SOURCE WATER ASSESSMENT

for

Rocky Gap State Park
Water Treatment Plant

Prepared by
Maryland Department of the Environment
Water Management Administration
Water Supply Program
March, 2006

MDE

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EXECUTIVE SUMMARY

The 1996 Safe Drinking Water Act Amendments require each state to develop and implement source water assessment programs to evaluate the potential for contaminants to affect the sources of all public drinking water systems. The Rocky Gap Water Treatment Plant's raw water source is Lake Habeeb, an impoundment located in Rocky Gap State Park in Allegany County, Maryland. In accordance with the Section 303(d) of the federal Clean Water Act, the states are also required to establish a Total Maximum Daily Load (TMDL) for water bodies that the current required controls of a specified substance are inadequate to achieve water quality standard. A TMDL report for Lake Habeeb was completed by MDE and approved by EPA in March 2, 2002 (See Appendix A). The TMDL report describes the Lake Habeeb watershed characteristics, maps, water quality and impairment assessments and TMDL and allocations. The TMDL report should be considered as an integral part of source water assessment for the Rocky Gap Water Treatment Plant.

Rocky Gap Water Treatment Plant is owned by Maryland DNR and operated by the Maryland Environmental Service. Withdrawals from the Lake Habeeb vary depending on the demand for water.

Based on water quality data from the operation of the Rocky Gap water plant and the Lake Habeeb watershed and TMDL assessment, the water supply for Rocky Gap Water Treatment Plant is susceptible to disinfection by-product precursors and phosphorus. Like all surface water sources, protozoas, viruses and bacteria and turbidity are significant concerns.

Recommendations regarding watershed management particularly relevant to the location of the Rocky Gap intake are explained in Section 8 of this report and should be considered for implementation.

1.0 BACKGROUND

The 1996 Safe Drinking Water Act Amendments require states to develop and implement source water assessment programs to evaluate the potential for contaminants to affect the sources of all public drinking water systems. A Source Water Assessment (SWA) follows a process for evaluating the susceptibility of a public drinking water supply. The assessment does not address the treatment process or the storage and distribution of the water system, which are covered under separate provisions of the Safe Drinking Water Act. The Maryland Department of the Environment (MDE) is the lead state agency in this SWA effort.

There are three main steps in the assessment process: (1) *delineating* the watershed drainage area that is likely to contribute to the drinking water supply, (2) *identifying* potential contaminants within that area and (3) *assessing* the vulnerability of the system to those contaminants. This document reflects all of the information gathered and analyzed required by those three steps for the Rocky Gap Water Treatment Plant's surface water source (Lake Habeeb). MDE looked at many factors to determine the vulnerability of this water supply to contamination, including the size and type of water system, available water quality data, the characteristics of the potential contaminants, and the capacity of the natural environment to attenuate any risk.

Maryland has more than 3,800 public drinking water systems. Approximately 50 of Maryland's public drinking water systems obtain their water from surface supplies, either from a reservoir or directly from a river. The remaining systems use ground water sources. Maryland's Source Water Assessment Plan was submitted to the Environmental Protection Agency (EPA) in February 1999, and received final acceptance by the EPA in November 1999. A copy of the plan can be obtained at MDE's website, www.mde.state.md.us, or by calling the Water Supply Program at 410 537-3714.

2.0 DEVELOPMENT OF WATER SUPPLY

The Rocky Gap water system is a nontransient noncommunity system that serves approximately 200 employees and guests of Rocky Gap Resort and Campgrounds. Maryland's Department of Natural Resources (DNR) owns the facility and the Rocky Gap Water Filtration Plant. The facility is located near Flintstone, Allegany County, Maryland. The plant was originally constructed in 1998 with the design capacity of 240,000 gallons per day (gpd) with average flow of 60,000 gpd.

Maryland Environmental Service, an agency of the State of Maryland, is currently operating the water treatment facility at the Rocky Gap State Park. The plant treats water from Lake Habeeb and the treatment consists of diatomaceous earth filters, and disinfection.

3.0 DESCRIPTION OF SURFACE WATER SOURCE

The raw water source is Lake Habeeb, a 208.5 acre impoundment that is primarily fed by Rocky Gap Run and two unnamed tributaries flowing down from Evitts and Martin Mountains.

A copy of the TMDL report that includes information regarding watershed characterization, water quality and impairment assessment recommendations is attached and should be considered as an integral part of the source water assessment for the Rocky GapWater Treatment Plant. Additional water quality data (raw and finished water from the water treatment plant) was reviewed to complete this assessment.

4.0 RESULTS OF SITE VISITS

The Water Supply Program conducted a site survey of the Rocky Gap Water Treatment Plant water sources and other facilities in order to accomplish the following tasks:

- To collect information regarding the locations of raw water sources by using Global Positioning System (GPS) equipment.
- To determine the general condition and structural integrity of intakes and other raw water facilities.
- To conduct a windshield survey of the watershed and to document potential problem areas. Additional tours of watershed were taken on follow-up visits.

4.1 Intake Description

The Rocky Gap Water Treatment Plant's intake is located in Lake Habeeb. The main intake line is located approximately 4 feet below the surface of the water and 10 feet from the shore. The raw water from Lake Habeeb pumps through a 6-inch pipe to the treatment plant by two alternately run pumps with 166 gpm capacity each. There is also an emergency intake line with a submersible pump located in Lake Habeeb approximately 8 feet below the water surface and 20 feet from shore.

4.2 Operator Concerns

The primary concern was livestock activities along the Rocky Gap Run and other unnamed tributaries in the watershed.

5.0 WATERSHED CHARACTERIZATION

Please refer to MDE's TMDL report for Lake Habeeb.

6.0 REVIEW OF WATER QUALITY DATA

In addition to water quality data review conducted by MDE for establishing the Total Maximum Daily Load to Lake Habeeb (Appendix A). Rocky Gap Water Treatment Plant's data are also reviewed and summarized.

6.1 Existing Plant Data

The DNR is required to perform water quality tests on the drinking water produced from Rocky Gap Water Treatment Plant in order to ensure compliance with the EPA's Safe Drinking Water Act (SDWA) requirements. They are also required to submit monthly operating reports to MDE's Water Supply Program, which includes daily testing of some raw water quality parameters such as turbidity (cloudiness of water), alkalinity and pH. Other plant data included in the Monthly Operating Report (MOR) reflect the quality of treated (finished) water.

6.1.1 Raw Water Turbidity and pH

Below is a summary of Monthly, Maximum and Minimum values for raw water turbidity and pH and hours in service during the year 2004.

Months	Turbidity (NTU)		PH		Hours in Service
	Max.	Min.	Max.	Min.	
January	4.5	2.9	7.6	7.5	78
February	2.8	2.1	7.6	7.3	86
March	6.2	2.2	7.8	7.4	187
April	8.0	3.4	8.0	6.8	255
May	5.8	3.6	7.8	6.8	252
June	5.0	3.4	7.9	7.5	214
July	5.2	2.9	7.7	7.5	299
August	3.0	2.4	8.0	7.4	284
September*	3.2	2.5	8.1	6.9	280
October	3.1	2.3	7.7	6.8	224
November	4.1	2.7	7.9	7.4	193
December	4.6	3.4	7.8	7.2	133

6.1.2 Inorganic Compounds (IOCs)

Rocky Gap Water Treatment Plant regularly tests for presence of nitrates and other inorganic compounds in finished drinking water. Below is a summary of testing results for IOCs detected in finished water. No IOCs exceeded any MCL in the treated or raw water.

Contaminant Name	Sample Date	Result	Units	MCL
BARIUM	8/11/98	0.03	mg/L	2
BARIUM	6/14/99	0.03	mg/L	2
BARIUM	8/28/01	0.03	mg/L	2
BARIUM	8/5/03	0.03	mg/L	2
BARIUM	8/10/04	0.03	mg/L	2
CHLORIDE	10/21/96	9	mg/L	

IRON	10/21/96	0.5	mg/L	
NITRATE	8/16/94	0.25	mg/L	10
NITRATE	11/12/96	0.13	mg/L	10
NITRATE	1/8/97	0.2	mg/L	10
NITRATE	4/29/97	0.07	mg/L	10
NITRATE	4/29/97	0.07	mg/L	10
NITRATE	8/11/98	0.26	mg/L	10
NITRATE	4/13/00	0.1	mg/L	10
NITRATE	3/14/03	0.14	mg/L	10
NITRATE	5/20/03	0.1	mg/L	10
NITRATE	12/30/03	0.15	mg/L	10
NITRATE	7/28/04	0.2	mg/L	10
NITRITE	11/12/96	0.13	mg/L	1
NITRITE	1/8/97	0.2	mg/L	1
SODIUM	8/11/98	1.33	mg/L	
SODIUM	6/14/99	1.48	mg/L	
SODIUM	4/13/00	2.39	mg/L	
SODIUM	4/12/01	1.58	mg/L	
SODIUM	8/28/01	1.75	mg/L	
SODIUM	4/11/02	1.8	mg/L	
SODIUM	5/6/03	2.26	mg/L	
SODIUM	8/5/03	1.76	mg/L	
SODIUM	7/28/04	1.5	mg/L	
SODIUM	8/10/04	1.67	mg/L	
SULFATE	10/21/96	10	mg/L	

6.1.3 Synthetic Organic Compounds (SOCs)

Following is a summary of SOCs detected for the years 1993-2004. SOCs include herbicides, pesticides and other man-made organic compounds. Di(2-ethylhexyl) phthalate was detected six times during this period not exceeding 50% of the maximum contaminant level (MCL). This contaminant was detected in laboratory blanks analyzed at the same time as the samples and is therefore not considered to be reflective of actual levels in the source water. Low levels of Dalapon were also detected in finished water. Dalapon is a herbicide commonly used on highways and roads right of ways.

