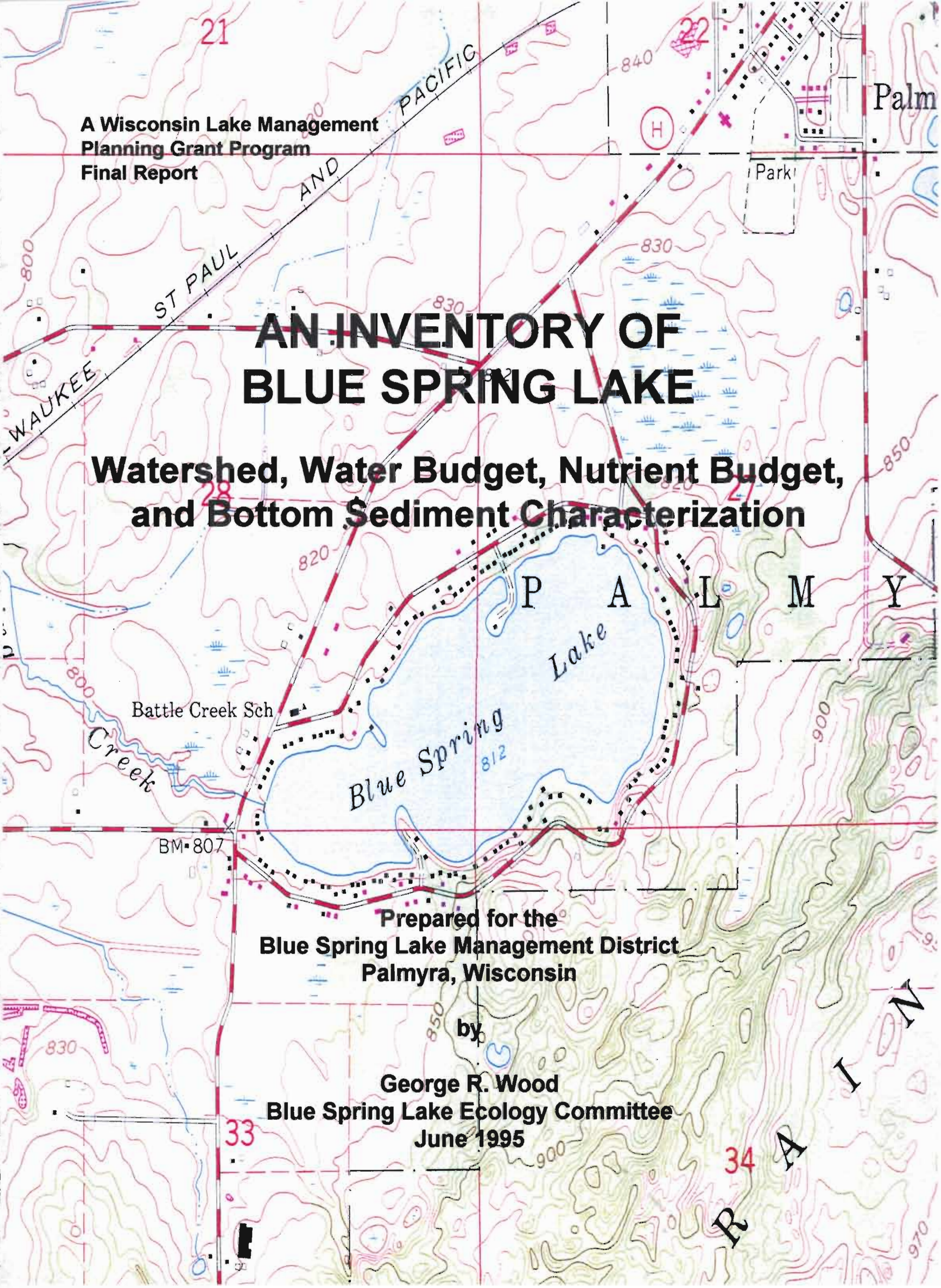
A Wisconsin Lake Management Planning Grant Program Final Report

AN INVENTORY OF BLUE SPRING LAKE

Watershed, Water Budget, Nutrient Budget, and Bottom Sediment Characterization



Prepared for the
Blue Spring Lake Management District
Palmyra, Wisconsin

by

George R. Wood
Blue Spring Lake Ecology Committee
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FOREWORD

This inventory documents information that characterizes Blue Spring Lake and its watershed. It is intended to serve as a resource to lake managers and stewards as they make decisions to protect and improve the lake's quality. It should be especially useful for the development of a long range, lake management plan. Such a plan will require a great deal of additional thought and input from the wide spectrum of people interested in the lake. Combining that input with this inventory will form a sound basis for a comprehensive Blue Spring Lake management plan.

The report is written primarily for people interested in knowing how Blue Spring Lake works. The information is inherently quantitative and often very technical. Unfortunately, not all readers will have the same depth of interest nor the same technical background to appreciate the data. Because many of the measurements were new to Blue Spring Lake, details of the methodology are presented in order to validate the data and to enable comparative measurements to be made in the future. Those not interested in such detail may want to skim these sections.

For readers less familiar with technical issues, I have tried, in some places, to introduce or explain basic concepts. Readers needing more background information can refer to the many monographs that do a good job of introducing people to the technical aspects of lake ecology. These include: "Life on the Edge... Owning Waterfront Property," by M. D. Dresen and R. M. Korth, University of Wisconsin - Extension, Madison, WI (1994); "Lake Smarts," by S. McComas, Terrene Institute, Washington, D.C. (1993); "Volunteer Lake Monitoring: A Methods Manual," by J. T. Simpson, Environmental Protection Agency, EPA 440/4-91-002, Washington, DC (1991); and "Understanding Lake Data," by Byron Shaw, et al, University of Wisconsin - Extension, Report No. G3582, Madison, WI (1993). To help those that have an interest, the monograph "Understanding Lake Data," is included at the end of this report. For most readers, it is suggested that this excellent booklet be read first, before examining Blue Spring Lake's specific data. Thanks to these authors and to the UWEX for permission to use the booklet here.

ACKNOWLEDGMENTS

The work and influence of many people contributed to this inventory. Special thanks to Jim Leverance at the DNR for his help and guidance on examining the lake. For their professional expertise, thanks also goes to the DNR's Dave Marshall, Tim Asplund, John Panuska and Jo Temte; to the State Lab of Hygiene's George Bowman, Bob Schuknecht, and Chris McSweeny; to Craig Sandgren at UW-Milwaukee; and a very special thanks to UWEX County Resource Agent Steve Grabow for connecting me to so many useful resources.

Closer to home, thanks goes to the many contributors on the lake including: Eileen and Ed Oelke for starting the Blue Spring Lake Ecology Committee; to Roanne Barnes, Alice and George Ventura, and the Blue Spring Lake Association for supporting the Committee; to the Blue Spring Lake Sanitary District and the Lake Management District for supporting the Planning Grant work; to Committee members: Ted Hauf, Jim O'Hern, Clayton Meier, George Mischio, Dan Nelson, Irene and Jerry Peplinski, and Bill von Rohr for the many hours of committee work; and to Greg Twelmeyer for his continuing interest and practical insights into lake ecology. Special thanks to Ted Hauf and Jerry Peplinski for bearing the hard work and risks associated with sediment sampling; to Jim O'Hern, resident climatologist, for complete and reliable rainfall monitoring; and to Chester Gdaniac for much help and enthusiastic discussions on mehtods of instrumental measurements.

Closest to home, a big thanks to my wife, Bonnie, who not only helped collect samples, recorded data, "bagged" water, hosted committee meetings, and formatted this document, but also spent many hours of separation as I immersed myself in the myriad of facts, numbers, charts, tables, and other details associated with getting to know Blue Spring Lake.

AN INVENTORY OF BLUE SPRING LAKE
Watershed, Water Budget, Nutrient Budget,
and Bottom Sediment Characterization

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SUMMARY

In 1994, the Blue Spring Lake Ecology Committee conducted an inventory of Blue Spring Lake with the help of a $13,333 Wisconsin Lake Management Planning Grant. This inventory characterizes many of the lake's physical, chemical, and biological properties. Collecting this information is a prerequisite for developing a comprehensive lake management plan. Conducting the inventory was in keeping with the Ecology Committee's charge to develop a better understanding of the lake and to make proposals for improving its quality. The Ecology Committee is supported by the community surrounding the lake through their organizations – the Blue Spring Lake Association and the Blue Spring Lake Management District. The grant application and partial funding was sponsored by the Blue Spring Lake Sanitary District which has since been converted to the Lake Management District.

INVENTORY PURPOSE AND OBJECTIVES

Aspects of the lake considered to be in the greatest need of improvement were the excessive growth of aquatic plants, and poor water clarity. The inventory, therefore, focused on developing information that could lend insight into these problems. The objectives of the inventory were to:

- characterize the lake's watershed and land uses
- characterize all water flows to and from the lake
- characterize the lake water quality and sources of nutrients
- characterize the lake's sediment

METHODS USED

Professional consultants were hired to make critical measurements and to apply their knowledge of other lakes to Blue Spring Lake. However, most of this inventory was completed by extensive studies of the Ecology Committee using the professional resources of public organizations such as the University of Wisconsin, the Department of Natural Resources, the UW-Extension Service, and the United States Geological Survey.

Historical records of the lake, particularly physical property measurements, were compiled before beginning the inventory. The watershed boundaries were defined using topographic maps, aerial photographs, and field surveys. Water flow measurements were made on and around the lake, two to three times a week, from March to November 1994, with more frequent measurements made during rain storms. Rainfall on the lake was monitored daily and the responses of the lake level and stream flows to the rainfall were determined. Physical and chemical properties of the lake water and inflowing streams were monitored from April 1994 to February 1995. Sediment characterization was done using probes, a core sampler, and a floating platform designed, constructed, and operated by the Ecology Committee. All laboratory analyses of water and sediment samples were done by the State Laboratory of Hygiene.

RESULTS

Lake and Watershed

Blue Spring Lake is a 137-acre lake, has a 12-foot maximum depth, a 7-foot mean depth, and is located at the base of an interlobate glacial moraine. It was formed in 1929 by damming the outflow of a large natural spring that is still its primary source of water. It sits in an 880-acre watershed and has only one small inlet stream that passes through a 30-acre marsh before entering the lake. About 90% of the watershed soils have a high permeability to rainfall, draining water rapidly and reducing the potential for surface runoff. The watershed comprises 28% woodlands, 21% agricultural, 21% residential (14% medium density and 7% low density), 16% lake surface, and 14% split primarily between open grass lands and wetlands.

The 2.5 mile lakeshore is completely developed with 152 riparian homes. A total of 198 homes lie within 1000 feet of the water. All these homes have been sewered since 1990. About 30% of homeowners use lawn fertilizers. Homeowners value boating/skiing as much as lake aesthetics and about 100 power boats were kept on the lake in 1994; average horsepower

was 143. More than 450 boats of all types were kept on the lake that year.

Table S-1

BLUE SPRING LAKE AND WATERSHED CHARACTERISTICS

PROPERTY	VALUE
LAKE	
Surface Area	137 acre
Maximum Length	0.80 mile
Maximum Width	0.39 mile
Shorelength	2.42 mile
Maximum Depth	12 feet
Mean Depth	7 feet
Volume	41,800,000 ft^3
Main Water Source	Springs
Turnover Rate	110 days
WATERSHED	
Surface Area	878 acre
Watershed/Lake Ratio	6.4
Soil Hydrology Types	Well drained with low runoff potential
Percent Area Use:	
Woodlands	28%
Agricultural	21%
Residential	21%
Lake Surface	16%
Open	9%
Wetland	4%

The lake has high populations of bluegill and largemouth bass that are somewhat stunted in size. In the late 70's the lake was treated with rotenone to remove over 85,000 lbs of carp and then restocked with game fish. Following the carp removal, aquatic plant growth flourished to nuisance proportions, with Eurasian water milfoil dominating.

Harvesting has been a full time activity since 1980 and about 1600 tons of plants are removed in a typical year. In 1993, use of 2,4-D herbicide on about 10% of the lake's surface area resulted in the near eradication of Eurasian water milfoil over the *entire* lake. This resulted in an increase in native plant species, a greatly improved recreation environment, and a large savings in harvesting cost with less than 70 tons of plants needing removal during 1994. However, an increase in the frequency of algal blooms has occurred since the reduction in rooted plants.

Water Flows

On an annual basis, the lake receives 75% of its water from natural springs which is equivalent to 3.6 cfs (cubic feet per second) or 2,300,000 gal/day. Eleven percent of its water comes from rain falling directly onto the lake, 9% from seepage of rainfall through the ground, and only 5% from surface runoff. About 90% of the lake's outflow goes over the dam at an average annual rate of 4.3 cfs or 2,800,000 gal/day. The remaining 10% is lost via evaporation. The lake's turnover rate is 3.3 times/year which means that every 110 days, a volume of water flows into the lake that is equal to the entire lake volume. The flow rate of the natural springs appears to be fairly constant year round and the total water flow through the lake appears to be no less than that measured 24 years ago.

The response of the lake level and stream flow rates to rainfall events confirmed that little surface runoff results from the highly permeable soils of the watershed. Only 8% of all the rain falling on the agricultural sub-watershed east of the lake, was measured to reach the lake via surface flow through the marsh. This represents less than 3% of the total annual water supply to the lake. Most of the remainder of the rainfall filters through the ground to the water table, some of which may then enter the lake as groundwater seepage. The lake level was very constant and did not increase more than 2.5 inches, even after substantial rainfalls of almost 3 inches in 24 hours. All these measurements indicate that Blue Spring Lake receives very low inputs of storm water runoff that could be rich in nutrients and pollutants.

Water Quality

The average summertime phosphorus level in the surface water of Blue Spring Lake is 0.020 mg/L of Total-P. This is relatively low for a lake in Wisconsin's southeast region. Chlorophyll-a concentrations, an indicator of algae, and water clarity were on the normal to poor side for this region. About

Table S-2

ANNUAL WATER BUDGET FOR BLUE SPRING LAKE

Stream	Average Annual Flow Rates (L-inch/yr)[1]	(cfs)[2]	%
Inflows			
Springs & Deep Ground Water	227.6	3.59	75%
Direct Rainfall on Lake	32.4	0.51	11%
Surface Runoff from:			
Agri. lands & marsh (Inlet)	8.3	0.13	3%
Residential & other lands	8.3	0.13	3%
Seepage of Rainfall into Lake	26.8	0.42	9%
Total Inflow	303.4	4.79	100%
Outflows			
Dam Outlet	274.0	4.33	90%
Evaporation	29.4	0.46	10%
Total Outflow	303.4	4.79	100%

[1] – "L-inch" is the volume of water that would add 1 inch to the lake's level.

[2] – "cfs" is cubic feet per second.

80% of all Wisconsin lakes have better water clarity than Blue Spring Lake. The relationship between these properties suggests that much of the poor water clarity may be due to resuspended sediment rather than algal growth.

Table S-3

BLUE SPRING LAKE WATER QUALITY

PROPERTY, (units)	VALUES
Secchi Depth, (ft)	3.9
Chlorophyll-a, (ug/L)	12
Total-P, (mg/L)[b]	0.020
Total-N, (mg/L)	1.08
pH	8.6
Chloride, (mg/L)	8
Alkalinity, (mg/L)	201
Calcium, (mg/L)	38
Magnesium, (mg/L)	32

[a] – Averages for summer samples

[b] – Surface samples only.

The shallow lake is well mixed with little difference in temperature or oxygen concentrations between surface measurements and measurements at one foot from the bottom. However, Total-P concentration was 50% greater, on average, near the bottom than at the surface and may be indicative of disturbed sediment. The lake was well oxygenated from spring through winter, usually near saturated levels and frequently supersaturated.

Properties of Blue Spring Lake water are dominated by the properties of the spring water feeding the lake. The water is very rich in minerals, particularly calcium and magnesium. These minerals can precipitate as carbonates in the lake which has the beneficial effect of also adsorbing some of the phosphorus from the water column. The lake has a very high alkalinity and a pH of about 8.6. The nitrate content of the spring water is also very high at about 5 mg/L and provides a substantial supply of this nutrient for plant growth. The nitrogen/ phosphorus ratio in the water column is greater than

50 and suggests phosphorus is much more likely to be the limiting nutrient for algal growth.

Table S-4

BLUE SPRING LAKE PHOSPHORUS LOADING

Phosphorus Source	(lb/year)	%
Inflows		
Natural Springs	100	39%
Surface Runoff	70	27%
Atmospheric	40	16%
Marsh Effluent	20	8%
Seepage of Rainfall	20	8%
Homeowner Activities	5	2%
Total	255	100%
Outflows		
Over Dam	160	14%
Harvesting	960	86%
Total	1120	100%

The calculated annual phosphorus loading to the lake is quite small and estimated to be about 250 lbs/year. In fact, the harvesting operations on the lake remove almost four times the amount of phosphorus that goes into the lake. The greatest source of phosphorus (39%) is the natural springs which have a low concentration (0.014 mg/L), but a very high volume. Phosphorus contained in surface runoff from riparian and near shore lands was estimated to be the next highest contributor at 27%, while contributions from the atmosphere (dust, rainfall, leaves, pollen, etc.) are estimated at 16%. Effluent from the marsh, which drains the sub-watershed containing all the agricultural lands, is high in phosphorus content, but has such a low volume as to only contribute about 8% of the total loading. Contributions from homeowner activities such as lawn fertilizing and construction amounted to only 2% combined.

The phosphorus concentration in the lake water today is only one-third the concentration it was 17 years ago. This improvement is primarily the result of having eliminated the high carp population with some contribution probably coming from the sewer installation. Chloride concentration in the lake today is almost twice the concentration of 17 years ago and probably reflects the high use of road salt in southeast Wisconsin.

Sediments

Soft sediments at the bottom of Blue Spring Lake were found to vary in thickness from 1.7 feet to over 10 feet, and averaged 3.6 feet. This amounts to about 700,000 cubic yards of material. Unlike many lakes, the thickness did not increase with increasing water depths. The nature of the sediment also varied widely, with black muck being predominant, but also including sand, gravel, gray marl, green clay, and brown, fibrous, spongy peat.

Table S-5

BLUE SPRING LAKE
SOFT SEDIMENT PROPERTIES

Property (units)	Average	Minimum	Maximum
Thickness, (feet)	3.9	1.7	>10.1
Moisture Content, (wt%)	67	28	88
Dry Density, (g/mL)	0.5	0.1	1.4
Organic Content. (wt%)	12	1	47
NH_3–N, (mg/kg, dry)	38	2	180
Total–P, (mg/kg, dry)	520	50	1500

[1] – Based on 26 sample sites

The organic content of the dried sediment varied from 1 wt% to 47 wt%, and averaged 12 wt%. Other properties correlated well with the sediment's organic content; as the organic content increased, the phosphorus (Total-P) and ammonia-nitrogen concentrations also increased. Sediment samples containing higher organic content also retained more moisture and showed lower densities.

The phosphorus content in the top four inches of sediment, considered the root zone of most aquatic plants, is about 500 mg/kg, which is not uncommon for southeast Wisconsin lakes. However, this is an enormous supply of the one plant nutrient that is most capable of limiting aquatic plant growth. At these concentrations, little limitation occurs. While harvesting aquatic plants essentially mines phosphorus from the sediment, with a typical removal rate approaching 1000 lbs/year of phosphorus from Blue Spring Lake, this annual reduction is quite small compared to the 300,000 lbs of phosphorus estimated to be present. Reducing the phosphorus content in only the top few inches of sediment by harvesting would probably take decades to have a noticeable effect on aquatic plant productivity.

Water lying within the sediment is also rich in phosphorus and ammonia nutrients. Disturbing the sediment can release these nutrients to the water column and promote algal growth. In addition, the finer sediment particles, also rich in nutrients, are slow to settle out after disturbance and can serve as additional sites for algae. Sediment disturbances are more likely to occur in the absence of rooted aquatic plants, which tend to hold the soils together and to shield it from turbulence caused by wind, waves, and boating.

CONCLUSIONS

This inventory was successful in developing knowledge about the physical and chemical properties of Blue Spring Lake and its watershed. This data should be useful in monitoring long term changes and in assessing the value of management programs to improve the quality of the lake.

While the inventory compared and categorized Blue Spring Lake with other lakes, it has shown perhaps most clearly, that Blue Spring Lake, like almost all lakes, is unique. There are so many properties that define a lake, that simple comparisons, based on only a few properties are inadequate. And this inventory has not even touched on many other important characteristics such as the lake's phytoplankton and zooplankton communities, it's benthic communities, its fungi, insects, invertabrae, crustaceans, amphibians, waterfowl and other wildlife habituating in and around the lake. Considering all the possible variations, there can be no other lake exactly like Blue Spring Lake.

Blue Spring Lake has many positive natural characteristics that contribute to its meeting its users' quality standards; i.e., suitable for full-body-contact recreational use while maintaining healthy, balanced, and diverse biological communities. These include:

- A small watershed, only 6.4 times the lake's surface area.
- Permeable watershed soils, resulting in low storm water runoff.
- Only one small inlet stream, comprising less than 3% of all inflows.
- Large spring water inputs, providing 75% of all inflowing water.
- A high flushing rate – 110 days for turnover.
- A constant lake level, varying less than 2.5 inches even after heavy rains.
- Very low nutrient and pollution loadings from watershed land uses.
- A well-mixed and well-oxygenated lake, frequently supersaturated in oxygen.
- High alkalinity which buffers the lake from acid rain and other pollutants.
- Available nutrients to support biotic communities.
- A productive fishery, with large populations of bluegills and largemouth bass.
- An increasingly diverse aquatic plant community.

A most important positive characteristic of Blue Spring Lake is its well-organized and supportive homeowner community. This community has provided much money and many volunteers for the last 45 years in efforts to maintain and improve the quality of the lake. It has:

- restored the fishery and plant community by eliminating carp,
- managed nuisance plant growth through harvesting and herbicide treatments,
- eliminated any wastewater pollution of the lake by sewering the entire community,
- reduced Eurasian water milfoil dominance and increased the diversity of aquatic plants, and
- supported an Ecology Committee charged with increasing the knowledge of the lake.

Attributes of the lake that stand in the way of reaching user quality goals are:

- Shallowness. Even the deepest part of the lake still receives sunlight enabling plant growth. While some growth is desirable, excessive growth has prevailed and has interfered with recreational uses and the balance and diversity of the lake's biotic community.

- Fine-textured, nutrient-rich sediments. While nutrients are desirable for biotic communities, the high levels in Blue Spring Lake augment the nuisance growth levels of aquatic plants.

- Disturbed sediments. The fine sediments are easily disturbed, adding nutrients to the water column which then support algal growth.

- Overuse. The high level of development on the lake and the intensity of power boating reduce recreational opportunities at times. Sediment is frequently disturbed from activities such as boating, harvesting, and shoreline raking. This not only adds nutrients to the water column, but also provides areas of open sediment which are easily invaded by exotic plants such as Eurasian water milfoil or curly leaf pondweed.

RECOMMENDATIONS

The purpose of this inventory was to develop a better understanding of how Blue Spring Lake works in order to have that knowledge available for development of a lake management plan. The primary recommendation then, is to now take that next step and initiate the development of a long range plan for maintaining or improving the quality of the lake. A good example of procedures to follow in developing such a plan can be found in the UWEX publication,"A Model Lake Plan for a Local Community."

Specific recommendations that may be considered for incorporating into the plan include:

Aquatic Plant Management

Rooted Plants - The current strategy of fostering the growth of native species while eliminating Eurasian water milfoil infestations should continue to be used. The concept of a "weed free" lake is not compatible with the characteristics of Blue Spring Lake nor with the concept of a healthy, balanced biotic community. The objective of the current strategy is to replace the fast-growing, domineering, recreation-inhibiting Eurasian water milfoil with native species that grow slower and lower in the water such as chara and wild celery. If successful, the lake will develop a more diverse plant community but without widespread interference with recreational uses. Principle methods recommended for achieving this objective are to:

- Stop the complete removal of native species by such methods as raking, dragging, harvesting with the cutting blade below the sediment surface, and power boating in shallow waters.

- Use 2,4-D herbicide for spot treatments to systemically eliminate dense stands of Eurasian water milfoil. Most native species are not affected by this selective herbicide.

- Only monitor scattered milfoil plants growing amongst native species; the native species frequently can compete with the milfoil preventing it from becoming dominant.

- Continue harvesting excessive plant growths as this not only provides immediate relief from the nuisance, but also removes phosphorus from the lake.

Algae - An inventory and monitoring of the plankton communities is recommended using professional help and should be initiated as soon as possible. This is especially so in view of the severe algal blooms that occurred on the lake during 1994. A better understanding of the types and behaviors of the alga and other plankton present in Blue Spring Lake is needed in order to develop controls for establishing a more desirable biological balance in the lake.

Efforts to minimize sediment disturbances are recommended and should help reduce the likelihood of algal blooms. Disturbed sediment adds nutrients to the water column and promotes algal growth. Also, success in establishing more complete coverage of the sediment with native plants than what exists today, will help shield the fine sediment from the turbulence created by wind, waves, and boating activities.

Water Quality Improvement

Intense monitoring of water clarity during the spring is recommended and should include specific identification of matter responsible for the major loss in clarity that typically occurs at that time. This should lead to a better understanding of the clarity loss and to controls that can prevent it.

While land uses and homeowner practices in the watershed are not the cause of significant nutrient or pollution loadings to the lake, they should not be ignored as they could become more serious problems in the future. To this end management should:

- develop a process for encouraging homeowners to test their soils for nutrient needs before fertilizing and to discourage excessive fertilization

- work with local governments and local contractors to enact ordinances prescribing construction practices that protect the lake from construction site runoff.

Monitoring

The condition of the lake should be monitored on a frequent basis in order to be on top of changes that are occurring and to evaluate the success or failure of management practices. The following are suggested:

- Monitor water quality as measured by the DNR's Trophic State Index (TSI) program. Blue Spring Lake is currently enrolled in this program in which a volunteer measures or samples the lake for clarity, phosphorus, and chlorophyll-a five times a season.

- Monitor aquatic plant species, their distributions and densities. Harvester operators, who are on the lake almost daily and in close contact with the lake's aquatic plants are ideal candidates to be trained in species identification and to conduct this monitoring activity.

- Monitor plankton, which form an important part of the lake's ecology and of the balance within the food chain. Frequency to be determined by professional help.

- Monitor the fishery, also an important part of the overall balance. Monitoring is necessary for manipulating that balance through fish stocking activities. A once-a-year electroshocking survey by the DNR is desirable.

- Monitor the impact of unusual events such as very heavy rain storms or heavy lake use on holiday weekends. Water clarity, flow rates, and nutrient content in the lake and in inflowing waters should be determined to confirm conclusions drawn in this inventory.

- Monitor community attitudes and practices that impact the quality of Blue Spring Lake. Surveys conducted every two to three years are recommended.

Feasibility Study on Sediment Removal

If the above recommended strategy for rooted plant and algae control is not successful in eliminating nuisance plant and algal growths, the feasibility of sediment removal should be studied. While a cursory treatment in this inventory indicated extremely high costs, there are many positive attributes to the method, and a more thorough study is merited. The knowledge and actual sediment samples obtained in this inventory should prove useful in evaluating sediment removal projects.

SECTION I

INTRODUCTION

In 1993, the Blue Spring Lake Ecology Committee recognized the need for a better understanding of the lake and of factors affecting the condition of the lake. With support of the Blue Spring Lake Association and sponsorship of the Blue Spring Lake Sanitary District, the Committee applied for and received a Wisconsin Lake Management Planning Grant of $10,000 to carry out a $13,333 study of the lake. The Blue Spring Lake Sanitary District, which was converted to a Lake Management District in September 1994, provided the additional $3,333 necessary to complete the study.

The purpose of this work was to provide an inventory of knowledge about the lake. This knowledge should serve as the basis for developing future lake management plans. With factual knowledge of the lake and an understanding of how external activities impact the lake, better management plans can be developed. By using the information presented in this study, it is hoped that management decisions will be made that will not only resolve current problems, but will avoid future problems as well.

Lakes are very complex and a single study such as this is not sufficient to develop a complete understanding of Blue Spring Lake. Therefore, this work did not try to be comprehensive, but instead, focused on generating knowledge that could address the needs most important to today's lake users. These needs are:

- to significantly reduce the excess, nuisance growth levels of both rooted aquatic plants and algae, and
- to ensure good water quality for both full-body contact recreational use and for supporting a healthy population of fish and native aquatic plants.

This study of Blue Spring Lake fell into four distinct but interrelated categories, each important to understanding how the lake works and lending insight into the causes of its excessive aquatic plant growth. The four categories studied were the lake's watershed, water flow rates, water quality, and bottom sediment. Characterization of the watershed was done because the amounts of water, nutrients, and pollutants that run off the watershed and into the lake depend on watershed properties and on how the land is used. The flows of water to and from the lake are also important for determining the total amount of nutrients that are contained in the different streams. Quantitative flow measurements also indicate how frequently the lake is flushed with fresh water. Measurements of water quality and nutrient content in the lake and in inflowing streams were done to quantify the input of nutrients that are critical for plant growth. Finally, characterization of the bottom sediment was done because the sediment provides the support and much of the nutrients needed for rooted aquatic plant growth.

To summarize, the specific work undertaken was to:

- Characterize the lake's watershed and land uses in the watershed.
- Identify all sources and amounts of water flowing into and out of the lake.
- Characterize the lake's water quality and its seasonal and event related variations.
- Identify sources and amounts of nutrients that go into the lake and contribute to excessive aquatic plant growth.
- Characterize the nature of the bottom sediments that support rooted aquatic plants.

In approaching this work, an effort was made to maximize the information generated given the limited amount of money available. These efforts included:

- Making use of existing knowledge and not re-discovering it. For example: using water quality data generated in other studies or programs;

using aquatic plant surveys done by the DNR; and using existing community surveys of lake user needs.

- Focusing primarily on the information needed to develop an understanding of the lake's major problem -- excess growth of aquatic plants and algae to nuisance levels.
- Using trained volunteers for sample collection and on-lake monitoring, unless special equipment and skills were needed.
- Using consultants to assess information needs and to aid in the development of experimental designs and in the interpretation of data. They were intended to be used as consultants and not for managing and executing the overall project.

Most of this inventory was completed by extensive studies of the Blue Spring Lake Ecology Committee using the professional resources of public organization such as the University of Wisconsin, the Department of Natural Resources, the UW-Extension Service, and the United States Geological Survey.

SECTION II

LAKE AND WATERSHED CHARACTERIZATION

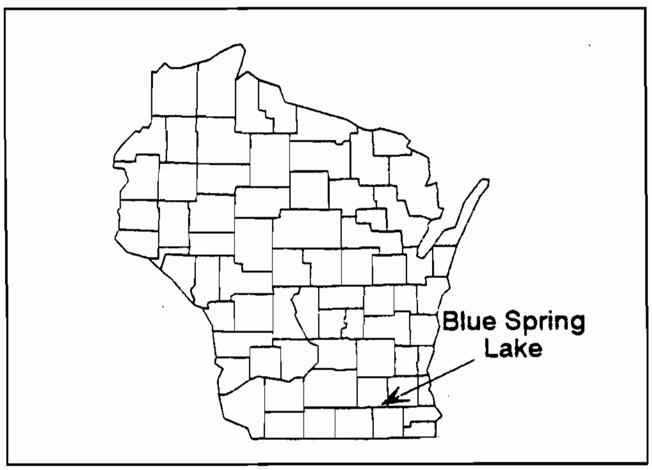
Many properties are used to characterize a lake, such as its surface area, depth, water flows, and the types of fish, plants, and other biota in the water itself. The quality of a lake is also affected by its watershed – the land at higher elevations surrounding a lake that can drain water into the lake. Watershed properties, such as its relative size, soil types, slopes, and how the land is used, all impact the lake. In this chapter we will characterize these properties of both Blue Spring Lake and its watershed.

LOCATION

Figure 2-1 shows the location of Blue Spring Lake at the southeast corner of Jefferson County, Wisconsin, in the Town of Palmyra. Figure 2-2 shows a portion of the USGS 7.5 Minute Series Topographic Map for the region. The lake is located at the base of an interlobate moraine formed by the Green Bay and Lake Michigan lobes during the Wisconsin glaciation about 14,000 years ago.

Fig. 2-1

LOCATION OF BLUE SPRING LAKE



LAKE FORMATION

Blue Spring Lake did not exist prior to about 1928. There was no dam and only a large spring was present on the present site of the lake. In the late 1800's, this mineral spring and others in the Palmyra area were well known for their good taste and therapeutic value.[1] About 1928, a Milwaukee industrialist, Kurt Froedtert, purchased all the land around the spring, built the dam which flooded the surrounding low lands and formed the lake. Fish, including sturgeon, were stocked in the lake, trees and shrubs planted along shore, and a few exclusive homes built for Froedtert and his friends.

In 1948, all the property surrounding the lake was sold to a development company which divided the land into 240 parcels, 161 of which were along shore and 79 off-shore. In 1949, 83 property owners agreed to form the Blue Spring Lake Association under Chapter 180 of Wisconsin Statutes for the purpose of "maintaining, improving, policing, and preserving properties for members' use and enjoyment." In 1950, a committee was formed to take charge of weed cutting on the lake.

