Big Butternut Lake
Wisconsin Lake Planning Grant LPL-452
Final Report

Prepared for
Big Butternut Lake Protection and
Rehabilitation District

April 1999

BARR

Executive Summary

The Big Butternut Lake Protection and Rehabilitation District (BBLPRD) conducted two Lake Planning Grant Projects during 1995-1996. Both projects focussed on in-lake processes, which included water quality, lake water level, and macrophyte (rooted aquatic plant) density and distribution. The results of the studies indicated that by late-summer the water quality in the lake is severely degraded, with total phosphorus and chlorophyll a concentrations at the hypereutrophic level (Figure ii). Late-summer water transparency is typically only 2 or 3 feet, as compared to 6 to 8 feet in the spring. This decline in summer water quality condition is due to input both from the lake's watershed and from internal sources. Part of the internal phosphorus load to the lake is from its sediments and part is from decomposition of aquatic macrophytes, especially curlyleaf pondweed.

This report covers the results of a study supported by a third Lake Planning Grant (LPL-452). The scope of this project was to conduct the following lake management activities on Big Butternut Lake:

1. Establish watershed delineation
2. Create maps showing the GIS database and land use for the watershed
3. Collect stream flow data entering the lake and in-lake water quality conditions
4. Prepare hydrologic and phosphorus budgets
5. Identify BMP's (best management practices) and potential remediation measure for water quality in Big Butternut Lake
6. Identify the specific watershed sensitive areas

A watershed geographical information system (GIS) was prepared, using ArcView 3.1 software. The GIS database includes the watershed delineations and the locations of sample sites on topographic and aerial photo basemaps. Watershed areas, color maps and figures were prepared from the GIS. The total drainage area of Big Butternut was divided into 10 subwatersheds (**Figure i**). In 1997, samples were collected from 10 watershed runoff locations and in-lake water quality was monitored at the deepest location throughout the ice-free period. This report also includes in-lake data collected in 1998. The watershed and lake data were used to calculate hydrologic and phosphorus budgets.

A comparison of the water transparency for four years (**Figure ii**) shows the water quality may have declined somewhat in 1998, compared to three previous years, but considering natural year-to-year variability, the water quality does not show either a positive or negative trend over the four years.

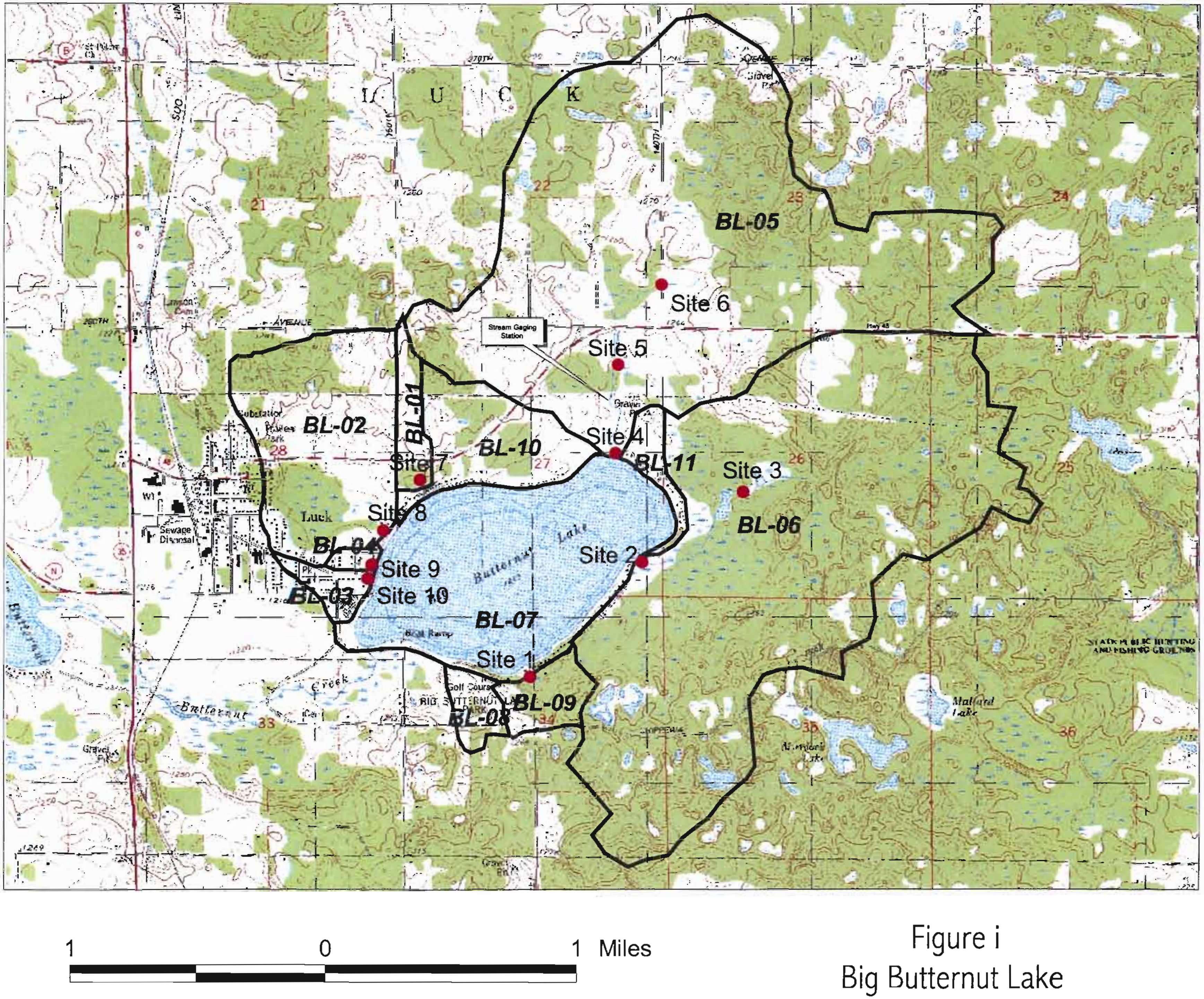


Figure i
Big Butternut Lake
Watershed and Sample Sites

Barr: Arcview 3.1,PIIBC, i:\projects\49\49\017\gis\projects\bigbutt.apr, Layout: Figure i, bam, Tue Apr 06 10:28:17 1999

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

The Big Butternut Lake Protection and Rehabilitation District (BBLPRD) conducted two Lake Planning Grant studies during 1995-1996. Grant Study I (#LPL-260) investigated the lake outlet and potential controls on lake outflow, as well as the density and distribution of aquatic macrophytes, especially curlyleaf pondweed, in the lake. Grant Study II (#LPL-289) surveyed the current water quality in the lake. The results of both projects are summarized in one final report (Barr 1996). The results of the studies indicated that by late-summer the water quality in the lake is severely degraded, with total phosphorus and chlorophyll a concentrations at the hypereutrophic level (Barr 1996). It appears that part of the phosphorus load to the lake is from release of phosphorus from the sediments and from decomposition of aquatic macrophytes (especially curlyleaf pondweed). This report covers the results of a third Lake Planning Grant project (LPL-452) awarded to BBLPRD to determine the magnitude of all sources of phosphorus to the lake (i.e., watershed, internal load, point source, atmospheric, etc.). Based on the results of this study, the report concludes with recommendations for best management practices for protecting the lake's water quality.

The water quality in Big Butternut Lake was assessed in 1983 by the Wisconsin Department of Natural Resources (DNR 1986). Data collection included lake water quality data, but not storm water runoff quality or quantity. Based on the 1983 data, the trophic status of the lake was classified as eutrophic. The report included general management strategies for the watershed, such as minimizing phosphorus-based fertilizer use, controlling soil erosion of agricultural lands through conservation tillage practices, controlling macrophyte growth by mechanical harvesting, and curtailing septic system runoff by replacement of failing systems. The 1986 report identified agricultural land as the largest source of phosphorus to the lake; however, very little of the watershed is currently used for agriculture. No specific best management practices (BMPs) were identified for the lake or its watershed.

The BBLPRD has worked with the Village of Luck and Luck Township to implement the management strategies recommended by the 1986 DNR report. The village and township have passed ordinances banning the use of phosphorus-based fertilizer. All septic systems have been inspected and failing systems were replaced with holding tanks.

This third planning grant study focuses on additional BMPs that will reduce targeted phosphorus loads to the lake. Targeting the phosphorus loads required data collection and development of hydrologic and watershed budgets for the lake. To control external loading of phosphorus to the lake, the considered BMPs include oil and grit chambers (also known as "hydrodynamic separators" or simply, "grit chambers") for the storm sewers in the Village of Luck and improved storm water detention in the watersheds to the north and east of the lake. To control internal loading of phosphorus, in-lake BMPs include alum (aluminum sulfate) application to the lake and aeration (i.e., artificial circulation). Alum can effectively lock phosphorus in the sediments and prevent the release of phosphorus from the sediments. Aeration can improve fish habitat in addition to providing some phosphorus reduction. The combination of the external and internal controls on phosphorus entering the lake will reduce the quantity of algae in the lake and thereby improve the water clarity. Improved water clarity can improve conditions for rooted plant (macrophyte) growth. Therefore, the lake management plan should include macrophyte management (harvesting and/or herbicide application).

2.0 Methods

2.1 In-Lake Sample Collection and Analysis

During 1997, BBLPRD volunteers collected samples from the deepest spot in the lake and from ten locations on tributary streams (**Figure** 1); the sample sites are described in Table 1. Temperature and dissolved oxygen data were collected using a YSI Model 57 oxygen and temperature meter at 1-meter depth intervals from lake surface to 0.5 m above the bottom sediments. Water transparency was determined using a standard Secchi disk. Water samples were collected at 0 m (lake surface), 4 m, and 5.5 m (approximately 0.5 m above bottom sediments) depths. A portion surface water samples were stored in an opaque 1-liter bottle, and were filtered on shore for chlorophyll a and soluble-reactive phosphorus analysis. Analysis for total phosphorus was performed on all samples collected from the three depths. As required by the planning grant program, all laboratory analyses were performed at the Wisconsin State Laboratory of Hygiene in Madison, Wisconsin.

2.2 Stream Flow Gaging and Water Quality Monitoring

The stream flow at one location on the North Stream (Figure 1) was monitored using an ISCO Model 4150 automatic flow logger. The equipment was installed in an unhindered portion of the streambed; there did not appear to be any backwater influences from the lake or from beaver activity. The flow logger was equipped with a marine battery and solar panel. Flow data were collected every 15 minutes from May through September. A staff gage was installed adjacent to the flow logger; a BBLPRD volunteer collected water level and stream flow profiles several times to create a stage-discharge curve for the site. For stream flow prior to May 1, 1997 and after September 31, 1997 was estimated using correlations with St. Croix River and Apple River daily flow data.

Grab samples were collected at 10 inflow stations (**Table 1**), which represented most of the subwatersheds. Grab samples from the stream sites were collected during the following storm events:

- 1 snowmelt event (collected during March, 1998)
- 2 spring rain events
- 2 summer rain events
- 2 fall rain events

Table 1 **Big Butternut Lake Subwatershed Areas**

Sample Sites	Description of Sample Location	Water-shed ID	Watershed Area (acres)
1	Small tributary creek flowing under South Shore Drive immediately east of the golf course	BL-09	47.4
2	Tributary creek at SE end of lake; just upstream of lake	BL-06	1113.6
3	Tributary creek at SE end of lake; upstream of private campsite	BL-06	
4	Tributary creek at NE end of lake; just upstream of lake	BL-05	1190.2
5	Tributary creek at NE end of lake; at culvert under County Road 48	BL-05	
6	Tributary creek at NE end of lake; at culvert under 140th Street	BL-05	
7	Small tributary creek flowing under Pine Street	BL-01	39.0
8	Village of Luck storm sewer	BL-02	272.1
9	Village of Luck storm sewer	BL-04	9.4
10	Village of Luck storm sewer	BL-03	27.0
Subwatersheds with no tributaries:			
—	Watershed along S shoreline (golf course & park), no tributaries.	BL-08	31.8
—	Watershed along N shoreline, no tributaries.	BL-10	132.6
—	Watershed along NE shoreline, no tributaries.	BL-11	30.1
		Total*	2,893

* Does not include lake surface, which was assigned ID, BL-07

Based on the continuous flow data, runoff volumes were calculated for monitored subwatersheds. The runoff per unit area was used to estimate runoff from the three subwatersheds that had direct drainage to the lake and no tributaries. Water volume data was combined with total phosphorus concentrations from grab samples as input to the U.S. Army Corps of Engineer's FLUX model to determine phosphorus loading (lb P/year) from seven of the subwatersheds. For the other three watersheds that did not have tributary monitoring, a unit area load value was used to estimate the phosphorus loading.

The Flux model uses the average daily discharges and phosphorus concentrations to calculate loadings. The model can be used to test the relationships, and then stratify (or group) the sample results based upon flow and/or date. The model uses five different loading calculation methods and computes the variances of the estimated mean loadings to provide relative indications of error in the estimated loads. The calculation with the smallest amount of bias and variance was used to estimate the annual phosphorus loadings for each of the monitored sites.

