EVALUATION OF TROPHIC STATUS FOR LAKE HAMILTON

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Submitted in Partial Fulfillment of the Requirmements
for the Degree of
Master of Science
in the School of Engineering
Civil Engineering Department

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Youngstown State University
December 1992

Y-10-4
(5)

Abstract

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There were two main goals of this project, the first was to evaluate the trophic status of Lake Hamilton, using empirical and simple mechanistic models. The second was to obtain a detailed data base for 1987 that could be used to model eutrophication with a sophisticated model.

Field sampling was performed on 25 dates during 1987; temperature and dissolved oxygen profiles were determined at the sampling sites. Samples were collected and analyzed for soluble reactive phosphorus, total soluble phosphorus, nitrate, ammonia and chlorophyll a.

Many hydrologic and morphometric parameters were calculated for Lake Hamilton. Also, the large amount of data collected for the lake is suitable for future use in more detailed water quality modeling. Lake Hamilton trophic status was predicted to be eutrophic using Vollenweider's (1975) loading plot. Based on the procedure of Dillon and Rigler (1975), the phosphorus loading to Lake Hamilton was estimated to be 2524 kg/Yr. It was also estimated that a 60%

reduction in phosphorus loading would be required to improve the lake from a eutrophic to a mesotrophic condition.

To my Mother, Father, and Uncle

Without your Love, Support, and Encouragement

I would not be here.

To my dear wife

Your Help, Affection, and Understanding

Made this project a simpler task.

ACKNOWLEDGMENTS

Special thanks to my advisor, Dr. Scott C. Martin, who initiated my interest in Environmental Engineering, and who has been a continuous source of advisement throughout my college career. Also special thanks to my teachers in the Civil Engineering Department: Dr. Jack Bakos, Chairman, Dr. Irfan Kahn, Dr. John Cernica, Dr. Javed Alam, and Professor John Ritter. Also special thanks to the faculty and staff of Youngstown State University whose help has been indispensable to this project.

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Chapter One

Introduction

Eutrophication is the natural process of fertilizing surface waters by the input of nutrients (nitrogen and phosphorus); these nutrients will promote algal growth when adequate light is available. Algae will, in turn, settle to the bottom of the basin and die. Aerobic bacteria at the bottom then start working to decompose the dead material, consuming dissolved oxygen. The more nutrients introduced to a lake, the more algae are produced in the epilimnion (upper waters) and the more oxygen is depleted by the bacteria in the hypolimnion (bottom waters). Algal growth causes turbidity that limits light penetration and may limit production to the surface layers of the lake. The depletion of dissolved oxygen by the bacteria may result in anaerobic conditions.

Eventually, enough algae die and fill up the lake, producing what we know as a peat bog. This process takes thousands of years to occur naturally, but can be accomplished in only a decade if enough nutrients are introduced into the lake as a result of human activities. Often the growth-limiting algal nutrient is phosphorus (P), which is introduced from agricultural runoff, detergents, and human or animal waste. The trophic status of lakes is classified into one of three categories:

1. Oligotrophic: very low nutrient levels and algal productivity.

2. Mesotrophic: moderate nutrient and productivity levels.

3. Eutrophic: high nutrient levels and productivity. Eutrophic conditions make a water undesirable for body contact recreation or use as a drinking water source.

Mathematical models are used to analyze water quality in a lake; these models range from very simple, empirical equations to sets of very complex, theoretical (or "mechanistic") equations that must be solved using numerical techniques. These models can be used to evaluate the adequacy of existing data, determine what processes are most important in lakes, and predict how the lake will respond to changes in external loadings (for example, of P) or environmental conditions. Many different models have been developed to provide insight into the problem of eutrophication.

The focus of this study was Lake Hamilton in Struthers, Ohio (Figure 1.1). This man-made lake was constructed in 1905 by the damming of Yellow Creek, and it is owned by the Ohio Water Service Company. It is currently used as the source of drinking water by the City of Campbell, Ohio. It is also used by several different industries in the area.

There were two main objectives of this study. The first was to evaluate the trophic status of Lake Hamilton, using convenient empirical and mechanistic models. The second was

Figure 1.1 Map Showing Location of Lake Hamilton

to obtain a detailed data base for 1987 that could be used to model eutrophication with a more detailed mechanistic model (such as USEPA's WASP4 program).

Chapter Two

Literature Review

2.1. Basic Concepts of Mathematical Modeling

The goals of this study were to apply some simple models to classify the trophic status of Lake Hamilton, and to develop a data base that could be used in applying more complex models. A mathematical model is defined as an equation or graphical representation describing the relationship(s) between two or more parameters or characteristics in a body of water. There are two types of mathematical models - empirical and deterministic. The empirical models are developed from observations on many different systems (lakes). Examples include: a plot of chlorophyll *a* versus mean depth by Sakamoto (1966); a regression equation of Secchi depth versus dissolved oxygen (D.O.) deficit by Lasenby (1975); a regression equation of chlorophyll *a* versus total phosphorus by Dillon and Rigler (1974); and phosphorus loading plots developed by Vollenweider (1968, 1975), to name only a few. Deterministic (or "mechanistic") models are derived from theoretical considerations and equations. A simple deterministic model for total phosphorus (TP) in lakes was proposed by Dillon and Rigler (1974): This model was based on the assumption that the lake is completely mixed and at steady-state. The model equation is:

$$TP = \frac{L_a (1-R)}{q_s} \qquad (2.1)$$

where TP = total P concentration, g/m^3;

L_a = areal TP loading rate; $g/m^2/yr$;

R = phosphorus retention coefficient, unitless;

q_s = areal water loading rate, m/yr.

An empirical equation for R was developed by Kirchner and Dillon (1974).

Another similar deterministic model was proposed by Chapra (1975). The model equation is:

$$TP = \frac{L_a}{q_s + v} \qquad (2.2)$$

where v = TP settling rate, m/yr. Various values have been proposed for v. Vollenweider (1975) suggested 10.0 m/yr; Dillon and Kirchner (1975) recommended 13.2 m/yr; and Chapra (1975) used a value of 16.0 m/yr.

2.2 Methods Used for Lake Trophic Status Classification:

Phosphorus loading plots are used to predict whether a lake will be oligotrophic, mesotrophic, or eutrophic. The simplest is by Vollenweider (1968), which involves plotting areal TP load versus mean lake depth. A more advanced plot was developed by Vollenweider (1975), which involves plotting areal TP loading versus a real water loading. The plot is divided into three regions corresponding to the different trophic status classifications.

Lake Trophic Status Indices (TSI) are equations or tables used to classify a lake according to its trophic status based on experimental observations. There are several different methods for calculating (TSI). Examples include Shannon and Brezonik (1972), and Carlson (1977). The latter is based on average values of TP, Secchi depth, and chlorophyll a. Walker (1979) proposed an averaged modification of Carlson's equations.

Dillon and Rigler (1975) developed a simple procedure for evaluating the trophic status of a lake and capacity to withstand additional development based on phosphorus loading, morphometry and hydrology. This "desk method" requires a minimum of field data, and combines several empirical models with the simple TP model of Dillon and Rigler (1975); i.e., equation 2.1.

Chapter Three

Methods and Procedures

3.1 Field Work

Field sampling was performed on 25 dates during 1987. A deep water site (Figure 3.1) was visited on all dates; a shallow site was visited on only four dates. Grab samples were also obtained by hand from Yellow Creek upstream or downstream of Lake Hamilton on most sampling dates. Temperature and dissolved oxygen profiles were determined at the sampling sites, using a Yellow Springs Model 57 dissolved oxygen meter. Dissolved oxygen profiles were checked by comparison with measurements made using the Azide Modification of the Winkler method (APHA, 1985) at two depths, and adjusted if necessary. Samples were collected from four depths (usually 1, 4, 8, and 12 m) using a Wildco Alpha Bottle, and the water column transparency was measured using a standard 20 cm diameter Secchi disk attached to a rope with 0.1 meter increments marked on it.

3.2 Lab Preparation

Upon return to the YSU Environmental Engineering Lab, a portion of each water sample was filtered through a 0.45 µm pore size membrane. This filtrate was used for the soluble reactive phosphorus (SRP), total soluble phosphorus (TSP), nitrate and ammonia tests. Filtrations for the chlorophyll a test were performed on the day of sampling using Fisher GF/C glass fiber filters (effective pore size 1.0 µm). Unfiltered water was saved for the total phosphorus (TP) test. All samples were stored in the dark at 4°C until the analyses were performed.

3.3 Lab Analysis

All methods used for analysis are according to "Standard Methods" (APHA, 1985), except ammonia (Lind, 1985). Total phosphorus and total soluble phosphorus were measured using the persulfate digestion method. Then the phosphorus measurements were done using the ascorbic acid method. Chlorophyll a concentrations were measured for all samples using the spectrophotometric method. These measurements were done on a Bausch and Lomb Model 1001 spectrophotometer. The nitrate and ammonia analyses were performed by the YSU Biology Department. The nitrate measurements were done using the cadmium reduction method and ammonia measurements were done using the phenate method.

Figure 3.1 Location of Sampling Sites, 1987

Chapter Four

Results and Discussions

4.1 Morphometry and Hydrology:

Several parameters describing the morphometry and hydrology of the lake were calculated in this study and should be useful in future studies on this lake. Using a planimeter, the areas enclosed by 10 ft. depth contours were measured. The lake basin was divided into a shallow region and a deep region, as shown by the dashed line in Figure 3.1. The area versus depth data is presented in Table 4.1.

A number of important hydrologic and morphometric parameters for Lake Hamilton are summarized in Table 4.2. Although details of some of these calculations are presented later, the values are also listed here to give the reader a feel for the physical characteristics of Lake Hamilton. Details of the water budget calculations are given in Table 4.3. A summary is shown in Figure 4.1.

4.2 Summary of Field Data:

All data obtained during 1987 is tabulated in Tables 4.4 through 4.13. Volume-weighted average concentrations calculated by Kotwal (1992) are presented in Table 4.14. Plots of representative profiles (Parameters versus depth) from the 1987 Lake Hamilton field data are presented for temperature in Figure 4.2, dissolved oxygen in Figure 4.3, and soluble reactive phosphorus in Figure 4.4. In addition, a plot of Secchi depth versus time is shown in Figure 4.5.