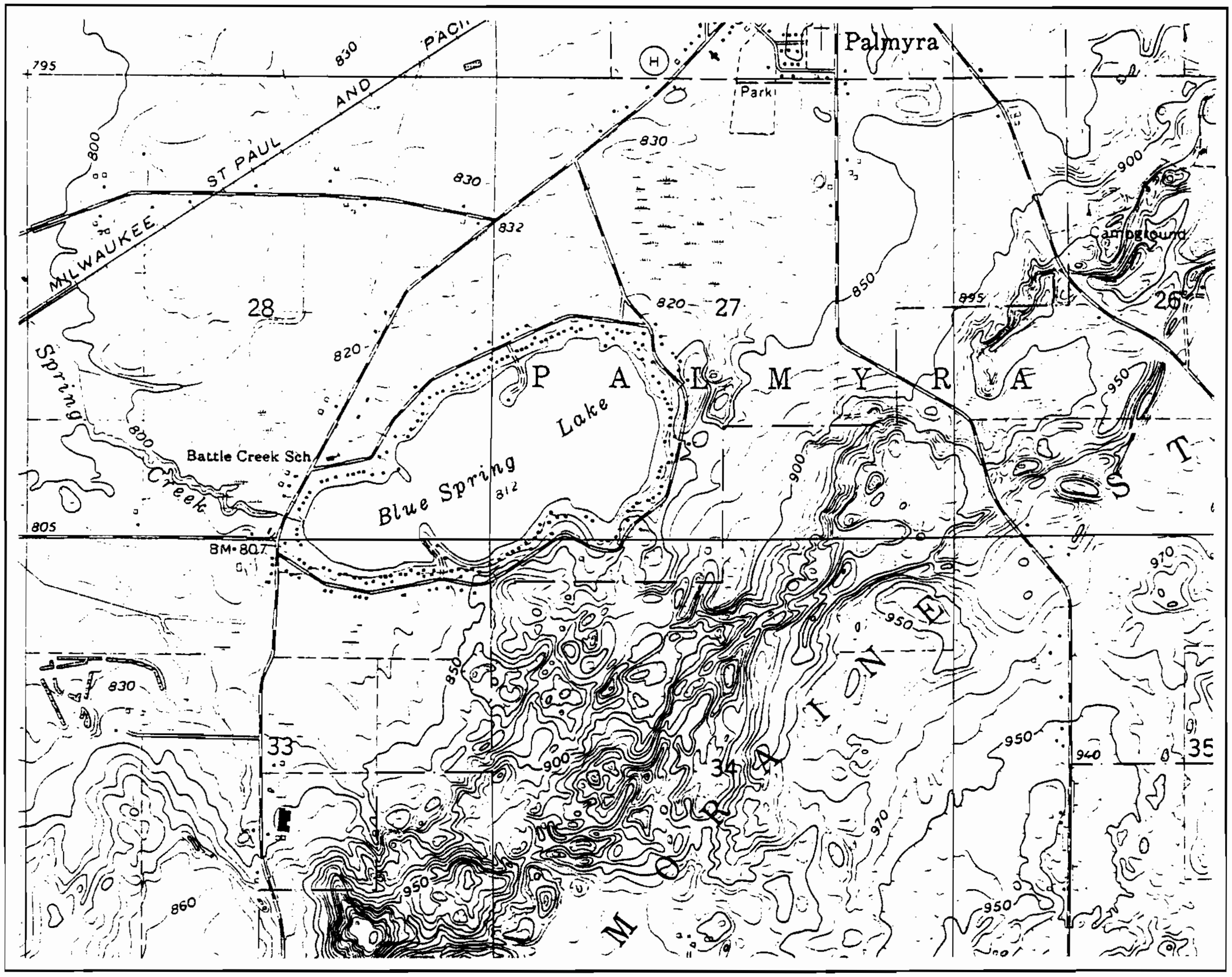
PHYSICAL PROPERTIES

Table 2-1 lists physical characteristics of Blue Spring Lake and its watershed. Figure 2-3 presents a bathymetric mapping of the lake done in the early 1950's. The lake receives most of its water from springs and very little from surface streams; it is classified as a ground water drainage lake. Only one surface stream enters the lake at its northeast corner. The stream passes through a 30 acre marsh immediately before entering the lake.

[1] *R.A.Barton, Blue Spring Lake - Eighth Wonder of the World, Palmyra Historical Society, 1992.*

Fig. 2-2

TOPOGRAPHIC MAP OF BLUE SPRING LAKE AREA



The lake's water level is very constant and is controlled by a dam on the lake's west end. A stack of 2x4 boards placed at the top of the dam regulate the water level. Boards are removed in the fall to lower the level by about 4.5-inches, which helps protect the lakeshore from ice damage; the boards are replaced again in the spring. Lake elevation is reported as 812.5 feet MSL USGS.[2]

Few locations exist around the lake that channelize storm water runoff toward the lake. One drainage ditch on the southwest side of the lake (at the west side of W1466 South Shore Drive in Figure 2-4) drains a low area to the lake; however, this ditch is usually dry except during the spring thaw and after very heavy rains, and even then the flows are estimated at less than 40 gpm. Two storm water sewers are known on the lake road, one on the north shore road at W1267 and one on the south shore road at W1322. They are believed to carry water directly to the lake, but this and their capacities during rain storms remain to be measured.

[2] *C. Amundsen, DNR Letter to Blue Spring Lake Association, May 6, 1985.*

Table 2-1

PHYSICAL PROPERTIES OF BLUE SPRING LAKE AND ITS WATERSHED

Property	Value	Reference
LAKE		
Surface Area	137 acre	1
Maximum Length	0.80 mile	2
Maximum Width	0.39 mile	2
Shorelength	2.42 mile	2
Maximum Depth	12 feet	1
Mean Depth	7 feet	Bathymetric map estimate
Volume	41,800,000 ft^3	Calculated
Type	Ground Water Drainage Spring	3 4
WATERSHED		
Surface Area	878 acre	This Study
Watershed/Lake Ratio	6.4	This Study

1 – Congdon, J. C., DNR Environmental Impact Assessment, "Chemical Rehabilitation of Fish Population, Blue Spring Lake," June 14, 1976.
2 – USGS, 7.5 Minute Series Map, 1971 photorevision.
3 – Shaw, B., "Understanding Lake Data," UWEX Report G3582, 1993.
4 – "Wisconsin Lakes," WDNR Publication, Publ-FM-800 91, Madison, WI, 1991.

Fig. 2-3

BLUE SPRING LAKE BATHYMETRIC MAP

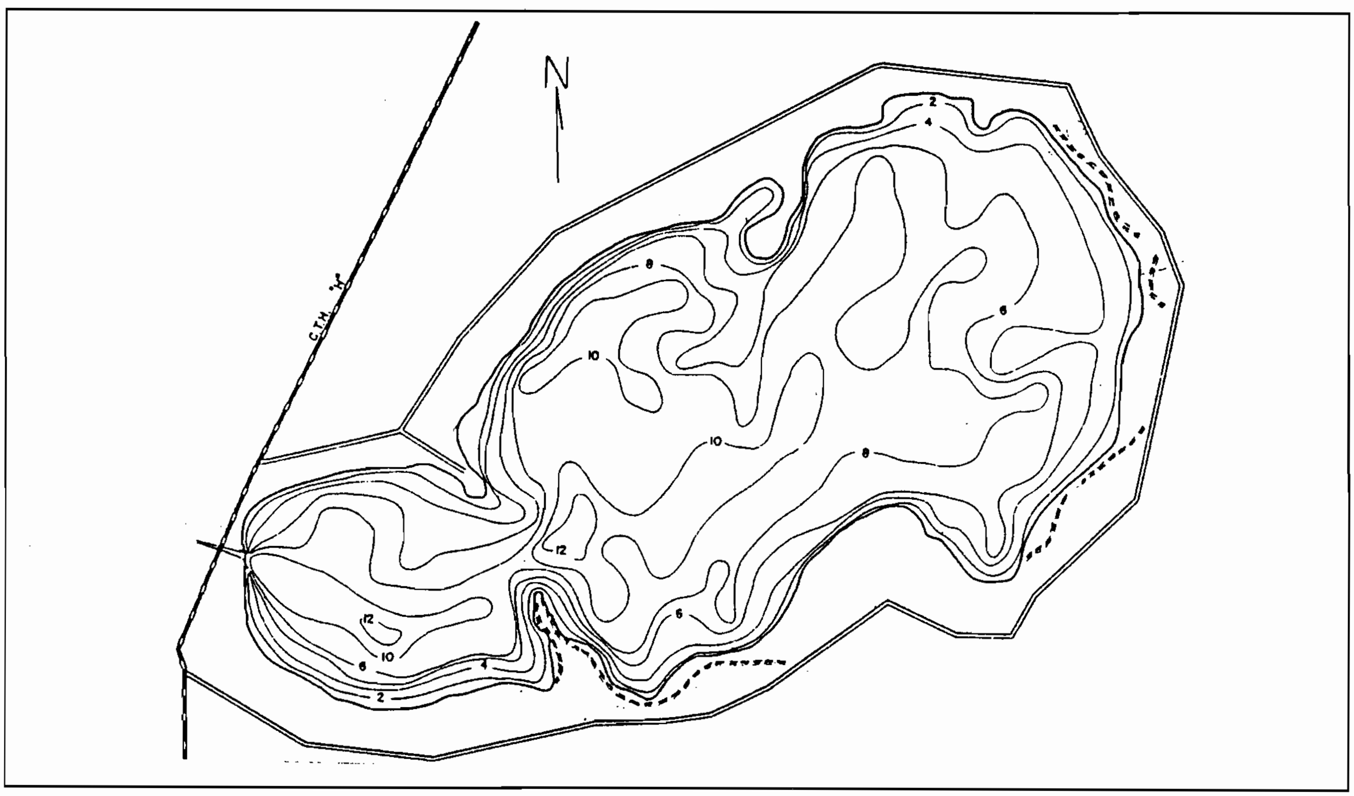
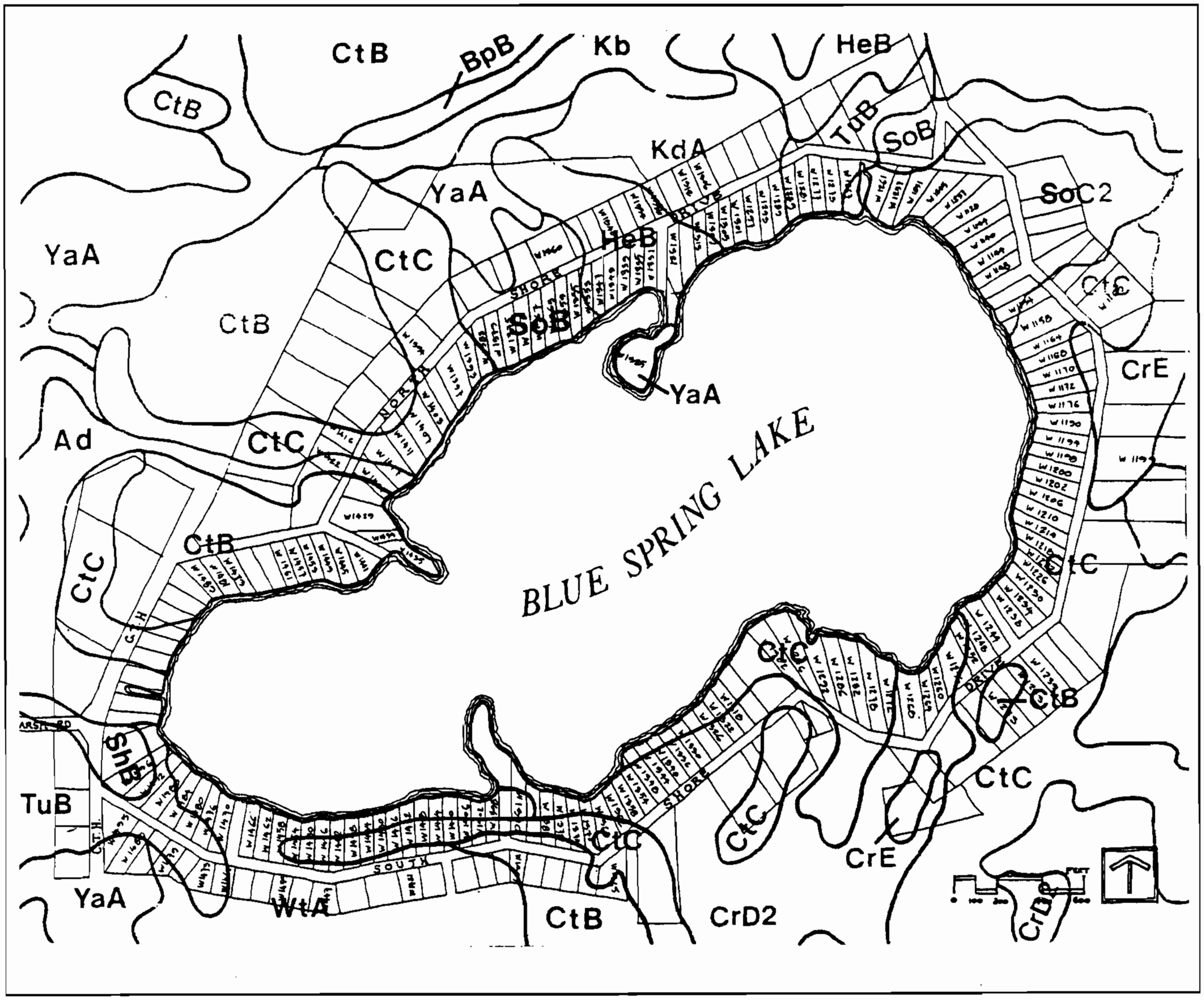


Fig. 2-4

SOILS AND LOT MAP FOR BLUE SPRING LAKE AREA



WATERSHED SOILS

Soils in the Blue Spring Lake watershed are classified as Rodman-Moundville-Casco which describe soils that are "excessively drained to moderately well drained, nearly level to very steep, that have a loamy or sandy subsoil and are underlain by sand or sand and gravel."[3] Water infiltrates these soils very rapidly and the potential for surface runoff is low. These soils are considered poorly suited for on site waste disposal systems because the very rapid infiltration of polluted waters through the soils could contaminate ground drinking water.

Figure 2-4 shows soil types in the immediate vicinity of the lake and also shows the location of homeowner properties. The hydrologic characteristics of these soils, which explain how they respond to rainfall, are described in Table 2-2. Soils are grouped from A, which have high water infiltration rates and low run-off potential, to Group D, which have very slow infiltration rates and a high potential for surface run-off. The soils around Blue Spring Lake take up water quite rapidly with about

[3] *U.S. Department of Agriculture, Soil Conservation Service,* *Soil Survey of Jefferson County, 1979.*

90% in the A and B Groups. An examination of the soils in the lake's entire watershed showed a similarly high percentage of well drained soils. This feature bodes well for Blue Spring Lake as the soils will rapidly take up polluted surface waters, and filter and absorb nutrients/pollutants, rather than allowing this water to channelize and run off into the lake.

Table 2-2

HYDROLOGIC CHARACTERISTICS OF BLUE SPRING LAKE SHORELAND SOILS

Soil Type (Map Symbols)	Hydrologic Group	Hydrologic Characteristics (Response to rainfall)	% of BSL's Shoreland*
CtC CtB WtA	A	High infiltration rates Well drained and excessively drained sandy or gravelly soils High rate of water transmission Low surface runoff potential	61%
CrD2 CrE	A/B	Approximately 60/40 mixture of A/B soils	20%
SoB, SoC2 KdA, TuB ShB, BpB	B	Moderate infiltration rates Moderately well drained Moderately coarse textures Moderate rate of water transmission Slight surface runoff potential	9%
HeB YaA	C	Slow infiltration rates Fine textures or layers that impede downward movement of water Slow rate of water transmission Moderate surface runoff potential	6%
Ad	D	Very low infiltration rates Clay soils; soils with high permanent water table; shallow soils over impervious substrates Very slow rate of water transmission High surface runoff potential	4%

* – Shoreland is land within 1000 feet of the lake shore.

Table 2-3

LAND USE IN THE BLUE SPRING LAKE WATERSHED

Land Use Description	Acres	%
Agriculture	188	21
Residential – Medium Density (2–6 res/ac)	120	14
Residential – Low Density (<2 res/ac)	63	7
Institutional	8	1
Wetland	33	4
Woodland	245	28
Open	83	9
Other	1	0
Lake Surface	137	16
Total	878	100

LAND USES

Woodward-Clyde Consultants were contracted to determine the watershed boundaries and the various land uses by analyzing aerial photographs, USGS topographic maps, a subdivision lot map, and by field inspection. Figure 2-5 presents their mapping of watershed land uses while Table 2-3 shows the percent distributions found.

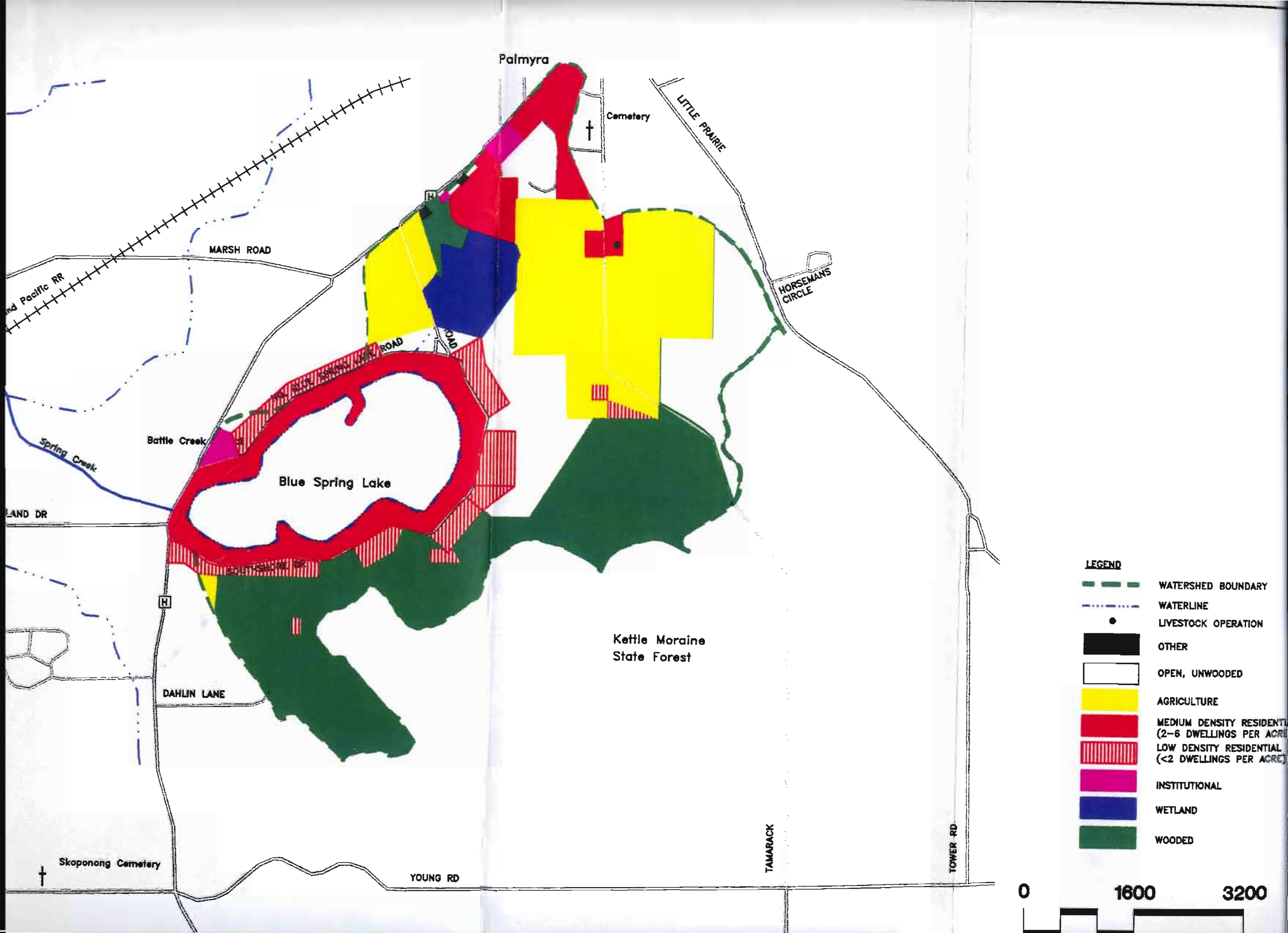
Land immediately adjacent to the lake is completely developed with both seasonal and full time, single family, residents on primarily 65-foot lake frontages. Within this shoreland zone (defined as 1000 feet from water's edge) there are 152 riparian residences and an additional 46 off-shore residences. About 40% of the residences are occupied year-round; the rest are used only seasonally, on weekends and holidays. There are no commercial operations within the shoreland zone.

During 1990, all residences were hooked up to a central collection sanitary system. Since the installation of sewers, an increase has occurred in new construction on empty off-shore lots as well as remodelling/additions on riparian lots. Little control has been exercised toward preventing soil erosion from these construction sites. Silt fences, for example, have rarely been used.

Essentially all residential properties in the shoreland zone have lawns. In a 1995 survey, about one-third of the responding residents indicated they use lawn fertilizer on their property each year.[4]

About 25% of the watershed land area is in agricultural use, primarily corn. Some of these farms include livestock operations. Drainage from all the agricultural operations is buffered from the lake by the wetland marsh. Most of the watershed land (44%) is in woodlands and open grassland.

[4] *W. von Rohr, "Homeowner Survey Results," Blue Spring Lake Ecology Committee Newsletter, Spring 1995.*


Palmyra
Cemetery
LITTLE PRAIRIE
MARSH ROAD
HORSEMANS CIRCLE
Pacific RR
ROAD
Battle Creek
Spring Creek
Blue Spring Lake
LAND DR
DAHLIN LANE
Kettle Moraine
State Forest
Skoponong Cemetery
YOUNG RD
TAMARACK
TOWER RD
LEGEND
WATERSHED BOUNDARY
WATERLINE
LIVESTOCK OPERATION
OTHER
OPEN, UNWOODED
AGRICULTURE
MEDIUM DENSITY RESIDENTI
(2-6 DWELLINGS PER ACRE
LOW DENSITY RESIDENTIAL
(<2 DWELLINGS PER ACRE)
INSTITUTIONAL
WETLAND
WOODED
0
1600
3200

LAKE USE

The lake is used most by homeowners living around the lake. There are six public accesses to the lake, one being a paved boat ramp, the other five being fifty-foot wide walk-ins. Surveys of homeowners in 1993 and 1995 indicate that their most important use of the lake is equally split between lake aesthetics and boating/skiing.[5] While lake aesthetics is most often rated as the highest use of Wisconsin lakes, the high rating for boating/skiing highlights the importance of this recreational activity on Blue Spring Lake. The surveys showed that about 100 power boats reside on the lake with engines averaging 119 horsepower in 1992 and 144 horsepower in 1995. The lake experiences other recreational boating activities including pontoon boats, fishing boats, jet skis, sail boats, and paddle boats. Counting all vessels, homeowners cited over 450 boats on the lake in both survey years.

The lake community has accommodated these varied interests and heavy recreational use by regulating no-wake hours and requiring only counter-clockwise power boat travel. On most days, power boating and skiing are allowed between the hours of 10 a.m. and 4 p.m. At all other times, a no-wake rule is in effect which provides quality time for the more quiet uses of the lake.

FISHERY

From 1965 to 1979, Blue Spring Lake was infested with carp.[6] In 1965 the first reference to carp being in the lake was recorded, but by 1977, the large carp population stirred up so much bottom sediments as to reduce water clarity to less than 2.5 feet and to eliminate all vegetation at depths greater than 4 feet.[7] In September 1979, the DNR poisoned the entire lake with rotenone and removed 85,000 pounds of carp. The DNR restocked the lake with fathead minnows, rainbow trout, largemouth bass, and northern pike. The following years saw a dramatic increase in macrophtyes (rooted aquatic plants), probably due to the increased water clarity..

A DNR fish survey in Fall 1993 indicated Blue Spring Lake has very high populations of bluegills and largemouth bass, but that these fish are somewhat stunted in size.[8] Northern pike are also in the lake as well as other types of pan fish. The stunting of fish is believed due to the high density of macrophytes that existed in the lake in prior years. The dense plant cover helps small fish escape predation, increases their population, which then stresses their food supply and results in a stunted population. In addition, the resulting reduction in zooplankton, which are fed upon by small fish, can result in an increase in the zooplankton's food supply, algae. In 1994, in an effort to move the fishery toward a better balance, the association added to the lake over three hundred predator, northern pike, 7-10-inch in length.

MACROPHYTES

Since the early 50's, dense plant growth in the lake has been considered a nuisance by residents because it interfered with recreational use. "Weed" cutting and weed harvesting have been the primary management tools used to combat the problem, with herbicide treatments occurring periodically ever since 1952[9]. During the carp infestation years, macrophytes were much less of a nuisance because of the poor water clarity; however, following the fish kill in 1979, macrophyte growth returned with a vengeance. This was met with increased cutting and harvesting efforts which led to the purchase in 1985 of the harvester that is in use today. This machinery can cut a 10-foot swath at a 5-foot depth and has 800 cubic feet of storage. Since its purchase, it has been used almost daily during the growing season by a permanently hired operator and a crew of part-time operators. In a typical season, over 400 loads

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[5] *G. Wood, "Survey Statistics", Blue Spring Lake Association Newsletter, March 1993; W. von Rohr, "Homeowner Survey Results," Blue Spring Lake Ecology Committee Newsletter, Spring 1995.*

[6] *G. R. Wood, History of Nuisance Weeds at Blue Spring Lake 1950-1993, Blue Spring Lake Ecology Committee Report, January 1995.*

[7] *J. Schmidt, Water Quality Analysis and Fisheries Assessment of Blue Spring Lake, Marine Biochemists, Inc. (report for the Blue Spring Lake Association), December, 1977.*

[8] *D. Bush, Electrofishing Survey, DNR letter to Ted Hauf, Feb. 10, 1994.*

[9] *G.R. Wood, History of Nuisance Weeds..., Jan 95.*

of plants are harvested and hauled to a local farm field. A harvester load has been reportedly weighed at five tons.

During the 80's, Eurasian water milfoil became the dominant plant in the lake. By Spring 1993, it was present in over 90% of the lake and had grown either to the surface or to within one foot of the surface. Typical of this plant, its density was very high which essentially excluded the presence of native species and even reduced the density of other exotic plants such as curly leaf pondweed.

In May 1993, a 50-foot margin near the lake shore was treated with 2,4-D liquid herbicide. Surprisingly, all the Eurasian water milfoil in the *entire* lake was affected and appeared to die off. This was very unexpected because the treated area represented only about 10% of the entire lake's surface area, and the recommended herbicide dosage for only this small area was used. For lack of "weeds," very little harvesting was done for the remainder of that year at a great cost savings to residents. Equally important, the lake was completely open for recreational purposes. Perhaps most important, the return of native macrophytes to the lake followed the apparent Eurasian water milfoil eradication.

In July 1993, the DNR conducted a macrophyte survey over 12 transects on the lake and confirmed the 99+% reduction in Eurasian water milfoil.[10] Live, native plants were found in the survey, with chara and naiad being most abundant; however, all plants were at low densities because of the earlier dominance of Eurasian water milfoil. A follow-up survey was again done by the DNR in August of 1994, and concluded that naiad and chara had benefitted most from the milfoil decline and had increased their ranges and densities.[11] All plant species observed in the lake are listed in Table 2-4.

Table 2-4

PLANTS IDENTIFIED IN BLUE SPRING LAKE, 1993-4

Common Name	Scientific Name
Bushy Pondweed, Naiad	Najas Flexilis
Muskgrass	Chara sp.
Sago	Potamogeton pectinatus
Waterweed	Elodea canadensis
Illinois Pondweed	Potamogeton illinoensis
Wild Celery	Vallisneria americana
Curly-leaf Pondweed	Potamogeton crispus
Eurasian water milfoil	Myriophyllum spicatum
Richardson Pondweed*	Potamogeton richardsonii
Stonewart*	Nitella
Coontail*	Ceratophyllum demersum
Northern water milfoil*	Myriophyllum exalbescens
Duckweed*	Lemna minor

* – Observed only in 1994

Unfortunately, live stands of Eurasian water milfoil were also found at most locations but at low densities. Three small, but particularly dense stands of milfoil, had been spot-treated with granular 2,4-D in June 1994, resulting in its slow, but eventual decline, in those areas. No negative effects of these spot treatments were evident on the native plant communities. Because of the greatly reduced levels of Eurasian water milfoil, harvesting activities were minimal in 1994, resulting in only thirteen harvester loads compared to typical annual loads of over 400. Significant cost savings also resulted from the reduced need to harvest.

Current management strategy is to encourage the development of native plant communities, which grow slower and lower than Eurasian water milfoil. Areas containing dispersed Eurasian water milfoil are to be monitored to determine if they are stable communities, while dense stands of Eurasian water milfoil are to be treated with 2,4-D herbicide, if permitted by the DNR. The 2,4-D herbicide is preferred over other general, contact herbicides, because it is specific for Eurasian water milfoil, systemically killing this exotic plant, while not affecting most native species.

Historical herbicide and algaecide usage on the lake is shown in Table 2-5.

[10] *J.Leverance, Blue Spring Lake Macrophyte Survey, Summer 1993, Wisconsin Department of Natural Resources, Southern District, unpublished report, December 1993.*

[11] *J.Leverance, Blue Spring Lake, 1994 Macrophyte Survey Follow-up, Wisconsin Department of Natural Resources, Southern District, unpublished report, 1995.*

Table 2-5

HERBICIDE AND ALGAECIDE TREATMENTS OF BLUE SPRING LAKE

Year	Herbicide	Application Area	Algicide
1952	sodium arsenate	200 ft width at shoreline	
1953	sodium arsenate	200 ft width at shoreline	copper sulfate
1954	sodium arsenate	200 ft width at shoreline	copper sulfate
1955–1959	None		
1960	None		copper sulfate
1961–1980	Various, Individuals	?	
1981	Aquathol K; 2,4–D	50 ft width at shoreline	Cutrine–Plus
1982	60 gal. "K"	75–100 ft width at shore	Cutrine–Plus
1983	12 gal. Diquat	50 ft width at shoreline	Cutrine–Plus
1984	None		Yes
1985	None		Yes
1986	Diquat	?	?
1987	Diquat	?	Yes
1988	Diquat	?	?
1989	Diquat	25 ft width at shoreline	None
1990	Diquat	?	?
1991	None		None
1992	None		None
1993	2,4–D	50 ft width at shoreline	None
1994	2,4–D	Midlake, 3 sites, 3 acres	None

ALGAE

Algae blooms have been reported on the lake periodically, but in general have not been a major problem, except for last year, 1994. As Table 2-5 shows, no algaecides were used in the last four to seven years. Prior to that, Cutrine-Plus was used, but this may often have been applied to support the effectiveness of the herbicides being applied at the same time.

From late July to mid-September 1994, a series of blooms occurred about once a week. Many residents felt these were much more severe than any blooms ever seen previously. The blooms were mustard-yellow in color, often covered the entire lake, and developed thick accumulations on shores. In the fall, a sample collected with a plankton net was qualitatively analyzed at the Center for Great Lakes Studies and identified as microcystis aeruginosa, a blue-green alga.[12] As some strains of blue-green algae can be toxic, it was recommended that future blooms of this type be analyzed for the specific strain.

[12] *C.Sandgren, UW-Milwaukee, personal communication, 1995.*

SECTION III

WATER FLOW RATES

To understand a lake, we need to understand the lake's water dynamics -- the sources and flow rates of water going into and out of the lake. Averaged over time, the sum of all flows going into a lake will equal the sum of all flows exiting the lake. Identifying and balancing these flows is called a water budget which is an important part of any lake's inventory. Knowing a lake's water budget allows calculation of "turn-over" time, or the time necessary for inflowing streams to completely flush the water present in the lake. Most importantly, combining water budget information with measurements of pollutant and nutrient concentrations in all streams, allows calculation of actual pollutant/nutrient loadings to the lake. The nutrient loadings identify those streams that lake management should focus on in order to protect or improve the quality of the lake water.

The major streams comprising the water budget for Blue Spring Lake are shown in Figure 3-1 and include:

Inflows:

- Rain that falls directly on the lake.

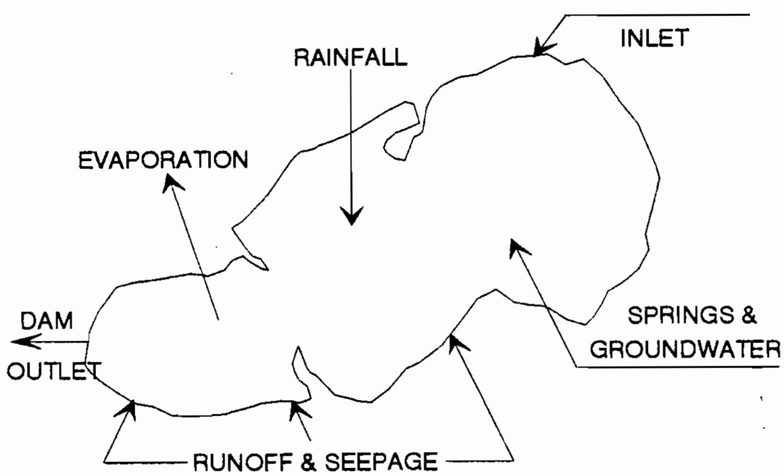
- Inlet flow on the northeast side of the lake that drains the marsh. This marsh effluent drains about 2/3 of the lakes watershed, including most of it's agricultural and livestock operations.

- Surface runoff and seepage that are not included in the Inlet flow. This includes runoff from rain falling in the watershed not drained by the marsh and incorporates all riparian land.

- Springs and ground water. This major flow includes all natural springs, both in the lake and along shore, as well as any deep ground water that seeps into the lake.

Fig. 3-1

WATER BUDGET COMPONENTS



WATER BALANCE

RAINFALL + INLET + SPRINGS + RUNOFF & SEEPAGE = DAM + EVAPORATION + STORAGE

Outflows:

- Dam outflow which includes all water going over the dam.

- Evaporation

Storage:

- Changes in lake level can result in either storage, or depletion of stored lake water.

OBJECTIVES

The objectives of the water flow measurements were to:

- Characterize all inflow and outflow rates and their responses to rainfall.

- Calculate an average annual water budget showing the percent distribution of inflows and percent distribution of outflows.

METHODS

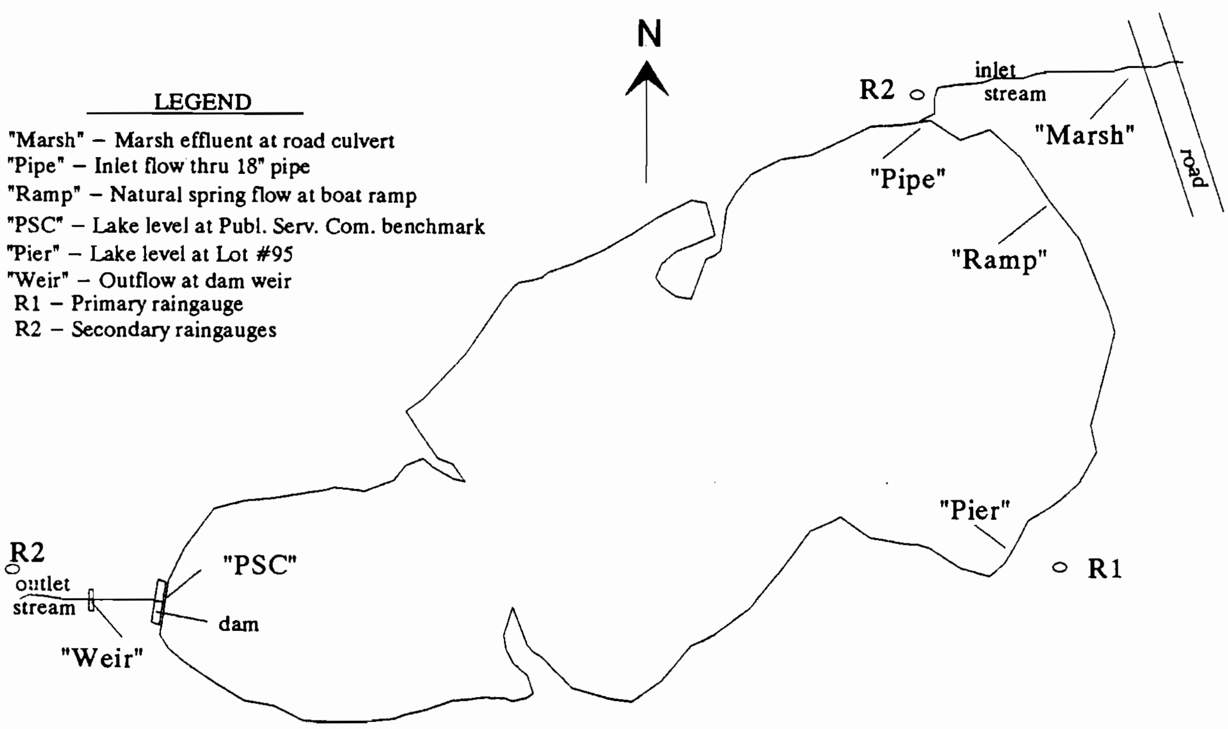
Stream Level Monitoring

The level of water in the lake and in the different streams flowing into and out of the lake were measured periodically from early March to late November, 1994. Simple rulers were used to determine the water levels. These measurements were later converted to flow rates using calibration curves (discussed below). Measurements were generally made two to three times per week and more frequently during events such as heavy rainfalls. Most measurements were done early in the morning, 6-7 a.m., which was generally a time of calm in which wind and waves did not interfere with the readings.

