NUTRIENT LOADINGS TO MILL CREEK WATERSHED AND LAKE NEWPORT

by

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Nutrient Loadings to Mill Creek Watershed and Lake Newport

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ABSTRACT

Nutrient Loadings to the Mill Creek Watershed and Lake Newport

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Estimates of external nutrient loadings were made for Lake Newport, a shallow extremely productive (hypereutrophic) lake in Mill Creek Park, Youngstown, Ohio, to provide a basis for lake management decisions. Mill Creek drains a watershed area of about 73.85 square miles. Runoff contributes large nonpoint nutrient loading to the Mill Creek system and Lake Newport. In addition, the Boardman Wastewater Treatment Plant discharge contributes major point source nutrient loading.

Primarily empirical models or simple deterministic models of trophic status were applied to Lake Newport. Determination of only a few parameters were required. Field sampling was performed during July to October 1994; temperature, dissolved oxygen ammonia, nitrate, suspended solids, 5-day BOD and both total and soluble reactive phosphorus were determined. A detailed analysis was done on 1993 NPDES monitoring data from the Boardman Wastewater Treatment Plant. Many hydrologic and morphometric parameters were calculated for Lake Newport. Lake Newport's trophic status was predicted to be hypereutrophic using Vollenweider's (1975) loading plot.

Also, Dillon and Rigler's (1975) method was used to estimate the total phosphorus

loading. It was also estimated that if the sewage effluent (major point source) is minimized, it is likely that the lake would still remain hypereutrophic, but the water quality should improve significantly. Also, the data collected in this study can be used for more detailed water quality modeling.

DEDICATION

With respect and humility, I dedicate this book to my parents, and my wife.

ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. Scott C. Martin, for his kindly advice and guidance in the design and writing of this study. I apologies for my demand on his time and patience. I would also like to express my appreciation to Dr. Lauren Schroeder, and Dr. L.S. Garton who faithfully served on my graduate committee.

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CHAPTER I

INTRODUCTION

1.1 Background of Mill Creek Park and Lake Newport

Mill Creek Park consists of 2383 acres that begins were Mill Creek joins the Mahoning River and extends southward along the Creek's deep gorge for more than seven miles. The park was established in 1891, largely through the efforts of Volney Rogers, and is one of the largest urban parks in the United States. The park provides its visitors with a variety of attraction, from animals to wild flowers. There are three reservoirs, one of which is Lake Newport, which is of interest in this study.

Lake Newport, named for Mary Newport who was a Youngstown settler, is the largest of the Mill Creek Park lakes. The lake was built in 1928. It originally had an area of 97 acres, with five acres of island. Lake Newport has had many problems associated with its water quality for many years. It receives its nutrient loading from Mill Creek, which results in heavy algal blooms. The major point source loading to Lake Newport is Boardman Waste Water Treatment Plant (WWTP). Being a hypereutrophic (highly productive) lake, its large algal blooms make it less attractive for recreational use. There is also a depletion of oxygen content, for when such large masses of algae die and decompose they impose a great demand upon the oxygen content of the water. These conditions of depleted oxygen supply can cause death of fish and produce foul odors. Several feet of sediment deposits have also accumulated at the bottom of the lake. Internal nutrient loading exists due to this accumulation. Phytoplankton and macrophytes increase as a result of this internal loading. Decreased lake depth resulting from organic and inorganic sedimentation is one common step in the aging sequence of lakes. In 1994, the lake was reflooded after structural modifications that reduced the spillway elevation by 2 ft. This reduced the lake surface area from 97 acres to about 77 acres.

1.2 Scope and Purpose

The purpose of this research was to perform a preliminary survey of water quality in Mill Creek and assess the impact of nutrient loading to Lake Newport. Also, several models of lake trophic status were applied to Lake Newport. In the first phase of this study, samples were collected at eight different locations throughout summer and early fall of 1994. Temperature and dissolved oxygen were measured in the field. Samples were collected and analyzed for ammonia, nitrate, suspended solids, 5-day BOD, and both total and reactive phosphorus.

The second phase of this study was the estimation of phosphorus loading to Lake Newport. First, a detailed analysis was done on 1993 NPDES monitoring data from Boardman Wastewater Treatment Plant. This was combined with the data from phase one to give an estimate of the total phosphorus load. The third phase of this study was the application of trophic status models to Lake Newport. The models examined are primarily empirical models or simple deterministic models that require determination of only a few parameters. Since phosphorus is assumed to be the limiting nutrient for eutrophication in most lakes, models which stress phosphorus were given priority. Models that were examined in this study include the following:

- A "desk method" for predicting the capacity of a lake for development outlined by Dillon and Rigler (1975).

- An expression developed by Vollenweider (1976) to include the effects of hydraulic flushing on lake trophic status.
- A plot of areal phosphorus loading rate to a lake versus overflow rate presented by Vollenweider (1975).
- A simplified "one-box" deterministic model for predicting steady state phosphorus concentration in lakes derived by Vollenweider (1969) and revised by Dillon and Rigler (1974). These models are discussed in detail in Chapter II.

The ultimate goal of this research is to identify the main sources of phosphorus to Lake Newport and investigate ways to reduce the amount of this nutrient in the future.

CHAPTER II

LITERATURE REVIEW

2.1 Eutrophication of Lakes

2.1.1 Causes and effects of eutrophication:

Eutrophication, or enrichment of water by organic or inorganic nutrient material, is one of the major problems in management of water resources. The term "eutrophic" originated in 1907 from consideration of the nutrient condition or chemical nature of the soil solution in bogs. In 1919, the term was introduced in limnology and has come to be widely accepted as describing a lake rich in nutrients. The term "nutrient" refers to the chemical substances essential to the growth of plants (Hutchinson, 1969). Thus, eutrophication can be defined as a condition of lakes in which excess nutrients have caused an augmentation of algal production.

Eutrophication can occur both naturally and artificially. Natural eutrophication is an inherent process in the aging of impounded waters, whereas artificial or "cultural" eutrophication results from the discharge of domestic and industrial waste waters, and runoff and leaching from heavily fertilized agricultural land. The general symptoms of eutrophication are the increased fertility of water with resultant increase in the primary productivity, leading in the most severe cases to "blooms" of algae, which in turn leads to depletion of oxygen content.

The blooms of algae are frequently dominated by the "blue greens" which sometimes produce toxins; there are instances of such toxins causing mortalities of fish and other animals, and on some occasions harmful effects to human have been reported (Gorham, 1964). In some instances fisheries may be damaged. The recreational value of the water may be affected as a result of the replacement of game fish, such as salmonids, by less desirable fish.

Excessive amounts of phytoplankton and/or macroscopic plants in the water create aesthetic problems and reduce the value of the body of water as a recreational resource. From a purely aesthetic standpoint, clear water is most attractive for swimming or boating. High phytoplankton concentrations cause the water to appear turbid and aesthetically unappealing. Macroscopic plants can cover literally the entire surface of lakes and consequently make the water almost totally unfit for swimming or boating. The death and decomposition of large amounts of plant biomass may cause oxygen depletion and create foul odors. The various potential uses of a water body, such as flood control, recreation, fish production, and irrigation, frequently conflict with one another. The high concentration of phytoplankton in a well-managed catfish pond, for example, would hardly be conducive to use of the pond for swimming; nor would the periodic raising and lowering of the water level in a reservoir used for flood control be desirable for boating. The importance attached to the pros and cons of some eutrophication effects depends to a certain degree on the intended use of the body of water. Causes and effects of eutrophication are shown in Figure 2-1 (Thomas, et al, 1992). Because the value of these lakes is often reduced due to their conditions, considerable efforts have been made to predict the productivity of lakes in order to reduce eutrophication.

2.1.2 Classification of lake trophic status:

Lakes may be classified according to nutrient concentrations (e.g., phosphorus and nitrogen), dissolved oxygen deficits, secchi depth, chlorophyll a concentrations and/or trophic state indexes, as oligotrophic, mesotrophic, eutrophic or hypereutrophic. Oligotrophic lakes are the lakes of low primary productivity and low biomass associated

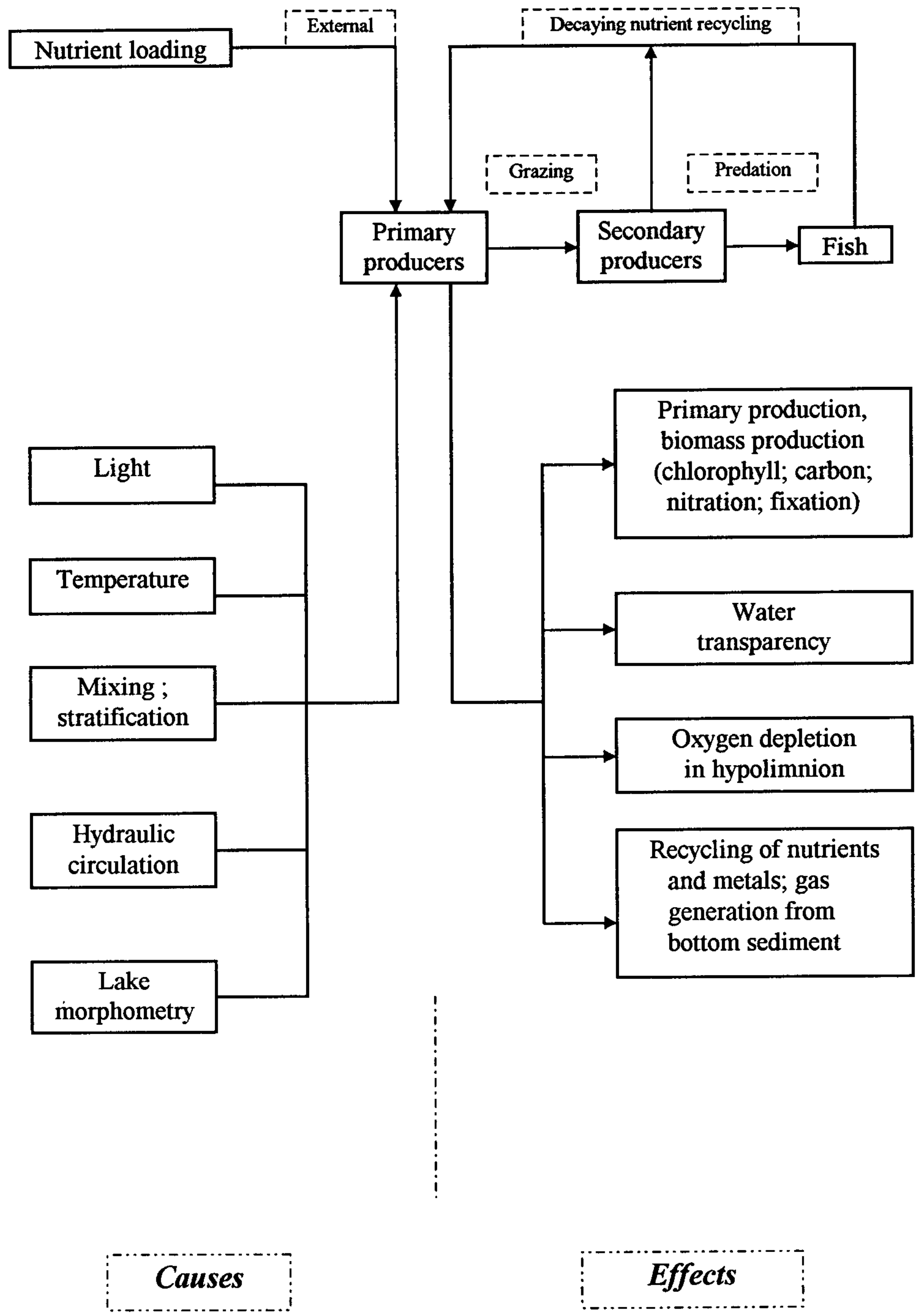


Figure 2-1: Causes and Effects of Eutrophication (Thomas, et al, 1992)

with low concentrations of nutrients (nitrogen and phosphorus). In temperate regions the fish fauna is dominated by species such as lake trout and whitefish. These lakes tend to be saturated with oxygen throughout the water column.

Eutrophic lakes are lakes that display high concentrations of nutrients and are associated with high biomass production, usually with a low transparency. In temperate regions fish like perch are dominant (Thomas, et al, 1992). Such lakes may also display many of the effects that begin to impair water use. Oxygen concentrations can get very low, often less than 1 mg/l in the hypolimnion during summer stratification. Mesotrophic lakes are the lakes that are less well defined than either oligotrophic or eutrophic lakes and are generally thought to be lakes in transition between the two conditions. In temperate regions the dominant fish may be whitefish and perch. Some depression in oxygen concentrations occurs in the hypolimnion during summer stratification.

Hypereutrophic lakes are the lakes at the extreme end of the eutrophic range with exceedingly high nutrient concentrations and associated biomass production. Anoxia or complete loss of oxygen often occurs in the hypolimnion during summer stratification.

2.2 Processes and Parameters Related to Lake Trophic Status

Before modeling trophic condition of lake waters, it is necessary to understand the various processes occurring within the lake and its watershed that can influence the trophic status. It is also necessary to describe several parameters that are commonly used in the analysis of the trophic status.

2.2.1 Sources and forms of phosphorus:

Phosphorus is supplied to lakes in various forms and amounts from different sources. Natural sources include precipitation on the surface of the lake, runoff from surrounding watersheds, animal wastes, vegetation deposits, groundwater influxes and recycling. Cultural or artificial sources include domestic and industrial waste waters, agricultural runoff, urban runoff, septic tank leachate, and landfill drainage. These may be either organic or inorganic forms.

Although phosphorus can occur in many forms in nature, only a few are important to lake trophic status. Phosphorus with the coordination number four is the most important to the environmental scientist. In the water column of the lake, most inorganic phosphorus exists as soluble phosphates. The most important component of organic phosphates is that present in cells of viable plankton. Other storage sites of organic phosphorus in natural waters include dead plankton suspended in water or present in the bottom of the lake, free swimming animals, soluble organic excretions of both plants and animals, and colloidal organo-metal-phosphate complexes (Griffith, et al, 1973).

Hutchinson (1957) suggested the following categories as useful in limnology:

- Soluble inorganic phosphate (PO_4^{-3})
- Acid-soluble sestonic phosphorus, consisting of inorganic phosphorus, mostly as ferric and calcium phosphates, becoming soluble phosphates under acidic condition.
- Organic soluble phosphorus consisting of phosphorus present in organic excretions.
- Organic sestonic phosphorus consisting of phosphorus mostly associated with living and dead plants and animals.

The total inorganic and organic phosphorus has been separated in various ways in analysis; often, these fractions are related poorly to the metabolism of phosphorus. The most important quantity, in view of the metabolic characteristics within a lake, is the total phosphorus content of unfiltered water, which consists of phosphorus in suspension in particulate matter, and the phosphorus in "dissolved" (filterable) form. Both compartments consist of several components. The common procedure used in the analysis of phosphorus involves the preliminary separation of the phosphorus into two fractions by filtration using a 0.45 μm membrane filter. This method is described in Standard Methods for the Examination of Water and Wastewater, 2540 D. (APHA, et al, 1992). Although the phosphorus present in the filterable fraction is often referred to as "soluble", this is frequently inaccurate. Phosphorus associated with colloidal material may account for a significant part of this fraction.

A large proportion (often greater than 90%) of the phosphorus in lake water is bound as organic phosphates and cellular constituents of living and dead plankton. Of the total organic phosphorus, about 70% or more is typically within the particulate organic material, and the remainder is present as dissolved and colloidal organic phosphorus. Because of the fundamental importance of phosphorus as a nutrient and major cellular constituent, much emphasis has been placed on analytical evaluation of its changes in concentrations with time. Chemical analyses all center around the reactivity of orthophosphate with molybdate. Enzymatic and acidic hydrolysis of complex forms of phosphorus result in the conversion of these compounds to orthophosphate (Wetzel, 1975).

2.2.2 Phosphorus dynamics within lakes:

Phosphorus can enter a lake in various forms as explained earlier. The fate of phosphorus upon entering a lake is largely dependent upon the form in which it enters. Soluble inorganic phosphates are readily taken up by littoral vegetation and phytoplankton for growth. Organic matter, on the other hand, must undergo decomposition before the phosphorus present in it can be utilized. This is partly accomplished by the heterotrophic bacteria that use organic matter as a source of carbon and energy. Soluble organics, which come from the runoff of partially decomposed plants and other materials, are also decomposed in the water column; however, insoluble organic matter is only partially decomposed before settling to the bottom of the lake. Phosphorus associated with insoluble inorganic material such as minerals is much less biologically available. Inorganic phosphorus compounds often make up less than 10% of total phosphorus in water columns, which is very inadequate to support the algal cells during blooms. Thus the rate of biological productivity in a lake depends upon the rate at which the nutrients are available to growing biological populations.