Temperature profiles show that the Lake is thermally stratified in the summer, and the temperature gradient causes resistance to mixing between top and bottom waters. Dissolved oxygen profiles show severe anaerobic conditions during the summer. Soluble Reactive Phosphorus profiles show low levels when the lake water contains oxygen, and show large releases when lake bottom water becomes anoxic during the summer. Secchi Depth profiles show dramatic fluctuations during the year, and that is due to the change in algal species in the lake.

Table 4.1 Area Versus Depth for Lake Hamilton

A. Segment #I - Shallow Region

Depth (ft)	Area (Acres)	Area (ft^2)
0	55.539	2,419,244
10	42.847	1,866,410
20	17.996	783,889
25′ (7.62m)	0	0

B. Segment II & III - Deep Region

Depth (ft)	Area (Acres)	Area (ft^2)
0	42.600	1,855,663
10	40.934	1,783,123
20 (6.1 m)	36.223	1,577,903
30	26.951	1,173,972
40	10.295	448,467
50	3.06	133,300
55 (16.76 m)	0	0

Table 4.2 Lake Hamilton Morphometry and Hydrology

Lake Volume = V_{Lake} = 2.750×10^6 m^3

Total Outflow = Q_{out} = 2.53×10^7 m^3/yr (excluding evaporation)

Lake Surf. Area = A_o = 3.971×10^5 m^2

Lake Drainage Area = A_d = 2.519×10^6 m^2

Mean depth = $Z = \frac{\text{Vol.}}{\text{Surf Area}}$ = 6.90 m

Hydraulic Retention Time = $t = \frac{\text{Vol.}m^3}{Q\text{ out, }m^3/yr}$ = 0.11 yr. = = 40 days

Flushing Rate = ρ = 9.13/yr.

Table 4.3 Water Budget for Lake Hamilton

Outflows (MG) - Data from Ohio Water Service

	1983	1984	1985	1986	1987	Ave 83,84,86,87
Withdrawals	1764	1007	736	995	386	1038
Over Spillway	4551	5403	16979	6871	5764	5647
Total	6315	6410	17715	7866	6150	6685

Ave Total = 6685 MG/yr = 2.53×10^7 m^3/yr

Withdrawals - 3.93×10^6 m^3/yr

Over Spillway - 2.14×10^7 m^3/yr (excluding 1985)

Direct Precipitation:

Mean Annual Rainfall = 37.90 in. (NOAA, 1982)

= 0.9627 m/yr

Lake Surface Area = 3.972×10^5 m^2

Direct precip. = $(3.972 \times 10^5\ m^2)(0.9627\ m/yr)$

= 3.82×10^5 m^3/yr

Direct Runoff

Runoff coefficients (Viessman, et al, 1989):

Residential: $0.32 = C_1$

Unimproved: $0.20 = C_2$

Watershed areas:

Residential: 1,967,022 $m^2 = A_1$

Unimproved: 551,702 $m^2 = A_2$

Direct Runoff = Rainfall x $(C_1A_1 + C_2A_2)$

= 712,193 m^3/yr = 7.12×10^5 m^3/yr

Evaporation = 31 in/yr (Linsley, et al, 1992) = 0.787 m/yr

Table 4.3 (continued)

Evaporation Loss $= 0.787 \text{ m} \times (3.972 \times 10^5 \text{ m}^2)$

$= 3.13 \times 10^5 \text{ m}^3/\text{yr}$

$$\text{Yellow Creek Inflow} = \text{Total Outflow} + \text{Evaporation} - \text{Direct Precip.} - \text{Direct Runoff}$$

$$= 2.53 \times 10^7 + 3.13 \times 10^5 - 3.82 \times 10^5 - 7.12 \times 10^5 \text{ m}^3/\text{yr}$$

$Q_{in} = 2.45 \times 10^7 \text{ m}^3/\text{yr}$

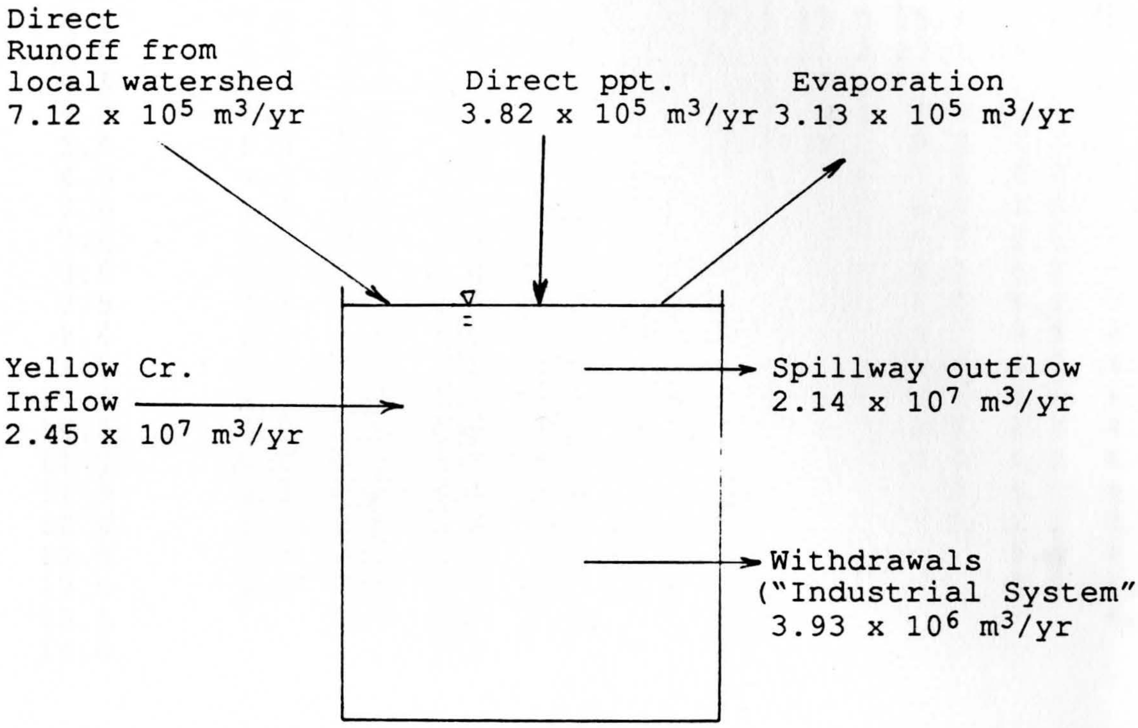

Figure 4.1 Water Budget for Lake Hamilton

Table 4.4. Temperature Profiles (°C) for Lake Hamilton, 1987

Depth (m)	3/27	4/9	4/23	4/30	5/08	5/15	5/21	5/28	6/04	6/12
0.5	7.9	5.9	17.4	9.8	13.0	18.0	17.3	22.0	23.0	21.1
1.0	7.8	5.8	17.3	9.8	13.0	17.6	17.3	21.9	23.0	21.1
1.5	7.8	5.8	14.5	10.0	12.8	17.4	17.3	21.8	23.0	21.0
2.0	7.7	5.1	10.5	10.0	11.4	16.8	17.3	19.8	22.6	21.2
2.5	7.5	4.6	9.5	10.0	10.8	16.2	17.3	18.7	21.2	21.1
3.0	7.3	4.1	9.0	10.0	10.4	15.2	15.0	17.1	19.0	20.9
3.5	7.2	4.0	8.3	9.8	10.0	13.5	13.0	15.5	16.8	20.0
4.0	6.0	3.8	7.4	9.5	9.7	10.5	11.2	13.1	14.0	17.9
4.5	5.7	3.8	6.5	9.3	8.5	9.6	10.1	11.1	12.2	14.5
5.0	5.3	3.8	6.0	7.8	7.8	8.7	9.1	9.5	10.5	12.1
5.5	5.2	3.8	5.8	7.0	6.9	8.3	8.2	8.3	9.0	10.6
6.0	4.9	3.8	5.4	6.0	5.9	7.5	7.5	7.6	8.2	9.5
7.0	3.5	3.9	4.9	5.2	5.2	6.0	6.0	6.0	6.5	7.0
7.5	2.9	3.9	4.8	5.0	4.9	5.5	5.6	5.7	6.0	6.1
8.0	2.7	3.8	4.4	4.8	4.5	5.1	5.2	5.2	5.5	5.9
8.5	2.1	3.7	4.0	4.4	4.5	4.7	5.1	5.0	5.2	5.1
9.0	2.0	3.4	3.9	4.0	4.2	4.5	4.8	4.7	4.8	4.9
9.5	2.0	3.1	3.9	3.8	3.9	4.3	4.5	4.5	4.7	4.8
10.0	2.0	2.8	3.9	3.6	3.8	4.2	4.2	4.3	4.4	4.5
10.5	2.0	2.3	3.4	3.5	3.6	4.0	4.0	4.2	4.3	4.4
11.0	2.0	2.2	3.0	3.3	3.5	3.8	3.9	4.0	4.2	4.3
11.5	2.0	2.2	3.0	3.3	3.4	3.5	3.8	4.0	4.0	4.1
12.0	2.0	2.5	3.0	3.0	3.3	3.5	3.6	3.8	4.0	4.1
12.5	2.0	2.5	2.9	3.0	3.2	3.4	3.5		4.0	4.1
13.0	2.0	2.5	2.9	3.0	3.2	3.4	3.5		3.8	4.1
13.5		2.6	2.9	2.9		3.4				4.1
14.0			3.0							

Table 4.4. (Continued)

Temperature (°C)