Locations of all measurements are shown in Figure 3-2. Marsh effluent entering the lake was measured at the west end of the 30-inch diameter culvert passing under Blue Spring Lake Drive (labeled "Marsh") and at the 18-inch diameter "Pipe" on the lakeshore of Lot #56A. The latter empties marsh water directly into the lake.

Fig. 3-2

FLOW MEASUREMENT LOCATIONS



The lake level was also measured at two places. "PSC" labeled measurements were made relative to the Public Service Commission Benchmark 886A, a bronze tablet on the north abutment wall of the dam. The measurement was made with a square rule off the abutment, at a location 3-feet east of the benchmark. This measured the lake water level at a position about 1-foot from the 2X4 boards that set the dam height. Lake level was also measured from the top surface of the "Pier" at lot 95A. A square rule was again used and was set at the corner where the west edge of the pier intersects the seawall.

Outflow of water over the dam was measured at a small weir, located in a concrete channel about 100 feet downstream of the dam. These measurements were labeled "Weir." The wooden weir boards formed an almost square channel with the concrete spillway which was 61.5-inches wide. The north end of the weir was 1.0-inch higher than the south end. All measurements of water depth over the weir were made at the same location near the mid-point of the channel (32-1/8 inch from the south concrete wall, to be exact).

The flow rates from the natural spring at the boat "Ramp" were made throughout the year by measuring the water height in the 7-1/8 inch pipe (inside diameter) that carried the spring water to the lake.

Flow Rate Calibrations

Calibration curves were developed that enable the linear measurements described above to be converted to flow rates. Woodward-Clyde Consultants developed the calibrations for the dam outflow and the marsh water inflow by use of a pygmy current meter. Calibration of the dam outflow was based on three measurements, each at a different flow rate. The marsh inflow was based on one calibrating measure and use of a known model relating flow rate changes in a pipe to the water depth in the pipe.

Flow rate measurements of both the marsh effluent and the "Ramp" spring were also made by diverting the effluent into a plastic bag lying in the water for measured periods of time. The volume of water collected was then determined using calibrated pails. This method is simple, reproducible, but very laborious, especially for higher flow rates.

Rainfall

Figure 3-2 also shows the locations of rain gauges used around the lake to monitor rainfall. The primary measurements were made by Jim O'Hern at Lot #47B and readings were taken there every day, at 6:00 p.m., beginning in April, 1994. Readings from the other locations were taken much less frequently and were averaged with Jim's measurements. For the annual water budget, historical rainfall data was used from the University of Wisconsin's, Soil Science Station located in Whitewater (6 miles east of the lake).

Evaporation Rates

Loss of water from the lake by evaporation was based on historical, averaged evaporation flow rates derived from "pan evaporation" measurements in southeast Wisconsin, as reported by our consultants[1].

Data Logging and Analyses

All measurements were logged into a Lotus 123 worksheet. This software was also used to analyze the data, establish relationships and develop graphics.

RESULTS AND DISCUSSION

All measurements made in developing the water budget are contained in Appendix I.

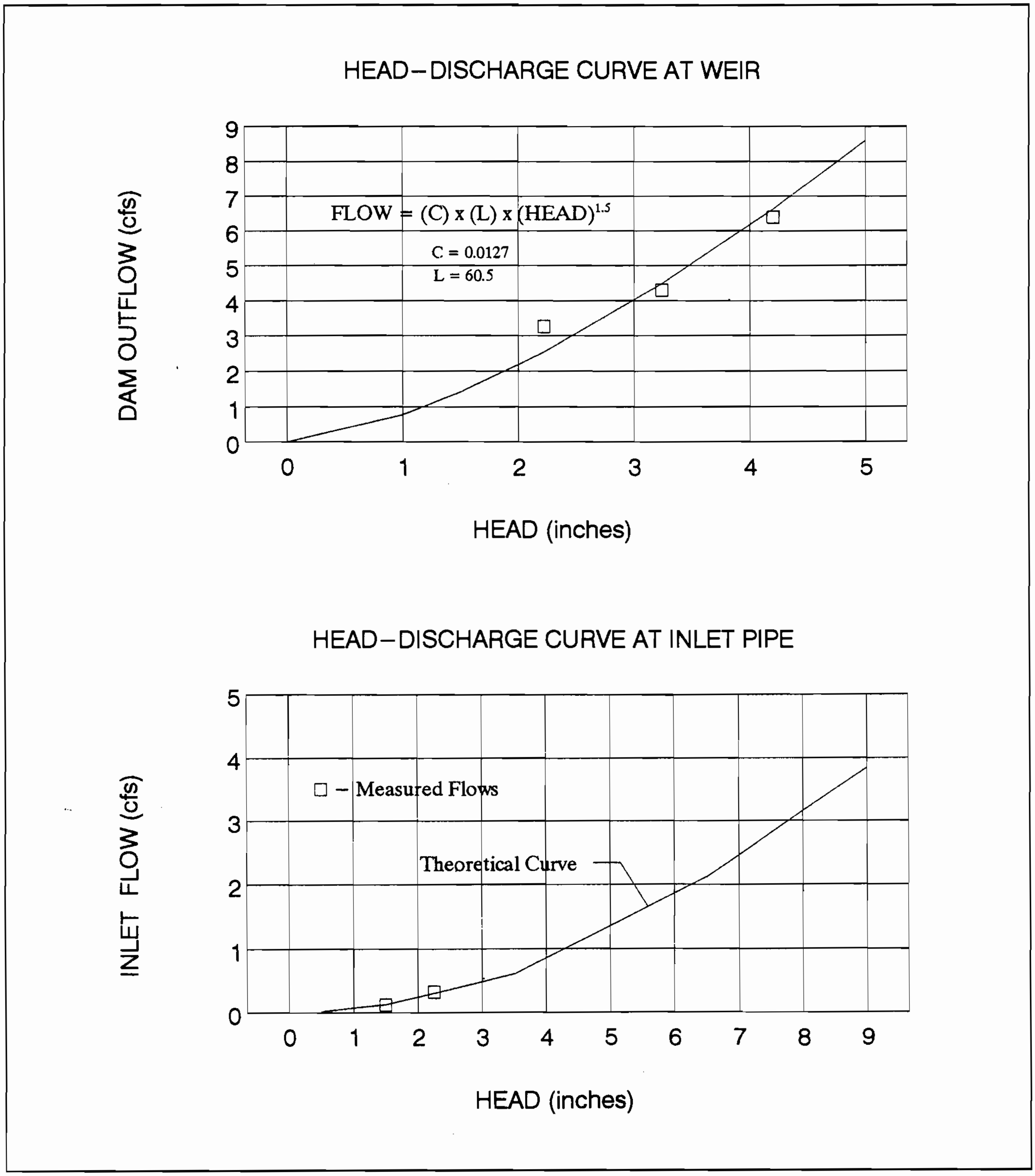
Calibration Curves

Figure 3-3 shows the calibration curves relating the heights of water over the dam weir and in the inlet pipe to flow rates. The forms of the equations relating these variables were known from previous studies and the equations were fitted to the calibration data points. The pygmy meter

[1] *Woodward-Clyde Consultants, 1995, Blue Spring Lake: Water Budget and Nutrient Budget, Prepared for the Blue Spring Lake Sanitary district, March 1995.*

Fig. 3-3

CALIBRATION CURVES AT DAM WEIR AND INLET PIPE



measurements for the calibrations are given in Appendix II.

Water bagging flow measurements at the inlet showed good agreement with the pygmy meter calibration. On April 17, with water level in the "Pipe" at 2.25 inch, 94 quarts of effluent were collected in 10 seconds. A repeat measurement bagged 49 quarts in 5 seconds. These gave an average flow rate of 0.32 cfs which is plotted in Figure 3-3 and is in good agreement with the calibration curve.

Flow Rate Responses to Rainfall

Detailed analysis of flow rates and their responses to rainfall were made for the period May 1 to September 27, 1994. This period was selected because measurements made before May 1 may have been affected by the raising of the dam height, which occurred on April 17, while measurements in October were often affected by fall leaves collecting at the dam and confounding both lake level and dam outflow measurements.

Figure 3-4 shows how rainfall, inlet, and dam outlet flows varied during the detailed analysis period. As expected, the inlet flow and dam outflow showed good correspondence with rainfall. These flow rates increased after a rainfall and, the more rain that fell, the greater the increase in flow rate.

The rainfall plots in Figure 3-4 are based on daily measurements. Other flows were measured less frequently, however, the rainfall data allowed daily estimates to be made of water levels in the lake, inlet pipe, and over the dam weir. When there was no rain, these levels always decayed, whereas a rainfall always resulted in an increase in level. Estimates for the rates of decay and level increases were calculated based on occasions when actual measurements of these changes were made. The results of this treatment are presented in Appendix III. After converting the water level changes to flow rates using the calibration curves previously described, the data was plotted as shown in Figure 3-4. Both the measured and the "deduced" data given in Appendix III were used to make the plots, but only the "measured" data points are represented by symbols in the figures.

Figure 3-5 shows more clearly how flow rates change with rainfall. These plots have been smoothed by using a three day trailing average of daily flow rates. Three day averaging makes it easier to distinguish periods of rain and periods of drought and to see their effects on flow rates. All flow rates were plotted on the same scale which highlights the relative contributions of each stream to the lake's total water supply. Note how small the inlet flow is compared to the outflow over the dam.

The plots in Figure 3-5 show that rainfalls added large volumes of water to the lake in short periods of time. The lake level responded immediately to these additions by rising. The dam outflow also increased rapidly and, over the following few days, drained the excess volume. After very heavy rains, such as on August 3-4 when almost 3 inches of rain fell, the lake level did increase as expected, but by not more than 2.5 inches. This relative stability of lake level shows the effectiveness of the dam to release excess water, but also indicates a low surface runoff of rainwater from the watershed.

The inlet flow also increased with rainfalls, but the total volumes here were quite small. During very dry periods, such as most of June, the inlet flow totally ceased and portions of the marsh and inlet went completely dry.

Runoff/seepage flows, also plotted in Figure 3-5, were not measured but were calculated as the difference between all outflows and all inflows. Surface runoff is rainwater that accumulates at the soil surface and runs off directly into the lake; seepage flow, as used here, represents rainwater that infiltrated the ground and eventually flowed into the lake from below the lake bottom. While it is desirable to separate these flows because surface runoff can carry much more nutrient to the water than seepage flow, it is very difficult to experimentally measure them separately. Figure 3-5 shows the sum of these flows, runoff + seepage, correlated well to rainfall events. Note the peak flow rates of runoff/seepage trailed the rainfall peaks.

Fig. 3-4

WATER FLOW RATES ON BLUE SPRING LAKE
MAY 1 TO SEPTEMBER 27, 1994

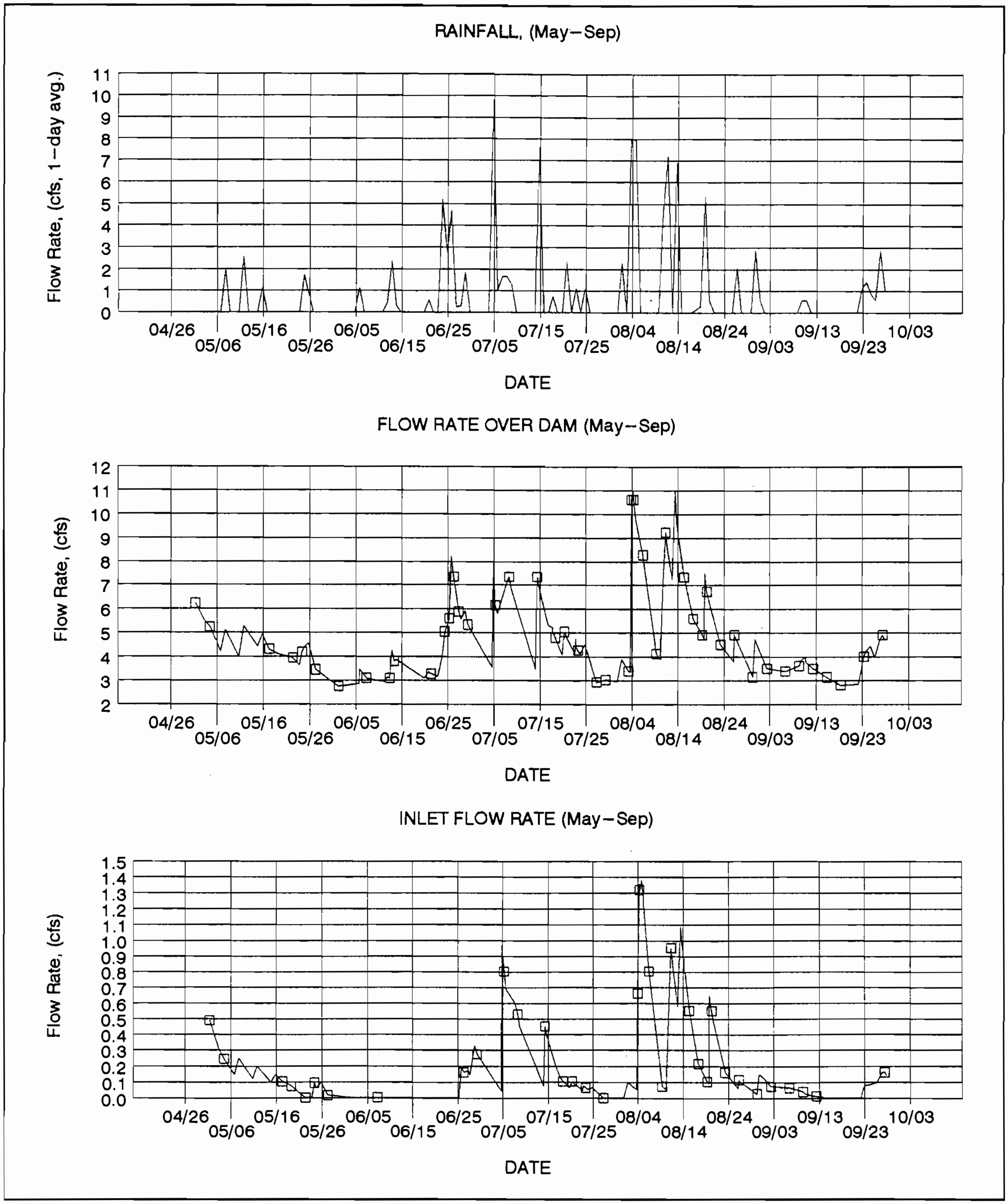
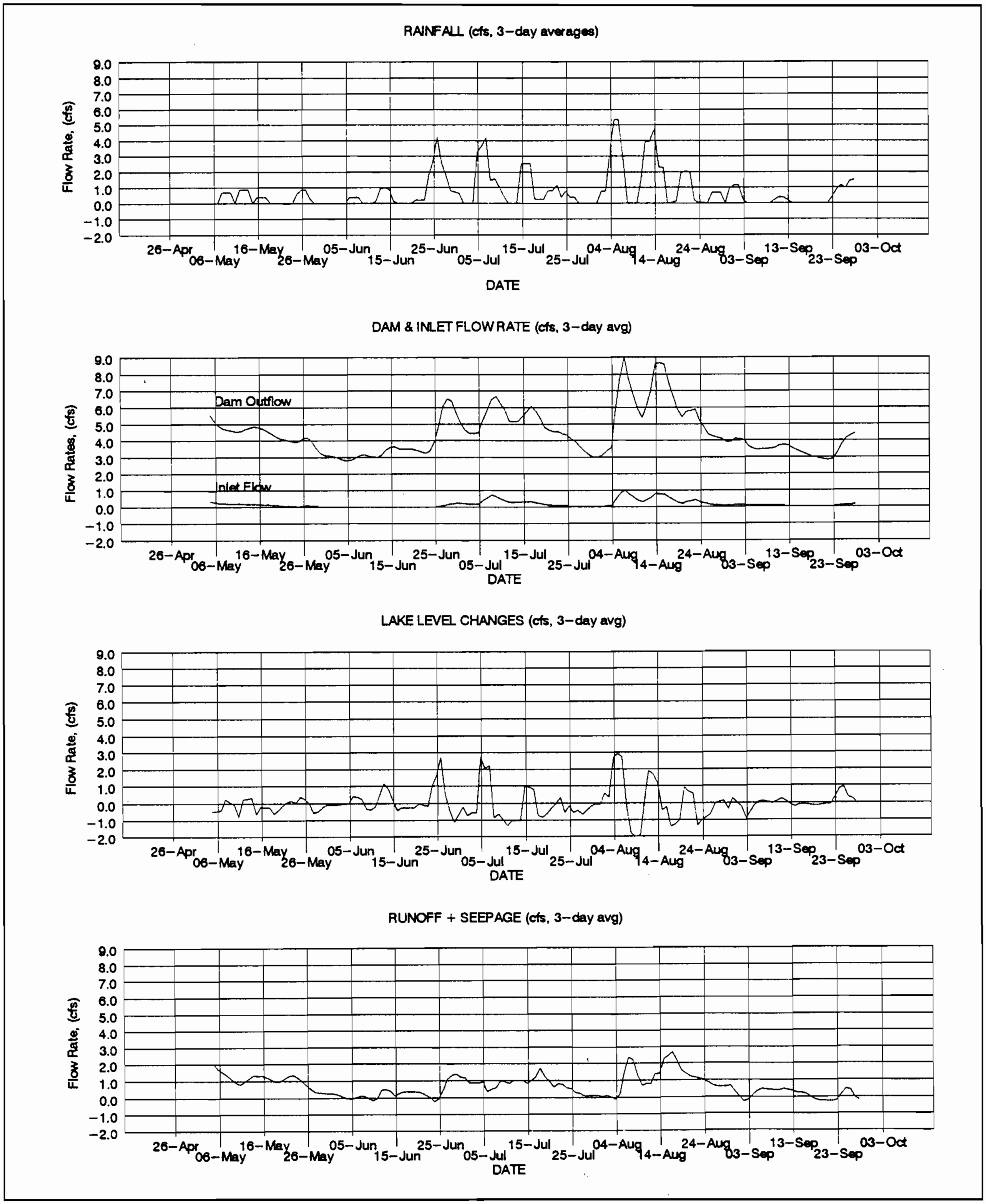


Fig. 3-5

THREE-DAY AVERAGED FLOW RATES
MAY 1 TO SEPTEMBER 27, 1994



This time lag probably indicates the seepage portion of the combined flows predominates because more time would be require for these waters to permeate the soils and eventually reach the lake as compared to a relatively fast surface runoff.

Evaporative Flow

A significant amount of water is lost from the lake through evaporation. Estimates of this "flow" were based on pan evaporation rates for southeast Wisconsin. Monthly evaporation rates are shown in Table 3-1, along with average monthly rainfall. The average annual evaporation loss from the lake surface amounts to 29.4 inches of water and, typical for southern Wisconsin, this water loss is close to the average water gain due to rainfall, 32.4 inches. A more refined water budget and rainfall response assessment could be calculated if actual daily evaporative flows were used rather than historical monthly averages. However, these were not available at the time of data analysis.

Table 3-1

AVERAGE MONTHLY EVAPORATION AND RAINFALL

Month	Evaporation[1]		Rainfall[2]	
	(inches)	(cfs)	(inches)	(cfs)
January	0.50	0.09	1.11	0.21
February	0.75	0.15	1.00	0.20
March	1.25	0.23	2.19	0.41
April	2.49	0.48	3.11	0.60
May	4.48	0.83	3.12	0.58
June	3.74	0.72	3.62	0.69
July	3.99	0.74	4.02	0.75
August	3.86	0.72	3.86	0.72
September	2.99	0.57	3.80	0.73
October	3.11	0.58	2.57	0.48
November	1.49	0.29	2.38	0.46
December	0.75	0.14	1.66	0.31
Totals	29.40	0.46	32.44	0.51

Notes

1 – SE Wis. averages reported by Woodward–Clyde Consult.

2 – 1961–1990 average for UW Soil Science Station in Whitewater, WI.

Springs and Ground Water Flow

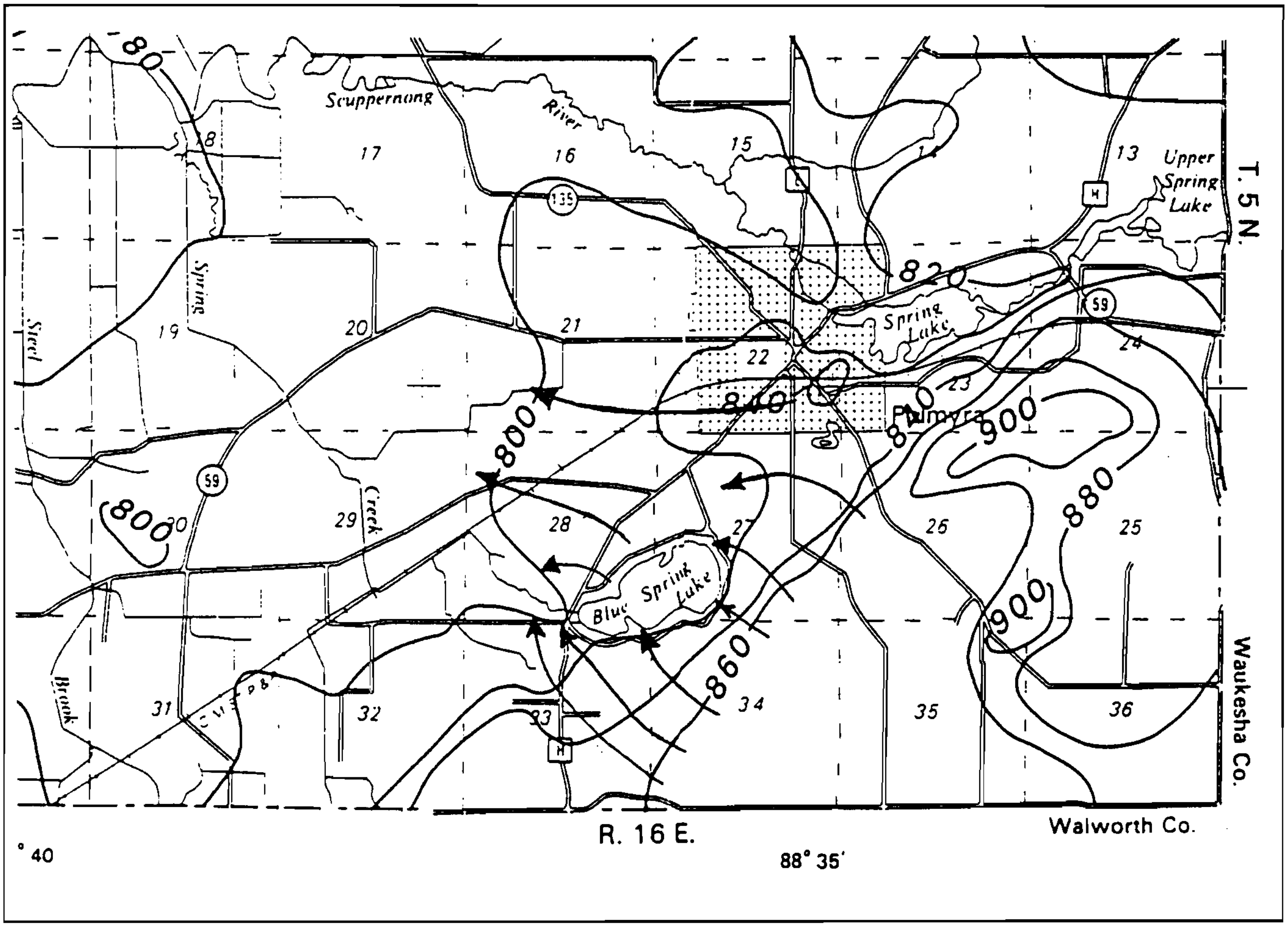
Most ground water probably enters the lake at the main spring in the center of the lake. However, springs near shore, particularly along the southeast shore, also contribute significant flows. These relative flows are apparent by the fact ice seldom forms directly over the main spring except in the coldest of winters and that the southeast shorelines are the first additional areas to become ice free in early spring. Further support for this comes from Woodward-Clyde Consultant's examination of the water table in the Blue Spring Lake area as shown in Figure 3-6. The water level of the lake surface is at 812 feet and the figure shows much higher water levels to the south and east of the lake and lower levels to the north and west. Based on this, the ground water should flow from the southeast to the northwest. The consultants believe the primary recharge area for the large springs in the lake is the hilly area south of the lake as opposed to the relatively flat areas north of the lake. Because there are also springs on the north and west ends of the lake, it is probable that essentially all ground water flows into the lake and very little outflow seepage occurs.

The net flow rate of spring water into the lake was estimated to be a constant 3.59 cfs. This was calculated by noting the dam outflow at the end of four different dry periods. During these periods, which ended on June 4, June 10, July 31, and September 21, no significant rainfall had occurred for some time, the inlet flow was zero, and portions of the inlet and marsh were dry. Because of the dryness, the runoff/seepage flow was also assumed to be zero. Under these conditions and assumptions, the flow rates from all natural springs was equivalent to the flow over the dam less evaporative flow. Taking evaporative flow rates from Table 3-1, the calculated spring flow rates were fairly constant for these different dates, ranging from 3.40 to 3.72 cfs and averaging 3.59 cfs.

Another indication of the constancy of the flow rate of natural spring waters is the behavior of the smaller springs surrounding the lake shore. These are observed to run year around, just as the water flowing over the dam, and, at least qualitatively,

Fig. 3-6

GROUNDWATER FLOW DIRECTION NEAR BLUE SPRING LAKE



Source: Ground-Water Resources and Geology of Jefferson County, Wisconsin

Wisconsin Geological and Natural History Survey, 1976 appear to flow at a constant rate. Measurements on one of these springs, located at the boat ramp, was made throughout the 1994 year. The depth of water in the pipe carrying this spring was measured over the nine month period from March to December and the level seldom varied by more than 10% (see Appendix I).

Long Term Changes

The outflow at the dam was measured by the DNR in July, 1970 using a single measurement with a pygmy current meter. The flow was 2.4 cfs which is lower than the lowest rate observed in this study of about 2.8 cfs during very dry periods. It is not known whether it was a rainy or dry period during the 1970 measurement, but the comparison gives little indication that the lake's springs are going dry.

Water Budgets

May through September: Flow rates for the 149 day detailed analysis period (May 1 to September 27) were converted to cumulative volumes for each day of the period and are presented in Appendix IV. The cumulative volumes are expressed in units of "Lake-inches" (L-inch), and represent the volume of water that could cover Blue Spring Lake with one inch of water. It is hoped this unit of measure is easier for the reader to visualize and associate with our lake than the more common units of gallons or acre-feet. For example, when two inches of rain fall, the volume of water added directly to the lake is 2 L-inch. Also, knowing the mean depth of the lake is 6 feet (72 inches), we then know the total volume of water in the lake is 72 L-inch.

A summary water budget was calculated for the May to September period using the cumulative volumes of Appendix IV. The results, Table 3-2, show that for this period 85% of the water leaving the lake went over the dam, while 15% left by evaporation. They also show 70% of the inflowing water came from the ground (springs), 15% from direct rainfall, and 3% from marsh effluent. After accounting for the small change in lake storage over the period (-.27 L-inch), an additional 13%, or 17 L-inches, of inflowing water was required in order to balance the sum of all outflows with the sum of all inflows. This additional inflow was attributed to runoff/seepage.

Table 3-2

SUMMARY WATER BUDGET FOR MAY 1 TO SEPTEMBER 27, 1994

Stream	Cumulative Volumes* (L-inch)	Average Flow Rates (L-inch/wk)	(cfs)	% of Flow
Inflows				
Springs	92.9	4.36	3.59	69%
Rainfall	19.9	0.93	0.77	15%
Marsh Drainage	4.1	0.19	0.16	3%
Runoff/Seepage	17.3	0.81	0.67	13%
Total Inflow	134.2	6.30	5.19	100%
Outflows				
Dam Outlet	115.9	5.44	4.48	86%
Evaporation	18.6	0.87	0.72	14%
Storage	−0.3	−0.01	−0.01	−0%
Total Outflow	134.2	6.30	5.19	100%

Notes

* – Volume of water added to, or removed from lake during 149 day period from May 1 to September 27, 1994.

An estimate of the relative proportions of seepage and surface runoff was made after examining the inlet flow rate. The inlet flow represents the surface runoff from all the watershed east of the lake. From Figure 2-5, this can be seen to be at least half the total land area of the watershed, or about 370 acres. During the May 1 to September 27 period, 19.9 inches of rain fell on this acreage, which is equivalent to 53.7 L-inches of water (19.9 inches X 370 acres / 137 acres/Lake). Yet, only 4.1 L-inches of water (Table 3-2) ran off the surface of this area and through the inlet. This surface runoff represents less than 8% of the rain that fell on the area and again shows the porosity of the areas soils. Estimating that this same percentage applies to the other half of the watershed results in a calculated 4.1 L-inches of water as the surface runoff portion of the 17.3 L-inches of combined Runoff/Seepage. This surface runoff represents only 3% of the total water flow to the lake.

Annual Water Budget: The preceding analysis shows the proportions of water flowing to and from the lake, and their response to rainfall, for only five months of the 1994 year. In characterizing a lake, we are most often interested in a water budget determined over a typical, full year, including seasonal variations in precipitation. An annual budget was calculated for the lake using the data collected during the five month and the following information and assumptions:

- The flow rate of the natural springs was taken to be constant at 3.59 cfs, or 228 L-inch/yr.
- Flow rates from precipitation and evaporation as per Table 3-1.
- Flow rates from the inlet and from runoff/seepage were proportioned to rainfall. The proportions found in the five month period were applied to the rest of the year during which the ground was not frozen.
- From mid-December to mid-March, the ground is usually frozen, and flow rates from the inlet and from runoff/seepage due to precipitation during this time were estimated to be three times their normal ratios to precipitation. This flow can be considered runoff/seepage during spring thaws.

The calculated annual water budget is given in Table 3-3 and shows the calculated contributions from winter precipitation and the following spring thaw. The overall water budget is not that much different than the five-month budget and reflects the dominating influence of the natural springs. The total amount of inlet water and runoff/seepage water reaching the lake during unfrozen periods amounts to 20% of the total precipitation falling on all land surfaces in the watershed (740 acres, or 5.4 times the lake's surface area). During frozen periods, it was assumed that 60% of all precipitation eventually reached the lake during spring thaw. On average, for the year, 18% of precipitation on all watershed land was estimated to reach to lake. Considering the permeability of the soils around Blue Spring Lake, these runoff estimates are very liberal and actual watershed runoff is probably less than calculated. For example, Wind Lake found that 22% of the precipitation on its watershed land reached the lake; however, Wind Lake has very impervious soils that promote runoff.[2] Also, DNR analysis of 34 watersheds (27 in southern Wisconsin) showed the mean runoff to be 26% of the mean rainfall. For some watersheds, values as low as 1% had been found.[3]

Estimating the contribution of surface runoff, separate from seepage, is important for developing a nutrient budget. Using the same methods as applied to the May 1, to September 27 period, the annual surface runoff contribution was calculated and is summarized along with other flows in Table 3-4 and Figure 3-7. These results will be used later in the calculation of a nutrient budget for Blue Spring Lake.

