Report

Lake Beulah Study

Prepared for:

The Lake Beulah Management District

By:

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1.0 PROJECT BACKGROUND AND INTRODUCTION

The Lake Beulah Management District contracted with Earth Tech, Inc. to conduct several tasks related to the lake's water quality. The tasks included:

1) Analyze groundwater flow direction around the lake based on existing well log data,
2) Review historical water quality data and summarize trends,
3) Assess the lake's watershed and nonpoint source pollution loadings; and
4) Develop a "citizen handbook" to inform lake residents about their role in protecting Lake Beulah.

This report documents the methods, results, and recommendations from conducting these tasks.

This study was funded in part through a Lake Management Planning Grant from the Wisconsin Department of Natural Resources. The grants provided by this program funded about 75% of the project's costS. The remaining 25% of the project's cost was funded from the Lake Beulah Management District.

2.0 GROUNDWATER FLOW DIRECTION ANALYSIS

INTRODUCTION

An analysis was conducted to estimate the direction of groundwater flow in the region surrounding the lake. The purpose of the analysis was to identify potential areas where groundwater contamination could affect the lake. In some areas surrounding the lake, it is likely that groundwater flows towards Lake Beulah. If contaminants, such as septic system discharges, are introduced into the groundwater in these zones, they could enter the lake and have adverse effects. The techniques employed in this analysis provided a very general, "screening" level of analysis. No specific pollutant sources could be identified with this approach.

METHODOLOGY

Well Constructor's Reports (WCRs) were obtained from the Wisconsin Geologic and Natural History Survey. These reports are completed when a new well is drilled. The WCRs contain information such as:

- Date of well completion
- Location of well, according to the Public Land Survey System (sometimes a street address is also given)
- Depth from land surface to observed groundwater level
- Soil/bedrock conditions encountered
- Property owner or agent

Approximately 230 WCRs were obtained for the area surrounding Lake Beulah. In most cases, only records from wells drilled since 1980 were used. In a few areas around the lake, no wells were drilled after 1980, so earlier reports were used. A total of 166 well records were selected to estimate groundwater levels in the area. About 64 well records were not used, either because the well location could not be determined precisely enough or the well was in an area where no additional data was necessary.

The selected wells were located in a Geographic Information System (GIS), using a digital USGS topographic map and a local street address map provided by the Town of East Troy. The surface elevation at the well location was estimated using the USGS topographic map (10-foot contour interval). Selected information from the well reports, including location and depth to groundwater, was entered into a database and linked to the GIS coverage. Appendix A contains information on the depth to groundwater, surface elevation, and street address for the 166 well records selected for study. Figure 2-1 shows the locations of these wells.

The elevation of the water table was estimated by subtracting the depth to groundwater from the estimated surface elevation. The elevation of Lake Beulah was assumed to be 808 feet, as reported on the USGS 7.5 minute quadrangle map. Although the lake's water fluctuates seasonally and year to year; these changes are not great enough to affect the analysis.

By comparing the approximate groundwater elevation at a well location to the lake elevation, the direction of groundwater flow was estimated. Groundwater flows from higher elevations to lower elevations. Thus, if the groundwater elevation at a point near the lake is 820 feet, the groundwater is probably flowing towards the lake. Figure 2-1 shows the estimated groundwater elevations around the lake at the well sites.

The limitations of this analysis should be recognized. The surface elevation at a well site was estimated using a USGS map which displays contours every 10 feet. This limits the precision of the ground surface elevation estimates. Furthermore, the horizontal location of some wells is also an estimate. Well logs generally provide well locations to the nearest ¼, ¼ section or a street address. Due to these approximations, the estimated groundwater elevations should be considered to be accurate to approximately +/- 10 feet in most cases. All groundwater elevations that were within ten feet of the lake elevation were assumed to essentially be at lake level. Only elevation differences greater than 10 feet were deemed to be significant.

Other factors, such as short and long term changes and/or seasonal variations in the groundwater elevation were not factored into this analysis.

RESULTS/CONCLUSIONS

Figure 2-1 shows the relative elevations of groundwater to lake for the 166 wells. Of the 166 wells plotted on Figure 2-1, 154 wells were selected for further analysis, based on their proximity to the lake. Table 2-1 summarizes how the groundwater elevation in the 154 wells compared to the lake elevation.

Table 2-1: Summary of Groundwater Elevations in Wells

Relative Groundwater Elevation	Number of Wells	% of Wells
Higher than Lake	20	13%
Lower than Lake	51	33%
Same as Lake	83	54%
Total	154	100%

Based on this data [redacted] analyzed had groundwater [redacted]

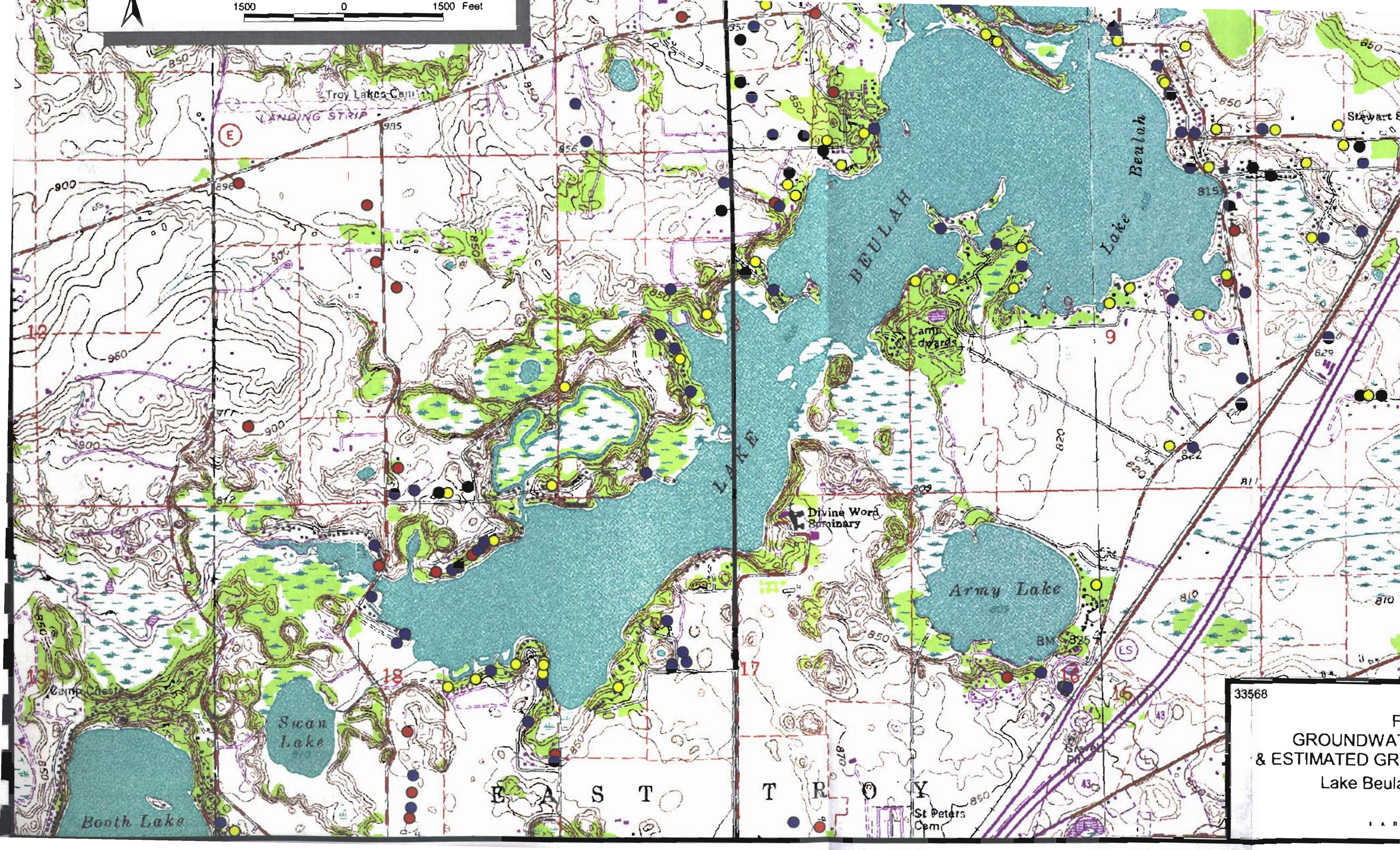
A second analysis was conducted to find out if groundwater at certain areas of the lake's surrounding showed a tendency to be lower, higher, or the same elevation as the lake. To conduct this analysis the selected 154 wells were classified as being located in the southwest or northeast portion of the lake's surrounding area. The dividing line for this analysis was the mid-point of the lake as shown on Figure 2-1. Table 2-2 summarizes the groundwater elevation for this analysis.

Table 2-2: Summary of Groundwater Elevations by NE and SW Sectors

	Northeast Sector	Southwest Sector
Total # of Wells	95	59
% of wells with groundwater higher than lake	6%	24%
% of wells with groundwater lower than lake	40%	22%
% of sells with groundwater same as lake	54%	54%

Of the wells located in the northeast sector, 94% of them are near or lower than the average lake elevation. Of the wells located in the southwest sector, 76% are near or higher than the average lake elevation. This would suggest a general groundwater flow direction to the lake is from the southwest and out of the lake is to the northeast. If this is correct, then pollutants in the groundwater south and west of the lake have the highest potential for entering the lake proper.

To reach more definitive conclusions, a more precise analysis of groundwater flow around the lake would need to be conducted. The next step would first involve field measurements. A monitoring well network could be constructed or existing water supply wells might be used. The top-of-wells and lake elevation would be accurately surveyed. Then synoptic depth-to-groundwater measurements would be taken at selected wells. If existing water supply wells were used, the well record would be carefully analyzed to ensure that the measured water level is representative of an aquifer that is connected to the lake. With this data, a more detailed and precise model of groundwater flow could be constructed. Monitoring of the water quality in the wells could also be conducted, to see if quality problems are actually present.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3.0 HISTORICAL WATER QUALITY DATA ANALYSIS

INTRODUCTION

Lake Beulah has a relatively long history of water quality studies. The three main sources of data are the Wisconsin Department of Natural Resources, the Self-Help monitoring program, and private firms under contract with the Lake Beulah Management District (or the Sanitary District). The purpose of this task was to 1) compile the various sources of data into one "library;" 2) create an electronic database of the information; and 3) plot values of key parameters over time to observe changes in the lake's water quality.

METHODOLOGY

Water quality data from over 40 source documents and references were compiled into a database (Microsoft *Access 97*). Approximately 8000 records entered into the database with monitoring dates ranging from 1960 to 1998. A more detailed explanation of the database structure and content is in Appendix B. A list of source documents utilized in this study is shown in Table 3-1. A document I.D. number was assigned to each information source and is marked on each hard copy document.

Table 3-1: Sources of Water Quality Data for Lake Beulah

I.D #	Document Title	Date	Author/Agency
1	Survey of Lake Beulah	27-Sep-70	Aqua-Tech
2	Limnological Survey of Lake Beulah: Part 1	27-Jul-71	Aqua-Tech
3	Limnological Survey of Lake Beulah: Part 2	21-Aug-71	Aqua-Tech
4	Aqua-Tech Letter to Lake District	18-Oct-71	Aqua-Tech
5	Aqua-Tech Letter to Lake District	20-Apr-72	Aqua-Tech
6	Limnological Survey of Lake Beulah	07-Jul-72	Aqua-Tech
7	Limnological Survey of Lake Beulah	15-Oct-72	Aqua-Tech
8	Limnological Survey of Lake Beulah	25-Jun-73	Aqua-Tech
9	Limnological Survey of Lake Beulah	14-Aug-73	Aqua-Tech
10	Limnological Survey of Lake Beulah	12-Oct-73	Aqua-Tech
11	Limnological Survey of Lake Beulah	20-Mar-74	Aqua-Tech
12	Limnological Survey of Lake Beulah	25-Apr-74	Aqua-Tech
13	Limnological Survey of Lake Beulah	24-Jul-74	Aqua-Tech
14	Limnological Survey of Lake Beulah	26-Oct-74	Aqua-Tech
15	Limnological Survey of Lake Beulah	20-Feb-75	Aqua-Tech
16	Limnological Survey of Lake Beulah	19-May-75	Aqua-Tech
17	Limnological Survey of Lake Beulah	01-Jul-75	Aqua-Tech
18	Limnological Survey of Lake Beulah	17-Oct-75	Aqua-Tech
19	Limnological Survey of Lake Beulah	24-May-76	Aqua-Tech
20	Aqua-Tech Letter to Lake District	16-Jun-76	Aqua-Tech
21	Limnological Survey of Lake Beulah	22-Jul-76	Aqua-Tech
22	Aqua-Tech Special Report on Coliforms	30-Aug-76	Aqua-Tech

Table 3-1: Sources of Water Quality Data for Lake Beulah

I.D #	Document Title	Date	Author/Agency
23	Aqua-Tech Special Report on Organisms	30-Aug-76	Aqua-Tech
24	Lake Beulah Limnological Survey	25-Oct-76	Aqua-Tech
25	Limnological Assessment of Lake Beulah	30-Jun-77	Aqua-Tech
26	Limnological Assessment -- 1st Quarterly Report	02-Mar-78	Aqua-Tech
27	Limnological Assessment -- 2nd Quarterly Report	14-Jul-78	Aqua-Tech
28	Limnological Assessment of Lake Beulah	19-Oct-78	Aqua-Tech
29	Lake Beulah 1978 Limnological Assessment – Special Test Objectives	01-Dec-78	Aqua-Tech
30	Limnological Assessment of Lake Beulah	16-Jun-82	Aqua-Tech
31	Inland Lake & Stream Feasibility Studies	01-Aug-83	Aqua-Tech
32	Inland Lake & Stream Feasibility Studies	01-Sep-84	Aqua-Tech
33	1985 Limnological Assessment	01-Sep-85	Aqua-Tech
34	1986 Limnological Assessment	15-Feb-87	Aqua-Tech
35	1987 Limnological Assessment	01-Dec-87	Aqua-Tech
36	1988 Limnological Assessment	01-Jan-89	Aqua-Tech
37	Lake Self-Help Monitoring	*	LBD, WDNR
38	An Aquatic Plant Management Plan for Lake Beulah	01-Jun-96	Carlson, Kreinbrink, & Davis
39	WDNR Recent Self-Help Monitoring Data – Electronic Data from James Vinnie	*	LBD, WDNR
40	Lake District Self-Help Field Monitoring	*	Kreinbrink
41	WDNR Field Monitoring Results	*	WDNR

LBD = Lake Beulah District
WDNR = Wisconsin Department of Natural Resources
* Sampling results over a period of years; no formal report

Once the historical water quality data was entered into the database, it was analyzed to determine whether or not there have been any observable water quality trends over the period of record in the Lake Beulah watershed. Trend plots and data summaries were constructed for the following water quality parameters:

- Spring turnover phosphorus (Figure 3-2)
- Summer DO (surface, mid-depth, and bottom) (Figures 3-3 to 3-10)
- Average summer Secchi depths (Figure 3-11)
- Average summer Chlorophyll a (Figure 3-12)
- Average Trophic Status Index values (Figure 3-13)

CHALLENGES AND CAUTIONS IN DATA INTERPRETATION

A significant challenge in organizing and analyzing the data was the various systems used over the past 30 years in identifying monitoring locations. Agencies and private firms often used different monitoring site identification codes, or changed the codes over time. Many monitoring sites had more than one code depending on the source of the data. Table 3-2 lists the various sources of water quality data and the monitoring site identification codes used by each source. Where one site was identified by more than one code, the multiple codes appear on the same row in the table. The last column on Table 3-2 lists a sequential identification number that is displayed on Figure 3-1 to show the location of the monitoring site.