Depth (m)	6/17	6/23	7/02	7/07	7/14	7/21	7/27	8/04	8/10	8/21
0.5	23.8	24.3	21.5	23.4	25.2	26.2	26.3	25.5	23.5	23.9
1.0	23.8	24.3	21.5	23.4	25.2	26.2	26.1	25.2	23.5	23.9
1.5	23.8	24.3	21.5	23.4	25.2	26.0	26.0	25.2	23.5	23.9
2.0	22.5	24.3	21.5	22.3	24.4	25.2	26.0	25.1	23.5	23.9
2.5	21.5	23.5	21.3	20.7	22.8	24.3	26.0	24.8	23.2	23.9
3.0	20.9	21.8	20.0	19.9	21.5	22.8	24.4	24.6	22.8	23.8
3.5	19.8	20.5	19.6	19.5	20.5	21.5	22.0	22.7	22.4	23.0
4.0	17.1	19.0	19.3	19.1	19.5	19.8	20.7	22.0	22.2	22.0
4.5	15.7	17.0	19.3	18.0	18.5	19.0	19.2	20.5	20.3	20.9
5.0	13.1	14.0	18.0	18.0	17.5	17.4	18.0	18.5	18.5	17.2
5.5	11.5	12.2	14.5	15.5	16.0	15.8	16.2	16.5	17.1	15.8
6.0	9.9	10.6	13.0	12.0	13.0	14.0	15.6	15.1	15.8	13.7
6.5	8.8	9.0	11.0	10.5	11.2	12.2	13.0	13.0	13.7	12.4
7.0	7.5	7.8	9.5	9.0	9.6	10.5	10.8	11.7	12.2	11.1
7.5	6.9	7.0	8.3	7.9	8.2	8.8	9.2	10.5	10.7	12.8
8.0	6.2	6.5	7.6	7.2	7.5	8.0	8.2	9.0	9.3	11.5
8.5	5.8	5.8	6.5	6.4	6.8	7.2	7.0	8.2	7.8	9.5
9.0	5.4	5.5	6.0	5.8	6.0	6.5	6.7	7.5	7.2	8.5
9.5	5.1	5.2	5.6	5.5	5.8	6.0	6.1	6.7	6.8	7.6
10.0	4.8	5.0	5.2	5.2	5.4	5.7	5.9	6.1	6.3	7.1
10.5	4.8	4.7	5.0	5.1	5.3	5.5	5.7	5.8	6.0	6.5
11.0	4.5	4.5	4.7	4.9	5.2	5.4	5.4	5.5	5.8	6.1
11.5	4.5	4.5	4.6	4.7	5.0	5.2	5.2	5.4	5.5	6.0
12.0	4.4	4.5	4.5	4.7	4.8	5.2	5.0	5.2	5.3	5.8
12.5	4.2	4.5	4.5	4.5	4.8	5.0	5.0	5.1	5.2	5.5
13.0	4.1	4.3	4.5	4.5		5.0	5.0	5.0	5.1	5.3
13.5	4.1	4.3	4.5	4.5		4.8		5.0	5.0	5.2
14.0										5.2

Table 4.4. (Continued)

Temperature (°C)

Depth (m)	9/01	9/16	9/30	10/16	11/06
0.5	19.0	18.9	16.9	11.0	8.5
1.0	19.0	18.9	16.8	10.9	8.2
1.5	19.0	18.7	16.8	10.9	8.2
2.0	19.0	18.6	16.8	10.8	8.2
2.5	18.9	18.1	16.8	10.6	8.2
3.0	18.8	17.8	16.8	10.8	8.2
3.5	18.8	17.4	16.8	10.6	8.2
4.0	18.8	17.4	16.5	10.6	8.2
4.5	18.7	17.2	16.2	10.6	8.2
5.0	18.5	17.0	16.1	10.5	8.2
5.5	17.3	16.7	16.0	10.5	8.2
6.0	16.4	16.2	15.9	10.5	8.2
6.5	15.1	15.7	15.3	10.5	8.2
7.0	13.3	14.7	15.2	10.5	8.2
7.5	12.1	13.5	14.5	10.5	8.2
8.0	11.1	12.0	13.0	10.2	8.2
8.5	9.8	11.0	11.8	10.1	8.2
9.0	8.9	9.8	10.8	10.1	8.2
9.5	7.8	8.4	9.8	10.1	8.2
10.0	7.2	7.9	8.5	9.9	8.1
10.5	6.8	7.3	7.9	9.2	8.1
11.0	6.5	6.9	7.0	8.6	8.1
11.5	6.2	6.6	7.0	8.0	8.1
12.0	5.9	6.3	6.8	7.6	8.1
12.5	5.7	6.1	6.5	7.2	8.0
13.0	5.6	5.9	6.2	7.0	7.9
13.5	5.3	5.8	5.8	6.5	7.9
14.0			5.8		7.9
14.5					7.6
15.0					7.6

Table 4.5. Dissolved Oxygen (mg/L) Profiles for Lake Hamilton, 1987

Depth (m)	3/27	4/9	4/23	4/30	5/08	5/15	5/21	5/28	6/04	6/12
0.5	14.4	12.8	15.9	12.2	15.4	13.3	9.5	10.1	9.3	11.5
1.0	14.1	12.5	16.3	12.0	15.3	13.5	9.3	9.8	9.2	10.9
1.5	14.1	12.4	18.6	11.8	15.0	13.5	9.2	9.7	9.1	10.6
2.0	13.9	12.1	15.4	11.7	14.4	13.5	9.2	9.6	8.4	10.7
2.5	13.9	11.6	13.8	11.6	11.5	13.3	9.1	8.6	7.1	10.5
3.0	13.7	11.4	11.6	11.4	10.0	12.9	11.1	9.5	7.3	10.3
3.5	13.3	11.2	10.5	11.3	9.1	11.8	11.7	12.2	8.8	9.6
4.0	12.7	10.9	9.0	11.1	7.8	5.0	7.6	13.6	12.8	7.6
4.5	12.5	10.7	8.6	10.2	6.8	2.2	2.7	10.4	13.5	10.2
5.0	12.3	10.6	8.2	8.3	5.4	1.9	1.4	0.6	10.1	13.2
5.5	12.2	10.4	8.1	7.3	5.0	1.7	1.4	0.4	1.5	13.4
6.0	12.	10.4	8.2	6.8	4.7	1.6	1.5	0.4	1.4	2.1
6.5	11.9	10.3	8.0	6.7	5.0	2.1	1.7	0.6	1.4	1.1
7.0	11.4	10.2	8.1	6.8	5.4	2.5	2.0	0.9	1.5	0.9
7.5	10.0	10.2	7.6	6.8	5.7	3.0	2.6	1.5	1.1	0.8
8.0	9.2	9.7	7.8	6.8	5.9	3.7	2.8	1.8	1.4	0.6
8.5	8.7	8.5	7.3	6.7	5.8	3.7	2.8	1.8	1.8	1.0
9.0	8.4	8.2	7.0	6.6	5.8	3.5	3.3	1.9	1.7	1.1
9.5	8.1	7.6	6.6	5.8	5.5	3.5	3.0	2.2	1.4	1.3
10.0	7.4	6.7	5.5	5.3	4.9	3.5	3.9	2.2	1.9	1.3
10.5	7.2	7.1	6.3	4.7	4.1	3.5	2.4	1.9	1.5	0.2
11.0	6.8	7.0	5.6	4.2	5.0	2.8	2.0	0.9	0.9	0.1
11.5	6.4	6.6	5.1	4.8	3.5	1.8	1.4	0.5	0.4	0.0
12.0	5.8	5.8	4.8	3.9	3.0	1.3	0.9	0.0	0.3	0.0
12.5	5.6	5.2	4.1	4.0	2.7	0.5	0.5		0.3	0.0
13.0	4.7	4.8	4.0	3.8	2.5	0.3	0.5		0.3	0.0
13.5		4.5	3.6		1.7	0.3				0.0
14.0										

Table 4.5. (Continued)

Dissolved Oxygen (mg/L)

Depth (m)	6/17	6/23	7/02	7/07	7/14	7/21	7/27	8/04	8/10	8/21
0.5	12.4	11.5	8.8	17.0	11.7	9.2	10.6	14.8	9.8	10.8
1.0	12.6	11.3	8.6	17.2	11.6	9.1	10.6	15.1	9.6	10.3
1.5	12.1	11.1	8.1	17.4	11.5	9.3	10.5	15.1	9.5	10.2
2.0	10.9	10.9	7.9	10.3	8.8	10.4	10.3	14.9	8.5	10.2
2.5	9.3	7.6	6.4	5.2	4.2	10.0	10.0	14.0	4.1	9.8
3.0	7.1	4.9	5.2	4.1	3.8	7.7	11.5	13.5	1.0	9.0
3.5	5.3	2.9	5.0	3.8	1.9	6.4	11.7	2.8	0.7	0.9
4.0	5.1	2.7	5.1	3.3	0.0	0.3	0.9	0.0	0.0	0.7
4.5	7.7	4.4	5.4	3.1	0.0	0.0	0.0	0.0	0.0	0.0
5.0	11.2	9.9		2.0	0.0	0.0	0.0	0.0	0.0	0.0
5.5	13.1	12.5	4.8	2.3	0.0	0.0	0.0	0.0	0.0	0.0
6.0	6.4	7.4	7.0	4.6	2.4	0.3	0.0	0.0	0.0	0.0
6.5	0.4	0.1	4.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
7.0	0.4	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
7.5	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.5	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.0	0.4	0.0	0.1	0.0		0.0	0.0	0.0	0.0	0.0
13.5	0.4	0.0	0.1	0.0		0.0		0.0	0.0	0.0
14.0										0.0

Table 4.5. (Continued)

Dissolved Oxygen (mg/L)

Depth (m)	9/01	9/16	9/30	10/16	11/06
0.5	8.7	14.3	12.8	10.6	
1.0	8.6	14.1	12.7	10.3	11.3
1.5	8.5	13.8	12.7	10.4	
2.0	8.5	8.4	12.6	10.0	
2.5	8.5	5.3	12.2	8.4	
3.0	8.4	2.2	12.3	8.3	10.6
3.5	8.3	2.0	10.9	8.0	
4.0	7.6	2.2	7.9	8.0	
4.5	7.4	1.8	6.8	8.5	
5.0	0.7	1.1	5.4	8.6	
5.5	0.0	0.0	4.6	8.7	
6.0	0.0	0.0	3.7	8.6	10.4
6.5	0.0	0.0	0.9	8.6	
7.0	0.0	0.0	0.2	8.8	
7.5	0.0	0.0	0.1	8.8	
8.0	0.0	0.0	0.0	8.1	
8.5	0.0	0.0	0.0	8.3	
9.0	0.0	0.0	0.0	5.7	9.5
10.0	0.0	0.0	0.0	3.2	
10.5	0.0	0.0	0.0	0.0	
11.5	0.0	0.0	0.0	0.0	
12.0	0.0	0.0	0.0	0.0	10.1
13.0	0.0	0.0	0.0	0.0	
14.0			0.0		9.8

Table 4.6. Secchi Depth (m) for Lake Hamilton, 1987

Date	Depth
03/27	0.9
04/09	0.7
04/23	0.9
04/30	1.1
05/08	-
05/15	-
05/21	3.7
05/28	4.7
06/04	5.3
06/12	4.1
06/17	4.6
06/23	1.8
07/02	1.0
07/07	1.1
07/14	2.6
07/21	2.9
07/27	2.1
08/04	1.4
08/10	1.3
08/21	2.2
09/01	1.7
09/16	-
09/30	1.7
10/16	2.1
11/06	-