Data collection responsibilities for the 1997 lake and watershed monitoring were as follows:

Stream samples and velocity data:	Ben Kustelski
Lake levels:	Village of Luck
In-lake:	Gaylon Jensen
Automated flow meter:	Marti Messar

2.3 Hydrologic and Phosphorus Budgets

Hydrologic (i.e., water) and phosphorus budgets were compiled from the stream gaging and water quality monitoring data, as well as estimates of internal loading of phosphorus in the lake. Internal loading refers to the release of phosphorus from the sediments to the water column. Internal phosphorus release is usually calculated from the measured concentrations of phosphorus in the lake over the growing season, and through modeling the expected in-lake phosphorus concentration.

The Dillon and Rigler phosphorus model (1974) was used to reconcile the phosphorus loadings from the watershed with the phosphorus concentrations observed in the lake. The Dillon and Rigler model as modified by Nurenberg (1984) was used to analyze the effects of sediment phosphorus release (i.e., internal loading) on late-summer phosphorus concentrations in the lake. The model uses inputs of phosphorus loading, lake mean depth, phosphorus retention, and water flushing rate to calculate the spring time total phosphorus concentration in the lake. Late summer total phosphorus concentration is calculated from the spring TP mass, internal TP mass, phosphorus retention, and the additions and losses of phosphorus from the lake through the summer.

3.0 Results

3.1 In-Lake Sample Collection and Analysis

Water quality results are discussed below and data are tabulated in Appendices A, B and C.

3.1.1 Lake Characteristics

The general physical features of the lake are listed in **Table 2**. The subwatersheds were delineated on a 7.5 minute USGS quadrangle map. The total watershed area, excluding the lake, is 2,893 acres. This is different from the watershed size reported in the 1986 feasibility study. The difference in watershed area is most likely attributable to differences in interpretation of the watershed boundary where there are only small changes in slope.

Table 2 Big Butternut Lake's Morphometric Data

Characteristic	Dimension
Watershed Area (excluding lake)	2,893 acres (1171 hectares)
Lake Area	378 acres (153 hectares)
Ratio of Watershed to lake area	7.6:1
Average Annual Flow	5.4 cfs (10.6 ac-ft/d)
Lake Volume (V)	4,877 ac-ft (6.015 x 10^6 m^3)
Maximum Depth	19 ft (5.8 m)
Mean Depth (V/A)	13 ft (4.0 m)
Water Residence Time	460 days

3.1.2 Secchi Disc Transparency

A lake user's perceptions and expectations are generally associated with water clarity. Secchi disc transparency is a measure of water clarity. The depth at which the Secchi disc can no longer be seen is given units of either meters or feet. Results of a survey completed by the Metropolitan Council (Osgood 1989) revealed the following relationship between a lake's recreational use impairment and Secchi disc transparencies: less than 1 meter (3.3 feet) Secchi *feet) Secchi depth indicates moderate to severe impairment; greater than 2 meters (6.6 feet) indicates minimal use impairment.*

Secchi disk transparencies measurements are shown in **Figure 2** for 1995, 1996, 1997, and 1998. The four years of readings between late April and early October generally show a consistent pattern from year to year. The exception is 1997, when mid-June water clarity was much better than other years at that time. 1997 was a good year for water clarity in early summer because of low precipitation and therefore relatively low runoff of nutrients into lakes. Although the late summer Secchi depths are similar in that they are in the eutrophic range of water quality, the readings in 1998 were the lowest of the four years.

3.1.3 Chlorophyll *a*

Chlorophyll a is a measure of algal abundance, or biomass, within a lake. Algae are also referred to as phytoplankton. High chlorophyll a concentrations indicate excessive algal abundance (i.e., algal blooms), which can lead to recreational use impairment. Chlorophyll a concentration is given in units of micrograms per liter (µg/L), which is equivalent to parts per billion (ppb).

Chlorophyll *a* concentrations are compiled for 1995 and 1997 (**Figure 3**). In both years, the phytoplankton remained low through June, but then increased to algal "bloom" levels in August. These very high concentrations in August cause low water clarity, possibly foul odors, and lead to low oxygen concentrations as the phytoplankton die and decompose.

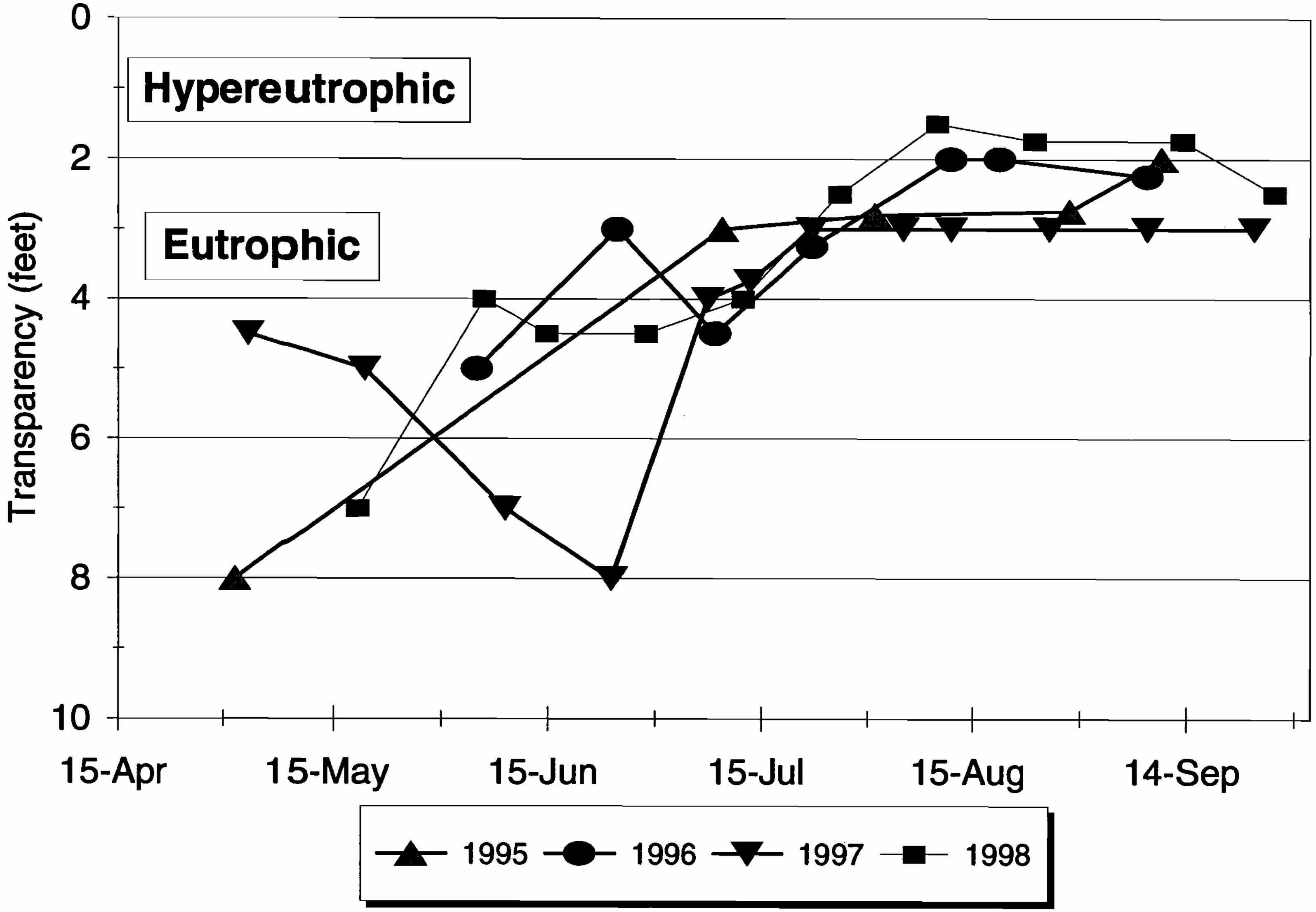
The chlorophyll *a* concentrations do not reflect the biomass of macrophytes. Macrophyte biomass and density must be measured by surveying the shallow area around the lake. This was done in previous planning grant studies and showed curlyleaf pondweed was the predominant species.

3.1.3 Total Phosphorus

Phosphorus is the plant nutrient that most often limits the growth of algae. Phosphorus-rich lake water indicates a lake has the potential for abundant algal growth, which can lead to lower water transparency and a decline in hypolimnetic oxygen levels in a lake. Near-surface total phosphorus concentration is an indicator of the amount of nutrients available to the algae. Phosphorus concentration is given in units of micrograms per liter (µg/L), which is equivalent to parts per billion (ppb).

Figure 2

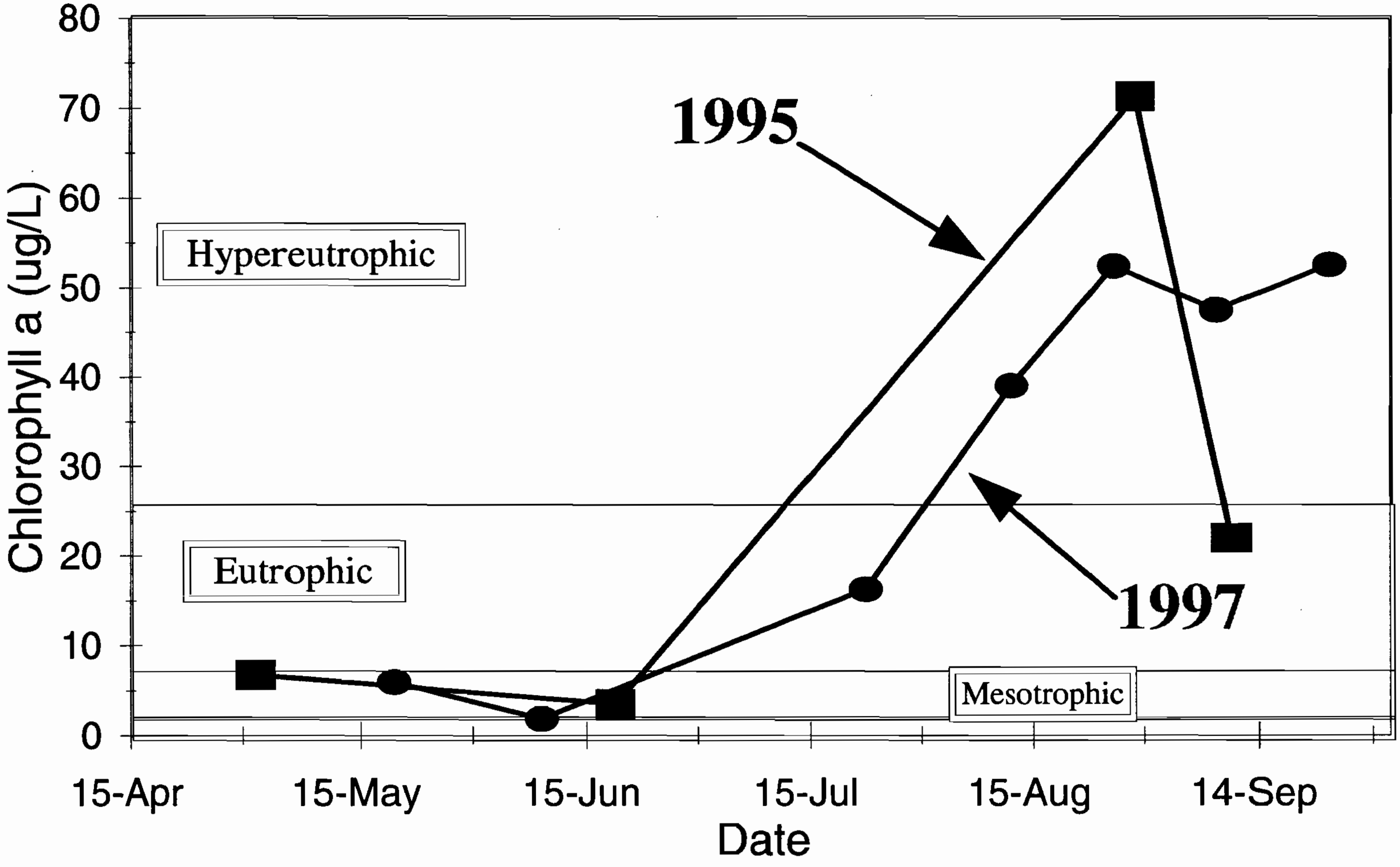
Big Butternut Lake
Secchi Disk Transparencies



C:\PROJEC~1\BUTTERNU\WATERQUA.WB2

Figure 3

Big Butternut Lake
Near Surface Chlorophyll a



C:\PROJEC~1\BUTTERNU\WATERQUA.WB2

Results of total phosphorus concentrations in the surface water of Big Butternut Lake are shown for 1995 and 1997 in **Figure 4**. The seasonal pattern of total phosphorus concentration in the two years are quite different: in 1995, there were low concentrations in the early half of the growing season, but then the phosphorus concentrations increased to over 100 µg/L by the first of September; in 1997, the phosphorus concentrations were initially high in the first part of the growing season and remained high until mid-September.

The highest and lowest chlorophyll *a* concentrations correspond to the highest and lowest total phosphorus, but in the mid-ranges, there is a poor correlation between chlorophyll *a* and total phosphorus, based on 1995 and 1997 data (**Figure 5**). This is undoubtedly caused by other variables, such as zooplankton grazing on phytoplankton, sunlight, and wind-induced mixing of the water.