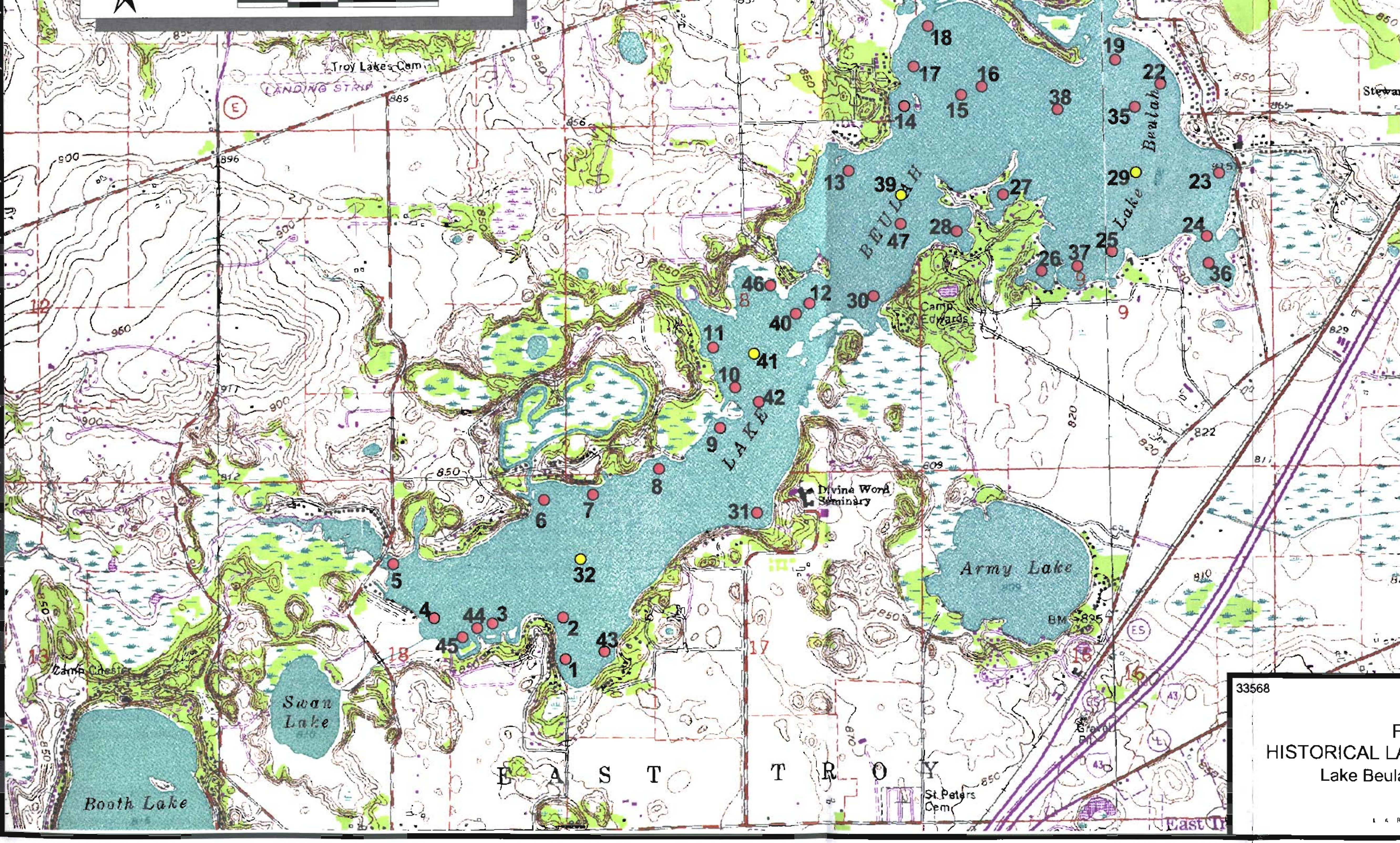
A second issue in interpreting the data is the variability in terms of data analyses among the laboratories, analytical methodologies, detection levels, and quality control. Laboratory techniques have changed over the past thirty years, and sample-handling procedures have also changed. The source documents reviewed for this study did not provide detailed information on these factors. Thus, when comparing total phosphorus values, for example, from samples obtained and analyzed from the 1970's – 90s; it was assumed that similar procedures were used in the handling and analysis.

Table 3-2: Monitoring Site Locations and Identification Codes

Reference Documents:	AquaTech Reports 1971-77	AquaTech Reports 1978; 1982-89	Self-Help Monitoring 1990-98	WDNR Monitoring 1973-75	WDNR Monitoring 1973-75	AquaTech Report January 1989	AquaTech Reports 8/1/83 & 9/1/84	WDNR Monitoring 1973-75	Assigned Site # on Figure 3-1
Monitoring Site Identification Codes	AQ01					BL-A			1
	AQ02								2
	AQ03					BL-B			3
	AQ04					BL-E			4
	AQ05			68001	653120	BL-F	AQ(83)BL-3	INLET	5
	AQ06	BL-11							6
	AQ07								7
	AQ08								8
	AQ09								9
	AQ10								10
	AQ11					BL-G			11
	AQ12								12
	AQ13								13
	AQ14								14
	AQ15								15
	AQ15A								16
	AQ16								17

Table 3-2: Monitoring Site Locations and Identification Codes

Reference Documents:	AquaTech Reports 1971-77	AquaTech Reports 1978; 1982-89	Self-Help Monitoring 1990-98	WDNR Monitoring 1973-75	WDNR Monitoring 1973-75	AquaTech Report January 1989	AquaTech Reports 8/1/83 & 9/1/84	WDNR Monitoring 1973-75	Assigned Site # on Figure 3-1
Monitoring Site Identification Codes	AQ17								18
	AQ18								19
	AQ19								20
	AQ20	BL-3	SH4						21
	AQ21	BL-8							22
	AQ22	BL-13							23
	AQ23								24
	AQ24								25
	AQ25								26
	AQ26								27
	AQ27								28
	AQ28		SH5						29
	AQ29								30
	AQ30								31
	AQ31	BL-1	SH1	68010	653121		SOUTH		32
		BL-12							33
		BL-7							34
							AQ(84)BL-11		35
							AQ(84)BL-8		36
		BL-9							37
		BL-6							38
		BL-2	SH1A						39
		BL-5							40
			SH2						41
		BL-4							42
		BL-10							43
						BL-C			44
						BL-D			45
						BL-H			46
			SH3						47



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RESULTS

Classifying Lake Water Quality

There are a variety of approaches to assessing a lake's water quality. What is considered "good" water quality for some uses may not be considered good for other uses. For example, high quality fish habitat may include a mix of native macrophytes and structures such as logs and rocks. This lake condition may not be considered "good" by people who wish to swim or boat.

For purposes of this discussion, Lake Beulah's water quality will be presented in terms of its *trophic status*. The trophic status of a lake is generally based upon the waters' nutrient content and how the lake responds to the nutrient levels. In most cases, lakes in Wisconsin with higher levels of nutrients will exhibit higher levels of macrophyte growths and/or more frequent algae blooms. Higher nutrient level lakes will often have algae populations with more of the "blue-green" species compared to the green algae. In Wisconsin lakes, the nutrient generally most responsible for macrophyte and algae growth is phosphorus.

A lake's trophic status (how prone it is to nuisance levels of macrophyte and/or algae growth) can be reflected by an index number. The index is calculated from any one of three measurements: spring phosphorus concentrations, Secchi disk, and summer chlorophyll *a* concentrations. Table 3-3 shows the index values and associated levels of the three parameters. This table will be the basis for the discussions on Lake Beulah's water quality. The conditions listed in the first column provide a general qualitative condition to associate with the trophic status index (TSI) value.

Table 3-3
Water Quality Index for Wisconsin Lakes Based on Total Phosphorus, Chlorophyll-*a*, and Water Clarity *

Water Quality	Approximate Total Phosphorus (mg/L)	Secchi Disk Depth (ft)	Approximate Chlorophyll-*a* (ug/L)	Approximate Trophic Status Index**
Excellent	<0.001	>20	<1	<34
Very Good	0.001—0.01	10—20	1—5	34—44
Good	0.01—0.03	6—10	5—10	44—50
Fair	0.03—0.05	5—6	10—15	50—54
Poor	0.05—0.15	3—5	15—30	54—60
Very Poor	>0.15	<3	>30	>60

*Source: DNR Technical Bulletin 138 (1983)
**After Carlson (1977)

Spring Turnover Phosphorus Concentration

Spring phosphorus concentrations are useful because they show the amount of nutrients available for aquatic plant growth early in the growing season. "Turnover" is the period of time when the lake's temperature is the same at all depths; thus the lake's water (and nutrients) are completely mixed. Since phosphorus is the nutrient most responsible for excessive algae and/or macrophytes growth, this is an important parameter.

There were limited data available for spring phosphorus turnover levels. Table 3-4 and Figure 3-2 summarize the available data on record for monitoring site 32 (a deep hole in the southwest portion of the lake). This site was selected because it had the most spring phosphorus data available. Since only five years have monitored data, no trends should be inferred from the results. The TSI results of this parameter are discussed at the end of Chapter 3.

The Southeast Wisconsin Regional Planning Commission (SEWRPC) generally recommends a spring phosphorus turnover concentration of 0.02 mg/l, or less, as a target level "...for the prevention of excessive aquatic plant growth and the maintenance of a warmwater fishery and recreational use objectives" (SEWRPC Planning Report Number 30, June, 1979). Based on the available data reviewed, Lake Beulah is somewhat above this level.

Table 3-4: Spring Phosphorus Concentrations for Site 32
(April – mid-May monitoring, values in mg/l)

Year	Total Phosphorus
1960	0.100
1974	0.030
1975	0.035
1978 *	0.034
1998	0.014

* 1978 values based on average results from monitoring conducted in March and April

Figure 3-2: Spring Phosphorus Concentrations (Site 32)

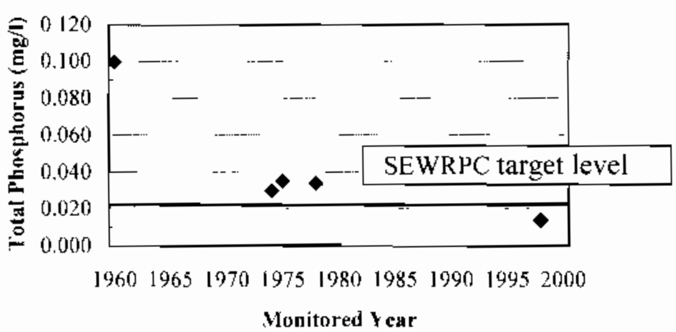


Table 3-5: Spring Phosphorus Concentrations for All Sites Other Than #32
(April – mid-May monitoring; values in mg/l)

Site #	Sample Date	Total Phosphorus
5	4/4/74	0.020
5	4/29/75	0.030
39	3/2/78	0.048
39	4/25/78	0.050
39	5/6/95	0.028
41	4/28/96	0.013

Summer Dissolved Oxygen (DO)

The dissolved oxygen concentration in a lake is critical to the support of fish. The amount of dissolved oxygen in a lake is dependent on the rate of biological decay in the lake bottom, and the amount of aquatic plant respiration occurring within the lake. These factors, in turn, are dependent on a number of environmental conditions including water temperature and sunlight. During the summer, the colder, denser water remains on the bottom of the lake (hypolimnion) and the warmer, less dense water remains in the lake's upper layer (epilimnion). The metalimnion marks the intermediate depth region where the temperature between the upper and lower lake levels changes quickly. The point where this temperature change occurs is known as the thermocline. This lake temperature stratification is usually maintained throughout the summer and acts as a barrier, preventing the upper warmer layer of water from mixing with the lower colder layer.

Since DO is typically measured in the deepest part of a lake, at various levels from the surface to the lake bottom, only data characteristic of this sampling standard was analyzed. Data from shallow, near-shore sampling locations were not analyzed, and neither were data sets with too few data points to observe any DO trends from surface to lake bottom. Appendix C summarizes the DO data from eightdeep water sites in the lake. The locations of these sites can be found on Figure 3-1. The average DO concentration during the summer for the epilimnion (upper layer) and hypolimnion (lower layer) at each site is presented in the appendix. The figures 3-6 through 3-10 show the trends for each site.