Table 4.7. Soluble Reactive Phosphorus (μg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/09	4/23	4/30	5/08	5/15	5/21	5/28
1.0	4.6	3.8	2.7	3.8	2.0	2.5	5.4	6.3
4.0	-	-	-	-	1.6	1.7	1.7	4.8
5.0	-	-	2.0	2.8	-	-	-	-
6.0	2.5	1.6	-	-	-	-	-	-
8.0	-	-	-	-	1.7	1.6	2.7	8.4
12.0	1.4	1.4	1.7	2.8	8.7	12.6	30.1	52.0
outlet	-	-	-	2.7	-	-	6.2	-
inlet	2.8	1.9	1.9	-	2.4	11.4	-	51.6

Depth (m)	6/04	6/12	6/17	6/23	7/02	7/07	7/14	7/21
1.0	3.3	4.1	4.0	3.7	2.8	9.9	2.9	3.0
4.0	3.3	1.9	2.4	2.3	7.1	6.1	1.3	1.1
8.0	3.6	2.7	1.9	32.9	5.5	32.4	31.0	55.9
12.0	107.1	150.5	194.8	178.8	65.6	210.1	513.4	542.5
outlet	7.3	-	39.5	2.1	-	10.6	3.9	7.9
inlet	-	36.8	58.7	105.7	64.8	17.7	62.7	15.5

Depth (m)	7/27	8/04	8/10	8/21	9/01	9/16	9/30	10/16
1.0	1.3	1.5	3.9	0.0	0.0	1.0	1.7	5.9
4.0	0.2	2.1	4.8	0.0	0.0	0.5	0.4	4.6
8.0	72.6	52.2	88.9	136.4	214.7	128.3	0.5	4.9
12.0	532.1	578.0	458.9	516.0	123.2	562.8	654.7	802.5
outlet	8.1	1.7	4.2	8.3	1.4	0.9	41.8	13.4
inlet	14.2	21.2	24.2	31.5	31.7	19.7	60.5	26.6

Depth (m)	11/6
1.0	27.5
4.0	20.8
8.0	0.0
12.0	0.3
outlet	2.2
inlet	41.7

Table 4.8. Total Soluble Phosphorus (μg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/09	4/23	4/30	5/08	5/15	5/21	5/28
1.0	17.6	18.2	16.3	14.8	15.6	5.5	16.8	21.3
4.0	-	-	-	-	11.6	6.5	12.3	13.4
5.0	0	0	11.5	12.9	-	-	-	-
6.0	11.9	11.8	-	-	-	-	-	-
8.0	-	-	-	-	10.2	3.7	8.5	23.9
12.0	11.6	14.2	17.3	18.2	33.9	21.0	39.3	62.7
outlet	-	-	-	10.8	-	-	18.4	-
inlet	13.1	13.1	10.5	-	11.6	22.7	-	56.1

Depth (m)	6/04	6/12	6/17	6/23	7/02	7/07	7/14	7/21
1.0	31.4	23.5	37.6	18.9	21.2	30.6	18.3	31.4
4.0	142.6	14.5	17.7	14.2	17.2	15.9	9.3	13.5
8.0	6.9	7.7	6.6	34.5	14.8	45.8	48.2	76.4
12.0	119.4	168.0	212.4	168.6	74.0	218.1	549.9	544.9
outlet	16.9	-	51.3	9.5	-	26.6	14.5	16.8
inlet	-	52.4	72.1	102.2	81.6	23.0	68.4	21.6

Depth (m)	7/27	8/04	8/10	8/21	9/01	9/16	9/30	10/16
1.0	16.6	36.4	21.1	34.9	11.5	16.7	15.4	20.0
4.0	11.7	27.1	15.0	13.4	14.5	11.9	10.6	20.6
8.0	96.3	88.9	122.2	170.0	258.9	173.2	10.1	33.7
12.0	562.1	550.5	608.5	619.0	183.1	684.1	641.6	814.5
outlet	21.3	38.3	12.3	33.8	14.6	28.9	48.2	21.8
inlet	31.5	105.4	62.7	49.3	72.1	59.7	70.0	34.7

Table 4.9. Total Phosphorus (μg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/09	4/23	4/30	5/08	5/15	5/21	5/28
1.0	60.9	84.3	44.8	58.8	47.0	13.9	31.9	25.2
4.0	-	-	-	-	51.9	47.2	60.2	38.5
5.0	-	-	56.1	47.2	-	-	-	-
6.0	38.2	45.9	-	-	-	-	-	-
8.0	-	-	-	-	29.3	13.9	26.7	36.8
12.0	52.1	57.1	49.7	47.6	56.6	38.0	112.4	117.2
outlet	-	-	-	44.3	-	-	47.7	-
inlet	23.9	57.7	41.1	-	47.1	127.0	-	219.7

Depth (m)	6/04	6/12	6/17	6/23	7/02	7/07	7/14	7/21
1.0	27.2	30.8	46.1	33.7	72.7	107.3	42.7	41.0
4.0	24.5	24.8	45.9	44.5	89.1	47.4	29.6	72.1
8.0	29.3	29.3	44.0	58.8	33.4	67.2	74.7	84.9
12.0	152.2	187.8	245.4	204.0	86.8	240.7	560.8	548.9
outlet	29.6	-	75.6	37.6	-	90.2	60.4	24.5
inlet	-	93.2	89.6	126.4	-	54.9	166.1	36.2

Depth (m)	7/27	8/04	8/10	8/21	9/01	9/16	9/30	10/16
1.0	34.0	50.3	59.0	51.0	63.1	41.2	41.8	149.4
4.0	83.4	113.0	56.1	86.1	40.7	25.7	31.4	53.8
8.0	128.4	122.9	127.8	183.8	168.1	191.2	47.4	64.4
12.0	603.2	826.8	574.8	625.3	247.2	616.3	667.8	814.5
outlet	29.8	52.3	74.0	31.7	61.8	28.9	61.5	29.4
inlet	41.6	113.8	88.3	59.6	115.6	59.7	78.9	40.0

Depth (m)	11/6
1.0	57.4
4.0	79.2
8.0	79.7
12.0	86.0
outlet	24.7
inlet	67.5

Table 4.10. Chlorophyll a (µg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/09	4/23	4/30	5/08	5/15	5/21	5/28
1.0	2.1	11.5	25.34	16.95	14.73	7.42	4.01	0.65
4.0	-	-	-	-	13.53	27.21	32.98	6.36
5.0	-	-	19.73	10.32	-	-	-	-
6.0	19.8	14.9	-	-	-	-	-	-
8.0	-	-	-	-	2.71	2.66	3.01	4.11
12.0	6.87	12.6	9.62	7.32	4.61	3.86	2.61	3.36
outlet	-	-	-	-	-	-	-	-
inlet	-	-	-	-	-	-	-	-

Depth (m)	6/04	6/12	6/17	6/23	7/02	7/07	7/14	7/21
1.0	3.21	5.31	4.91	29.87	47.11	79.66	10.32	7.62
4.0	3.91	7.72	9.72	14.33	17.91	4.41	8.12	64.55
8.0	5.11	8.42	14.13	6.11	4.81	2.1	3.31	2.81
12.0	3.11	3.41	4.81	3.81	3.91	2.21	5.31	3.01
outlet	-	-	-	-	-	-	-	-
inlet	-	-	-	-	-	-	-	-

Depth (m)	7/27	8/04	8/10	8/21	9/01	9/16	9/30	10/16
1.0	13.23	26.36	58.34	7.9	17.22	19.72	19.6	9.4
4.0	62.15	18.04	4.94	2.8	8.9	2	6	6
8.0	3.51	4.01	3.31	1.9	1	0.7	12	0.7
12.0	3.91	4.31	3.41	3	0.8	0.74	1.4	0.9
outlet	-	-	-	-	-	-	-	-
inlet	-	-	-	-	-	-	-	-

Depth (m)	11/6
1.0	1.5
4.0	0.7
8.0	1.6
12.0	0.8
outlet	-
inlet	-

Table 4.11. Nitrate Nitrogen (μg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/9	4/23	4/30	5/8	5/15	5/21
1	-	1087.5	0	201.8	77.7	42.6	737.7
4	-	-	-	-	228.6	98.2	81.8
8	-	-	-	-	499.5	459.9	397.0
12	-	399.3	318.9	-	294.8	248.2	213.5
outlet	-	522.1	-	196.7	-	-	157.9
inlet	-	-	-	-	57.3	647.8	-

Depth (m)	5/28	6/4	6/12	6/17	6/23	6/30	7/2
1	199.1	258.1	268.0	189.3	81.4	-	-
4	10.9	16.3	63.0	182.1	147.2	219.9	-
8	360.7	349.9	-	64.7	-	-	-
12	185.1	87.4	42.9	8.2	39.2	58.6	-
outlet	-	242.6	-	197.1	760.2	-	-
inlet	559.7	-	625.8	454.9	48.1	1077.8	-

Depth (m)	7/7	7/14	7/21	7/27	8/4	8/10	8/21
1	973.2	446.9	529.9	362.9	-	9.1	35.2
4	1065.6	509.6	775.8	407.1	243.3	80.0	-
8	-	21.2	-	-	-	-	-
12	-	-	-	-	-	-	-
outlet	846.1	427.4	92.3	143.6	-	-	88.5
inlet	710.1	567.3	243.5	461.5	54.6	630.5	118.0

Depth (m)	9/1	9/16	9/13
1	-	-	-
4	-	117.9	4.2
8	-	-	-
12	-	9.5	-
outlet	-	-	103.5
inlet	415.7	574.6	333

Table 4.12. Ammonia Nitrogen (μg/L) in Lake Hamilton, 1987:

Depth (m)	3/27	4/9	4/23	4/30	5/8	5/15	5/21
1	-	9.2	11.6	20.4	5.6	9.5	54.8
4	-	-	-	-	55.2	11.0	0.1
8	-	-	-	-	175.3	191.5	186.7
12	-	372.2	-	393.0	721.5	656.2	745.7
outlet	-	16.8	11.9	19.4	-	-	40.1
inlet	-	-	-	-	2.6	85.1	-