3.1.5 Stratification and Internal Loading of Phosphorus

Phosphorus can enter the lake from the watershed runoff, the atmosphere, groundwater, septic systems, or sediment release. The latter, sediment release, occurs when the oxygen near the sediments is depleted. In a deep lake the phosphorus released from the sediments remains cut off from the mixed layer above because of the strong thermal stratification. In a shallow lake, such as Big Butternut, the lake can stratify long enough to cause oxygen depletion in the bottom waters, but then destratify from strong winds or storms. This pattern of intermittent phosphorus release from the sediments and entrainment in the mixed layer effectively pumps phosphorus to algae. This process appears to occur in Big Butternut. **Figure 6** shows time-depth diagrams for temperature, dissolved oxygen, and total phosphorus, during the years 1995 and 1997. The relative time in these figures is from the first sample day, which was in early May. When the isopleth lines are horizontal, the lake is stratified and when the lines are vertical the water column in the lake is mixed. These isopleth diagrams illustrate the temporary mixing that occurs in Big Butternut during the summer; in a deep lake the isopleth lines would remain relatively horizontal throughout the summer. The likelihood that the pattern of polymixis (multiple mixing) occurs in Big Butternut is supported by the total phosphorus concentrations near the bottom over the summer, which ranged from 38 µg/L to 318 µg/L in 1995 and 69 µg/L to 246 µg/L in 1997.

Figure 4

Big Butternut Lake
Near Surface Phosphorus

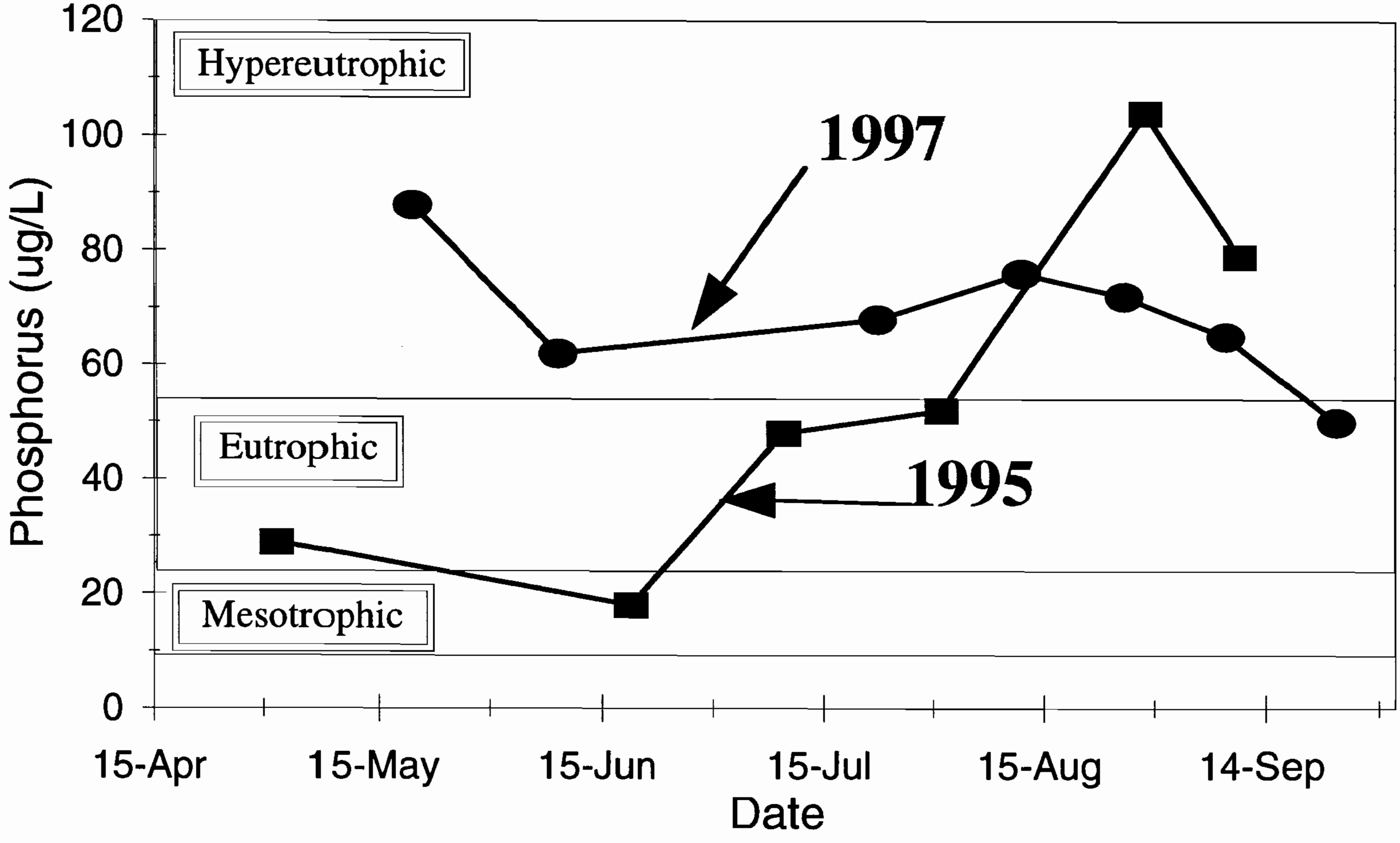
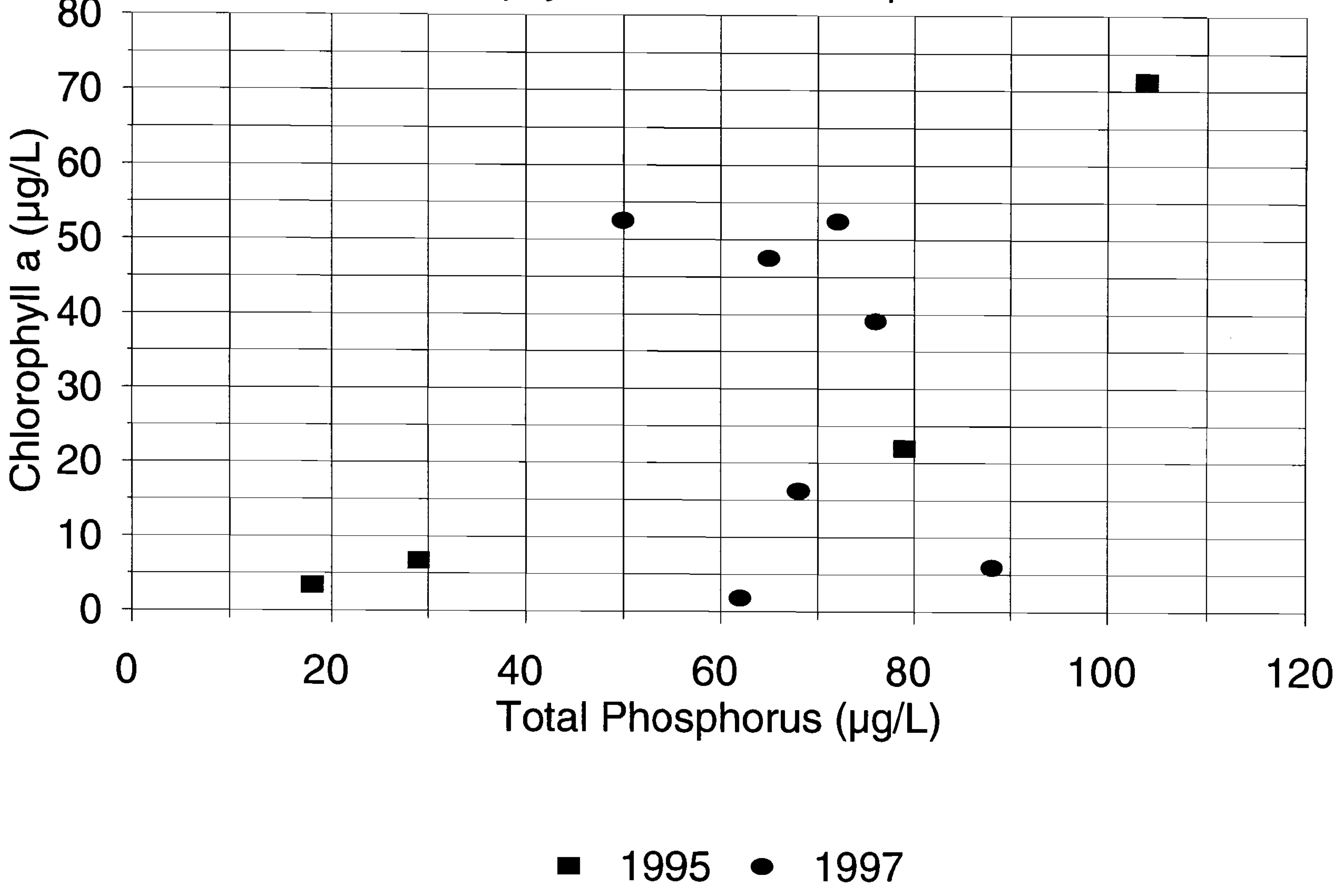


Figure 5

Big Butternut Lake 1995 and 1997
Chlorophyll a and Total Phosphorus



C:\PROJEC~1\BUTTERNU\WATERQUA.WB2

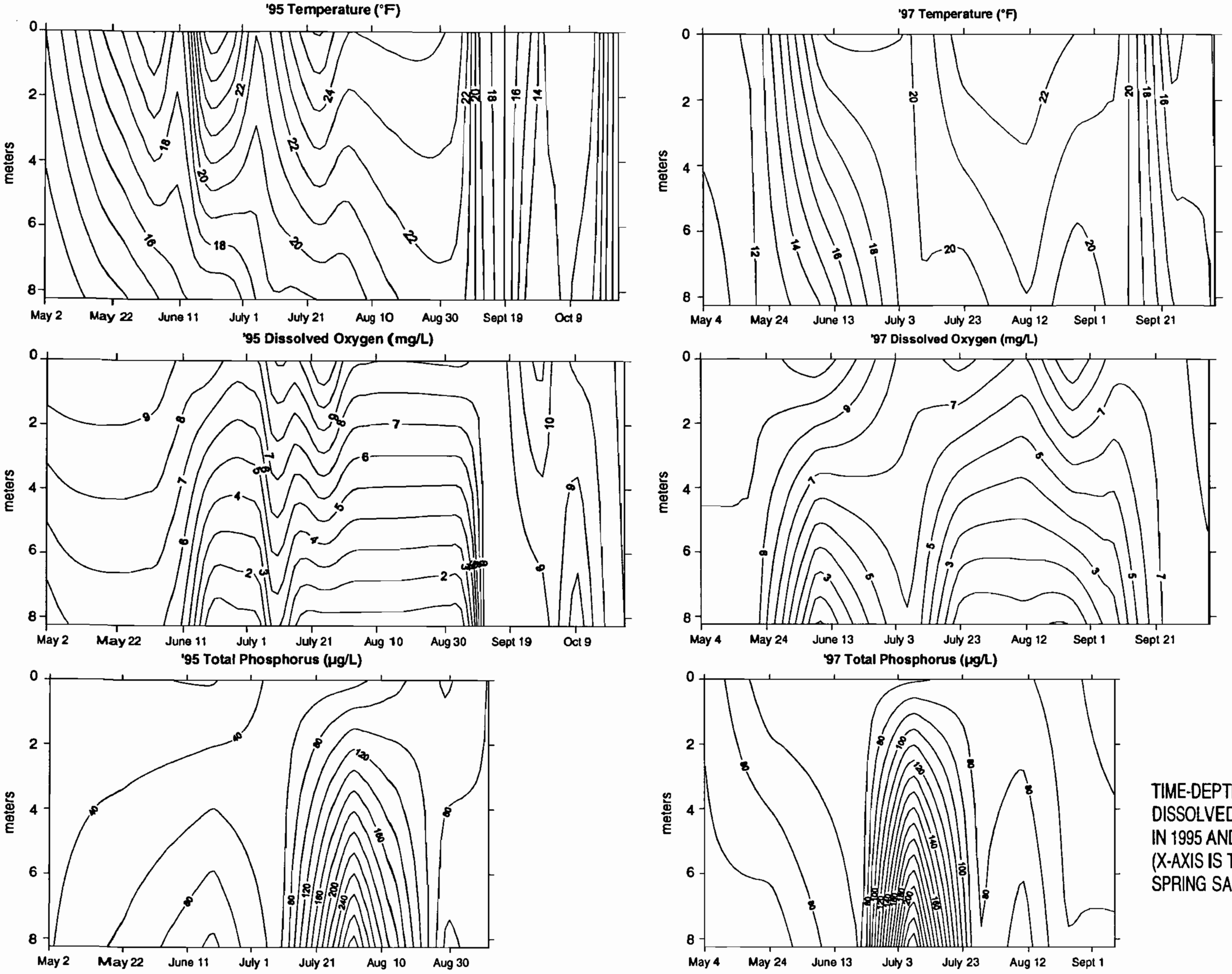


FIGURE 6

TIME-DEPTH DIAGRAMS OF TEMPERATURE, DISSOLVED OXYGEN, AND TOTAL PHOSPHORUS IN 1995 AND 1997 AT BIG BUTTERNUT LAKE, WI (X-AXIS IS TIME IN UNITS OF DAYS FROM THE FIRST SPRING SAMPLING)

c: projects-98
butternut
iso95-7b.srf
BAM9APR99

3.2 Stream Sampling and Flow Gaging

Total phosphorus concentrations from the 10 stream sites during 6 sample events in 1997 and a snowmelt sample collection in March of 1998 is summarized in **Table 3**. Stream Site 2 in subwatershed BL-06 could not be sampled four times because of insufficient stream flow. The flow were very low in the storm sewers from the Village of Luck (Sites 8, 9, and 10), but only one sample from each was not collected due to low flows. These storm sewer samples had the highest phosphorus concentrations, with the two highest concentrations coming from Site 7 in subwatershed BL-01. Because of the high phosphorus concentrations and low flows (based on small watershed size), subwatershed BL-01 had the highest unit area loading of phosphorus and highest (**Figure 7**). A high unit area loading is usually an indicator that the subwatershed should be a focus for best management practices (BMPs) because it would be the most cost-effective reduction of phosphorus to the lake. Overall phosphorus loading is highest from the two largest subwatersheds: BL-05 and BL-06 (**Figure 8**), because of their constant flows, in contrast to the intermittent flows from the storm sewers. The relatively low phosphorus concentration in these undeveloped watersheds is more difficult to remove than in the storm sewers that have higher phosphorus concentrations; therefore, while BL-05 and BL-06 contribute the greatest amount of phosphorus to Big Butternut Lake, it may not more cost effective to remove phosphorus from other sources to reduce the total phosphorus load to the lake.