Figure 3-3 : DO Levels - Site 15
Average Summer Epilimnion & Hypolimnion Values

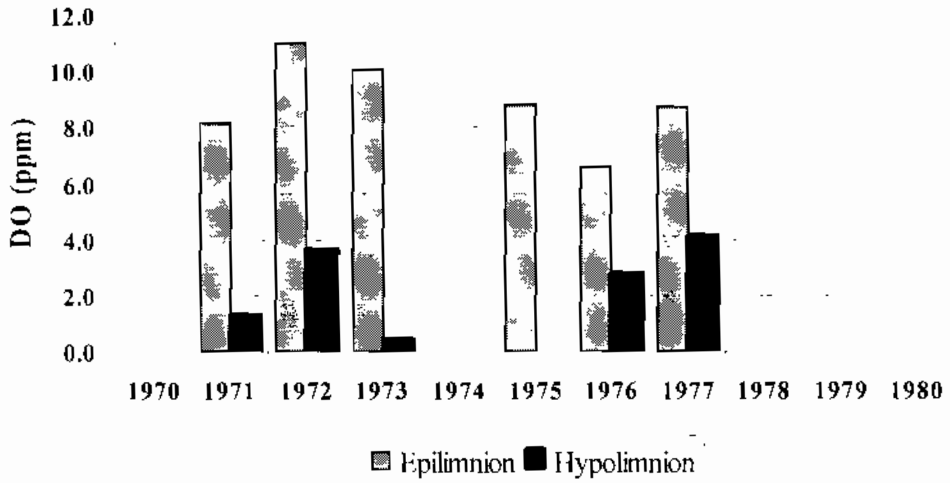


Figure 3-4 : DO Levels - Site 20
Average Summer Epilimnion & Hypolimnion Values

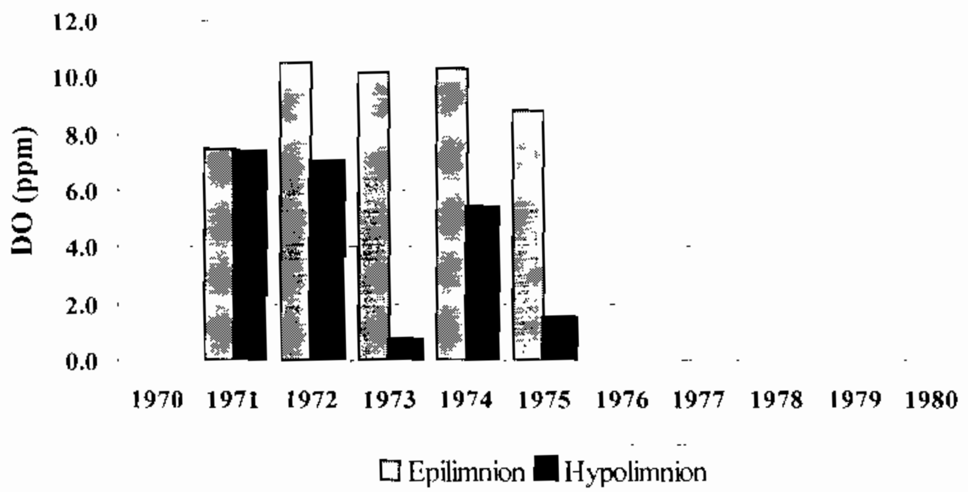


Figure 3-5 : DO Levels - Site 21
Average Summer Epilimnion & Hypolimnion Values

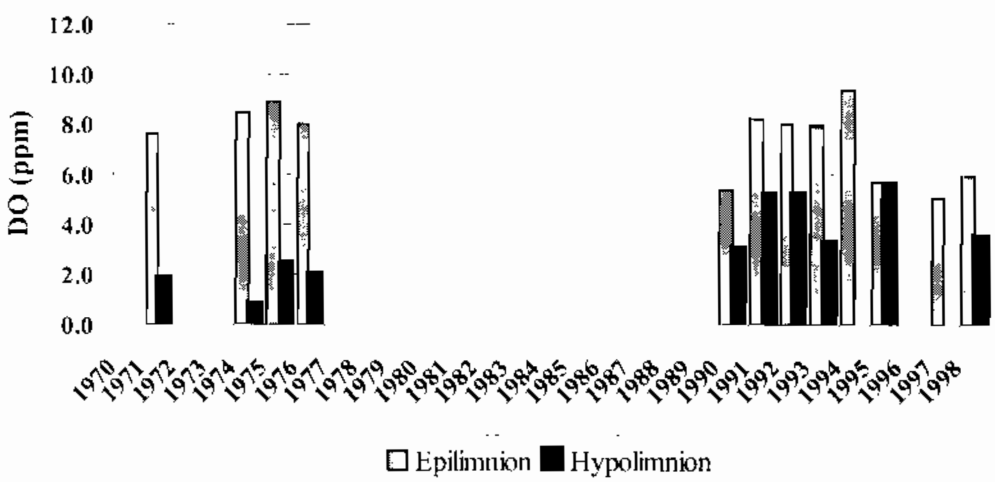


Figure 3-6 : DO Levels - Site 29
Average Summer Epilimnion & Hypolimnion Values

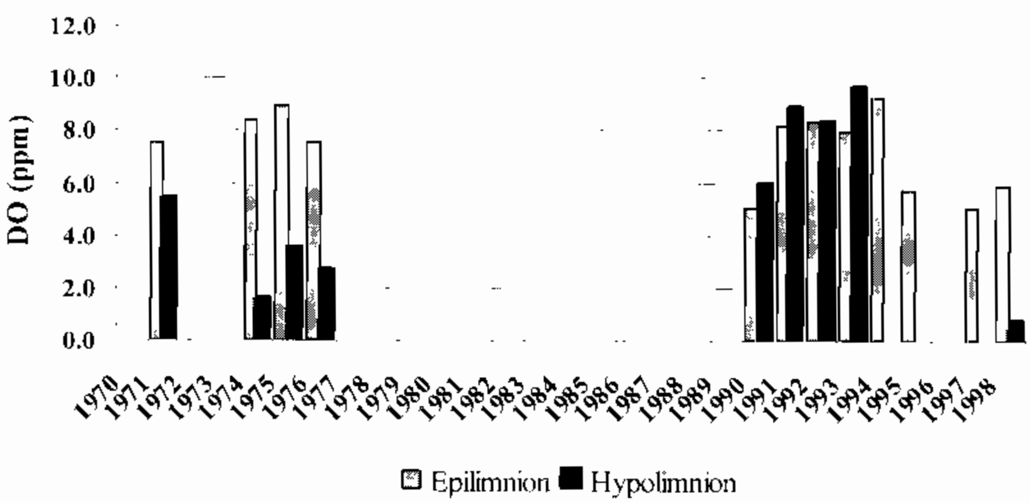


Figure 3-7 : DO Levels - Site 32
Average Summer Epilimnion & Hypolimnion Values

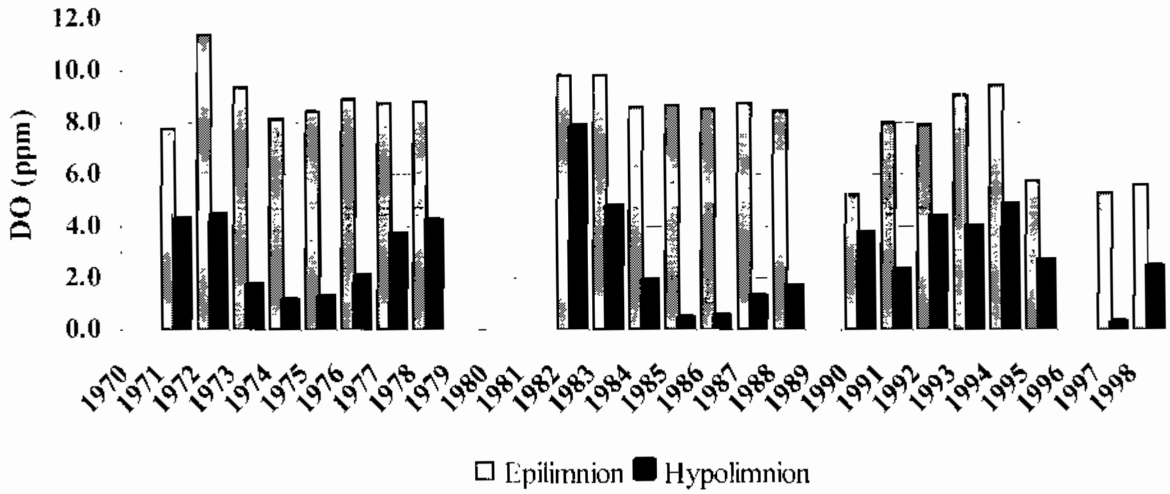


Figure 3-8 : DO Levels - Site 39
Average Summer Epilimnion & Hypolimnion Values

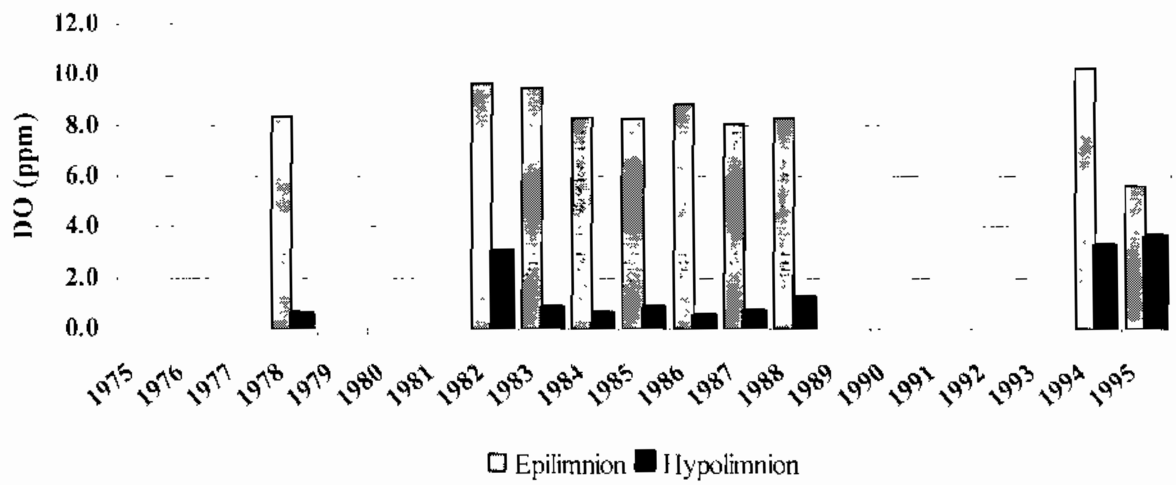


Figure 3-9 : DO Levels - Site 41
Average Summer Epilimnion & Hypolimnion Values

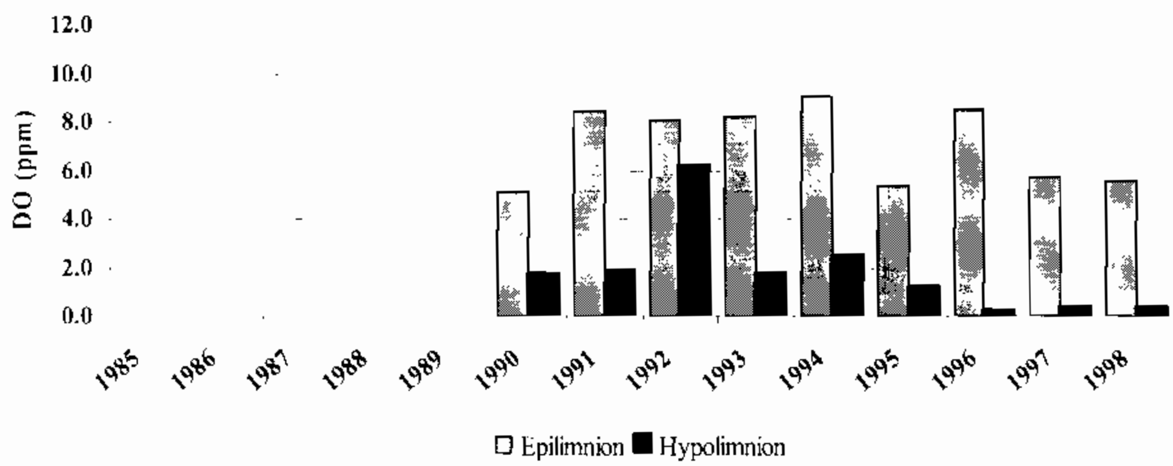
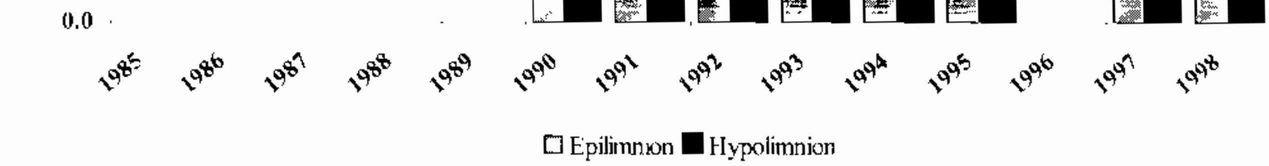


Figure 3-10 : DO Levels - Site 47
Average Summer Epilimnion & Hypolimnion Values



The analysis indicates that the historical DO levels in Lake Beulah are quite good and display no obvious trends over time or location. [redacted] levels greater than the state's water quality [redacted] In most years, at most sites, the average [redacted] This is not unusual for lakes in the region. On average, the thermocline at the deeper sites [redacted] The [redacted]line is [redacted] gets deeper in the later summer.

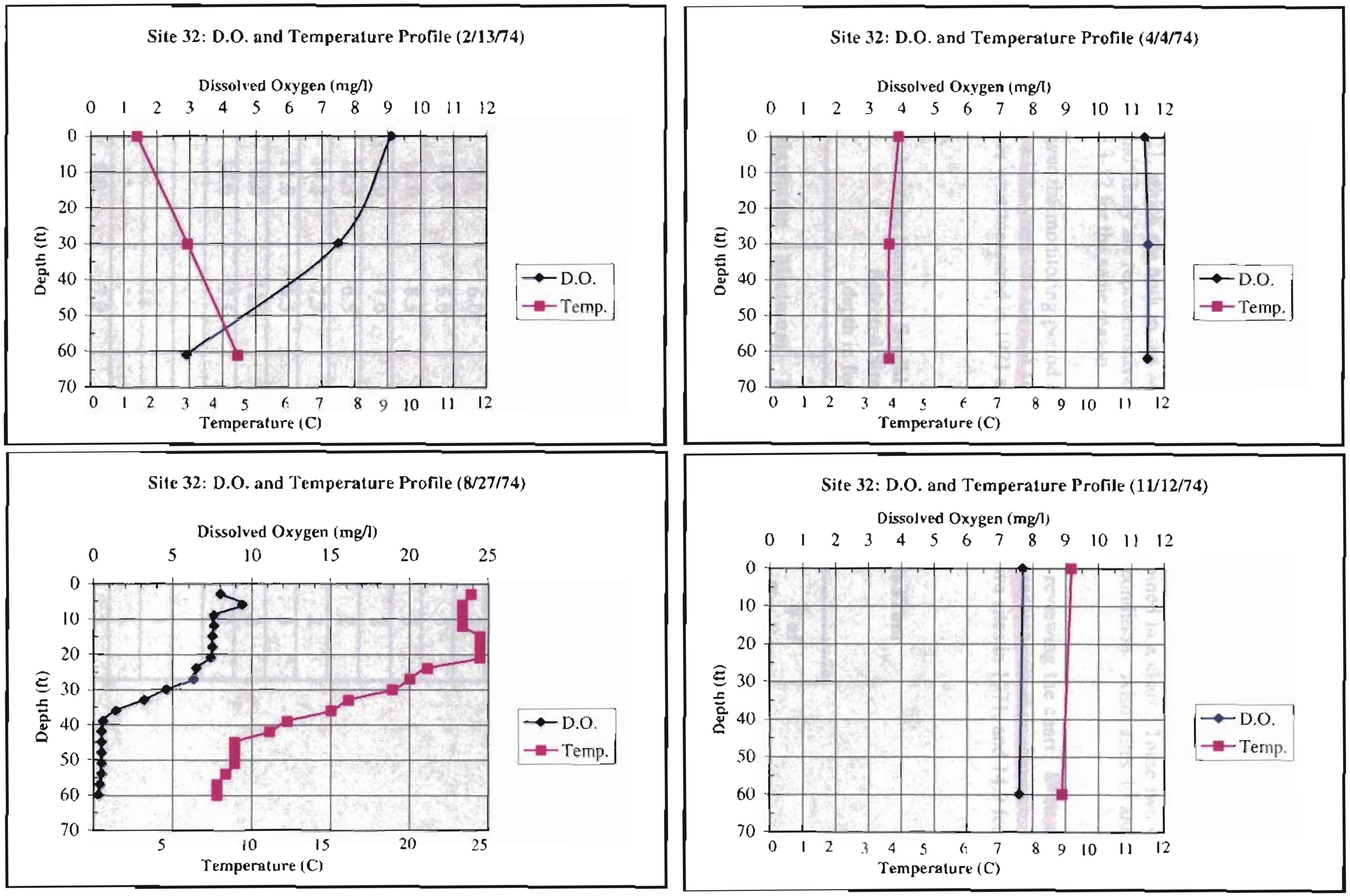
The Mill Pond area (sample sites 20 and 21) is the most isolated body of water in the lake, however it did not appear to differ greatly from the main body of the lake in DO levels over the monitored periods.