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[2] *SEWRPC, etal, A Management Plan for Wind Lake, Racine County, WI., Community Assistance Report No. 198, December 1991.*

[3] *Panuska, J. C., and Lillie, R. A., "Phosphorus Loadings from Wisconsin Watersheds: Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds," Research Management Findings, No. 38, WDNR Bureau of Research, April 1995.*

Table 3-3

SEASONAL WATER BUDGETS FOR BLUE SPRING LAKE

Stream	Volumes (L-inch)		Average Annual Flow Rates		
	Winter	Sprg-Fall	(L-inch/yr)	(cfs)	%
Inflows					
Springs	55.9	171.7	227.6	3.59	75%
Rainfall	4.0	28.4	32.4	0.51	11%
Inlet (marsh drainage)	2.5	5.9	8.3	0.13	3%
Runoff/Seepage	10.4	24.7	35.1	0.55	12%
Total Inflow	72.8	230.6	303.4	4.79	100%
Outflows					
Dam Outlet	70.5	203.5	274.0	4.33	90%
Evaporation	2.3	27.2	29.4	0.46	10%
Total Outflow	72.8	230.7	303.4	4.79	100%

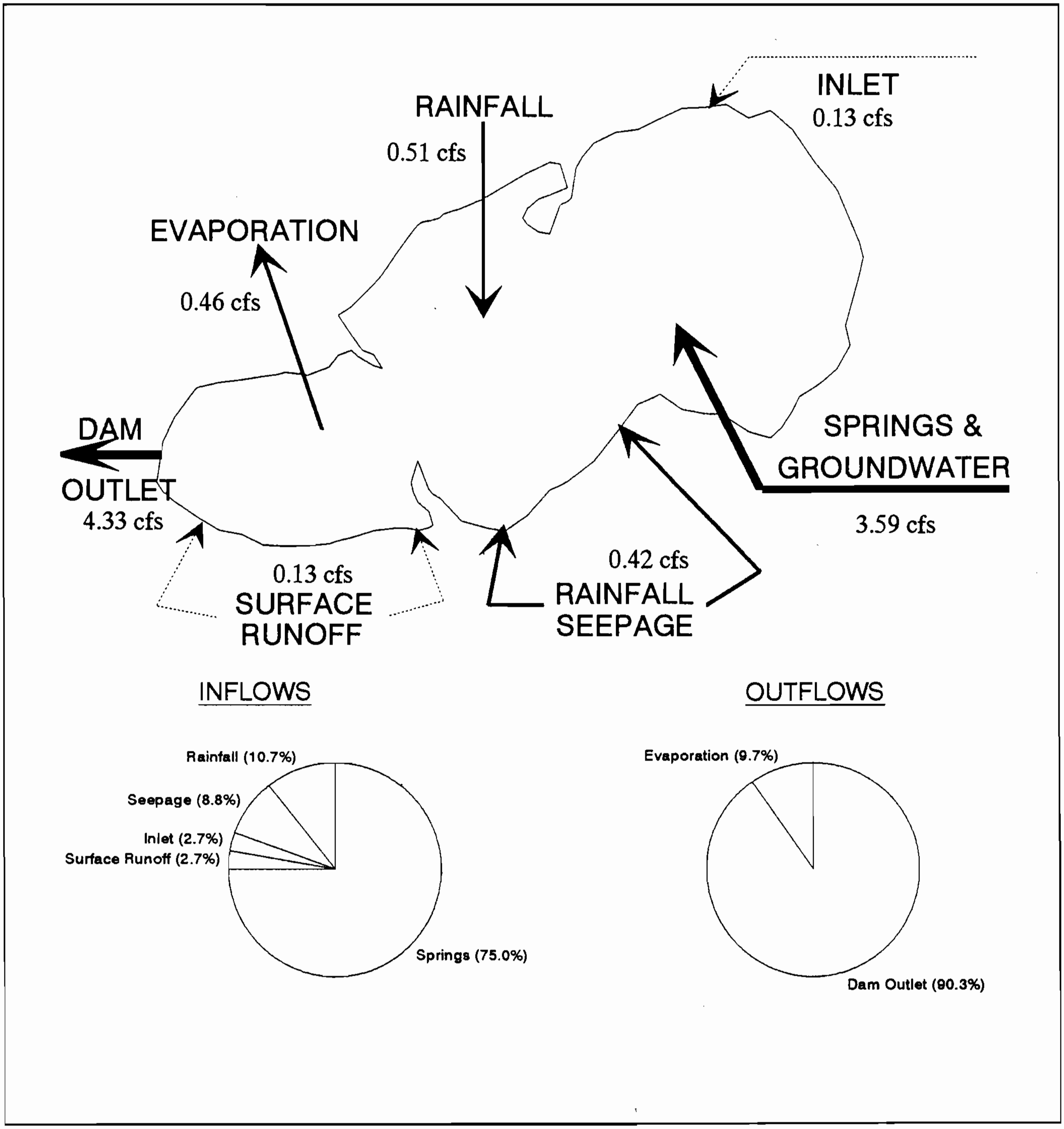
Table 3-4

ANNUAL WATER BUDGET FOR BLUE SPRING LAKE

Stream	Average Annual Flow Rates		
	(L-inch/yr)	(cfs)	%
Inflows			
Springs & Deep Ground Water	227.6	3.59	75%
Direct Rainfall on Lake	32.4	0.51	11%
Surface Runoff from:			
Ag. lands & marsh (Inlet)	8.3	0.13	3%
Residential & other lands	8.3	0.13	3%
Seepage of Rainfall	26.8	0.42	9%
Total Inflow	303.4	4.79	100%
Outflows			
Dam Outlet	274.0	4.33	90%
Evaporation	29.4	0.46	10%
Total Outflow	303.4	4.79	100%

Figure 3-7

BLUE SPRING LAKE ANNUAL WATER BUDGET



CONCLUSIONS

- Almost all waters feeding Blue Spring Lake are from relatively pure sources. About 75% comes from natural springs, 11% from direct rainfall onto the lake, and 9% from seepage of rainwater through the ground.

- Surface runoff, which is most likely to contain nutrients and pollutants, only comprises about 6% of all waters reaching the lake.

- Only 8% of rain that fell on the agricultural watershed, east of the lake, was measured to have reached the lake as surface water. The high permeability of watershed soils account for the low runoff.

- The direction of ground water and rainfall seepage flows are into the lake. No significant subsurface outflow is believed to occur.

- The general flow of ground water and rainfall seepage is from the southeast moraine area to the northwest region.

- The flow rate of spring water to the lake is relatively constant year around at about 3.6 cfs or 0.62 L-inches/day, or 2,300,000 gallons/day.

- Ninety percent of the water lost from the lake goes over the dam at an average rate of 4.3 cfs or 2,800,000 gallons/day. Ten percent is lost by evaporation.

- The turnover rate for Blue Spring Lake is 3.3 times per year, or about every 110 days.

- The lake level is relatively insensitive to rainfalls. The level changed less than 2.5 inches even after receiving almost 3 inches of rain in 24 hours.

SECTION IV

WATER QUALITY

The quality of a lake to each of us depends on how well the lake meets our needs. If the lake fulfills all our expectations, we consider it to be a high quality lake. But because different people use lakes differently, there are different standards of quality. Boaters and skiers may not care about the fishery the same as those that fish; and the latter may prefer the presence of aquatic plants that many swimmers find unpleasant. And the swimmers and skiers would certainly prefer the waters to be free of microbial parasites, yet these would be of little concern to those users that simply like to look at a lake, enjoying its serenity and overall beauty.

Because of this diverse use of lakes by people, it is hard to define a single standard of quality for a lake or for its water. For most Blue Spring Lake users, however, water quality goals might best be described as:

> that suitable for full-body-contact recreational use, while maintaining a healthy balance of native aquatic plant and animal life.

This goal envisions the lake essentially free of those bacteria and parasites that are harmful to humans; a clear lake, but with a dynamically active food chain including phytoplankton, zooplankton, invertebrate, crustacean, and fish; and all within a diverse, productive (but not too productive) aquatic plant habitat.

PURPOSE and OBJECTIVES

The purpose of this part of the inventory was to:

- characterize Blue Spring Lake's water quality, and to
- identify sources of nutrients going into the lake.

Specific objectives were to:

- measure physical and chemical properties seasonally and to contrast these properties with other Wisconsin lakes,
- measure nutrient content in the water at different locations to assess the impact of the watershed and of user activities on water quality,
- measure properties and nutrient content of streams entering the lake to determine their impact on water quality,
- estimate nutrient/pollutant loadings to the lake using knowledge of land uses within the watershed and compare these estimates to measured values, and to
- measure fecal contamination in the lake by monitoring indicator bacteria levels.

METHODS

Historical Review

Before beginning this study, all analyses of Blue Spring Lake water quality that could be found in the records of the Department of Natural Resources (DNR), Blue Spring Lake Association, and Ecology Committee files were compiled. Only very limited data was found. Most was collected between 1975 and 1977 by the DNR. Other than a few bacterial analyses done in the 80's as part of efforts to determine if sewers were needed, no other water samples were analyzed for quality until 1993. Some water quality monitoring was started in 1988 when residents Marv Simmons, and later, Jerry Peplinski, began taking Secchi disc readings as part of the DNR's Self-Help Lake Monitoring Program. In 1993, Blue Spring Lake became part of the Trophic Status Index (TSI) Program which, in addition to Secchi readings, monitors the total phosphorus (Total-P) and chlorophyll-a content in lake water samples five times a year from spring to fall.

Sample Location and Frequency

Samples of lake water were taken from sites shown in Figure 4-1. These included: the Dam, which provided an indication of the outflow of nutrients; the Hole, which is the deepest part of the lake, is where TSI sampling is done, and provides the single, most representative sample of the lake; the Inlet, which is a spot on the lake within 75-feet of the inlet that drains the marsh which may carry both urban and agricultural nutrients; and a site named Runoff, which is also on the lake and within 75-feet of a shore area that drains steep sloped terrain that may carry nutrients from roadways, residences, a horse stable, and a brush collection site. Additional water samples were also taken from the main spring in the center of the lake as well as from three secondary springs along the shoreline. Samples of the marsh effluent were taken directly from the "Pipe" that drains the marsh into the lake. Table 4-1 summarizes the sampling program and shows the properties analyzed.

Complete characterization of the lake's water chemistry was done once each season, four times a year, using a single sample from the Hole site. These analyses were expected to be useful for long term monitoring as well as identifying seasonal fluctuations. Because the lake does not stratify and previous sampling had shown small property differences with depth, only a single, 5-foot depth sample was taken to be representative of the lake.

Fig. 4-1

WATER SAMPLE LOCATIONS

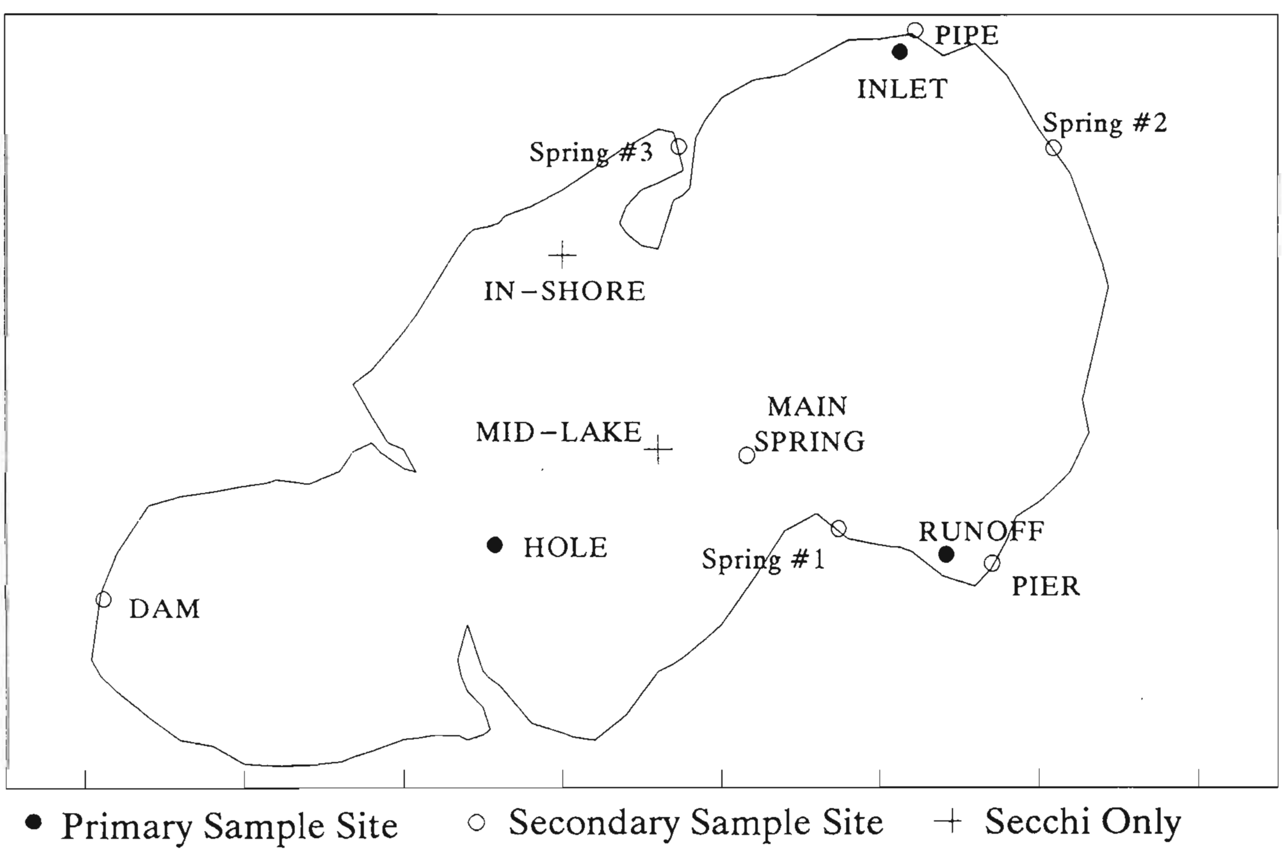


Table 4-1

BLUE SPRING LAKE WATER SAMPLING PROGRAM - 1994

Analyses	Sample Dates & Locations													
	Spring			Summer						Fall			Winter	Other
	4/18	5/4	5/19	6/1	6/15	6/29	7/4	7/20	8/17	9/15	10/19	11/21	2/2/95	Samples
NO_3-NO_2	DHIR	HIR	HIR	HIR	HIR	HIR	HI	DHIR	HIR	HIR	DHIR	HIR	H	SCP
NH_3	DHIR	HIR	HIR	HIR	HIR	HIR	HI	DHIR	HIR	HIR	DHIR	HIR	H	SCP
TKN	DHIR	HIR	HIR	HIR	HIR	HIR	HI	DHIR	HIR	HIR	DHIR	HIR	H	P
Dissolved P	DHIR	HIR	HIR	HIR	HIR	HIR	HI	DHIR	HIR	HIR	DHIR	HIR	H	P
Total P	DHIR	HIR	HIR	HIR	HIR	HIR	HI	DHIR	HIR	HIR	DHIR	HIR	H	SCP
Ca	H							H			H		H	SC
Cl	DHIR	HIR	HIR	HIR	HIR	HIR		DHIR			DHIR		H	SCP
Mg	H							H			H		H	SC
Na	H							H			H		H	
K	DHIR	HIR	HIR	HIR	HIR	HIR		DHIR			DHIR		H	SCP
Alkalinity	H							H			H		H	SC
Hardness	H							H			H		H	SC
Conductivity	H							H			H			SC
Fe	H							H			H		H	
Mn	H							H			H		H	
Color	H							H			H		H	
Dis. Solids	H							H					H	
Tot. Solids								H			H			
SO_4	H							H			H		H	
Chlorophyll a	H	HIR	HIR	HIR	HIR	HIR	HI	H	HIR	HIR	H		H	P
E-coli		HIR	HIR	HIR	HIR	HIR		HIR	HIR					

Sample Location Key:

D = Dam
H = Hole, deepest part of lake.
<u>H</u> = Hole sample analyzed for the DNR's TSI Program
I = Inlet, near marsh effluent.
R = Runoff, from steep slopes.
S = Main Spring
C = Spring Water Composites
P = Pipe, carrying marsh effluent.

Sampling for Anthropogenic Effects

An effort was made to measure the effects on water quality that are derived from human activities; these are called *anthropogenic* effects. The Inlet and Runoff sites, being in 2 to 3-feet of water and close to shore, were expected to reflect nutrient inputs from land uses in the watershed. Increases in nitrogen and phosphorus nutrients as well as chloride (Cl) and potassium (K) were expected to indicate the magnitude of anthropogenic activity. Sampling frequency was designed to be more intense during May and June when fertilization and heavy rainfalls typically occur.

Power Boat Impact on Water Quality

An effort to measure nutrient contributions to the water column from agitated bottom sediments was made by sampling immediately before and after the Fourth-of-July weekend, a period when the lake experiences very heavy boating activity. In general, all other sampling was done on Wednesdays, about noon, at which time a no-wake rule is in effect.

Sampling for Bacteria

Because the lake is used extensively for full body contact, analyses were made for the presence of fecal bacteria from warm blooded animals. Blue Spring Lake and its shoreline area draw a substantial number of migrating waterfowl in the spring and also has a significant number of resident canada geese, ducks, muskrats, dogs, cats, and a few barnyard animals throughout the spring and summer. Fecal matter from these animals can be washed into the lake or directly deposited there. In a healthy, well balanced lake, biodegradation of this material would eliminate measurable levels of fecal bacteria. Blue Spring Lake was sampled during the spring and summer months and the water tested for the presence fecal matter.

Sampling Equipment and Procedures

Essentially all chemical analyses were done by the State Laboratory of Hygiene whose sampling protocols and pre-conditioned sample bottles were used. Exceptions were: dissolved oxygen which was done on the lake using a Yellow Springs Instrument (YSI) Model 55 Dissolved Oxygen Meter. This instrument also provided temperature readings. The meter was calibrated each day before use and periodically tested with air saturated water and, on one occasion, with a Winkler titration. Sample pH was measured on shore, approximately within one hour of sampling, using an Orion Model 420A pH Meter. This instrument was calibrated with buffered standards of pH 7 and 10 immediately before using.

Water clarity was measured with a standard, 8-inch diameter, black and white Secchi disc provided by the DNR as part of the Self-Help Monitoring Program. All lake water samples were collected with a Van Dorn water sampler and were kept out of the sunlight after being bottled. On shore, nutrient samples were preserved with 2 mL of 12.5% sulfuric acid, and metals samples were preserved with 2.5 mL of 35% nitric acid. Some chlorophyll-a analyses were done as part of the 1994 TSI Program and these samples were filtered, according to TSI protocols, with only the filter paper submitted for analyses. All samples were placed on ice and hand delivered to the State Laboratory of Hygiene in Madison within five hours of being collected.

Only three samples, taken near the end of the program in late December, were analyzed for nutrients by a commercial laboratory, National Environmental Testing (NET), Watertown, WI. These analyses were given to NET at this late date because they could report results in less than 14 days and the information could be included in this report. The State Lab / DNR reporting process took two to four months to get analytical results back to this investigator.

RESULTS

All measurements of Blue Spring Lake water quality during 1994 are presented in Appendix V. A condensation of results from the sampling program at the Dam, Hole, Inlet, and Runoff sites is presented in Table 4-2. For comparison purposes, the compilation of all pre-1993 water sample analyses is given in Table 4-3.

Lake Water Temperature

Figure 4-2 shows how the lake water temperature at depths less than five feet varied during the season. Measurements at all sample locations are included in the plot. Temperatures at depths more than five feet were not greatly different than those shown. Table 4-4 shows how same day measurements of surface (1-2 feet) water temperature compared to bottom (8-10 feet) water temperatures at the Hole location. The lake does not experience significant thermal stratification.

The temperature of the Main Spring water and of the waters from shore line Springs #1 and #2 were measured at different times of the year and always found to be 50°F. The cold water from the lake's main spring does not readily mix with warmer lake water during the summer. Figure 4-3 shows temperature profiles taken directly over the Main Spring in May and July. The Main Spring has a depth of 24 feet, and a diameter of about 50 feet, whereas the surrounding lake bottom surface is only 8-10 feet deep. The data indicates the cold, dense spring water "spills" out of the Spring's "well" and, rather than mix with the warmer, less dense lake water, flows laterally along the bottom. During winter, the spring water is warmer and less dense than the lake water and readily rises to the surface causing open water over the Main Spring for most of the winter.

Table 4-2. BLUE SPRING LAKE WATER QUALITY - 1994

DATE	TIME	LOCATION	SAMPLE DEPTH (ft)	TEMP (F)	TOT. P (mg/L)	CHLORO (ug/L)	%O2 Saturation	pH	TOT. N (mg/L)	NO2-NO3 (mg/L)	NH3 (mg/L)	TKN (mg/L)	DIS. P (mg/L)	K (mg/L)	Cl (mg/L)
13-Apr	930	INLET	1.0	47.0	<0.02	--	--	--	1.63	1.23	0.010	0.4	0.002	1.03	8.1
13-Apr	900	RUNOFF	1.5	47.0	<0.02	--	--	--	1.90	1.50	0.006	0.4	0.002	1.10	7.7
13-Apr	1000	HOLE	3.0	46.5	<0.02	8.41	--	8.45	1.67	1.27	0.012	0.4	0.004	1.21	8.0
13-Apr	830	DAM	0.3	46.0	<0.02	--	--	--	1.55	1.15	0.008	0.4	0.004	1.09	8.1
			Avg. =	46.6	<0.02	8.41	--	8.45	1.69	1.29	0.009	0.4	0.003	1.11	8.0
4-May	1300	INLET	2.0	55.0	<0.02	7.58	128	8.60	1.23	0.83	0.043	0.4	< 0.002	1.33	8.9
4-May	1230	RUNOFF	2.0	53.0	<0.02	8.24	122	8.60	1.49	0.89	0.030	0.6	< 0.002	1.37	8.2
4-May	1345	HOLE	5.0	54.0	<0.02	7.40	126	8.65	1.36	0.86	0.042	0.5	< 0.002	1.50	8.2
			Avg. =	54.0	<0.02	7.74	125	8.62	1.36	0.86	0.038	0.5	< 0.002	1.40	8.4
19-May	1127	INLET	2.0	64.9	0.020	10.00	134	8.55	1.20	0.60	0.047	0.6	<0.002	1.11	8.7
19-May	1118	RUNOFF	2.0	64.0	<0.02	5.78	120	8.46	1.29	0.69	0.048	0.6	< 0.002	1.09	8.3
19-May	1140	HOLE	5.0	64.0	<0.02	4.14	124	8.61	1.09	0.59	0.051	0.5	< 0.002	1.04	8.4
			Avg. =	64.3	<0.02	6.64	126	8.54	1.19	0.63	0.049	0.6	< 0.002	1.08	8.5
1-Jun	1200	INLET	2.0	72.7	0.032	4.63	116	8.53	1.28	0.48	0.216	0.8	< 0.002	0.95	8.4
1-Jun	1200	RUNOFF	2.0	72.0	0.019	4.82	110	8.53	1.29	0.59	0.178	0.7	< 0.002	0.97	8.3
1-Jun	1200	HOLE	5.0	72.3	0.019	4.94	114	8.57	1.29	0.59	0.189	0.7	< 0.002	0.99	8.3
			Avg. =	72.3	0.023	4.80	113	8.54	1.28	0.55	0.194	0.7	< 0.002	0.97	8.3
15-Jun	1215	INLET	2.0	78.0	0.04	9.71	121	8.60	1.11	0.41	0.126	0.7	<0.002	1.07	8.4
15-Jun	1200	RUNOFF	2.0	77.5	0.03	9.13	--	8.59	1.25	0.45	0.123	0.8	<0.002	0.98	8.3
15-Jun	1230	HOLE	5.0	77.7	0.023	10.10	130	8.66	(a)	(a)	(a)	(a)	<0.002	1.01	8.4
			Avg. =	77.7	0.03	9.65	126	8.62	1.18	0.43	0.125	0.8	<0.002	1.02	8.4
29-Jun	1200	INLET	2.0	73.0	0.026	11.30	124	8.67	1.17	0.37	0.046	0.8	<0.002	0.75	8.4
29-Jun	1200	RUNOFF	2.0	73.0	0.052	13.00	120	8.64	1.82	0.42	0.065	1.4	<0.002	0.77	8.2
29-Jun	1200	HOLE	5.0	74.7	0.022	13.10	110	8.62	0.92	0.32	0.145	0.6	<0.002	0.96	8.4
			Avg. =	73.6	0.033	12.47	118	8.64	1.30	0.37	0.085	0.9	<0.002	0.83	8.3
4-Jul	1715	INLET	2.0	75.4	0.023	13.10	108	8.51	1.10	0.30	0.086	0.8	<0.002	--	--
4-Jul	1730	HOLE	5.0	75.0	0.022	14.20	103	8.53	1.10	0.30	0.163	0.8	<0.002	--	--
			Avg. =	75.2	0.023	13.65	106	8.52	1.10	0.30	0.125	0.8	<0.002	--	--
20-Jul	1030	INLET	1.0	75.9	0.065	10.40	104	8.56	1.39	0.29	0.048	1.1	0.002	1.01	8.2
20-Jul	1200	RUNOFF	2.0	77.4	0.019	7.23	94	8.51	1.16	0.36	0.114	0.8	0.002	1.01	7.8
20-Jul	1100	HOLE	5.0	76.0	0.019	10.50	99	8.56	0.98	0.28	0.221	0.7	<0.002	1.18	7.9
20-Jul	1130	DAM	0.5	77.5	0.019	--	84	8.51	1.14	0.24	0.243	0.9	0.002	1.04	7.9
			Avg. =	76.7	0.031	9.38	95	8.54	1.17	0.29	0.157	0.9	0.002	1.06	8.0
17-Aug	1100	INLET	2.0	73.0	0.036	12.50	114	8.46	1.23	0.29	0.157	0.94	<0.002	1.15	8.5
17-Aug	1200	RUNOFF	2.0	72.7	0.028	8.28	117	8.50	1.38	0.40	0.175	0.98	<0.002	1.11	7.9
17-Aug	1130	HOLE	5.0	71.2	0.014	11.00	121	8.51	1.16	0.33	0.225	0.83	<0.002	1.17	7.8
			Avg. =	72.3	0.026	10.59	117	8.49	1.25	0.34	0.186	0.92	<0.002	1.14	8.1

Table 4–2 (continued). BLUE SPRING LAKE WATER QUALITY – 1994

DATE	TIME	LOCATION	SAMPLE DEPTH (ft)	TEMP (F)	TOT. P (mg/L)	CHLORO (ug/L)	%O2 Saturation	pH	TOT. N (mg/L)	NO2–NO3 (mg/L)	NH3 (mg/L)	TKN (mg/L)	DIS. P (mg/L)	K (mg/L)	Cl (mg/L)
15–Sep	1130	INLET	2.0	75.6	0.035	12.70	113	8.45	1.11	0.41	0.070	0.70	<0.002	– –	– –
15–Sep	1300	RUNOFF	2.0	75.0	0.027	11.70	118	8.46	1.38	0.49	0.074	0.89	<0.002	– –	– –
15–Sep	1230	HOLE	5.0	74.3	0.012	13.80	119	8.47	1.23	0.42	0.112	0.81	<0.002	– –	– –
			Avg. =	75.0	0.025	12.73	117	8.46	1.24	0.44	0.085	0.80	<0.002	– –	– –
19–Oct	1130	INLET	2.0	61.0	0.019	9.00	100	8.35	1.52	0.62	0.271	1.00	<0.002	1.10	8.3
19–Oct	1245	RUNOFF	2.0	60.4	0.016	9.00	98	8.36	1.56	0.66	0.267	0.90	<0.002	1.10	8.2
19–Oct	1200	HOLE	5.0	59.9	0.019	9.15	95	8.33	1.53	0.63	0.285	0.90	<0.002	1.10	8.3
19–Oct	1215	DAM	0.5	59.9	0.019	– –	95	– –	1.52	0.52	0.258	1.00	<0.002	1.00	8.3
			Avg. =	60.3	0.018	9.05	97	8.35	1.53	0.61	0.27	0.95	<0.002	1.08	8.28
21–Nov	900	INLET (c)	2.0	– –	0.088	– –	– –	– –	2.00	0.90	0.342	1.10	<0.002	– –	– –
21–Nov	930	RUNOFF	2.0	– –	0.019	– –	– –	– –	1.56	0.96	0.331	0.60	0.002	– –	– –
21–Nov	915	HOLE	5.0	43.9	0.023	6.00	94	8.3	1.80	0.90	0.361	0.90	0.002	– –	– –
			Avg. =	43.9	0.043	6.00	94	8.3	1.79	0.92	0.345	0.87	<0.002	– –	– –
2–Feb–95	:030	HOLE	5.0	40.3	0.008	2.2	78	7.69	2.32	1.72	0.24	0.6	0.002	1.3	8.7
OTHER WATER SAMPLES															
24–Apr	1015	PIPE	1.5 inches	– –	0.07	2.4	– –	– –	0.90	0.00	0.047	0.9	– –	1.16	27.3
4–May	1030	PIPE	1.5 inches	53.8	0.04	2.07	85	7.96	0.80	0.00	0.052	0.8	0.022	1.37	27.4
6–Aug	830	PIPE	1.5 inches	60.3	0.116	– –	16	7.50	1.27	0.04	0.077	1.23	0.067	1.68	23.1
		The above "PIPE" samples were taken from inside the inlet pipe on NE side of lake.													
15–Sep	1215	Main Sprg	20.0	50.0	0.012	– –	59	7.81	5.16	5.16	0.007	– –	– –	0.93	7.9
15–Sep	1330	50/50 Sprg #1/Sprg #2		51.2	0.016	– –	68	8.11	3.92	3.92	<0.005	– –	– –	0.86	6.5
28–Dec	1500	Sprg #2 (b)		– –	– –	– –	– –	– –	– –	<0.2–4.3	– –	– –	– –	– –	– –
28–Dec	1530	Sprg #3 (b)		– –	– –	– –	– –	– –	– –	<0.2–4.9	– –	– –	– –	– –	– –

OTHER ANALYSES

DATE	TIME	LOCATION	SAMPLE DEPTH (ft)	Ca (mg/L)	Mg (mg/L)	HARDNESS (mg/L) [d]	ALKALIN (mg/L)	CONDUCT (umhos/cm)	T.D.S. (mg/L)	Fe (mg/L)	Mn (ug/L)	Na (mg/L)	SO4 (mg/L)	COLOR SU	T.SLDS (mg/L)
13–Apr	1000	HOLE	3.0	51	30	250	215	460	264	<0.05	<40	3	24	10	– –
20–Jul	1100	HOLE	5.0	38	32	230	201	417	244	<0.05	<40	3	23	10	280
19–Oct	1200	HOLE	5.0	48	34	260	224	475	– –	<0.01	6.6	3.1	24	5	306
02–Feb	1030	HOLE	5.0	62	35	299	257	556	322	<0.01	3.3	3.1	28	5	344
15–Sep	1215	Main Sprg	20	71	35	320	266	582							
15–Sep	1330	50/50 Sprg #1/Sprg #2		68	34	310	262	557							

Notes:
"– –" property not analyzed
"lab" – lab results not yet released
(a) – sample lost at laboratory
(b) – separate analyses for NO2 and for NO3
(c) – sample suspect due to highly agitated waters.
(d) – calculated value = 2.497[Ca] + 4.118[Mg]

Table 4–3. Historical Water Quality Analyses for Blue Spring Lake[a]

DATE		6/24/70	7/11/75			2/27/76			4/12/76		8/27/76			4/20/77		10/12/77		11/18/87	
SECCHI, ft		4.8	2			5			9		2.5			3.2		2.3		----	Inlet
SAMPLE DEPTH, ft			0	5	10	0	5	8	0	8	0	5	8	0	8	0	10	0	Stream
TEMP, °F			75	74	67	43		43	53	51	75	75	73	65	61	48	47	41	38
Sample Analysis[b]																			
#	Avg.[c]																		
O_2, ppm	9.5		8.4	8.5	8.7	11.2	11.2	11.2	11.4	11.2	7.2	7.1	4.5		10.4	11.4	10.5	13.8	2.8
Nitrogen																			
NO_2–N	0.027		0.012	0.012	0.014	0.014	0.013	0.008	0.015	0.013	0.005	0.098	0.011	0.003	0.143	0.019	0.028		
NO_3–N	0.53		0.26	0.29	0.43	1.12	1.21	1.17	0.42	0.5	0.57	0.34	0.4	0.41	0.48	0.14	0.16	0.84	0.07
NH_3–N	0.23		0.05	0.03	0.06	0.32	0.6	0.28	0.24	0.15	0.44	0.33	0.46	0.04	0.04			<0.02	0.03
ORG.–N	0.58		0.51	0.71	0.7	0.2	0.17	0.72	0.82	0.68	0.76	0.78	0.68	0.34	0.49			0.4	0.7
TOTAL–N	1.4		0.84	1.04	1.21	1.65	2	2.18	1.49	1.35	1.78	1.54	1.55	0.79	1.14			1.2	0.8
Phosphorus																			
PO_4–P	0.02		0.029	0.016	0.012	0.013	0.015	0.017	0.021	0.022	0.039	0.023	0.025	0.018	0.016			0.004	0.036
TOTAL–P	0.05		0.07	0.06	0.06	0.01	0.01	0.03	0.06	0.05	0.07	0.05	0.07	0.03	0.04	0.05	0.07	<0.02	0.06
Cations																			
Ca	40		34	32	8	49	48	54	44	46	34	37	34	47	51				
Mg	34		40	40	40	33	33	33	32	32	33	34	31	27	34				
Na	8		13	12	1	13	15	29	12	8	2	1	1	2	1				
K	3.3		6.2	6.8	3.5	2.3	1.8	2.3	9.2	5.3	1.6	1.3	1.1	0.7	0.8				
Fe	0.34		1	1.1	1.3	0.09	0.09	0.41	0.09	0.09	0.24	0.19	0.19	0.06	0.06	0.06	0.15		
Cu	0.03															0.02	0.04		
Mn	0.08		0.24	0.2	0.26	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.05				
Anions																			
SO_4	21		23	20	20	21	21	23	21	21									
Cl	5		5	5	5	5	5	4	5	4	5	5	5	5	4			6.5	27
Other																			
pH	8.0	8.6	8.1	8.2	8.1	7.9	7.9	7.9	8.2	8.2	7.9	7.9	7.9	7.5	7.5	8.3	8.3		
Alkalinity	191	205	172	168	179	212	270	211	196	188	177	167	172	185	190	186	188		
Turbidity	8.2		9	8.9	10.3	2.5	2.5	12	5	5	11	9.2	14	3.8	7.1	11	11		
Conductvty	391	338	350	339	359	378	431	421	407	397	389	384	387	423	432	380	390	420	670
Hardness	209															210	207		

Notes

a) All data was generated by the DNR, except for 10/12/77 data by Marine Biochemists, Inc.

b) All concentrations are in ppm.

c) Average values for all data prior to 1980.

References

* Marshall, D., WDNR Letter to Marvin Simmons, Decemeber 18, 1987

* Marine Biochemists, Inc., "Water Quality Analysis and Fisheries Assessment," Report to Blue Spring Lake Association, Palmyra, WI, December 1977.

* Druckenmiller, H. S., "Basic Inventory Survey – Blue Spring Lake," WDNR Memo to J. Brasch, Southern District, July 30, 1970.