Depth (m)	5/28	6/4	6/12	6/17	6/23	6/30	7/2
1	14.5	43.8	29.1	34.0	14.5	13.5	-
4	-	9.5	11.1	80.2	85.5	21.7	-
8	212.3	258.4	232.7	268.4	451.0	112.5	-
12	769.1	934.9	962.1	1635.6	1149.5	721.5	-
outlet	-	66.8	-	433.6	9.5	-	-
inlet	102.2	-	55.1	102.3	104.8	160.2	-

Depth (m)	7/7	7/14	7/21	7/27	8/4	8/10	8/21
1	7.2	48.3	22.6	3.1	20.2	9.9	31.0
4	121.5	171.0	14.2	-	124.8	157.0	2.0
8	274.5	347.1	404.2	523.8	621.3	417.9	537.8
12	1034.4	1944.6	1790.8	1826.3	2546.9	1711.8	844.0
outlet	21	-	118.5	113.9	27.2	11.1	113.4
inlet	-	68.5	17.0	0.2	31.3	-	22.0

Depth (m)	9/1	9/16	9/30
1	56.7	4.5	78.8
4	68.4	253.1	28.7
8	1330.7	1157.9	26.4
12	1163.7	2346.7	2738.2
outlet	40.8	44.1	288.9
inlet	620.7	20.1	17.4

Table 4.13. Data for Shallow Sites in Lake Hamilton, 1987:

06/23

Depth (m)	Temp. °C	D.O. mg/L	SRP µg/L	TP µg/L	TSP µg/L	Chla µg/L
0.5	24.4	12.0	-	-	-	-
1.0	24.2	11.9	3.6	42.4	11.8	33.3
1.5	24.2	11.3	-	-	-	-
2.0	24.1	10.7	-	-	-	-
2.5	23.5	7.3	-	-	-	-
3.0	22.0	3.9	-	-	-	-
3.5	21.0	1.8	12.3	72.1	22.9	6.7
4.0	18.7	2.2	-	-	-	-

07/07

Depth (m)	Temp. °C	D.O. mg/L	SRP µg/L	TP µg/L	TSP µg/L	Chla µg/L
0.5	24.8	15.4	-	-	-	-
1.0	23.7	14.0	4.0	71.5	11.8	24.9
1.5	22.5	11.4	-	-	-	-
2.0	21.3	7.8	-	-	-	-
2.5	20.2	4.7	-	-	-	-
3.0	20.0	4.4	-	-	-	-
3.5	19.8	4.0	2.8	71.0	11.8	6.9
4.0	19.8	2.8	-	-	-	-

07/27

Depth (m)	Temp. °C	D.O. mg/L	SRP µg/L	TP µg/L	TSP µg/L	Chla µg/L
0.5	26.2	12.1	-	-	-	-
1.0	26.1	11.6	0.8	54.2	17.3	43.8
1.5	26.0	11.3	-	-	-	-
2.0	26.0	11.2	-	-	-	-
2.5	26.0	10.9	-	-	-	-
3.0	24.5	5.5	0.5	96.6	15.4	46.3
3.5	22.5	3.4	-	-	-	-

Table 4.14. Volume-Weighted Average Concentrations for Lake Hamilton, 1987 (provided by Kotwal, 1992)

VOLUME WEIGHTED AVERAGE CONCENTRATIONS FOR LAKE HAMILTON: 1987

JULIAN	DATE	DO(PPM)		PO4(PPB)		OP(PPB)		TP(PPB)		CHLa(PPB)		NH3(PPB)		NO3(PPB)		ON(PP PPB)	
DAY		EPI.	HYPO.	EPI.	HYPO	EPI.	HYPO.	EPI.	HYPO	EPI.	HYPO.	EPI.	HYPO	EPI.	HYPO.	EPI.	HYPO.
0	12/31/86	11.35	8.35	14.98	13.68	49.26	47.2	64.22	60.88	10.7	4.13	10	70	460	430	1000	850
86	3/27	13.8	9.3	3.95	2.09	49.97	41.28	53.92	43.37	20.63	14.99						
99	4/9	11.7	8.6	3.12	1.53	69.38	48.53	72.5	50.08	12.55	14.04	9.2	284.24	1087.5	566.08		
113	4/23	13.1	7	2.42	1.87	48.87	51.45	49.29	53.32	23.11	15.3	11.6	11.6	0	241.63		
120	4/30	11.2	8	3.4	2.8	50.79	44.57	54.19	47.37	14.31	9.02	20.4	302.71	201.8	201.8		
128	5/8	11.5	4.8	1.8	3.52	47.61	35.8	49.41	39.32	14.14	4.59	29.97	302.72	151.85	411.42		
135	5/15	10.4	2.4	2.11	4.49	28.15	19.96	30.26	24.45	17.14	8.11	10.24	289.91	69.92	358.41		
141	5/21	8.1	2	3.58	9.73	42.23	43.64	45.81	53.37	18.24	6.73	27.92	308.97	415.42	308.81		
148	5/28	9.3	1	5.58	19.34	26.18	38.69	31.74	58.03	3.46	4.2	7.38	330.72	106.63	270.16		
155	6/4	9.1	1.3	3.15	30.57	22.72	30.24	25.87	60.81	3.55	4.43	26.95	403.43	139.29	238.72		
163	6/12	10.7	1.7	3.02	41.22	24.83	28.93	27.85	70.15	8.49	7.02	20.26	395.04	167.27	52.94		
168	6/17	9.8	1.6	3.21	52.38	42.79	44.5	48	96.88	7.27	11.13	56.7	601.69	185.76	64.92		
174	6/23	8.3	1.7	3.01	67.12	36	27.8	39.01	94.92	22.23	6.56	49.39	588.9	113.73	29.03		
183	7/2	6.8	1.7	4.91	21.41	75.85	33.08	80.76	54.47	32.76	6.25						
188	7/7	9.2	0.7	8.03	75.48	69.84	34.54	77.87	110.02	42.69	2.42	63.36	453.57	1018.8	136.02		
195	7/14	6	0.3	2.11	153.28	34.15	42.7	36.28	195.98	9.24	4.45	108.59	742.12	477.71	78		
202	7/21	6.6	0.04	2.07	176.01	54.21	28.52	56.28	204.53	35.59	10.74	18.47	716.8	650.72	99.02		
208	7/27	7.95	0	0.78	183.45	57.51	63.29	58.27	246.74	37.27	11.1	1.58	797.34	384.62	51.98		
216	8/4	9.68	0	1.79	183.22	79.32	122.38	81.11	305.6	22.27	5.88	71.6	1061.17	119.55	31.08		
222	8/10	4.88	0	4.34	174.86	53.24	60.81	57.58	235.47	32.1	3.54	82.18	722.75	43.94	10.21		
233	8/21	6.7	0	0	218.2	68.25	68.51	68.25	286.71	5.39	2.3	16.75	549.43	17.9	0		
244	9/1	7.51	0	0	163.38	52.09	70.23	52.09	233.61	13.13	1.96	62.45	1125.93	0	0		
259	9/18	7.22	0	0.75	225.54	32.83	55.63	33.58	281.17	11.01	0.88	126.65	1353.09	87.41	25.19		
273	9/30	10.82	0.86	1.06	171.46	35.63	36.04	36.69	207.5	12.92	8.46	54.18	735.5	2.06	0.54		
289	10/16	9.26	5.98	5.26	213.31	97.17	45.77	102.43	259.08	7.73	1.43						
310	11/6	10.86	9.99	24.21	2.73	43.9	78.55	68.11	81.28	1.11	1.28						

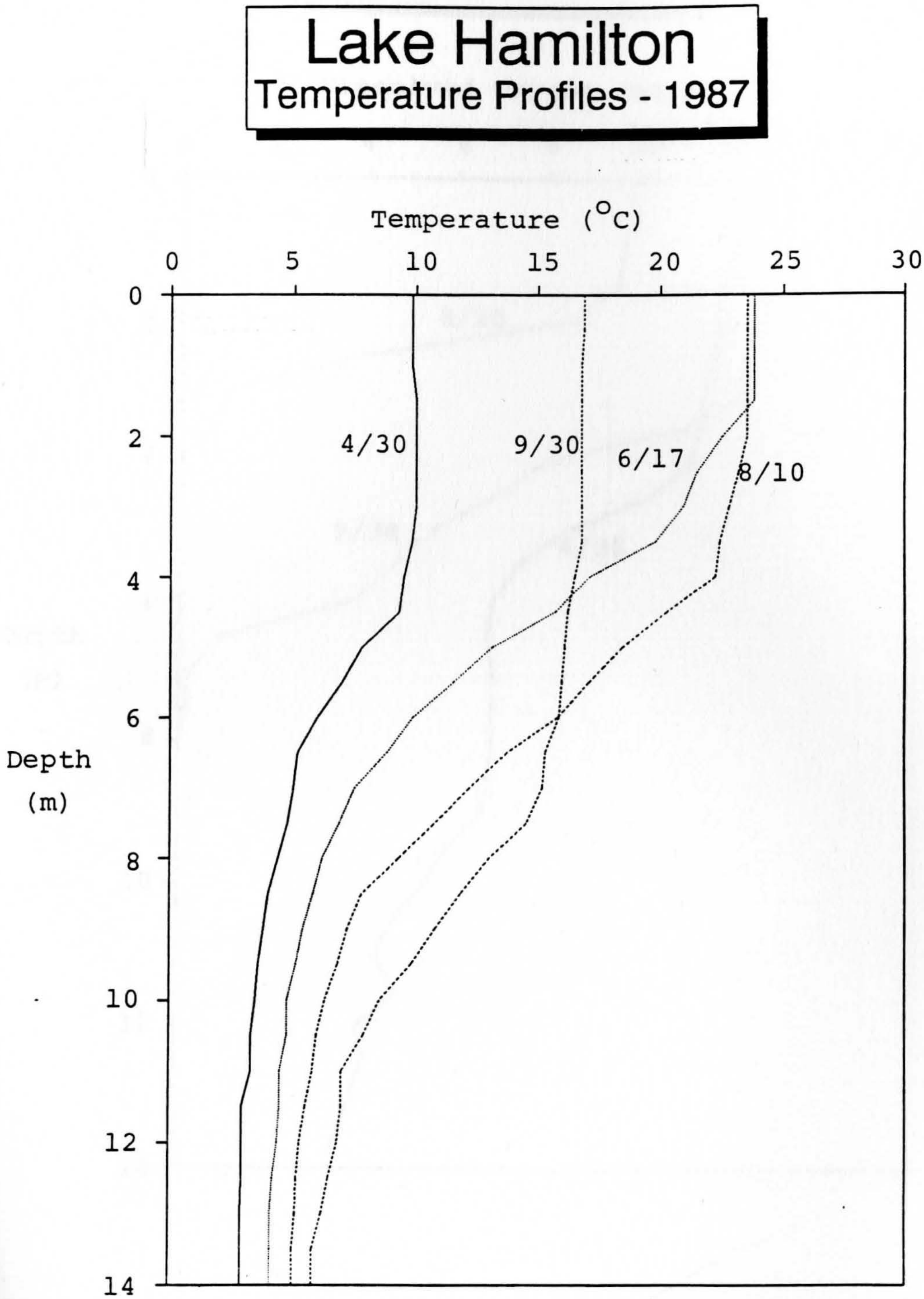

Figure 4.2. Selected Temperature Profiles for Lake Hamilton, 1987.