As part of the stream sampling, samples were collected upstream in subwatersheds BL-05 and BL-06 to evaluate the water quality impacts of existing ponds. In BL-06, sample site 2 was located at the mouth of the stream draining the watershed and sample site 3 was located upstream of a private campsite. In BL-05, sample site 4 was at the mouth of the stream draining the watershed; sample site 5 was immediately downstream of Highway 48; and sample site 6 was immediately downstream of 140th street. In Bl-06, the main sample site (2) only had sufficient flow to sample in May, June, and July, but then did not have sufficient flow in the remaining months, including the snow melt sample on March 27, 1998. The upstream stations, site 3 had sufficient flow to collect samples at all seven sample periods. The results do not show a clear difference between the two sites (**Figure 9a**). At the June and July sampling, the total phosphorus concentrations were lower at the downstream than at the upstream station, suggesting that there was some water treatment between the two stations. This apparent in water quality as it traveled through the watershed could be attributable to wetlands or pools that providing settling of particulates from the water. A similar pattern was seen in BL-05: phosphorus concentration declined from upstream stations to downstream (**Figure 9b**). In May and July there the phosphorus concentrations were

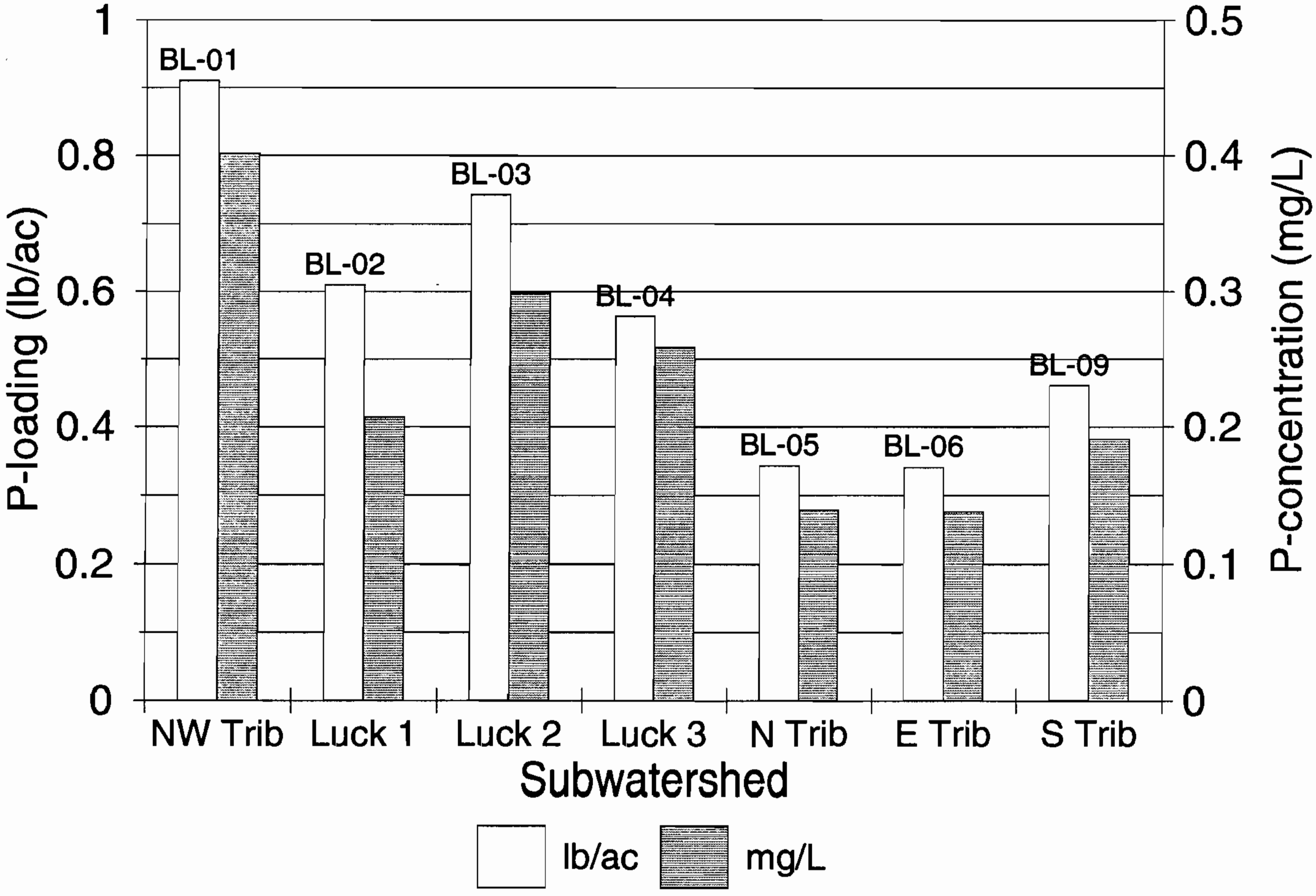
Table 3 Total Phosphorus Concentrations in Stormwater

Date	Total Phosphorus Concentration (mg/L)									
Watershed:	*BL-09*	*BL-06*		*BL-05*			*BL-01*	*BL-02*	*BL-04*	*BL-03*
Site:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
05/29/97	0.128	0.130	0.100	0.117	0.085	0.098	0.131	0.056	**	**
06/24/97	0.275	0.152	0.168	0.192	0.301	0.19	0.963	0.282	0.738	0.301
07/08/97	0.135	0.132	0.168	0.115	0.118	0.099	0.113	**	0.080	0.440
08/19/97	0.125	**	0.128	0.108	0.208	0.144	0.138	0.192	0.130	0.143
09/16/97	0.265	**	0.220	0.159	0.249	0.272	0.742	0.267	0.173	0.111
10/11/97	0.273	**	0.116	0.151	0.365	0.181	0.500	0.371	0.161	0.631
03/27/98	0.137	**	0.112	0.135	0.28	0.197	0.224	0.074	0.267	0.163

** indicates no sample taken due to low flow rates

Figure 7

Big Butternut Lake Phosphorus Loading from Streams and Stormsewers

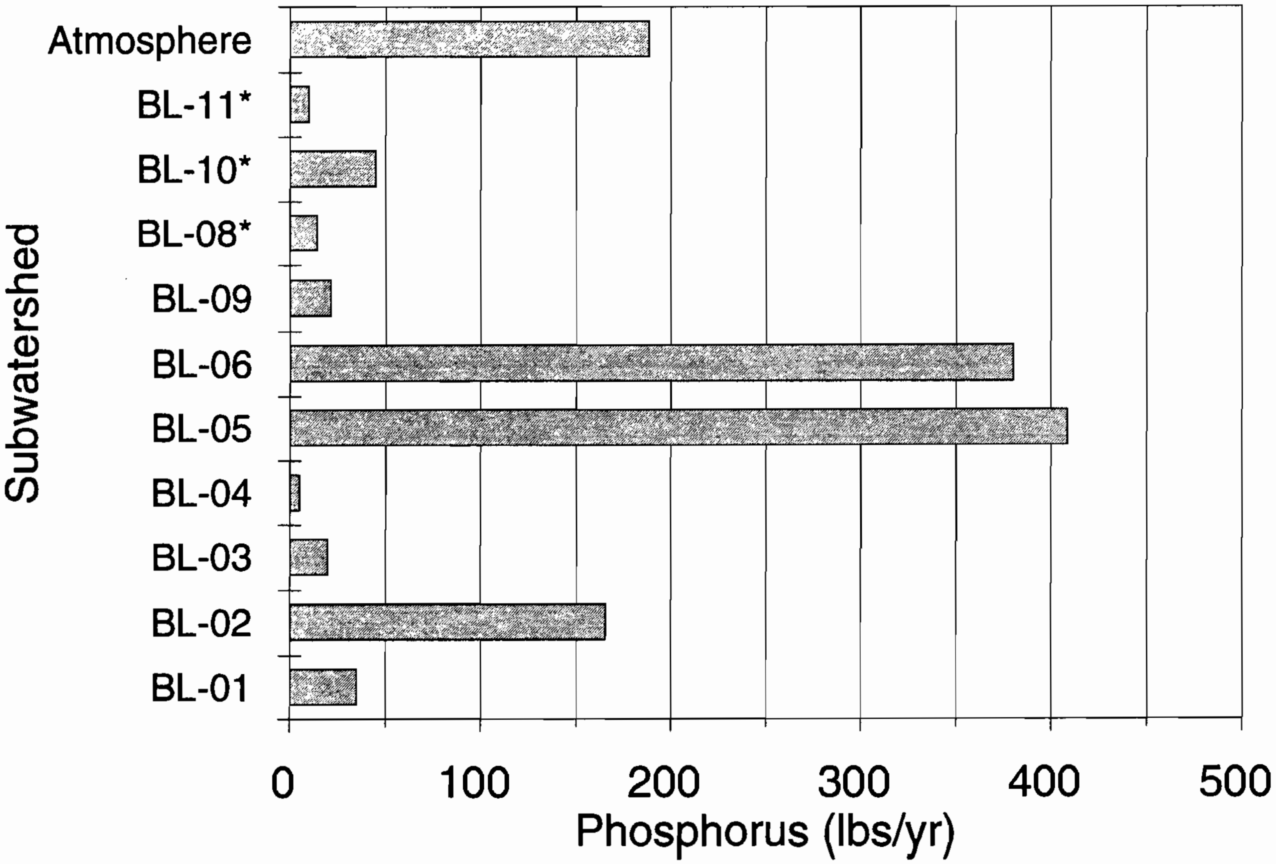


C:\PROJEC~1\BUTTERNU\BUDGETS.WB2

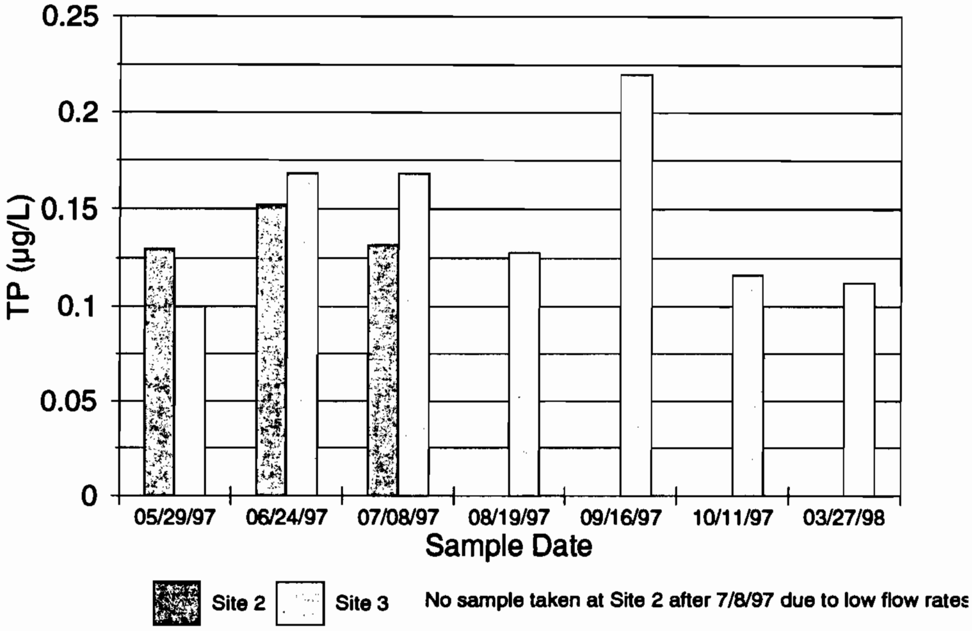
Figure 8

Big Butternut Lake

1997 Phosphorus External Load

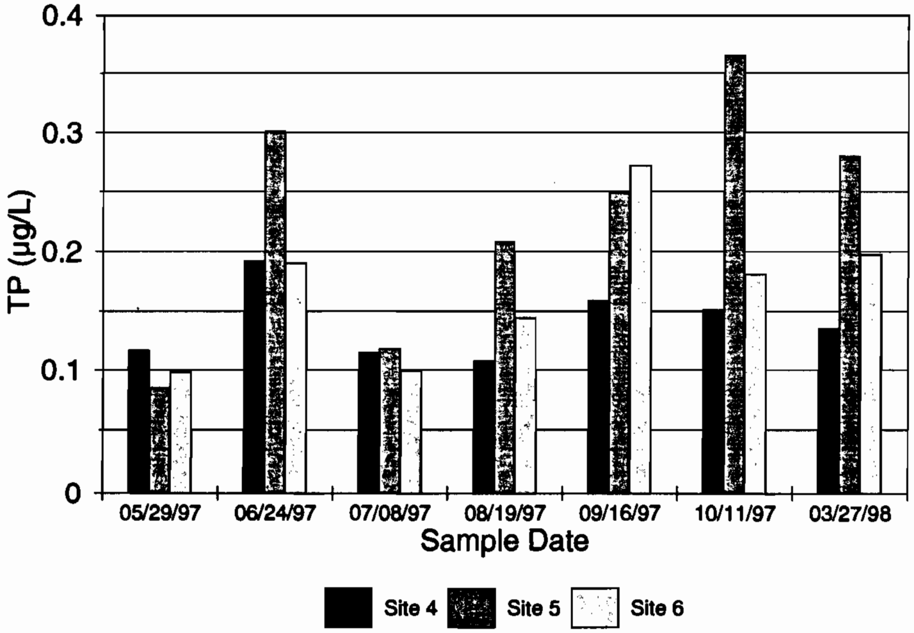


* Loads in these 3 subwatersheds were estimated from unit area loading factors that had been derived from the monitored subwatersheds.



