	0.47	4.8	2.5	8	< 0.2	0.9	0.3	< 0.2	0.2
8/27/98	1.05	3.6	4.5	4	< 0.2	1.1	< 0.2	< 0.2	0.2

Peggy Branch

Date	Flow (cfs)	DO (mg/l)	BOD (mg/l)	SS (mg/l)	NH3 (mg/l)	TKN (mg/l)	NO2,3 (mg/l)	OP (mg/l)	TP (mg/l)
7/23/98	5.50	5.4	4.5	9	< 0.2	1.1	3.0	< 0.2	< 0.2
7/29/98	5.20	4.5	< 2.0	4	< 0.2	0.8	3.0	< 0.2	< 0.2
8/20/98	5.10	5.4	< 2.0	5	0.2	0.6	2.8	< 0.2	< 0.2
8/27/98	----	4.4	3	< 1	0.2	0.9	2.0	< 0.2	< 0.2

Brewington Branch average D.O. = (4.5+3.8+4.8+3.6) = 4.175 mg/l

Brewington Branch average flows = (0.48+0.60+0.47+1.05)/4 = 0.65 cfs

Peggy Branch average D.O = (5.4+4.5+5.4+4.4)/4 = 4.925 mg/l

Peggy Branch average flows = (5.5+5.2+5.1+10.2)/4 = 6.5 cfs

Mass balance for D.O. = (4.175x0.65+4.925x6.5)/7.15 = 4.86 mg/l

Supporting Calculations for the Vollenweider Analysis

Johnson Pond Mean Depth $\overline{Z}$

The pre- 1989 design volume can be computed as the sum of the current volume plus displaced volume. A survey of in-lake sediment accumulation was conducted by Coastal Environmental Service, Inc. in August 1989 as part of the field study program. Six sampling transects were established so as to adequately reflect and represent the major morphometric features of Johnson Pond. At least one transect was located in each arm of the lake and in the lake's main body. At approximately 15-foot intervals along each transect, a calibrated rod was hand-driven through the loose sediments to the point of first refusal. The depth of penetration was recorded and then mapped. This survey indicated that sediment deposition was generally greatest (ranging to 6 feet) in the deeper, southern basin of the lake. Deposition in the 1-3 foot range was more frequently found in the northern, headwater sections of the lake. From the survey data, it was determined that the average depth of accumulated sediment was about 3.5 feet. This depth was used to calculate the volume of lake lost to sediments.

Original Volume of the pond = (current volume) + (volume lost to sediments)
Current Volume = (55 hectares (ha)x10000 m^2 /ha x 10.76 ft^2 /m^2x7 ft)/10^6 = 41.4 Million cu. ft
Volume lost to sediments = (42 hax10000 m^2 /ha x10.76 ft^2 /m^2x3.5 ft)/10^6 = 20.7 Million cu. feet
Original Volume of the pond = 41.4 Million cu. ft + 20.7 Million cu. feet = 62.1 Million cu. feet
= 62.1 Million cu. feet x 0.02832 cu. m /cu. ft =1,758,672 cu. m

Surface Area of the Pond = (55 ha)(10^4 m^2/ha) = 550,000 m^2
The mean depth of Johnson Pond is (Volume)/(Surface Area) is computed as:
1,758,672 $m^3 \div$ 550,000 m^2 = 3.20 m = $\overline{Z}$

Phosphorus Loading to Johnson Pond (Lp):

The total phosphorus loading was computed as follows:
From GIS, total drainage area contributing to Johnson Pond = 10114.4 ha
Drainage area contributing to Johnson Pond from Brewington, Middle Neck and Peggy Branch tributaries = 3213.1 ha
Rest of the drainage from the northern tributaries contributing to Station WIW 0241 and below = 10114.4 - 3213.1 = 6901.3 ha

TABLE - A-9

Land Use for Johnson Pond Watershed

Land Use	% of Total Area	Area in Hectares	Runoff Coefficients*
Agriculture	40.8%	4126.7	0.36
Forest	42.2%	4268.3	0.31
Urban (unpaved)	8.5%	859.7	0.37
Urban (paved)	8.5%	859.7	0.73

* Applied Hydrology, Crtow, et al 1988

Mean Runoff Coefficient = {(.408)(.36)+(.422)(.31)+(.085)(.37)+(.085)(.73)}/1 = 0.371
Mean annual precipitation at Salisbury from NOAA web site = 1.07 m/yr
Total annual unit runoff = r =(1.07 m/yr)(0.371) = 0.397 m/yr ≈ 0.400 m/yr