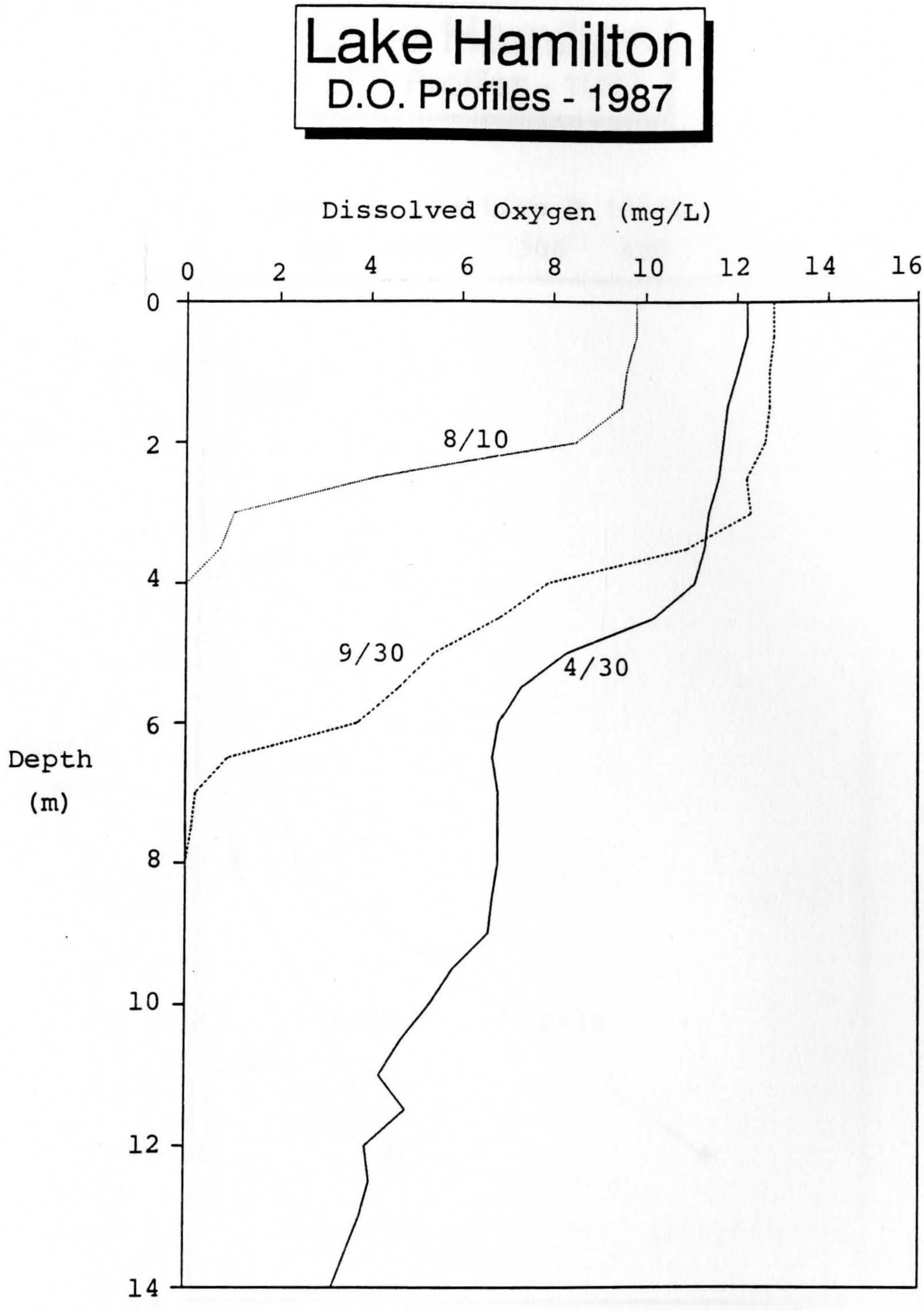

Figure 4.3. Selected Dissolved Oxygen Profiles for Lake Hamilton, 1987.

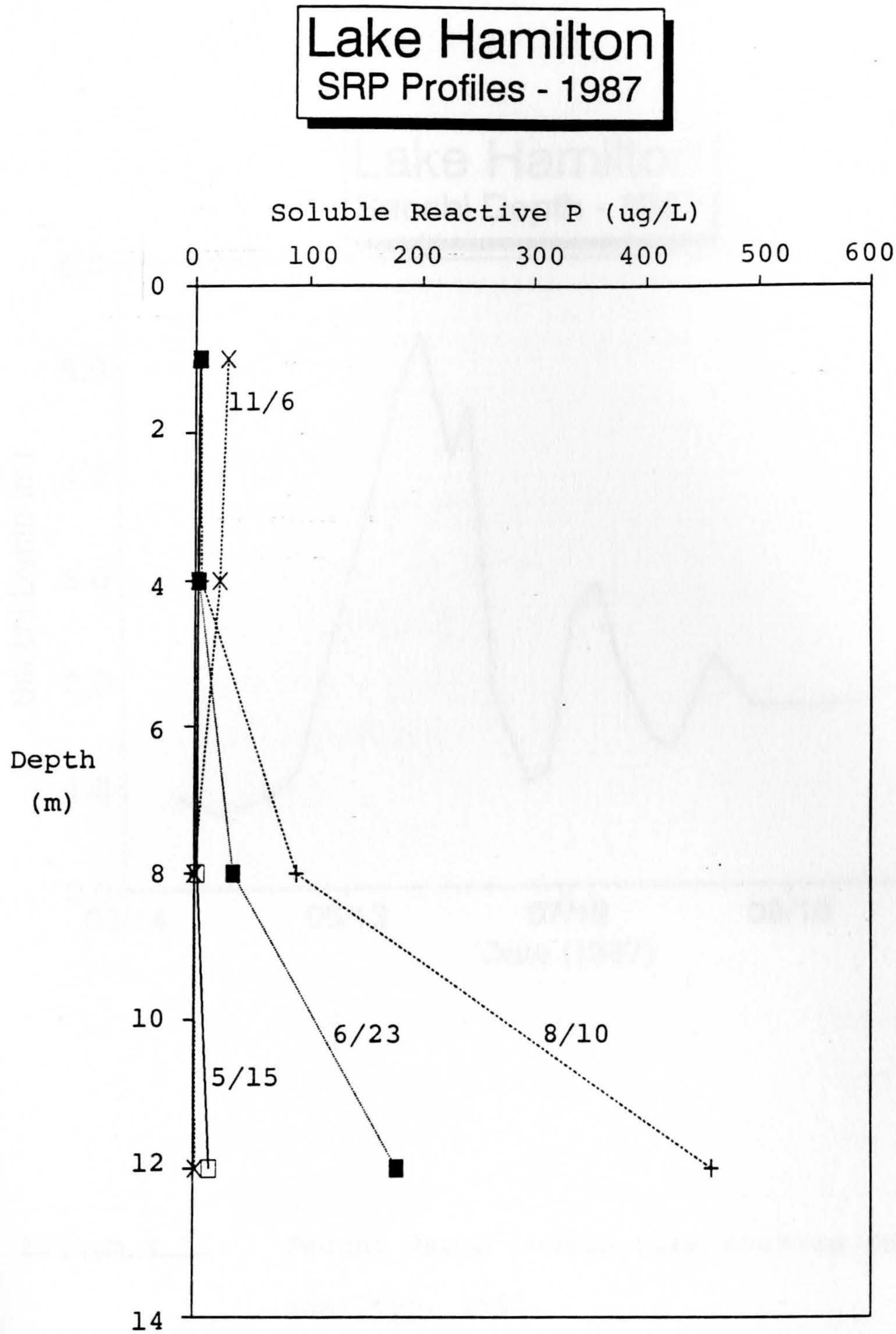

Figure 4.4. Selected Soluble Reactive Phosphorus Profiles for Lake Hamilton, 1987.