Figure 3-11 shows the seasonal changes in the dissolved oxygen and temperature profile of a single site (Site 32) in the lake. During the spring and fall (April 4, 1974 and November 12, 1974 monitoring dates) there is little or no "stratification" of the lake. The water column is nearly the same temperature, and thus the nutrients (and other material in the lake) mix throughout the lake's depths. The dissolved oxygen levels at these times are also nearly the same from top to bottom.

In the winter (February 13, 1974) the water at the top is near freezing (0° C) and the most dense water (4° C) remains at the bottom. Biological and chemical processes at the lake's bottom reduce the dissolved oxygen level during this time period.

In the summer (August 27, 1974) the lake strongly stratifies. This means that the dense (colder) water stays near the lake's bott[redacted]. T[redacted] zone the water temperature changes rapidly with each change in lake depth. In the August 27, 1974 monitoring figure, the metalimnion is generally between 20 and 40 feet of depth. Lake water (and the nutrients in the water) generally do not mix across the metalimnion during the period of stratification. This means that nutrients in theepilimnion will remain available for algae growth during the summer months. In the hypolimnion, biological decomposition reduces the oxygen level. Under certain conditions the hypolimnion can be depleted of oxygen, however this was not the case at the time of the August 27, 1974 monitoring. The previous figures (3-3 through 3-10) show that the average summer hypolimnion never reached zero dissolved oxygen, however very low dissolved oxygen levels (below 2.0 mg/l) were measured occasionally.

Figure 3-11: Seasonal Changes of Dissolved Oxygan and Temperature Profiles at Site 32



Secchi Depths

Table 3-6 summarizes the average summer Secchi disk measurements (June, July, and August) for selected deep water sites sampled over the period of record. Following the table is a chart (Figure 3-12) showing the data in a graphical form. Site 15 was not graphed because only 3 years of data were available. Sites 20 and 21, which are both in the Mill Pond, were combined in a chart. These two sites are close to each other and likely are representative of the Mill Pond's condition. Also, sites 39 and 47 were combined in Figure 3-12 for the same reason.

Trends in water clarity over the monitoring period are not evident from reviewing the chart. [redacted] The highest average values were measured in 1971 and 1997 (15 feet at two sites in 1971; and 14.9 feet in the Mill Pond in 1997).

Table 3-6: Average Summer Secchi Disk Measurements From Selected Sites *
(depth in feet)

Year	Maximum	Minimum	Mean	Standard Deviation	# of Readings
Site 15					
1971	15.0	13.0	14.0	1.4	2
1974	- -	- -	9.0	- -	1
1977	- -	- -	5.0	- -	1
Site 20					
1971	14.0	11.0	12.5	2.1	2
1974	- -	- -	11.0	- -	1
Site 21					
1990	7.0	6.0	6.7	0.6	3
1991	9.5	6.0	7.9	1.7	5
1992	11.0	8.5	10.2	1.4	3
1993	12.0	7.0	9.5	3.5	2
1994	12.3	6.5	9.4	4.1	2
1995	14.3	7.3	10.8	4.9	2
1996	11.0	6.5	8.3	2.4	3
1997	18.0	11.3	14.9	4.4	2
1998	16.0	7.5	11.8	4.3	3
Site 29					
1971	- -	- -	15.0	- -	1
1974	- -	- -	9.0	- -	1
1990	8.0	7.0	7.3	0.6	3
1991	10.3	6.5	9.5	1.7	5

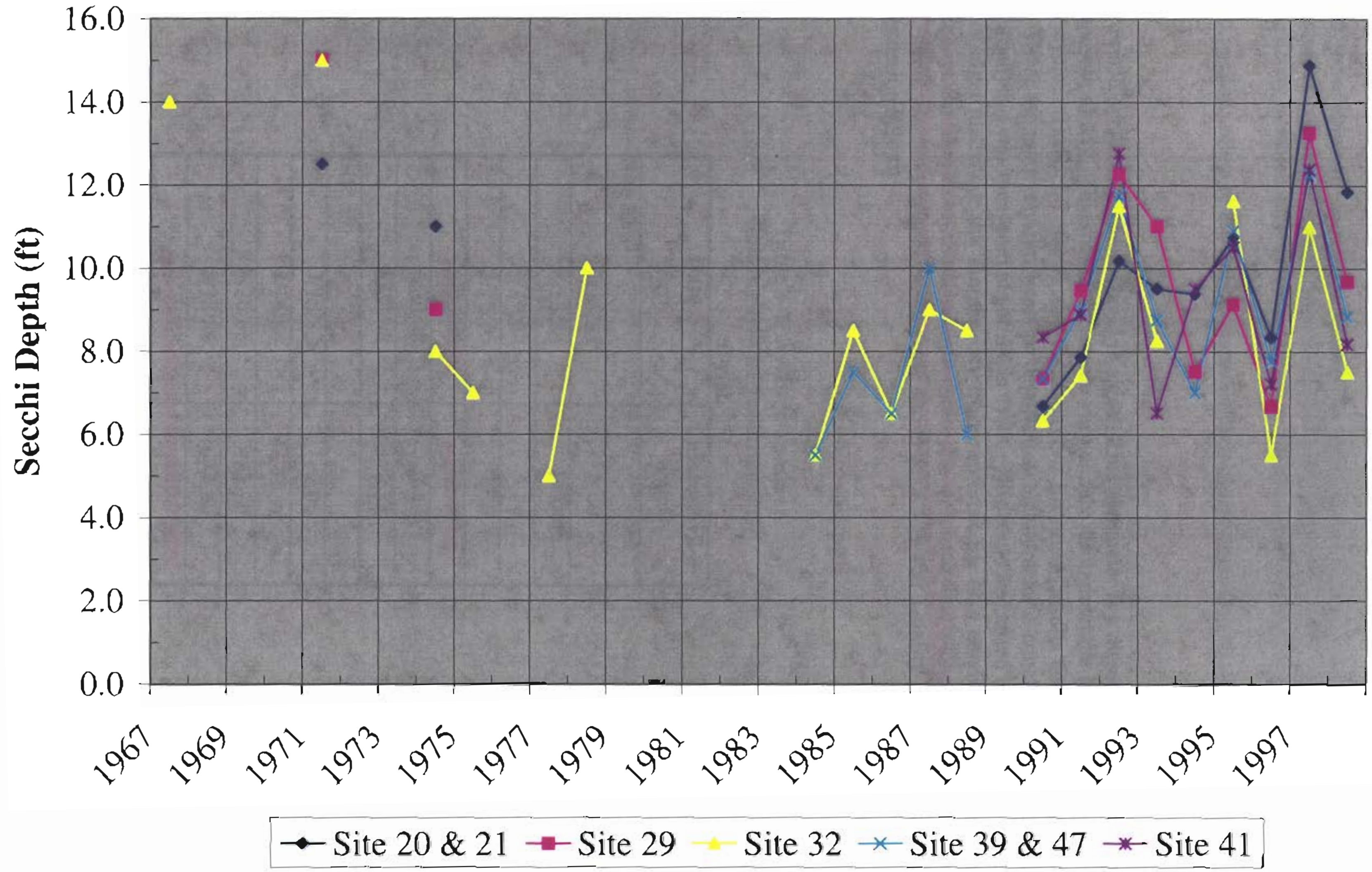
Table 3-6: Average Summer Secchi Disk Measurements From Selected Sites *
(depth in feet)

Year	Maximum	Minimum	Mean	Standard Deviation	# of Readings
1992	13.0	11.5	12.3	1.1	2
1993	12.0	10.0	11.0	1.4	2
1994	9.5	5.5	7.5	2.8	2
1995	9.5	8.8	9.1	0.5	2
1996	7.0	6.0	6.7	0.6	3
1997	15.3	11.3	13.3	2.8	2
1998	14.0	7.5	9.7	3.8	3
Site 32					
1967	- -	- -	14.0	- -	1
1971	- -	- -	15.0	- -	1
1974	10.0	6.0	8.0	2.8	2
1975	- -	- -	7.0	- -	1
1977	- -	- -	5.0	- -	1
1978	- -	- -	10.0	- -	1
1984	- -	- -	5.5	- -	1
1985	- -	- -	8.5	- -	1
1986	- -	- -	6.5	- -	1
1987	- -	- -	9.0	- -	1
1988	- -	- -	8.5	- -	1
1990	7.0	6.0	6.3	0.6	3
1991	10.0	4.5	7.4	1.8	6
1992	12.0	11.0	11.5	0.7	2
1993	9.5	7.0	8.3	1.8	2
1995	17.3	6.0	11.6	5.4	4
1996	7.3	4.3	5.5	1.6	3
1997	12.0	10.0	11.0	1.4	2
1998	10.0	4.5	7.5	2.0	6
Site 39					
1984	- -	- -	5.5	- -	1
1985	- -	- -	7.5	- -	1
1986	- -	- -	6.5	- -	1
1987	- -	- -	10.0	- -	1
1988	- -	- -	6.0	- -	1
1992	13.0	13.0	13.0	0.0	2
1994	8.0	4.5	6.4	1.9	4

Table 3-6: Average Summer Secchi Disk Measurements From Selected Sites *
(depth in feet)

Year	Maximum	Minimum	Mean	Standard Deviation	# of Readings
1995	15.0	7.8	11.7	3.7	3
Site 41					
1990	9.0	8.0	8.3	0.6	3
1991	11.3	5.3	8.9	2.2	9
1992	13.0	12.5	12.8	0.4	2
1993	8.0	5.0	6.5	2.1	2
1994	12.5	6.5	9.5	4.2	2
1995	11.5	9.5	10.5	1.4	2
1996	8.3	6.3	7.2	0.8	6
1997	14.8	10.0	12.4	3.4	2
1998	10.5	5.5	8.2	2.5	3
Site 47					
1990	8.0	7.0	7.3	0.6	3
1991	11.0	6.5	9.0	2.0	5
1992	11.0	10.0	10.5	0.7	2
1993	9.0	8.5	8.8	0.4	2
1994	10.0	6.5	8.3	2.5	2
1995	12.3	7.3	9.8	3.5	2
1996	9.3	6.8	7.8	1.3	3
1997	14.0	10.5	12.3	2.5	3
1998	10.5	7.5	8.8	1.5	3

Figure 3-12: Comparison of Average Summer* Secchi Readings Over Time and Location



* June, July August

Figure 3-12 does show apparent correlation among the sites for each year. It appears water clarity increases and decreases consistently at all sites throughout the lake from year to year. There does not appear to be consistency in which sites have the highest or lowest clarity from year to year.

How these Secchi readings relate to the trophic status index is discussed at the end of this chapter.

Chlorophyll-*a*

Chlorophyll-*a* is a photosynthetic pigment found in algae This parameter is a direct measure of the algal biomass found in a water body. This measurement can vary widely throughout the summer depending on the algal bloom cycle. Table 3-7 shows the chlorophyll-*a* historical results for Lake Beulah from monitored sites. There are relatively few years of data from which to draw a conclusion. An unusually high level of chlorophyll-*a* was measured at site 39 in 1989. This could be caused by lab error, a sample with a "clump" of algal matter, or the sample may truly represent the lake conditions at that site and sample time. Except for this exceptionally high value, the chlorophyll-*a* values are quite low and correspond to a "good" to "very good" rating from the WDNR's Water Quality Index for Wisconsin Lakes (see the discussion below).