Fig. 4-2

SURFACE WATER TEMPERATURES

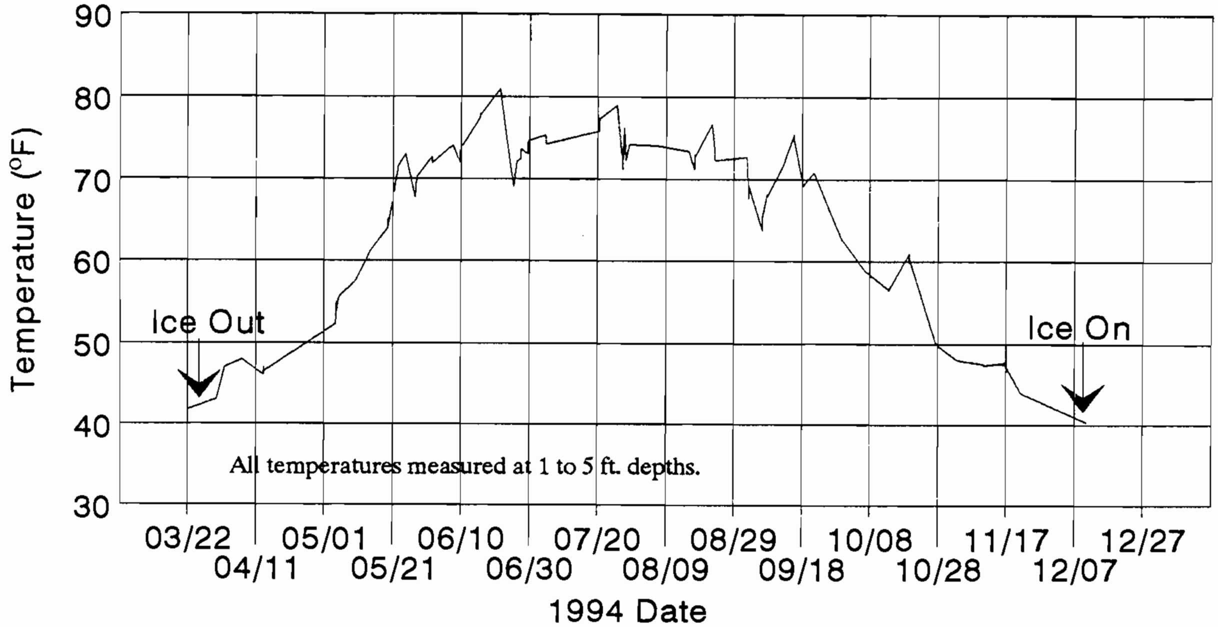


Fig. 4-3

WATER TEMPERATURE PROFILES OVER MAIN SPRING

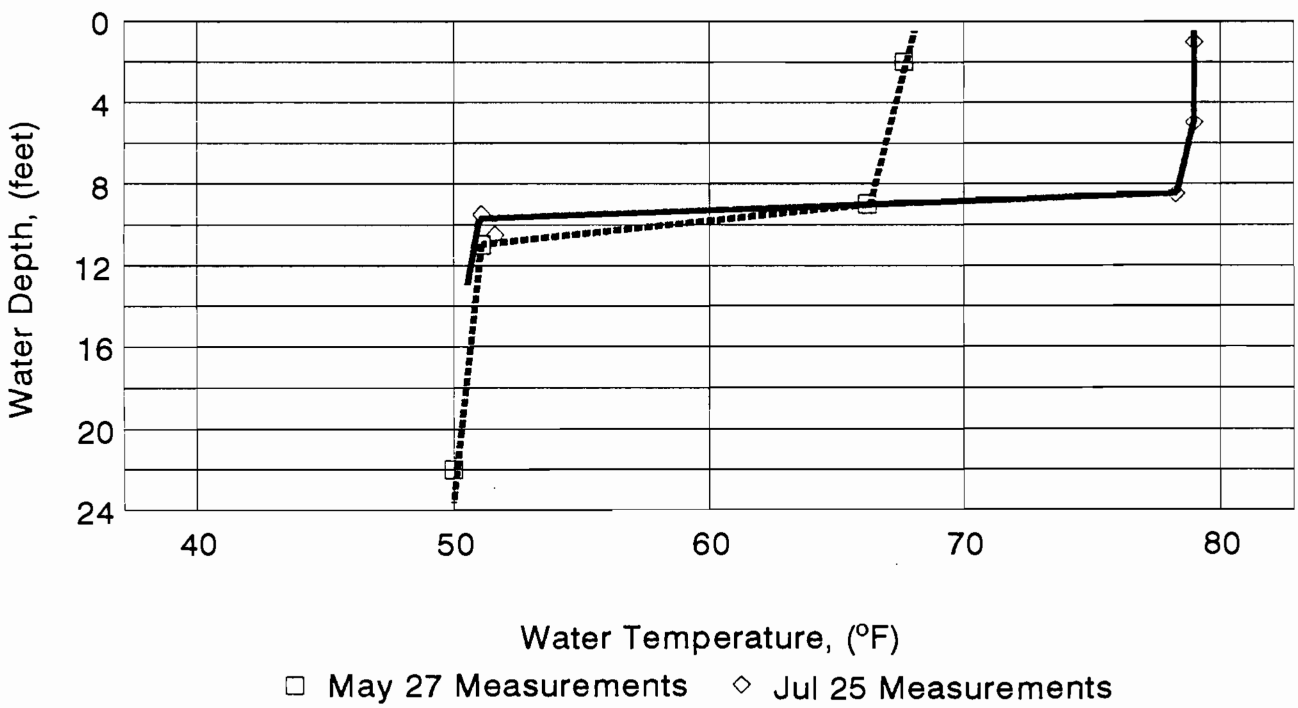


Table 4-4

SURFACE AND BOTTOM TEMPERATURE DIFFERENCES[1]

Season	Temperature Difference, (°F) Average	High	Low	Number of Readings
Spring	0.5	1.0	−0.9	5
Summer	4.0	7.9	0.8	6
Fall	0.4	1.3	0.0	9

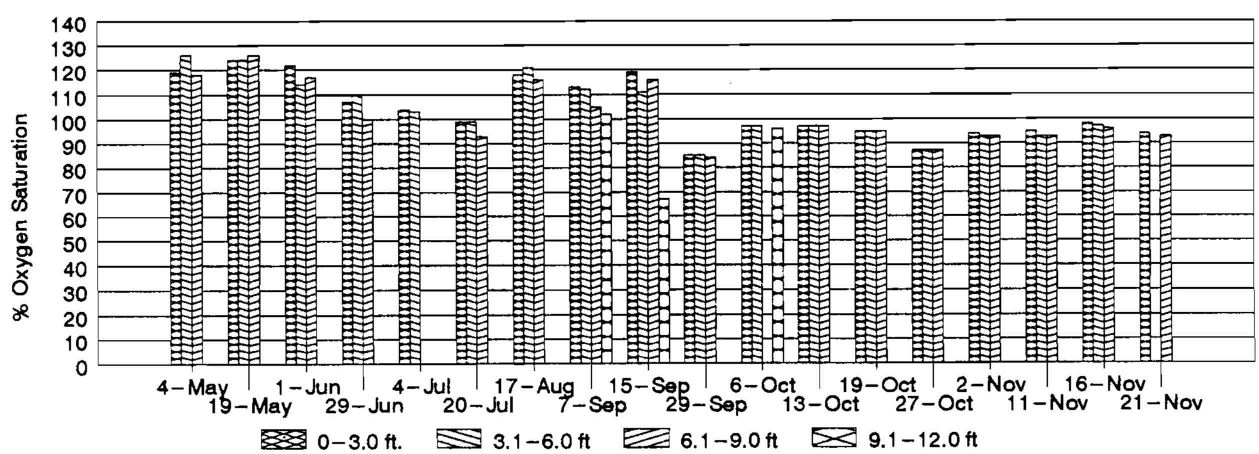
[1] – Based on same day measurements at 1–2 ft surface depths compared to 8–10 ft bottom depths; at Hole location.

Dissolved Oxygen Content

Dissolved oxygen is necessary in lake waters to support aquatic life. The dissolved oxygen concentration in Blue Spring Lake was found to be very high. From May through September it was generally supersaturated and from September through November it was near saturation. Figure 4-4 compares the percent oxygen saturation at different depths throughout the season. While oxygen generally diminishes with depth, the changes were very small. The deepest measurements were usually within 1-2 feet of the bottom sediment. When the probe was at the interface or in the sediment, the oxygen content was always observed to fall off significantly. Measurements were purposely not attempted in the sediment because of the potential for contaminating the instrument's sensing probe.

Fig. 4-4

% OXYGEN SATURATION AT DIFFERENT DEPTHS AND DATES

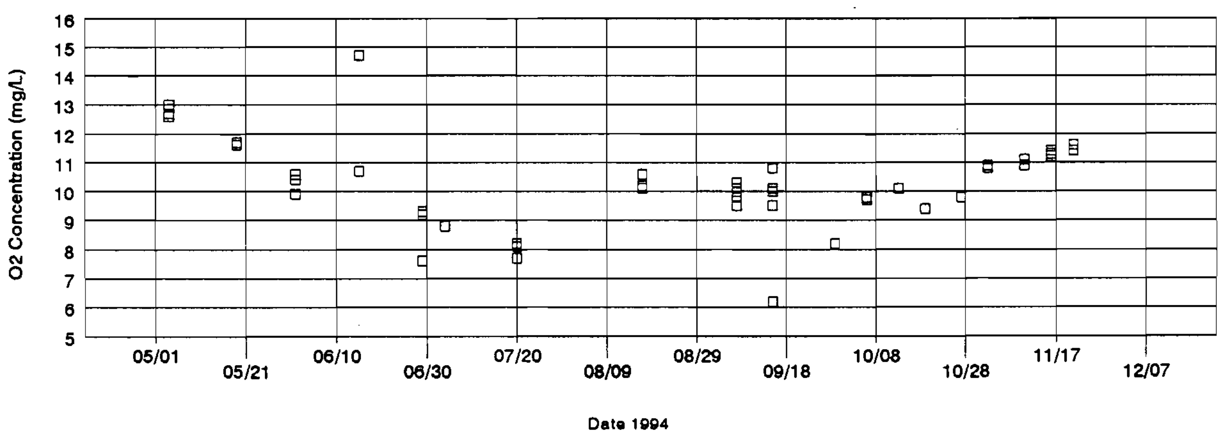


Various tests were done to confirm the lake water was really supersaturated with oxygen. On May 22, oxygen content was measured in the water both before and after it flowed over the dam. Above the dam, the water was supersaturated at 121% while below the dam it measured 98% of saturation, apparently relieving itself of excess oxygen while cascading down the dam stairway. Similarly, vigorous shaking of a supersaturated lake water sample resulted in its return to a saturated level. The YSI probe was further tested by aerating tap water, initially at 65% saturation, with an air compressor, and observing its oxygen saturation slowly increase to 95-98%.

The variation of oxygen content during the seasons is shown in Figure 4-5 in which actual concentration, rather than percent saturation, is plotted for all measurements made at the Hole location. A minimum of 4 mg/L is generally considered necessary for maintaining a warm water fishery. The measurements show Blue Spring Lake levels are generally above 8 mg/L. The saturation level of oxygen in water is inversely related to temperature, and the curvature seen in the data of Figure 4-5 largely reflects the lake's temperature changes during the seasons.

Fig. 4-5

OXYGEN CONCENTRATIONS AT "HOLE" LOCATION, ALL DEPTHS



Hour-to-hour variations in oxygen content were also seen. Plants produce oxygen through photosynthesis and help oxygenate the water during daylight hours. The comparisons of oxygen measurements at the Pier location in 2.5-feet of water, shown in Figure 4-6, reflect this photosynthetic effect. Other factors also cause variations including a depletion of supersaturation by rainfalls which create agitation at the air-water interface.

<u>pH</u>

pH is a measure of acidity, or hydrogen ion concentration, and is an important component of the biological processes occurring in the lake. pH values are inversely related to acidity, so high pH values mean low acidity. A pH value of 7.0 is neutral and is the pH of pure, distilled water. The pH of Blue Spring Lake and its seasonal variations are shown in Figure 4-7. The lake has very low acidity with an

Fig. 4-6

OXYGEN SATURATION AT DIFFERENT TIMES OF DAY

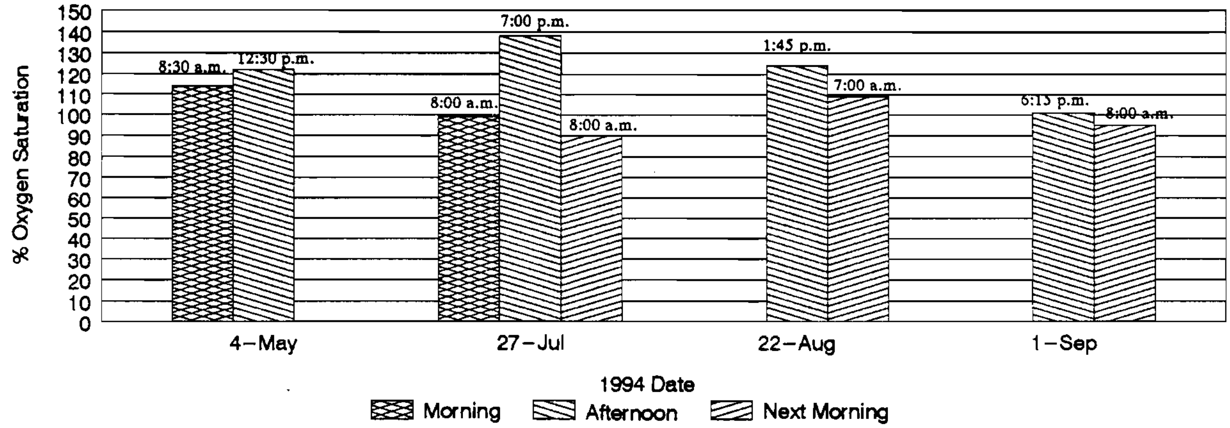
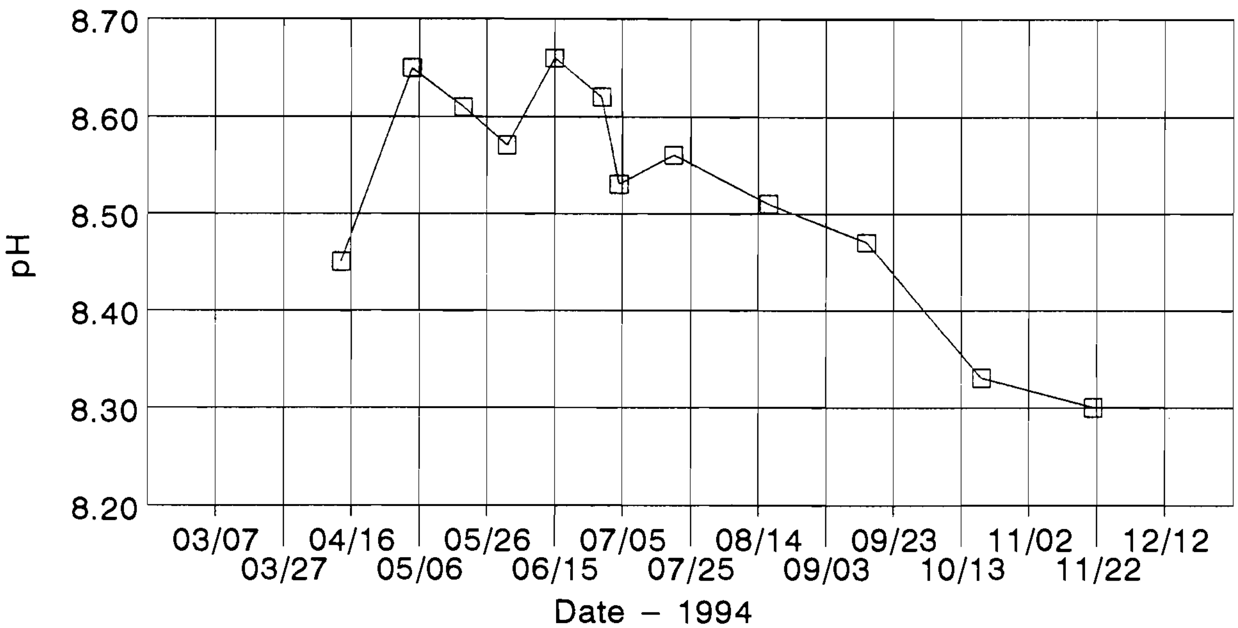


Fig. 4-7

BLUE SPRING LAKE - pH



average summertime pH of about 8.6. The pH appears to increase during early spring and then decline from summer to winter. Not shown in the Figure, but confirming this trend, was the pH value of 7.7 measured on a water sample taken through the ice on February 2, 1995.

The lake water's high pH likely derives from two sources; first, the incoming spring water, providing about 75% of the lake's water, has a high pH of 8.0 (see Table 4-2), and second, this pH further increases during photosynthesis. This occurs because dissolved bicarbonates in the spring waters are in equilibrium with dissolved carbon dioxide (CO_2) in the lake water, as shown in Equation 1. As CO_2 is consumed in the photosynthetic process to make simple sugars and plant tissue, shown in Equation 2, more bicarbonates and hydrogen ions are consumed to replace the spent CO_2. The loss of hydrogen ions in this process causes an increase in pH.

$$HCO_3^- + H^+ \Longleftrightarrow CO_2 + H_2O \quad \text{Eq (1)}$$

$$6CO_2 + 6H_2O \Longleftrightarrow C_6H_{12}O_6 + 6O_2 \quad \text{Eq (2)}$$

The changes in pH during the seasons shown in Figure 4-7 probably most reflect the photosynthetic process, but also are the result of variations in temperature and rainfall.

<u>Alkalinity and Hardness</u>

Properties related to the water's pH are its alkalinity and hardness. These have been measured for both the lake and incoming spring water and are shown in Table 4-2. The alkalinity of a water is its acid neutralizing ability. For most lake waters it primarily represents the sum of carbonate, bicarbonate, and hydroxide ion content and is expressed as equivalents of $CaCO_3$. Alkalinity can buffer a lake against the effects of acid rain because of its capability to neutralize additions of acid to the lake. Lakes with alkalinities less than 2 mg/L $CaCO_3$ are highly susceptible to acid rains, while lakes with alkalinities greater than 25 mg/L are nonsensitive. Blue Spring Lake's alkalinity is more than 200 mg/L and its incoming spring water is more than 250 mg/L.

Hardness is also expressed in mg/L equivalents of $CaCO_3$ and is a measure of the Ca and Mg content of the water. (These are the metal ions in water capable of precipitating soaps which render such waters as "hard"). Soft water lakes have a hardness less than 60 mg/L, while waters with hardness greater than 180 mg/L are considered very hard. Blue Spring Lake's hardness is about 250 mg/L while the incoming spring water is over 300 mg/L.

These properties indicate Blue Spring Lake's water supply comes from aquifers containing limestone minerals such as calcite ($CaCO_3$) and dolomite ($CaCO_3$ and $MgCO_3$). The decrease in Ca, hardness, and alkalinity, of the lake water compared to the incoming spring waters probably reflects the precipitation of $CaCO_3$ marl which accompanies the decrease in acidity resulting from plant photosynthesis. The formation of the $CaCO_3$ marl can be seen as a fine white precipitate on plant leaves. Such precipitates often incorporate phosphorus, removing some of it from the water column and reducing the amount of algal growth.

<u>Fecal Bacteria Content</u>

Twenty-one samples from three locations taken from May 4 to August 17 were analyzed for E-coli bacteria. All samples but three were at below the detection limit of 10 counts/100 mL. A June 15 Runoff sample and a June 29 Inlet sample each showed 20 counts/100 mL. On July 20, a sample of Inlet waters analyzed at 200 counts/100 mL. There were no known events surrounding this sampling that would suggest such an increase in water contamination. The unusually high analysis stands out from the rest of the data, but it is not clear whether it is indicative of real lake water pollution or if the sample was somehow contaminated during sampling and handling. In either case, the four month lag time between sampling and reporting precluded any follow-up analysis of the event.

Equally unfortunate, as was learned after completing the sampling program, is the fact that E-coli is a useful indicator bacteria for contamination by human feces, but not for animal feces. Consequently, these measurements could not test the health impacts of wildlife on the lake.

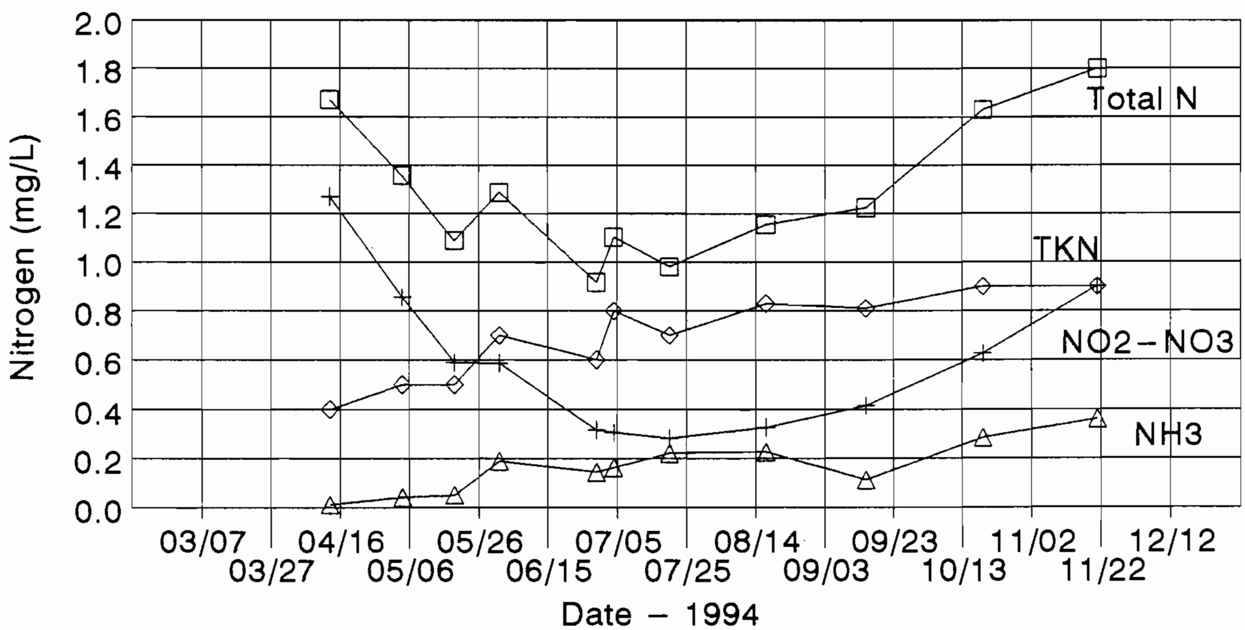
Nitrogen Nutrients

Nitrogen is an essential element in the formation of plant and animal life. It can be present in lakes in many different forms and, if at high concentrations, can lead to nuisance growth of algae and weeds. Nitrogen pollution of lakes often occurs from the high concentration of nitrogen compounds in runoff from barnyards, agricultural fields, and overly fertilized lawns. The forms of nitrogen typically measured in lakes are: ammonia nitrogen (NH_3-N); organic nitrogen, often called "TKN" which refers to the analysis method "Total Kjeldahl Nitrogen," and includes the NH_3 content in the analysis; and nitrite-nitrate nitrogen (NO_2-NO_3) which are the primary forms of inorganic nitrogen present. In oxygenated lakes, most nitrites have usually been converted to nitrates. Total nitrogen is calculated as the sum of TKN nitrogen and nitrite-nitrate nitrogen.

Figure 4-8 shows the seasonal variation of Blue Spring Lake's nitrogen compounds measured for the Hole location. NO_2-NO_3 was the major form in early spring, but declined in mid-summer, and then increased again in the fall. The pattern appears to correlate well with water temperature. Both ammonia and organic nitrogen showed steady increases during the season.

Fig. 4-8

BLUE SPRING LAKE NITROGEN CONTENT



Clarity, Chlorophyll-a, and Phosphorus. Water Quality Rankings

Assessments of lake water quality are most often done through measurements of water clarity, chlorophyll-a concentration, and phosphorus concentration. Each of these properties is an indicator of nutrient enrichment. Water clarity is determined by the depth of visibility of a Secchi disc which is usually affected by how much algal growth has occurred in a lake. Other measures of this growth are often obtained from chlorophyll-a content (the green pigment in algae), or from phosphorus content, which is usually the limiting nutrient for algal growth. Based on thousands of summertime measurements, including human perceptions of water quality, limnologists have ranked these measures into six quality categories ranging from "very poor" to "excellent." These rankings are shown in Table 4-5.

Table 4-5

WATER QUALITY RANKINGS

Quality Ranking	Secchi Depth (feet)	Chloro-phyll a (ug/L)	Total-P (ug/L)
Very Poor	<3.25	>30	>150
Poor	3.25 – 5	15 – 30	50 – 150
Fair	5 – 6.5	10 – 15	30 – 50
Good	6.5 – 10	5 – 10	10 – 30
Very Good	10 – 20	1 – 5	1 – 10
Excellent	>20	<1	<1

Blue Spring Lake's water quality based on these measurements and rankings is shown in Figure 4-9 for both 1993 and 1994. The plotted data is only for those measurements taken at the Hole location, which is most representative of the lake. Also, only surface samples were used for phosphorus analyses which is the standard practice when comparing lake waters. To be consistent with the development of the quality rankings, only measurements made during the summer months should be compared to the quality categories.

An important use of these plots is to show trends in water quality over many years. This allows detection of negative trends or events that may call for remediation; alternatively, they can provide a measure of improvements caused by management efforts toward a specific goal or target condition. While most of the data for Blue Spring Lake covers no more than two years, this information will serve as a base point for all future monitoring. Comparing 1994 data with 1993 data shows that the absolute level and seasonal changes for each quality parameter are similar and no yearly trends are evident. Longer term measurements are available for Secchi depth readings and these are shown in Figure 4-10. The lake's water clarity was exceptionally good in 1992.

Although all three quality indices (clarity, chlorophyll-a, and phosphorus) attempt to indicate only one property of the lake, i.e., the level of nutrient enrichment, each plot in Figure 4-9 results in a different assessment of that level. During the summer months, water quality based on Secchi disc measurements was firmly in the "poor" category, while chlorophyll-a measures indicated a "fair-to-good" rating, and surface phosphorus concentrations were solidly in the "good" category. This inconsistency appears to be a short-coming of the quality indices, at least with respect to Wisconsin lakes. Lillie and Mason found in their study of many Wisconsin lakes that, based on Secchi readings, about half (53%) ranked in the "good" or better categories, while the other half (47%) fell in the "fair" to "very poor" categories.[1] However, they also found for chlorophyll-a measurements, about two-thirds (65%) of these same Wisconsin lakes fell into the "good" or better category, and for phosphorus almost three-fourths (71%) were in the higher categories. While these different ratings can be combined into a single, simple average, the meaningfulness of the exercise becomes lost.

[1] *Lillie, R.A. and Mason, J.W., Limnological Characteristics of Wisconsin Lakes, Wisconsin Department of Natural Resources, Madison, WI, Technical Bulletin No. 138, 1983.*

Fig. 4-9

BLUE SPRING LAKE WATER QUALITY, 1993-1994

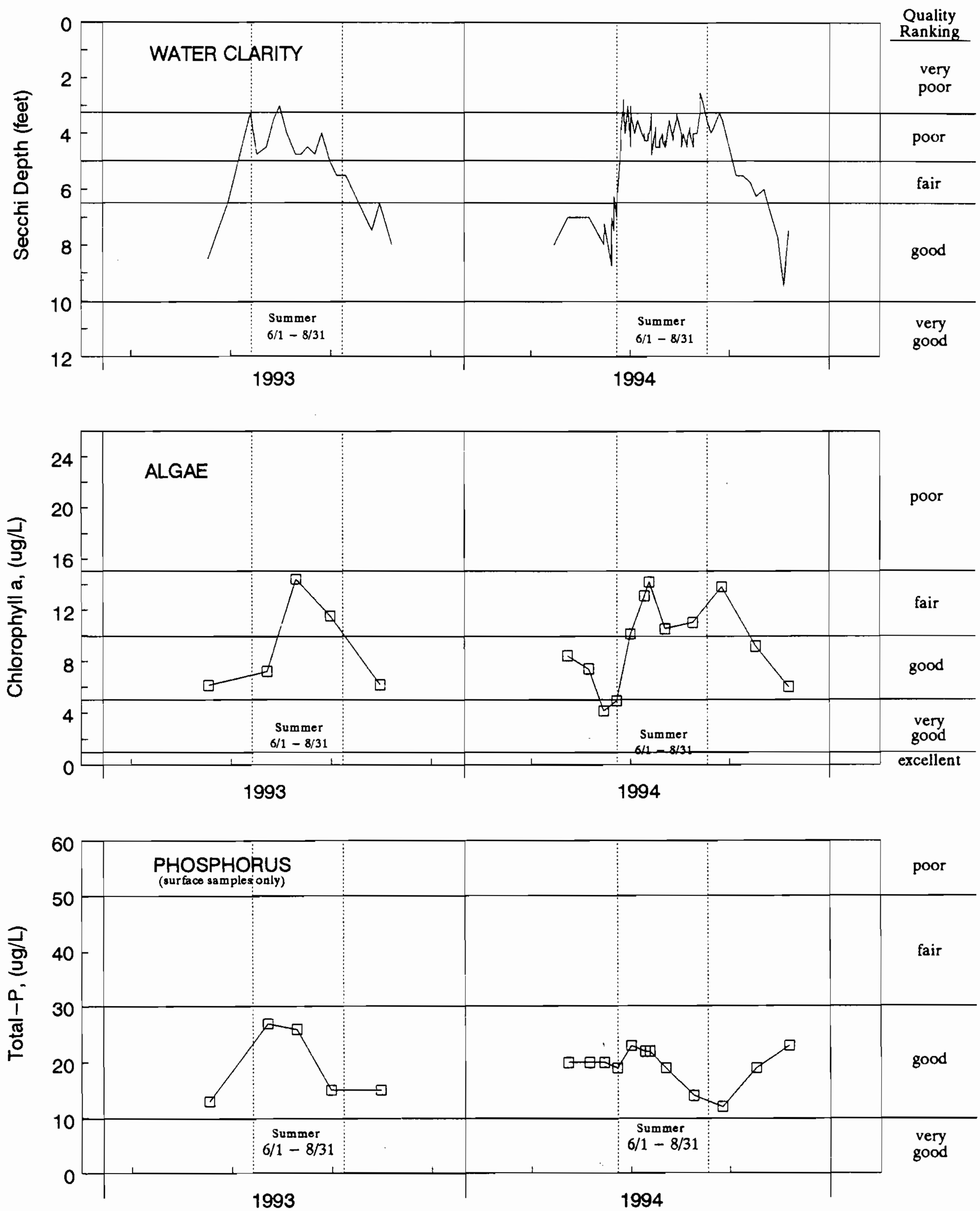
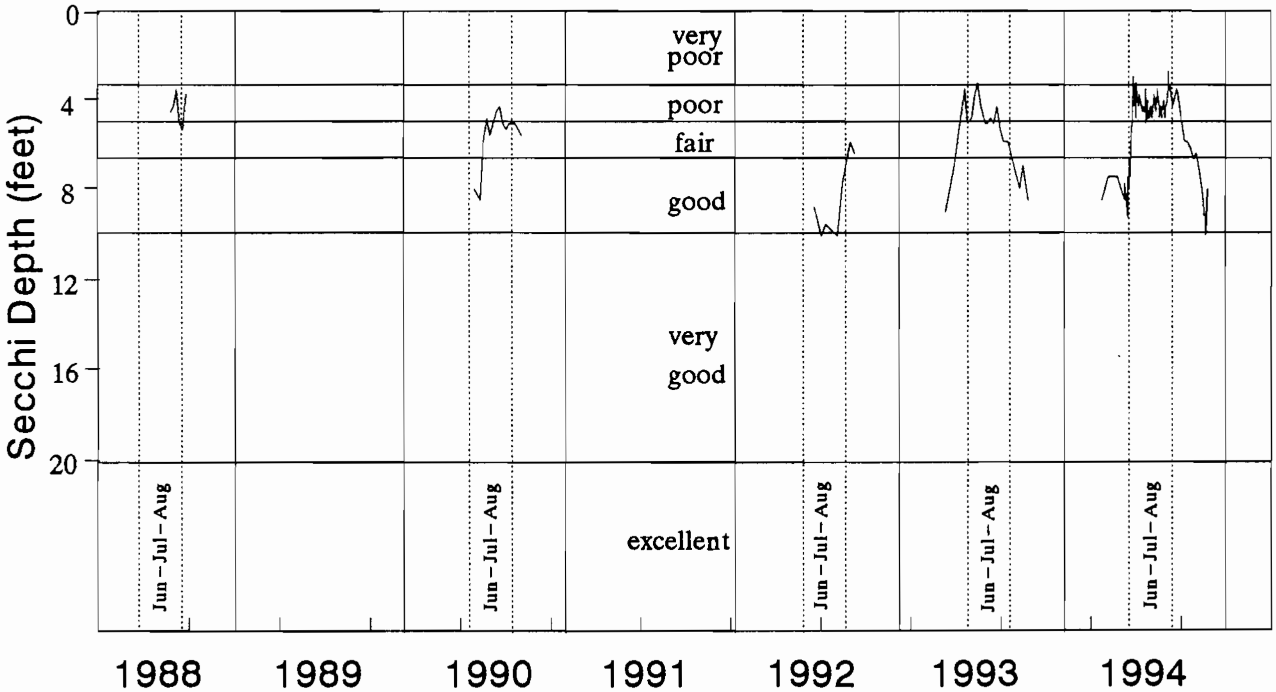


Fig. 4-10

BLUE SPRING LAKE WATER CLARITY, 1988-1994



Blue Spring Lake Compared to Other Lakes

Trying to categorize lakes as "good," "bad," or "ugly" is too much of a simplification. Less judgmental comparisons are found in the plots of Figure 4-11 which show how Blue Spring Lake's properties compare to other Wisconsin lakes. Each graph shows how the percentage of Wisconsin lakes having a given level of a characteristic changes as that level increases. The location of Blue Spring Lake on these plots was determined by using the 1994, average summer values for each characteristic. Plotting this value then shows the percent of Wisconsin lakes having larger values for this characteristic than Blue Spring Lake. In this comparison we do not try to assess whether the measured property is "good" or "bad", but only whether it is typical or atypical.

The database for the plots was taken from a comprehensive survey reported by Lillie and Mason in 1983 that covered over 600 Wisconsin lakes.[2] All lakes in the survey were greater than 25 acres, were randomly selected, and most were sampled in 1979. Because many more lakes exist in northern Wisconsin, the survey data was dominated by those types of lakes.