Flow from the northern tributaries contributing to Station WIW0241 =
(6901.ha)(10000 m^2/ ha)(0.400 m/yr) + (0.65 mgd)(1.547 cfs/mgd)(3600 s/h)(24 h/d)(365 d/yr)/ 35.32 cf/m^3 = (27605200)+ (897800) = 28,300,000 m^3/yr

Average total phosphorus concentration at station WIW0241 (see Table A-1) =
((0.0521+0.0314+0.0288+0.0347+0.0278+0.0349)/6 = 0.034 95 mg/l or g/m^3

Total phosphorus loading = (0.03495 gr/m^3)(28296236 m^3/yr) = 988,953 g/yr

Flow contributing to Johnson Pond from Brewington, Middle Neck and Peggy Branch tributaries =
(3213.1 ha)(10000 m^2/ ha)(0.400 m/yr)+
(0.960 mgd)(1.547cfs/mgd)(3600 s/h)(24 h/d)(365 d/yr)/35.32 cf/m^3) = 14,082,395 m^3/yr

Total flow to Johnson Pond = 28,296,236 m^3/yr + 14,082,395 m^3/yr = 42,378,631 m^3/yr

Average total phosphorus concentration from Brewington, Middle Neck and Peggy Branch tributaries (see Table A-1) = (0.14+0.155+0.08+0.15+0.19+0.32)/6 = 0.1725 mg/l or g/m^3
Total phosphorus loading from Brewington, Middle Neck and Peggy Branch =
(14,082,395 m^3/yr)(0.1725 g/m^3) = 2,429,213 g/yr
Total phosphorus loading for the Johnson Pond = (2,429,213 + 988,953) = 3,418,166 g/yr
= (3,418,166 g/yr)/453.6 lbs/g = 7,536 lbs/yr
Using the estimated lake surface area (550,000 m^2), total phosphorus loading can be converted to grams per square meter per year as follows: 3,418,166g/yr ÷ 550,000 m^2 = 6.2 g/m^2 yr.

Total phosphorus load from Delmar WWTP (4/98-8/98) = (0.55x0.42x8.34) = 1.93 lbs/d
Total phosphorus from Perdue, Inc WWTP = (0.160 MGD)(8.34 lbs/MG)(0.1) = 0.13 lb/d
Total point source load = (1.93+0.13) = 2.06 lbs/ d = (2.06 lbs/d)(365 d/yr) = 752 lbs/yr
= 341062 g/yr

Total NPS load = 3,418,166 - 341,062 = 3,077,104 g/yr = 6783.7 lbs/yr

Johnson Pond 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. The estimated hydraulic residence time of 15.1 days was estimated based on the lake volume of 1,758,672 m^3 and an estimated 42,378,631 m^3/year discharge rate. That is, (1,758,672 m^3) ÷ (42,378,631 m^3/yr) /365 d/yr= 15.1 days; 15.1 days ÷ 365 d/yr = 0.0415 **yr**

Ratio of Mean Depth to Hydraulic Residence Time (Z/τ_w)

From the computations above the mean depth of Johnson Pond (Z) is 3.20 m, and the hydraulic residence time (τ_w) is 0.0415 yr. The ratio was computed as: 3.20m / 0.0415 yr = 77.1 m/yr

Graphing of Trophic Status of Johnson Pond using the Vollenweider Relationship

The intersection of the phosphorus loading rate (L_p) = 6.2 g/m^{2}yr and the ratio (Z/τ_w) = 77.1 m/ yr was plotted on log log paper to establish the current trophic status of Johnson Pond as shown in the graph below by a ♦.