Hutchinson (1957) has postulated seven mechanisms important in the cycling of phosphorus during summer stratification in lakes:

- Liberation of phosphorus into the eplimnion from the littoral zone, due to the decay of littoral vegetation; excretions from living littoral plants may also act as a source of phosphorus.
- Uptake of phosphorus from water by littoral vegetation.

- Uptake of liberated phosphorus by phytoplankton.
- Loss of phosphorus as a soluble compound from phytoplankton.
- Sedimentation of phytoplankton and other phosphorus containing particulates into the hypolimnion.
- Liberation of phosphorus from the sedimenting seston in the epilimnion and hypolimnion by autolysis and bacterial decomposition.
- Diffusion of phosphorus from the sediments into the water column under anoxic conditions.

A portion of phosphorus in the sediments is present as phosphate adsorbed on and complexed with ferric oxide and hydroxide and as phosphate coprecipitated with iron and manganese. When the overlying waters are aerated, oxygen will penetrate a few centimeters into the sediments. This oxidized microzone reduces the transport of phosphorus into the overlying waters. However, if the dissolved oxygen content of the hypolimnion is greatly reduced as a result of bacterial decomposition of organic matter, the thickness of this oxidized microzone may be decreased considerably. Under such anaerobic conditions, ferric iron (Fe^{+3}) is reduced to ferrous iron (Fe^{+2}) and Mn^{+3} to Mn^{+2}, resulting in the release of phosphate into the water (Wetzel, 1975).

2.3 Models to Determine Lake Trophic Status

2.3.1 Empirical models:

Most of the early models developed were empirical in nature. Although deterministic models have received increased attention in recent years, empirical models are still widely used because they are usually simple and inexpensive. One of the earliest methods developed merely involves the use of areal hypolimnetic dissolved oxygen deficit (e.g., Hutchinson 1957, Lasenby 1975). Although the collection and interpretation of dissolved oxygen data are not difficult, the utility of the index is restricted by the fact that it may be applied only to deeper stratified lakes.

Rawson (1955) developed plots of productivity versus mean lake depth using data from several large lakes in Canada. There are some disadvantages to this model. First of all, there are several difficulties in sampling the standing crop of plankton. The difficulties involved are the inability to separate dead organic and inorganic materials from the living plankton. This model was found to be useful to large lakes, but the applicability to small lakes requires additional data.

Sakamoto (1966) plotted productivity versus mean depth using chlorophyll content as a measure of productivity. The curves obtained were similar to that of Rawson. Also, Sakamoto was one of the first researchers to incorporate the role of algal nutrients into a model of lake trophic status. He found that plots of chlorophyll content versus total nitrogen and total phosphorus content on log-log scales yield approximately linear relationships. The only serious deviations from the chlorophyll-total nitrogen regression curve occurred for lakes having high N: P ratios. In these lakes, the lack of phosphorus is likely to limit algal growth, causing the chlorophyll content to be lower than expected for a given nitrogen content. Likewise, the only serious deviations from the chlorophyll-total phosphorus regression curve occurred for lakes having low N: P ratios, in which case nitrogen limitation of algal growth is likely to occur.

Vollenweider (1968) examined data on lake mean depth in conjunction with data on lake nutrient loading. On the basis of the available data and his assessment of the trophic state of the lakes studied, Vollenweider proposed nutrient loading criteria appropriate to the transition zones between trophic states. The result was a table of "permissible" and "dangerous" loading levels for nitrogen and phosphorus with the levels in each category increasing as mean depth increases. Thus, knowing the mean depth, the plot can be used to determine the loading necessary to attain a desired trophic status. The following empirical equation was developed describing the transition range between oligotrophy and eutrophy as a function of mean depth:

$$L_C = (25 \text{ to } 50)\ \overline{Z}^{0.6} \qquad (2\text{-}1)$$

where, L_C = critical phosphorus loading rate in mg/m^2/yr

$\overline{Z}$ = mean depth in meters

The lower value in parentheses (i.e. 25) represents the upper limit of oligotrophy and the upper value (i.e. 50) the lower limit of eutrophy.

Dillon and Rigler (1974) refined the chlorophyll-total phosphorus model developed by Sakamoto (1966). To make the collection of data simpler, more accurate and more consistent, they specified the plot to be one of the average summer chlorophyll a versus spring total phosphorus. The following regression equation was calculated:

$$\text{Log}\,[\text{chl } \underline{a}] = 1.449\ \text{Log}\,[P] - 1.136 \qquad (2\text{-}2)$$

Correlation coefficient = 0.95

Kirchner and Dillon (1975) developed a mathematical (or statistical) estimate of phosphorus trapping. They found that the fraction of phosphorus loading retained within a lake, R_P, could be estimated as a function of areal water loading rate, q_S (m/yr):

$$R_P = 0.426 \exp(-0.271\, q_S) + 0.574 \exp(-0.00949\, q_S) \qquad (2\text{-}3)$$

Carlson (1977) proposed the trophic state index (TSI) equations based on various trophic parameters, with TSI varying from 0 (very clean) to 100 (hypereutrophic):

$$TSI = 10\,(6 - \log_2 SD) \qquad (2\text{-}4)$$

$$TSI = 10\,[\,6 - (\,2.04 - 0.68 \ln(\text{Chl } \underline{a}\,) / \ln 2)] \qquad (2\text{-}5)$$

$$TSI = 10\,[\,6 - (\ln 48 / TP\,(\ln 2))]\ \ln 2 \qquad (2\text{-}6)$$

where, SD = Secchi depth, m

Chl a = Chlorophyll a concentration, µg/l

TP = Total phosphorus concentration, µg/l

Although various researchers have used different parameters to estimate trophic status of a lake, Dillon and Rigler (1975) expressed a desire to estimate lake trophic condition without extensive data collection. They proposed a method whereby, with a knowledge of the geology, land use, size and hydrology of the lake and its watershed, it would be possible to estimate phosphorus loading rates, total phosphorus concentration, average summer chlorophyll a concentration and secchi depth. First, the natural phosphorus load from land is estimated by applying phosphorus export values reported by Dillon and Kirchner (1975) (see Table 2-1).

The natural phosphorus load to the lake from precipitation is estimated by multiplying the lake surface area by 75 $mg/m^2/yr$, a value suggested by Dillon and Rigler (1975) for southern Ontario. The total natural load to the lake (J_W) is the sum of the land and precipitation loads. The total phosphorus load to the lake is calculated by summing the total natural and artificial loads. The areal phosphorus load (L, $mg/m^2/yr$) is equal to the total load divided by lake surface area.

Table 2-1

Ranges and Mean Values for Export of Phosphorus from 43 Watersheds ($mg/m^2/yr$) (from Dillon and Kirchner, 1975)

	Geological Classification	
Land Use	**Igneous**	**Sedimentary**
Forest		
Range	0.7 - 8.8	6.7 - 18.3
Mean	4.7	11.7
Forest and Pasture		
Range	5.9 - 16.0	11.1 - 37.0
Mean	10.2	23.3

Once the areal phosphorus load has been estimated, the steady state total phosphorus concentration ([TP], in µg/l) can be predicted using a simple deterministic model (discussed in detail in section 2.3.2)

$$[TP] = \frac{L\,[1-R]}{\bar{Z}\,\rho} \qquad (2\text{-}7)$$

where L = areal phosphorus loading ($mg/m^2/yr$)

ρ = hydraulic flushing rate (yr^{-1})

$\bar{Z}$ = mean depth of the lake (m)

R = retention coefficient of phosphorus within the lake (Equation 2-3)

Although empirical models can provide easy and rapid estimates of the present lake condition or of its response to a change in nutrient loading, they do not account for the three-dimensional, time-varying character of the actual lake. Thus, caution should be exercised when choosing simplified models.

2.3.2 Deterministic models:

Mass-balance models are frequently used in deterministic analyses of lake trophic condition. These are sometimes called “box models” since the state variables are represented by boxes in conceptual diagrams. A simple one-box nutrient model for phosphorus was developed by Vollenweider (1969). In doing so, the following assumptions were made:

- The sedimentation rate of phosphorus is proportional to the amount present in the lake.

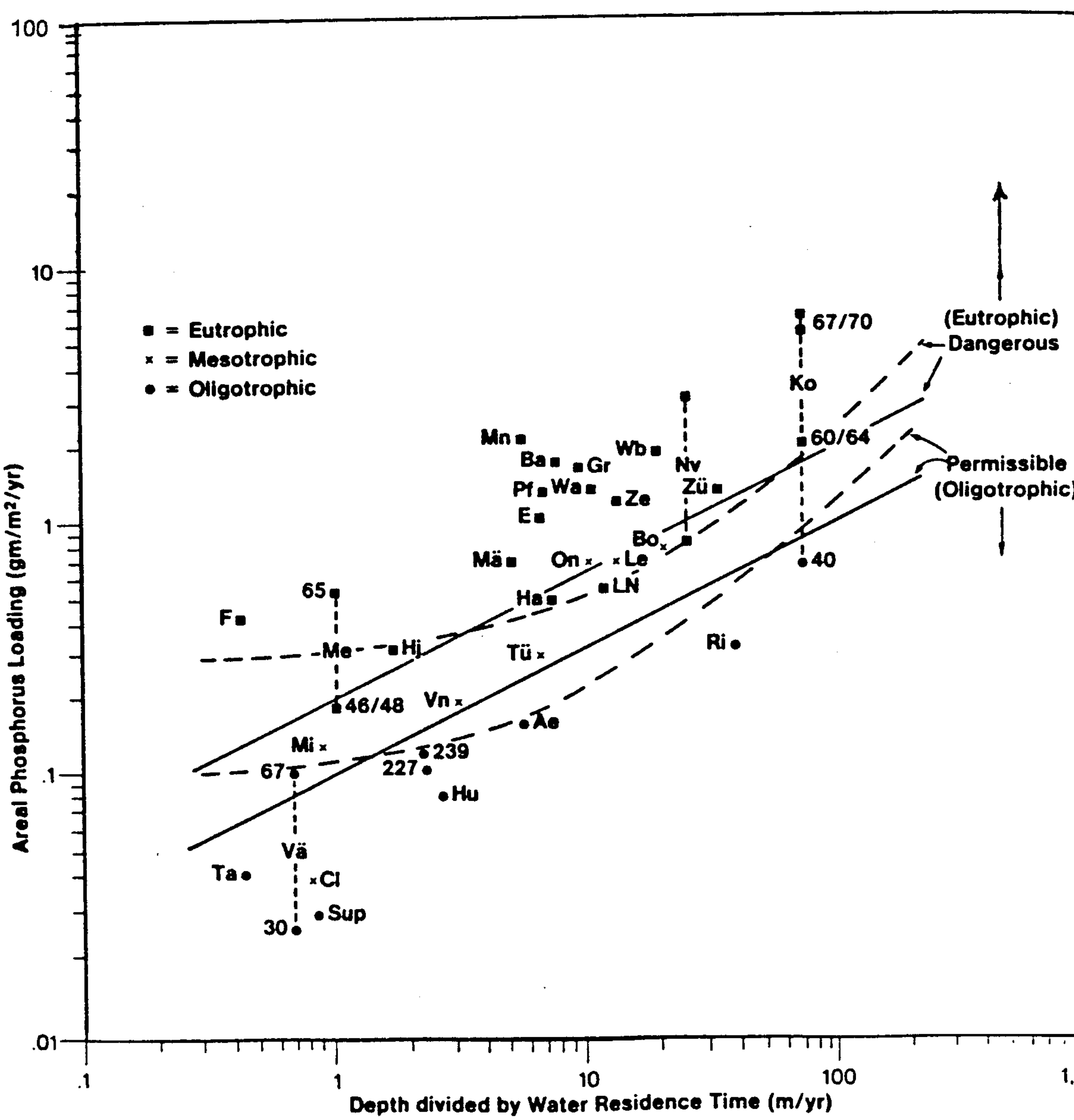


Figure 2-2: Lake Trophic Status Prediction Plot Developed by Vollenweider (1975)

CHAPTER III

METHODS AND PROCEDURES

3.1 Lake Characteristics and Sampling Procedures

Eight locations in Mill Creek and its tributaries were sampled for chemical and physical parameters from July-October 1994. Of these eight locations, five were in the mainstem of Mill Creek and three were near the mouths of major tributaries. Sampling dates are listed in Tables 4-1 to 4-8 for all eight locations. The monitoring stations selected for this study (shown in Figure 3-1) are as follows:

Station # 1 : Mill Creek at Western Reserve Road bridge.

Station # 2 : Indian Run at Route 224 bridge.

Station # 3 : Mill Creek at Route 224 bridge.

Station # 4 : Cranberry Run at culvert under Shields Road.

Station # 5 : Mill Creek about 100 ft. downstream of Anderson's Run.

Station # 6 : Anderson's Run at Lockwood Boulevard bridge.

Station # 7 : Downstream of Lake Newport dam.

Station # 8 : Mouth of Mill Creek.

A map of the Lake Newport drainage basin, including Stations # 1 through # 6, is shown in Figure 3-2. Station # 1 includes flow from 15 tributaries and 14 direct runoff areas. Other than Turkey Creek, these tributaries are mostly small and unnamed. With the exception of the City of Columbiana, this area is largely rural, with some agriculture, small residential and commercial developments. The drainage area of Station # 1 is 28.78 square miles, or 39 % of the total Lake Newport watershed (MRB-HER, 1994).

Station # 2 accounts for essentially all of the Indian Run watershed. The northern portion of this watershed, along Tippecanoe Road both north and south of State Route

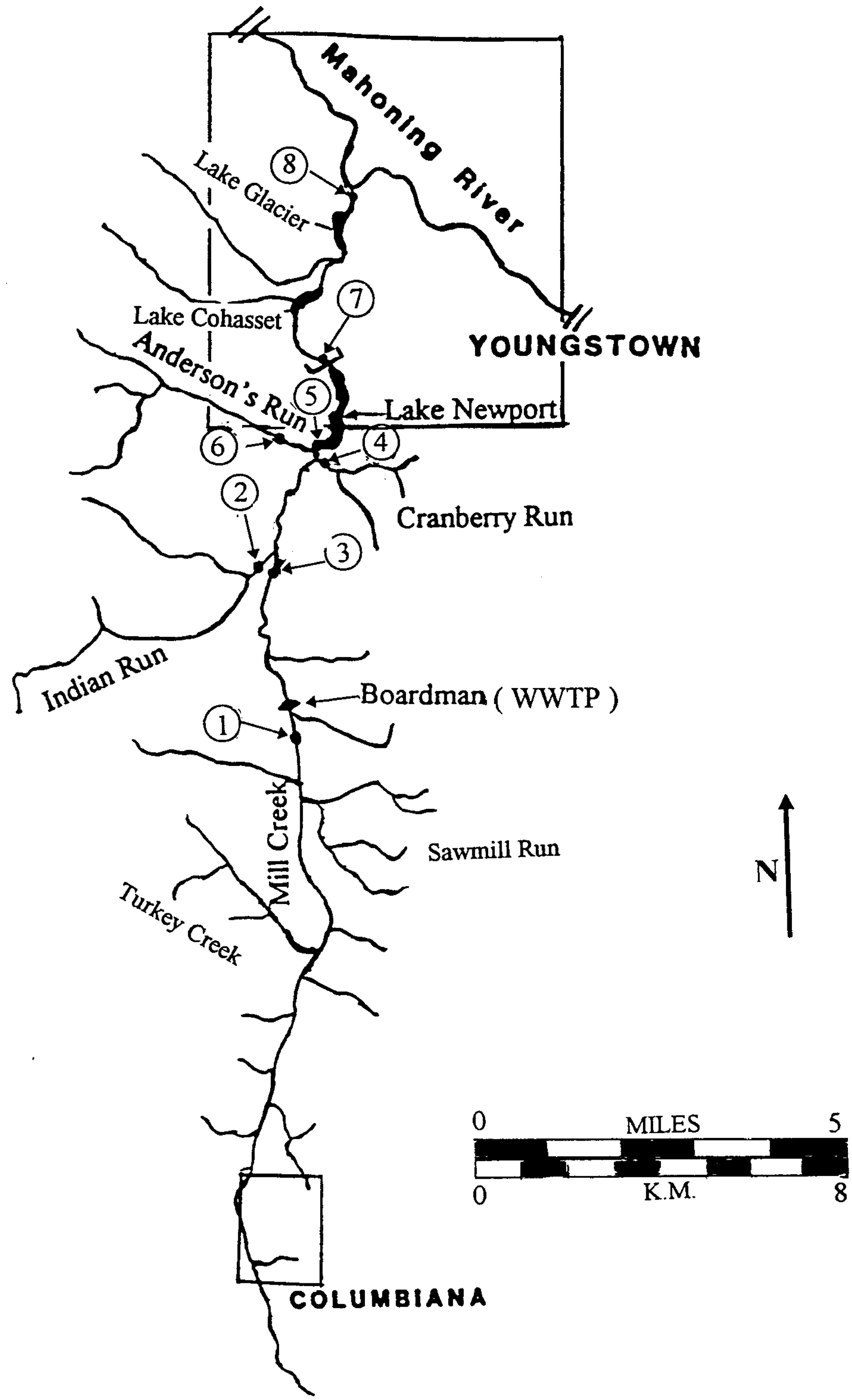


Figure 3-1: Locations of Sampling Stations in Mill Creek Area, July-October, 1994