a. Total Phosphorus at East Stream Subwatershed BL-06

No sample taken at Site 2 after 7/8/97 due to low flow rates



b. Total Phosphorus at North Stream Subwatershed BL-05

Figure 9
Total Phosphorus Concentrations
Within Subwatersheds BL-06 (a) and BL-05 (b)

essentially the same at the three stations, but at the other sample dates the phosphorus concentrations at site 5 were considerably higher than the downstream station, site 4. These results indicate that phosphorus inputs to the stream in the vicinity of Highway 48 are reduced downstream.

3.3 Hydrologic and Phosphorus Budgets

Table 4 shows the water and phosphorus budgets for Big Butternut Lake in 1997. Subwatershed BL-01 to BL-09 were based on measurements and the phosphorus loading from the other three watersheds was estimated using average unit areal loading from the gaged watersheds. Subwatersheds BL-05 and BL-06 contributed the greatest quantity of water and phosphorus to the lake, which is not surprising given they are the largest watersheds. Together these two subwatersheds represent 80 percent of the watershed, but contribute approximately 71 percent of the watershed phosphorus to Big Butternut Lake (**Figure 10**). The greatest relative contribution, that is pounds of phosphorus per acre was BL-01, contributing 0.91 lb/ac of phosphorus. The three Luck storm sewers contributed less than BL-01, but more than north, east and south tributaries that are relatively undeveloped. The Village of Luck contributes 8.2 percent of the water to the lake and 12.4 percent of the phosphorus, which is the same as the amount from direct atmospheric deposition (12.3 percent). Internal loading of phosphorus (see above) contributes 15.8 percent of the total phosphorus load to the lake. Thus, the storm sewer runoff contributes a disproportionately larger amount of phosphorus to the lake.

Table 4 Big Butternut Lake Annual Hydrologic and Phosphorus Budgets

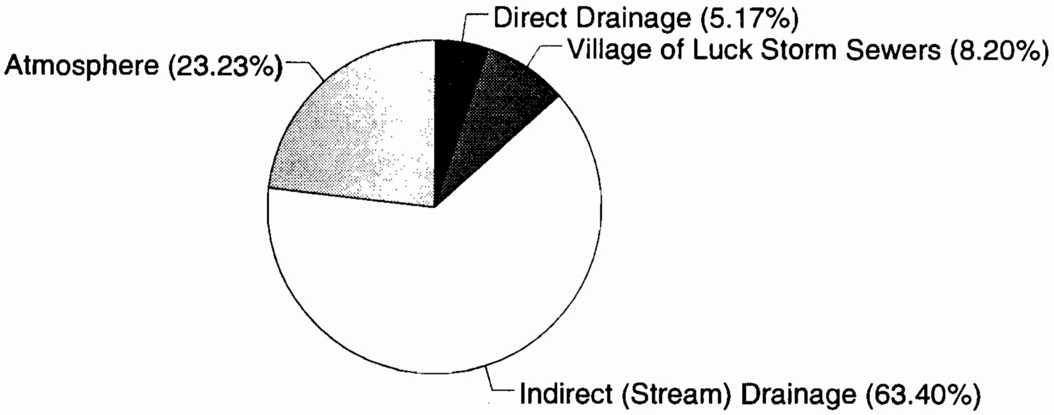
	Water Volume		Phosphorus Mass		Area	
Source	(ac-ft)	(cu. m)	(lbs)	(kg)	(acres)	(hectares)
BL-01	36	44,000	35.5	16.1	39	16
BL-02	250	308,000	166.0	75.3	272	110
BL-03	25	31,000	20.1	9.1	27	11
BL-04	9	11,000	5.3	2.4	9	4
BL-05	1,093	1,348,000	408.8	185.4	1190	482
BL-06	1,022	1,261,000	380.1	172.4	1114	451
BL-09	44	54,000	21.8	9.9	47	19
BL-8*	29	36,087	14.6	6.6	32	13
BL-10*	122	150,475	45.1	20.4	133	54
BL-11*	28	34,158	10.2	4.6	30	12
Watershed Runoff	2,657	3,277,719	1,108	502		
Atmosphere	804	992,056	189	86		
Internal	---	---	243	110		
Total	3,461	4,269,775	1,539	698	2,893	1,171

*Loading was calculated from average unit areal loading from gaged watersheds (0.38 lb P/ac/yr and 0.92 ft water/yr)
Internal load estimated from Dillion-Rigler In-lake model and corresponds to a P release rate of ~ 6 mgP/m2/d for a week

C:\PROJEC~1\BUTTERNU\BUDGETS.WB2

Big Butternut Lake, 1997

Water Loading (ac-ft/yr)



P-loading (lbs P/yr)

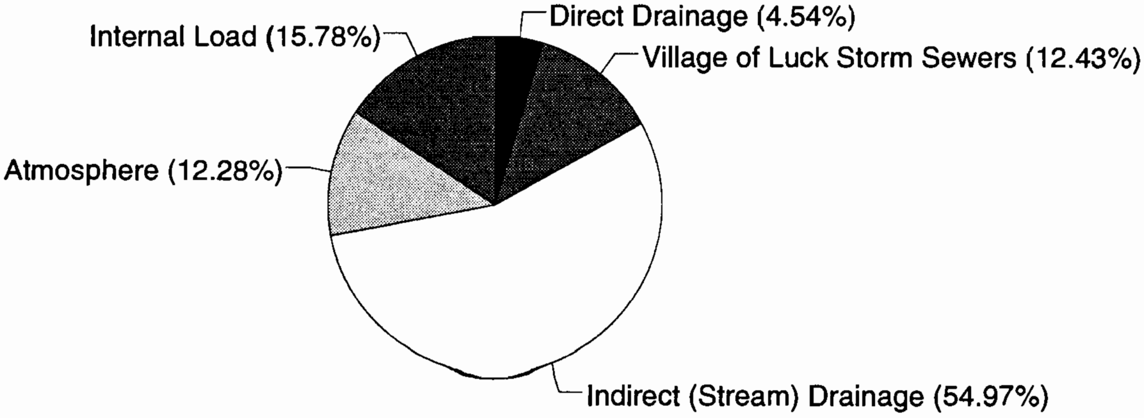


Figure 10

4.0 Discussion

4.1 General Discussion of Improvement Options

4.1.1 Introduction

This section discusses improvement options and general best management practices (BMPs) to remove phosphorus and/or reduce sediment and litter entering a lake. Three types of BMPs were considered during the preparation of this report: structural, nonstructural, and in-lake.

- **Structural BMPs** remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into receiving waters.
- **Nonstructural BMPs** (source control) eliminate pollutants at the source and prevent pollutants from entering stormwater flows.
- **In-Lake BMPs** reduce phosphorus already present in a lake, and/or prevent the release of phosphorus from anoxic lake sediments.

4.1.2 Structural BMPs

Structural BMPs temporarily store and treat stormwater runoff to reduce flooding, remove pollutants, and provide other amenities (Schueler, 1987). Water quality BMPs are specifically designed for pollutant removal. Examples of structural BMPs commonly installed to improve water quality include:

- Wet detention ponds
- Vegetative buffer strips
- Oil and grit separators
- Alum treatment plants

Their effectiveness is summarized in **Table 5**. Structural BMPs control total suspended solids and total phosphorus loadings by slowing stormwater and allowing particles to settle in areas before they reach the stream. Settling areas can be ponds, storm sewer sediment traps, or vegetative buffer strips. Settling can be enhanced by treatment with a flocculent prior to entering the settling basin (see alum treatment plants below).

Table 5 General Effectiveness of Stormwater BMPs at Removing Common Pollutants from Runoff

Best Management Practice (BMP)	Suspended Sediment	Total Phosphorus	Total Nitrogen	Oxygen Demand	Trace Metals	Bacteria	Overall Removal
Wet Pond	5	3	2	3	4	?	4
Infiltration Trench or Basin	5	3	3	4	5	4	4
Porous Pavement	4	4	4	4	4	5	4
Water Quality Inlet (Oil & Grit Chamber)	1	?	?	?	?	?	?
Filter Strip	2	1	1	1	1	?	1

Percent Removal	Score
80 to 100	5
60 to 80	4
40 to 60	3
20 to 40	2
0 to 20	1
Insufficient Knowledge	?

When choosing a structural BMP, the ultimate objective must be well understood. The BMP should accomplish the following:

- **Reproduce, as nearly as possible, the stream flow before development**
- **Remove at least a moderate amount of most urban pollutants**
- **Require reasonable maintenance**
- **Have a neutral impact on the natural and human environments**
- **Be reasonably cost-effective compared with other BMPs**

Source: Schueler 1987

4.1.2.1 Wet Detention Ponds

Wet detention ponds (sometimes called "NURP" ponds after the Nationwide Urban Runoff Program) are impoundments that have a permanent pool of water and also have the capacity to hold runoff and release it at slower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of stormwater runoff. Wet detention ponds are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides. When designed properly, wet detention ponds can also provide some removal of dissolved nutrients. Detention ponds have also been credited with reducing the amount of bacteria and oxygen-demanding substances as runoff flows through the pond.

During a storm, polluted runoff enters the detention basin and displaces "clean" water until the plume of polluted runoff reaches the basin's outlet structure. When the polluted runoff reaches the outlet, it has been diluted by the water previously held in the basin. This dilution further reduces the pollutant concentration of the outflow. In addition, much of the total suspended solids and total phosphorus being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin. A well designed wet detention pond could remove approximately 80 to 95 percent of total suspended solids and 40 to 60 percent of total phosphorus entering the pond (MPCA, 1989).

As storm flows subside, finer sediments suspended in the pond's pool will have a relatively longer period of time to settle out of suspension during the intervals between storm events. These finer sediments eventually trapped in the pond's permanent pool will continue to settle until the next storm flow occurs. In addition to efficient settling, this long detention time allows some removal of dissolved nutrients through biological activity (Walker, 1987). These dissolved nutrients are mainly removed by algae and aquatic plants. After the algae die, the dead algae can settle to the bottom of the pond, carrying with them the dissolved nutrients that were consumed, to become part of the bottom sediments.

The wet detention process results in good pollutant removal from small storm events. Runoff from larger storms will experience pollutant removal, but not with the same high efficiency levels as the runoff from smaller storms. Studies have shown that because of the frequency distribution of storm events, good control for more frequent small storms (wet detention's strength) is very important to long-term pollutant removal.

4.1.2.2 Vegetated Buffer Strips

Vegetative buffer strips are low sloping areas that are designed to accommodate stormwater runoff traveling by overland sheet flow. Vegetated buffer strips perform several pollutant attenuation functions, mitigating the impact of development. Urban watershed development often involves disturbing natural vegetated buffers for the construction of homes, parking lots, and lawns. When natural vegetation is removed, pollutants are given a direct path to the lake—sediments cannot settle out; nutrients and other pollutants cannot be removed. Additional problems resulting from removal of natural vegetation include streambank erosion and loss of valuable wildlife habitat (Rhode Island Department of Environmental Management, 1990).

The effectiveness of buffer strips is dependent on the width of the buffer, the slope of the site, and the type of vegetation present. Buffer strips should be 20 feet wide at a minimum, however 50 to 75 feet is recommended. Many attractive native plant species can be planted in buffer strips to create aesthetically pleasing landscapes, as well as havens for wildlife and birds. When properly designed, buffer strips can remove 30 to 50 percent of total suspended solids from lawn runoff. In addition, well designed buffer strips will discourage waterfowl from nesting and feeding on shoreland lawns. Such waterfowl can be a significant source of phosphorus to the pond, by grazing turfed areas adjacent to the water and defecating in or near the water's edge where washoff into the pond is probable.