Contaminant Name	Sample Date	Result	Units	MCL
DALAPON	11/22/99	0.57	ug/L	200
DI(2-ETHYLHEXYL) PHTHALATE	11/22/99	0.8	ug/L	6
DI(2-ETHYLHEXYL) PHTHALATE	4/13/00	0.7	ug/L	6

DI(2-ETHYLHEXYL) PHTHALATE	4/12/01	1.7	ug/L	6
DI(2-ETHYLHEXYL) PHTHALATE	4/11/02	2.7	ug/L	6
DI(2-ETHYLHEXYL) PHTHALATE	5/6/03	0.6	ug/L	6
DI(2-ETHYLHEXYL) PHTHALATE	7/28/04	0.9	ug/L	6
2,4-D	4/12/01	0.15	ug/L	70

6.1.4 Volatile Organic Compounds (VOCs)/Disinfection Byproducts (DBPs)

No volatile organic compounds, other than disinfection byproducts, have been detected in monitoring treated water for Rocky Gap State Park. Chloroform is the dominant trihalomethane present in the treated water. Disinfection byproducts in finished water from Rocky Gap Water Treatment Plant occasionally exceeded the MCL for total THM (80 ug/l) and Haloacetic acids (HAA) (60 mg/l), prior to the installation of carbon filters in 2005. Currently the running average for TTHM and HAA are consistently below the MCL.

Date	Location	TTHMs	HAAHAA5
08/13/03	ROCKY GAP-BATHROOM FLINTSTONE	68.79	76.66
07/28/04	ROCKY GAP-BATHROOM FLINTSTONE	94.67	34.94
12/14/04	ROCKY GAP-BATHROOM FLINTSTONE	70	71
03/08/05	ROCKY GAP-BATHROOM FLINTSTONE	38.3	62.59

6.1.5 Fecal Coliform/E.coli

At the request of MDE, the Rocky Gap Water Treatment Plant operators began a raw water monitoring program starting in September 2000. The raw water samples were collected bi-weekly and tested for fecal and E.coli. A limited number of results are shown below.

Date	Fecal Count	E-Coli Count
09/07/00	17	6.3
09/21/00	2	1
10/05/00	13	8.6
10/12/00	2	1
10/19/00	11	10.9
10/19/00	2	1
11/09/00	2	4.1
12/21/00	2	1
01/11/01	2	1
01/25/01	2	1

7.0 SUSCEPTIBILITY ANALYSIS

Based on water quality data from Rocky Gap Water Treatment Plant and review of the TMDL report, the water supply is not susceptible to volatile organic compounds, synthetic organic compounds and inorganic compounds. Protozoas, viruses and bacteria and turbidity are of significant concern as they are at all surface water supplies. The limited data available for our review indicated that the intake water meets water quality standards for microbiological contaminants. Lake Habeeb is susceptible to disinfection byproduct precursors and phosphorus, as the limiting nutrient for production of algae in the Lake. Excessive algae can lead to higher concentration of disinfection byproduct precursors and objectionable tastes and odors. Maryland's TMDL analysis determined that a 24% reduction in phosphorus loads is needed.

8.0 RECOMMENDATIONS FOR SOURCE WATER PROTECTION PLAN

This report is compiled based on the existing and available data from several sources. It provides general information as a first step toward establishing and implementing a source water protection plan for Lake Habeeb. Most of the watershed is either under government land ownership or protected by restrictive regulations for small portion of privately owned agricultural land. The following is a list of recommendations regarding watershed management.

- Road signs explaining to the public that they are entering a protected drinking water supply watershed are an effective way to keep the relationship of land use and water quality in the public eye and help in the event of spill notification and response.
- Continue to monitor for all Safe Drinking Water Act as required by MDE, including raw water sources when feasible.
- Resume and continue to monitor for E.coli.
- Allegany County Health Department should notify the water treatment operators the results of monitoring program of public beaches and Rocky Gap State Park.
- Consider incorporating Urban BMPs that are intended to improve the quality of stormwater runoff in the design of any future parking lots or other facilities near the lake.
- Golf course operators should notify water treatment plant personnel of the type and application rate of fertilizers and other maintenance procedures during the growing season.
- Encourage farmers in the watershed to contact Allegany County Soil Conservation District for cost share payments and technical assistance concerning resource conservation practices such as:
    - diverting runoff from animal waste storage areas,
    - planting and maintaining buffer strips, and
    - installing fences to exclude livestock from streams.

9.0 ADDITIONAL REFERENCES

- MDE Water Supply Program Inspection Reports.
- Rocky Gap Water Treatment Plant Monthly Operating Reports (MORs) and Self-Monitoring Reports.
- MDE Water Supply Program database (PDWIS).

APPENDIX

Appendix A

Total Maximum Daily Load of Phosphorus to Lake Habeeb, Allegany County, MD

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EPA Submittal: December 23, 1999
EPA Approval: March 2, 2000

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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 nutrients, Lake Habeeb was identified on Maryland's 1998 list of WQLSs as being impaired. This report proposes the establishment of a TMDL for Lake Habeeb for phosphorus.

Once the TMDL is approved by the United States Environmental Protection Agency (EPA), it will be incorporated into the State's Continuing Planning Process. In the future, the established TMDL will support reservoir restoration and nonpoint source control measures needed to restore water quality in Lake Habeeb.

EXECUTIVE SUMMARY

On the basis of water quality problems associated with nutrients, Lake Habeeb in the Evitts Creek watershed (2141002) was identified on Maryland's 1998 list of WQLSs as being impaired. This document establishes a Total Maximum Daily Load (TMDL) for the nutrient phosphorus entering Lake Habeeb.

Lake Habeeb is an impoundment located in Rocky Gap State Park, in Allegany County, Maryland. The impoundment lies on Rocky Gap Run, a tributary of the Evitts Creek. The watershed lies in a valley between Evitts and Martin Mountains. Lake Habeeb is a highly used recreational facility, with a major resort, conference center and Jack Nicklaus-designed golf course at the south end 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 cause fish kills. Analysis suggests that phosphorus is the limiting nutrient for the production of algae in Lake Habeeb.

The water quality goal of this TMDL is to reduce long-term phosphorus loads to an acceptable level consistent with the physical characteristics of Lake Habeeb. This reduced loading rate is predicted to resolve nuisance problems and maintain a dissolved oxygen concentration above the State water quality standard. The TMDL for phosphorus was determined using an empirical method known as the Vollenweider Relationship.

The average annual TMDL for phosphorus is about 930 lb/yr. There are no point sources in the Habeeb basin. Consequently, the allocation is partitioned between nonpoint sources and the margin of safety.

Preliminary estimations of the phosphorus controls necessary to achieve the load reduction were conducted to provide a reasonable assurance that the TMDL could be implemented. It is estimated that a 24% reduction in phosphorus loads would be necessary to meet the TMDL for phosphorus.

1.0 INTRODUCTION

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

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting and Source Assessment

Lake Habeeb is an impoundment located in Rocky Gap State Park, in Allegany County, Maryland (Figure 1). The watershed lies in a valley between Evitts and Martin Mountains. The impoundment, which is owned by Maryland Department of Natural Resources, lies on Rocky Gap Run, a tributary of the Evitts Creek. An earthen dam was installed for the purpose of recreational uses in 1969. Rocky Gap State park has swimming, hunting, camping, boat launching facilities, and is stocked with walleye, striped bass hybrids, smallmouth bass, and trout (DNR 1985). A major resort and conference center has been constructed at the south end of the lake, including a Jack Nicklaus signature golf course.