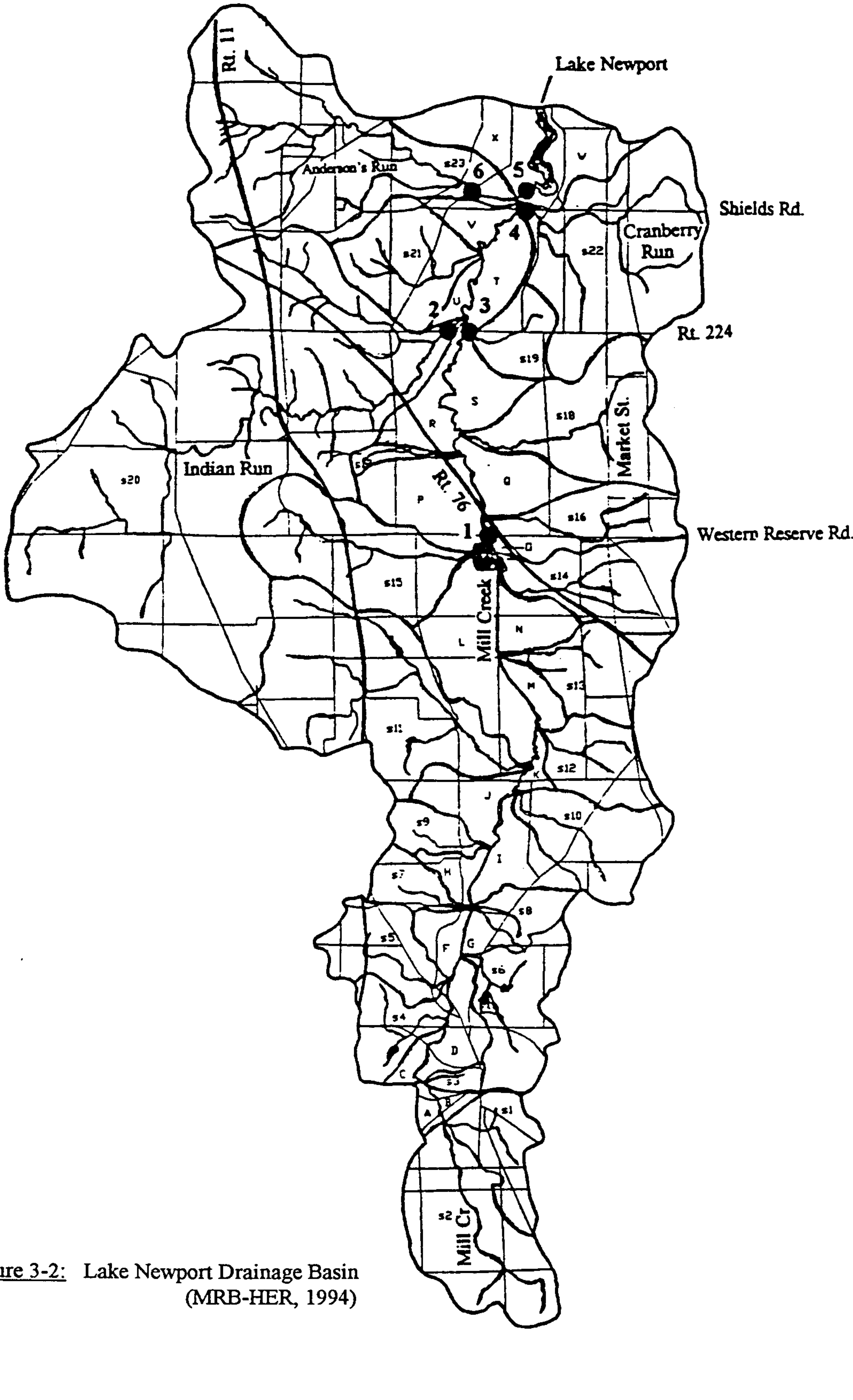


Figure 3-2: Lake Newport Drainage Basin (MRB-HER, 1994)

224, has experienced intense development, mostly residential with some commercial, over the past 10 years. The drainage area is 17.64 square miles, 23.9% of the Lake Newport watershed. Indian Run is 4.8 miles in length. Elevation at the source is 1118 ft and at the mouth is 986 ft. It has an average fall of 27.5 ft/mile (MRB-HER, 1994).

Station # 3, on the main channel of Mill Creek, drains the entire area upstream of Station # 1, plus flow from Sawmill Run and a few other small drainage subareas. The main reason for including this station was to observe the impact of the Boardman Sewage Treatment Plant, which discharges treated effluent to Mill Creek about one mile upstream of State Route 224 (MRB-HER, 1994).

Station # 4 includes virtually the entire watershed of Cranberry Run. Land use in this area is almost all urban residential. Most of the homes were built 15 to 25 years ago. The watershed area of 5.11 square miles is 6.9% of the total Lake Newport drainage basin. Cranberry Run is 1.6 miles in length. Elevation at the source is 1050 ft. and at the mouth is 985 ft. It has an average fall of 40.6 ft/mile (MRB-HER, 1994).

Station # 5 is located on Mill Creek just before it enters Lake Newport. This station accounts for essentially 100% of the flow and sediment loading rates to Lake Newport from Mill Creek (MRB-HER, 1994).

Station # 6 accounts for over 95% of the drainage area of Anderson's Run, or about 7.0 square miles. This area is predominately residential, with a mixture of new and established developments. Land use is intermediate between that of Cranberry Run and Indian Run, both in terms of the density and the age of residential development. Anderson's Run is 4.5 miles in length. Elevation at the source is 1150 ft. and at the mouth is 984 ft. It has an average fall of 36.9 ft/mile (MRB-HER, 1994).

Station # 7 is downstream of Lake Newport. The main reason for including this station is to see the effect of impoundment on water quality. Station # 8 is at the mouth of Mill Creek at Mahoning Avenue. The data from this location show the effects of the additional impoundments - Lakes Cohasset and Glacier.

The following physical and chemical parameters were analyzed:

- Flow (field)
- Temperature (°C) (field)
- Dissolved oxygen (field)
- pH (field, lab)
- Suspended Solids (SS)
- Biochemical Oxygen Demand (BOD_5)
- Nitrate-Nitrogen (NO_3-N)
- Ammonia-Nitrogen (NH_3-N)
- Total phosphorus (TP)
- Soluble reactive phosphorus (SRP)

At the sampling sites, dissolved oxygen and temperatures were determined using a Yellow Springs Instruments (YSI) model 51B oxygen meter.

Flow in a stream is calculated as the product of the water velocity and submerged cross-sectional area. Water surface elevations at Stations #1, #2, #3, #4 (initially), and #6 were determined by measuring the distance from a fixed point on the bridge to the water surface using a plastic tape attached to a plastic bottle filled with gravel. This distance is called the "plumb depth", PD.

The following equations developed by MRB-HER (1994) to relate "plumb depth" (PD) to flow rates were used to calculate the flows at Stations #1, #2, #3, and # 6:

Station # 1: Mill Creek at Western Reserve Road

$$\log Q = (-0.431867 \times PD) + 5.99689 \qquad r^2 = 0.9732$$

Station # 2 : Indian Run at State Route 224

$$\log Q = (-0.673406 \times PD) + 7.11195 \qquad r^2 = 0.9349$$

Station # 3 : Mill Creek at State Route 224

$$\log Q = (-0.393113 \times PD) + 5.21019 \qquad r^2 = 0.9788$$

Station # 6: Anderson's Run at Lockwood Blvd.

$$Q = (-23.544 \times PD) + 228.215 \qquad r^2 = 0.9145$$

where,

Q = flow rate (cfs)

PD = "plumb depth" to water surface from a fixed point on the bridge (ft)

r^2 = correlation coefficient for linear regression (1.0 = perfect fit)

At Station # 4, Cranberry Run under Shields Road, flow was estimated by measuring the velocity, depth and width of flow in the culvert. Flow measurements were not taken for Stations #5, #7 and #8, due to difficulties with stream access or characterization of the cross-section.

3.2 Handling of Samples and Preparation for Analyses

Surface grab samples were collected in 1 L bottles. Upon return to the laboratory where analyses were performed, the samples were placed in a refrigerator at about 4^0C. Filtrations were performed on all samples using Fisher G4 glass fiber filters within 24 hours after the samples were returned to the lab. Filtrates were stored in plastic bottles in the refrigerator until analyses were performed.

In this study, filtrates were analyzed for soluble reactive phosphorus (SRP), nitrate-nitrogen and ammonia-nitrogen, while unfiltered samples were analyzed for total phosphorus. Using unfiltered samples, biochemical oxygen demand (BOD_5) was also analyzed.

3.3 Analyses of Samples

All analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Ammonia-nitrogen was determined using the phenate method (4500-NH_3 D). Ammonia-nitrogen was analyzed only after August 26, 1994.

Soluble reactive phosphorus concentrations were determined using the ascorbic acid method (4500-P E). Total phosphorus concentrations were measured using preliminary digestion by the persulfate method (4500-P B.5). Nitrate-nitrogen was measured using the cadmium reduction method (4500-NO_3^- E). Dissolved oxygen measurements for the biochemical oxygen demand (BOD_5) analyses were performed using the azide modification of Winkler (Iodometric) method (4500-O C). The suspended solids (SS) analyses were performed by filtering a known volume of original sample through a Fisher G4 glass fiber filter (effective pore size approximately 1.2 μm) and drying for at least one hour at 103^0C (2540 D) (APHA, 1992).

3.4 Analyses of Monitoring Data from Boardman WWTP

Boardman Wastewater Treatment Plant is the primary point source to Mill Creek Watershed and it brings a large nutrient loading through its effluent to Lake Newport. Statistical analyses on 1993 Boardman Wastewater Treatment Plant NPDES monitoring data were performed. Monthly means and standard deviations for several parameters (total phosphorus, ammonia nitrogen and nitrite and nitrate nitrogen) in the plant effluent were determined through tabulation using spreadsheets (Microsoft Excel version 5). Plots of these data were also developed using Microsoft Excel version 5. The average phosphorus loading was calculated from the product of flow and mean concentration. This was used as the point source loading entering the Lake Newport and this was combined with the nonpoint source loading estimate in order to obtain the total phosphorus loading (calculations are shown in Chapter IV).

3.5 Application of Trophic Status Models

The models examined are primarily empirical models or simple deterministic models that require determination of only a few parameters. Phosphorus is considered as the limiting nutrient. A "desk method" for predicting the capacity of the lake for the development outlined by Dillon and Rigler (1975) was used. A simplified "one box" deterministic model for predicting steady state phosphorus concentration in lakes derived by Vollenweider (1976) to include the effects of hydraulic flushing on lake trophic status along with a plot of areal phosphorus loading rate to a lake versus overflow rate presented by Vollenweider (1975) were also examined. These models are discussed in Chapter II and the calculations performed are shown in Chapter IV.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Results of Water Quality Monitoring

4.1.1 Field monitoring program:

All the results of the chemical analyses performed on the field samples in 1994 are shown in Tables 4-1 to 4-9. It was observed from the summarized results in Table 4-9 that the water quality downstream of the Boardman WWTP (station # 3) is severely degraded as evidenced by low levels of dissolved oxygen (DO), high ammonia-nitrogen and high BOD_5 concentrations. The trend in DO concentrations (from monitoring data, 1994) followed a typical sag profile by declining to a minimum value (6.87 mg/l) at station # 3, 1.8 miles downstream from Boardman WWTP. Values throughout the remainder of the study area averaged over 8 mg/l, except at station # 8 (mouth of Mill Creek). BOD_5 values downstream from Boardman WWTP were higher than upstream and remained elevated up to station # 8 (mouth of Mill Creek). The values exceeded 3 mg/l and went up to 4.7 mg/l.

High ammonia-nitrogen concentrations occurred downstream from Boardman WWTP with a maximum value of 1.09 mg/l (station # 3). Values declined downstream (station # 8) with mean concentrations greater than 0.135 mg/l. Nitrate-nitrogen (NO_3-N) values were highest at station # 3 (downstream of Boardman WWTP) with a maximum value of 1.39 mg/l. Anderson's Run (station # 6) also shows a high average value of more than 1 mg/l. Total phosphorus (TP) concentration at station # 3 again reflected inputs from Boardman WWTP and had an average value of 1.2 mg/l. Mean TP concentrations decreased to less than 0.3 mg/l at the mouth of Mill Creek. High soluble reactive phosphorus (SRP) concentrations also occurred downstream of the Boardman WWTP (station # 3), and decreased to less than 0.13 mg/l.

Table 4-1

Results of Analyses Performed on Samples Collected at Western Reserve Road (Station 1)

Date	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	12.12	29.60	0.16	0.07		1.13					
8/1/94	2.24	32.00	0.16	0.04		0.47		2.45			
8/8/94	3.65	16.40	0.11	0.03	0.09	0.77		1.25			
9/1/94	4.31	25.40	0.14	0.02	0.08	1.52		1.00			
9/12/94	4.49	57.05	0.26	0.03	0.17	0.66		3.95			
9/27/94	8.90	39.60	0.16	0.02	0.14	1.07		1.65		7.17	23.00
10/4/94	6.26	14.40	0.05	0.01	0.07	0.34	8.80	0.48	11.00	7.55	11.00
10/11/94	6.52	12.80	0.08	0.01	0.17	0.39	9.35	0.00	8.50	7.67	13.50
10/18/94	6.80	3.00	0.03	0.02	0.00	0.03	8.30	0.00	9.25	7.45	2.80
Average	**6.14**	**25.58**	**0.13**	**0.03**	**0.10**	**0.71**	**8.82**	**1.35**	**9.58**	**7.46**	**12.58**
SD	**2.82**	**15.37**	**0.06**	**0.02**	**0.06**	**0.44**	**0.43**	**1.25**	**1.05**	**0.18**	**7.20**

Table 4-2

Results of Analyses Performed on Samples Collected at Indian Run @ 224 (Station 2)

Date	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	2.20	18.60	0.08	0.07		0.51					
8/1/94	0.80	18.00	0.07	0.01		0.26		0.45			
8/8/94	3.60	10.80	0.06	0.02	0.04	1.18		0.60			
9/1/94	2.38	6.40	0.04	0.01	0.03	0.39		0.60			
9/12/94	2.38	9.00	0.04	0.01	0.06	0.19		1.40			
9/27/94	2.52	26.00	0.12	0.03	0.04	0.56		1.45		7.77	34.00
10/4/94	2.46	3.00	0.04	0.01	0.03	0.15	9.40	0.00	9.00	7.85	4.00
10/11/94	2.80	1.60	0.03	0.01	0.41	0.02	10.20	0.00	7.50	7.56	3.50
10/18/94	2.80	2.20	0.03	0.02	0.00	0.03	8.70	0.70	9.00	7.40	2.90
Average	**2.44**	**10.62**	**0.06**	**0.02**	**0.09**	**0.36**	**9.43**	**0.65**	**8.50**	**7.65**	**11.10**
SD	**0.70**	**8.07**	**0.03**	**0.02**	**0.13**	**0.34**	**0.61**	**0.51**	**0.71**	**0.18**	**13.23**

Table 4-3

Results of Analyses Performed on Samples Collected at Mill Creek @ 224 (Station 3)