4.1.2.3 Oil and Grit Separators

Oil-grit separators are concrete chambers designed to remove oil, sediments, and floatable debris from runoff, and are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations, roads, and holding areas. A three-chamber design is common; the first chamber traps sediment, the second chamber separates oil, and a third chamber holds the overflow pipe. The three-chambered unit is enclosed in reinforced concrete. They are good at removing coarse particulates, but soluble pollutants probably pass through. Proper operation requires regular clean out (at least twice a year). The major benefit of a water oil-grit separator is as a pre-treatment for an infiltration basin or pond. They can also be incorporated into existing stormwater system or included in an underground vault detention system when no available land exists for a surface detention basin. NURP results indicated the chambers provided only moderate removals of total suspended solids; however, oil and floatable debris are effectively removed from properly designed oil and grit separators, and more recent designs have improved the treatment efficiency of these BMPs.

4.1.2.4 Alum Treatment Plants

In addition to the commonly installed structural BMPs discussed above, alum treatment plants are becoming an option for efficiently removing phosphorus from tributaries, rather than directly treating the lake with alum to remove phosphorus. Alum (aluminum sulfate) is commonly used as a flocculent in water treatment plants and as an in-lake treatment for phosphorus removal. To treat inflows in streams or storm sewers, part of the flow is diverted—up to 5 cfs—from the main flow and treated with alum. After the alum is injected in the diverted flow it passes to a detention pond to allow the flocculent to settle out before the water enters the lake. Treatment is generally only for spring and fall runoff. Alum treatment has been shown to remove 90 percent of the soluble and particulate phosphorus from the inflows.

4.1.3 Nonstructural BMPs

Nonstructural ("Good Housekeeping") BMPs discussed below include:

- Public education
- Local ordinances
- Street sweeping
- Deterrence of waterfowl
- Fertilizer management

Good housekeeping practices reduce the pollutant at its source.

4.1.3.1 Public Education

Public education regarding proper lawn care practices, such as fertilizer use and disposal of lawn debris, would result in reduced organic matter and phosphorus loadings to the lake. A public information and education program may be implemented to teach residents within the Big Butternut Lake watershed how to protect and improve the quality of the lake. The program would include distribution of fliers to all residents in the watershed and placement of advertisements and articles in the city's newsletters and the local newspapers. Information could also be distributed through organizations such as local schools, Girl Scouts and Boy Scouts, and other local service clubs.

Initiation of a stenciling program to educate the public would help reduce loadings to the storm sewer system. Volunteers could place stenciled messages (i.e., "Dump No Waste, Drains to Big Butternut Lake") on all storm sewer catch basins within the watershed.

4.1.3.2 Local Ordinances

Legislative methods of addressing water quality could include a watershed-wide ban on the use of phosphorus fertilizers or a commercial lawn care ordinance to control content of mixture and ensure that no phosphorus is present in the case of a complete phosphorus ban. Indeed, the Village and Township of Luck have passed such ordinances. Exceptions to such a ban would be granted in cases where a resident was able to demonstrate, by means of soil analyses, that phosphorus was required. Other ordinances pertaining to littering, pet feces, and buffer strips adjacent to lakes and other water bodies could be strengthened or created.

4.1.3.3 Street Sweeping

Most often, street sweeping is performed only in the spring, after the snow has melted. Street sweeping should also be performed in the fall, after the leaves have fallen, to reduce this potential source of phosphorus from entering the storm sewer. For most urban areas, street sweeping has relatively low effectiveness from late spring (after the streets are cleaned of accumulated loads) until early fall (prior to the onset of leaf fall) (Bannerman, 1983). In addition, the use of vacuum sweepers is preferred over the use of mechanical, brush sweepers. The vacuum sweepers are more efficient at removing small phosphorus-bearing particles from impervious surfaces within the watershed. Fall street sweeping is particularly important in the watershed directly tributary to the lake, where treatment of stormwater is not available.

4.1.3.4 Deterrence of Waterfowl

The role of waterfowl in the transport of phosphorus to lakes is often not considered. However, when the waterfowl population of a lake is large relative to the lake size, a substantial portion of the total phosphorus load to the lake may be caused by the waterfowl. Waterfowl tend to feed primarily on plant material in or near a lake; the digestive processes alters the form of phosphorus in the food from particulate to dissolved. Waterfowl feces deposited in or near a lake may result in an elevated load of dissolved phosphorus to the lake. One recent study estimated that one Canada goose may produce 82 grams of feces per day (dry weight) while a mallard may produce 27 grams of feces per day (dry weight) (Scherer et al., 1995). Waterfowl prefer to feed and rest on areas of short grass adjacent to a lake or pond. Therefore, shoreline lawns which extend to the water's edge will attract waterfowl. The practice of feeding bread and scraps to waterfowl at the lakeshore not only adds nutrients to the lake, but attracts more waterfowl to the lake and encourages migratory waterfowl to remain at the lake longer in the fall.

Two practices often recommended to deter waterfowl are construction of vegetated buffer strips, and prohibiting the feeding of waterfowl on public shoreline property. As stated above, vegetated strips along a shoreline will discourage geese and ducks from feeding and nesting on lawns adjacent to the lake, and may decrease the waterfowl population.

4.1.3.5 In-Lake BMPs

In-lake BMPs reduce phosphorus already present in a lake or prevent the release of phosphorus from the lake sediments. Two in-lake BMPs are discussed below: alum application and aeration.

Application of Alum (Aluminum Sulfate)

As discussed above, there is a net internal load of phosphorus from the sediments in Big Butternut Lake. Sediment release of phosphorus to the lake basins occurs during the summer months, when the oxygen in the water overlying the sediments is depleted of oxygen. This internal load of phosphorus is transported to the entire lake during late summer, when the surface waters cool sufficiently for wind-mixing to mix the entire lake (often referred to as "fall turnover"). Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Areal application of alum has proven to be a highly effective and long-lasting control of phosphorus release from the sediments, especially where an adequate dose has been delivered to the sediments and where watershed sediment and phosphorus loads have been minimized (Moore and Thornton, 1988). Alum will remove phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents phosphorus from entering the lake as internal load. An alum treatment will likely be effective for 10 years, depending on the control of watershed nutrient loads.

Aeration (Artificial Circulation)

This BMP can be effective at reducing internal phosphorus loading by preventing anoxic conditions that lead to phosphorus release from the sediments. Aeration is more commonly used to prevent winter fishkills and to enhance fish habitat by increasing the area of the lake with sufficient dissolved oxygen concentrations. The capital costs represent only a fraction of the total cost of aeration. The long-term costs for electricity to operate the pumps become the primary cost of an aeration system. If the water quality management objectives include enhancing or restoring fishery habitat, aeration is certainly an option to consider.

4.2 Feasibility Analysis

4.2.1 Selection and Effectiveness of Alternatives

Three types of BMPs were considered for recommendation in this plan:

- Structural
- Nonstructural
- In-lake

Each of these types are defined and discussed above; cost analysis details are given in Appendix D. Specific BMP alternatives that were considered for the Big Butternut Lake and its watershed are discussed below. Not all of the BMP alternatives discussed below are recommended for implementation. **Table 6** summarizes the cost and phosphorus removal efficiency of the BMPs. The watershed and in-lake BMPs are compared on the basis of pounds of phosphorus removed for a ten year period. **Figure 11** summarizes the water quality benefits of the BMPS, based on a model of in-lake phosphorus concentrations for the predicted reductions in phosphorus loading.

4.2.2 Structural BMP Alternatives

Phosphorus discharged to the lake is mainly associated with small particles (with slow settling rates) or is not associated with particles (i.e., soluble phosphorus). Stormwater detention basins designed according to NURP criteria can remove the smaller particles and even allow for removal for soluble phosphorus through uptake by algae and other aquatic life.

The following additional structural BMPs were considered during the preparation of this report:

4.2.2.1 Subwatersheds BL-05 and BL-06—Detention Ponds or Wetlands

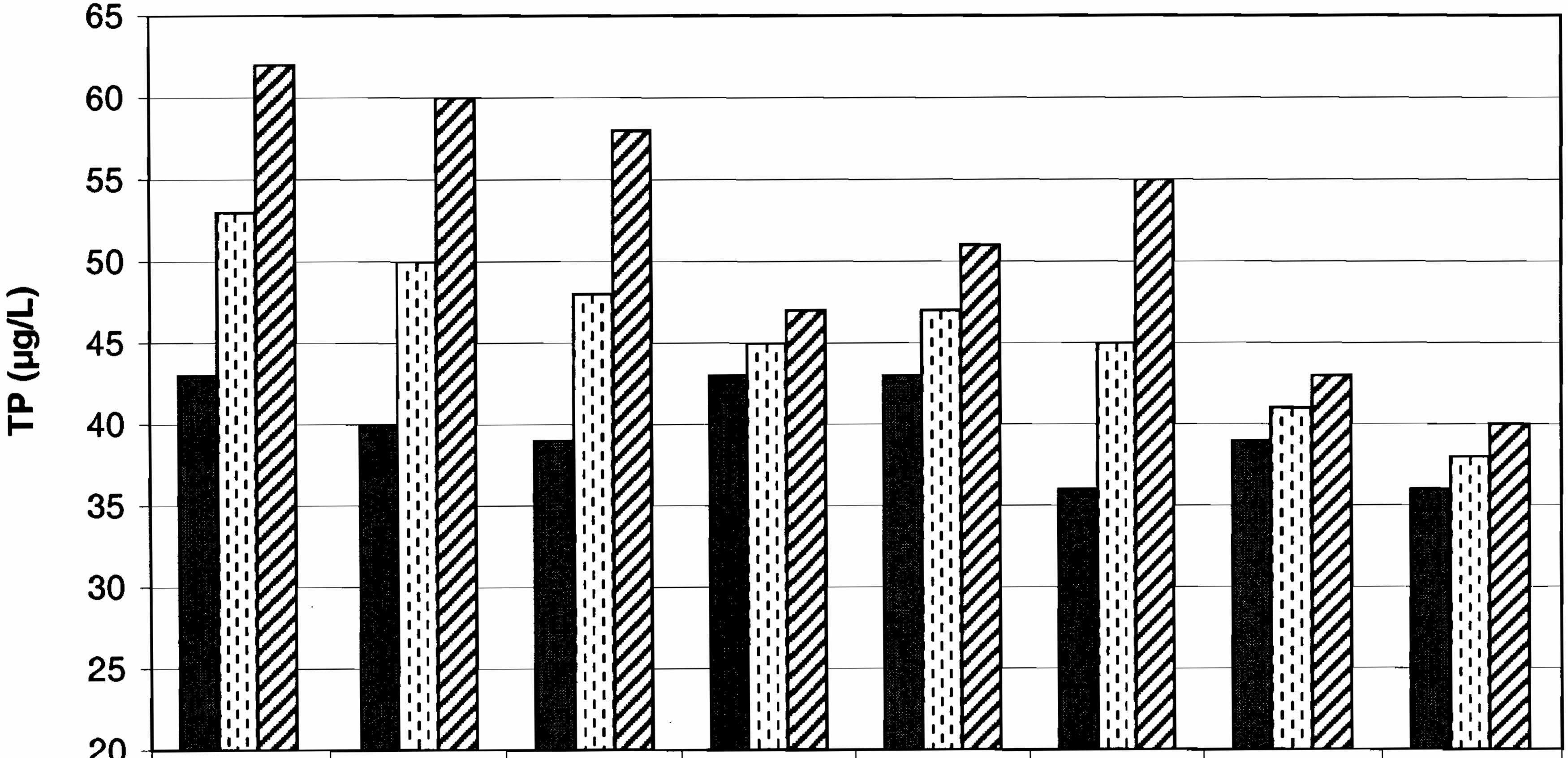
BL-05 and BL-06 represent the largest proportion of the lake's watershed and phosphorus loading to the lake. Because both subwatersheds are mostly undeveloped, ordinances that require storm water control on new developments will not have much effect on the phosphorus loading from these watersheds. To reduce phosphorus loading from these watersheds, the best option is constructing stormwater detention ponds or maintain the integrity of existing wetlands to collect particulate phosphorus and possibly remove some soluble phosphorus through biological uptake.