The Lake Habeeb watershed lies in the Allegheny Plateau. Evitts Mountain is located east of the watershed and Martin Mountain lies west of the watershed. Soils are formed in material weathered from limestone, sandstone, shale and siltstone. The soils in the watershed are in the Elliber-Dekalb-Opequon Association. The Elliber soils are on top and sides of the ridges and are deep over cherty limestone, and contain large quantities of chert fragments. The Dekalb soils are moderately deep over sandstone and are mostly very stony. The Opequon soils are generally on the sides of the limestone ridges (U.S. Department of Agriculture, Soil Survey of Allegany County, 1977).

Inflow to the lake is primarily via Rocky Gap Run, located primarily in Rocky Gap State Park, and two unnamed tributaries flowing down from the mountains. Discharge from the lake is to Evitts Creek. The watershed map (Figure 2) shows that land use in the watershed draining to Lake Habeeb is predominantly forested/herbaceous. Land use distribution in the watershed is approximately 80% forested/herbaceous, 9% developed, 7% agricultural and 4% water (Figure 3).

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

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

Table 1

Current Physical Characteristics of Lake Habeeb

Location:	Allegany County, MD lat. 39° 42' 01" long. 78° 39' 42"
Surface Area:	208.5 acres
Length:	1.76 mi
Maximum Width:	2100 feet
Average Lake Depth:	25.8 feet
Maximum Depth:	82 feet
Volume of Lake:	5,381 acre-feet (6,637,463 m^3)
Drainage Area to Lake:	8.8 mi^2
Average Discharge:	11.93 cfs

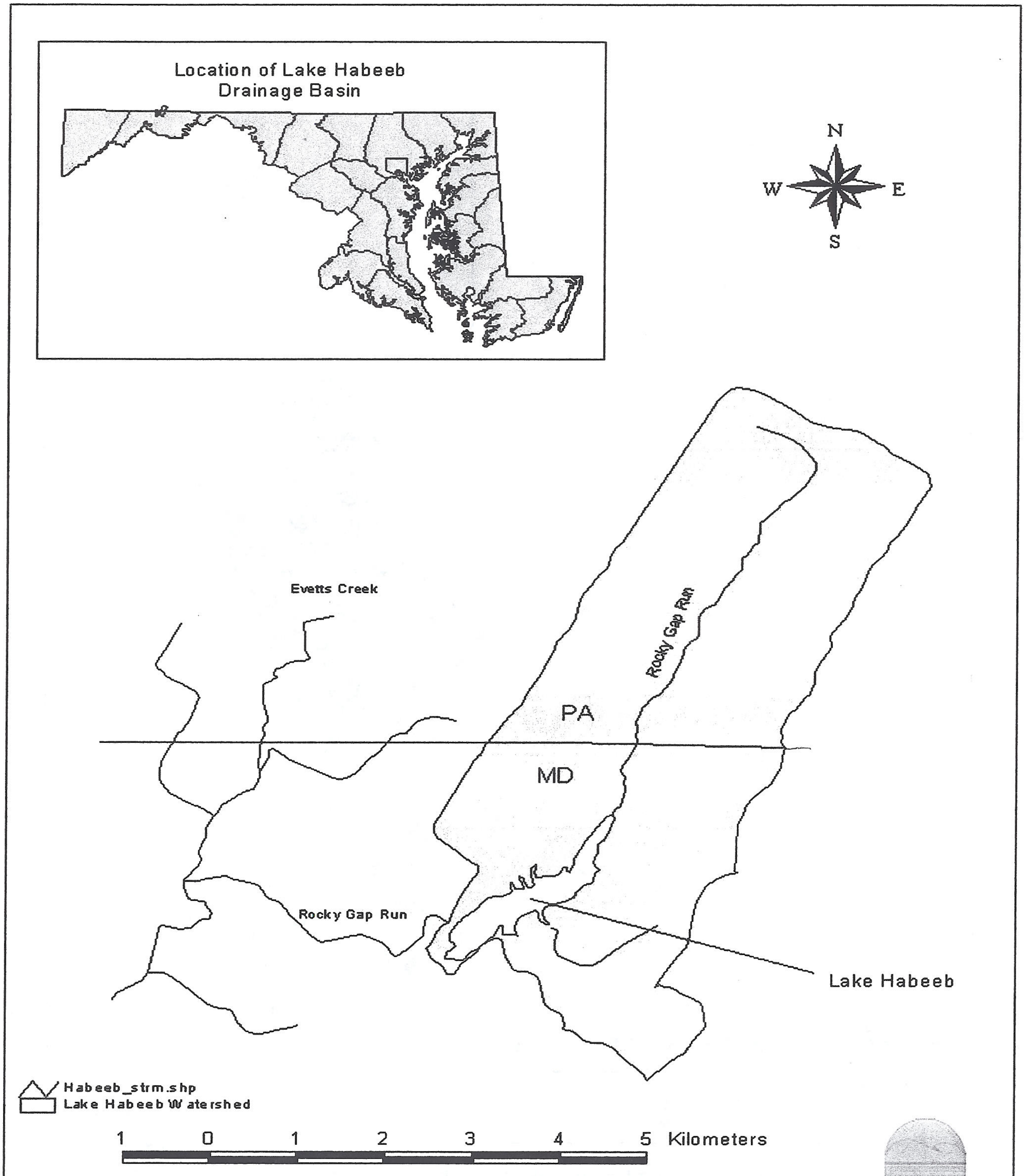
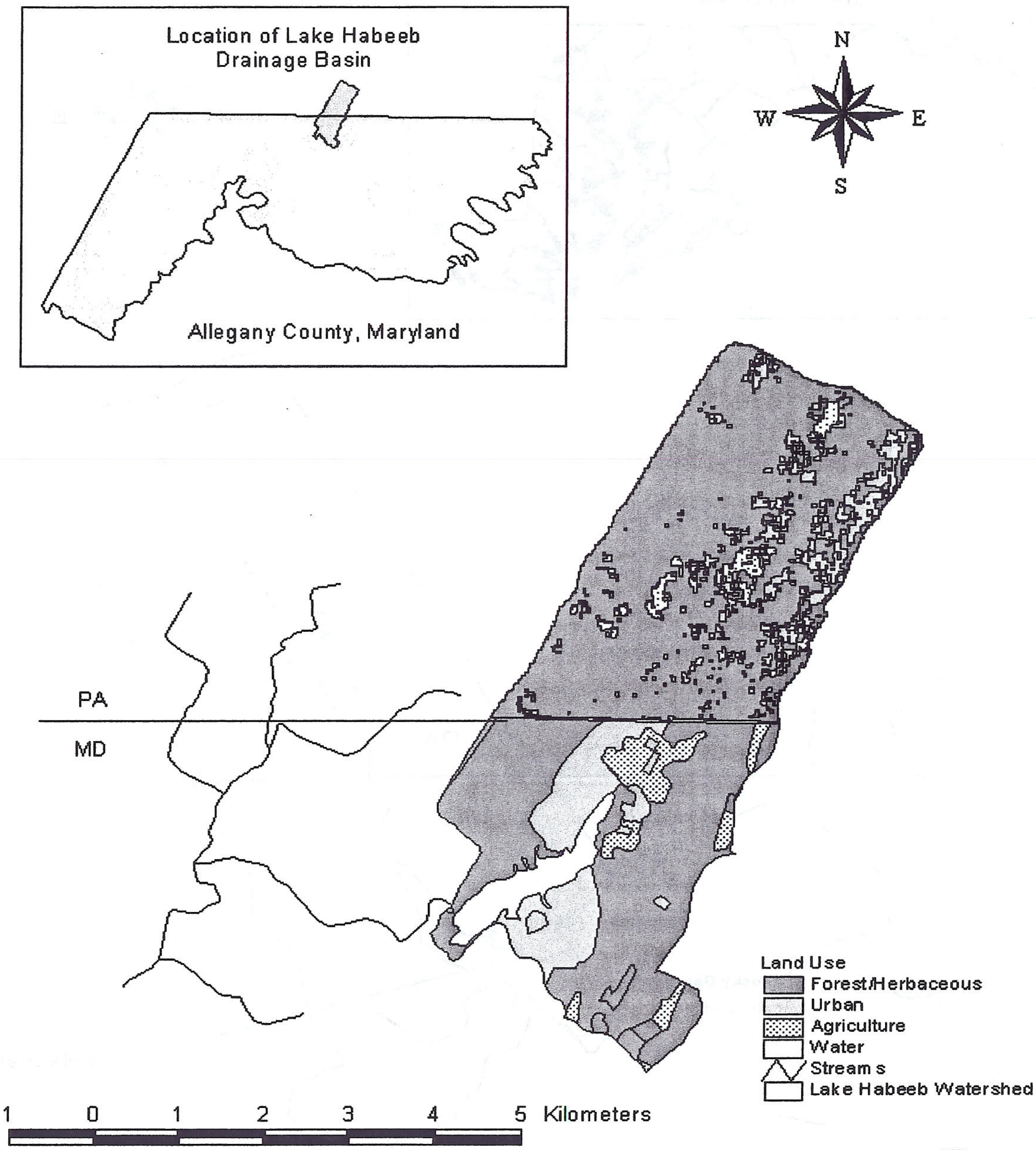