Date	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	21.80	4.20	1.37	1.09		0.38					
8/1/94	11.10	5.10	1.20	1.10		0.66		0.80			
8/8/94	19.40	15.40	1.24	0.64	1.05	1.55		3.60			
9/1/94	20.50	39.40	1.90	1.26	1.54	0.65		7.70			
9/12/94	20.12	32.67	0.77	0.34	2.49	1.54		5.25			
9/27/94	28.25	79.80	0.82	0.11	0.46	1.21		5.40		7.24	49.00
10/4/94	21.69	20.20	2.10	1.79	0.76	0.96	7.10	1.71	11.00	7.47	18.00
10/11/94	19.74	20.20	0.73	0.54	0.73	2.71	7.50	1.66	9.50	7.40	18.50
10/18/94	19.74	22.20	0.69	0.48	0.61	2.85	6.00	3.55	11.25	7.60	14.00
Average	20.26	26.57	1.20	0.82	1.09	1.39	6.87	3.71	10.58	7.43	24.88
SD	4.13	21.66	0.49	0.50	0.66	0.83	0.63	2.18	0.77	0.13	14.04

Table 4-4

Results of Analyses Performed on Samples Collected at Cranberry Run (Station 4)

Date	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	0.77	1.60	0.12	0.08		0.68					
8/1/94	0.31	1.00	0.03	0.02		0.11		0.25			
8/8/94	0.40	0.40	0.05	0.04	0.06	0.30		0.00			
9/1/94	0.31	0.20	0.08	0.06	0.10	0.63		0.40			
9/12/94	0.17	2.20	0.04	0.03	0.17	0.36		1.70			
9/27/94	9.01	108.00	0.26	0.04	0.05	0.87		0.30		7.77	90.00
10/4/94	0.33	4.40	0.06	0.03	0.03	0.75	9.20	0.28	9.00	7.90	9.00
10/11/94	0.19	0.40	0.04	0.03	0.04	0.35	10.00	0.33	7.00	7.83	1.40
10/18/94	0.27	0.40	0.03	0.02	0.02	0.41	9.80	0.00	8.10	7.89	1.40
Average	**1.31**	**13.18**	**0.08**	**0.04**	**0.07**	**0.49**	**9.67**	**0.41**	**8.03**	**7.85**	**25.45**
SD	**2.73**	**33.55**	**0.07**	**0.02**	**0.05**	**0.23**	**0.34**	**0.51**	**0.82**	**0.05**	**37.40**

Table 4-5

Results of Analyses Performed on Samples Collected at Mill Creek at Lake Newport (Station 5)

Date	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	10.40	1.09	1.06		0.86					
8/1/94	25.33	1.55	1.10		0.34		6.35			
8/8/94	28.80	0.60	0.44	0.70	1.05		1.95			
9/1/94	20.00	1.06	0.63	1.57	1.06		5.35			
9/12/94	20.40	0.79	0.50	2.40	1.18		6.15			
9/27/94	59.00	0.51	0.09	0.28	1.23		1.00		7.35	47.00
10/4/94	16.60	0.59	0.40	0.21	2.07	8.50	0.45	10.00	7.69	16.00
10/11/94	12.20	0.45	0.27	0.75	0.39	8.75	1.81	8.25	7.58	14.50
10/18/94	11.00	0.37	0.63	0.38	0.91	7.70	1.05	9.80	7.58	11.00
Average	**22.64**	**0.78**	**0.57**	**0.90**	**1.01**	**8.32**	**3.01**	**9.35**	**7.55**	**22.13**
SD	**14.18**	**0.36**	**0.32**	**0.75**	**0.48**	**0.45**	**2.33**	**0.78**	**0.12**	**14.48**

Table 4-6

Results of Analyses Performed on Samples Collected at Anderson Run (Station 6)

Date	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94	1.75	15.60	0.37	0.31		0.89					
8/1/94	0.20	21.35	0.21	0.16		0.19		0.00			
8/8/94	2.10	11.80	0.15	0.12	0.70	1.05		0.50			
9/1/94	3.57	17.40	0.23	0.21	0.10	0.94		1.00			
9/12/94	2.09	21.60	0.19	0.10	0.13	0.96		1.00			
9/27/94	6.01	23.80	0.19	0.10	0.04	1.18		0.45		7.58	33.00
10/4/94	3.57	17.20	0.15	0.09	0.09	1.94	8.70	0.43	9.00	7.70	12.00
10/11/94	2.09	5.00	0.14	0.09	0.04	0.93	9.25	0.00	7.25	7.80	7.00
10/18/94	3.07	3.00	0.14	0.09	0.01	1.27	8.60	0.00	8.50	7.75	4.80
Average	2.72	15.19	0.20	0.14	0.16	1.04	8.85	0.42	8.25	7.71	14.20
SD	1.52	6.88	0.07	0.07	0.22	0.43	0.29	0.39	0.74	0.08	11.16

Table 4-7

Result of Analyses Performed on Samples Collected at Down Stream of L.Newport (Station 7)

Date	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94										
8/1/94	29.00	1.22	0.64		0.24		7.25			
8/8/94	13.20	0.30	0.25	0.16	0.62		7.10			
9/1/94	6.00	0.41	0.26	0.36	0.52		2.95			
9/12/94	11.43	0.61	0.42	0.71	0.94		5.40			
9/27/94	21.60	0.49	0.30	0.22	0.97		3.15		7.70	28.00
10/4/94	13.80	0.29	0.14	0.35	1.29	9.30	1.05	13.50	7.79	13.00
10/11/94	5.00	0.24	0.12	0.14	0.90	9.60	1.40	12.50	7.82	4.40
10/18/94	7.40	0.20	0.04	0.07	0.27	9.10	9.35	12.20	8.84	5.20
Average	13.43	0.47	0.27	0.29	0.72	9.33	4.71	12.73	8.04	12.65
SD	7.71	0.31	0.18	0.20	0.35	0.21	2.83	0.56	0.47	9.48

Table 4-8

Results of Analyses Performed Collected at Mill Creek at Mahoning River (Station 8)

Date	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
7/3/94										
8/1/94	9.20	0.35	0.22		0.26		2.30			
8/8/94	14.40	0.35	0.16	0.15	0.61		8.90			
9/1/94	10.80	0.24	0.11	0.24	0.87		4.45			
9/12/94	16.60	0.23	0.07	0.14	0.22		5.85			
9/27/94	18.25	0.44	0.25	0.16	0.89		4.25		7.98	16.00
10/4/94	16.60	0.26	0.14	0.13	1.24	9.10	1.41	13.50	8.00	17.00
10/11/94	11.60	0.17	0.06	0.04	0.79	9.00	2.61	12.00	8.15	8.90
10/18/94	7.80	0.14	0.02	0.08	0.11	9.60	5.00	12.30	8.77	6.20
Average	13.16	0.27	0.13	0.13	0.63	9.23	4.35	12.60	8.23	12.03
SD	3.60	0.09	0.07	0.06	0.37	0.26	2.22	0.65	0.32	4.59

Table 4-9

Averages and Standard Deviations of Field Data

Station #	River mile	Flow (ft^3/s)	S.S (mg/l)	T.P (mg/l)	SRP (mg/l)	NH_3-N (mg/l)	NO_3-N (mg/l)	D.O (mg/l)	BOD_5 (mg/l)	Temp (°C)	pH	Turbidity (NTU)
1	11.40	6.14	25.58	0.13	0.03	0.10	0.71	8.82	1.35	9.58	7.46	12.58
		(2.82)	(15.37)	(0.06)	(0.02)	(0.06)	(0.44)	(0.43)	(1.25)	(1.05)	(0.18)	(7.20)
2	7.70	2.44	10.62	0.06	0.02	0.09	0.36	9.43	0.65	8.50	7.65	11.10
		(0.70)	(8.07)	(0.03)	(0.02)	(0.13)	(0.34)	(0.61)	(0.51)	(0.71)	(0.18)	(13.23)
3	7.80	20.26	26.57	1.20	0.82	1.09	1.39	6.87	3.71	10.58	7.43	24.88
		(4.13)	(21.66)	(0.49)	(0.50)	(0.66)	(0.83)	(0.63)	(2.18)	(0.77)	(0.13)	(14.04)
4	5.47	1.31	13.18	0.08	0.04	0.07	0.50	9.67	0.41	6.03	7.85	25.45
		(2.73)	(33.55)	(0.07)	(0.02)	(0.05)	(0.23)	(0.34)	(0.51)	(0.82)	(0.05)	(37.40)
5	5.25		22.64	0.78	0.57	0.90	1.01	8.32	3.01	9.35	7.55	22.13
			(14.18)	(0.36)	(0.32)	(0.75)	(0.48)	(0.45)	(2.33)	(0.78)	(0.12)	(14.48)
6	5.30	2.72	15.19	0.20	0.14	0.16	1.04	8.85	0.42	8.25	7.71	14.20
		(1.52)	(6.88)	(0.07)	(0.07)	(0.22)	(0.43)	(0.29)	(0.39)	(0.74)	(0.08)	(11.16)
7	3.80		13.43	0.47	0.27	0.29	0.72	9.33	4.71	9.55	8.04	12.65
			(7.71)	(0.31)	(0.18)	(0.20)	(0.35)	(0.21)	(2.83)	(0.56)	(0.47)	(9.48)
8	0.10		13.16	0.27	0.13	0.13	0.63	6.93	4.35	12.60	8.23	12.03
			(3.60)	(0.09)	(0.07)	(0.06)	(0.37)	(0.26)	(2.22)	(0.65)	(0.32)	(4.59)

Values in ( ) indicate standard deviations

4.1.2 NPDES monitoring data:

A statistical analysis was done on 1993 NPDES monitoring data obtained from Boardman Waste Water Treatment Plant. Monthly means and standard deviations for several parameters (total phosphorus, ammonia-nitrogen, nitrite and nitrate nitrogen) from plant effluent were determined through tabulation using spreadsheets (Microsoft Excel version 5) and are shown in Appendix A. Plots of these mean monthly data were developed using Microsoft Excel version 5 and are also shown in Appendix A. The average phosphorus loading (kg/d) was calculated from the product of flow (ft^3/sec) and mean concentration (mg/l). This was used as a point source phosphorus loading entering Lake Newport. The estimated average total phosphorus loading was 32.73 kg/d (Table A-13). Pie charts were developed on the basis of point source and nonpoint source contributions of phosphorus to the lake (Figure 4-3, section 4.3.7.2).

4.2 Hydrologic Budget for Lake Newport

A hydrologic budget for Lake Newport was developed with the following objectives:

1. It was desired that the budget serve as a summary of all of the hydrologic data collected for Lake Newport.
2. It was desired that the budget serve as the preliminary step to calculate the total phosphorus concentration (using a model) in order to predict the trophic status of Lake Newport.

4.2.1 Hydrologic Outflows :

The outflows considered are an average spillway overflow of 58 ft^3/s (from U.S.G.S. 1944 to 1971 monitoring data measured below Lake Newport) and an additional 12 ft^3/s to account for increases in Boardman Waste Water Treatment Plant discharges and runoff due to urbanization between 1971 to 1993.

$$\text{Average } Q_{out} = 70 \text{ ft}^3/\text{s} = 6.25 \times 10^7 \text{ m}^3/\text{yr}$$

4.2.2 Direct Precipitation:

An estimate of average annual net precipitation is taken from NOAA data (The Vindicator, January 19, 1995). The direct precipitation is calculated as follows and is expressed in m/yr.

Mean annual rainfall = 37 in/yr

= 0.9398 m/yr

Lake surface area = 77.4 acres

= 3.13×10^5 m^2

Direct Precipitation = Mean annual rainfall x Lake surface area

2.94×10^5 m^3/yr

4.2.3 Direct Runoff and Evaporation:

Direct Runoff areas to Lake Newport were delineated by MRB-HER (1994) from the USGS 7.5 minute series quadrangles (1: 24,000). Based on these maps the watershed areas dedicated to various land uses were identified and calculated by using a planimeter.

Runoff coefficients were taken from Viessman, et al, 1989. Direct runoff is then calculated as follows:

Runoff Coefficients:

Urban = 0.31 (C_1)

Rural = 0.20 (C_2)

Direct runoff areas to Lake Newport:

Urban = $336.38 \times 10^4 \text{ m}^2$ (A_1)

Rural = $150.04 \times 10^4 \text{ m}^2$ (A_2)

Direct Runoff from watershed = Rainfall x $(C_1 A_1 + C_2 A_2)$

= $1.262 \times 10^6 \text{ m}^3/\text{yr}$

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

= 0.787 m/yr

Loss due to evaporation = evaporation x lake surface area

= $0.787 \text{ m/yr.} \times 3.13 \times 10^5 \text{ m}^2$

= $2.46 \times 10^5 \text{ m}^3/\text{yr}$

4.2.4 Hydrologic inflow Q_{in}:

The hydrologic inflow in this budget was calculated based on estimates of all other including flows, precipitation directly on the lake surface, evaporation from the surface of the lake, hydrologic outflow and also direct runoff. The inflow was calculated as follows:

Mill Creek inflow (Q_{in}) = [Total outflow + Evaporation - Direct precipitation - Direct runoff]

$$= [(6.25 \times 10^7) + (2.46 \times 10^5) - (2.94 \times 10^5) - (1.262 \times 10^6)]$$

$$= 6.126 \times 10^7 \ m^3/yr.$$

The hydrologic budget for Lake Newport is summarized in Figure 4-1.

4.3 Application of Dillon and Rigler's (1975) Model

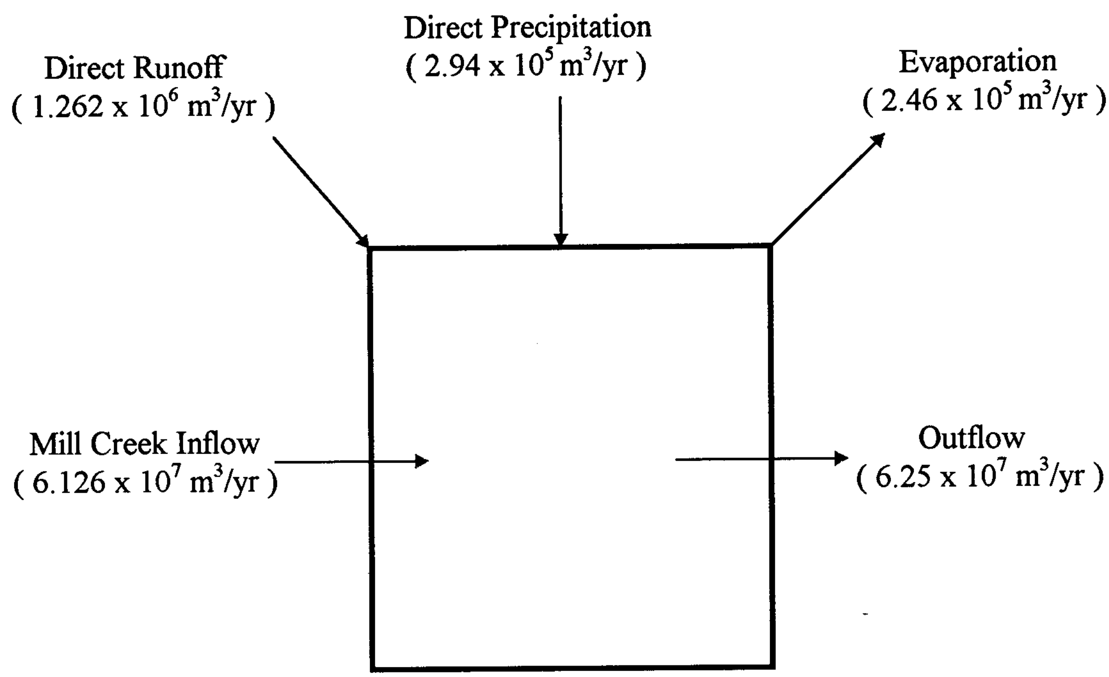
Dillon and Rigler (1975) developed a simple procedure to estimate the trophic status of lakes. This provides useful information on hydrology, phosphorus loading, and predicted water quality (concentration of phosphorus). The step-by-step procedure was applied to Lake Newport. The hydrologic budget developed for Lake Newport was used in applying the Dillon and Rigler procedure.

4.3.1 Lake morphometry:

Several parameters describing the morphometry of the lake were calculated in this study. Using a planimeter and contour map of the lake bed, the areas were calculated by MRB-HER (1993). The area versus depth data and graph are shown in Table 4-10 and Figure 4-2 respectively. A number of important hydrologic and morphometric parameters for Lake Newport are summarized in Table 4-11. Details of these calculations are presented in this section. These values are listed together in Table 4-11 in order to give the reader a feel for the physical characteristics of Lake Newport.