[2] *Ibid.*

Fig. 4-11a

BLUE SPRING LAKE PROPERTIES COMPARED TO OTHER WISCONSIN LAKES

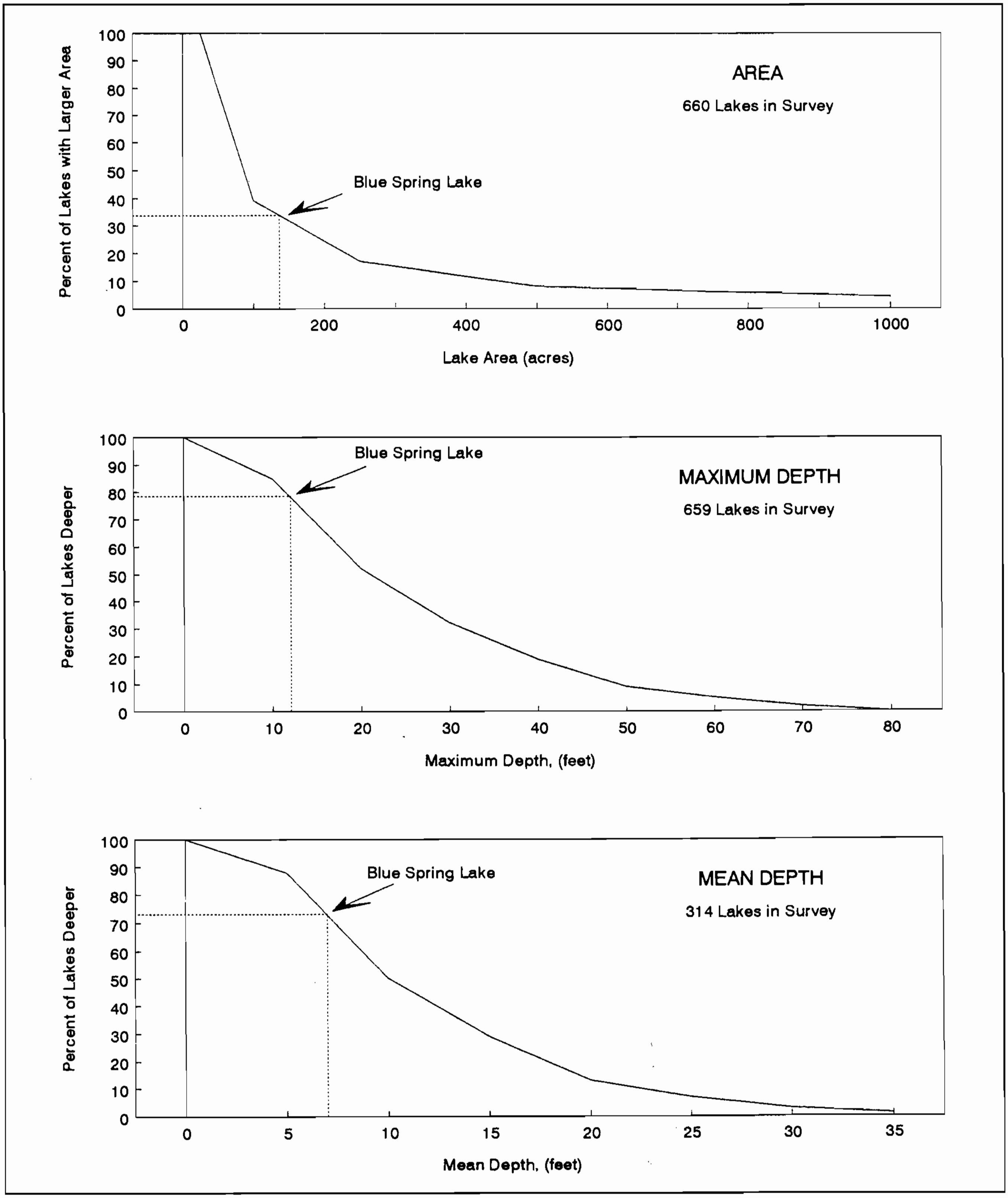


Fig. 4-11b

BLUE SPRING LAKE PROPERTIES COMPARED TO OTHER WISCONSIN LAKES

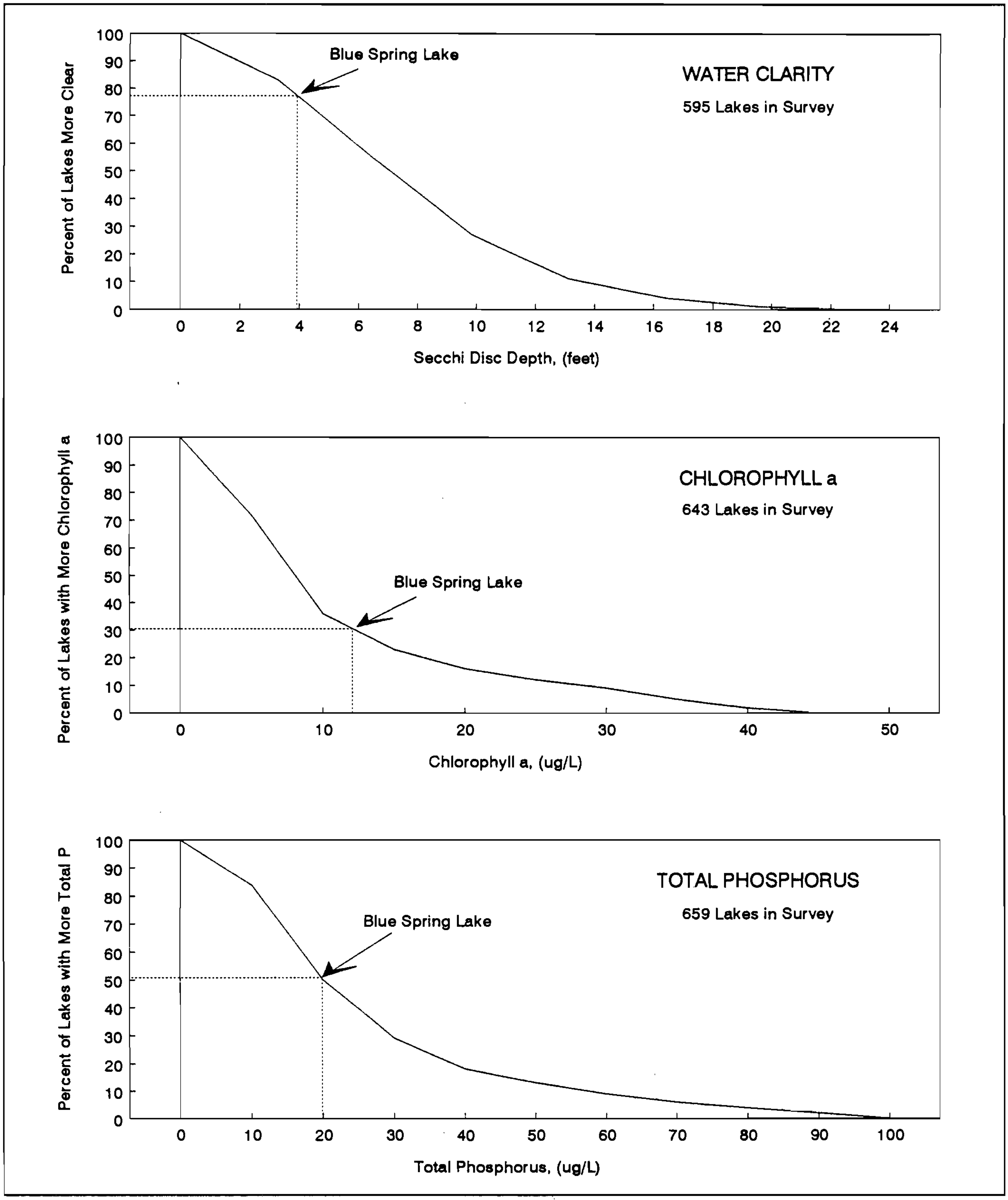


Fig. 4-11c

BLUE SPRING LAKE PROPERTIES COMPARED TO OTHER WISCONSIN LAKES

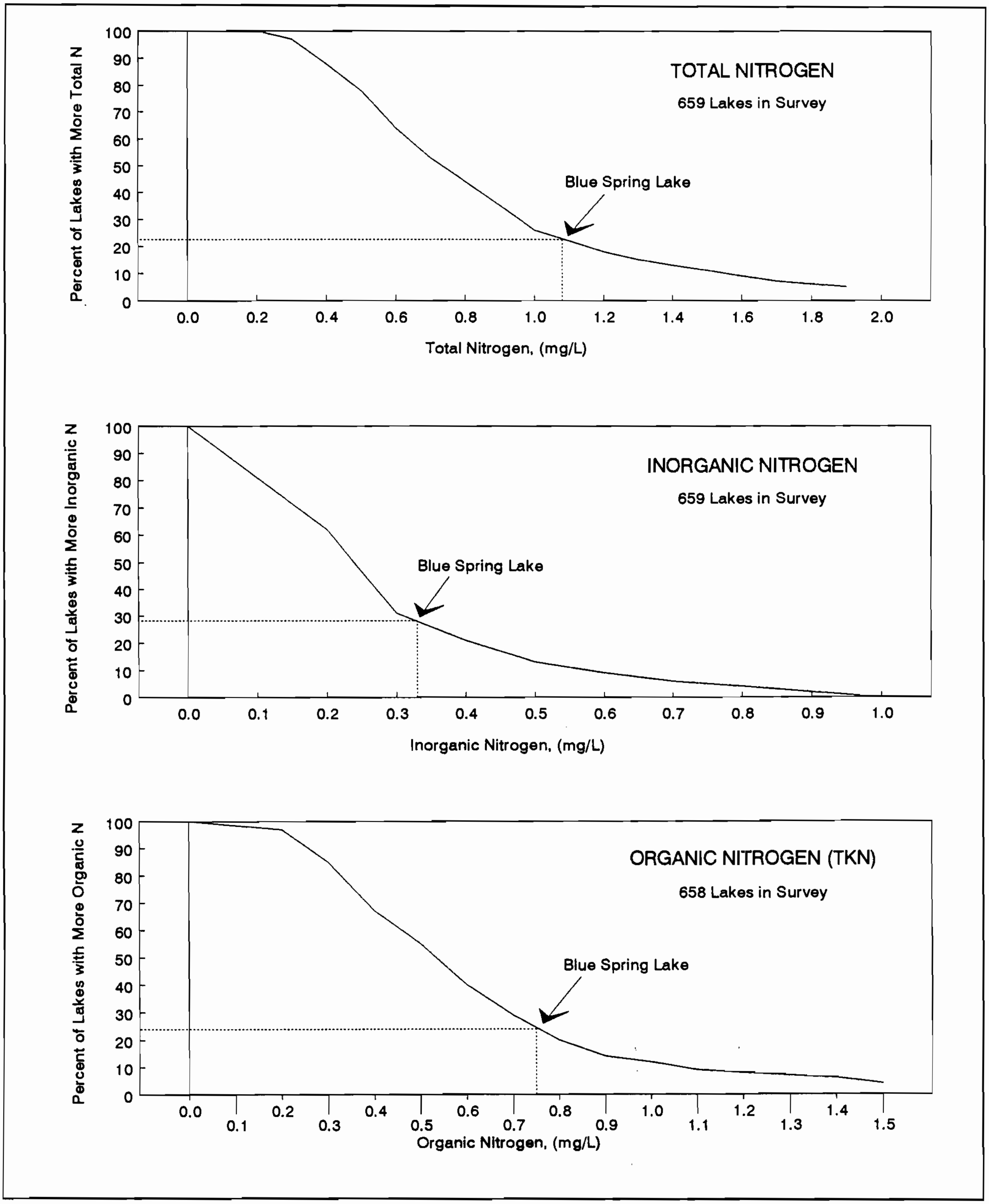


Fig. 4-11d

BLUE SPRING LAKE PROPERTIES COMPARED TO CTHER WISCONSIN LAKES

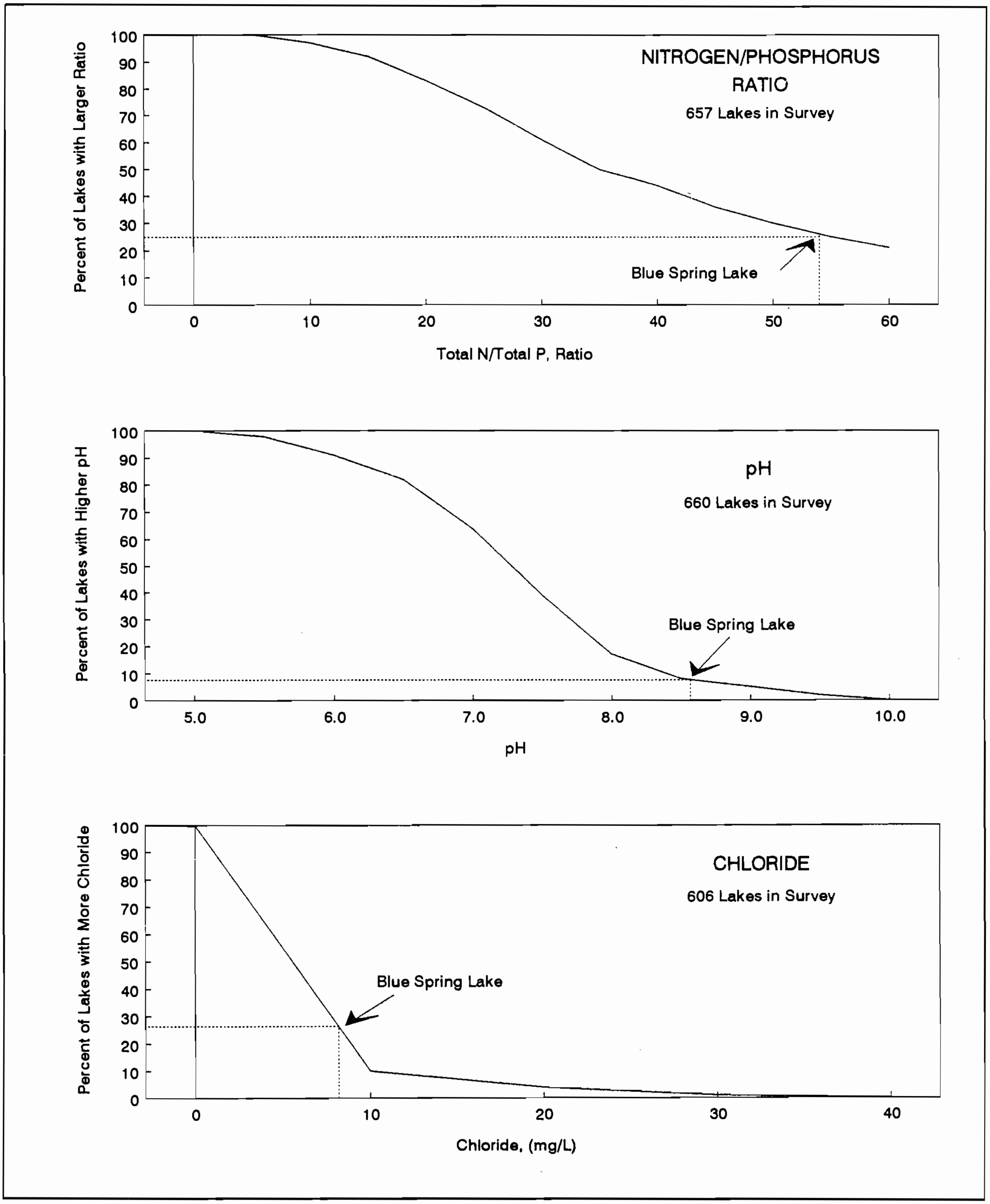
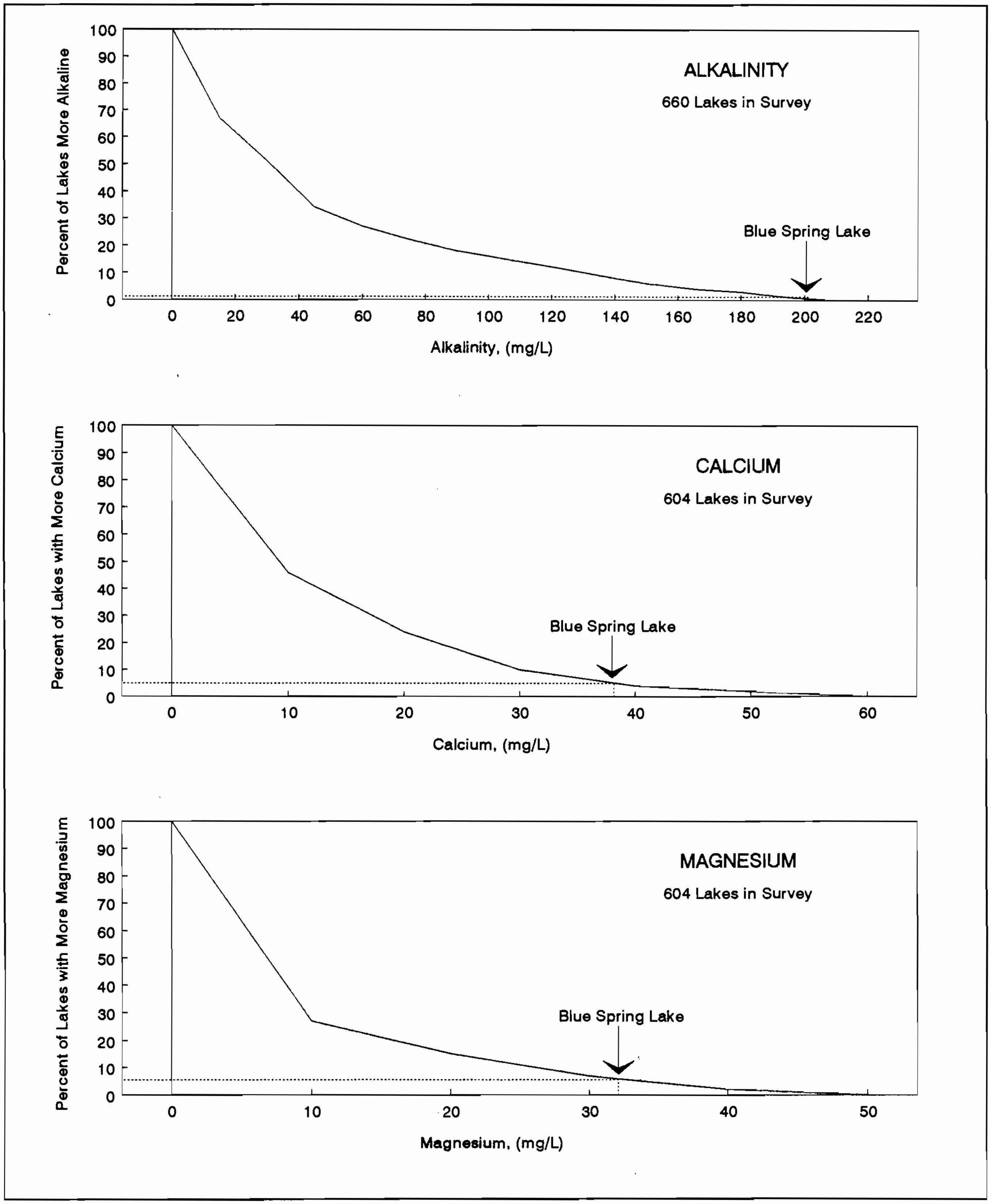


Fig. 4-11e

BLUE SPRING LAKE PROPERTIES COMPARED TO OTHER WISCONSIN LAKES



Results of these comparisons are summarized in Table 4-6 which also shows median values for each lake characteristic. The median value is the 50/50 value, meaning that 50% of the surveyed lakes had values greater than the median, and 50% had values less than the median. (The median is more useful for comparison than average values because the latter are often greatly distorted due to very unusual properties on just a few lakes). Here's how Blue Spring Lake stacks-up to all other Wisconsin Lakes:

Table 4-6

COMPARISON OF LAKE PROPERTIES[a]

Property, (units)	Average of BSL Summer Values	% of Lakes With Larger Values	Median of 660 Wisconsin Lakes	Median of 61 SE Wisc. Lakes
Area, (acres)	137	34%	73	89
Maximum Depth, (ft)	12	78%	20	16
Mean Depth, (ft)	7	73%	10	6.6
Secchi Depth, (ft)	3.9	77%	6.6	4.6
Chlorophyll-a, (ug/L)	12	31%	7.5	9.9
Total-P, (mg/L)[b]	0.020	50%	0.019	0.030
Total-N, (mg/L)	1.08	23%	0.73	1.18
Inorganic-N, (mg/L)	0.33	28%	0.2	0.41
Organic-N, (mg/L)	0.75	24%	0.53	0.77
pH	8.6	7%	7.2	8.0
Chloride, (mg/L)	8	26%	2	16
Alkalinity, (mg/L)	201	1%	30	160
Calcium, (mg/L)	38	5%	8	31
Magnesium, (mg/L)	32	5%	2	34

Notes

[a] Data based on Lillie, R. A., and Mason, J. W., "Limnological Characteristics of Wisconsin Lakes," Department of Natural Resources, Technical Bulletin No. 138, 1983.

[b] Surface samples only.

Surface Area - Surprisingly, Blue Spring Lake is a "relatively" big lake; only 34% of all lakes are bigger. This is true even though the survey used a minimum lake size of 25 acres. The median size of the surveyed lakes was 73 acres.

Depth - Blue Spring Lake is a shallow lake with 70-80% of all other lakes being deeper.

Clarity - Almost 80% of all other lakes have better clarity than Blue Spring. Summer Secchi disc visibility on most lakes is greater than six feet; for Blue Spring it averaged less than four feet during summer, 1994.

Chlorophyll-a - Blue Spring's algae content, as measured by chlorophyll-a, is relatively high with almost 70% of other lakes having lower concentrations.

Phosphorus - Levels in Blue Spring are fairly typical being only slightly greater than the median of all lakes. In view of other characteristics like clarity, chlorophyll-a, and nitrogen content, this level is actually better than expected.

Nitrogen - Both organic and inorganic forms of nitrogen are at higher concentrations in Blue Spring Lake than the state medians with more than 70% of other lakes having lower values.

Chlorides - Blue Spring Lake chloride concentration is four times greater than the state median.

pH - Less than 10% of all lakes have a higher pH.

Alkalinity - Blue Spring Lake has one of the highest alkalinities measured in the survey with only about 1% of the lakes being more alkaline. Acid rain would have a negligible affect on Blue Spring Lake.

Calcium and Magnesium - Corresponding to the high alkalinity, these hardness ions are also present in very high concentrations and exceed 95% of all other lakes.

While this comparison distinguishes Blue Spring Lake from other lakes, some of the distinguishing characteristics are not so unique to Blue Spring Lake per se, but are more characteristic of Wisconsin's southeastern geo-region. Characteristics of southeast Wisconsin lakes are also shown in Table 4-6 and represent the 61 lakes in the southeastern region that were part of the overall survey. Lakes in this region contrast with all Wisconsin lakes in that they are larger in area, more shallow, less clear, more nutrient rich, contain more chloride, and especially are much more alkaline with higher pH and greater concentrations of calcium and magnesium. Comparing Blue Spring Lake averages to the southeast medians shows Blue Spring to still have less clarity, and more chlorophyll, but its nutrient content (nitrogen and phosphorus) is now in the lower half of the southeast lakes surveyed. Chloride content is also in the lower half, being only one-half the median level found in southeast region lakes. Blue Spring's alkalinity, pH, calcium, and magnesium are still higher than the southeast median values.

Sample Depth Effects

Samples taken about one-foot off the bottom at the Hole site showed a 50% higher Total-P content than did surface samples (1-5 feet) taken at the same time. Table 4-7 shows the differences for the five instances when a comparison could be made. This difference is somewhat surprising because temperature and oxygen concentrations did not indicate any significant water stratification. The differences may be due to an increased concentration of fine particles both organic and inorganic in nature, that had settled toward the bottom. Because surface sample concentrations are generally used to characterize lake waters, they were used for all comparisons in this inventory.

Table 4-7

TOTAL–P AT DIFFERENT DEPTHS

Sample Date	Total–P, (ug/L) Surface[1]	Bottom[2]
Jun 15	23	36
Jul 20	19	32
Aug 17	14	21
Sep 15	12	30
Oct 19	19	18
Averages	17	27

[1] Sampled 1 to 5 feet from surface at Hole

[2] Sampled 1 to 2 feet from bottom at Hole

Sample Location Effects

Measurements shown in Table 4-2 were analyzed to determine if any persistent differences existed between measurement locations, some of which might point to anthropogenic effects on the lake.

Comparing measurements taken at the Dam with those at the Hole showed, as expected, no significant differences. This result supports the contention that water properties measured at the Hole also represent the properties of the lake water spilling over the dam.

In general, most water properties at the Hole, Inlet, and Runoff locations were also very similar to each other. The properties that did show statistically significant differences are shown in Table 4-8. The most important of these was the Total-P at the Inlet which was consistently higher and averaged 50% more than the Hole concentration. This difference may reflect the higher Total-P content of the Pipe effluent which was two-to-six times more concentrated than the lake water.

Table 4-8

SAMPLE LOCATION EFFECTS. DIFFERENCES IN WATER PROPERTIES BETWEEN TWO SAMPLE LOCATIONS

Property: Location: DATE	TOT P H–I (mg/L)	NO2–NO3 H–R (mg/L)	NO2–NO3 I–R (mg/L)	NH3 H–I (mg/L)	NH3 H–R (mg/L)	K H–I (mg/L)	K H–R (mg/L)	Cl H–I (mg/L)	Cl I–R (mg/L)
13–Apr		−0.23	−0.27	0.002	0.006	0.18	0.11	−0.1	0.4
4–May		−0.04	−0.06	−0.001	0.012	0.17	0.13	−0.7	0.7
19–May		−0.10	−0.09	0.004	0.003	−0.07	−0.05	−0.3	0.4
1–Jun	−0.013	0.00	−0.11	−0.027	0.011	0.04	0.02	−0.1	0.1
15–Jun	−0.017		−0.05			−0.06	0.03	0.0	0.1
29–Jun	−0.004	−0.10	−0.05	0.099	0.080	0.21	0.19	0.0	0.2
4–Jul	−0.001			0.077					
20–Jul	−0.046	−0.08	−0.07	0.173	0.107	0.17	0.17	−0.3	0.4
17–Aug	−0.022	−0.07	−0.11	0.068	0.050	0.02	0.06	−0.7	0.6
15–Sep	−0.023	−0.07	−0.07	0.042	0.038				
19–Oct	0.000	−0.03	−0.04	0.014	0.018	0.00	0.00	0.0	0.1
21–Nov		−0.06	−0.06	0.019	0.030				
Average =	−0.016	−0.079	−0.089	0.043	0.036	0.07	0.07	−0.24	0.33
Std Dev =	−0.014	0.059	0.061	0.055	0.033	0.10	0.08	0.27	0.21
Count =	8	10	11	11	10	9	9	9	9
Min =	−0.046	−0.23	−0.27	−0.027	0.003	−0.07	−0.05	−0.7	0.1
Max =	0	0.001	−0.039	0.173	0.107	0.21	0.19	0	0.7

Locations: H = Hole; I = Inlet; R = Runoff

Similarly, the Inlet Cl content was consistently higher than that at the Hole or Runoff locations, although these differences only averaged 3% and 4% respectively. Here, again, this probably reflects the higher Pipe Cl content which was about three times more concentrated than lake water. This high Cl content is generally considered a result of human activities, such as salting roads during winter. The chloride salts readily dissolve in rain water and work their way through the watershed and into the lake.

Potassium (K), like chloride, also is found in readily soluble salts, and also showed concentration differences between locations. Unexpectedly, however, the near shore areas at the Inlet and Runoff showed an average 7% lower content than the Hole location. Potassium is often linked to fertilizer use as it is a key ingredient in many fertilizers. Its concentration in Pipe effluent was about 30% higher than lake water, but this difference was not sufficient to be seen in higher Inlet values. If potassium from fertilizer use were impacting the lake, it is not apparent in these measurements.

Nitrite-Nitrate (NO_2-NO_3) content at the Runoff location averaged 14% and 20% more than at the Hole and Inlet locations, respectively. The NO_2-NO_3 content of the Pipe effluent was very low, but its concentration in water from the Springs was very high, being five-to-twenty times more concentrated than the lake water. The higher NO_2-NO_3 content of the Runoff location probably reflects the fact that there are more shore-line springs near this location than at the other locations.

The average ammonia (NH_3) content at the Hole was about 30% higher than at the other locations. While NH_3 content in the Pipe was higher during the spring season and lower during the summer than the lake water, this difference did not show up in the Inlet values. NH_3 content in the Spring waters was insignificant. NH_3 is used locally for agricultural fertilization, but does not appear in this study to be impacting the lake. The ratio NO_3/NH_3 can range from 25/1 for unpolluted hard water lakes to 1/10 for agriculturally polluted lakes.[3] Blue Spring Lake's NO_3/NH_3 is about 5/1.

Power Boating Impact

A comparison of measurements made on July 4th with those made a few days earlier on June 29 was intended to show the impact, if any, of power boating on water quality. The period between these days was the 4th-of-July holiday which normally sees heavy boating traffic. However, none of the parameters measured for these samples, collected at the Inlet and Hole locations showed significant differences (see Table 4-2) Secchi readings differed by only 0.25 feet which was not significant. These samples were also analyzed for turbidity by the DNR Bureau of Research with the following results showing no significant difference:

LOCATION	DATE	TURBIDITY (NTU)*
Inlet	6/29	2.4
Inlet	7/04	2.6
Hole	6/29	2.5
Hole	7/04	2.5

*Nephelometric Turbidity Units[4]

[3] *Wetzel, R.G. Limnology, Saunders College Publishing, Philadelphia, 1983.*

[4] *Standard Methods for the Examination of Water and Wastewater, Published by the American Pubic Health Association, et al, Washington, D.C., 16th ed., 1985.*

Because water quality had deteriorated so much in early June, the question remains as to whether there was enough quality left by the 4th-of-July to show an impact, or whether there really is no significant motor boating impact on quality.

Marsh Effluent

Water coming into the lake from the marsh was sampled four times from April through December at the Pipe location. The culvert pipe under the north shore road appears completely blocked and some filtration of the marsh water probably occurs before it enters the pipe.

Samples from the Pipe generally showed higher concentrations of nutrients and pollutants than existed in the lake water. Two exceptions were chlorophyll-a and NO_2-NO_3, the first, perhaps showing the effects of filtration. The marsh effluent tended to be more acid than lake water and contained significantly higher concentrations of Total-P, Dissolved-P and Cl. Interestingly, the two samples taken on April 24 and May 4, were before and after rainfalls which followed the fertilization of nearby agricultural fields, yet they showed little evidence of this fertilization.

The Pipe sample taken on August 6 was after heavy rainfalls with Pipe flow at 0.82 cfs. (This compares to 0.25 cfs flow rates during the spring sampling or a 0.16 cfs average from May through September.) Most nutrient and pollutant concentrations in the pipe effluent were at higher levels after this heavy rainfall. However, attempts to correlate changes in Inlet concentrations with rainfall amounts or with actual inlet flow rates were not successful, except for a slight correlation for chloride.

Spring Waters

A sample of the water coming out of the Main Spring was obtained at a depth of 20 feet using the Van Dorn sampler. In addition, a composite sample was formed with a 50/50 mixture of waters from Spring #1 and Spring #2. Analyses of both samples were similar and showed low Total-P and NH_3 content, but very high NO_2-NO_3 content. The high NO_2-NO_3 content was verified by sampling Spring #2 and

Spring #3 in December and analyzing each for their separate NO_2 and NO_3 content. These confirmed that NO_2 concentration was low and that the NO_3 concentration was at a very high level of about 5 mg/L.

A similar nitrate content was also found in the tap water of a resident with a shallow well that draws water from the same aquifer that supplies the lake. While high, this nitrate level is still below the 10 mg/L NO_3-N level recommended for drinking water in order to prevent the illness known as methemoglobinemia in infants.[5] Nitrate levels in some ground water aquifers in southeast Wisconsin have been measured above the recommended concentration.[6] Whether the nitrates in these waters are naturally present or are the result of agricultural activity is not known. Continued long term monitoring of the NO_3 level in the ground water should be done to determine if it is stable or if it is increasing to a health hazard level.

It is interesting that the NO_2-NO_3 content of all lake samples averaged less than 0.7 mg/L and never exceeded 1.5 mg/L, while the spring water, which constitutes greater than 70% of all lake water, contains a much higher concentration of 5 mg/L NO_2-NO_3. The difference in NO_2-NO_3 content is evidently being consumed, in part by denitrification processes losing nitrogen to the atmosphere, and in part by plant growth.

DISCUSSION

Estimating a Phosphorus Budget

Results of this work can be used to estimate the loadings of phosphorus to and from the lake. Phosphorus is important because in most Wisconsin lakes, including Blue Spring, it is the likely limiting nutrient for macrophyte growth. Phosphorus inputs to a water body can be from point sources such as an industrial plant or waste water treatment plant, or from non-point sources such as surface runoff from overly fertilized lawns and agricultural fields. For Blue Spring Lake, there are no point sources of phosphorus pollution, and non-point sources have generally been considered the primary source of nutrients and the main cause of excess macrophyte growth.

Table 4-9 shows calculated estimates of phosphorus loadings to Blue Spring Lake. Wherever possible, the estimates are based on actual measurements made in this study. It also makes use of results from other studies done on similar lakes. To help establish a feel for the level of uncertainty, maximum values for phosphorus loadings were also estimated and are presented in the table.

Natural Springs - The spring water contains only a low concentration of phosphorus, but because of its huge flow rate, contributes almost 40% of the total phosphorus loading to the lake. Because other sources of phosphorus are added to the spring water as it passes through the lake, it's concentration increases by about 33% from 0.014ppm to 0.019 ppm before passing over the dam.

Marsh Effluent - The flow rates and phosphorus content of the marsh effluent indicate a relatively small phosphorus loading of 20 to 30 lbs/year to the lake. This is less than 10% of the total phosphorus estimated to be entering the lake and is very surprising. Considering that the marsh drains two-thirds of the watershed, including all it's agricultural and barnyard operations, this is a very small loading. There are three reasons that may account for this. First, the soils in this watershed are very permeable and do not result in much runoff after most rainfalls. Second, when runoff does occur, the marsh acts as a catch basin, holding excess water and allowing time for phosphorus-rich sediment to settle out. Finally, plants and animals in the marsh consume some of the nutrients before they are flushed into the lake. These features of the marsh are very important to minimizing nutrient loading to Blue Spring Lake.

Atmospheric - A significant amount of phosphorus nutrient can reach the lake by airborne means. Estimates indicate 15 to 20% of the annual

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[5] *Ibid.*

[6] *Brown, B.E., and Cherkauer, D.S., 1991, Phosphate and Carbonate Mass Balances and Their Relationships to Groundwater Inputs at Beaver Lake, Waukesha County, Wisconsin, Wisconsin Water Resource Center Technical Report 91-01.*

Table 4-9

ESTIMATED ANNUAL PHOSPHORUS BUDGET

Phosphorus Source	Phosphorus Load: Best Estimate (lb/year)	Best Estimate %	Maximum Estimate (lb/year)	Maximum Estimate %
IN-FLOWS				
Natural Springs	100	39%	100	16%
Marsh Effluent	20	8%	30	5%
Atmospheric	40	16%	120	20%
Surface Runoff	70	27%	220	36%
Seepage	20	8%	50	8%
Lawn Fertilizers	2	1%	60	10%
Construction Projects	2	1%	20	3%
Shoreline Erosion	1	0%	10	2%
Total	255	100%	610	100%
OUT-FLOWS				
Over Dam	160	14%		
Harvesting	960	86%		
Total	1120	100%		

BASIS FOR ESTIMATIONS		
Source	**Best Estimate**	**Maximum Estimate**
Natural Springs	(Avg. annual flow rate) x (Avg. Total-P) (3.59 cfs) x (0.014 ppm)	Same as Best Estimate
Marsh Effluent	(Avg. annual flow rate) x (Avg. Total-P) (0.13 cfs) x (0.075 ppm)	(Avg. annual flow rate) x (Highest Total-P) (0.13 cfs) x (0.120 ppm)
Atmospheric	Used P loading factor of the Wisconsin Lake Model Spreadsheet (WILMS); = 0.27 lb P/acre of lake. (Panuska, 1994)	Applied highest P loading factor found in literature; = 0.89 lb P/acre of lake. (Wetzel, p280)
Surface Runoff	Proportioned to Marsh Effluent assuming 1/2 the drainage area, but twice the runoff rate, to give an annual average of 0.13 cfs. Total-P of runoff taken as 0.27 ppm as used in WILMS.	Highest loading consistent with lake water concentrations measured after periods of increased runoff. (Higher loadings would have resulted in measurable Total-P increases.)
Seepage	Used estimated groundwater Total-P content of 0.020 ppm, (Wetzel, p 281).	Estimated Total-P as 3X best estimate, or 0.060 ppm.
Lawn Fertilization	Assumed 30% of homeowners applied fertilizer as in the maximum estimate, but only 10% of this eventually reached the lake.	Assumed 150 riparian homeowners each dump a 30 lb bag of Scotts Plus 2 fertilizer directly into the lake once a year. This fertilzer contains 3 wt% P_2O_5 and is normally applied to 10,000 square feet of lawn.
Construction	Applied SEWRPC estimate for construction site soil erosion of 10 tons/acre/yr (SEWRPC, 1991) to the 13 constructions sites on BSL in 1994, each 1/4 acre and under construction for about 1/2 year. Total-P in soil estimated at 75 ppm, which is actually considered "excessively high," by the Department of Soil Science, UW.	Used same assumptions as in best estimate, but assumed Total-P to be 650 ppm in eroded soils (SEWRPC, 1991).
Shoreline Erosion	Assumed average annual erosion of 2.5 inch wide by 1 inch deep volume of shoreline soil, along its entire 2.5 mile length, and containing 75 ppm Total-P.	Same as best estimate, but assumed 6 inch wide and 3 inch deep annual erosion.
Dam Outflow	(Avg. annual flow rate) x (Avg. Total-P) (4.33 cfs) x (0.019 ppm)	
Harvesting	Used 400 harvester loads per year, at 4 tons per load, 10 wt% dry biomass per load, and 0.003 lb of P/lb of dry biomass.	

phosphorus load is airborne. The best and maximum estimates differ considerably and reflect differences reported in the literature. The loading depends on such factors as the region's soil and vegetation types as well as geological relief. The density of shoreline trees, with their falling leaves and pollen, are also important.