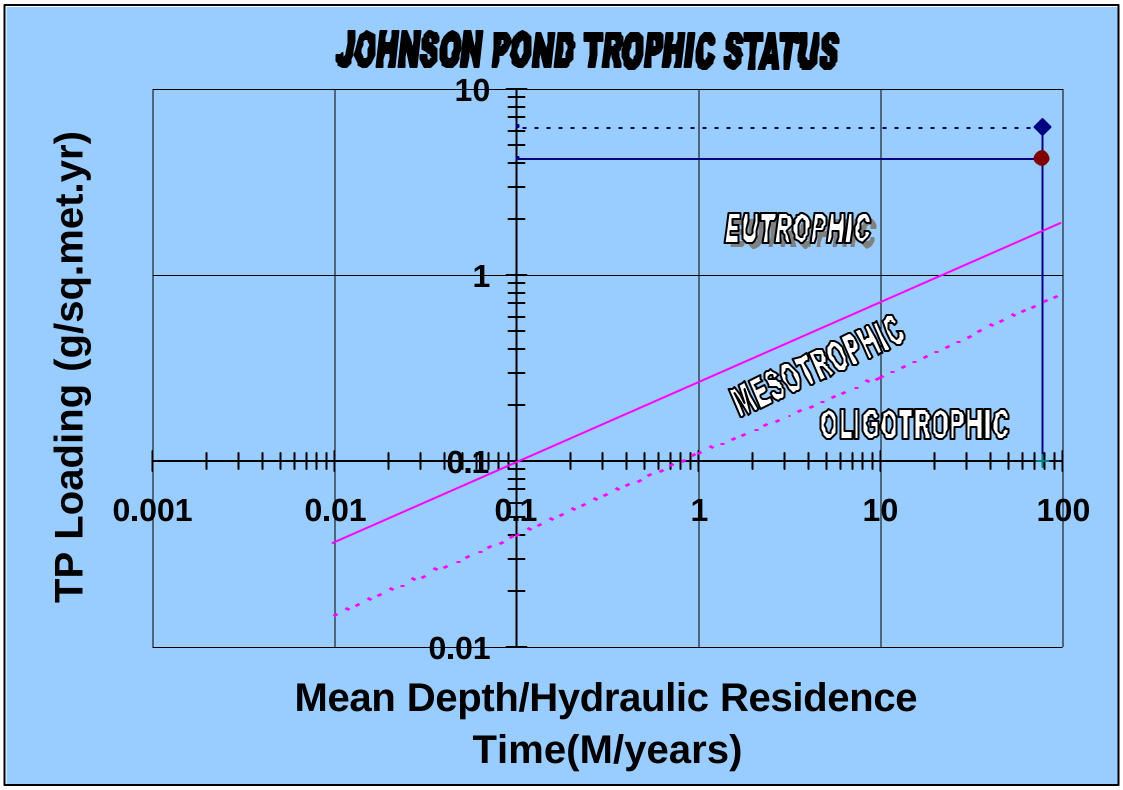


Figure 7. Vollenweider Results for Johnson Pond

In-lake to tal phosphorus concentration = (3,418,166 g/yr)/(42,378,631 m^3/yr) = 0.081 g/m^3

This in-lake total phosphorus concentration of 0.081 g/m^3 can also be represented by Carlson's Trophic State Index (TSI) by using the following relationship:

TSI(TP) = 4.15+14.42 LN(TP in µg/l) = 4.15+14.42 LN(81µg/l) = 67.5

According to EPA's TMDL technical guidance document (November 1999), if the Carlson's three indices calculated using total phosphorus, chlorophyll *a* and secchi depth are approximately equal, then total phosphorus is the limiting nutrient. Conversely, since in this case the total phosphorus is the limiting nutrient, the three indices should be approximately equal. Using the TSI of 67.5, we calculate the corresponding chlorophyll *a* value as follows:

TSI(Chl) = 30.6+9.81 LN(Chl) = 67.5; LN(Chl) = (67.5-30.6)/9.81 = 3.76: Chla = 43 µg/l

Raschke (1994) gathered data for 17 small southeastern piedmont impoundments to establish a management relationship between algal bloom frequency and seasonal mean chlorophyll-a concentration. Bases on the bloom frequency analysis, literature values, and experience, Raschke proposed a mean growing season limit of < 15 µg/l for chlorophyll-a for attaining drinking water supply use in small southeastern impoundments. For other uses, such as fishing and swimming, a mean growing season limit of < 25 µg/l was recommended.

Johnson Pond is significantly used as a recreational warm water fishery. A reasonable management goal is to enhance or maintain support of this fishery. A possible endpoint, seeking to maintain the fishery and avoid nuisance algal blooms, is a maximum permissible TSI of 60. A TSI of 60 results in a total phosphorus of approximately 48 µg/l and chlorophyll a of 20 µg/l , which is in the lower range of eutrophic conditions.