Figure 1 – Location Map of Lake Habeeb in Allegany County, Maryland



Sources:
Land Use for Maryland: Maryland Office of Planning, 1997.
Land Use for Pennsylvania: MRLC 1994

Figure 2 – Predominant Land Use In Lake Habeeb Watershed

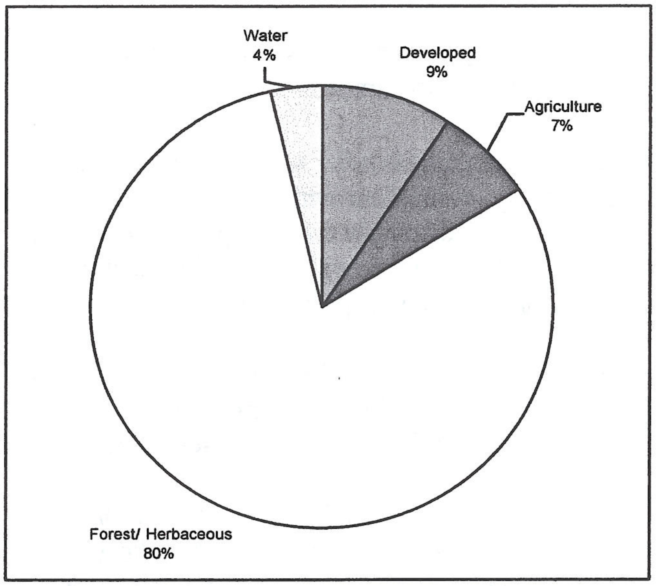


Figure 3. Land Use in Drainage Basin of Lake Habeeb

2.2 Water Quality Characterization

Lake Habeeb was identified as oligo-mesotrophic, with low dissolved oxygen levels, in the *Maryland Lake Water Assessment Report* (March 1998). As a result of this evaluation, Lake Habeeb was added to Maryland's 1998 303(d) list.

Lake Habeeb was monitored in July and September of 1993 (MDE Lake Water Quality Assessment Project, 1993). Water quality samples were collected once in each month. Samples were collected from one station near the spillway, and one station at mid-lake, off the water intake. Water samples were collected from a vertical profile of the water column. Samples were analyzed by the Maryland Department of Health and Mental Hygiene for total phosphorus, soluble orthophosphorus, nitrate and nitrite N, total Kjeldahl nitrogen, total organic solvents and chlorophyll *a*. Physical measurements of depths, water temperatures, pH, conductivity and dissolved oxygen were recorded in the field from the surface, middle and lower portion of the water column. A summary from the MDE Lake Water Quality Assessment Project follows. Detailed water quality data are presented in Appendix A.

Lake Habeeb has recently been monitored once a month by MDE, in March, April, May, June, and July 1999. Water quality samples were collected once in each month. Samples were collected in Rocky Gap Run from one station at the base of the dam and one station near the road leading to the campground. Samples were analyzed by the Maryland Department of Health and Mental Hygiene for total phosphorus, particulate carbon, total dissolved phosphorus, nitrite-nitrate, nitrite, ammonia, total dissolved nitrogen, silica, orthophosphate, particulate nitrogen, dissolved organic compound, particulate phosphorus, and total suspended solids.

Observed chlorophyll *a* concentrations ranged from 1.0 to 3.4 µg/l during the 1993 sampling events, and from 0.2 to 5.4 µg/l during the 1999 sampling events.

Dissolved oxygen (DO) concentrations ranged from 0.1 to 11.3 mg/l along the vertical profile. Oxygen depletion occurs discontinuously, coincident with the depth at which thermal stratification was observed (i.e. about 8 m) during the two sampling events in 1993. Low DO conditions in the reservoir during the summer were observed by Department of Natural Resources (Inventory of Maryland Dams and Hydropower Resources, DNR 1985).

In 1993, total Kjeldahl nitrogen ranged from 0.17 to 0.23 mg/l in Lake Habeeb. Total phosphorus concentrations ranging from 0.01 mg/l to 0.039 mg/l slightly exceeded the range of 0.01 mg/l to 0.03 mg/l for lakes that do not exhibit signs of over-enrichment (Reid 1961).

During the 1999 sampling event, total dissolved phosphorus concentrations ranging from 0.001 mg/l to 0.026 mg/l were observed in Lake Habeeb. Particulate phosphorus concentrations in 1999 ranged from 0.001 mg/l to 0.032 mg/l. Total dissolved nitrogen ranged from 0.25 mg/l to 0.80 mg/l and particulate nitrogen ranged from 0.014 mg/l to 0.123 mg/l in Lake Habeeb.

Water temperatures taken during the 1993 summer sampling period ranged from 25.2°C to 26.6°C in the surface water depth (0.3-1 meter column); 23°C to 26.5°C in the 2-4 meter water column; 11.7°C to 24.5°C in the 5-7 meter water column; 7.8°C to 12.3°C in the 8-11 meter water column; and 6.9 to 8.6°C in the 12-18 meter water column. A similar range was observed again in 1999. This wide range of water temperatures, with an abrupt discontinuity at about 5 m, indicates that Lake Habeeb is thermally stratified and not well mixed.

2.3 Water Quality Impairment

The Maryland water quality standards Surface Water Use Designation (COMAR 26.08.02.07) for Lake Habeeb is Use III-P – *Natural Trout Waters, and Public Water Supply*. The water quality impairments of Lake Habeeb consist of a violation of the numeric water quality for dissolved oxygen, and violations of general narrative criteria applicable to Use III-P waters. The substance causing these water quality violations is phosphorus (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). Growth of the spiny naiad requires drawdown of the reservoir biennially during winter months (Inventory of Maryland Dams and Hydropower Resources, DNR 1985).

According to the numeric criteria for dissolved oxygen (DO), concentrations may not be less than 5.0 mg/l at any time, with a minimum daily average of not less than 6.0 mg/l (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 the numeric criteria is expected in the well-mixed surface waters.

Lake Habeeb water temperatures indicate that the lake is thermally stratified and not well mixed. During the 1993 sampling period (July and September), DO concentrations as high as 8.1 mg/l were observed at the surface (0.3-4 meter depths) of Lake Habeeb, with DO values as low as 0.1 mg/l at a depth of 13-16 meter. Low DO levels in the summer are a common occurrence (Inventory of Maryland Dams and Hydropower Resources, DNR 1985).

3.0 TARGETED WATER QUALITY GOALS

The overall objective of the TMDL established in this document is to reduce phosphorus loads to levels that are expected to result in meeting all water quality criteria that support the Use III-P designation. Specifically, one goal is to reduce the phosphorus load. This is predicted in turn to reduce excessive algae growth, which leads to violations of the numeric DO criteria and the violation of various narrative criteria associated with nuisances.

In summary, the TMDL for phosphorus is intended to:

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

   - A minimum of 5.0 mg/l, and a minimum daily average of not less than 6.0 mg/l, in the surface layer (epilimnion);
   - A minimum DO saturation of 56% and associated temperature-dependent DO concentration below the epilimnion (see Appendix A); and

2. Resolve violations of narrative criteria associated with phosphorus enrichment of Lake Habeeb, to assure that algal production is consistent with the desired trophic status.

4.0 TOTAL MAXIMUM DAILY LOAD AND ALLOCATIONS

4.1 Overview

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

4.2 Analytical Framework

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

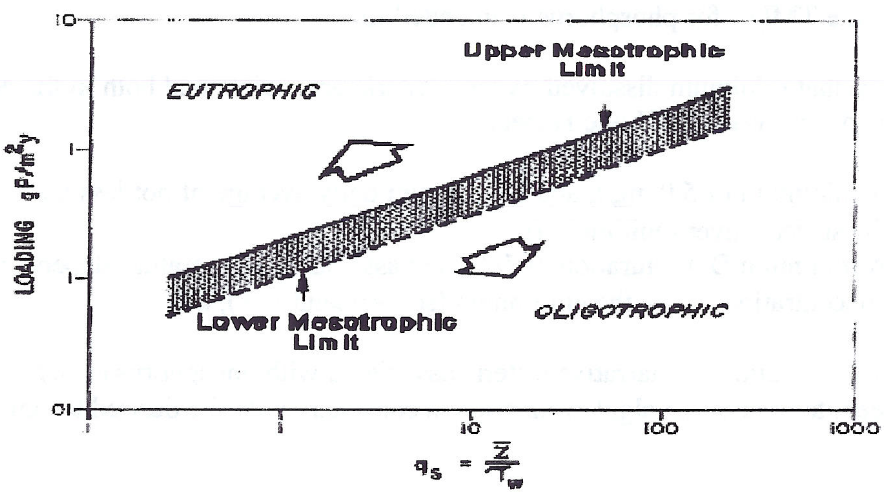


Figure 4. The Vollenweider Relationship

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 constitutes a sufficient, readily available tool.