Table 6 Big Butternut Lake—Cost and Water Quality Benefits of Structural and In-Lake BMPs

Option	Total Phosphorus Load Removed (lbs)	Percent Reduction of Total Phosphorus to Lake	Capital Cost	Annual Operation & Maintenance Cost	Cost per Pound of Phosphorus for a 10-Year Period ($/lb P)
1. No Additional BMPs	0	—	$0	$0	—
2. Storm Sewer Chambers in Village of Luck	91	8%	$350,000	$1500	$401
3. Detention Pond on North Stream (BL-05)	137	12%	$180,000	$1000	$139
4. In-Lake Alum Treatment	242	22%	$115,000	$0	$48
5. In-Lake Aeration	242	22%	$84,000	$16,000	$101
6. Chambers & Pond (2 & 3)	228	21%	$530,000	$2500	$243
7. North Pond & In-lake Alum Treatment (3 & 4)	379	34%	$295,000	$1000	$80
8. Chambers, Pond, & Alum Treatment (2, 3, and 4)	470	42%	$645,000	$2500	$143

Figure 11

Effects of BMPs on Big Butternut Lake Phosphorus Concentration



	1. No BMPs	2. Storm Sewer Chambers	3. BL-05 Detention Pond	4. In-lake Alum Treatment	5. In-lake Aeration	6. Chambers and Pond (2&3)	7. Pond and In-lake Alum (3&4)	8. Chambers, Pond, & Alum (2,3,&4)
■ Spring	43	40	39	43	43	36	39	36
□ Mid-summer	53	50	48	45	47	45	41	38
▨ Late Summer	62	60	58	47	51	55	43	40

Big Butternut In-Lake Model Results: in lake model BMPs.xls

For subwatershed BL-05, a stormwater detention basin could be constructed south of Highway 48 (see Figure 1 for location). This area has had beaver ponds that periodically break and flush nutrients downstream to Big Butternut Lake. A permanent structure would provide a more reliable treatment system of stormwater than the incidental and somewhat unpredictable treatment from the beaver ponds. A detention basin will remove both nutrients and suspended solids from stormwater runoff from the highway and from other sources upstream in the watershed. Estimated cost for this BMP (excluding land acquisition costs) is approximately $180,000. Operation and maintenance cost is primarily dredging to remove collected sediment. Dredging would most likely occur approximately ten years after construction and would cost an estimated $10,000. Additional design engineering would be necessary to predict the phosphorus removal efficiency and construction of the pond. The wet detention pond design used to estimate the cost should provide at least 40 percent removal of the inflow phosphorus to the pond. This translates to 137 lb phosphorus per year, or 12 percent of the total annual watershed phosphorus load to the lake.

In subwatershed BL-06, a location for a detention pond is not as apparent as it is in BL-05. The lake district may want to continue to monitor nutrients in BL-06 watershed to determine if there are hot spots in the watershed that could either be removed or controlled. The natural wetlands in subwatershed BL-06 may provide some removal of phosphorus; therefore, an alternative BMP for this watershed would be enhancement of the treatment capacity of the wetlands, such increasing the retention time in the watershed through extended meandering of the stream. Stream restoration techniques would likely provide a means of increasing retention time and thereby improving the phosphorus removal in the stream.

4.2.2.2 Subwatersheds BL-01, BL-02, BL-03, BL-04—Oil and Grit

Oil and Grit chambers in storm sewer lines are an effective BMP for urban areas when they are properly maintained. Given the modifications taking place on roads and storm sewers in the Village of Luck, grit chambers are recommended for subwatersheds BL-01, BL-02, BL-03, and BL-04. Normally stormwater runoff from streets contains large amounts of particulates that contain metals as well as nutrients and are not removed before they enter the lake. An in-line or off-line storm water treatment system, such as the Stormceptor™ or Vortecs™, will concentrate and collect a large fraction of the particulates. The chambers should be cleared of grit and debris at least once per year. The cost of the chambers varies with the size of the chamber, which is based on the size of the watershed. The grit chambers do not, generally, treat more than a 20 acre watershed, thereby requiring several chambers with a storm sewer network. Each chamber is approximately $50,000 for capitol cost, engineering, and installation. Given the areas of the subwatersheds in the Village, at least four chambers would need to be installed and preferably seven chambers. Therefore the estimated cost for the preferred number is $350,000. The chambers would need to be vacuumed annually, at a cost of approximately $250 per unit. With a predicted phosphorus removal efficiency of 40 percent, the grit chambers are expected to remove 91 lb of phosphorus per year, or 8 percent of the total phosphorus load to Big Butternut Lake.

4.2.3 Nonstructural BMP Alternatives

Removing phosphorus at the source is an obvious cost-effective strategy when the sources are readily identified. Source control usually relies heavily on nonstructural BMPs that are effective at reducing the amount of phosphorus on-site, before transport into stormwater runoff. Studies have shown that nonstructural BMPs are moderately effective at reducing phosphorus loads. Examples of effective nonstructural BMPs that would be appropriate to this watershed include:

- Public education programs to inform the residents in the Big Butternut Lake watershed of ways to reduce phosphorus loading through proper handling of yard wastes, fertilizers, pet wastes, soaps and detergents.

- Encourage good housekeeping practices from industrial and commercial sites, including appropriate disposal of yard wastes, appropriate disposal of trash and debris, appropriate storage and handling of soil and gravel stockpiles.

- Discourage the feeding of waterfowl at shoreline areas around the lake.

- Encourage vegetated buffers between yards and wetlands and ponds; maintain vegetated buffers between yards/roads and the shore of Big Butternut Lake.

- Perform regular street sweeping, including school and church parking lots. Spring and fall street sweeping will provide the most benefits for phosphorus source reduction.

Because nonstructural BMPs are often a part of volunteer community programs and their effectiveness is not as readily quantified as in structural BMPs, their costs have not been estimated for this feasibility analysis. Nevertheless, they should be included as a part of the lake and watershed management plan.

4.2.4 In-Lake BMP Alternatives

4.2.4.1 Alum Treatment

Monitoring data and water quality modeling indicate that sediment-released phosphorus can severely affect the late summer water quality in the lake. In-lake application of alum (aluminum sulfate) to prevent sediment phosphorus release is, therefore, a good option for Big Butternut Lake. The alum treatment is expected to reduce the internal phosphorus load by 90 percent (219 lb), which is a 22 percent reductic in the total phosphorus load to the lake. This would have the greatest single impact on the phosphorus concentrations in the lake in the short-term (i.e., for approximately 10 years). Approximate cost of an in-lake alum application is $115,000.

4.2.4.2 Aeration

Another in-lake BMP that was considered for Big Butternut Lake was aeration. As described above, this BMP can be effective at reducing internal phosphorus loading by preventing anoxic conditions that lead to phosphorus release from the sediments. This BMP has the added benefit of enhancing fish habitat by increasing the area of the lake with sufficient dissolved oxygen concentrations. The biggest disadvantage of this option is its cost. The approximate cost of an aeration system is $84,000 to install the system and $16,000 for annual operation and maintenance, which is primarily electricity costs. Therefore, in the first year, the aeration system would cost approximately $100,000. The system is designed to operate 10 years before rebuilding maintenance is needed. To compare the aeration to the alum treatment would be the 10-year cost of $244,000. Unlike alum treatment, where a fairly confident prediction of phosphorus removal can be made, the effectiveness of aeration in reducing phosphorus is not well understood. Thus, there is more uncertainty in the outcome of an aeration system than with alum treatment. The aeration system is, therefore, only the best alternative if the goal to improve the fishery habitat. Based on discussions with the lake district board and with others present at the 1998 annual meeting, there did not appear to be a strong desire to improve the fishery habitat in this way. Therefore, the alum treatment remains the only recommended in-lake BMP for Big Butternut Lake.

Table 6 and Figure 11 includes the effect of combining the BMPs. Separately each BMP is predicted to remove less than 25 percent the total phosphorus load to Big Butternut Lake. Implementing more than one BMP would have an additive effect in reducing the TP concentration in the lake. In addition, reducing watershed phosphorus loading would extend the effective life of the alum treatment. The greatest phosphorus reduction would obviously come from implementing all BMPs. Option 8 includes the storm sewer chambers, detention pond, and alum treatment. The combined treatment would reduce the phosphorus load by 42 percent and result in a predicted mid-summer phosphorus concentration of 38 µg/L, compared to a predicted 53 µg/L with no BMPs. This 28 percent reduction in the phosphorus load could increase the average Secchi depth from approximately 4 feet to 5.7 feet. Alum treatment alone would increase the Secchi depth to approximately 5.3 feet.

5.0 Conclusions and Recommendations

The analysis of trends in total phosphorus, chlorophyll *a*, and Secchi disc transparency indicated the Big Butternut Lake is eutrophic to hypereutrophic. Based on four years of Secchi depths (1995-1998), water quality remained fairly stable from year-to year and throughout the summer. A phosphorus budget for Big Butternut Lake was developed from stormwater runoff in 1997 and in-lake water quality monitoring. The budget calculations show the watershed contributes approximately 71 percent of the phosphorus to Big Butternut Lake. The average areal loading of phosphorus from the watershed was 0.38 lb P/ac/yr. Internal release of phosphorus accounts for approximately 16 percent of the total phosphorus budget. Stormwater from the Village of Luck contributes slightly more than 12 percent of the total phosphorus to the lake.

Based on the phosphorus loading from subwatersheds and calculations of internal phosphorus loading, several best management practices (BMPs) have been evaluated for their effectiveness at reducing phosphorus concentrations in the lake during the spring, mid-summer, and late summer. In terms of the cost per pound of phosphorus removed, the BMPs are ranked as follows from lowest cost per pound to highest cost:

1. In-lake alum treatment ($48/lb-P)
2. In-lake aeration ($101/lb-P)
3. North Stream detention pond ($139/lb-P)
4. Storm sewer chambers in the Village of Luck ($401/lb-P)

A combination of BMPS can reduce the average cost per pound and the total pounds of phosphorus removed is additive. Alum treatment is the most cost effective at removing phosphorus, but to maximize the effectiveness of the in-lake treatment, watershed BMPs should be encouraged. The combination of North Stream detention pond and alum treatment ($80/lb-P) is probably the best option in terms of cost per pound; however, adding the storm sewer chamber to these two BMPs ($143/lb-P) would extend the effective life of the alum treatment and could reduce the in-lake phosphorus by 42 percent. The actual option selected by the BBLPRD will depend on other factors such as financing, availability of land for BMPs and DNR staff support.

Program provide up to $200,000 per project and up to a 75 percent state cost share. The grant can be used to pay for the lake improvement BMPs, including land acquisition. The BBLPRD will need to have a lake management plan approved by the Department of Natural Resources, which the compiled planning grant reports are likely to provide. The deadline for applying for the protection grants is May 1. If the BBLPRD wants to support both the watershed BMPs and the in-lake alum treatment, the watershed BMPs should be considered as a first phase.

In addition to considering investments in BMPs, monitoring of water quality and aquatic plant growth in the lake should continue. Stakeholders will certainly want to know the effect of BMPs when they are implemented and long term lake water quality monitoring is the best way to separate year-to-year variability from actual trends. Another consideration is that improvements in lake water clarity will most likely lead to an increase in some aquatic plant growth because the rooted plants get their nutrients from the sediments and their growth is often light-limited. Therefore, aquatic plant removal activities, such as mechanical harvesting or herbicide application, should continue.

References

Barr Engineering. 1996. Wisconsin Lake Planning Grants LPL-260 and LPL-289 Final Report. Prepared for the Butternut Lake Protection and Rehabilitation District.

Bannerman, R., K. Baun, M. Bohn, P. Hughes, and D. Graczyk. 1983. Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee, Wisconsin, Volume I. Urban Stormwater Characteristics, Pollutant Sources and Management by Street Sweeping. Prepared for the U.S. Environmental Protection Agency, Region V, Chicago, IL. PB 84-114164.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs, Second Edition. Lewis Publishers, Boca Raton, FL. 548 pp.

Dillon, P.J. and F.H. Rigler. 1974. A test of a simple nutrient budget model predicting the phosphorus concentrations in lake water. J. Fish. Res. Bd. Can. 31: 1771-1778.

LaMarr, V.J., Jr. 1975. Digestive activities of carp as a major contributor to the nutrient loading of lakes. Verh. Int. Verein. Limnol. 19: 2461-2468.

Minnesota Pollution Control Agency (MPCA). 1989. Protecting Water Quality in Urban Areas.

Moore, L., and K. Thornton, (Eds.). 1988. Lake and Reservoir Restoration Guidance Manual. EPA 440/5-88-002

Nürnberg, G.K. 1984. The prediction of internal phosphorus loads in lakes with anoxic hypolimnia. Limnol. Oceanogr 29(1): 111-124.

Pullmann, G.D., 1992. The Lake Association Leader's Aquatic Vegetation Management Guidance Manual. The Midwest Aquatic Plant Management Society, Flint, Michigan.

Ramsey County Department of Public Works, Environmental Services Division, November 1988. Phalen Chain of Lakes Restoration Project. EPA Project No. S-500-5678.

Rhode Island Department of Environmental Management, 1990. The Land Management Project.

Scherer, N.M., H.L. Gibbons, K.B. Stoops, and M. Muller. 1995. Phosphorus Loading of an Urban Lake by Bird Droppings. Lake and Reserv. Manage. 11(4): 317-327.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Prepared for Washington Metropolitan Water Resources Planning Board. Metropolitan Washington Council of Governments, Washington, D.C. 275 pp.

Osgood, R.A. 1989. Assessment of Lake Use-Impairment in the Twin Cities Metropolitan Area. Prepared for the Minnesota Pollution Control Agency. Metropolitan Council Publication 590-89-130. 12 pp.

Walker, W.W., 1987. Phosphorus Removal by Urban Runoff Detention Basins. Lake and Reservoir Management: Volume III. North American Lake Management Society.