Supporting Calculations for the TMDL Analysis

Computing the Phosphorus TMDL

Allowable in-lake total phosphorus concentration = 48µg/l = 0.048 mg/l = 0.048 g/m^3

Using Vollenweider's approach for a steady state completely mixed lake we have the following model:

$P = W / \overline{Z} /(1/\tau_w+K_s)$; Where
P = total phosphorus concentrations in the lake in mg/l
W = areal loading rate in g/m^2-yr
$\overline{Z}$ = mean depth in meters (m)
τ_w = hydraulic residence time in yr
K_s = phosphorus loss rate in 1/yr
$K_s = 10/\overline{Z}$, where $\overline{Z}$ is in meters
$\overline{Z} /(1/\tau_w+K_s)$; $K_s = 10/\overline{Z}$; 3.20/(1.0.0415+10/3.20) = 87.5 1/yr

Allowable total phosphorus loading = W = (0.048 g/m^3)(87.5 m/yr) = 4.20 g/m^2.yr (shown by • in the graph on page A-13).
Annual Allowable Loading = (Unit loading) x (Lake Surface Area) =
(4.20 g/m^2yr) x (550,000 m^2) = **2,310,000 g*/yr***
Converted to pounds per year:
(2,310,000 g/yr) / (453.6 g/lb) = 5093 **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 (2,310,000) = 231000 **g/**yr;
Actual allowable PS+NPS load = 0.9*2,310,000 = 2079000 g/yr
Converted to pounds per year:
231,000g*/yr/* (453.6 g/lb) **= 509 lbs/yr**

The annual TMDL for Phosphorus (lbs/yr): $\text{WLA} = \text{WLA}_{\text{Delmar}} + \text{WLA}_{\text{Perdue}}$
WLA = {0.65 mgdx0.5 mg/l x 8.34x 365 d/yr) +(0.16 MGD x 0.3 x 8.34 lbs/MG x 365 d/yr)}
= 1135 lbs/yr

LA = TMDL - WLA - MOS = 5093 -1135 -509 = 3449 lbs/yr = 1,564,466 g/yr

Computing the Percentage Phosphorus Reduction

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

$$\frac{\text{(current load)} - \text{(allowable load*)}}{\text{(current load}} = \frac{(3{,}418{,}166\ \text{g/yr}) - (2{,}079{,}000\ \text{g/yr})}{(3{,}418{,}166\ \text{g/yr})} = 39\%\ \text{in PS+NPS}$$

% Reduction in NPS load = (3,077,104 - 1,564,466)/3,077,104 = 49% reduction in NPS load

* 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:

$$DO = f(T)\{(DO_{AMBIENT} + DO_{PSN} + \textit{Re-aeration}\,) - (\textit{Metabolic Demands} + SOD + CBOD)\}$$

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:

$$DO_{MIN} = f(T)\{(DO_{AMBIENT}) - (\textit{Max. Metabolic Depletion}) - (SOD + CBOD)\}$$

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 kills. The diurnal dissolved oxygen variation due to photosynthesis and respiration can be estimated based on the amount of chlorophyll *a* in the water. The phosphorus TMDL will result in a sightless eutrophic status for Johnson Pond. Chlorophyll *a* concentrations ranging from 10- 20 μg/l are typical in mesotrophic lakes (Chapra 1997). In order best to simulate critical conditions, MDE has assumed a chlorophyll *a* concentration of 20 μg/l, at the high end of this range. The equations used to calculate the diurnal dissolved oxygen are shown below:

Diurnal Dissolved Oxygen Calculations

$$\frac{D}{P_{av}} = \frac{(1-e^{-Ka\,f\,T})(1-e^{-Ka\,T(1-f)})}{f\,K_a(1-e^{-Ka\,T})}$$

$$P_{av} = p_s\,G(I_a), \text{ where : } P_s = 0.25\,P$$

$$G(I_a) = \frac{2.718\,f}{K_e\,H}\{e^{-a1} - e^{-a0}) \text{ Where : } \alpha_1 = I_a / I_s\,(e^{-Ke\,z}) \text{ and } \alpha_0 = I_a / I_s$$

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

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 (*langly/day*)

I_a = average solar radiation during the day (*langly/day*)

z = depth at which photosynthetic activity is calculated (*m*)

Δ = total dissolved oxygen variation due to phytoplankton in mg/l

$\Delta / 2$ = dissolved oxygen swing in either direction in mg/l

K_a = reaeration coefficient (day^{-1})

T = period (Thomann and Mueller 1987)