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

In general, an N:P ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P ratio is greater than 10:1, phosphorus tends to be limiting, and if the N:P ratio is less than 5:1, nitrogen tends to be limiting (Chiandani et al., 1974). The average of the two concentrations, total nitrogen (calculated by adding the total dissolved nitrogen and particulate nitrogen) and total phosphorus (calculated by adding the total dissolved phosphorus and particulate phosphorus), of the March, April, May, June, and July 1999 sampling events were used to calculate the N:P ratio. A N:P ratio of 19:1 was computed, which supports the use of the Vollenweider Relationship. A ratio was also calculated using the average concentrations of total dissolved nitrogen and total dissolved phosphorus of the March, April, May, June, and July 1999 sampling events. A N:P ratio of 62:1 was computed, which also supports the use of the Vollenweider Relationship. Supporting data are provided in Appendix A.

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 (ž) 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 (ž), and (3) the hydraulic residence time (τ_w). The computations and results of the Vollenweider Relationship are summarized below. See Appendix A for details of the computations and supporting data.

Lake Habeeb Mean Depth (ž):

The application of the Vollenweider assumes the lake's physical dimensions when the lake and dam were constructed in 1969. 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 Lake Habeeb are 208.5 acres (9,082,260 ft^2) and 5381 acre feet (234,396,360 ft^3), respectively.

The mean depth was thus calculated as follows:

- ***Lake Habeeb Mean Depth (ž): (Volume)/(Surface Area) = 7.8 m or 25.8 ft***

Phosphorus Loading to Lake Habeeb (Lp):

The current estimated total phosphorus loading is 1095 lbs/year (or 497,727 g/year) based on loading coefficients from the Chesapeake Bay Program, segment 160, Phase 4 Watershed Model. Expressing this value as a loading per surface area of the lake gives:

- ***Annual Phosphorus Load (L_p) is: 0.6 g/m^2 yr.*** Details are provided in Appendix A.

Lake Habeeb Hydraulic Residence Time (τ_w)

Residence time (τ_w) is computed by dividing the lake volume by annual discharge. For Lake Habeeb, average discharge data are unavailable. Since discharge data are unavailable, this parameter was estimated by examining a number of watersheds of various sizes on the North Potomac Branch Basin 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 the average annual flow. Flow from Lake Habeeb is estimated as follows (details are shown in Appendix A):

- **Flow (Q) = watershed area (8.8 mi^2) x 1.356 = 11.93 cfs = 8,643 acre feet/year**

The hydraulic residence time is computed as volume/outflow; the time it would take to drain the lake. Assuming a volume of 5,381 acre feet (DNR, 1985), from above, and a discharge rate of 8,643 acre per year (DNR, 1985) the hydraulic residence time is calculated as follows:

- **5,381 acre feet ÷ 8,643 acre feet/year =** 0.62 years

- ***Lake Habeeb Hydraulic Residence Time (τ_w): 0.62 years = 226 days***

The mean depth of the lake (7.9 m) is then divided by hydraulic residence time (0.62 years) to yield q_s, the parameter with which to compare phosphorus loading using the Vollenweider Relationship to assess the lake's trophic status. For Lake Habeeb, **q_s = 12.58 m/yr.**

4.4 Vollenweider Relationship Results

The basic elements of the Vollenweider Relationship, established above, were combined to estimate both the current trophic status of Lake Habeeb, and the maximum allowable unit loading. The current estimated loading rate of 0.6 g/m^{2}yr would suggest a current trophic status slightly within the mesotrophic range, as indicated on Figure 5 by a diamond "♦". Lake Habeeb is classified as oligo-mesotrophic (DNR 1998). The maximum allowable unit loading of 0.5 g/m^2 yr for a lake with mean depth of 7.9 m and hydraulic residence time of 0.62 years is indicated by the intersection of the cross-hairs (See Appendix A). The TMDL implications are presented below in Section 4.5.

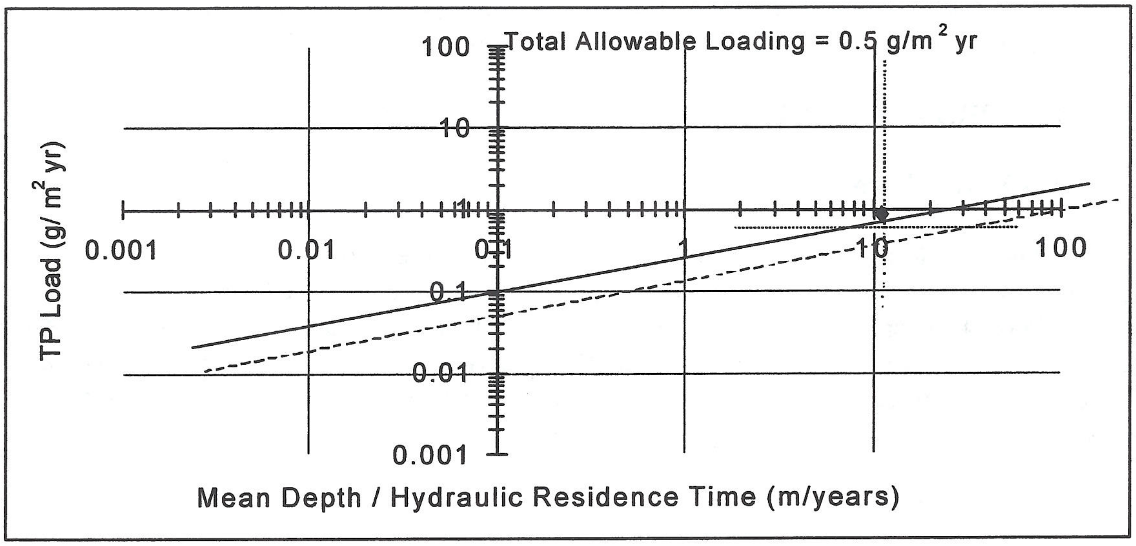


Figure 5. Vollenweider Results for Lake Habeeb

4.5 Total Maximum Daily Load

This TMDL considers seasonal variations by estimating loading rates over the entire year. This captures the dry weather loading rates, which generally occur during the warmer months when algae production is most prevalent. It also captures the wet-weather loading rates, which contribute significant sediment-bound sources of phosphorus. The Vollenweider Relationship specifically uses long-term loading estimates to avoid adopting a single transient loading pulse, which would yield erroneous results. The critical conditions are accounted for implicitly in the empirical Vollenweider Relationship. 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 (0.5 g/m^2 year) times the total surface area of the lake (844,076 m^2) or 422,038 g/yr. This represents a 24% reduction in phosphorus loading.

The link between DO concentration and the lake's trophic status (as defined by the Vollenweider Relationship) is indirect, but may be inferred as described below. Nutrient overenrichment causes excess algal blooms, which eventually die off and decompose, consuming DO.

The DO in the surface layer of Lake Habeeb is currently within State standards (see Table A-1, Appendix A). An assessment is made of the processes that determine DO concentration in the sub-epilimnetic portion of the lake (see Appendix A). The assessment is based on critical conditions and uses conservative assumptions. These processes, as they apply to Lake Habeeb, are outlined below:

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

According to calculations presented in Appendix A, it is expected that an areal phosphorus load of 0.5 g/m^2 will result in hypolimnetic DO concentrations of about 4.8-6.9 mg/l.

PHOSPHORUS TMDL 422,038 *g/yr* = 929 lb/yr

4.6 TMDL Allocation

The watershed that drains to Lake Habeeb contains no permitted point source discharges. Hence, the entire allocation will be made to nonpoint sources. The model uses Chesapeake Bay Program, Phase 4 Phosphorus loading coefficients to estimate the loading rates, which represent the cumulative impact from all sources—naturally-occurring and human-induced. Details are described in the technical memorandum entitled "Significant Phosphorus Nonpoint Sources in the Lake Habeeb Watershed".