Surface Runoff - This contributor was very difficult to estimate and the values have much uncertainty. Nevertheless, surface runoff is probably a significant phosphorus contributor and is one that, unlike the springs or airborne contributions, can be controlled by homeowner practices. This contribution derives from surface runoff waters going directly into the lake but excludes that coming through the marsh. As the marsh drains two-thirds of the watershed, the surface runoff estimated here is only for the remaining one-third. This land includes all riparian properties which, of course, are very close to the lake. Consequently, twice the amount of runoff water per unit surface area of land was assumed to reach the lake for this sub-watershed. The phosphorus concentration in this runoff water was generously estimated at 0.27 ppm, which is based on studies of other Wisconsin lakes,[7] and is four times higher than that actually observed from the marsh. This concentration reflects the amount of phosphorus that can be picked up by rainwater from decaying vegetation, excess fertilization, and from droppings of resident dogs, cats, geese, ducks, etc.

Because lake water samples did not show measurable increases in phosphorus content after rainy periods a maximum phosphorus runoff value was taken as that, above which, would have produced a measurable effect.

Seepage - Rainwater that passes through the soil, rather than over the top, before reaching the lake can contain phosphorus and contribute to the lake's phosphorus load. The sources of the phosphorus include all the same contributors as to runoff water. However, soils are very good at adsorbing phosphorus from waters passing through it. For example, functional septic field soils are typically expected to retain from 80% to 98% of their phosphorus loadings.[8] Because of this adsorbtion, most groundwaters only contain about 20 ug/L of phosphorus.[9] For this reason, the phosphorus content of seepage water going into Blue Spring Lake was estimated to be lower than runoff water and to range from 20 ug/L as a best estimate to three times that concentration, or 60 ug/L, as a maximum estimate.

Lawn Fertilization - A component of phosphorus loading from surface runoff is that due to homeowners fertilizing their lawns. The maximum estimate for this contribution was made by assuming that all 150 riparian homeowners each dumped a 30-pound bag of Scotts Plus 2 fertilizer, which contains 3 wt% P_2O_5, directly into the lake. This would add 60 pounds of phosphorus to the lake annually. A more realistic estimate makes use of the 1995 survey result that only about 30% of homeowners use fertilizer and, because of soil porosity and adsorbtion, only about 10% of this may reach the lake, adding about two pounds of phosphorus annually.

These estimates indicate lawn fertilization is not a major contributor of phosphorus addition to the lake. While fertilizing lawns that don't need it is certainly not recommended (a soil analysis should be done first), it seems the amount of effort spent in the past to discourage fertilization, and the blame attributed to fertilization for many of the lake problems, are not well founded.

Construction - Estimates for phosphorus loading from soil-breaking construction projects vary considerably depending on assumptions used. The estimates in the table use two different soil phosphorus concentrations, the best estimate being 75 ppm, which is still about twice the level actually

[7] *Panuska, J. C., and Lillie, R. A., "Phosphorus Loadings from Wisconsin Watersheds: Recommended Phosphorus Export Coefficients for Agricultural and Forested Watersheds," Research Management Findings, No. 38, WDNR Bureau of Research, April 1995.*

[8] *Panuska, J. C., and Wilson, A. D., Wisconsin Lake Model Spreadsheet Users Manual, WDNR, Madison, WI, Publ-WR-363-94, June, 1994.*

[9] *Wetzel, R. G., Limnology, Saunders College Publishing, Philadelphia, 1983, p.280.*

measured in one lakeshore soil sample. Even with thirteen construction projects noted on the lake in 1994, the estimated phosphorus contributions are relatively small, representing only 1% to 3% of the total load.

Shoreline Erosion - Shoreline erosion varies between homesites depending on lakeshore protection (rip-rap, bulkhead, sand, natural, etc.). Using liberal estimates for average shoreline erosion, up to six inches per year over its 2.5-mile length, indicates that erosion is not a significant contributor of phosphorus to Blue Spring Lake and amounts to less than 2% of the total phosphorus loading.

Dam Outflow - About 160 lbs of phosphorus leave the lake annually via the dam outflow. This is approximately equivalent to all estimated phosphorus inputs, excepting surface runoff and seepage. The difference between all inputs and this outflow is phosphorus that goes into the formation of aquatic life forms, primarily plants and algae, or into storage in the lake's sediments.

Harvesting - Blue Spring Lake's harvesting program can remove a very large amount of phosphorus in a typical year. Records indicate about 200 harvester loads are typically removed by early June,[10] and it is likely that at least 400 loads are typically removed each season. Harvester operators have reported weighing full loads at five tons. Assuming an average load weighs four tons, contains 90 wt% water and only 10 wt% dry biomass[11], which, in turn contains only 0.3 wt% phosphorus,[12] results in 960 lbs of phosphorus removal each year. This amount is almost four times the total amount of phosphorus entering the lake. This indicates that phosphorus is essentially being mined from the lake by removing aquatic vegetation that obtained some, if not most, of its phosphorus from the lake's sediments. To the extent that phosphorus is a limiting nutrient for plant growth, this activity should eventually result in reduced amounts of phosphorus available and in a reduction in plant growth. How long this may take will depend on the amount of phosphorus in the sediments which we will address in the next chapter. Directionally, harvesting is a good long term strategy for reducing excessive plant growth because it does remove a necessary nutrient.

Nitrogen Budget

Another necessary nutrient for plant growth is nitrogen. However, nitrogen budgets are generally not estimated because some aquatic plants can obtain nitrogen from the atmosphere and because nitrogen is generally not the nutrient limiting plant growth. (Waters with total nitrogen to total phosphorus ratios (N/P) less than 15:1 may be nitrogen limiting, but most Wisconsin lakes have a N/P greater than 35,[13] while Blue Spring Lake's N/P is over 50. In addition, the very high nitrate content of the spring waters (5 mg/L) provides a huge amount of this nutrient. Of interest here may be the relative nitrogen contribution from homeowners using high nitrogen concentration fertilizers. Using the unrealistically high estimate of all homeowners dumping 30 lb bags of 35 wt% nitrogen fertilizer into the lake results in a 1600 lb annual nitrogen addition. This, however, is still less than 5% of the 36,000 lbs of nitrate nitrogen that comes into the lake each year with the spring waters.

Long Term Changes

Changes in Blue Spring Lake water quality over time can be determined by comparing the 1994 measurements to measurements made in 1975-1976 (see Table 4-3). Many properties show a significant change and these are contrasted in Table 4-10 for measurements made during summer months. Some of the differences are probably related to the high carp population that existed in the lake in the late

[10] *Wood, G.R., History of Nuisance Weeds at Blue Spring Lake, 1950-1993, Blue Spring Lake Association Report, Palmyra, WI, January 1995.*

[11] *Wetzel, R. G., Limnology, Saunders College Publishing, Philadelphia, 1983, p.544.*

[12] *Carpenter, S., "Phosphorus Loadings in Lake Wingra," Ecology, 61, (5), 1980. Nichols, S. A., and Shaw, B. H., "Ecological life histories of the three aquatic nuisance plants, myriophyllum spicatum, potamegeton crispus, and elodea canadensis," Hydrobiologia, 131, 3-21, (1986).*

[13] *Lillie, R. A., and Mason, J. W., "Limnological Characteristics of Wisconsin Lakes," Wisconsin Department of Natural Resources, Madison, WI, Technical Bulletin No. 138, 1983.*

70's.[14] For example, even though water clarity in 1994 was considered rather poor, it was almost twice as clear (3.9 Secchi feet) as it was during the summers of 1975-76 (2.3 Secchi feet). The turbidity accompanying the carp also blocked out sunlight, reducing the amount of photosynthesis, which may account for the lower pH of 8.0 verses today's value of 8.6. In 1977, a macrophyte survey showed essentially no plants at depths greater than four feet because of the high turbidity.

Table 4-10

LONG TERM WATER QUALITY CHANGES

Water Quality Property	1995 (summer)	1975-6 (summer)
Secchi Depth, (feet)	3.9	2.3
pH	8.6	8.0
Total-P, (mg/L)	0.020	0.063
Dissolved P, (mg/L)	<0.002	0.024
Chloride, (mg/L)	8	5

A most important long term change has been in the phosphorus content. Summer values for Total-P in 1975-6 were about 0.060 mg/L or about three times as concentrated as in 1994. Dissolved phosphorus (also called PO_4-P) was also very high 18 years ago with levels at 0.020 mg/L verses 1994 levels of <0.002 mg/L. The main cause(s) for these dramatic and very desirable changes is not entirely clear. While the installation of sanitary sewers in 1990 certainly helped, the biggest contributor was probably the DNR's eradication of the carp in 1979 which eliminated their agitation of phosphorus rich bottom sediments.

Chloride concentration appears to have nearly doubled since 1976, from 4-5 mg/L to 8 mg/L. This is most often attributed to increased use of road salt during winter months and was previously seen in the high concentration of chloride in the marsh effluent. Comparisons of sodium (Na) and potassium (K) concentrations, which are other indicators of anthropogenic activities, was confounded due to the high variability in the early data.

[14] *Wood, G. R., History of Nuisance Weeds at Blue Spring Lake, 1950-1993, Blue Spring Lake Association Report, Palmyra, WI, January 1995.*

Motor Boating Impacts

During this inventory assessment, one of the most significant changes in Blue Spring Lake's water quality occurred during the first week of June. Clarity fell from about eight feet to less than four feet, and remained at the low level for the rest of the summer. At the same time, the chlorophyll-a concentration doubled during the first half of June, and then nearly tripled by the end of the month. Total phosphorus also showed a slight increase during early June.

Many residents have felt that the loss in water clarity during the summer was due to power boating activities. Power boating and water skiing are very popular on Blue Spring Lake and the number of boats with large engines has increased over the last few years. During the winter of 1992-93, a homeowner survey showed the average horsepower for 99 speedboats kept on the lake was 119. A more recent survey completed in January 1995, showed 98 speedboats were kept on the lake, ranging from 35 to 425 horsepower, and with an average of 144 horsepower.

There may be many possible reasons for the rapid loss in clarity last June, including increasing algal growth due to increasing water temperature and hours of sunlight, but suspension of fine bottom sediments by prop effects should also be considered. Disturbances of sediment can contribute stored nutrients to the water column which would further decrease water clarity by promoting additional algal growth. The 1994 Memorial Day weekend saw an unusually high level of boating on Blue Spring Lake. Unlike previous years, the lake was not partially choked with Eurasian water milfoil and was completely open for boating. The low level of macrophytes in the lake during 1994 was characterized by the fact that only 18 loads of plants were harvested for the year, compared to a typical annual yield of over 400 loads. The absence of nuisance weeds may also have induced more people to put their boats in early. In addition, the reduced amount of biomass increased exposure of the bottom sediments to prop effects.

The DNR's Bureau of Research conducted a statewide study of the impact of motor boats on water clarity during 1994.[15] Preliminary findings of this study, which included Blue Spring Lake along with 19 other lakes in Wisconsin, did not find a strong correlation between changes in water clarity and changes in power boating activity. While clear lakes tended to show clarity loses due to suspension of bottom sediments, less clear lakes appeared to have variations due to other variables besides motor boating. Part of the study did show the capacity of sediments to provide nutrients to support algal growth, even with the nutrients in insoluble forms.

On Blue Spring Lake, water quality measurements around the 4th-of-July holiday also did not detect any deterioration of quality due to boating. However, it may have been that fine sediments had already been suspended by early June and no further deterioration could take place. The fact that both phosphorus levels and chlorophyll-a levels are not as high as one would expect based on clarity measurements suggests that much of the clarity loss is not due to algae formation, but due to suspended inorganic materials. A better understanding of this phenomenon could be gained in future work by sampling before and after the rapid loss in clarity, which seems to occur in early June, and identifying the specific nature of the suspended material causing the clarity loss.

CONCLUSIONS

- Water quality of Blue Spring Lake is characteristic of a spring-fed lake in southeast Wisconsin. It is, however, very high in alkalinity and hardness, and also has a high pH.

- The water is well oxygenated throughout the year and is often supersaturated.

- Contamination of the lake water by fecal bacteria of human origins is not evident.

- The lake is well mixed with no major differences in properties for different locations or water depths. The lake does not significantly stratify or turnover seasonally.

- Water clarity is on the low side with almost 80% of all Wisconsin lakes having better clarity.

- Algal content, measured by chlorophyll-a, is on the high side, but is close to typical for a southeast Wisconsin lake.

- Nutrient concentrations in the water are not particularly high. Total-P concentration is actually quite low for a southeast Wisconsin lake, while Total-N is fairly typical.

- Relatively small amounts of nutrients are contributed to the lake from the marsh effluent, even though this drains two-thirds of the watershed including its agricultural and barnyard activities. The marsh is an effective buffer between watershed nutrients/pollutants and the lake.

- The springs feeding the lake have a high nitrate concentration (5 mg/L) and provide a huge source of nitrogen for plant growth.

- Phosphorus is the limiting nutrient for algal growth; N/P is greater than 50 for Blue Spring Lake.

- A significant source of phosphorus entering the lake is contained in the spring water, albeit at low concentrations.

- Estimates of phosphorus contributions from homeowner lawn fertilization, construction projects, and shoreline erosion appear to be very small for Blue Spring Lake.

- The total contribution of nutrients from the watershed to the lake is relatively low because the high permeability of the watershed soils results in low surface runoff.

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[15] *Asplund, T., Motor Boat Impacts on Water Clarity: Results of a 1994 Volunteer Monitoring Study, WDNR, Bureau Of Research, Pre-publication Draft Report, April 8, 1995.*

- Harvesting removes more than three times the amount of phosphorus that enters the lake each year. It essentially mines phosphorus from the lake's sediments and represents a long term strategy for reducing excessive aquatic plant growth.

- Phosphorus in the lake water today is about one-third the concentration of 17 years ago. The improved conditions are most likely the result of having eliminated resuspension of bottom sediments by carp.

- The lake's chloride content is about twice the level of 17 years ago and probably reflects the high use of road salt in southeast Wisconsin.

SECTION V

SEDIMENT SURVEY

A lake inventory would not be complete without addressing the character of the lake's bottom surface, or sediment. The sediment can have many strong interactions with the lake and account for many of the lake's characteristics. It also impacts our aesthetic perceptions of the lake; we touch it when wading, and see it as reduced water clarity if stirred up by wind or boating activity. The sediment acts as both a sink and a source for nutrients and pollutants. These nutrients accumulate as dead plankton, macrophytes, and other biota, and, as insoluble precipitates that settle to the bottom, they can be returned to the water column during seasonal lake turnovers or from turbulence. Perhaps most important for Blue Spring Lake, the sediment provides the support and nutrients for macrophyte growth. Considering that excess macrophyte growth is a major concern of lake users, it is important to better understand this sediment, and particularly the top four-inch layer which is considered the primary zone for hosting macrophyte roots.

OBJECTIVES

- characterize the lake sediment properties including:
  - type (sand, gravel, silt, muck, etc.),
  - thickness of the soft sediment,
  - density and moisture content, and
  - nutrient content
- characterize the distribution of the above properties over the entire lake
- characterize how these properties change with depth in the sediment
- determine if these properties correlate with excess macrophyte growth

METHODS

Sampling Site

Twenty-six different sites were sampled as show in Figure 5-1. An attempt was made to distribute the sites evenly over the entire lake, but to also include most of the sites previously surveyed for macrophytes (see Section II for descriptions). Of the twelve sites surveyed for macrophytes, ten were covered in this sediment sampling program as shown in the figure. Seventeen of the sediment sites were located in shallow waters (three to five feet), while the remaining nine sites were located in deeper waters (greater than six feet).

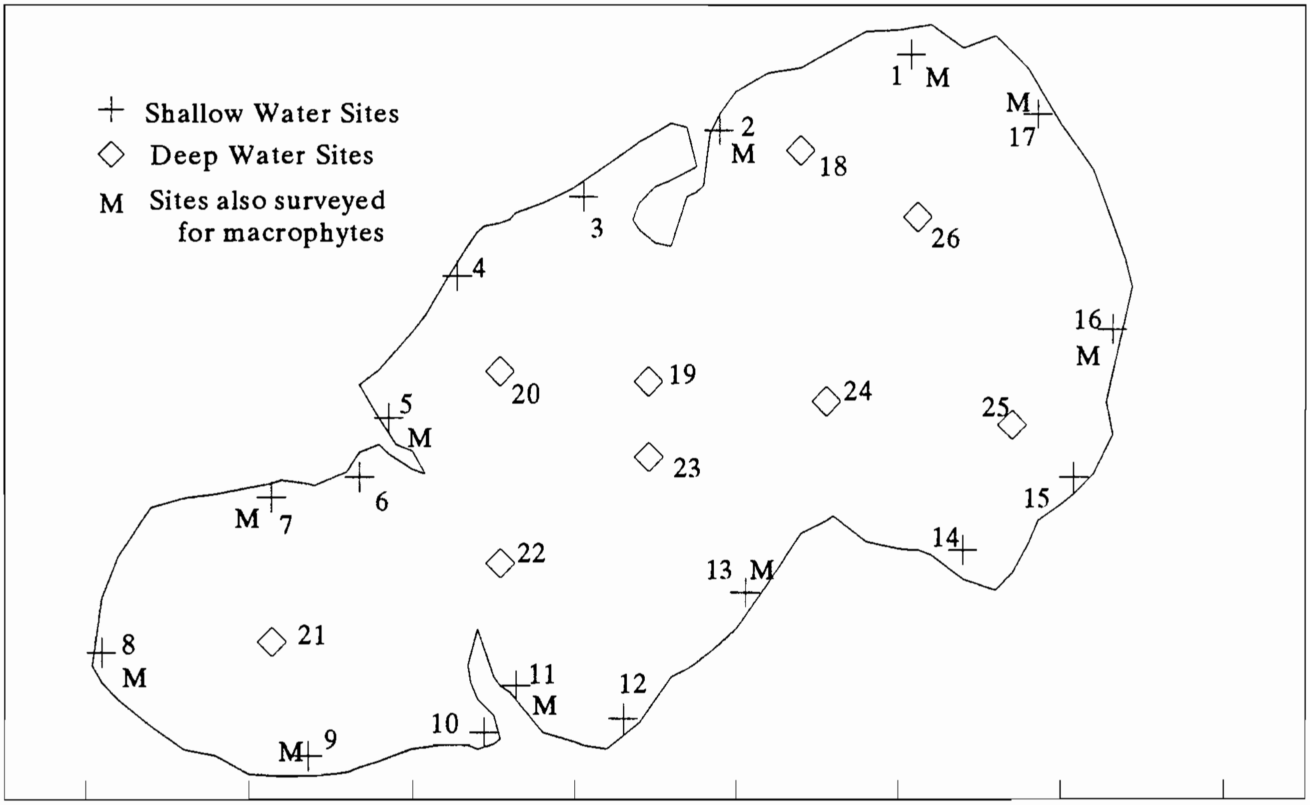
Sediment Thickness Probes

Two probes, shown in Figure 5-2, were used to measure the thickness of soft sediment. One probe, a light weight, 3/4" X 10' PVC pipe with a paint can lid attached at the bottom, measured the depth of the sediment's top surface in the water. The probe was graduated with one-inch markings and could be extended in length with couplings. When allowed to settle in the water, the probe would come to rest on the sediment surface, penetrating it by less than one inch.

The other probe, made of 1/2" galvanized pipe, was used for measuring the depth of the interface between the bottom of the soft sediment and the hard bottom. This probe's length was 10 feet but could be extended to 15 feet when needed. The probe was also graduated with one-inch markings. When measuring, full body weight was applied to the probe, driving it through soft sediment until it abruptly stopped at a harder substrate. Typical of this type of probing, "false bottoms" (increased resistance, followed by a "breakthrough") were periodically found on the lake.

Fig. 5-1

LOCATION OF SEDIMENT SAMPLE SITES



<u>Sediment Sampling Apparatus</u>

Core samples of sediment were taken in order to characterize properties as a function of depth. The homemade sampling apparatus is shown in Figure 5-2 and incorporates ideas provided by Dave Marshall, Water Resource Manager, WDNR.[1] Two main pieces of the apparatus were a sampler and an extruder.

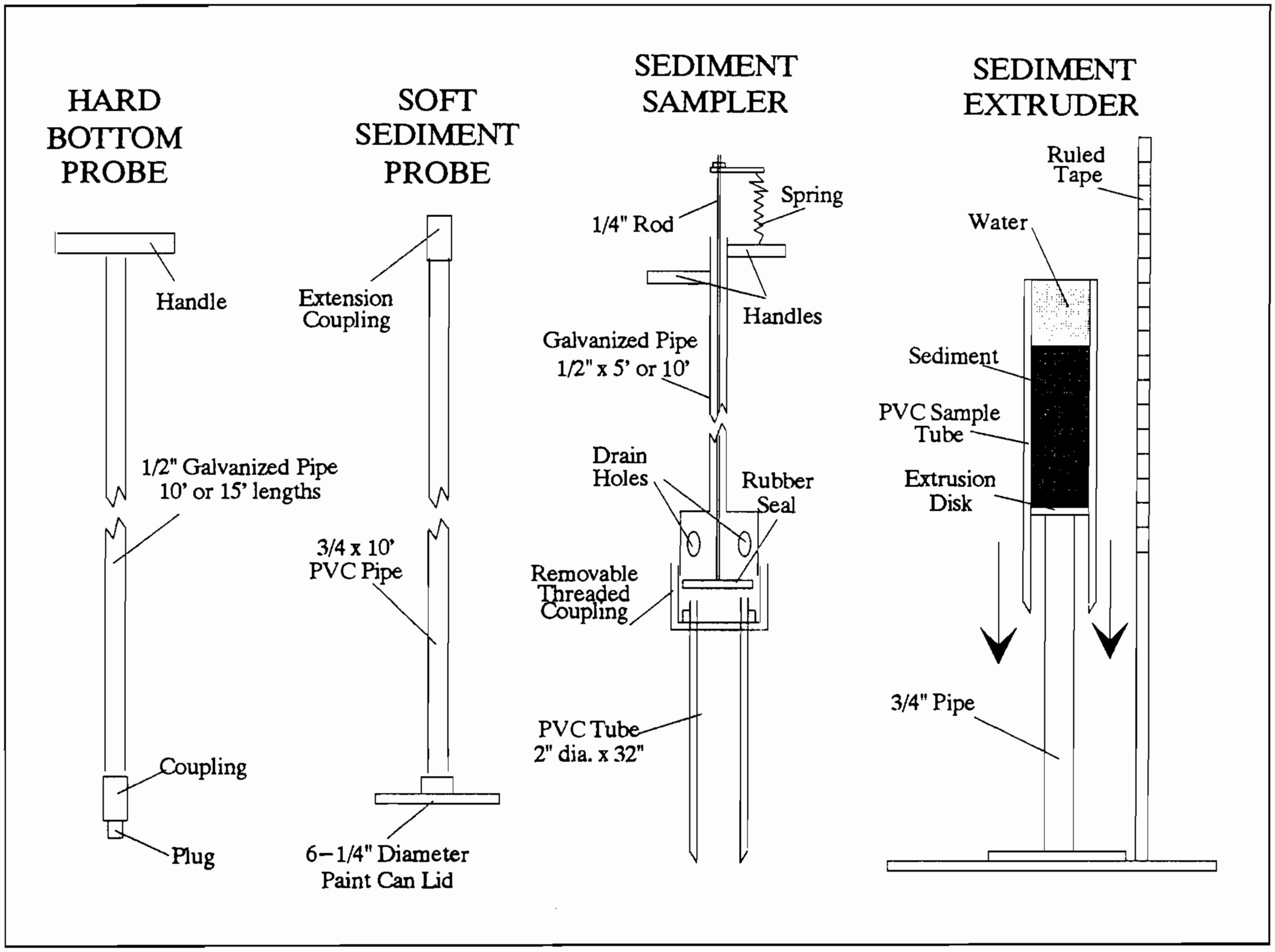
Soft sediment core samples were collected in a 2" diameter X 32" long PVC tube. The PVC tube was attached to a length of 1/2" galvanized pipe used for driving the sampler into the sediment. The pipe was graduated with 1-inch markings in order to measure the depth of sediment penetration. The connecting piece between the PVC tube and galvanized pipe was constructed to allow water to flow out of the sampler as it filled with sediment. The connecting piece was also fitted with a movable rubber seal, operated from the top, that allowed sealing the sediment sample in the PVC tube once it was collected, thus preventing water or air from displacing sediment during handling. After the sampler was taken out of the water, a rubber stopper was inserted into the bottom of the PVC tube, the tube uncoupled from the pipe, and then transferred to the extruder.

The extruder shown in Figure 5-2 was a stationary, 3/4" galvanized pipe, fitted with a 2" diameter metal disk at its top. The latter was sized to allow the PVC tube to slide over it, thus extruding the sediment core sample out the top of the tube. To keep track of the lengths of sediment being extruded, a stationary

[1] *Marshall, D., <u>Nutrient Levels in Littoral Zone Sediments from Lake Ripley and Fish Lake</u>, WDNR Report, Southern District Water Resource Management, May, 1993.*

Fig. 5-2

SEDIMENT PROBING AND SAMPLING EQUIPMENT



measuring tape was placed next to the pipe and the height of the tube top recorded for each segment collected.

General Procedures - All sampling and probing work was carried out from the surface of an 8' X 10' swimming raft. The center boards of the raft had been removed and provided a hole through which to sample. The raft was outfitted with a rack for holding the sampler, probes, tools, and a pulley system to assist in extracting probes from deep muck.

The raft was towed by a power boat to each sampling site and "anchored" there with two 15' X 1/2" galvanized pipe rods that were attached to the ends of the raft. This anchoring worked well in shallow waters but was less stable in water depths greater than six feet. The actual sample locations in shallow waters were determined by estimating the distance from shore (always less than 70 feet) from well known, mapped, homeowner lots. In deeper waters, four compass bearings of mapped landmarks were used. Uncertainties of a few hundred feet resulted with this latter method and a GPS (global positioning system) instrument is recommended for future use.

Sediment samples were extruded on the raft into segments with each segment stored in either an 18-oz polyethylene bag or in a glass jar and immediately placed on ice. The first segment was always four inches in length and all subsequent segments were five inches in length. The top of the first segment was usually very fluid and was initially removed with a turkey baster, and then spooned out of the PVC sample tube as it increased in consistency. Deeper sediment segments generally became increasingly firm, and would maintain their integrity when extruded, allowing the segments to be sliced off with a putty knife.

Back on shore, sample densities were obtained by weighing known volumes of well mixed sediment segments on a triple beam balance. These measurements have an estimated uncertainty of +/- 5%. In order to reduce the cost of laboratory analyses, composite samples were formed with some segments having similar characteristics. Composites were formed using equal volumes of individual segments. All laboratory samples were placed on ice and driven to the State Laboratory of Hygiene in Madison, arriving there within nine hours from being sampled on the lake.

The analyses chosen for the sediments followed protocols used by other researchers investigating sediment properties.[2] The laboratory analyses included: wt% moisture, wt% organic content (Wt% Volatile Solids), Total Phosphorus (Total-P), and Ammonia Nitrogen (NH_3 -N).

In order to deliver the samples to the lab on the same day as they were collected, only enough time was available to sample eight or nine sediments per day. Consequently, the entire lake sediment survey required three separate sampling days, which were May 12, May 19, and June 1. Three of the 26 sites were sampled again on September 21 in order to determine the repeatability of the entire sampling and analysis procedure. These samples were also used to analyze the sediments interstitial liquid; i.e., the liquid phase lying between the fine solid particles of the sediment.

RESULTS

Sediment Types

Table 5-1 lists descriptions of sediment segments as they were collected during extrusion. These descriptions are not intended to judge the sediments as being either good or bad, but to only characterize what was found. The descriptions shown that the lake's sediments are not very uniform and exhibit a wide range of characteristics. While most segments were black muck, other textures included sand, gravel, peat, and clay (marl), while colors included grays, greens, and browns. Some gravel sediments near shore appeared to be very uniform in size and shape and were probably introduced, at some time, by homeowners.

Sediment Thickness

Probing and sampling measurements are presented in Table 5-2 which separates data according to shallow or deep water sites. For three deep water sites and one shallow water site, the hard bottom substrate was deeper than the probe length and the actual soft sediment thicknesses at these sites were greater than recorded. The greatest thickness measured was over 10 feet and occurred in a shallow location. The least thick layers occurred in both deep and shallow waters and was about 1.7 feet. The average thickness of soft sediments over the 26 sites was 3.6 feet with no significant difference between shallow and deep site. The variation of soft sediment thickness over the lake is graphically shown in Figure 5-3. No apparent pattern is evident from this mapping.

Sample Core Lengths

During the extrusion process, the sediment/water interface was always clear and well-defined. As the sediment core was pushed up through the tube, clear water spilled out of the tube until the sediment surface was reached. There was no indication that the sediment/water interface had been disturbed during the sampling procedure.

Sediment core lengths, however, were generally much less than the length expected based on the depth that the sampler was driven. The depth to which the sampler could be driven by hand varied depending on the sediment's resistance. By measuring the actual depth of penetration, an expected core length was calculated and compared to the actual length extruded. These values are shown in Table 5-2. Core length reductions ranged as high as 77% and

[2] *Barko, J.W., Personal Communications, Feb. 1994.*
Marshall, D., Personal Communications, Jan./Feb. 1994

Table 5-1

SEDIMENT SAMPLE DESCRIPTIONS

SAMPLE SITE #	SAMPLE SEGMENT DEPTH (Inches Below Sediment Surface)				
	0 to 4	4 to 9	9 to 14	14 to 19	19 to 24
1	Fluid; very silty to soft silt	Peaty to paste (black)	More peaty	Very peaty	–
2	Very fluid; watery	Sandy, fine gravel with some firm black pasty muck	Very pasty muck	Very pasty to slightly peaty	–
3	Very fluid silty muck to sand & gravel	Very firm - stiff sandy muck	Stiff and clay-like	–	–
4	Sand & muck with roots; then drier black sand; very sandy	Very sandy muck; gray	Very sandy muck - gray	Very sandy muck - gray; somewhat drier	Less sand; stiff black clay
5	Very liquid - weeds - sandy	Black sand	Pasty black sand	Pasty black sand	–
6	Very watery	Watery paste to firm clay on bottom	–	–	–
7	Very fluid; weedy; brown-black	Stiffer; like dough	Stiffer; like dough, a little drier	–	–
8	Very fluid; sandy muck; then gravelly stones	Pasty black muck	Pasty; a little peaty	–	–
9	Weedy on top turning to sand (black-brown)	Firm turning to peat	Peaty	–	–
10	Very soft black muck to pasty	Very sticky; putty-like	Putty-like to brown peaty at bottom	–	–
11	Watery to firm black sandy gravel	Black; sandy	Firm sand; no peat	–	–
12	Very soft muck to slightly firm	Firm black sand	Firm black sand	–	–
13	Watery; very sandy; firm black sand	Very dense black sand	More dense black sand	–	–
14	Pasty fluid	Paste to firm	Firm	Firm; non-peaty	–
15	Very fluid to wet paste	Black muck with much fiber	Stiff black paste	Stiff black paste; not peaty	–
16	Niad weeds on top; fluid gravelly muck; black gravel	Black pea gravel to brown peat	All peat	–	–
17	Fluid muck to paste	Pasty muck	Firm muck	Firm muck	–
18	Very fluid; gray-black	Pasty; pudding-like	Much firmer; stiff dough	Slightly peaty	–
19	Very fluid; gray-green to gravelly; stiff, black, almost dry	Definite gray-green clay; very dry	–	–	–
20	Very fluid; gray-green	Gray-green; a little dark black; soft	Doughy mix of black & gray	Somewhat peaty; black, gray & brown	–
21	Fluid, soft, gray-green	Very fluid to very hard gray clay (1/2")	–	–	–
22	Very liquid; gray-green	More sticky; soft	Little stiffer; peaty	Sticky dough with peat	–
23	Gray-green; very fluid; some yellow	Bottom peaty; long fibers	Peat on bottom along with gray clay last 1/2"	–	–
24	Very fluid; gray-green, somewhat yellow	More peaty; sticky; black	Black-gray clay; stiff	–	–
25	Pasty; hetrogeneous water/paste	Firm paste; beige dense clay (marl)	–	–	–
26	Fluid gray muck; many fibers	Pasty black muck	Pasty black muck; somewhat firm	–	–

Table 5-2

SEDIMENT PROBING AND SAMPLING RESULTS

	Site #	Sample Date	Probing: Water Depth (feet)	Probing: Hard Bottom Depth (feet)	Probing: Soft Sediment Thickness (feet)	Sampling: Expected Core Length (inch)	Sampling: Actual Core Length (inch)	Sampling: Core Length Reduction %	Sampling: Wet Sample Density[c] (g/mL)
	1	May-12	3.6	6.4	2.8	27	17.6	35	1.39
	2	May-12	3.4	8.4	5.0	32	18.4	43	1.30
	3	May-12	4.2	7.0	2.8	19	13.9	27	1.79
	4	May-12	2.6	5.7	3.1	32	22.6	29	1.85
	4	Sep-21	4.2	6.7	2.5	15	15.0	0	1.93
	5	May-19	3.8	6.6	2.8	28	18.6	34	1.49
S	6	May-19	3.1	4.8	1.7	8	9.5	-19	1.08
H	7	May-19	3.8	5.4	1.7	17	12.0	29	1.20
A	8	May-19	4.5	8.8	4.3	32	11.7	63	1.85
L	9	May-19	3.9	7.6	3.7	19	12.6	34	1.65
L	10	May-19	4.6	9.1	4.5	32	11.1	65	1.09
O	11	May-19	3.5	6.9	3.4	16	12.4	22	1.68
W	12	May-19	3.9	6.3	2.3	21	13.3	37	1.12
	13	May-19	3.3	6.0	2.7	18	13.6	24	1.43
	14	May-12	4.2	7.4	3.3	24	17.4	28	1.13
	15	May-12	4.1	9.0	4.9	32	18.1	43	1.10
	15	Sep-21	3.8	8.2	4.3	37	18.5	50	1.05
	16	May-12	3.3	7.3	4.0	28	13.3	53	1.76
	17	May-12	4.1	14.2+	10.1+	32	16.4	49	1.15
	18	Jun-01	7.8	14.1+	6.3+	29	19.1	34	1.05
	19	Jun-01	5.8	7.5	1.7	11	9.1	17	1.34
	19	Sep-21	8.0	a	a	b	b	b	1.13
D	20	Jun-01	8.5	14.1+	5.6+	44	19.1	57	1.03
E	21	Jun-01	8.5	10.3	1.8	14	8.6	39	1.10
E	22	Jun-01	10.4	14.1+	3.7+	32	17.1	47	1.07
P	23	Jun-01	9.3	13.6	4.3	30	12.6	58	1.07
	24	Jun-01	8.2	9.9	1.8	15	12.1	19	1.09
	25	Jun-01	6.0	13.6	7.6	33	7.5	77	1.17
	26	Jun-01	6.7	8.6	1.9	23	13.1	43	1.11
Statistics									
Shallow Depths; < 5 ft.									
		Avg. =	3.8	7.5	3.7	25	15.1	34	1.42
		S.D. =	0.5	2.0	1.8	8	3.3	19	0.31
Deep Depths; > 5 ft									
		Avg. =	7.9	10.6	3.5	23	11.8	39	1.12
		S.D. =	1.4	4.3	2.3	12	5.6	21	0.08
All Depths									
		Avg. =	5.2	8.5	3.6	24	13.9	36	1.32
		S.D. =	2.2	3.3	2.0	10	4.5	20	0.29

Notes

Double outlined data are replicates for the indicated sample site.