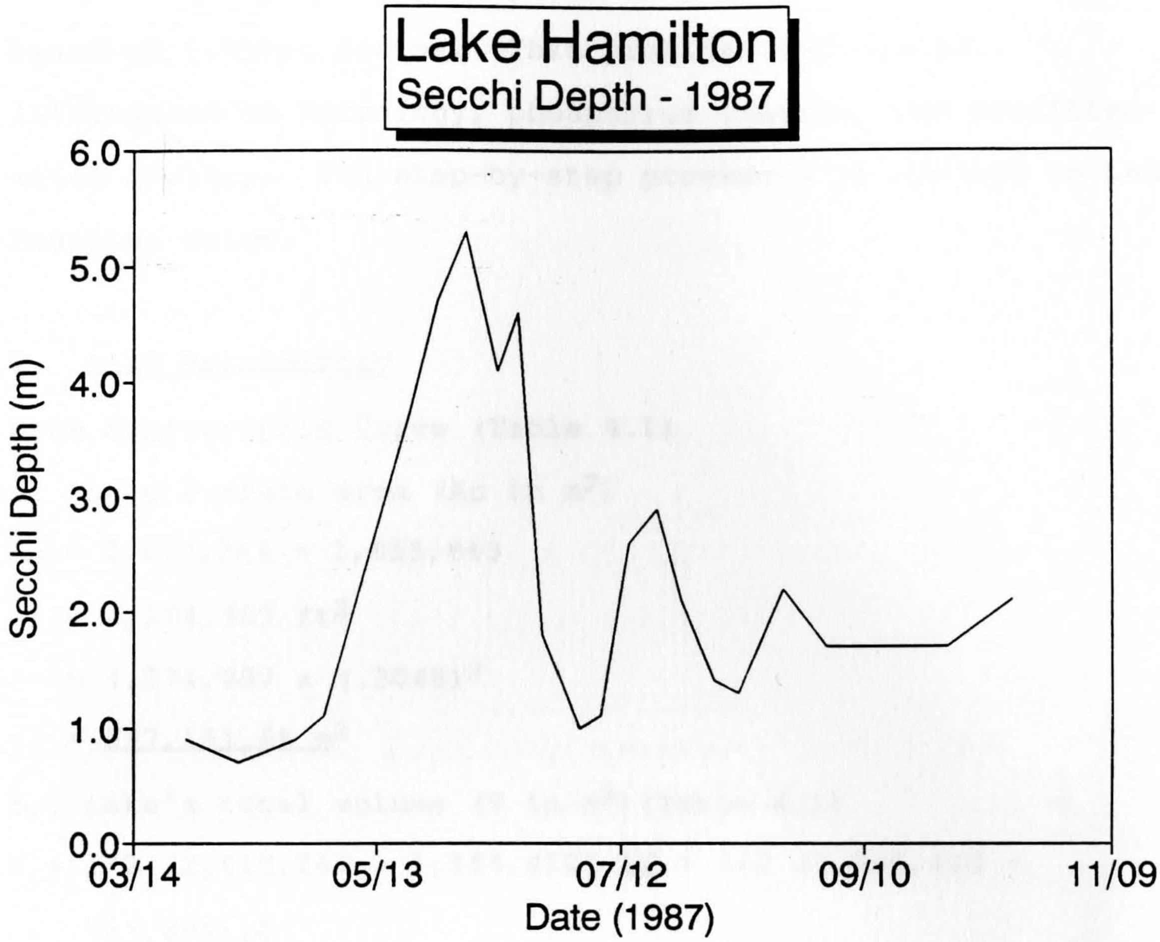

Figure 4.5. Secchi Depth versus time profile for Lake Hamilton, 1987.

4.3 Application of Dillon & Rigler Desk Method

Dillon and Rigler (1975) developed a simple procedure for estimating the capacity for development in a watershed based on trophic status. This provides much useful information on hydrology, phosphorus loading, and predicted water quality. The step-by-step procedure is applied to Lake Hamilton below.

1. Lake Morphometry

From Hypsographic Curve (Table 4.1)

a. Lake surface area (A_o in m^2)

A_o = 2,419,244 + 1,855,663

= 4,274,907 ft^2

= 4,274,907 x $(.3048)^2$

= 397,151.68 m^2

b. Lake's total volume (V in m^3) (Table 4.1)

V = 1/2 (2,419,244 + 1,866,410) 10 + 1/2 (1,866,410 + 783,809)10

+ 1/2 (783,889)5 + 1/2 (1,855,663 + 1,783,123)10

+ 1/2 (1,783,123 + 1,577,903)10 + 1/2 (1,577,903 + 1,173,972)10

+ 1/2 (1,173,972 + 448,467) 10 + 1/2 (448,467 + 133,300) 10

+ 1/2 (133,300) 5

= 96,752,202.5 ft^3

= 96,752,202.5 x $(0.3048)^3$

= 2,739,717.28 m^3

c. Mean Depth (Z in m)

$$Z = \frac{2,739,717.28 \ m^3}{397,1515.86 \ m^2} = \underline{6.9} \ m$$

2. Drainage area Ad was calculated on a 1:50,000 scale topographic map (Figure 4.6), and was found to be, A_d = 27,111,334 ft^2 (by Planimetry) = 27,111,334 x $(.3048)^2$ = 2,518,725.3 m^2. The underlying geology of the region is of sedimentary origin.

The watershed areas dedicated to various land uses are as follows:

Pasture = 5,938,476 ft^2 = 551,702.44 m^2

Urban = 21,172,858 ft^2 = 1,967,022.8 m^2

3. Calculating outflows from the lake. To find the total outflow, Q, we neglect the effect of precipitation and evaporation, and then the outflow is calculated by adding up the averages of annual flow over spillway, and output to industrial systems for the years 1983, 1984.

Then the flushing rate (ρ) is calculated by dividing the total flow by the total volume of the lake.

$$\rho = \frac{2.50 \times 10^7 \ m^3/yr}{2,739,717.28 \ m^3}$$

$$\rho = 9.13/yr$$

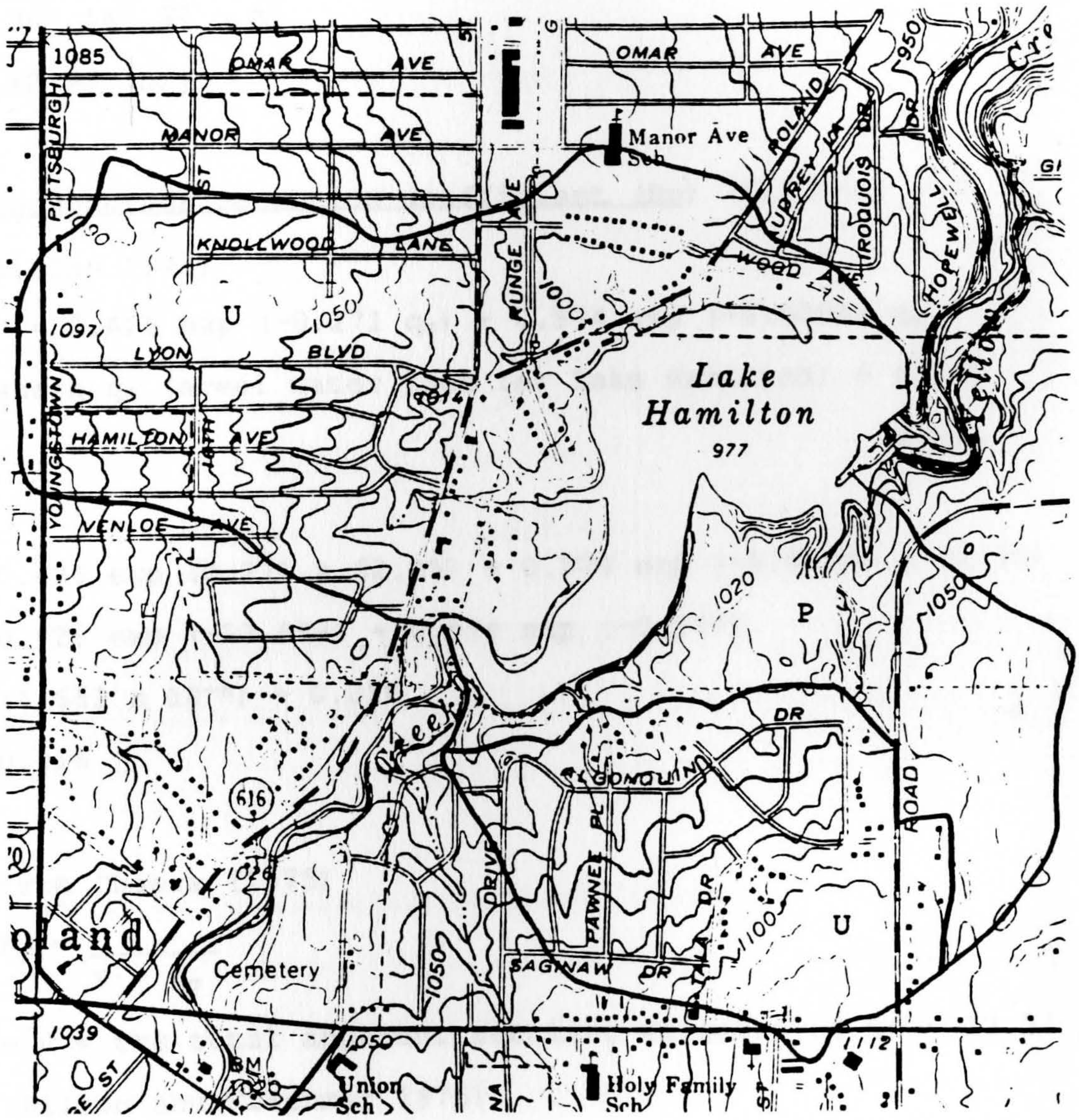

Figure 4.6 Local Drainage Basin of Lake Hamilton

4. Areal water load

$q_s = Q/Ao = \dfrac{\text{annual total outflow}}{\text{lake surface area}}$

$q_s = \dfrac{2.50 \times 10^7 \ m^3/yr}{397{,}151.86 \ m^2}$

$= 62.95 \ m/yr$

5. Phosphorous Retention coefficient (Rp) (Kirchner and Dillon 1975)

$R = 0.426 \exp(-0.271\ q_s) + 0.574 \exp(-0.00949\ q_s)$

where q_s (areal water load for Lake Hamilton) = 62.95 m/yr.

$$R = 0.426 \exp(0.271 \times 62.95) + 0.574 \exp(-0.00949 \times 62.95)$$
$$= 0.426 \exp(-17.059) + 0.574 \exp(-0.597)$$
$$= (1.663 \times 10^{-8}) + 0.316$$
$$R = 0.316$$

Or, from Chapra (1975)

$$R_p = \frac{v}{v + q_s}$$

where v = the total apparent settling velocity of Tp = 13.2 m/y (Dillon and Kirchner 1975).

q_s = areal water loading

= 62.95 m/yr.

Then $R_p = \frac{13.2}{13.2 + 62.95} = \frac{13.2}{76.15}$

$= 0.173$

and the range of R values based on this equation

$Rp_{min} = \frac{10}{10+62.95} = 0.137$ (v from Vollenweider 1975)

$Rp_{max} = \frac{16}{16+62.95} = 0.203$ (v from Chapra 1975)

6. Response time: This is the time for the lake to respond to a change in phosphorous loading.

Response Time $= \frac{5\ (0.69)}{\rho + 10/Z}$ ρ = flushing rate, 1/year; Z = lake mean depth, m

$\frac{5\ (0.69)}{9.13\ yr^{-1} + 10/6.9\ m}$

$= 0.326$ yr

Predicted response time to a change in P is short.

This is a good argument for the validity of a steady state model.

7. Phosphorous Transport from watershed:

The area of the drainage basin, not including the lake is A_d = 27,11,334 ft^2 = 2,518,725.3 m^2; the drainage basin A_d was divided into two areas depending on various land use as follows:

Pasture = 5,938,476 ft^2 = 551,702.44 m^2

Urban = 21,172,858 ft = 1,967,022.8 m^2

The phosphorus export coefficient is estimated from Dillon and Kirchner (1975) as follows, depending on land use.