4.7 Margin of Safety

A margin of safety (MOS) is required as part of a TMDL in recognition of the fact that there are many uncertainties in scientific and technical understanding of water quality in natural systems. Specifically, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural water bodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through one of two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = WLA + LA + MOS). The second approach is to incorporate the MOS as part of the design conditions for the WLA and the LA computations.

Maryland has elected to incorporate an explicit margin of safety for this phosphorus TMDL. 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.

4.8 Summary of Total Maximum Daily Load

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

TMDL	=	WLA	+	LA	+	MOS
929	=	0	+	836	+	93

On average, this TMDL represents a daily phosphorus load of 2.5 lbs/day.

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

5.0 ASSURANCE OF IMPLEMENTATION

Lake Habeeb is located in a watershed in which the impairment is driven entirely 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), and the EPA-sponsored Clean Water Action Plan of 1998 (CWAP).

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 have 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 (either 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 24% reduction of external phosphorus loadings.

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Appendix A

Lake Habeeb Water Quality

Water quality data from Lake Habeeb were collected in 1993 (DNR, Trophic Lake Assessment Study) and 1999 (MDE, Lake Water Quality Assessment Project). A summary of the water quality data was provided in the main body of this report. Tables A1 through A4 provide the underlying data from which the summaries were derived.

Assessment of the N:P Ratio for Lake Habeeb

Before considering the application of the Vollenweider Relationship, it is necessary to examine the ratio of nitrogen (N) to phosphorus (P) to establish whether phosphorus is the limiting nutrient. In general, an N:P ratio in the range of 5:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P ratio is greater than 10, phosphorus tends to be limiting, and if the N:P ratio is less than 5, nitrogen tends to be limiting (Chiandani, et al., 1974).

The N:P ratio was calculated using data from the two sampling events (MDE Lake Water Quality Assessment Project). The average of the two concentrations, total nitrogen (calculated by adding the total dissolved nitrogen and particulate nitrogen) and total phosphorus (calculated by adding the total dissolved phosphorus and particulate phosphorus), of the March, April, May, June, and July 1999 sampling events were used to calculate the N:P ratio. A N:P ratio of 19:1 was computed which supports the use of the Vollenweider Relationship. A N:P ratio of 62:1 was also calculated using the average concentrations of total dissolved nitrogen and total dissolved phosphorus of the March, April, May, June, and July 1999 sampling events. This also supports the use of the Vollenweider Relationship.

Table A1
Field Data For Lake Habeeb – 1993
Water Column Results

STATION	DATE	TIME	DEPTH (m)	WATER TEMP (°C)	PH FIELD	DO (mg/l)	COND (mg/l)
RKG0025	7/19/93	1130	0.3	26.6	7.9	7.9	97
RKG0025	7/19/93	1130	1.0	26.6	7.8	7.9	96
RKG0025	7/19/93	1130	2.0	26.5	7.6	7.9	96
RKG0025	7/19/93	1130	3.0	25.7	7.5	8.2	96
RKG0025	7/19/93	1130	4.0	23	7.1	10.5	92
RKG0025	7/19/93	1130	5.0	19.4	6.8	10.4	90
RKG0025	7/19/93	1130	6.0	14.4	6.7	9.5	90
RKG0025	7/19/93	1130	7.0	11.7	6.7	7.4	92
RKG0025	7/19/93	1130	8.0	9.4	6.6	5.2	94
RKG0025	7/19/93	1130	9.0	8.5	6.6	3.7	96
RKG0025	7/19/93	1130	10.0	8.0	6.6	3.1	99
RKG0025	7/19/93	1130	11.0	7.8	6.6	3.3	98
RKG0025	7/19/93	1130	12.0	7.6	6.6	2.3	99
RKG0025	7/19/93	1130	13.0	7.3	6.7	2.4	98
RKG0025	7/19/93	1130	14.0	7.3	6.7	2.4	98
RKG0025	7/19/93	1130	15.0	7.1	6.7	1.0	100
RKG0025	7/19/93	1130	16.0	7.0	6.7	0.1	102
RKG0025	7/19/93	1130	17.0	7.0	6.6	0.1	103
RKG0025	7/19/93	1130	18.0	6.9	6.7	0.1	108
RKG0025	7/19/93	1130	18.7	6.8	6.7	0.1	108
RKG0034	7/19/93	1225	0.3	26.4	8.0	7.7	94
RKG0034	7/19/93	1225	1.0	26.4	7.9	7.7	94
RKG0034	7/19/93	1225	2.0	26.4	7.7	7.8	94
RKG0034	7/19/93	1225	3.0	26.3	7.5	7.7	93
RKG0034	7/19/93	1225	4.0	24.6	7.0	6.2	93
RKG0034	7/19/93	1225	5.0	19.0	7.1	6.3	91
RKG0034	7/19/93	1225	6.0	14.0	7.3	4.3	94
RKG0034	7/19/93	1225	6.7	12.6	7.5	4.1	96
RKG0025	9/7/93	1350	0.3	25.5	8.0	8.1	99
RKG0025	9/7/93	1350	1.0	25.2	8.0	8.1	100
RKG0025	9/7/93	1350	2.0	25.0	8.0	8.1	100
RKG0025	9/7/93	1350	3.0	24.9	7.9	8.1	100
RKG0025	9/7/93	1350	4.0	24.8	7.9	8.1	99
RKG0025	9/7/93	1350	5.0	24.5	7.7	8.0	98
RKG0025	9/7/93	1350	6.0	20.8	7.3	11.3	93
RKG0025	9/7/93	1350	7.0	16.3	6.5	4.5	94
RKG0025	9/7/93	1350	8.0	12.3	6.5	3.0	95
RKG0025	9/7/93	1350	9.0	10.0	6.5	1.3	97
RKG0025	9/7/93	1350	10.0	9.4	6.5	1.3	98
RKG0025	9/7/93	1350	11.0	8.7	6.5	1.0	99
RKG0025	9/7/93	1350	12.0	8.6	6.5	0.5	100
RKG0025	9/7/93	1350	13.0	8.3	6.6	0.1	102
RKG0025	9/7/93	1350	14.0	8.1	6.6	0.1	102
RKG0025	9/7/93	1350	15.0	8.0	6.7	0.1	103
RKG0025	9/7/93	1350	16.0	7.8	6.8	0.1	110
RKG0025	9/7/93	1350	17.0	7.7	6.7	0.1	115
RKG0025	9/7/93	1350	18.0	7.7	6.8	0.1	116
RKG0025	9/7/93	1350	19.2	7.8	6.8	0.1	119
RKG0034	9/7/93	1445	0.3	26.0	8.0	8.0	98
RKG0034	9/7/93	1445	1.0	25.7	8.0	8.0	99
RKG0034	9/7/93	1445	2.0	25.4	7.9	8.0	99
RKG0034	9/7/93	1445	3.0	25.3	7.7	7.9	97
RKG0034	9/7/93	1445	4.0	25.1	7.5	7.8	98
RKG0034	9/7/93	1445	5.0	23.9	7.1	7.8	96
RKG0034	9/7/93	1445	6.0	20.3	6.8	7.0	92
RKG0034	9/7/93	1445	7.0	14.2	6.6	0.7	99
RKG0034	9/7/93	1445	8.2	11.5	6.7	0.1	101

Table A2
Lake Habeeb Nutrient Data (1993)

STATION	DATE	TIME	DEPTH (m)	TOC (mg/l)	TKN (mg/l)	TP (mg/l)
RKG0025	7/19/93	1130	0.3	N/A	0.19	0.032
RKG0025	7/19/93	1130	0.3	N/A	0.23	0.039
RKG0034	7/19/93	1225	0.3	N/A	0.17	0.037
RKG0025	9/17/93	1350	0.3	3.96	0.22	0.01
RKG0034	9/17/93	1445	0.3	3.86	0.19	0.01

N/A = No sample.