Big Butternut Lake Water Quality Data 1997

Date	Depth (m)	Temp-erature (C)	DO (mg/L)	Secchi (ft)	Depth (m)	TP (µg/L)	SRP (µg/L)	Chla (µg/L)
05/04/97				4.5	1.4			
05/20/97				5	1.5			
06/09/97				7	2.1			
06/24/97				8	2.4			
07/08/97				4	1.2			
07/14/97				3.75	1.1			
07/23/97				3	0.9			
08/05/97				3	0.9			
08/12/97				3	0.9			
08/26/97				3	0.9			
09/09/97				3	0.9			
09/24/97				3	0.9			
05/04/97	0	12	11	4.5	1.4			
05/04/97	1	11	11					
05/04/97	2	11	10.8					
05/04/97	3	11	10.8					
05/04/97	4	11	10.6					
05/04/97	5	10.5	9.5					
05/04/97	5.5	10	9.2					
05/20/97	0	12.2	10.3	5	1.5	88	2	6
05/20/97	1	12.2	10.3					
05/20/97	2	12.1	10.2					
05/20/97	3	12.2	10.2					
05/20/97	4	12	10.2			100	2	
05/20/97	5	12	9.9			89	2	
05/20/97	5.5	12	9.6					
06/09/97	0	20	11.8	7	2.1	62	2	1.85
06/09/97	1	20	11.6					
06/09/97	2	20	11.8					
06/09/97	3	19.8	9.6					
06/09/97	4	15	7.9			71	2	
06/09/97	5	14.5	4					
06/09/97	5.5	14	0.5			99	4	
07/08/97	0	20	7.3					
07/08/97	1	20	7.2					
07/08/97	2	20	7.2					
07/08/97	3	20	7					
07/08/97	4	20	6.9			71	3	
07/08/97	5	20	6.6					
07/08/97	5.5	20	6			69	5	

Big Butternut Lake Water Quality Data 1997

Date	Depth (m)	Temp-erature (C)	DO (mg/L)	Secchi (ft)	Depth (m)	TP (µg/L)	SRP (µg/L)	Chla (µg/L)
07/23/97	2	22.7	8.3					
07/23/97	3	22.5	8.1					
07/23/97	4	22.5	7.9			47	3	
07/23/97	5	19.8	0.5					
07/23/97	5.5	19.3	0.3			246	105	
08/12/97	0	22.7	6.8	3	0.9	76	1	39.1
08/12/97	1	23	6.7					
08/12/97	2	23	6					
08/12/97	3	22.8	4					
08/12/97	4	22.5	3.5			63	1	
08/12/97	5	21	0.5					
08/12/97	5.5					79	4	
08/26/97	0	22	10	3	0.9	72	4	52.5
08/26/97	1	21.1	9.9					
08/26/97	2	20.9	9.2					
08/26/97	3	20.5	8.5					
08/26/97	4	19.7	2.2			41	3	
08/26/97	5	19.2	0.06					
08/26/97	5.5	19.1	0.025			97		
09/24/97	0	14.5	7.4	3	0.9	50	3	52.6
09/24/97	1	17.5	7.4					
09/24/97	2	17.2	7.4					
09/24/97	3	17.2	7.3					
09/24/97	4	17.1	7.3			74	2	
09/24/97	5	17.1	7.3					
09/24/97	5.5	17.1	7.3			73	2	
09/09/97	0	21	7.4	3	0.9	65	4	47.6
09/09/97	1	21	7.4					
09/09/97	2	20.8	7.1					
09/09/97	3	20.8	7					
09/09/97	4	20.6	6.7			74	4	
09/09/97	5	20.5	6.2					
09/09/97	5.5	20.4	2.5			70	4	
10/07/97	0	16.1	8.6					
10/07/97	1	16	8.6					
10/07/97	2	16	8.4					
10/07/97	3	16	8.3					
10/07/97	4	16	8.3					
10/07/97	5	15.9	7.8					
10/07/97	5.5	15.9	7.7					

Big Butternut Lake Stream Water Quality Data

Sample Date	Stream Locations	TP (mg/L)
05/29/97	1	0.128
05/29/97	2	0.13
05/29/97	3	0.1
05/29/97	4	0.117
05/29/97	5	0.085
05/29/97	6	0.098
05/29/97	7	0.131
05/29/97	8	0.056
05/29/97	9	
05/29/97	10	
06/24/97	1	0.275
06/24/97	2	0.152
06/24/97	3	0.168
06/24/97	4	0.192
06/24/97	5	0.301
06/24/97	6	0.19
06/24/97	7	0.963
06/24/97	8	0.282
06/24/97	9	0.738
06/24/97	10	0.301
07/08/97	1	0.135
07/08/97	2	0.132
07/08/97	3	0.168
07/08/97	4	0.115
07/08/97	5	0.118
07/08/97	6	0.099
07/08/97	7	0.113
07/08/97	8	
07/08/97	9	0.08
07/08/97	10	0.44
08/19/97	1	0.125
08/19/97	2	
08/19/97	3	0.128
08/19/97	4	0.108
08/19/97	5	0.208
08/19/97	6	0.144
08/19/97	7	0.138
08/19/97	8	0.192
08/19/97	9	0.13
08/19/97	10	0.143
09/16/97	1	0.265
09/16/97	2	
09/16/97	3	0.22
09/16/97	4	0.159
09/16/97	5	0.249
09/16/97	6	0.272
09/16/97	7	0.742
09/16/97	8	0.267
09/16/97	9	0.173
09/16/97	10	0.111
10/11/97	1	0.273
10/11/97	2	
10/11/97	3	0.116
10/11/97	4	0.151
10/11/97	5	0.365
10/11/97	6	0.181
10/11/97	7	0.5
10/11/97	8	0.371
10/11/97	9	0.161
10/11/97	10	0.631
03/27/98	1	0.137
03/27/98	2	
03/27/98	3	0.112
03/27/98	4	0.135
03/27/98	5	0.28
03/27/98	6	0.197
03/27/98	7	0.224
03/27/98	8	0.074
03/27/98	9	0.267
03/27/98	10	0.163

Daily Precipitation Data and Lake taken by Village of Luck Staff

Date	Precip (inches)	Lake Level
01-Jan-97		
02-Jan-97		
03-Jan-97		
04-Jan-97	1.26	
05-Jan-97	0.29	
06-Jan-97		
07-Jan-97		
08-Jan-97	0.01	
09-Jan-97	0.06	
10-Jan-97	0.09	
11-Jan-97		
12-Jan-97		
13-Jan-97		
14-Jan-97		
15-Jan-97	0.04	
16-Jan-97	0.01	
17-Jan-97		
18-Jan-97		
19-Jan-97		
20-Jan-97		
21-Jan-97	0.06	
22-Jan-97	0.14	
23-Jan-97	0.01	
24-Jan-97	0.07	
25-Jan-97	0.01	
26-Jan-97		
27-Jan-97	0.08	
28-Jan-97		
29-Jan-97	0.05	
30-Jan-97		
31-Jan-97	0.06	
01-Feb-97		
02-Feb-97		
03-Feb-97		
04-Feb-97		
05-Feb-97		
06-Feb-97		
07-Feb-97		
08-Feb-97		
09-Feb-97		
10-Feb-97	0.01	
11-Feb-97		
12-Feb-97	0.02	
13-Feb-97	0.02	
14-Feb-97		
15-Feb-97		
16-Feb-97	0.02	
17-Feb-97		
18-Feb-97		
19-Feb-97		
20-Feb-97		
21-Feb-97		
22-Feb-97		
23-Feb-97		
24-Feb-97		
25-Feb-97		
26-Feb-97		
27-Feb-97		
28-Feb-97	0.08	
01-Mar-97		
02-Mar-97		
03-Mar-97	0.12	
04-Mar-97	0.2	
05-Mar-97	0.02	
06-Mar-97		
07-Mar-97		
08-Mar-97		
09-Mar-97	0.03	
10-Mar-97	0.01	
11-Mar-97		
12-Mar-97		
13-Mar-97	0.37	
14-Mar-97	0.24	
15-Mar-97		
16-Mar-97		
17-Mar-97		
18-Mar-97		
19-Mar-97		
20-Mar-97		
21-Mar-97		
22-Mar-97		
23-Mar-97		
24-Mar-97	0.18	
25-Mar-97	0.15	
26-Mar-97		
27-Mar-97		
28-Mar-97		
29-Mar-97		
30-Mar-97		
31-Mar-97		
01-Apr-97		
02-Apr-97		
03-Apr-97		
04-Apr-97		
05-Apr-97	0.06	
06-Apr-97	0.17	
07-Apr-97		
08-Apr-97		
09-Apr-97		
10-Apr-97		
11-Apr-97		
12-Apr-97		
13-Apr-97		
14-Apr-97		
15-Apr-97		
16-Apr-97		
17-Apr-97		
18-Apr-97		
19-Apr-97		
20-Apr-97		
21-Apr-97		
22-Apr-97		
23-Apr-97		
24-Apr-97		
25-Apr-97		
26-Apr-97		
27-Apr-97	0.08	
28-Apr-97		
29-Apr-97		
30-Apr-97	0.09	
01-May-97		
02-May-97	0.09	
03-May-97	0.1	
04-May-97		
05-May-97	0.08	
06-May-97		
07-May-97		
08-May-97	0.58	
09-May-97		
10-May-97		
11-May-97	0.07	
12-May-97		
13-May-97		
14-May-97	0.06	
15-May-97	0.26	
16-May-97		
17-May-97		
18-May-97	0.13	
19-May-97	0.06	
20-May-97		
21-May-97		
22-May-97		
23-May-97		
24-May-97	0.04	
25-May-97		
26-May-97		
27-May-97		
28-May-97		
29-May-97	0.44	
30-May-97	0.13	
31-May-97		

01-Jun-97		
02-Jun-97		
03-Jun-97		
04-Jun-97	0.18	1.2
05-Jun-97	0.06	
06-Jun-97		
07-Jun-97		
08-Jun-97		
09-Jun-97		
10-Jun-97		0.8
11-Jun-97		
12-Jun-97		
13-Jun-97		
14-Jun-97		
15-Jun-97	0.14	
16-Jun-97		-0.5
17-Jun-97	0.01	
18-Jun-97	0.17	
19-Jun-97	0.03	
20-Jun-97		
21-Jun-97		
22-Jun-97		
23-Jun-97		
24-Jun-97	1	-1
25-Jun-97		
26-Jun-97		
27-Jun-97		
28-Jun-97	1.09	
29-Jun-97	0.2	
30-Jun-97		
01-Jul-97		
02-Jul-97	1.74	3.2
03-Jul-97	0.18	
04-Jul-97	0.15	
05-Jul-97	0.3	
06-Jul-97	0.01	
07-Jul-97	0.22	4
08-Jul-97	0.45	
09-Jul-97		
10-Jul-97		
11-Jul-97	0.09	
12-Jul-97		
13-Jul-97	0.26	
14-Jul-97	0.73	4.7
15-Jul-97		
16-Jul-97		
17-Jul-97		
18-Jul-97		
19-Jul-97	0.06	
20-Jul-97	0.08	
21-Jul-97		
22-Jul-97	0.7	
23-Jul-97	0.03	
24-Jul-97	0.01	4
25-Jul-97	0.83	
26-Jul-97		
27-Jul-97		
28-Jul-97		
29-Jul-97		
30-Jul-97		
31-Jul-97		3.6
01-Aug-97		
02-Aug-97		
03-Aug-97		
04-Aug-97	0.61	
05-Aug-97		3.4
06-Aug-97		
07-Aug-97		
08-Aug-97		
09-Aug-97		
10-Aug-97	0.13	
11-Aug-97		
12-Aug-97		2.4
13-Aug-97		
14-Aug-97	0.16	
15-Aug-97	0.28	
16-Aug-97	0.33	
17-Aug-97	0.44	
18-Aug-97		
19-Aug-97	0.67	
20-Aug-97	0.67	
21-Aug-97	0.02	
22-Aug-97		
23-Aug-97	0.03	
24-Aug-97	0.01	
25-Aug-97		4
26-Aug-97		
27-Aug-97		
28-Aug-97		
29-Aug-97	0.38	
30-Aug-97	0.61	
31-Aug-97	0.02	4.8
01-Sep-97	0.48	
02-Sep-97	0.06	
03-Sep-97		
04-Sep-97		
05-Sep-97		
06-Sep-97		
07-Sep-97		
08-Sep-97		
09-Sep-97	0.85	
10-Sep-97		
11-Sep-97		5
12-Sep-97		
13-Sep-97		
14-Sep-97		
15-Sep-97	0.06	
16-Sep-97	1.77	
17-Sep-97	0.05	
18-Sep-97		
19-Sep-97		7.1
20-Sep-97		
21-Sep-97		
22-Sep-97		
23-Sep-97		
24-Sep-97		
25-Sep-97		
26-Sep-97		
27-Sep-97		
28-Sep-97		4.8
29-Sep-97	0.1	
30-Sep-97		
01-Oct-97		
02-Oct-97		
03-Oct-97		
04-Oct-97		
05-Oct-97		
06-Oct-97	0.11	3.6
07-Oct-97		
08-Oct-97	0.16	
09-Oct-97		
10-Oct-97		
11-Oct-97		
12-Oct-97	0.87	
13-Oct-97	0.79	
14-Oct-97	0.16	5.4
15-Oct-97		
16-Oct-97		
17-Oct-97		
18-Oct-97		
19-Oct-97		
20-Oct-97		
21-Oct-97	0.04	4.4
22-Oct-97		
23-Oct-97	0.03	
24-Oct-97	0.01	
25-Oct-97		
26-Oct-97		
27-Oct-97		
28-Oct-97		
29-Oct-97		
30-Oct-97	0.1	3
31-Oct-97	0.23	
01-Nov-97	0.41	
Total	25.51	