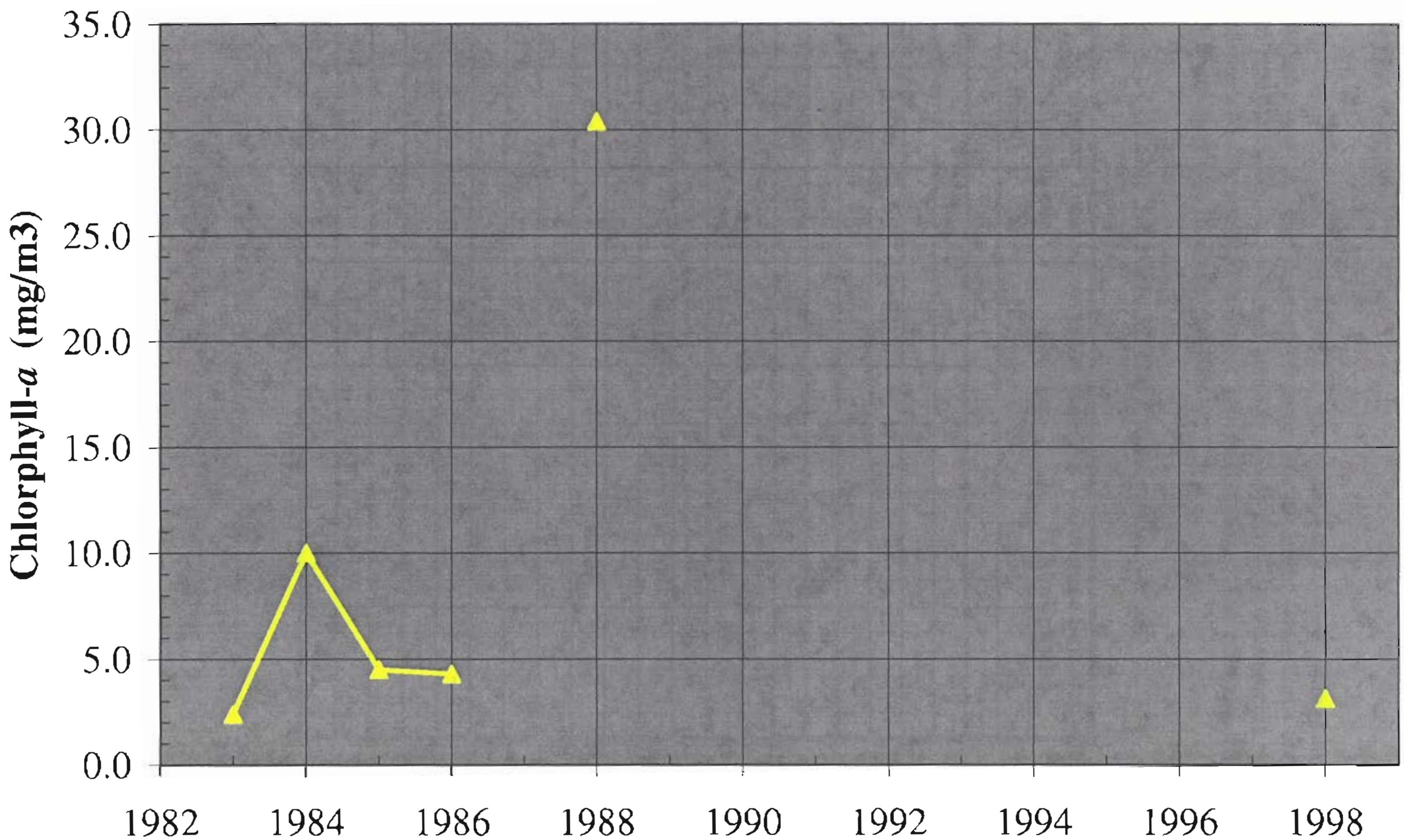
Table 3-7: Average Summer Chlorophyll- *a* Measurements
(ug/l)

Date	Chlorophyll-*a* (ug/l)
Site 32	
7/15/83	2.40
8/13/84	10.00
8/26/85	4.50
8/18/86	4.30
8/29/88	20.40
6/30/98	3.46
7/22/98	2.78
Site 39	
7/15/83	2.00
8/13/84	15.90
8/26/85	3.30
8/18/86	4.80
8/29/88	180.20
6/20/94	4.72
7/19/94	3.90
6/24/95	2.33
7/26/95	0.05
8/29/95	3.35

Table 3-7: Average Summer Chlorophyll- *a* Measurements
(ug/l)

Date	Chlorophyll-*a* (ug/l)
Site 41	
6/24/96	5.46
7/31/96	3.94
8/29/96	3.63
8/31/98	3.43

Figure 3-13: Comparison of Chlorphyll-*a* Levels Over Time (Site 32)



Trophic Status Index (TSI) Values

Trophic status modeling was conducted using WDNR's Wisconsin Lake Model Spreadsheet (WDNR, 1994). TSI values were calculated for site 32 based on three factors: spring phosphorus concentrations, average summer Secchi measurements, and average summer chlorophyll-*a* measurements. Site 32 was chosen for this analysis because this site had the most TSI related data. The resulting TSI values are summarized on Table 3-8 and displayed in Figure 3-14.

Table 3-8 : Site 32 TSI Calculations

Year	Spring Total Phosphorus		Average Summer Secchi		Average Summer Chlorophyll-*a*	
	(mg/l)	TSI	(ft)	(TSI)	(ug/l)	TSI
1960	0.100	64	- -	- -	- -	- -
1967	- -	- -	14	39	- -	- -
1971	- -	- -	15	38	- -	- -
1974	0.030	55	8.0	47	- -	- -
1975	0.035	56	7.0	49	- -	- -
1977	- -	- -	5.0	54	- -	- -
1978	0.034	56	10.0	44	- -	- -
1983	- -	- -	- -	- -	2.40	41
1984	- -	- -	5.5	53	10.00	52
1985	- -	- -	8.5	46	4.50	46
1986	- -	- -	6.5	50	4.30	46
1987	- -	- -	9.0	45	- -	- -
1988	- -	- -	8.5	46	30.40	60
1990	- -	- -	6.3	51	- -	- -
1991	- -	- -	7.4	48	- -	- -
1992	- -	- -	11.5	42	- -	- -
1993	- -	- -	8.3	47	- -	- -
1995	- -	- -	11.6	42	- -	- -
1996	- -	- -	5.5	53	- -	- -
1997	- -	- -	11.0	43	- -	- -
1998	0.014	49	7.5	48	3.02	43

Figure 3-14: Trophic Status Index Values for Site 32

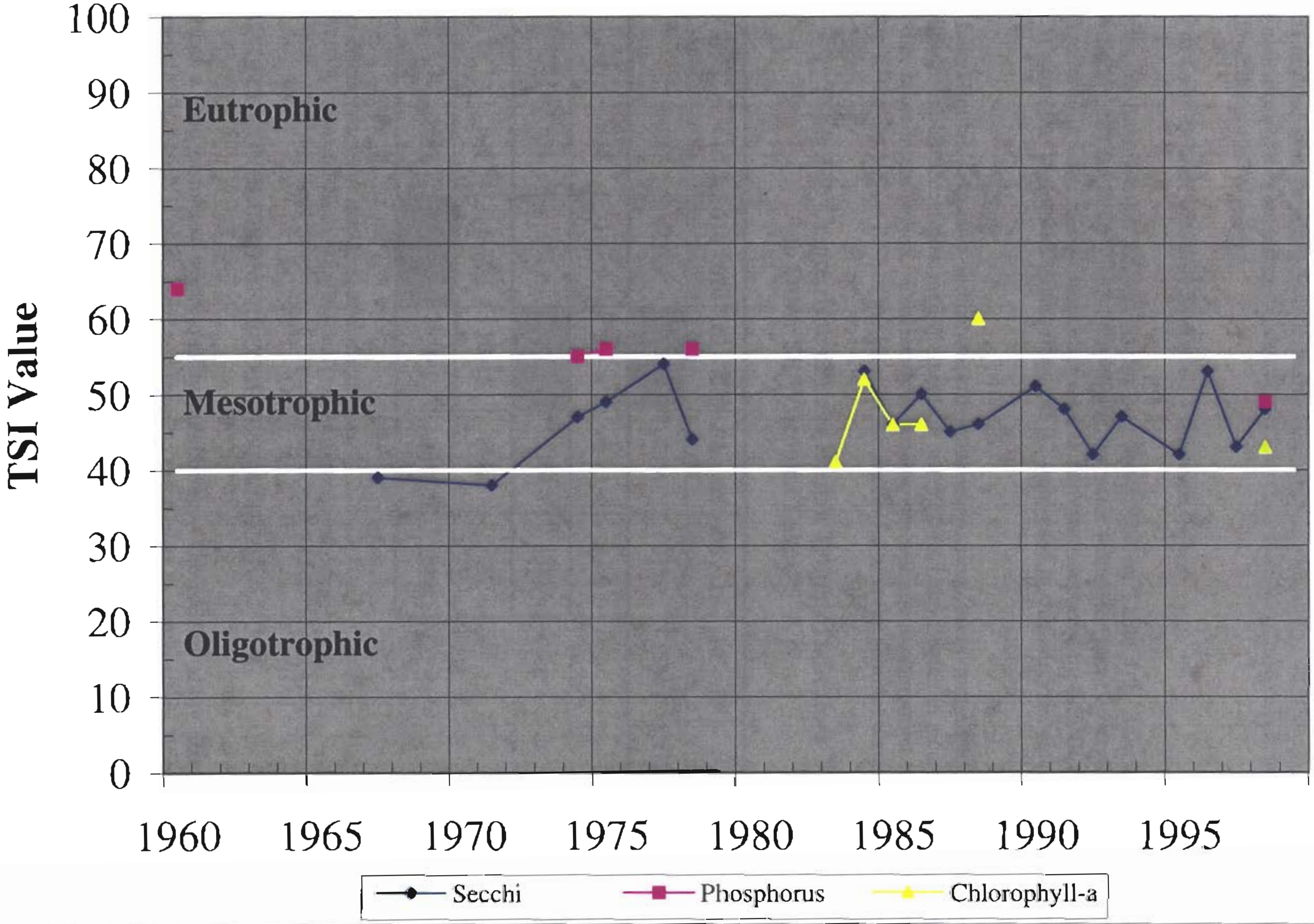


Figure 3-14 is divided into three trophic categories: eutrophic, mesotrophic, and oligotrophic. It can be seen that the indicators of trophic status for site 32 on Lake Beulah generally remained in the mesotrophic range throughout the period of record.

Comparison of Lake Beulah to Other Southeast Wisconsin Lakes

A final analysis on Lake Beulah's water quality is summarized on Table 3-9. In a 1983 publication (Technical Bulletin 138) the WDNR reported trophic indicator values for lakes by region of Wisconsin. The values monitored in Lake Beulah were compared to the values reported by WDNR for other lakes in southeastern Wisconsin. Monitored values from site 32 were used in this analysis, since site 32 had the most data.

In general, Lake Beulah's trophic indicators are better than most lakes monitored in southeastern Wisconsin. For example, Secchi disk measurements at site 32 puts Lake Beulah in a category better than 64% of the other lakes in the region. Furthermore; because the average measurement was 8.7 feet; it is probably closer to the top 10% – 15% of the lakes in the region for average summer water clarity.

Table 3-9: Comparison of Lake Beulah Trophic Indicators to Other SE Wisconsin Lakes *

Total Phosphorus (mg/l)	**<.01**	**.010 -.020**	**.02 - .03**	**.03 - .05**	**.05 - .10**	**.10 - .15**	**>.15**
% of Lakes in Category	7%	21%	15%	21%	21%	3%	12%
Secchi disk (ft)	**>18**	**18 - 9**	**9 – 6**	**6 - 3**	**3 - 0**		
% of Lakes in Category	0%	9%	26%	31%	33%		
Chlorophyll- *a* (ug/l)	**0-5**	**5-10**	**10-15**	**15-30**	**>25**		
% of Lakes in Category	22%	31%	14%	10%	24%		

* Average Lake Beulah values from site 32 shown in shaded boxes;
Source of data: WDNR Technical Bulletin 138 (1983) and Lake Beulah historical data
Site 32 average values: 0.025 mg/l Total Phosphorus; 8.7 feet Secchi disk; and 9.12 ug/l Chlorophyll *a*

WATER QUALITY CONCLUSIONS/RECOMMENDATIONS

Lake Beulah has a long history of water quality monitoring. The records show that the lake is in a mesotrophic condition, which is quite good compared to most lakes in southeastern Wisconsin. Changes in the lake's water quality over the monitoring period (early 1970's to present) are not evident based on the available monitoring data reviewed. Maintenance of the monitoring program currently in place will build upon the historical data. The Lake District should also update the water quality database developed for this project on a regular basis with new monitoring results.

4.0 WATERSHED INVENTORY/NONPOINT SOURCE POLLUTION IDENTIFICATION

INTRODUCTION

Nonpoint source pollution is the pollution that enters Lake Beulah from rainfall runoff, or snowmelt runoff. As water from rain or snowmelt flows over the land, it picks up whatever substances may be on the surface. These substances include sediment, pesticides, road salt, oil, grease, heavy metals, and bacteria. These pollutants are delivered to the lake at different times of the year and can result in turbid water, algae blooms, macrophyte growths, fish kills, and unsafe swimming conditions.

One of the tasks under this project was to estimate the relative quantity of nonpoint source pollution from the various sources to Lake Beulah.

METHODOLOGY

To calculate nonpoint source pollution loads, the Lake Beulah watershed was first subdivided into several smaller, sub-watersheds. The subwatersheds were delineated using USGS 7.5-minute topographic maps and based on the major tributaries draining the lake. The subwatersheds are shown in Figure 4-1.

Secondly, an assessment of current (1999) land use within the Lake Beulah watershed was made. Initial land use mapping was obtained from Southeastern Wisconsin Regional Planning Commission's (SEWRPC) 1990 land use map. This land use map was digitized into a GIS format and was subsequently revised by aerial photo analysis (from a 1995 air photo) and with field observations conducted in the summer of 1999. The resulting land use map is presented in Figure 4-2. The breakdown of 1999 land use is presented in Table 4-1.

Nonpoint source pollution loadings of sediment and phosphorus, based on land use, were determined using the Source Load and Management Model (SLAMM) in conjunction with monitored data from USGS reports. Table 4-2 summarizes the annual unit area pollutant loading rates (lbs/acre/year) that were used for each of the different land use types found within the Lake Beulah watershed. SLAMM was designed to calculate pollutant loads expected in the runoff waters from urban areas. Many factors are used in SLAMM including four major items: 1) land use, 2) soil hydrologic group; 3) drainage type, and 4) management practices. Table 4-2 shows the pollutant loadings values produced by SLAMM using these factors for Lake Beulah watershed land use conditions. Since SLAMM is not an appropriate model for agricultural and undeveloped lands, pollutant loadings from these undeveloped lands were estimated from WDNR and USGS (USGS Fact Sheet FS-195-97) monitored pollutant loads. The results of the nonpoint source pollution analysis are presented in Tables 4-3 and 4-4. Figures 4-4 and 4-5 provide another look at the land use types that contribute the highest pollutant loads.