4.3.1.1 Lake surface area (A_S, m^2):

$$A_S = 77.4 \text{ acres} = 3.13 \times 10^5 \ m^2$$



<u>Figure 4-1:</u> Hydrologic Budget for Lake Newport

Table 4.10

Lake Newport Area-Depth Data

Depth metres	Area acres	Area sq.mt
0.00	77.40	3.13×10^5
0.61	54.80	2.21×10^5
0.91	48.50	1.96×10^5
1.22	41.90	1.69×10^5
1.83	23.00	0.93×10^5
2.44	12.30	0.49×10^5
4.27	0.00	0.00

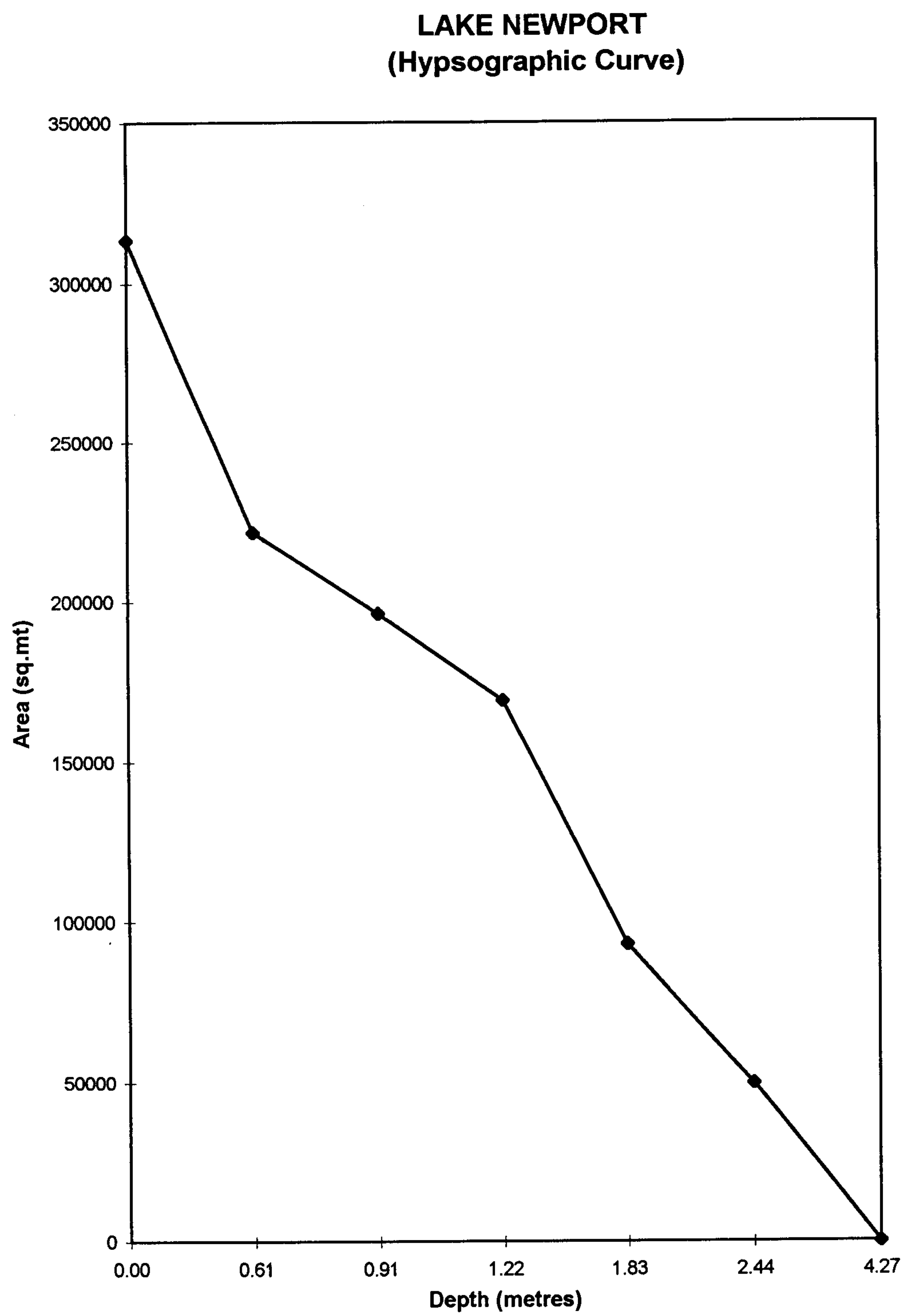


Figure 4-2: Area-Depth Curve for Lake Newport

Table 4-11

Lake Newport Morphometry and Hydrology	
Lake Volume (V)	4.37×10^5 m^3
Lake Surface Area (A_s)	$3.13 \times 10^5 m^2$
Lake Drainage Area (A_d)	1.9127×10^8 m^2
Mean Depth (Z)	1.397 m
Inflow (Mill Creek) (Q_{in})	6.126×10^7 m^3/yr
Outflow (spillway) (Q_{out})	6.25×10^7 m^3/yr
Hydraulic Detention Time	V/Q_{out} = 0.0071 yr (2.61 days)
Flushing Rate	140 yr^{-1}
Latitude	41°03'
Longitude	80°40'

4.3.1.2 Total volume of the lake (V, m^3):

The lake's volume was estimated by plotting the area-depth curve from the surface to the point of maximum depth, and finding the area under this curve by planimeter to calculate its volume.

$$V = 355 \text{ acre-ft}$$
$$= 4.37 \times 10^5 \text{ m}^2$$

4.3.1.3 Mean depth ($\overline{Z}$, m)

$$\overline{Z} = \frac{\text{Lake Volume}}{\text{Surface area of the lake}}$$

$$= \frac{4.37 \times 10^5 \text{ m}^3}{3.13 \times 10^5 \text{ m}^2}$$

$$= 1.397 \text{ m}$$

4.3.2 Watershed area A_d (Lake Newport):

The Lake Newport drainage basin includes all the areas drained by Mill Creek between its headwaters in Columbiana County and at the point where it enters Lake Newport (MRB-HER, 1994). USGS 7.5 minute series topographic maps (1984) were used to delineate different land usage within the watershed and corresponding areas (urban and rural) were estimated using a planimeter. The total area was found to be 47,267 acres = 1.9127×10^8 m^2. The underlying geology of the region is of sedimentary origin. The watershed areas dedicated to various land uses were estimated as follows:

Pasture = 40121.5 acres = 1.624×10^8 m^2

Urban = 7145.23 acres = $2.892 \times 10^7 m^2$

4.3.3 Flushing rate and hydraulic detention time:

The flushing rate (ρ) was calculated by dividing the total flow by the total volume of the lake.

$$\rho = \frac{Q}{V} = \frac{6.126 \times 10^7 m / yr}{4.37 \times 10^5 \ m^3} = 140 / yr$$

Hydraulic detention time is the inverse of the flushing rate.

$$\tau_w = \frac{1}{\rho} = \frac{V}{Q}$$

$$= \frac{1}{140 \ yr} = 0.0071 \ yr = 2.61 \ days$$

4.3.4 Estimation of areal water loading (q_s):

The areal water loading (q_s) is calculated by dividing annual total inflow by lake surface area. Therefore, the areal water loading is

$$q_s = \frac{Q}{A_s} = \frac{\text{annual total inflow}}{\text{lake surface area}}$$

$$= \frac{6.126 \times 10^7 \ m^3 / yr}{3.13 \times 10^5 \ m^2}$$

$$= 195.72 \ m/yr$$

4.3.5 Phosphorus retention coefficient (R_p):

Using the Kirchner and Dillon (1975) equation, the phosphorus retention coefficient was calculated as follows:

$$R_1 = 0.426 \exp(-0.271\ q_S) + 0.574 \exp(-0.00949\ q_S) = 0.0896$$

Alternately, by using Reckhow and Chapra (1982), the phosphorus retention coefficient was calculated as follows:

$$R_2 = -0.4088 \exp(-0.2899\ q_S) + 0.5912 \exp(-0.01019\ q_S) = 0.0805$$

4.3.6 Response time:

Response time is a measure of the time for a lake to respond to a change in phosphorus loading. The time calculated for Lake Newport was

$$\text{Response time} = \frac{5\ (0.69)}{\rho + 10/\overline{Z}} = 0.0234\ \text{yr}$$

where,

ρ = flushing rate, yr^{-1}

$\overline{Z}$ = lake mean depth, m

Predicted response time to a change in loading is short. This is a good argument for the validity of a steady state model.

4.3.7 Estimation of areal phosphorus loading (L):

Every watershed has a unique pattern of land use within its boundaries and each use makes a unique contribution, by way of diffuse (nonpoint) sources, to the phosphorus loading of a lake. The selection of appropriate phosphorus export coefficients is difficult.

Here in this study, coefficients from Dillon and Kirchner (1975) were used. Areal phosphorus loading (L, $kg/m^2/yr$) is expressed as total mass loading per unit lake surface area.

$$L = J_{tot} / A_S$$

where J_{tot} = Total annual phosphorus loading to lake, kg/yr

The total annual mass loading of phosphorus to a lake is estimated by summing the annual phosphorus contribution from each of the non-point sources plus any additional point source input within the watershed.

4.3.7.1 Phosphorus transport from non-point sources (J_{NPS}):

The total non-point source loading to Lake Newport is the sum of the phosphorus transport from the watershed (J_{WS}) and the phosphorus loading due to atmospheric precipitation (J_{PR}). The area of the watershed, not including the lake is $A_d = 1.9127 \times 10^8$ m^2. The phosphorus export coefficient is estimated from Dillon and Kirchner (1975) as follows, depending on the land use.

Urban land phosphorus export coefficient = 200 $mg/m^2/yr$

Pasture land phosphorus export coefficient = 23.3 $mg/m^2/yr$

Then the total annual phosphorus loading from the watershed runoff was estimated as follows:

$$J_{WS} = [\text{Drainage Area} \times \text{Export Coefficient}]_{urban} + [\text{Drainage Area} \times \text{Export Coefficient}]_{pasture}$$

$$= [(28.915 \times 10^6\ m^2) \times (200 \times 10^{-6}\ kg/m^2/yr)] + [(162.363 \times 10^6\ m^2) \times (23.30 \times 10^{-6}\ kg/m^2/yr)] = 9567.0\ kg/yr$$

The total annual phosphorus loading due to atmospheric precipitation on the lake was estimated as follows:

$$J_{PR} = 75\ A_S/10^6$$

$$= 23.5 \text{ kg/yr}$$

Therefore, the total annual phosphorus loading due to non-point sources was estimated as

$$J_{NPS} = J_{WS} + J_{PR}$$

$$= 9567.0 \text{ kg/yr} + 23.5 \text{ kg/yr} = 9590.5 \text{ kg/yr}$$

To check this estimate, a second calculation was performed using the 1994 monitoring data from this study. The approach taken was to first calculate a drainage area-weighted mean TP concentration in runoff:

$$[TP]_A = \frac{[TP]_1 A_1 + [TP]_2 A_2 + [TP]_4 A_4 + [TP]_6 A_6}{A_1 + A_2 + A_4 + A_6}$$

$$= \frac{[(0.13)(28.78) + (0.056)(17.64) + (0.078)(5.11) + (0.197)(7.0)]}{[28.78 + 17.64 + 5.11 + 7.0]}$$

$$= 0.111 \text{ mg/l}$$

where, $[TP]_1$ = mean total phosphorus concentration at station # 1, mg/l

A_1 = watershed area of station # 1, sq.miles

$[TP]_2$ = mean total phosphorus concentration at station # 2, mg/l

A_2 = watershed area of station # 2, sq.miles

$[TP]_4$ = mean total phosphorus concentration at station # 4, mg/l

A_4 = watershed area of station # 4, sq.miles

$[TP]_6$ = mean total phosphorus concentration at station # 6, mg/l

A_6 = watershed area of station # 6, sq.miles

This was then multiplied by the estimated total inflow to Lake Newport (70 ft^3/s including direct runoff).

$$J_{NPS} \text{ (area-weighed)} = Q_{out} \times [TP]_A \times 2.447$$

$$= (70\ ft^3/s)\ (0.111\ mg/l)\ (2.447)$$

$$= 19.035\ kg/d = 6{,}948\ kg/yr$$

The predicted total nonpoint source loading obtained by using Dillon and Rigler's (1975) equation was 9590.5 kg/yr and by using the area-weighted mean total phosphorus concentration in runoff was 6948 kg/yr. The area-weighted nonpoint loading estimate is 27.5% less than that predicted by Dillon and Rigler's method. However, the monitoring data used is based mostly on low flow conditions. Since total phosphorus generally increases with flow, including high flow samples would give a higher nonpoint loading estimate based on monitoring data. The first value (9590.5 kg/yr) was used in the subsequent calculations.

4.3.7.2 Phosphorus loading from point source (J_{PS}):

Lake Newport has a major point source contribution of phosphorus from the Boardman Waste Water Treatment Plant (WWTP). The annual total phosphorus contribution to the lake from this point source was estimated by performing stastitical analyses on the 1993 NPDES monitoring data obtained from the WWTP records (see Table B-13). The total phosphorus loading was estimated as follows:

$$J_{PS} = 32.73\ kg/d = 11946.1\ kg/yr$$

The total annual phosphorus loading (J_{tot}) was calculated as the sum of point source (J_{PS}) and the non-point source (J_{NPS}) loadings.

Using Dillon and Rigler (1975) for total nonpoint source loading (J_{NPS}), the total phosphorus loading was calculated as follows:

$$J_{tot} = J_{PS} + J_{NPS}$$

$$= 11946.1 \text{ kg/yr} + 9590.5 \text{ kg/yr}$$

$$= 21536.6 \text{ kg/yr}$$

A pie chart showing the relative contributions of point and nonpoint loadings is shown in Figure 4-3 (A). The contributions based on the drainage area-weighted nonpoint loading estimate is shown in Figure 4-3 (B) for comparison.

The total areal phosphorus loading (L) was estimated to be

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

$$= \frac{21{,}536.6 \text{ kg / yr}}{3.13 \times 10^5 \text{ m}^2}$$

$$= 0.06880 \text{ kg/m}^2\text{/yr}$$

$$= 68{,}880 \text{ mg/m}^2\text{/yr}$$

By using area-weighted total phosphorus concentration in runoff (nonpoint source), the total phosphorus loading was calculated as follows:

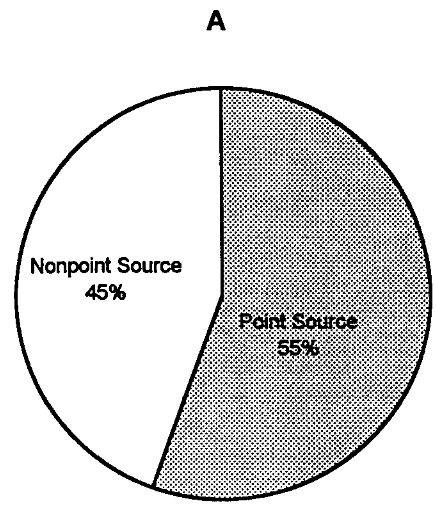
$$J_{tot} = J_{PS} + J_{NPS}\text{(area-weighted)}$$

$$= 11{,}946 \text{ kg/yr} + 6{,}948 \text{ kg/yr}$$

$$= 18{,}894 \text{ kg/yr}$$

The total areal phosphorus loading (L) was estimated to be

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



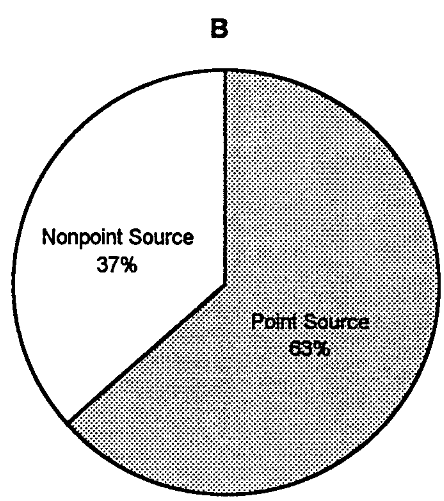


Figure 4-3: (A) Total Phosphorus Contribution of Point and Nonpoint Sources (Dillon and Rigler, 1975) to Lake Newport. (B) Total Phosphorus Contribution of Point and Nonpoint Sources (Monitoring Data, 1994) to Lake Newport.

$$= \frac{18{,}894 \text{ kg / yr}}{3.13 \times 10^5 \text{ m}^2}$$

$$= 0.0603 \text{ kg/m}^2\text{/yr}$$

$$= 60{,}300 \text{ mg/m}^2\text{/yr}$$

The first estimate of L was used in subsequent calculations.