Table A3
Lake Habeeb Chlorophyll Data (1993)

STATION	DATE	TIME	DEPTH (m)	CHLA (µg/l)	PHEA (mg/l)
RKG0025	7/19/93	1130	0.0	2.4	0.0
RKG0025	7/19/93	1130	0.3	1.2	0.2
RKG0025 (dup)	7/19/93	1130	0.3	1.3	-0.1
RKG0034	7/19/93	1225	0.0	1.5	0.0
RKG0034	7/19/93	1225	0.3	1.7	0.2
RKG0025	9/21/93	1350	0.0	3.4	0.9
RKG0025	9/21/93	1350	0.3	1.0	0.3
RKG0034	9/21/93	1445	0.0	2.3	0.1
RKG0034	9/21/93	1445	0.3	1.7	-0.1

Table A4
Lake Habeeb Surface Water Quality Data (MDE 1999[1])

Station	Date	PC (mg/l)	TDP (mg/l)	NO_{23} (mg/l)	NO_2 (mg/l)	NH_4 (mg/l)	TDN (mg/l)	Si (mg/l)	PO_4 (mg/l)	PN (mg/l)	DOC (mg/l)	PP (mg/l)	TSS (mg/l)
RKG0023	Mar 30, 1999	0.415	0.004	0.126	0.001	0.015	0.480	0.800	0.0018	0.055	3.420	0.002	2.400
RKG0041	Mar 30, 1999	0.176	0.003	0.129	0.001	0.004	0.310	2.250	0.0011	0.017	2.750	0.001	2.400
RKG0023	Apr 15, 1999	0.435	0.001	1.123	0.002	0.041	0.400	0.780	0.001	0.055	3.040	0.003	2.400
RKG0041	Apr 15, 1999	0.344	0.001	0.108	0.002	0.022	0.250	2.290	0.002	0.123	2.870	0.001	2.400
RKG0023	May 19, 1999	0.508	0.026	0.247	0.002	0.129	0.530	0.990	0.021	0.054	3.280	0.008	2.400
RKG0041	May 19, 1999	0.274	0.002	0.136	0.0007	0.003	0.290	2.320	0.001	0.034	2.670	0.003	2.700
RKG0023	Jun 2, 1999	0.344	0.023	0.132	0.0036	0.227	0.530	1.290	0.0044	0.049	3.430	0.005	2.400
RKG0041	Jun 2, 1999	0.221	0.003	0.524	0.0067	0.108	0.800	2.170	0.0036	0.031	4.340	0.003	2.400
RKG0023	July 13, 1999	0.865	0.003	0.118	0.0027	0.361	0.730	1.290	0.0033	0.086	3.260	0.032	8.500
RKG0041	July 13, 1999	0.092	0.001	0.225	0.0011	0.012	0.430	1.350	0.0006	0.014	1.900	0.001	2.400

[1] All samples were collected at the surface.

DOC = Dissolved Organic Carbon
NO_{23} = Nitrite Nitrate
NO_2 = Nitrite
NH_4 = Ammonia
PC = Particulate Carbon
PO_4 = Orthophosphate
PN = Particulate Nitrogen
PP = Particulate Phosphorus
Si = Silica
TDN = Total Dissolved Nitrogen
TDP = Total Dissolved Phosphorus
TSS = Total Suspended Solids

Table A5
Water Quality (Chlorophyll) Data Lake Habeeb - 1999

STATION	DATE	TIME	DEPTH (m)	CHLA (mg/l)
RKG0023	3/29/99	1300	0.0	5.4
RKG0041	3/29/99	1340	0.0	0.9
RKG0023	4/15/99	1310	0.0	3.3
RKG0041	4/15/99	1210	0.0	0.2

Table A6
Field Data For Lake Habeeb – 1999
Water Column Results

STATION	DATE	TIME	DEPTH (m)	WATER TEMP (°C)	PH FIELD	DO (mg/l)	COND (µohms/cm)
RKG0023	3/29/99	1340	0.0	6.5	6.6	12.8	60
RKG0041	3/29/99	1300	0.0	12.5	6.5	10.8	50
RKG0023	4/15/99	1245	0.0	6.7	6.4	11.8	55
RKG0041	4/15/99	1210	0.0	8.4	6.1	11.0	35
RKG0023	5/19/99	1350	0.0	11.0	6.4	9.5	65
RKG0041	5/19/99	1315	0.0	17.0	7.0	8.4	70
RKG0023	6/02/99	1455	0.0	11.9	6.2	8.4	70
RKG0041	6/02/99	1420	0.0	22.8	7.2	8.1	150
RKG0023	7/13/99	1500	0.0	13.9	6.6	8.6	126
RKG0041	7/13/99	1410	0.0	22.8	–	9.0	208
RKG0023	8/31/99	1505	0.0	9.2	7.1	7.62	47
RKG0025	8/31/99	1040	0.0	23.3	8.15	8.04	103
RKG0025	8/31/99	1040	1.0	23.3	8.15	8.09	103
RKG0025	8/31/99	1040	2.0	23.3	8.14	7.99	103
RKG0025	8/31/99	1040	3.0	23.3	8.14	8.04	104
RKG0025	8/31/99	1040	4.0	23.1	8.16	8.11	104
RKG0025	8/31/99	1040	5.0	23.1	8.09	7.97	103
RKG0025	8/31/99	1040	6.0	22.4	7.73	7.77	101
RKG0025	8/31/99	1040	7.0	17.3	6.97	7.44	99
RKG0025	8/31/99	1040	8.0	13.7	6.75	5.61	102
RKG0025	8/31/99	1040	9.0	11.8	6.67	4.32	104
RKG0025	8/31/99	1040	10.0	10.5	6.61	3.29	105
RKG0025	8/31/99	1040	11.0	9.7	6.58	2.42	106
RKG0025	8/31/99	1040	12.0	9.1	6.57	1.87	108
RKG0025	8/31/99	1040	13.0	8.8	6.53	0.96	110
RKG0025	8/31/99	1040	14.0	8.5	6.53	0.34	112
RKG0025	8/31/99	1040	15.0	7.8	6.61	0.34	115
RKG0025	8/31/99	1040	16.0	7.9	6.66	0.34	119
RKG0025	8/31/99	1040	17.0	7.9	6.68	0.35	123
RKG0025	8/31/99	1040	17.8	8.1	6.67	0.49	125
RKG0034	8/31/99	1305	0.0	23.3	7.98	7.91	103
RKG0034	8/31/99	1305	1.0	23.3	8.0	7.81	104
RKG0034	8/31/99	1305	2.0	23.2	8.01	7.91	104
RKG0034	8/31/99	1305	3.0	23.0	8.0	7.95	104
RKG0034	8/31/99	1305	3.5	22.9	7.98	7.89	104
RKG0034	8/31/99	1305	4.0	22.9	7.94	7.91	104
RKG0034	8/31/99	1305	5.0	22.7	7.87	7.8	104
RKG0034	8/31/99	1305	5.5	22.5	7.7	7.7	104
RKG0034	8/31/99	1305	6.0	22.3	7.73	7.67	104
RKG0034	8/31/99	1305	6.5	20.3	7.04	6.73	104
RKG0034	8/31/99	1305	7.0	17.9	6.8	5.96	101
RKG0034	8/31/99	1305	7.5	16.1	6.76	3.2	105
RKG0041	8/31/99	1305	0.0	18.1	7.8	8.83	72

Supporting Calculations for the Vollenweider Analysis

Lake Habeeb Mean Depth ($\bar{z}$):

The mean lake depth was calculated using lake volume and surface area given in the Inventory of Maryland Dams and Hydropower Resources (DNR 1985). The cited surface area and volume of Lake Habeeb are 208.5 acres (9,082,260 ft^2) and 5381 acre feet (234,396,360 ft^3), respectively.

Convert $feet^2$ to m^2 : 9,082,260 ft^2 x 0.092 m^2/ft^2 = 844,076 m^2

Convert acre feet to m^3 : 5381 acre feet x 1,233.5 m^3/ acre feet = 6,637,463 m^3

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

6,637,463 m^3 ÷ 844,076 m^2 = **7.9 m or 25.8 ft**

Current Phosphorus Loading to Lake Habeeb (Lp):

The total phosphorus loading from land is cited as 1095 lbs/year (497,727 g/yr) based on loading rates from the Chesapeake Bay Program Phase 4 Model, segment 160.

Using the estimated 1969 lake surface area (844,076 m^2), this value can be converted to grams per square meter per year as follows: 497,727 g/yr ÷ 844,076 m^2 = **0.6 g/m^2 yr.**

Lake Habeeb Hydraulic Residence Time (τ_w):

The hydraulic residence time is computed as volume/outflow; it is the time it would take to drain the lake.

Hydraulic residence time is calculated based on the lake volume and discharge rate. Since discharge data are unavailable, discharge was estimated by regressing watershed size versus all discharge data on record for ten watersheds of varying size in the North Branch of the Potomac Basin of Maryland. Linear regression provided a correlation coefficient (R^2) of 0.9702 when the Y-intercept was not forced to zero, and 0.9697 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 in the North Branch of the Potomac Basin. 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-1 below. The overall Lake Habeeb watershed measures 8.8 mi^2; the estimated discharge is thus 11.93 cfs (8,643 acre feet per year).