Table 4-1: 1999 Land Use by Sub-Watershed
(land use in acres)

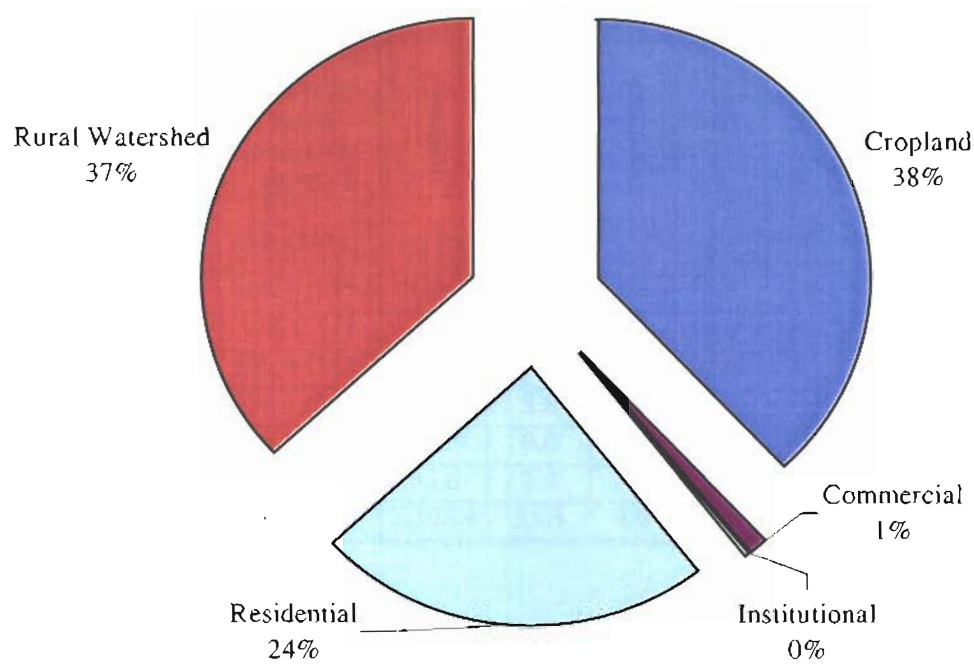
Land Use	Sub-Watersheds								
	Army Lake	Beulah (direct drainage)	Booth	Dorns Bay	Pickerel-1	Pickerel-2	Stringers Bridge	Total Area	%
Cropland	220.2	477.3	23.0	293.4	556.9	420.8	58.4	2,050.0	36%
Commercial	37.2	8.8			4.8		3.8	54.6	1%
Farmsteads	5.7	12.8	3.9	20.0	15.5	1.2	5.5	64.7	1%
Institutional	4.2	21.9						26.0	0%
Residential (Low Dens.)	48.6	516.1	41.5	105.9	47.2	67.2	169.8	996.3	17%
Residential (Med. Dens.)	0.0	197.2	34.2	0.6	0.9	23.1	14.3	270.4	5%
Open Space	110.5	217.8	35.3	44.5	387.6	33.1	186.9	1,015.6	18%
Open Water*	84.2	27.5	121.0	2.2	63.3	7.0	8.4	313.6	6%
Woodlot	144.9	351.5	0.4	177.6	78.0	12.2	144.8	909.3	16%
Total Area	655.4	1,831.0	259.4	644.2	1,154.2	564.6	591.8	5,700.4	100%
%	11%	32%	5%	11%	20%	10%	10%	100%	

* does not include Lake Beulah

Table 4-2: Pollutant Loads Per Unit Area Used in Lake Beulah Watershed Nonpoint Source Pollution Calculations

Land Use Category	Sediment unit load (lbs/acre/yr)	Phosphorus unit load (lbs/acre/yr)	Source of data
Residential (Light Density)	47	0.34	SLAMM
Residential (Medium Density)	33	0.30	SLAMM
Institutional	336	1.43	SLAMM
Commercial	1,191	1.51	SLAMM
Open Space (wetlands, undeveloped lands)	24	0.08	Phos. Load from Table 3; WDNR Research & Findings #38; April 1995; Sediment Load from ratio of sediment/phosphorus USGS monitoring
Wooded Area	24	0.08	Phos. Load from Table 3; WDNR Research & Findings #38; April 1995; Sediment Load from ratio of sediment/phosphorus USGS monitoring
Cropland	2,247	0.92	Phos. Load from Table 3; WDNR Research & Findings #38; April 1995; Sediment Load from ratio of sediment/phosphorus USGS monitoring
Farmstead	150	0.50	Phos. Load from Table 3; WDNR Research & Findings #38; April 1995; Sediment Load from ratio of sediment/phosphorus USGS monitoring
Open Water	0	0.00	Assumed

Figure 4-3: Land Use in Lake Beulah Watershed



RESULTS

Annual pollutant loadings (sediment and phosphorus) from the lake's watershed were calculated using the acres in table 4-1 and the unit loads in table 4-2. The analyses are reported for pollutant loadings by land use and for pollutant loadings by subbasin. In this way the critical land uses and the critical geographic locations of the pollutants are identified. Tables 4-3 and 4-4 detail the results for the sediment and phosphorus nonpoint source loading results. The tables are followed by charts which display graphically the results for each pollutant.

Table 4-3:
Annual Sediment Pollutant Loads – Lake Beulah Watershed Under 1999 Land Use

Subbasin	Total Area (acres)	Total Suspended Sediment Load (tons/yr & %)	Suspended Solids Annual Pollutant Load for Each Land Use (tons/yr)							
			cropland	commercial	farmstead	institutional.	residential (low density)	residential (medium density)	open Space	woodlots
Army Lake	655.4	275.0 (11%)	247.5	22.2	0.4	0.7	1.1	0.0	1.3	1.8
Beulah - Direct	2,623.0	568.3 (24%)	536.3	5.3	1.0	3.7	12.0	3.2	2.6	4.3
Booth	259.4	28.1 (1%)	25.8	0.0	0.3	0.0	1.0	0.6	0.4	0.0
Dorns Bay	644.2	336.4 (14%)	329.7	0.0	1.5	0.0	2.5	0.0	0.5	2.2
Pickerel-1	1,154.2	636.5 (27%)	625.8	2.8	1.2	0.0	1.1	0.0	4.7	0.9
Pickerel-2	564.6	475.4 (20%)	472.9	0.0	0.1	0.0	1.6	0.4	0.4	0.1
Stringers Bridge	591.8	76.5 (3%)	65.6	2.2	0.4	0.0	3.9	0.2	2.3	1.8
Totals	**6,492.4**	**2,396.3**	**2,303.6**	**32.5**	**4.9**	**4.4**	**23.2**	**4.4**	**12.3**	**11.0**

Table 4-4:
Annual Phosphorus Pollutant Loads – Lake Beulah Watershed Under 1999 Land Use

Subbasin	Total Area (acres)	Total Phosphorus Load (lbs/yr)	Total Phosphorus Annual Pollutant Load for Each Land Use (lbs/yr)							
			cropland	commercial	farmstead	institutional.	residential (low density)	residential (medium density)	open Space	woodlots
Army Lake	655.4	304.5 (11%)	202.6	56.2	2.8	5.9	16.5	0.0	8.8	11.6
Beulah - Direct	2,623.0	770.2 (29%)	439.1	13.3	6.4	31.3	175.5	59.2	17.4	28.1
Booth	259.4	50.3 (2%)	21.1	0.0	2.0	0.0	14.1	10.3	2.8	0.0
Dorns Bay	644.2	333.8 (13%)	270.0	0.0	9.9	0.0	36.0	0.2	3.6	14.2
Pickerel-1	1,154.2	580.8 (22%)	512.3	7.2	7.7	0.0	16.0	0.3	31.0	6.2
Pickerel-2	564.6	421.1 (16%)	387.1	0.0	0.6	0.0	22.8	6.9	2.6	1.0
Stringers Bridge	591.8	150.7 (6%)	53.7	5.7	2.7	0.0	57.7	4.3	15.0	11.6
Totals	**6,492.4**	**2,611.5**	**1,886.0**	**82.4**	**32.0**	**37.2**	**338.7**	**81.1**	**81.3**	**72.7**

Figure 4-4: Annual Sediment Sources to Lake Beulah by Land Use

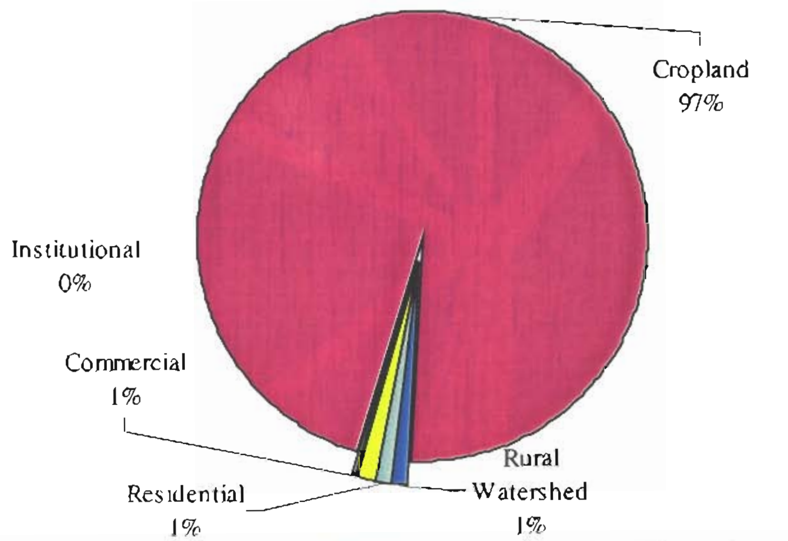


Figure 4-5: Annual Phosphorus Sources to Lake Beulah by Land Use

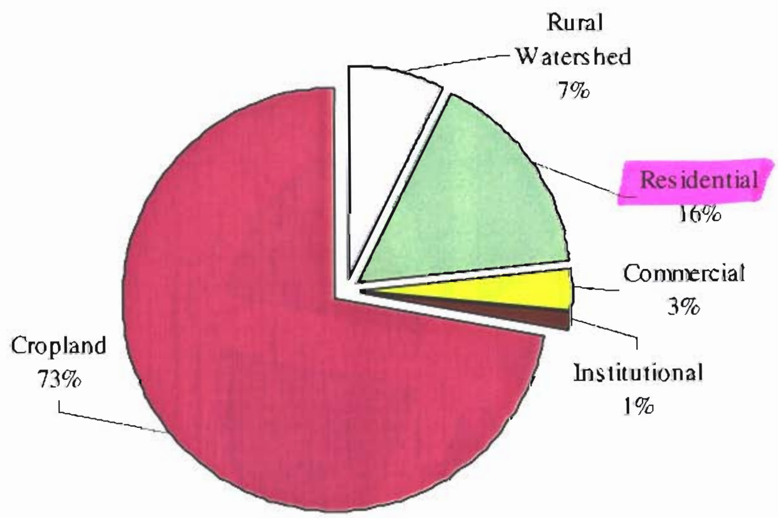


Figure 4-6: Annual Sediment Loads by Sub-Basins

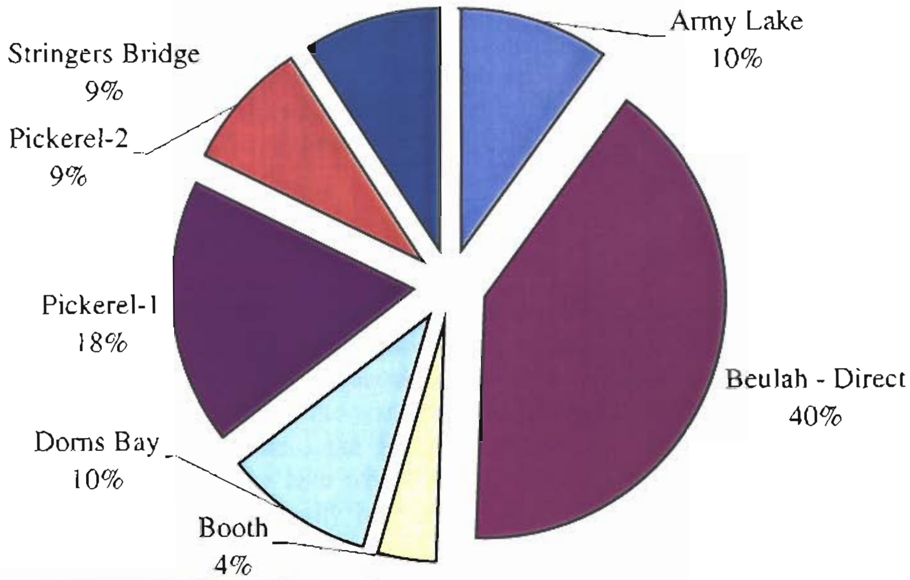
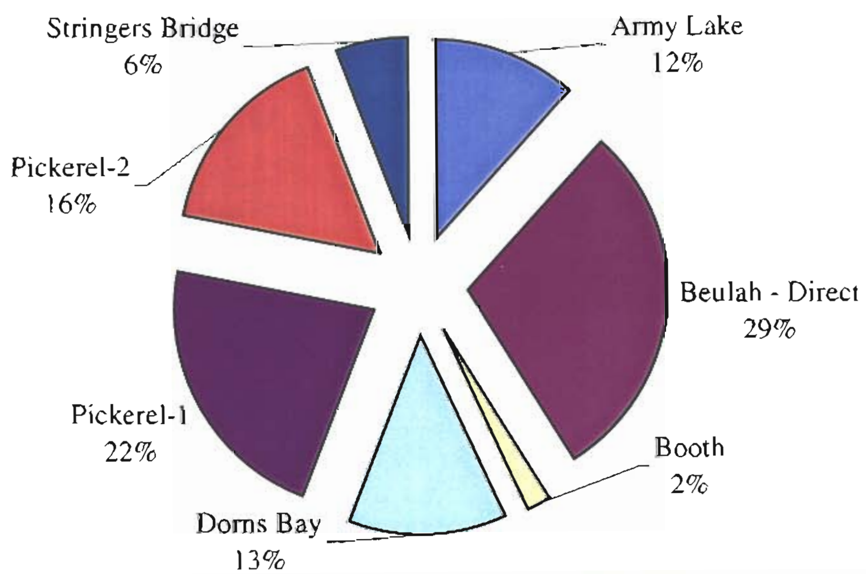


Figure 4-7: Annual Phosphorus Loads by Subbasin



As can be seen from these figures 4-4 and 4-5 cropland is by far, the largest source of sediment and phosphorus to Lake Beulah of all the land uses analyzed. Although cropland accounts for 36% of the land use in the Lake Beulah watershed it accounts for 97% and 73% of the annual sediment and phosphorus loads respectively.

The lands directly around the lake's shore also account for the highest percentage of the sediment and phosphorus delivery of all the sub-basins within the lake's watershed. This sub-basin is also the largest of the sub-basins in area (32% of the watershed), so it is not surprising that it produces the highest pollutant loads.

DISCUSSION/CONCLUSIONS

It must be noted that the nonpoint source pollution analysis did not include the impact of construction site erosion on the sediment or phosphorus loading to the lake. T[redacted]for c[redacted] This means that about 60 acres of construction sites in the watershed could equal the sediment contribution from 2,000 acres of cropland (as analyzed in the Lake Beulah watershed). Construction erosion control is especially important for sites nearer the lake where a high percent of the erosion is directly delivered to the lake. Construction erosion is a critically important issue for Lake Beulah since development pressures from East Troy and other areas in the watershed are increasing. As lands are developed, the potential for construction erosion impacts to the lake become more likely.

The potential water quality impacts from cropland runoff is best addressed through the Walworth County agencies: Land Conservation Department, Natural Resources Conservation Service, and the UW-Extension. These agencies have experience in working with the agricultural community, and may have, or be able to obtain, funding to help offset the costs of cropland management measures.