4.3.8 Predicted water quality:

Predicted concentration of total phosphorus was calculated using the Dillon and Rigler (1974) equation (2-7).

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

Using the Kirchner and Dillon (1975) for R:

$$[TP]_1 = \frac{L(1-R_1)}{\bar{Z}\rho}$$

$$= \frac{(68880 \text{ mg / m}^2 \text{ / yr})(1-0.0896)}{(1.397 \text{ m})(140 \text{ yr}^{-1})}$$

$$= 321 \text{ mg/m}^3 = 0.321 \text{ mg/l}$$

Alternately, using Reckhow and Chapra's (1982) equation for R:

$$[TP]_2 = \frac{L(1-R_2)}{\bar{Z}\rho}$$

$$= \frac{(68880 \text{ mg / m}^2 \text{ / yr})(1-0.0805)}{(1.397 \text{ m})(140 \text{ yr}^{-1})}$$

$$= 324 \text{ mg/m}^3 = 0.324 \text{ mg/l}$$

Also, using Vollenweider's (1976) equation (2-11) predicted total phosphorus concentration was estimated as follows:

$$[TP] = \frac{L\,\tau_w}{\overline{Z}\,(1 + \sqrt{\tau_w})}$$

$$= \frac{(68880\ \text{mg}/\text{m}^2/\text{yr})\ (0.0071\ \text{yr})}{(1.397\ \text{m})\ (1 + \sqrt{0.0071}\ \text{yr})}$$

$$= 323\ \text{mg/m}^3 = 0.323\ \text{mg/l}$$

The estimated total phosphorus concentration obtained by using the Kirchner and Dillon (1975) equation for R was 321 mg/m^3 (μg/l) and by using Reckhow and Chapra's (1982) equation for R was 324 mg/m^3 (μg/l). Using Vollenweider's equation the estimated total phosphorus concentration obtained was 323 mg/m^3. There is good agreement between these three equations. The total phosphorus concentration obtained from the field data at Lake Newport outlet was 0.47 mg/l, or 470 mg/m^3 (μg/l) (Station # 7, Table 4-9). This is 46% higher than the predicted value, but is based on limited data. Based on these estimates, the water quality of Lake Newport was determined to be in a hypereutrophic condition.

4.4 Application of Vollenweider (1975) Plot to Lake Newport

The phosphorus loading rate versus overflow rate plot developed by Vollenweider (1975) was applied for Lake Newport as shown in Figure 4-4. Vollenweider was able to identify regions corresponding to each trophic state classification. The trophic status of a lake can be estimated by finding its plotting position on the axes and comparing this position to the region boundaries.

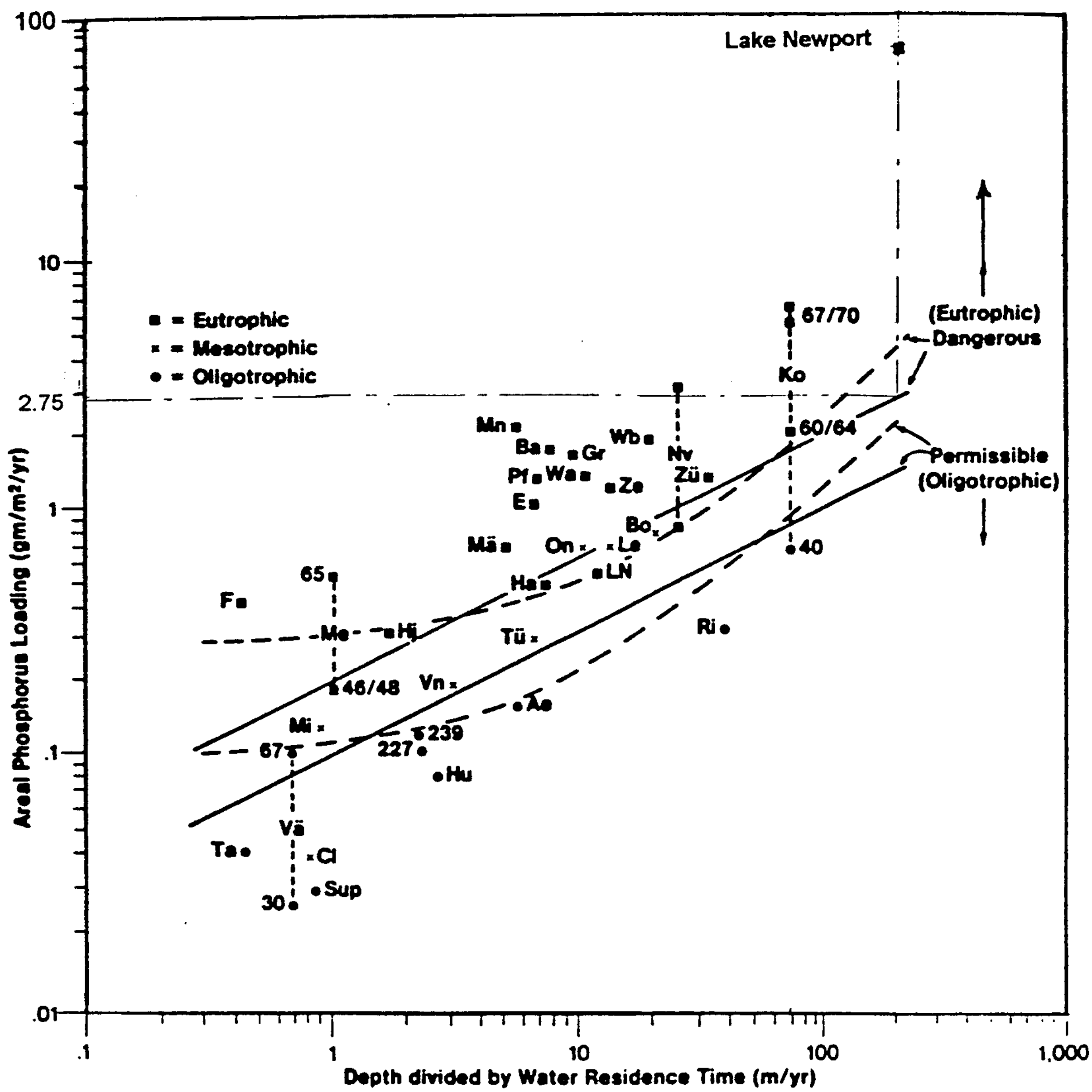


Figure 4-4: Lake Newport Trophic Status Prediction Using Vollenweider's (1975) Loading Plot

For Lake Newport:

$$\frac{\bar{Z}}{\tau_w} = \frac{1.397 \text{ m}}{0.0071 \text{ yr}} = 195.6 \text{ m / yr}$$

$$L = 68.77 \text{ g/m}^2\text{/yr}$$

From Vollenweider's (1975) plot it was again estimated that Lake Newport is in hypereutrophic condition. In order to bring the lake to mesotrophic status the annual areal phosphorus loading rate (L) should be reduced from 68.77 $g/m^2/yr$ to 2.75 g $/m^2/yr$ (Figure 4-4) or less, a reduction of 96%.

4.5 Potential for Water Quality Improvements

The nutrient loading and overflow rate relationship developed by Vollenweider (1974) and the equation of Dillon and Rigler (1975) were used to assess lake trophic status and predict changes in water quality resulting from changes in nutrient point source inputs. Table 4-12 was developed to estimate the changes in water quality by reducing the point source inputs by 50%, 75%, 90% and 100%. The corresponding areal phosphorus loading and total phosphorus concentrations were estimated. The predicted concentration of total phosphorus with 100% reduction in the point source was 142.53 mg/m^3 (μg/l). Even if 100% of the point source loading were to be eliminated, the water quality of Lake Newport would still be in hypereutrophic condition. Therefore, in order to substantially improve the water quality not only the point source, but also the nonpoint source loading should be controlled. The ratio of watershed area to lake surface area for Lake Newport is 610:1. Since this ratio is very large, nutrient loadings from runoff (nonpoint source) are very significant.

TABLE 4-12

Predicted Changes in Water Quality of Lake Newport Following Reduction in Phosphorus Loading

Percentage reduction in Point Source	Areal phosphorus loading (L) ($mg/m^2/yr$)	Predicted Total phosphorus conc. (mg/m^3)
0%	68880	320.62
50%	49724	231.00
75%	40182	187.00
90%	34457	160.40
100%	30640	142.60

During the last few decades, the depth of the lake has been reduced due to sediment accumulation. It is possible that the lake sediments may be a significant source of phosphorus. Internal phosphorus loading is most probable in shallow lakes that possess anoxic bottom waters. Since Lake Newport is a shallow lake, internal phosphorus loading is possible.

Long-term improvements in shallow lakes like Lake Newport may often be better attained by macrophyte harvesting and/or dredging. Macrophyte harvesting would interrupt annual P cycling, and may even promote sediment P depletion by removing macrophytes which in turn removes P from sediments. In addition, the removal of macrophyte stands would reduce their nuisance aspects (Lynch, 1982). Since Lake Newport does not experience significant macrophyte growth, however, this approach may have limited impact. Dredging of sediment deposits would reduce the surficial sediment P content. Removal of sediment from the southern end of the lake would be anticipated to have several benefits:

- Remove a portion of the sediment phosphorus reservoir.
- Expose sediment of lower phosphorus content.
- Expose sediments of a higher degree of consolidation and stabilization, and
- Reduce the growth rate and biomass of aquatic macrophytes in the area dredged.

Converting lake shoreline areas into wetlands can also have beneficial effects. Wetlands can be used as natural treatment plants as they trap and store nutrients and sediments that might otherwise lower the water quality. Wetland plants take up nitrogenand phosphorus, reducing the nutrient input that can overfertilize a lake. Water flows through wetlands slowly, allowing time for sediment to settle out. Establishment of a well-functioning wetland at the southern end of Lake Newport could yield some of these benefits.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

- Water quality in Mill Creek downstream from the Boardman WWTP is significantly degraded as evidenced by low levels of dissolved oxygen (DO) and high concentrations of ammonia-nitrogen, nitrate-nitrogen, total phosphorus, soluble reactive phosphorus and BOD_5.
- The data obtained from NPDES monitoring of Boardman Wastewater Treatment Plant for 1993 was used to analyze the point source phosphorus loading to Lake Newport. The estimated phosphorus loading from this data was 32.74 kg/d or 11,946 kg/yr.
- The total nonpoint source phosphorus loading to Lake Newport was estimated to be 9590.5 kg/yr using Dillon and Rigler's (1975) "desk method". A second estimate of nonpoint loading was based on monitoring data, and a rate of 6948.0 kg/yr was obtained.
- The total annual phosphorus loading was estimated at 21,536.6 kg/yr and the total areal phosphorus loading at 68,880 $mg/m^2/yr$. Of the total estimated annual phosphorus loading, the point source contributes 55% and the nonpoint source contributes 45%.
- Dillon and Rigler's (1975) procedure was applied to predict the trophic status of Lake Newport. The total phosphorus concentration was predicted to be 320 mg/m^3 ($\mu g/l$). If 100% of the sewage effluent (point source) were to be eliminated, the total phosphorus concentration was predicted to decrease to 142 mg/m^3 ($\mu g/l$). Thus, the water quality of Lake Newport would still be in hypereutrophic condition. In order to improve the water quality of the lake further, nonpoint source loading should also be controlled.

- In the absence of sewage effluent (point source), runoff would become the major nutrient source, but internal loading might also contribute nutrient loading. Although a significant improvement in water quality could be expected, it is likely that nuisance algal blooms would continue to occur.
- Using the plot of total phosphorus loading rate versus overflow rate developed by Vollenweider (1975), the condition of Lake Newport was found to be in hypereutrophic state. In order to bring the lake to mesotrophic state, the total annual mass phosphorus loading (L) should be reduced from 68.76 $gm/m^2/yr$ to 2.75 $gm/m^2/yr$, a 96% decrease.
- To gain more insight into processes in Lake Newport, data collected in this study should be used to apply more detailed mechanistic models of lake trophic status. Sufficient monitoring strategies need to be employed to accurately assess the contribution of both point source and non-point source pollutants, as well as internal loadings.

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APPENDIX A

Data from Boardman Wastewater Treatment Plant NPDES Monitoring of Plant Effluent, 1993

Table A-1

Boardman Waste Water Treatment Plant Plant Effluent (January 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	3.98						
2	3.41						
3	3.62						
4	3.87	1.36	19.89	0.07	1.02	7.12	104.16
5	3.12	1.82	21.46	0.20	2.36	3.63	42.81
6	2.98	1.99	22.42	0.08	0.90	2.32	26.13
7	2.74			0.08	0.83	3.31	34.28
8	2.67			0.07	0.71	6.11	61.67
9	2.83						
10	2.41						
11	3.10			0.08	0.94	8.61	100.89
12	4.48	2.53	42.84	0.07	1.19	4.70	79.59
13	5.42	0.97	19.87	0.65	13.32	1.45	29.71
14	5.18			0.20	3.92	3.80	74.41
15	4.01			0.04	0.61	3.90	59.12
16	3.38						
17	3.00						
18	2.79						
19	2.63	1.75	17.40	0.04	0.40	5.90	58.65
20	3.72	1.44	20.25	0.13	1.83	5.30	74.53
21	5.72	1.44	31.14	0.00	0.00	4.32	93.41
22	6.11	0.35	8.08	0.00	0.00	3.22	74.37
23	5.48						
24	4.20						
25	3.74	0.27	3.82	0.13	1.84	6.00	84.82
26	3.01	1.27	14.45	0.06	0.68	6.00	68.27
27	2.87	2.33	25.28	0.09	0.98	4.11	44.59
28	2.63	1.28	12.72	0.11	1.09	5.30	52.69
29	2.95	1.73	19.29			4.02	44.83
30	2.43						
31	2.51						
Average	3.58	1.47	19.92	0.12	1.81	4.69	63.63
SD	1.03	0.62	9.17	0.14	2.93	1.66	22.63

Table A-2

Boardman Waste Water Treatment Plant Plant Effluent (February 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	2.95	0.81	9.03	0.10	1.12	9.40	104.82
2	3.07	2.03	23.56	0.12	1.39	7.31	84.83
3	2.62	2.62	25.95	0.69	6.83	4.56	45.16
4	3.11	1.28	15.05	1.07	12.58	2.74	32.21
5	3.04			1.24	14.25	3.41	39.18
6	3.24						
7	3.20						
8	3.61			1.75	23.88	5.85	79.83
9	3.23	1.57	19.17	1.32	16.12	2.46	30.04
10	2.89	1.52	16.60	2.39	26.11	1.75	19.12
11	3.78	0.40	5.72	2.31	33.01	2.65	37.86
12	3.50	1.20	15.88	2.46	32.55	1.74	23.02
13	3.85						
14	3.70						
15	3.95			1.32	19.71		
16	4.31	0.83	13.52	1.01	16.45	2.15	35.03
17	4.76	0.83	14.93	1.07	19.25	2.23	40.12
18	4.82			0.84	15.30	3.83	69.78
19	5.17	0.56	10.94	1.29	25.21	2.83	55.31
20	6.00						
21	6.40						
22	7.60	1.95	56.02	0.52	14.94	5.64	162.03
23	9.70	0.98	35.93	0.76	27.87	5.31	194.70
24	6.90	1.19	31.04	0.92	24.00	5.51	143.71
25	4.21	1.97	31.35	0.14	2.23	5.21	82.91
26	4.87	1.58	29.09	1.22	22.46	5.21	95.91
27	3.95						
28	4.55						
Average	4.39	1.33	22.11	1.13	17.76	4.20	72.40
SD	1.61	0.59	12.22	0.68	9.34	2.01	48.37