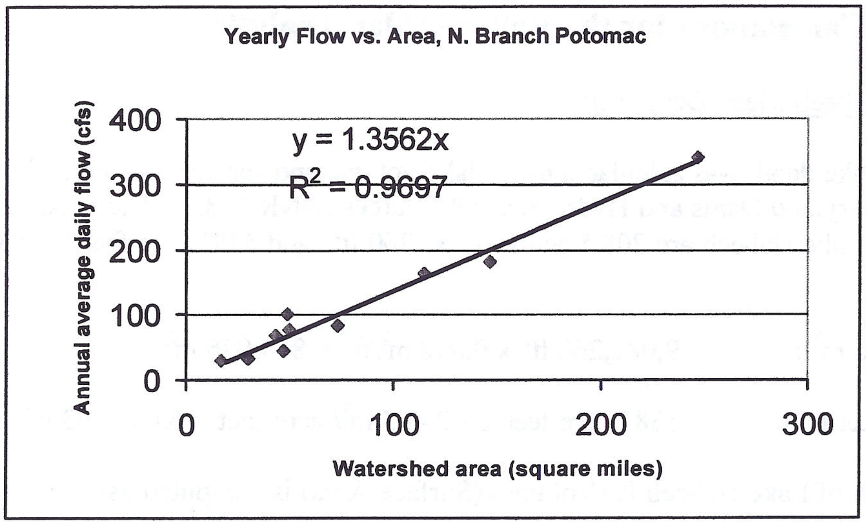

Figure A-1. Discharge as function of watershed area, North Branch Potomac of Maryland

Hydraulic residence time (τ_w) is calculated as follows:

(5381 acre feet) ÷ (23.6 acre feet per day) = 228 days.

228 days ÷ 365 days/yr = **0.62 yr**

Ratio of Mean Depth to Hydraulic Residence Time ($\check{z}/\tau_w$)

From the computations above the mean depth of Lake Habeeb ($\check{z}$) is 7.9 m, and the hydraulic residence time (τ_w) is 0.62 yr. The ratio was computed as:

7.9 m / 0.62 yr = **12.74 m/yr**

Graphing of Trophic Status of Lake Habeeb using the Vollenweider Relationship

The intersection of the phosphorus loading rate (L_p) = 1.4 g/m^{2}yr and the ratio ($\check{z}/\tau_w$) = 23.8 m/yr was plotted on log log paper to establish the trophic status of Lake Habeeb (See Figure 5).

Determination of the Oligo-mesotrophic Zone of Vollenweider's Diagram

Vollenweider's diagram categorizes lakes into three trophic states (eutrophic, mesotrophic, and oligotrophic) on the basis of the log-log relationship between areal P loading and q_s. Maryland's current methods categorize lakes into two additional trophic states—meso-eutrophic and oligo-mesotrophic. It was thus necessary to subdivide the mesotrophic portion of Vollenweider's diagram.

The oligo-mesotrophic range is the lower one-third of the mesotrophic portion of the Vollenweider's diagram.

For Lake Habeeb, the mesotrophic range of areal P loading was first estimated as per Vollenweider's methods. This "combined mesotrophic" range was then divided into three equal ranges to allow setting upper P loading limits for oligo-mesotrophic, mesotrophic, and meso-eutrophic lakes.

The combined mesotrophic portion of Vollenweider's diagram (i.e., before subdivision), for a lake with a q_s of 12.73 m/yr, ranges from 0.35 to 0.8 g/m^2/yr. Each subdivision of this combined mesotrophic range is assigned its own range spanning 0.15 g/m^2/yr. Thus, the oligo-mesotrophic range for Lake Habeeb lies within 0.35 – 0.50 g/m^2/yr. The phosphorus TMDL is set at 0.50 g/m^2/yr.

Supporting Calculations for the TMDL Analysis

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

Figure 5 (p.11) shows how the maximum allowable unit phosphorus loading can be read off of the log log paper. Point A represents the maximum allowable load, which includes the load allocation and the margin of safety (0.5 g/m^{2}yr).

Computing the Phosphorus TMDL

The TMDL is computed from the maximum unit load read from Point A on Figure 5:

(Unit loading) x (Lake Surface Area) = Annual Loading
(0.5 g/m^{2}yr) x (844,076 m^2) = **422,038 g/yr**

Converted to pounds per year:
(422,038 g/yr) x (0.0022 lb/g) = **929 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 (422,038) = **42,204 g/yr**

Converted to pounds per year:
42,204 *g/yr* x (0.0022 lb/g) = **93 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:

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

$$\frac{(497{,}727 \text{ g/yr}) - (379{,}834 \text{ g/yr})}{(497{,}727 \text{ g/yr})} = 24\% \text{ reduction}$$

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

Supporting Determination of the Expected Minimum DO below Epilimnion

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

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

Chapra (1997) presents ranges of hypolimnetic DO saturation as a function of trophic status in eutrophic, mesotrophic and oligotrophic lakes (Table A-4). MDE (1999) has adapted and extended this methodology to apply to the two additional trophic categories—oligo-mesotrophic and meso-eutrophic—used to classify Maryland's lakes (Table A-5).

Table A-4

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

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

Adapted from Chapra (1997)

Table A-5

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

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

MDE is establishing a phosphorus TMDL to manage Lake Habeeb at the oligo-mesotrophic status. Current phosphorus loading estimates place Lake Habeeb slightly in the eutrophic range. As phosphorus reductions result in a shift to an oligo-mesotrophic status, it is predicted that the DO saturation will increase to a range of 56% in the waters below the epilimnion, as indicated in Table A-5. This increased saturation is consistent with interim interpretation of Maryland's water quality criterion for dissolved oxygen in thermally stratified lakes (MDE, 1999).

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

Specifically, two line segments have been drawn from the ends of the observed range of temperatures (6.8 - 23°C), through the point at 56% on the diagonal scale for DO saturation. These two line segments intersect the lower horizontal scale indicating an expected DO concentration ranging from 4.8 – 6.8 mg/l. This range reflects an increase over the current minimum observed DO concentration of 0.1 mg/l, and reflects the DO endpoint expected to result from the TMDL. This increased sub-epilimnetic DO concentration is consistent with the interim interpretation of Maryland's water quality criterion for dissolved oxygen in thermally stratified lakes (MDE, 1999).

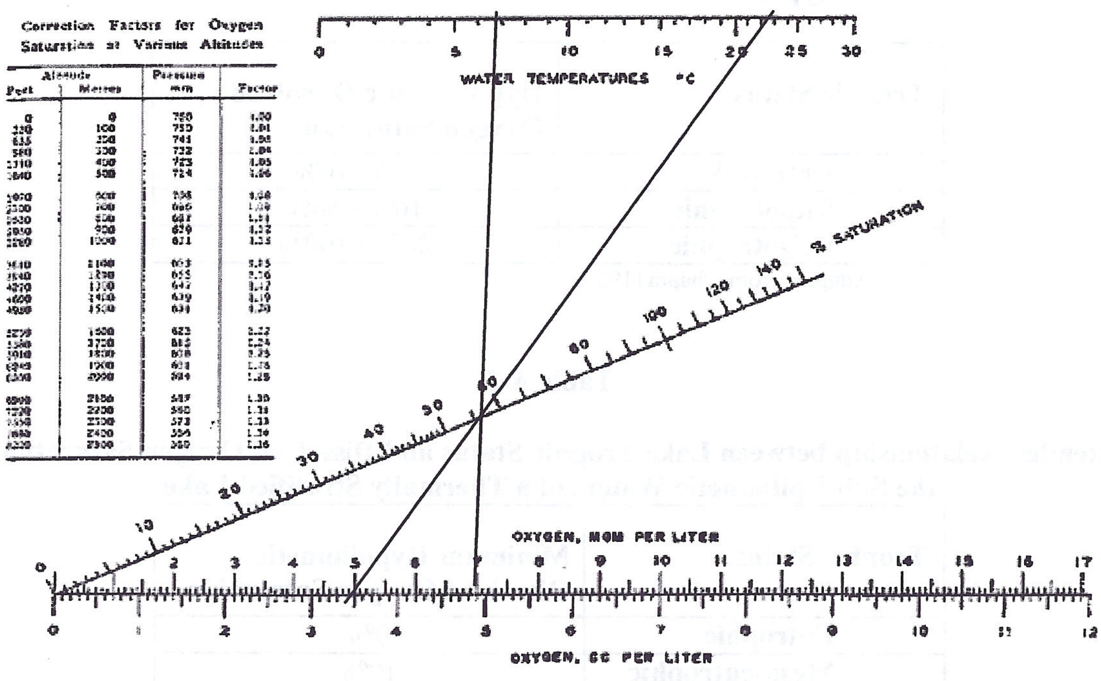

Figure A-2. Nomogram (adapted from Reid 1961) showing expected sub-epilimnetic DO concentrations at ambient temperatures in Lake Habeeb during periods of stratification.