Finally, the "citizen's handbook", developed as a separate task under this project, provides the residences around the lake with recommendations for minimizing lake water quality impacts from household activities.

APPENDIX A

Table A-1: Estimated Groundwater Elevation at Selected Well Sites

Well ID Number	Surface Elevation of Well Location on USGS Quad Map *	Estimated Groundwater Elevation *	Depth to Groundwater	Street Address
AF083	835	785	50	N9327 Stewart School Road
DR496	835	800	35	Hwy J
IJ211	835	645	190	Hwy I
HO039	835	800	35	W9628 Hwy I
CT289	835	799	36	N9676 Hwy I
CR540	820	789	31	569 Island Drive
CR547	820	802	18	555 Island Drive
AE265	825	802	23	557 Island Drive
HT431	822	802	20	N9463 East Shore Dr.
AX547	819	807	12	751 Beulah Park Rd.
EN921	836	781	55	1950 Beulah Lane
HO625	821	806	15	N9429 East Shore Dr.
HU333	825	802	23	N9393 Beulah Park Rd.
AB584	842	807	35	N9381 Woodfield Ct.
AH909	850	794	56	W1852 Hwy J
AU173	862	822	40	2949 Hwy J
CG910	860	815	45	680 Oakwood Lane
AK469	841	806	35	N9303 Woodfield Ct.
HL583	835	795	40	W1744 Lake Rd.
XX001	840	810	30	W1731 Lake Rd.
FK255	827	822	5	N9354 Romadka Park Rd.
FT799	835	793	42	1794 W. Lake Dr.
II311	852	808	44	W1849 Hwy J
DU213	837	799	38	N9240 Windy Way
DN393	830	810	20	N9274 Windy Way
AR064	831	797	34	N9258 Windy Way
XX002	832	798	34	W1785 Lake Rd.
DR462	825	798	27	N8901 Army Lake Rd.
XX003	833	810	23	N8978 Army Lake Rd.
FR644	833	802	31	N8991 Army Lake Rd.
CR520	823	813	10	N8908 Army Lake Rd.
FN183	830	770	60	N9096 Woodridge Ct.
KO054	833	808	25	N9047 East Shore Rd.
CR512	822	813	9	N9455 East Shore Rd.
EO666	856	804	52	W9528 Oakwood Lane
HO921	848	833	15	N9288 Windy Way
EP113	830	820	10	W1795 Hwy J
XX004	905	822	83	N9004 Townline Rd. (CTH E)
HW692	850	800	50	W2240 Beulah Heights Rd.

Table A-1: Estimated Groundwater Elevation at Selected Well Sites

Well ID Number	Surface Elevation of Well Location on USGS Quad Map *	Estimated Groundwater Elevation *	Depth to Groundwater	Street Address
AX543	850	810	40	W2244 Beulah Heights Rd.
DR482	850	809	41	W2292 Beulah Heights Rd.
XX005	862	807	55	W2278 Beulah Heights Rd.
XX006	870	820	50	N8958 Stringers Bridge Rd.
XX007	860	807	53	N8915 Austin Rd.
XX008	851	798	53	W2108 Beulah Heights Rd.
DF444	878	818	60	N9185 Stringers Bridge Rd.
CR538	890	830	60	W2452 Hwy J
GM440	885	825	60	Stringers Bridge Rd.
HO023	883	835	48	N9122 Stringers Bridge Rd.
DR499	820	812	8	W2035 Beulah Heights Rd.
EP161	860	798	62	N9066 Austin Rd.
XX009	815	805	10	N9265 East Shore Rd.
XX010	820	793	27	N9254 East Shore Rd.
DR290	828	806	22	N9084 Hwy ES
GK965	821	803	18	W1190 Spleas-Skoney Road
XX011	818	803	15	W1156 Spleas-Skoney Road
XX012	820	767	53	W1184 Spleas-Skoney Road
XX013	820	795	25	N9181 Deer Path Rd.
HM791	833	813	20	N9092 East Shore Rd.
CH669	820	804	16	N9182 Deer Path Rd.
CS872	820	804	16	N9168 Ravine Dr.
GI568	875	794	81	N8960 Lake Lane
EO675	812	807	5	W1307 Beach Rd.
XX014	818	812	6	N9238 East Shore Dr.
XX015	843	822	21	N9194 East Shore Rd.
XX016	836	786	50	W1234 Beach Rd.
FQ333	872	802	70	W1173 Beulah Rd.
HL921	872	798	74	W1193 Beulah Lane
XX017	871	808	63	W1174 Beach Rd.
XX018	840	804	36	W1562 Sawyer Lane
XX019	833	808	25	W1540 Sawyer Lane
XX020	833	793	40	W1540 Sawyer Lane
XX021	833	809	24	W1540 Sawyer Lane
XX022	860	820	40	W1588 Sawyer Lane
XX023	813	778	35	Army Lake Rd.
IE539	855	814	41	N8721 Grandview Dr.
XX024	820	797	23	W2032 Kings Parkway
HO014	860	808	52	N8693 Grandview Dr.
CR536	858	815	43	W1838 St. Peters Rd.
EP421	861	819	42	W1698 St. Peters Rd.

Table A-1: Estimated Groundwater Elevation at Selected Well Sites

Well ID Number	Surface Elevation of Well Location on USGS Quad Map *	Estimated Groundwater Elevation *	Depth to Groundwater	Street Address
CS880	820	783	37	N9367 Beulah Park Rd.
FM839	830	817	13	W2235 Country Club Lane
FM843	820	784	36	N9367 Beulah Park Rd.
XX025	830	777	53	W1913 Beulah Heights Rd.
AX511	830	812	18	W1905 Beulah Heights Rd.
XX026	838	812	26	W1900 Beulah Heights Rd.
HL917	820	810	10	W1951 Beulah Heights Rd.
CR529	880	803	77	W1975 It's A Little Road
CZ744	850	770	80	W1959 It's A Little Road
HW621	830	803	27	W1797 Lake Rd.
XX028	890	805	85	N9231 Oakwood Lane
XX029	860	805	55	N9283 Oakwood Lane
CM303	848	808	40	N9232 Windy Way
XX030	820	782	38	W1641 South Shore Dr.
XX031	810	796	14	W1687 South Shore Dr.
AX550	818	800	18	N9150 Humphrey Lane
XX033	815	812	3	N9188 Humphrey Lane
XX034	822	804	18	N9219 South Shore Dr.
DT407	810	796	14	N9234 South Shore Dr.
HU335	840	830	10	N8651 Wilmers Landing Rd.
DR674	855	801	54	N8694 Wilmers Grove Rd.
AX527	855	805	50	N8658 Wilmers Grove Rd.
CX684	850	815	35	N8609 Wilmers Landing Rd.
XX035	835	800	35	W2202 Wilmers Grove Rd.
XX036	835	790	45	W2236 Wilmers Grove Rd.
XX037	870	817	53	N8640 Stringers Bridge Rd.
XX038	869	811	58	N8634 Stringers Bridge Rd.
AE263	867	817	50	N8590 Stringers Bridge Rd.
DR470	867	812	55	N8568 Stringers Bridge Rd.
DR450	869	816	53	N8542 Stringers Bridge Rd.
HY677	850	795	55	W2449 St. Peters Rd.
CZ710	860	810	50	W2467 St. Peters Rd.
HO008	830	782	48	W2427 St. Peters Rd.
HO009	850	798	52	W2445 St. Peters Rd.
HT581	852	807	45	W1986 Kings Parkway
GM150	850	813	37	W1990 Kings Parkway
FI421	852	809	43	N8735 Grandview Lane
II308	810	806	4	W1297 Beach Rd.
BA034	825	819	6	N9113 East Shore Rd.
EO670	820	799	21	W9119 East Shore Rd.
CR549	812	796	16	W1442 South Shore Dr.

Table A-1: Estimated Groundwater Elevation at Selected Well Sites

Well ID Number	Surface Elevation of Well Location on USGS Quad Map *	Estimated Groundwater Elevation *	Depth to Groundwater	Street Address
AB559	811	797	14	W1482 South Shore Dr.
DR479	830	803	27	N9112 South Shore Dr.
AD953	811	807	4	W1785 South Shore Dr.
EO651	835	807	28	W2182 Wilmers Grove Rd.
GK975	811	807	4	N8784 Stringers Bridge Rd.
XX039	820	818	2	N8831 Stringers Bridge Rd.
GK969	820	803	17	W2315 New Deal Avenue
BA039	850	793	57	N8704 Wilmer Point Lane
XX040	840	790	50	N8720 Wilmer Point Lane
CR522	840	790	50	N8724 Wilmer Point Lane
HO646	813	723	90	N8782 Wilmer Point Lane
DT430	810	808	2	W2246 West Bay Road
DR288	850	791	59	W2195 Country Club Lane
ID134	865	805	60	W2201 Country Club Lane
XX041	840	813	27	W2235 Country Club Lane
XX042	830	805	25	W2259 Country Club Lane
ID128	834	805	29	W2263 Country Club Lane
EO674	835	822	13	W2273 Country Club Lane
CT849	870	806	64	W1270 Beulah Lane
CJ819	874	785	89	W1240 Beulah Lane
XX043	818	799	19	N9395 Island Drive
XX044	816	810	6	N9307 Beulah Park Rd.
XX045	820	805	15	N9304 Beulah Park Rd.
XX046	821	802	19	N9423 East Shore Dr.
XX047	821	799	22	N9415 East Shore Dr.
XX048	822	801	21	N9467 East Shore Rd.
XX049	823	804	19	N9479 East Shore Rd.
BA030	850	797	53	N9390 East Shore Rd.
HO020	840	802	38	N9546 Mill Site Rd.
XX050	809	794	15	N9518 Island Drive
CT802	810	802	8	W1689 Hwy J
XX051	809	809	0	W1618 Hwy J
AX526	810	805	5	W1571 Hwy J
CR535	828	823	5	W1575 Hwy J
XX052	810	804	6	W1521 Fairway Road
XX053	817	789	28	W1489 Hwy J
XX054	810	802	8	W1510 Brassie Drive
XX055	816	800	16	W1485 Brassie Drive
XX056	853	808	45	W9360 Oakwood Lane
CT203	840	808	32	W1840 Lake Rd.
AK467	838	806	32	W1818 Lake Rd.

Table A-1: Estimated Groundwater Elevation at Selected Well Sites

Well ID Number	Surface Elevation of Well Location on USGS Quad Map *	Estimated Groundwater Elevation *	Depth to Groundwater	Street Address
GI098	840	811	29	N9145 Oakwood Lane
GH987	830	795	35	N9144 Oakwood Lane
DR455	818	814	4	N9124 Oakwood Lane
XX057	811	809	2	N8774 Stringers Bridge Rd.

* elevation in feet above mean sea level

APPENDIX B

DESCRIPTION OF LAKE BEULAH WATER QUALITY DATABASE

The historical water quality data collected for Lake Beulah was entered into a Microsoft Access database A computerized database is a powerful and efficient way to store and analyze large amounts of related data. The database consists of a collection of tables and queries. Tables are primarily used to store the raw data. Queries are used to sort and analyze the data.

TABLES

TEST_ RESULTS Table

The heart of the database is the table entitled TEST_RESULTS. Raw data from almost 40 years of lake monitoring was entered into this table. This table, like the others, consists of records ("rows" of data) and fields ("columns" of data). All the information related to one unique test or sample makes up one record. The TEST_RESULTS table contains over 8000 records. A record contains a series of fields. In the TEST_RESULTS table, the fields are discussed following the example portion of the table.

TEST_RESULT Table
(example of portion)

DOC_ID	SPEC_LOCATION	DATE	TEST_TYPE	DEPTH	TEST_VALUE	COMMENTS
1	AQ31	9/27/70	FECAL_COLI	0	-1	<10
1	AQ31	9/27/70	TOT_COLI	0	80	
2	AQ01	4/22/71	ALKA	0	212	MG/L TOTAL
2	AQ01	4/22/71	ORTHOP	0	0.021	PHOSPHATE MG/L
2	AQ01	4/22/71	SECCHI	0	13	
2	AQ01	6/20/71	FECAL_COLI	0	110	
2	AQ01	6/20/71	TOT_COLI	0	1050	
2	AQ01	7/18/71	DO	1	8	
2	AQ01	7/18/71	DO	4	9.3	
2	AQ01	7/18/71	TEMP	1	25.5	
2	AQ01	7/18/71	TEMP	4	24.5	
2	AQ01	7/27/71	NITRATE	0	0 46	MG/L

DOC_ID: An identification number corresponding to a specific source document (Aqua-Tech report, DNR report, etc.). These ID numbers are also contained in a field in the DOCUMENT_SOURCE table, and these two tables are linked.

SPEC_LOCATION: The alphanumeric name assigned to the test location in the source document. These location names are also contained in a field in the LOCATION table, and the two tables are linked.

DATE: The date of the test or sample (not to be confused with the date of the report).

TEST_TYPE: The type of test or sample, such as dissolved oxygen (DO), total phosphorus, Secchi disk reading, etc. This field is also contained in the TEST_TYPE table.

DEPTH: The depth at which the test was taken. A depth of zero means the test was taken at the surface, or the depth is not relevant. A depth of "888" means the test was taken at or near the bottom of the lake at that location

TEST_VALUE: The numeric result of the test or sample, such as the concentration of a certain chemical, a temperature reading, or a Secchi disk reading. A test value of "-1" means the sample was below the detectable level for that kind of test. A test value of "-99" means that the test result was not available. A complete list of the tests contained in the database and their units is presented in the TEST_TYPE table discussion below.

COMMENTS: Any other relevant information.

LOCATION Table

The LOCATION table contains information on sample site locations. The table has two fields:

LOCATION_TABLE
(example of portion)

SPEC_LOCATION	UNIQUE_ID
653120	5
653121	32
68001	5
68010	32
AQ(83)BL-3	5
AQ(84)BL-11	35
AQ(84)BL-8	36
AQ01	1
AQ02	2
AQ03	3
AQ04	4
AQ05	5

SPEC_LOCATION: The alphanumeric name assigned to the test or sample location in the source document. The source documents contain a total of approximately 70 named test locations. These test location names are the same ones used in the SPEC_LOCATION field in the TEST_RESULTS table, and the two tables are linked through this field. A GIS coverage was developed showing the location of these test sites. In a few cases, the location of a test could not be determined.

UNIQUE_ID: The number assigned to a geographically unique test location. Some locations given different names in different source documents were effectively the same geographic location. Locations which were named differently but were the same geographically were all given the same UNIQUE_ID. The UNIQUE_ID field is the best way to select data based on geographic test location. If you use the SPEC_LOCATION field, you have to know all of the different names assigned to a location, or you will miss data. There are approximately 50 test/sample locations given unique ID's.