Table A-3

Boardman Waste Water Treatment Plant Plant Effluent (March 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	6.18	1.90	44.38	0.75	17.52		
2	6.79	3.21	82.39	0.34	8.73	5.52	141.68
3	5.74	1.79	38.84	0.82	17.79	3.12	67.70
4	11.03			0.60	25.02		
5	12.51	0.84	39.72	0.75	35.47	3.41	161.25
6	11.60						
7	7.75						
8	7.01	0.63	16.69	0.35	9.27	5.84	154.75
9	9.87	0.57	21.27	0.89	33.20	4.21	157.07
10	7.44	1.32	37.12	0.08	2.25	4.11	115.59
11	6.10	0.38	8.76	0.29	6.69	3.51	80.93
12	5.73	0.73	15.81	0.10	2.17	4.11	89.02
13	4.91						
14	4.72						
15	3.85	0.69	10.04	0.11	1.60	9.31	135.49
16	4.00	1.67	25.25	0.21	3.18	7.92	119.75
17	6.82	1.60	41.25	0.22	5.67	4.02	103.63
18	5.17	0.65	12.70	0.88	17.20	2.16	42.21
19	4.68			0.20	3.54	1.70	30.07
20	5.03						
21	7.12						
22	6.85	0.73	18.90	1.18	30.55	4.04	104.61
23	5.71	0.42	9.07	0.44	9.50		
24	9.22			0.08	2.79	2.50	87.13
25	8.11	0.37	11.34	0.39	11.96	2.54	77.87
26	5.07	0.61	11.69	0.71	13.61	1.68	32.20
27	4.88						
28	4.88						
29	3.85	0.79	11.50	0.29	4.22	3.01	43.80
30	3.36	0.67	8.51	0.34	4.32	1.76	22.35
31	3.72	0.38	5.34	0.14	1.97	2.37	33.33
Average	6.44	1.00	23.53	0.44	11.66	3.84	90.02
SD	2.36	0.70	18.37	0.31	10.33	1.97	44.90

Table A-4

Boardman Waste Water Treatment Plant Plant Effluent (April 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	2.86	1.16	12.54	2.63	28.43	2.46	26.59
2	3.47	1.71	22.43	3.66	48.01	1.64	21.51
3	3.93						
4	4.21						
5	3.31	0.85	10.64	1.35	16.89	7.09	88.71
6	3.56	2.55	34.31	3.11	41.85	3.30	44.41
7	3.01	1.53	17.41	0.08	0.91	2.57	29.24
8	4.25	2.00	32.13	0.06	0.96	2.89	46.43
9	5.17	2.22	43.38	0.09	1.76	4.80	93.80
10	3.82						
11	3.15						
12	2.87	1.25	13.56	0.04	0.43	3.19	34.61
13	3.38	3.38	43.18	0.09	1.15	3.29	42.03
14	3.24	2.12	25.96	0.12	1.47	2.78	34.05
15	4.11	2.47	38.37	0.12	1.86	2.22	34.49
16	4.13	2.83	44.18	0.13	2.03	4.28	66.82
17	3.97						
18	3.84						
19	3.13	0.51	6.03	0.13	1.54	3.46	40.94
20	3.73	2.58	36.38	0.18	2.54	3.29	46.39
21	3.61	2.18	29.75	0.39	5.32	4.73	64.54
22	3.57	2.78	37.51	0.35	4.72	3.45	46.56
23	3.48	0.76	10.00	1.20	15.79	0.70	9.21
24	4.21						
25	6.24						
26	9.14	1.53	52.86	2.00	69.10	2.36	81.54
27	7.81	5.38	158.83	2.04	60.22	3.17	93.58
28	2.31	0.63	5.50	0.43	3.75	1.94	16.94
29	4.78	1.00	18.07	0.57	10.30	1.86	33.61
30	3.98	2.13	32.04	0.75	11.28	1.86	27.98
Average	4.15	1.98	32.96	0.89	15.01	3.06	46.54
SD	1.45	1.11	31.62	1.08	20.41	1.31	24.11

Table A-5

Boardman Waste Water Treatment Plant Plant Effluent (May 1993)							
Days	Flow (MGD)	T.Phos (mg/l)	T.Phos (kg/d)	NH_3-N (mg/l)	NH_3-N (kg/d)	NO_2&NO_3-N (mg/l)	NO_2&NO_3-N (kg/d)
1	3.33						
2	3.71						
3	3.62	0.39	5.34	0.93	12.73	2.64	36.12
4	3.08	3.47	40.40	1.02	11.88	4.79	55.77
5	3.17	2.26	27.08			0.26	3.12
6	3.19	3.48	41.96			0.13	1.57
7	3.24	2.00	24.49			3.39	41.52
8	3.87						
9	3.56						
10	3.40	0.39	5.01			0.64	8.23
11	3.29	0.36	4.48			7.26	90.29
12	3.25	1.23	15.11			0.63	7.74
13	3.43	2.56	33.19			0.64	8.30
14	4.32	1.73	28.25			2.77	45.23
15	2.78						
16	3.61						
17	3.50	2.74	36.25			2.88	38.10
18	3.11	3.58	42.09			4.55	53.49
19	3.41	3.28	42.28			0.64	8.25
20	3.20	2.64	31.93			0.39	4.72
21	3.23	1.20	14.65			1.02	12.45
22	3.75						
23	3.55						
24	3.22	2.30	27.99			1.83	22.27
25	3.95	3.86	57.63			4.12	61.52
26	4.02	3.29	49.99			1.10	16.72
27	4.12	2.76	42.98			1.02	15.89
28	4.09	1.87	28.91			0.90	13.91
29	3.41						
30	3.68						
31	3.28						
Average	3.50	2.27	30.00	0.98	12.30	2.08	27.26
SD	0.35	1.08	14.70	0.04	0.43	1.88	23.71

Table A-6

Boardman Waste Water Treatment Plant Plant Effluent (June 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	3.91	1.11	16.41	0.47	6.95	4.08	60.30
2	3.07	1.93	22.40	3.88	45.03	2.70	31.33
3	3.24	0.76	9.31	2.31	28.29	1.92	23.51
4	4.01						
5	3.68						
6	3.24						
7	3.31						
8	11.12						
9	9.76	4.96	182.99				
10	5.68	0.53	11.38	0.34	7.30		
11	4.00	0.89	13.46	0.45	6.80		
12	3.97						
13	4.21						
14	3.71	0.27	3.79	1.98	27.77	4.11	57.64
15	3.33	0.86	10.83	0.79	9.94	1.51	19.01
16	3.20	0.88	10.64	0.45	5.44	2.02	24.43
17	3.79						
18	3.52						
19	3.48						
20	3.38						
21	3.11	1.58	18.57	3.58	42.09	3.46	40.68
22	3.68	1.26	17.53	1.55	21.56	1.02	14.19
23	3.53	1.12	14.94			1.43	19.08
24	2.97	2.01	22.57				
25	2.84	3.75	40.26	2.95	31.67	1.76	18.89
26	3.18						
27	3.47						
28	3.91						
29	4.07	4.61	70.92	0.05	0.77	2.18	33.54
30	3.42	2.47	31.93	0.39	5.04	1.86	24.05
Average	4.06	1.81	31.12	1.48	18.36	2.34	30.55
SD	1.79	1.39	42.17	1.28	14.57	0.99	14.52

Table A-7

Boardman Waste Water Treatment Plant Plant Effluent (July 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	3.71	1.92	26.93	0.37	5.19	2.41	33.80
2	3.32	1.40	17.57	0.29	3.64	2.40	30.12
3	3.84						
4	4.16						
5	4.07	1.76	27.08			3.10	47.69
6	4.61	0.41	7.14	0.41	7.14	3.60	62.73
7	3.95	4.40	65.70	0.29	4.33	2.65	39.57
8	3.35	5.69	72.05	0.39	4.94	3.30	41.79
9	3.69	5.93	82.71	0.40	5.58	1.52	21.20
10	3.24						
11	3.58						
12	3.78	0.29	4.14	0.39	5.57	3.56	50.87
13	3.11	1.85	21.75	0.31	3.64	2.14	25.16
14	3.98	2.51	37.76	0.25	3.76	2.06	30.99
15	4.02	1.47	22.34	0.41	6.23	2.47	37.53
16	4.10	3.98	61.68	0.53	8.21	1.71	26.50
17	3.62						
18	3.81						
19	3.42	0.75	9.70	0.23	2.97	4.50	58.17
20	3.12	4.73	55.78	0.47	5.54	2.48	29.25
21	3.42	4.65	60.11	0.61	7.89	2.56	33.09
22	2.96	4.49	50.24	0.49	5.48	1.94	21.71
23	3.02	1.79	20.43	0.30	3.42	1.63	18.61
24	3.17						
25	3.48						
26	3.91	2.56	37.84	0.79	11.68	1.78	26.31
27	3.28	1.78	22.07	0.28	3.47	2.89	35.83
28	3.11	1.10	12.93	0.21	2.47	3.79	44.55
29	3.33	3.75	47.20	0.45	5.66	1.43	18.00
30	3.62	0.47	6.43	0.28	3.83	2.29	31.34
31	3.58						
Average	3.59	2.62	34.98	0.39	5.27	2.56	34.76
SD	0.39	1.73	22.94	0.14	2.09	0.79	11.95

Table A-8

Boardman Waste Water Treatment Plant Plant Effluent (August 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	3.79						
2	3.48	1.24	16.31	0.57	7.50	6.73	88.53
3	3.92	3.35	49.64	0.90	13.34	4.62	68.46
4	3.31	4.70	58.81	1.05	13.14	5.87	73.44
5	3.26	2.35	28.96	0.19	2.34	2.98	36.72
6	3.98	1.10	16.55	0.21	3.16	3.47	52.20
7	4.01						
8	4.67						
9	3.54	2.05	27.43	0.35	4.68	8.70	116.42
10	3.16	4.00	47.78	0.79	9.44	5.33	63.67
11	4.61	5.75	100.20	0.38	6.62	1.98	34.50
12	6.82	4.05	104.41	4.29	110.59	2.42	62.39
13	5.11	1.30	25.11	3.51	67.80	4.31	83.25
14	3.97						
15	4.12						
16	3.68	0.85	11.82	4.36	60.65	3.44	47.85
17	3.63	7.82	107.30	5.70	78.21	0.16	2.20
18	3.74	4.33	61.21	3.40	48.07	1.38	19.51
19	3.52	0.20	2.66	0.16	2.13		
20	3.18	4.92	59.14	0.12	1.44	1.00	12.02
21	3.26						
22	3.71						
23	3.62	0.55	7.53	1.27	17.38	12.03	164.61
24	4.17	2.45	38.62	0.62	9.77	6.39	100.72
25	3.98	0.21	3.16	2.92	43.93	5.78	86.96
26	3.74	0.10	1.41	1.01	14.28	6.33	89.49
27	3.24	4.30	52.66	0.34	4.16	7.56	92.59
28	3.33						
29	3.28						
30	3.97	3.62	54.32	0.38	5.70	8.02	120.35
31	4.11	1.30	20.20	0.34	5.28	2.94	45.68
Average	3.87	2.75	40.69	1.49	24.07	4.83	69.60
SD	0.70	2.03	31.68	1.65	29.68	2.83	38.21

Table A-9

Boardman Waste Water Treatment Plant Plant Effluent (September 1993)							
Days	Flow (MGD)	T.Phos (mg/l)	T.Phos (kg/d)	NH_3-N (mg/l)	NH_3-N (kg/d)	NO_2&NO_3-N (mg/l)	NO_2&NO_3-N (kg/d)
1	5.12	1.64	31.74	1.90	36.77	0.15	2.90
2	4.76	1.37	24.65	0.00	0.00	0.06	1.08
3	3.83			1.80	26.06	1.92	27.80
4	3.76						
5	3.92						
6	3.31						
7	3.40	1.23	15.81	0.20	2.57	8.41	108.09
8	3.28	1.36	16.86	0.25	3.10	6.70	83.07
9	3.27			0.11	1.36		
10	3.94			0.11	1.64		
11	3.60						
12	3.72						
13	3.44	1.04	13.52	0.52	6.76	10.43	135.62
14	3.27	0.68	8.41	0.20	2.47	7.41	91.59
15	3.21	5.62	68.19	0.42	5.10	4.22	51.20
16	3.53	2.72	36.29	0.20	2.67	5.71	76.19
17	3.80	1.62	23.27	0.16	2.30	5.90	84.75
18	3.76						
19	3.19						
20	3.21	4.13	50.11	0.18	2.18	7.71	93.55
21	3.33	2.21	27.82	0.16	2.01	6.91	86.98
22	3.52	2.02	26.88	0.17	2.26	6.21	82.63
23	3.96	6.27	93.85	0.19	2.84	5.41	80.98
24	3.48	4.20	55.25	0.20	2.63	5.31	69.85
25	3.27						
26	4.09						
27	3.68	2.24	31.16	0.17	2.36	6.71	93.34
28	3.45	5.80	75.64	0.19	2.48	5.21	67.94
29	3.53	3.00	40.03	0.54	7.21	5.71	76.19
30	3.82	1.65	23.83	0.37	5.34	6.71	96.89
Average	3.65	2.71	36.85	0.38	5.72	5.62	74.24
SD	0.43	1.70	22.61	0.49	8.66	2.52	32.55

Table A-10

Boardman Waste Water Treatment Plant Plant Effluent (October 1993)							
Days	Flow (MGD)	T.Phos (mg/l)	T.Phos (kg/d)	NH_3-N (mg/l)	NH_3-N (kg/d)	NO_2&NO_3-N (mg/l)	NO_2&NO_3-N (kg/d)
1	3.12	5.35	63.10	0.35	4.13	6.03	71.12
2	3.40						
3	3.34						
4	3.11	3.36	39.50	0.46	5.41	8.01	94.16
5	3.90	4.74	69.88	0.32	4.72	7.17	105.70
6	5.40	4.56	93.08	0.19	3.88	5.45	111.25
7	5.10	5.49	105.84	0.14	2.70	4.87	93.88
8	4.02	4.16	63.21	0.16	2.43	6.07	92.24
9	3.88						
10	3.79						
11	3.44						
12	3.28	5.03	62.36	0.18	2.23	7.05	87.41
13	3.01	3.86	43.92	0.65	7.40	3.69	41.98
14	2.96	3.36	37.59	0.17	1.90	5.45	60.98
15	2.89	3.22	35.18	0.51	5.57	4.42	48.28
16	3.00						
17	3.27						
18	3.57	3.33	44.94	0.13	1.75	6.98	94.19
19	3.38	5.53	70.65	0.10	1.28	6.46	82.54
20	3.40	4.42	56.81	0.27	3.47	5.13	65.93
21	4.75	3.78	67.87	0.21	3.77	4.78	85.82
22	3.88	3.29	48.25	0.12	1.76	7.10	104.13
23	3.68						
24	3.67						
25	3.45	4.28	55.82	0.09	1.17	8.48	110.59
26	3.33	5.16	64.95	0.12	1.51	7.15	90.00
27	3.91	4.81	71.09	0.12	1.77	8.42	124.45
28	3.02	5.58	63.70	0.35	4.00	5.94	67.81
29	3.18	3.86	46.40	0.85	10.22	5.19	62.39
30	3.42						
31	4.28						
Average	3.61	4.36	60.21	0.27	3.55	6.19	84.74
SD	0.60	0.81	17.36	0.20	2.23	1.31	21.41

Table A-11

Boardman Waste Water Treatment Plant Plant Effluent (November 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	4.06	3.26	50.03	0.18	2.76	3.17	48.65
2	3.37	3.13	39.87	0.15	1.91	3.84	48.92
3	3.61	3.16	43.12	0.59	8.05	3.21	43.80
4	4.82	1.62	29.52	0.21	3.83	3.16	57.57
5	4.13	1.94	30.29	0.25	3.90	3.60	56.20
6	3.64						
7	3.07						
8	3.18	2.94	35.34	0.10	1.20	7.67	92.20
9	5.23	3.48	68.80	0.67	13.25	4.45	87.97
10	4.33	2.73	44.68	0.17	2.78	5.16	84.46
11	3.78						
12	3.18	1.72	20.68	1.31	15.75	2.75	33.06
13	3.04						
14	3.37						
15	3.35	1.46	18.49	0.08	1.01	5.11	64.71
16	3.60	4.12	56.06	0.08	1.09	5.79	78.79
17	4.99	4.32	81.48	0.13	2.45	6.31	119.02
18	3.54	0.73	9.77	0.08	1.07	2.55	34.12
19	3.24	1.33	16.29	0.08	0.98	2.68	32.82
20	3.57						
21	3.83						
22	3.48	3.36	44.20	0.21	2.76	8.35	109.84
23	5.82	4.20	92.40	1.25	27.50	3.94	86.68
24	3.09	3.99	46.60	1.28	14.95	2.35	27.45
25	3.02						
26	3.51	1.83	24.28	1.07	14.20	4.39	58.25
27	4.92						
28	4.68						
29	4.28	1.63	26.37	0.10	1.62	4.39	71.02
30	3.68	4.66	64.82	0.53	7.37	14.10	196.14
Average	3.85	2.78	42.15	0.43	6.42	4.85	71.58
SD	0.72	1.14	21.50	0.44	6.96	2.66	38.19