Urban Land P. export coef = 200 $mg/m^2/yr$

Pasture Land P. export coef = 23.3 $mg/m^2/yr$

Then the total phosphorus loading directly from the watershed per year is calculated as follows:

$J_w = 10^{-6}$ [(551,702.44 x 23.3) + (1,967,022.8 x 200)]

$= 10^{-6}$ (12.854667 + 3.934 x 10^8)

J_w = 406.25 kg/yr.

8. <u>Total Supply of Phosphorus per year</u>:

Mean of 21 measurements of TP in Yellow Cr. inlet was 83.2 ug/L, or 0.0832g/m^3, so the estimated loading is:

$.0832\ g/m^3 \times 10^{-3} kg/g \times 2.50 \times 10^7\ m^3/yr$

J_{yc} = 2087.5 Kg/yr

Phosphorus loading due to precipitation is estimated as:

$$J_{pr} = \frac{75\ Ao}{10^6} = \frac{75 \times 397{,}151.68}{10^6} = 29.79\ kg/yr$$

J_{tot} = 2087.5 + 406.25 + 29.79

J_{tot} = 2523.54 kg/yr

Then the areal phosphorus loading per year into the lake is:

$$L = \frac{J_{tot}}{Ao}$$

$$L = \frac{2523.54}{397{,}151.86} = 0.0063541 \quad kg\ m^{-2}\ yr^{-1}$$

$$L = 6354.1 \quad mg\ m^{-2}\ yr^{-1}$$

9. Predicted Water Quality
from Dillon & Rigler (1974):

$$[TP] = \frac{L\ (1-R)}{Z \times \rho}$$

Flushing Rate (Lake Hamilton) = 8.79 yr^{-1}

$Z = 6.90$ m

$R_1 = 0.316$ yr by Kirchner & Dillon (1975) equation

$R_2 = 0.173$ yr by Chapra (1975) equation and Dillon and Kirchner (1975) value of v.

$\rho = 9.13/yr$

Performing calculations for both retention coefficients:

$$[TP_1] = \frac{6354.1\ (1 - 0.316)}{6.9 \times 9.13} = \frac{4346.20}{63.00} = 68.99\ mg/m^3$$

$$= 68.99\ \mu g/L$$

$$[TP_2] = \frac{6354.1\ (1 - 0.173)}{6.9 \times 9.13} = \frac{5254.84}{63.00} = 83.41\ mg/m^3$$

$$[TP_2] = 83.41\ \mu g/L$$

Predicted chlorophyll a and secchi depth:

For $[TP_1] = 68.99\ \mu g/L$ (from $R_1 = 0.316$)

$$Log_{10}\ [chl\underline{a}]_1 = 1.45\ Log_{10}\ [TP] - 1.14$$

and $[chl\underline{a}]_1 = 33.69\ mg/m^3$

$$SD_1 = \frac{48}{[TP_1]} = \frac{48}{68.99} = 0.70\ m$$

$TP_2 = 83.41$ (from $R_2 = 0.173$)

and $[chl\underline{a}]_2 = 44.24\ mg/m^3$

$$SD_2 = \frac{48}{[TP_2]} = \frac{48}{83.41} = 0.58 \text{ m}$$

Comparison with Field Data

If we use the spring turnover values from our actual data we get 50 mg/L for an average total phosphorus value, so both TP_1 & TP_2 were high. Then from the actual data, and from the months of June, July and August we get

Actual $chl\underline{a}_{ave}$ = 21.4 mg/m^3 (n = 12)

using the volume weighted average in the epilimnion

Actual SD_{ave} = 2.53 m (n = 12)

by Dillon & Rigler Eqn. assuming L is correct

$$[TP] = \frac{L\ (1 - R)}{Z \times \rho}$$

for [TP] = 50 µg/L = 50 mg/m^3

$$50 = \frac{6354.1\ (1-R)}{6.9 \times 9.13} = \frac{6354.1 - 6354.1R}{63.00}$$

$$3149.85 - 6354.1 = -6354.1R$$

$$R = 0.504$$

Calculating L required to reduce [TP] to 20 µg/L (mesotrophic status) using this value of R:

$$L = \frac{Z \times \rho \times [TP]}{1 - R} = \frac{6.9 \times 9.13 \times 20}{1 - 0.504} = 2540.22 \text{ mg m}^{-2} \text{ yr}^{-1}$$

or J_{tot} = 1008.9 kg/yr

4.4 Application of Vollenweider Loading Plot

Dillon and Rigler's "Desk Method" is one way to evaluate lake trophic status. Another way is using a phosphorus loading plot, like the one developed by Vollenweider (1975). By plotting the areal total phosphorus loading rate versus depth divided by hydraulic residence time for a large number of lakes, Vollenweider was able to identify regions corresponding to each trophic status classification. The trophic status of a lake can be estimated by finding its plotting position on these axes and comparing this position to the region boundaries.

For Lake Hamilton

$$\frac{Z}{t} = \frac{6.9\ m}{0.11\ yr} = 62.7\ m/yr$$

$$L = \frac{J}{A} = 6.35\ g/m^2/yr$$

The location of Lake Hamilton on the Vollenweider (1975) plot is shown in Figure 4.7. This plot suggests that the lake is highly eutrophic, which is consistent with the field data.

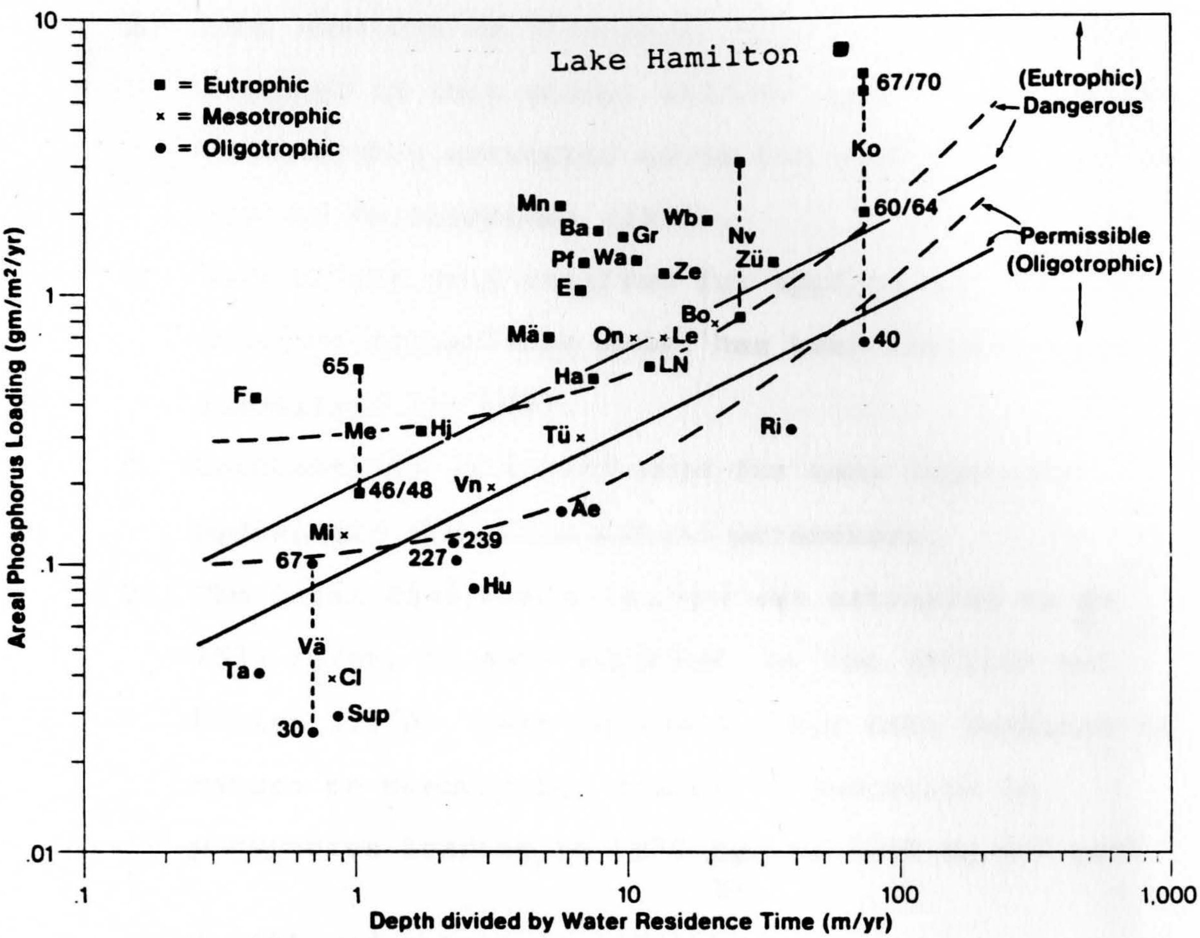

Figure 4.7 Lake Hamilton Trophic Status Prediction Using Vollenweider's (1975) Loading Plot

Chapter Five

Summary, Conclusions and Recommendations

5.1 Conclusions

A. Lake Hamilton in Struthers, Ohio, was sampled and analyzed in this study, and the lake was classified to be highly eutrophic using the phosphorus loading plot of Vollenweider (1975).

B. Much of the data required for application of a more detailed mechanistic model has been collected and summarized for 1987.

C. Calculations were performed for many important hydrologic and morphometric parameters.

D. The total phosphorus loading was estimated to be 2523 kg/yr, or 6354 $mg/m^2/yr$, by the [Dillon and Rigler (1975) "desk method"]. For Lake Hamilton to return to mesotrophic status, a reduction in phosphorus loading to 1000 $\frac{kg}{yr}$, or 2540 mg m^{-2} yr^{-1}, (a 60% reduction) is required.

E. Concentrations of total phosphorus (TP) predicted for Lake Hamilton using the procedure of Dillon and Rigler (1975) were higher than the average concentration actually measured in the lake during 1987. Using the average measured TP from 1987 field data, the phosphorus retention coefficient (R) was estimated to be 0.504.

5.2 Recommendations

A. To gain more insight into processes in Lake Hamilton, data collected in this study should be used to apply more detailed mechanistic models of lake trophic status.

B. The current estimate of total phosphorus (TP) loading to Lake Hamilton is very crude. Before evaluating different lake management strategies for controlling eutrophication, a more accurate estimate of TP loading is needed. This would require gauging of flows into Lake Hamilton from Yellow Creek and routine monitoring of TP concentrations.

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