Input variables for Johnson Pond diurnal DO swing calculations are shown below:

p_s = 0.25 P
P = 20.0 *mg/l*
f = 0.6 day
H = 6.2 m
K_e = 1.9/1.4 = 1.36 m^{-1}
I_s = 350 langley/day
I_a = 500 langley/day
z = 1.4 m
K_a = 0.5 day^{-1}
T = 1 d

Using the above 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_{av})

   $\alpha_o = I_a / I_s = 500/350 = 1.43$;
   $\alpha_1 = I_a / I_s \, (e^{-Kez}) = (1.43)(2.71828)^{-(1.36)(1.4)} = (1.43)(.149) = 0.213$

   $$G(I_a) = \frac{(2.718)(0.6\ d}{(1.36)(6.2)} [e^{-0.213} - e^{-1.43}] = (0.193)(0.808-0.239) = 0.110$$

   $$P_{av} = (0.25)(20)(0.110) = 0.55 \text{ mg.O}_2\text{/l-day}$$

2. $$\Delta = P_{av} \frac{[1-e^{-(0.5)(0.6)(1)}]\,[1-e^{-(0.5)(1)(0.4)}]}{(0.6)(0.5)[1-e^{-(0.5)(1)}]} = (0.55)(0.39) = 0.214 \text{ mg/l}$$

For Johnson Pond, the diurnal variation in DO, Δ, is calculated as a range of **0.214** mg/l—i.e., $\Delta / 2$ = **0.107** mg/l in either direction from the ambient DO concentration.

Calculations of Sediment Oxygen Demand (SOD):

Sediment oxygen demand is included as a component of the overall DO concentration in the equation below (Thomann and Mueller 1987):

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

where:

c = lakewide DO accounting for SOD and CBOD
Q = lake discharge = 116106 m^3/d
K_L = DO transfer rate = 0.87 m/d
K_d = effective deoxygenation rate = 0.285/d*
L = ambient lake CBOD 2.0 mg/l (common value for Maryland waters)
A = area = 550,000 m^2
V = volume = 1,758,672 m^3
S_B = SOD rate = 0.4 g/m^2/d (Ambrose *et al.* 1988)
c_s = ambient lake saturation DO level at T = 29^o C = 7.691 mg/l (Thomann and Mueller 1987)

C_{in} = DO of incoming flow to the lake = 7.20 mg/l (see below for details)

DO of incoming flow from Naylor Road = 7.75 mg/l; Flow = (33.7x3+20.3)/4 = 30.35 cfs
Average DO of flow coming from Peggy and Brewington Branch = 4.86 mg/l; Flow = 7.15 cfs
Flow coming from Naylor Road is 30.35 cfs/7.15 cfs = 4.25 times the flow coming from Peggy and Brewington Branch. Average incoming DO to the lake = {(7.75 mg/l)(4.25) + (4.86 mg/l)(1)}/5.25 = 7.20 mg/l. K_d is 0.18/d at 20° 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, $(K_d)_{30} = (0.18/d)(1.047)^{30-20}$

$(K_d)_{30} = 0.285/d$

$(S_B)_T = (S_B)_{20} (1.065)^{T-20}$ where $(S_B)_T$ and $(S_B)_{20}$ are SOD rates at water temperature T(°C) and 20°C, respectively (Thomann and Mueller 1987).

Thus, $(S_B)_T = 0.4$ g O_2/m^2/day $(1.065)^{30-20} = 0.75$ g O_2/m^2/day

K_L A = (0.87)(550,000) = 478500 m^3/day

VK_d = (1,758,672)(0.285) = 501221 m^3/day

S_B A = (0.75)(550,000) = 412970 g/m^3

$Q+K_LA$ = (116106)+(478500) = 594606 m^3/day

$(Q/(Q+K_L A)\}c_{in}$ = (116100/594606)7.20 = 1.406 mg/l

$(K_L A)/(Q + K_L A)\}c_s$ = (478500 /594606) 7.691 = 6.189 mg/l

$\{(VK_d)/(Q + K_L A)\} L$ = (501221/594606)(2.0) = 1.686 mg/l

$\{(S_B A)/(Q + K_L A)\}$ = (412970/594606) = 0.695 mg/l

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

c = 1.406 + 6.189 - 1.686 - 0.695 = 5.214mg/l

Final Estimate of Minimum DO under Critical Conditions:

Including SOD, an adjusted lakewide DO of 5.214 mg/l is estimated for Johnson Pond. Incorporating the DO depletion estimated to result from diurnal variation (0.214 mg/l), the predicted theoretical minimum DO concentration under the assumed conditions is 5.214 - .107 = 5.107 mg/l.