Table A-12

Boardman Waste Water Treatment Plant Plant Effluent (December 1993)							
Days	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
1	3.47	3.75	49.19	0.18	2.36	4.61	60.47
2	3.32	2.92	36.64	0.15	1.88	5.54	69.52
3	3.81	0.46	6.62	0.59	8.50	4.90	70.57
4	6.30						
5	8.70						
6	5.19	0.54	10.59	0.21	4.12	4.16	81.61
7	4.72	2.35	41.93	0.25	4.46	3.73	66.55
8	3.84	0.77	11.18	0.56	8.13	1.83	26.56
9	3.62	0.58	7.94			3.06	41.87
10	3.21	0.25	3.03	0.56	6.79	2.53	30.70
11	3.48						
12	3.21						
13	3.09	1.79	20.91	0.15	1.75	6.24	72.88
14	3.11	0.53	6.23	0.19	2.23	3.80	44.67
15	3.65	0.52	7.17	0.20	2.76	4.65	64.16
16	3.70	0.59	8.25	0.13	1.82	4.72	66.01
17	3.71	0.63	8.83	0.10	1.40	5.04	70.68
18	3.58						
19	3.55						
20	3.48	1.48	19.47			5.40	71.03
21	3.38	1.21	15.46			4.25	54.30
22	3.57	0.19	2.56			3.44	46.42
23	3.22	0.61	7.42			3.96	48.20
24	3.00						
25	3.14						
26	3.60						
27	3.19	3.06	36.90			6.90	83.20
28	3.58	3.19	43.17			4.36	59.00
29	3.27	1.26	15.57			3.68	45.49
30	3.48	1.81	23.81			4.36	57.35
31	3.00						
Average	3.78	1.36	18.23	0.27	3.85	4.34	58.63
SD	1.12	1.07	14.28	0.18	2.47	1.14	15.09

Table A-13

Boardman Waste Water Treatment Plant Plant Effluent (Monthly Averages 1993)							
Months	Flow	T.Phos	T.Phos	NH_3-N	NH_3-N	NO_2&NO_3-N	NO_2&NO_3-N
	(MGD)	(mg/l)	(kg/d)	(mg/l)	(kg/d)	(mg/l)	(kg/d)
January	3.58	1.47	19.92	0.12	1.81	4.69	62.63
February	4.39	1.33	22.11	1.13	17.76	4.20	72.40
March	6.44	1.00	23.53	0.44	11.66	3.84	90.02
April	4.15	1.98	32.96	0.89	15.01	3.06	46.54
May	3.50	2.27	30.00	0.98	12.30	2.08	27.26
June	4.06	1.81	31.12	1.48	18.36	2.34	30.55
July	3.59	2.62	34.98	0.39	5.27	2.56	34.76
August	3.87	2.75	40.69	1.49	24.07	4.83	69.60
September	3.65	2.71	36.85	0.38	5.72	5.62	74.24
October	3.61	4.36	60.21	0.27	3.55	6.19	84.74
November	3.85	2.78	42.25	0.43	6.42	4.85	71.58
December	3.78	1.36	18.23	0.27	3.85	4.34	58.63
Yearly Average	**4.04**	**2.20**	**32.74**	**0.69**	**10.48**	**4.05**	**60.25**

Table A-14

Boardman Waste Water Treatment Plant Plant Effluent (Monthly Standard Deviations 1993)							
Months	**Flow**	**T.Phos**	**T.Phos**	**NH_3-N**	**NH_3-N**	**NO_3&NO_2-N**	**NO_3&NO_2-N**
	(MGD)	**(mg/l)**	**(kg/d)**	**(mg/l)**	**(kg/d)**	**(mg/l)**	**(kg/d)**
January	1.03	0.62	9.17	0.14	2.93	1.66	22.63
February	1.61	0.59	12.22	0.68	9.34	2.01	48.37
March	2.36	0.70	18.37	0.13	10.33	1.97	44.90
April	1.45	1.11	31.62	0.89	15.01	1.31	24.11
May	0.35	1.08	14.70	0.04	0.43	1.88	23.71
June	1.79	1.39	42.17	1.28	14.57	0.99	14.52
July	0.39	1.73	22.94	0.14	2.09	0.79	11.95
August	0.70	2.03	31.68	1.65	29.68	2.83	38.21
September	0.43	1.70	22.61	0.49	8.66	2.52	32.55
October	0.60	0.81	17.36	0.20	2.23	1.31	21.41
November	0.72	1.14	21.50	0.44	6.96	2.66	38.19
December	1.12	1.07	14.28	0.18	2.47	1.14	15.09
Yearly SD	**1.05**	**1.16**	**21.55**	**0.52**	**8.73**	**1.76**	**27.97**

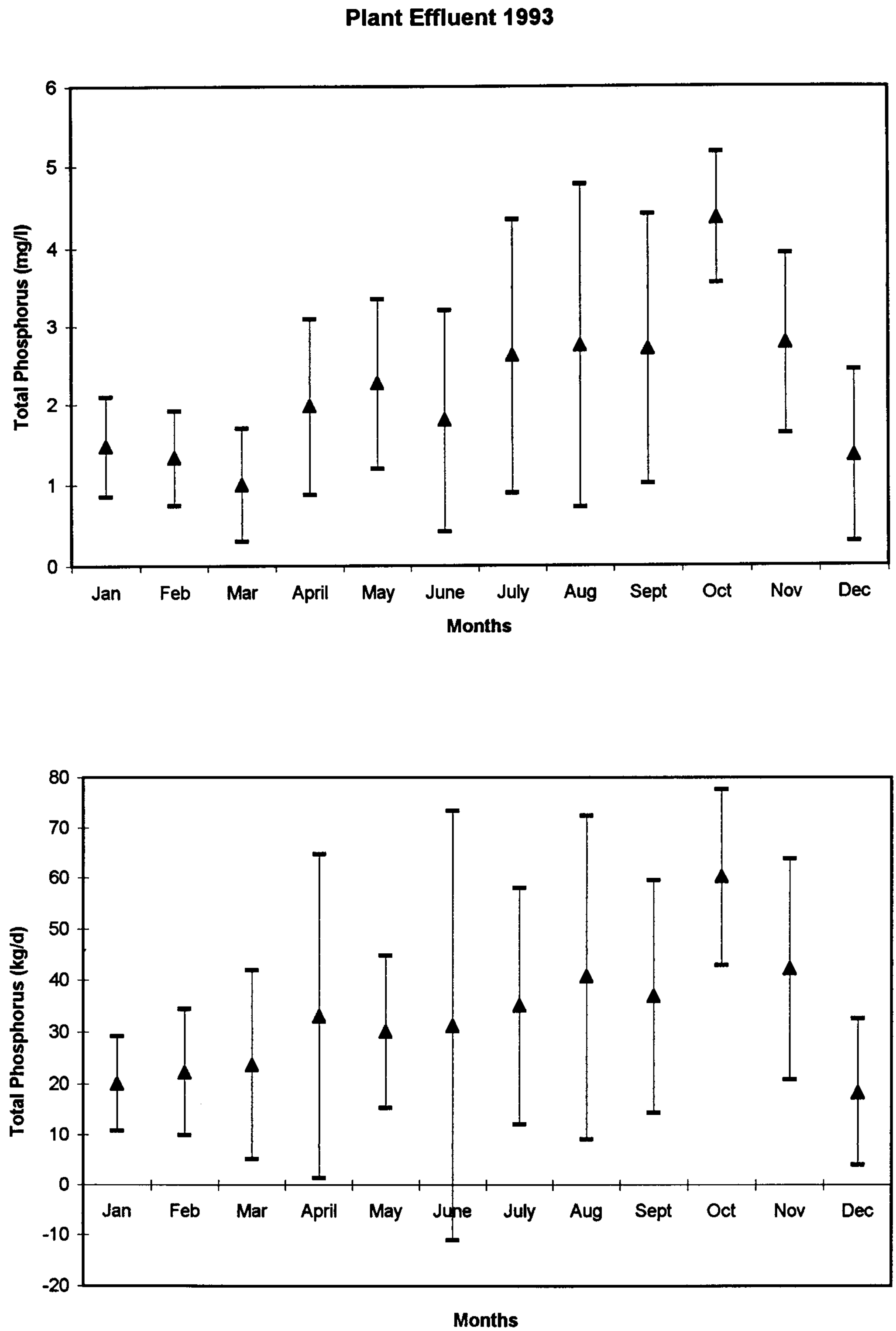

Figure A-1: Monthly Mean (± SD) Total Phosphorus Concentrations and Loadings from Boardman WWTP, Plant Effluent 1993

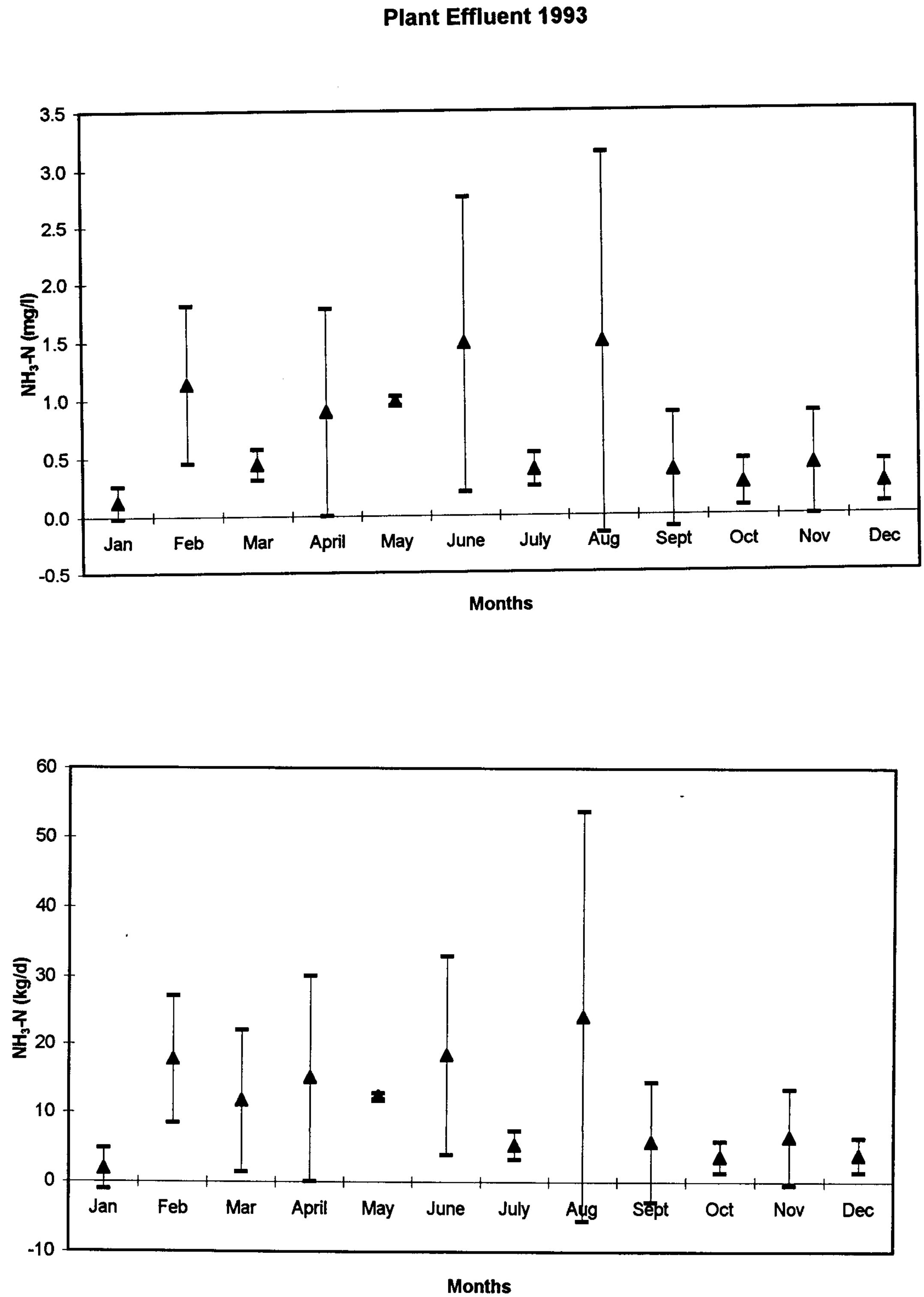

Figure A-2: Monthly Mean (± SD) Ammonia-Nitrogen Concentrations and Loadings from Boardman WWTP, Plant Effluent 1993

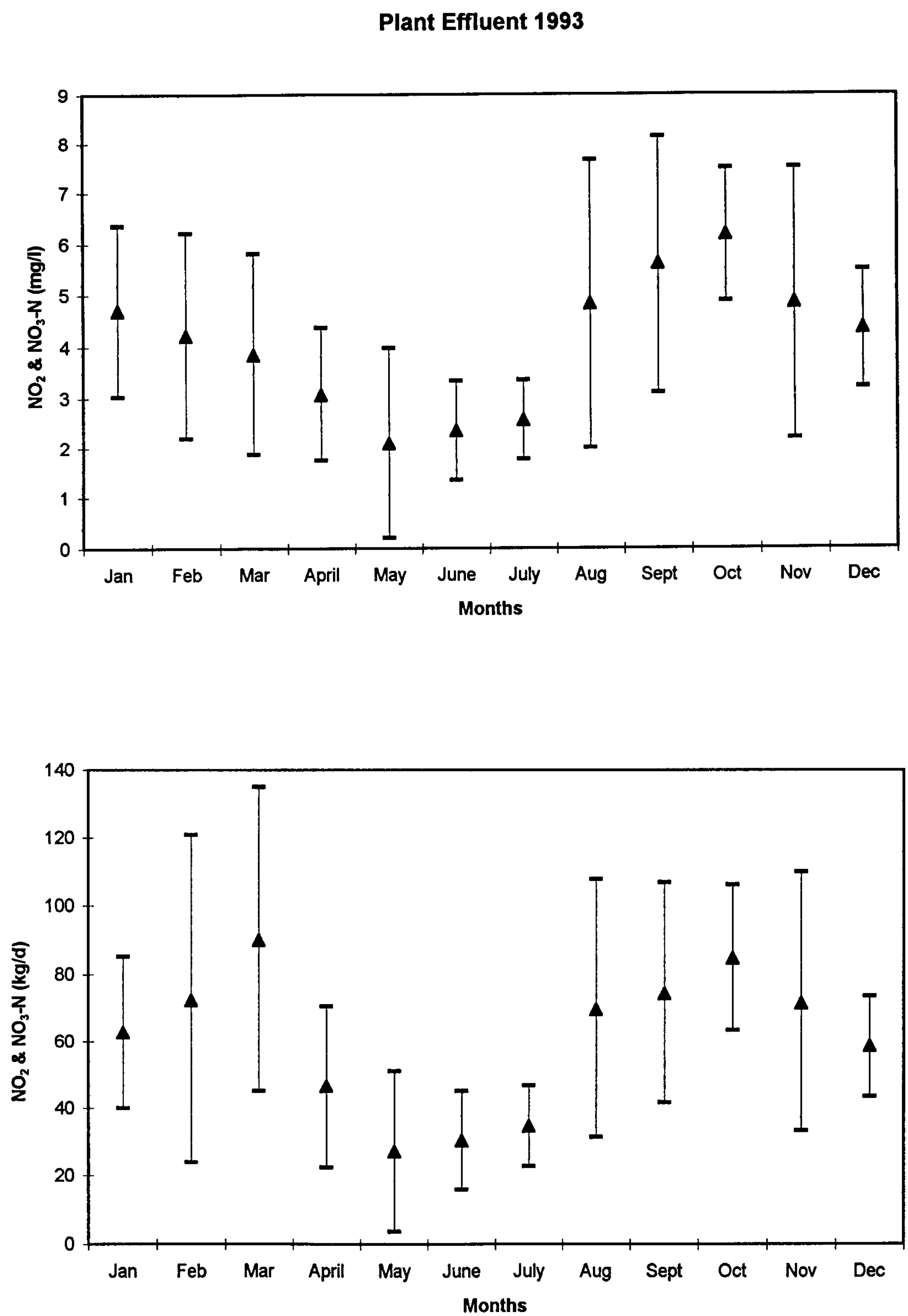

Figure A-3: Monthly Mean (± SD) Nitrite and Nitrate Nitrogen Concentrations and Loadings from Boardman WWTP, Plant Effluent 1993