TEST_TYPE Table

The TEST_TYPE table contains information on the type of test or sample taken. The fields contained in the table are discussed following the example of the table.

TEST_TYPE Table
(complete table)

test_type	type_des	units_of_measurement
ALKA	ALKALINITY (total)	mg/l
BOD	BIOLOGICAL_OXYGEN_DEMAND	5 day mg/l
CA	CALCIUM	mg/l
CHLORIDE	CHLORIDE	mg/l
CHLR_A	CHLOROPHYL_A	ug/l
CL	CHLORINE	mg/l
COND	CONDUCTIVITY	micromhos/centimeter
DO	DISSOLVED OXYGEN	mg/l
DRP	DISSOLVED_REACTIVE_PHOSPH	mg/l
FE	IRON	mg/l
FECAL_COLI	FECAL_COLIFORM	counts/100 mo
K	POTASSIUM	mg/l
MG	MAGNESIUM	mg/l
MN	MANGANESE	mg/l
NA	SODIUM	mg/l
NH3_N	AMMONIA	mg/l
NITRATE	NITRATE	mg/l
NITRITE	NITRITE	mg/l
NO2+NO3_N	NITRITE_PLUS_NITRATE_NITROG	mg/l
ORG_N	ORGANIC_NITROGEN	mg/l
ORTHOP	ORTHOPHOSPHATES	mg/l
PH	PH	SU (standard units)
PO4	PHOSPHATES	mg/l
SECCHI	SECCHI_DISK	feet
SI	SILICA	mg/l
SO4	SULFATE	mg/l
STREP	FECAL_STREP	counts/100 ml
TEMP	WATER_TEMPERATURE	Celcius
TKN	TOTAL_KJELDAHL_NITROGEN	mg/l
TOT_COLI	TOTAL_COLIFORM	mg/l
TOT_N	TOTAL_NITROGEN	mg/l
TOT_P	TOTAL_PHOSPHORUS	mg/l
TSS	TOTAL_SUSPENDED_SOLIDS	mg/l
TURB	TURBIDITY	JTU

test_type: An abbreviation for the type of test or sample taken. These abbreviations are the same ones used in the TEST_TYPE field in the TEST_RESULTS table, and the tables are linked through this field.

type_des: A description of the type of test or sample taken. If a sample was taken to determine the concentration of a particular chemical compound, the compound is simply listed (calcium, chlorine, nitrates, etc.). The test could also be for another parameter (fecal coliform, Secchi disk, water temperature, etc.).

DOCUMENT_SOURCE Table

This table contains information on the source documents which contain the raw test results. The source documents are items such as annual and quarterly reports from Aqua-Tech, other miscellaneous correspondence from Aqua-Tech, DNR reports, and results from the self-help monitoring program. The DOCUMENT_SOURCE table contains the following fields:

DOCUMENT_SOURCE Table
(example of portion)

DOC_ID	DOC_TITLE	DOC_DATE	AUTHOR/AGENCY	DOC_LOCATION
1	SURVEY OF LAKE BEULAH	27-Sep-70	AQUA-TECH	LBD
2	LIMNOLOG SURVEY OF LAKE BEULAH: PART 1	27-Jul-71	AQUA-TECH	LBD
3	LIMNOLOGICAL SURVEY-- LAKE BEULAH: PART 2	21-Aug-71	AQUA-TECH	LBD
4	AQUA-TECH LETTER TO LAKE DISTRICT	18-Oct-71	AQUA-TECH	LBD
5	AQUA-TECH LETTER TO LAKE DISTRICT	20-Apr-72	AQUA-TECH	LBD
6	LIMNOLOGICAL SURVEY OF LAKE BEULAH	07-Jul-72	AQUA-TECH	LBD
7	LIMNOLOGICAL SURVEY OF LAKE BEULAH	15-Oct-72	AQUA-TECH	LBD
8	LIMNOLOGICAL SURVEY OF LAKE BEULAH	25-Jun-73	AQUA-TECH	LBD
9	LIMNOLOGICAL SURVEY OF LAKE BEULAH	14-Aug-73	AQUA-TECH	LBD
10	LIMNOLOGICAL SURVEY OF LAKE BEULAH	12-Oct-73	AQUA-TECH	LBD
11	LIMNOLOGICAL SURVEY OF LAKE BEULAH	20-Mar-74	AQUA-TECH	LBD
12	LIMNOLOGICAL SURVEY OF LAKE BEULAH	25-Apr-74	AQUA-TECH	LBD
13	LIMNOLOGICAL SURVEY OF LAKE BEULAH	24-Jul-74	AQUA-TECH	LBD
14	LIMNOLOGICAL SURVEY OF LAKE BEULAH	26-Oct-74	AQUA-TECH	LBD
15	LIMNOLOGICAL SURVEY OF LAKE BEULAH	20-Feb-75	AQUA-TECH	LBD
16	LIMNOLOGICAL SURVEY OF LAKE BEULAH	19-May-75	AQUA-TECH	LBD
17	LIMNOLOGICAL SURVEY OF LAKE BEULAH	01-Jul-75	AQUA-TECH	LBD
18	LIMNOLOGICAL SURVEY OF LAKE BEULAH	17-Oct-75	AQUA-TECH	LBD
19	LIMNOLOGICAL SURVEY OF LAKE BEULAH	24-May-76	AQUA-TECH	LBD
20	AQUA-TECH LETTER TO LAKE DISTRICT	16-Jun-76	AQUA-TECH	LBD
21	LIMNOLOGICAL SURVEY OF LAKE BEULAH	22-Jul-76	AQUA-TECH	LBD

DOC_ID: A unique identification number for the document. 41 documents were identified. The ID numbers are in chronological order, so the earliest document has an ID of 1. This field is also used in the TEST_RESULTS table, and the two tables are linked.

DOC_TITLE: The title of the document.

DOC_DATE: The date of the document.

AUTHOR/AGENCY: The author or producer of the document. In most cases, an individual author of a document could not be identified, and the document is listed as authored by an agency or firm under contract to the Lake District (Aqua-Tech or WDNR for example). In a few cases, individual authors were identified.

DOC_LOCATION: Where the document is permanently held. Almost all of the documents are held by the Lake Beulah District (LBD). A few are held by the WDNR. This field is also contained in the DOC_LOCATION table.

DOC_LOCATION Table

This small table contains a description of where the various source documents were obtained from and permanently held. It contains the following two fields:

DOC_LOCATION Table
(complete table)

DOC_LOCATION	DOC_LOCATION_ID
LBD	LAKE_BEULAH_DISTRICT
LBMD	LAKE_BEULAH_MANAGEMENT_DISTRICT
WDNR-MILW,MAD	WISCONSIN_DEPT_OF_NATURAL_RESOURCES —MADISON

DOC_LOCATION: An abbreviation for the document location.

DOC_LOCATION_ID: A fuller description of the location, such as the Lake Beulah District or the Wisconsin Department of Natural Resources.

Other Tables

There are a number of other tables contained in the database. These tables contain results of different analyses performed on the data. For example, there are tables showing annual statistics for results of Secchi disk monitoring at various locations. These tables were created by using queries.

QUERIES

Queries allow you to select, sort, modify and perform other operations on data. The database contains many queries written to perform specific tasks. Almost all of these queries work with data in the TEST_RESULTS table. For example, a query was written to select all of the data on Secchi readings taken in the southwest deep hole of the lake during the summer months, and display only this data.

Many of these queries were written to generate the data needed to create the tables and graphs displayed in the report. In particular, pairs of queries were used to generate annual statistics for a particular test type at a particular location. One query in the pair is called the "data query", which selects all the data needed for a particular analysis (such as, in the example given above, all the Secchi readings for a particular location during the summer months). The other query in the pair is the "statistics maketable query". This query uses all the data selected in the data query to obtain some summary statistics, such as annual means, standard deviations, maximum and minimum values, for the location and test type in question. Users of this database are encouraged to learn about the different types of queries that can be used, and all the different operations that can be performed with queries. Querying a database can be a quick, powerful way to analyze and draw meaningful conclusions from a large amount of data. The existing queries can be used as a starting point. However, some caution should be exercised when using an existing query. The user should understand the design of the query, so it is clear what the query is doing and what information is being returned. Some of the queries update existing tables or create new ones, so unless the user is sure of what the query will do, other parts of the database could be mistakenly modified.

APPENDIX C

Average Epilimnion and Hypolimnion DO Concentrations During Summer Months (June – August)

Date	Epilimnion (average DO; mg/l)	Hypolimnion (average DO; mg/l)
Site 15		
7/18/71	8.16	1.30
8/20/72	11.00	3.6
8/27/73	10.08	0.40
7/1/75	8.8	- -*
7/22/76	6.61	2.77
6/30/77	8.70	4.13
Site 20		
7/18/71	7.46	7.32
8/20/72	10.55	7.00
8/27/73	10.14	0.68
8/27/74	10.28	5.35
7/1/75	8.83	1.48
Site 21		
7/18/71	7.6	1.8
8/27/74	8.4	0.9
7/1/75	9.0	2.4
7/22/76	8.0	2.0
6/21/90	5.0	4.2
7/23/90	6.0	2.2
8/17/90	5.1	2.8
6/13/91	9.2	8.6
7/2/91	8.2	4.7
7/17/91	6.6	7.2
8/1/91	8.8	0.4
7/15/92	7.8	2.2
8/3/92	8.1	8.2
7/12/93	7.5	2.6
8/20/93	8.3	3.9
6/14/94	9.9	- -
7/13/94	9.0	- -
6/29/95	5.6	5.6
7/31/95	6.1	- -
8/31/95	5.5	- -
8/26/97	5.1	- -
6/25/98	6.0	6.4
7/24/98	5.8	0.8
8/27/98	5.9	- -
Site 29		
7/18/71	7.6	5.4
8/27/74	8.4	1.6
7/1/75	9.0	3.5

Average Epilimnion and Hypolimnion DO Concentrations During Summer Months (June – August)

Date	Epilimnion (average DO; mg/l)	Hypolimnion (average DO; mg/l)
7/22/76	7.6	2.7
6/21/90	5.0	6.8
7/23/90	5.2	5.8
8/17/90	5.1	5.3
6/13/91	9.2	10.8
7/2/91	8.2	10.5
7/17/91	6.6	8.0
8/1/91	8.7	6.2
7/15/92	8.3	7.5
8/3/92	8.3	11.3
7/12/93	7.5	9.2
8/20/93	8.4	10.0
6/14/94	9.6	- -
7/13/94	9.0	- -
6/29/95	5.7	- -
7/31/95	6.1	- -
8/31/95	5.5	- -
8/26/97	5.1	- -
6/25/98	6.0	- -
7/24/98	5.8	0.8
8/27/98	5.9	- -
Site 32		
7/18/71	7.7	4.3
8/20/72	11.4	4.5
8/27/73	9.4	1.8
7/17/74	8.4	1.9
8/27/74	7.9	0.4
7/1/75	8.6	2.0
7/10/75	8.4	0.6
7/22/76	8.9	2.1
6/30/77	8.8	3.7
7/14/78	8.5	4.1
8/10/78	9.1	4.3
6/16/82	9.8	7.8
7/15/83	9.8	4.8
8/13/84	8.6	1.9
8/16/85	9.0	0.2
8/26/85	8.4	0.7
8/18/86	8.6	0.5
8/24/87	8.8	1.3
8/29/88	8.5	1.7
6/21/90	5.5	3.9
7/23/90	5.4	7.2
8/17/90	4.9	0.2

Average Epilimnion and Hypolimnion DO Concentrations During Summer Months (June – August)

Date	Epilimnion (average DO; mg/l)	Hypolimnion (average DO; mg/l)
6/13/91	9.7	6.9
7/2/91	8.8	5.3
7/17/91	6.6	1.1
8/1/91	8.5	0.4
7/15/92	7.7	5.5
8/3/92	8.2	3.2
7/12/93	9.7	5.8
8/20/93	8.4	2.1
6/14/94	9.6	6.9
7/13/94	9.4	2.9
6/29/95	6.1	4.8
7/31/95	5.6	2.6
8/31/95	5.5	0.8
8/26/97	5.3	0.3
6/25/98	6.1	3.7
6/30/98	5.6	4.8
7/22/98	5.5	3.0
7/24/98	5.7	1.2
8/27/98	5.6	0.1
8/31/98	5.3	2.2
Site 39		
7/14/78	8.4	0.6
8/10/78	8.4	0.6
6/16/82	9.6	3.0
7/15/83	9.5	0.9
8/13/84	8.3	0.6
8/26/85	8.3	0.8
8/18/86	8.8	0.5
8/24/87	8.1	0.7
8/29/88	8.3	1.2
6/20/94	8.6	4.9
7/19/94	11.9	1.7
6/24/95	6.4	2.8
7/26/95	5.3	0.3
8/29/95	5.1	7.8
Site 41		
6/21/90	5.1	2.9
7/23/90	5.3	1.4
8/17/90	5.0	1.0
6/13/91	10.4	4.4
7/2/91	7.9	1.8
7/17/91	6.4	0.8
8/1/91	9.2	0.3
7/15/92	8.0	5.6

Average Epilimnion and Hypolimnion DO Concentrations During Summer Months (June – August)

Date	Epilimnion (average DO; mg/l)	Hypolimnion (average DO; mg/l)
8/3/92	8.1	6.8
7/12/93	8.2	2.4
8/20/93	8.4	1.1
6/14/94	9.0	3.4
7/13/94	9.1	1.5
6/29/95	6.0	2.4
7/31/95	5.2	0.9
8/31/95	4.9	0.3
6/24/96	8.9	0.2
7/31/96	8.7	0.2
8/29/96	8.0	0.2
8/26/97	5.7	0.4
6/25/98	5.8	0.6
7/24/98	5.3	0.4
8/27/98	5.7	0.2
Site 47		
6/21/90	5.0	3.4
7/23/90	5.4	1.9
8/17/90	4.9	0.4
6/13/91	9.5	8.7
7/2/91	8.2	7.4
7/17/91	6.8	7.0
8/1/91	8.5	5.6
7/15/92	7.6	7.2
8/3/92	8.1	5.6
7/12/93	8.7	6.0
8/20/93	6.5	1.8
6/14/94	9.7	6.4
7/13/94	9.0	4.4
6/29/95	5.4	3.7
7/31/95	5.5	2.4
8/31/95	5.2	0.2
8/26/97	5.2	2.2
6/25/98	5.8	2.2
7/24/98	5.5	1.3
8/27/98	5.7	1.5

* Lake did not stratify or no hypolimnion samples were taken