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 BMPs 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 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 Johnson Pond 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 2

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 theJohnson Pond watershed are considered easily erodible (DNR, Oct. 1996).

To estimate the net sediment reduction associated with the 49% non-point source phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:
100* (0.5 * 0.49) = 24.5**%** reduction in sediment loads

From the Chesapeake Bay Program (CBP), Phase IV Sediment Areal Loading Rates (CBP model segment 420) for various land uses are as follows:

Land Use	Coefficients in Tons/Acre/Year
Agriculture	0.22
Forest	0.007
Urban	0.07

Total non-point source sediment load to the pond =
24993 Acres (0.22x0.408+0.007x0.422+0.07x0.17)Tons/Acre/year = 2615 Tons/year
Total Point Source Suspended Solids = 30 mg/l x 8.34 lbs/mgd x 0.810 mgd x 365 days/year = 33.6 Tons/year ≈ 34 Tons/year
Total Non-Point and Point Source loads = 2615+ 34 = 2649 Tons/year
Applying this 19.5% reduction (PS+NPS) to the current estimation of 2649 tons of sediments per year results in the estimated reduction, the converse of which is the estimated allowable load:

(0.195 * 2649) = 517 tons/year reduction of PS+NPS
2649 - (0.195 * 2649) = **2132 tons/year allowable sediment load**

Applying this 24.5% reduction in **NPS** to the current estimation of 2615 tons of sediments per year, results in the estimated reduction, the converse of which is the estimated allowable load:
2615 - (0.245 * 2615) = 1974 **tons/year allowable sediment load**

To estimate annual accumulation associated with this loading rate, we first considered the current accumulation rate. That is, 364 acre feet of 1092 acre feet, or 33% of the volume, was displaced between 1933 and 1989 (56 years). Assuming a 33% reduction in sediment loading, the current rate of lake volume displacement will be reduced accordingly. Thus, rather than a 33% loss of volume over 56 years, we would expect a 26.4**% loss of volume over 56 years**, computed as:

$$\frac{33\%\ \text{displacement in 56 years}}{100\%\ \text{of current loading}} = \frac{X\%\ \text{displacement in 56 years}}{2132/2649\ (80\%\ \text{of current loading})}$$

or, 0.33/1 = X/0.80
or, X = 0.80 * 0.33 = 0.264 (a 26.4% volume displacement over 56 years).

Implicit Sediment Load Reduction Due to (PS+NPS) Load Reduction:

$$\frac{\text{(current load) – (allowable load*)}}{\text{current load}} = (3,418,166 - 2,310,,000)/3,418,166 = 32\%\ \text{(PS+NPS)}$$

To estimate the net sediment reduction associated with the 32% phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:
100* (0.5 * 0.32) = 16% **reduction in sediment loads**

*** The allowable load does include the margin of safety**

Applying this reduction to the current estimation of 2649 tons of sediments per year, results in the estimated reduction, the converse of which is the estimated allowable load:

(0.16 * 2649) = 424 tons/year reduction

2649 - (0.16 * 2649) = 2225 **tons/year allowable sediment load**
Implicit additional sediment load reduction due to MOS for phosphorus load =
2225 - 2132 = 93 T/yr. (PS+NPS)

Implicit Sediment Load Reduction Due to NPS Load Reduction:

Margin of Safety allocated to allowable NPS load = 3449/(3449+1135) = 75%
% Reduction in NPS load = {(3,077,104 - (1,564,466+0.75x231,000})/3,077,104 = 44% reduction in NPS load

To estimate the net sediment reduction associated with the 39% phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:
100* (0.5 * 0.44) = 22 **percent reduction in sediment loads**

Applying this reduction to the current estimation of 2649 tons of sediments per year, results in the estimated reduction, the converse of which is the estimated allowable load:

(0.22 * 2615) = 575 tons/year reduction
2615 - (0.22 * 2615) = **2040 tons/year allowable sediment load**

Implicit additional sediment load reduction due to MOS for phosphorus load =

2040 - 1974 = 66 T/yr. due to NPS reduction

WLA = {(0.650+0.160) mgd x (8.34) x (30 mg/l)x 365} /2204 lbs/Ton = 33.6 Tons/yr