\+ = Hard bottom deeper than probe length; soft sediment thickness greater than indicated.

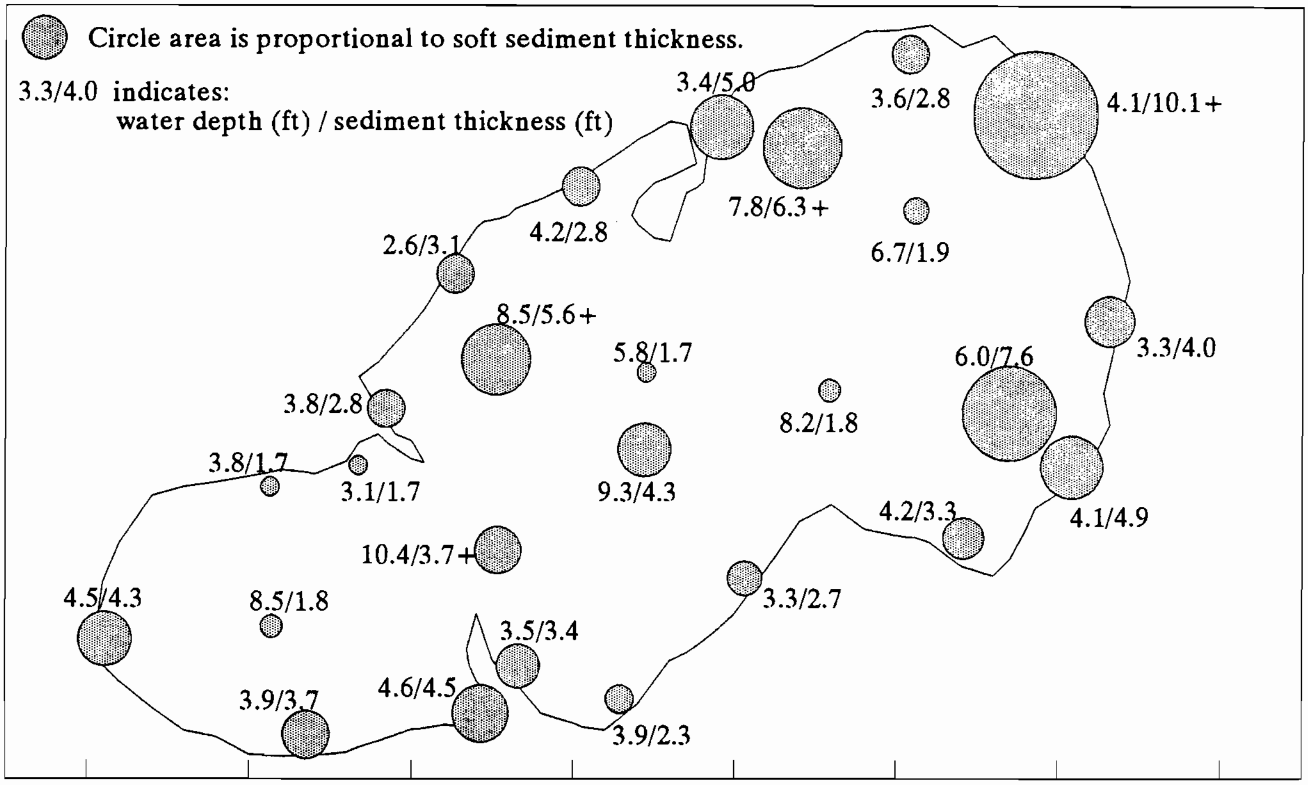
a = Hard bottom depth not measured

b = Core lengths not measured

c = Top 4-inch segment of sediment

Fig. 5-3

SOFT SEDIMENT THICKNESS



averaged 36% for the 28 measurements. This property appears independent of the water depth of the sampling sites. The percent reduction in core length correlated to the depth the sampling probe was driven as shown in Figure 5-4. The deeper the probe was driven, the greater the percent reduction in core sample. While this phenomenon is expected to be related to the physical properties of the sediment, no correlation could be found between core length reduction and wet sediment density, dry sediment density, wt% moisture, or wt% organic content. It is not clear what impact, if any, these core length reductions had on the measured physical properties such as density. Calculating properties on a dry sediment bases, as will most often be done in the following analyses, is likely to circumvent any effects that do exist.

Sediment Sample Density

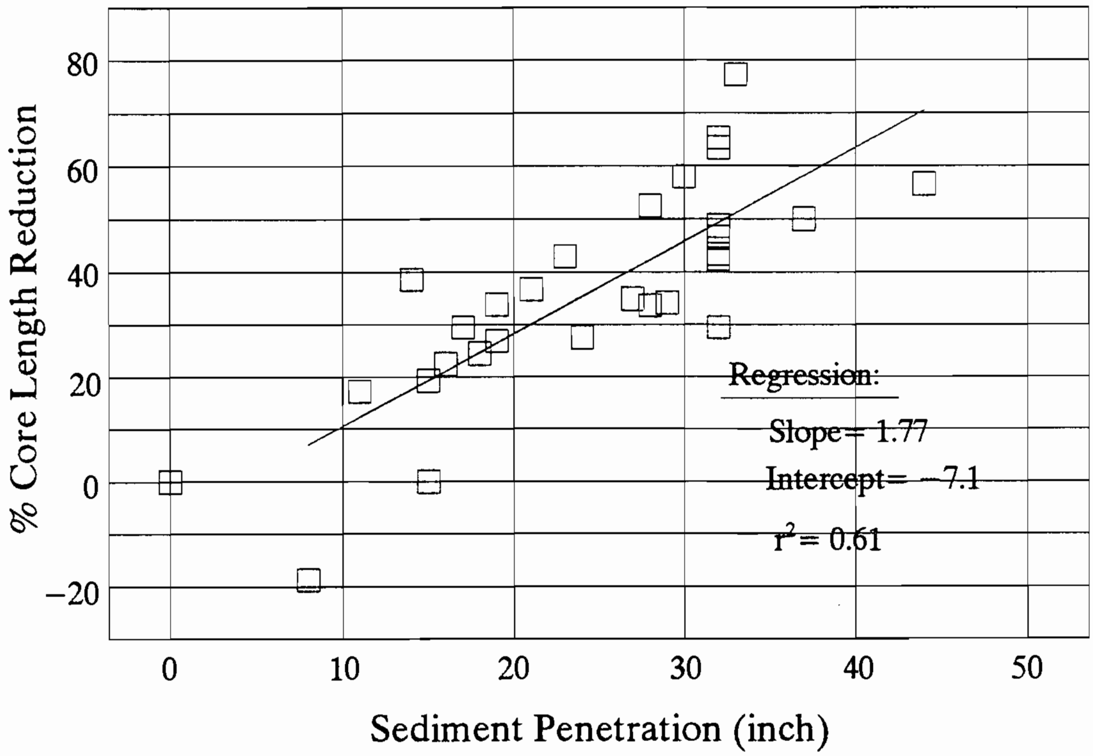
The density of the top four inches of wet sediment showed wide variations, ranging from a very watery 1.03 g/mL to a more solid 1.93 g/mL. Deep water sediments tended to be less dense, averaging 1.12 g/mL, than shallow water sediments which averaged 1.42 g/mL.

Sediment Composition

Physical and chemical properties of the top four inches of individual samples and composite samples are shown in Table 5-3. The wt % moisture, and concentrations of organic matter, NH_3-N and Total-P are as reported by the State Laboratory of Hygiene. The density of dry sediment was calculated using the

Fig. 5-4

CORE LENGTH REDUCTION VS PENETRATION



measured values of wet sample density and wt% moisture.

The sediment sample taken at site #25 showed many unusually high values which were well outside the ranges of the other data. This sample also showed the highest core length reduction of 77%. There is no known reason why this sample should have such unusual properties and it is. therefore, included in the database. However, in Table 5-3, statistical averages were calculated both with and without this sample. As can be seen, it does not have a very large impact on the averages.

The organic content of the dry sediments showed good correlations to most other properties. For sediments with increasing organic content, the moisture content also increased as shown in Figure 5-5; the Total-P content increased, Figure 5-6; and the dry sediment density decreased, Figure 5-7. NH_3-N content also showed correlation with organic content, r^2=0.56, but not as well as the other variables, Figure 5-8. Figure 5-9 shows the distribution of sediment organic matter over the entire lake and the fact that it tends to be most concentrated in deeper waters and on the eastern shore. Such concentration also occurs for the correlated variables of Total-P and NH_3-N nutrients as well as moisture content.

Table 5-3

PROPERTIES OF TOP FOUR INCHES OF SEDIMENT

Sample Name or Site #	Sample Date	Water Depth (feet)	Sediment Thickness (feet)	Sample Density (g/mL)	Moisture (wt %)	Dry Sediment Properties: Density[a] (g/mL)	Organic (wt %)	NH_3 (mg/kg)	Tot. P (mg/kg)
1	May−12	3.6	2.8	1.39	63.3	0.51	6	12	500
C1 (2 & 3)	May−12	3.8	3.9	1.55	55.3	0.69	3	39	190
4	May−12	2.6	3.1	1.85	31.1	1.27	1	13	220
4	Sep−21	4.2	2.5	1.93	28.1	1.39	1	7	51
5	May−19	3.8	2.8	1.49	43.3	0.84	2	18	200
C3 (6 & 7)	May−19	3.4	1.7	1.14	74.2	0.29	9	26	380
C4 (8 & 9)	May−19	4.2	4.0	1.75	42.6	1.00	4	22	220
10	May−19	4.6	4.5	1.09	74.9	0.27	10	48	350
11	May−19	3.5	3.4	1.68	29.4	1.19	1	15	110
C5 (12 & 13)	May−19	3.6	2.5	1.28	49.2	0.65	3	10	120
C2 (14 & 16)*	May−12	3.8	3.6	1.13	80.5	0.22	18	22	740
15	May−12	4.1	4.9	1.10	86.8	0.15	22	37	730
15	Sep−21	3.8	4.3	1.05	84.6	0.16	27	23	690
17	May−12	4.1	10.1+	1.15	74.5	0.29	14	36	600
C6 (18 & 26)	Jun−1	7.2	4.1+	1.08	84.0	0.17	17	25	700
19	Jun−1	5.8	1.7	1.34	58.6	0.55	7	36	640
19	Sep−21	8.0	b	1.13	88.0	0.14	17	2	630
20	Jun−1	8.5	5.6+	1.03	86.9	0.13	17	69	690
21	Jun−1	8.5	1.8	1.10	81.3	0.21	11	26	560
22	Jun−1	10.4	3.7+	1.07	88.4	0.12	16	89	830
C7 (23 & 24)	Jun−1	8.7	3.5	1.08	88.2	0.13	18	71	740
25	Jun−1	6.0	7.6	1.17	74.4	0.30	47	180	1500
Statistics For all sites									
Min =		2.6	1.7	1.03	28.1	0.12	1	2	51
Max =		10.4	10.1	1.93	88.4	1.39	47	180	1500
Avg =		5.3	3.9	1.30	66.7	0.49	12	38	520
S.D.=		2.2	1.9	0.28	20.5	0.40	11	38	320
N =		22	21	22	22	22	22	22	22
All sites, excluding #25									
Min =		2.6	1.7	1.03	28.1	0.12	1	2	51
Max =		10.4	10.1	1.93	88.4	1.39	27	89	830
Avg =		5.2	3.7	1.31	66.3	0.49	11	31	470
S.D.=		2.2	1.8	0.28	20.9	0.41	8	22	250
N =		21	20	21	21	21	21	21	21

Notes

– Top 4–inches (10 cm) of each core sample was thoroughly mixed before analyzing.
– Sample sets with double outlines are replicates.
– Averages of depths, thicknesses, and densities are shown for composite samples.

* – Densities of C–2 composite are based on Site #14 densities only; Site #16 sample contained large rocks.
\+ – Sediment thickness greater than indicated.
a – Density = g of dry sediment/mL of wet sediment volume.
b – Sediment thickness not measured.

Fig. 5-5

MOISTURE VS ORGANIC CONTENT

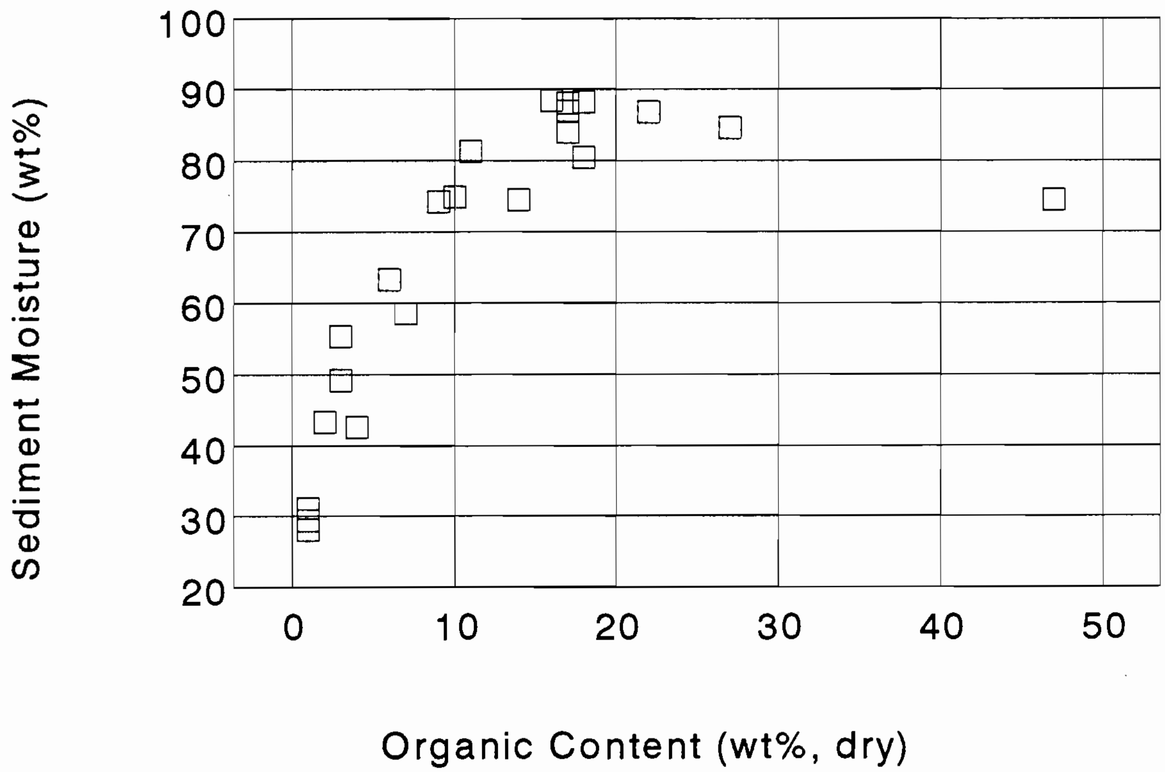


Fig. 5-6

SEDIMENT PHOSPHORUS VS ORGANIC CONTENT

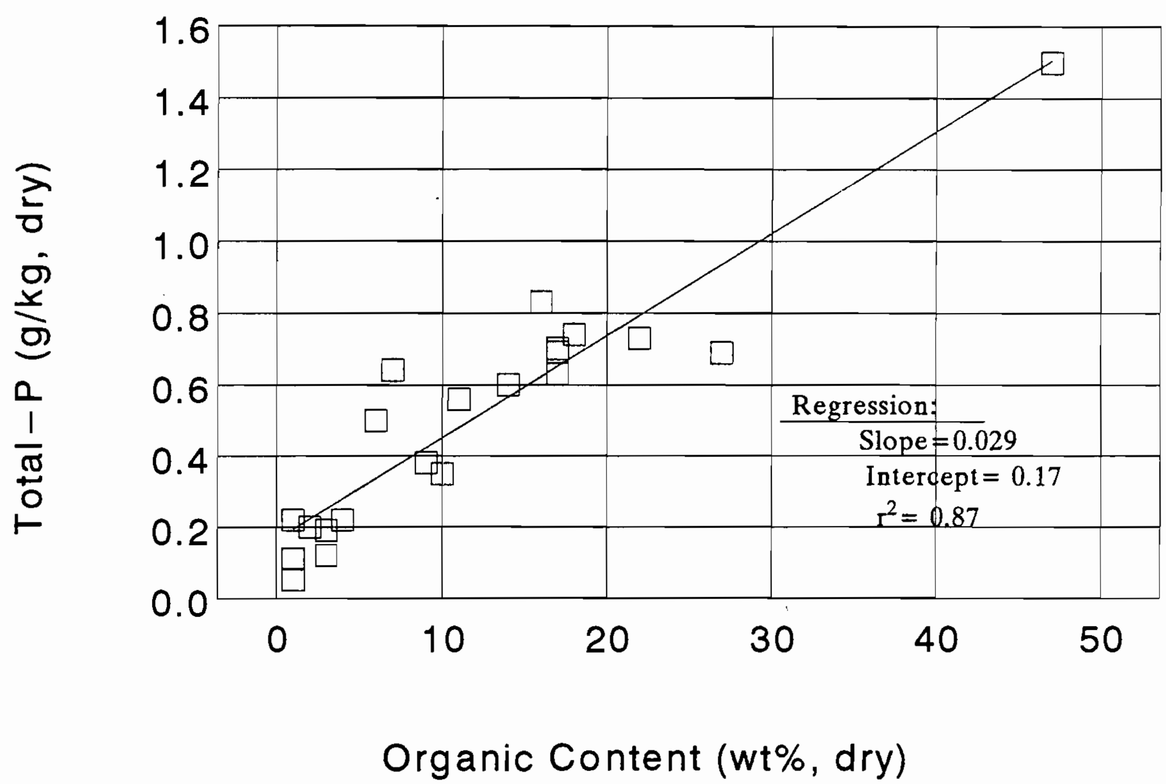


Fig. 5-7

SEDIMENT DENSITY VS ORGANIC CONTENT

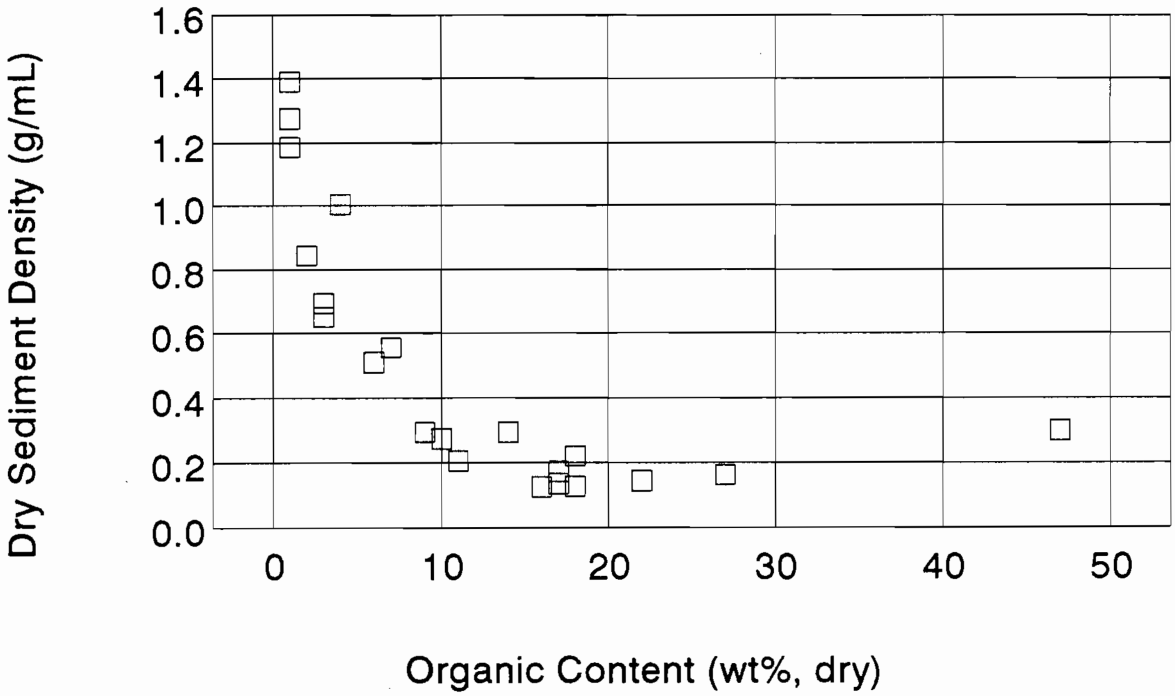


Fig. 5-8

SEDIMENT NH_3-N VS ORGANIC CONTENT

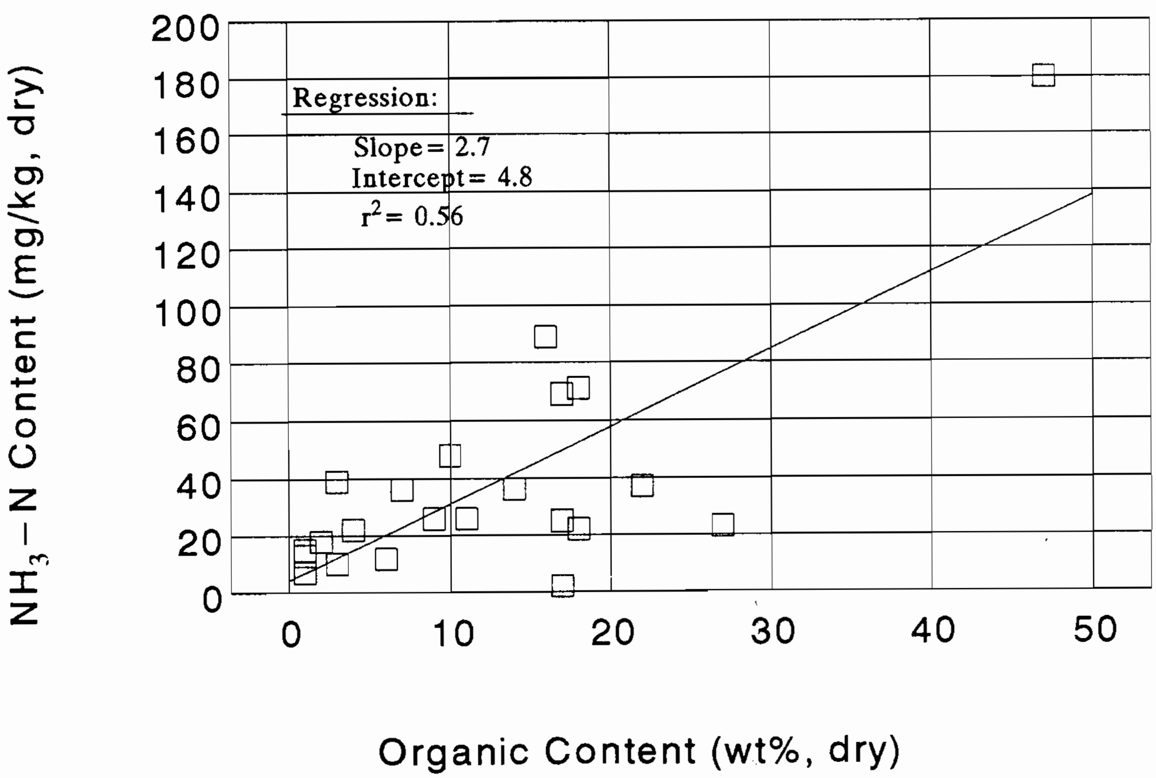
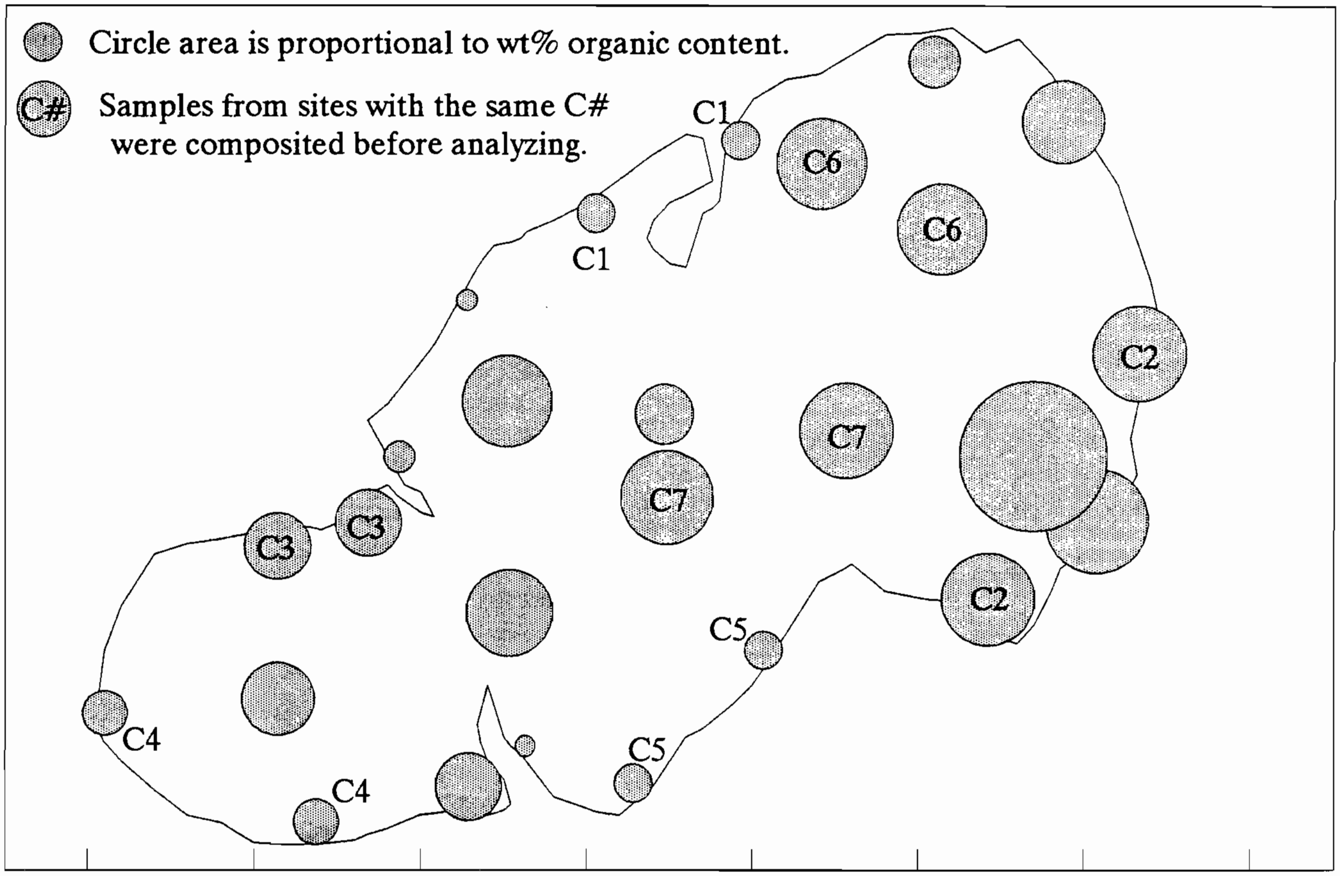


Fig. 5-9

SEDIMENT ORGANIC CONTENT



Deeper Sediment Properties

Individual sample core segments from Sites #15 and #22 were analyzed for their properties as shown in Table 5-4. Both series show that as sediment depth increases, it's moisture content decreases, and it's organic content increases. This inverse relationship between moisture and organic content is in contrast to what was seen for surface sediments and may reflect the influence of upper sediment weight compacting lower sediments and pressing out moisture content.

Changes in nutrient content with depth was less consistent. For Site #15, Total-P increased with depth, corresponding to the increase in organic content as would be expected. However, for Site # 22 segments, Total-P content decreased with depth. The NH_3-N content for both series showed no clear pattern, however, when TKN was measured for the Site #15 series, it followed the same trend as Total-P, increasing with increasing organic content. The TKN values show the high level of nitrogen nutrients in the sediment, which represent 4-6 wt% of the organic solids. Essentially none of the sediments nitrogen content was present in the more soluble forms of NO_2-NO_3.

Table 5-4

DEEP SEDIMENT PROPERTIES

Site & Sample #	Depth Range (inches)	Sample Density (g/mL)	Moisture (wt %)	Dry Sediment Properties: Density[a] (g/mL)	Organic (wt %)	NH3-N (mg/kg)	Total-P (mg/kg)	NO2-NO3 (mg/kg)	TKN (mg/kg)
15-1	0-4	1.10	86.8	0.15	22	37	730	3	12000
15-2	4-9	1.22	79.5	0.25	30	59	820	0	17000
15-4	14-19	1.20	72.6	0.33	58	45	1900	1	21000
22-1	0-4	1.07	88.4	0.12	16	89	830	--	--
22-2	4-9	1.05	81.0	0.20	17	103	760	--	--
22-3	9-14	1.21	80.0	0.24	27	131	700	--	--
22-4	14-17	1.16	77.0	0.27	29	82	510	--	--

Notes

a – Density = g of dry sediment/mL of wet sediment volume.

Nutrient Content in Interstitial Water

The analyses and calculations showing how Total-P was partitioned between the solid and liquid phases of the sediments are shown in Table 5-5. The top four-inch segments of sediment samples collected in September at Sites #4, #15, and #19, were each sub-sampled and subjected to extraction with a measured quantity of lake water of known chemistry.[3] After thorough mixing, and settling for one hour, the extracted liquid was decanted and analyzed for Total-P. This liquid, although not totally cleared after one hour, should be indicative of the level of nutrients that can be added to the water column when sediment is disturbed.

Although the three sediments sampled had different characteristics, they all showed that 98 to 99% of their Total-P content was tied up in the solid phase of the sediment and only 1 to 2% was in the interstitial liquid phase. However, this small percentage still amounts to a concentration of 1-3 mg/mL of Total-P, which is 30 to 100 times more concentrated than that normally in the water column.

The TKN, NO_2-NO_3, and NH_3-N concentrations in the extracted liquids was also sought, but only TKN could be analyzed by the State Laboratory due to limited sample size. These values are reported in Table 5-5. Doing similar calculations as were done for Total-P, and using other available measures of TKN (12,000 mg/kg in #15-1 dry sediment, and 1 mg/kg TKN in lake water), indicated that, like Total-P, 1% or less of the TKN is present in interstitial water. But, also like Total-P, this concentration in the interstitial water still represents a great increase (10 to 40-fold) over that normally found in lake water.

DISCUSSION

Comparison to Other Lakes

Characteristics of Blue Spring Lake sediments are quite variable, ranging from relatively compact sand to soft muck, but tending mostly toward the latter. This may reflect the general variability of soils found in the watershed which is a glaciated interlobate region. A comparison of sediment properties with those obtained from 40 different sediments taken from 17 geographically widespread lakes in North

[3] *Plumb, R.H., Jr., Procedures for Handling and Chemical Analysis of Sediment and Water Samples, prepared for EPA Technical Committee on Criteria for Dredged and Fill Material, Great Lakes Laboratory, State University College at Buffalo, NY, May 1981.*

Table 5-5

DISTRIBUTION OF TOTAL-P BETWEEN THE SOLID AND LIQUID SEDIMENT PHASES

Site # of Sediment Sample		4	15	19
Determination of Interstitial Liquid Total–P	Method			
Sediment Sample Wt. (g)	Expt'l	109.4	59.4	30.0
Wt% Interstitial Liquid in Sample (wt% Moisture)	Analysis	28.1	84.6	88.0
Wt of Interstitial Liquid in Sample (g)	Calc.	30.7	50.3	26.4
Wt of Extracting Lake Water (g)	Expt'l	150	150	90
Wt of Extracted Liquid (g)	Calc.	181	200	116
TKN Concentration in Extracted Liquid (mg/L)	Analysis	7.5	6.4	2.8
Total–P Concentration in Extracting Lake Water (mg/L)	Analysis	0.03	0.03	0.03
Total–P Concentration in Extracted Liquid (mg/L)	Analysis	0.51	0.34	0.25
Total–P Concentration in Interstitial Liquid (mg/L)	Calc.	2.9	1.3	1.0
Determination of Solid Phase Total–P	Method			
Total–P Concentration in Dry Sediment Solids (mg/kg)	Analysis	51	690	630
Wt of Liquid in 1 kg of Wet Sediment Sample (kg)	Calc.	0.280	0.846	0.880
Wt of Total–P in 1 kg of Wet Sediment (mg)	Calc.	37	106	76
Wt of Total–P in Liquid Phase of 1 kg of Wet Sediment (mg)	Calc.	0.8	1.1	0.9
Wt of Total–P in Solid Phase of 1 kg of Wet Sediment (mg)	Calc.	36	105	75
Wt % Tot–P in Liquid Phase	Calc.	2	1	1
Wt % Tot–P in Solid Phase	Calc.	98	99	99

America (including Florida, New York, Wisconsin, and Washington) is shown in Table 5-6.[4] The table also includes comparisons to sediment data that was available on nearby southeast Wisconsin Lakes.

The comparisons show Blue Spring Lake sediments cover a wide range of property values but are not unlike other lake sediments. It's organic and Total-P contents are on the low side of the national averages, but, compared to other southeast Wisconsin lakes, Total-P appears typical, while NH_3-N content is slightly low. The single measurement of TKN on Blue Spring Lake sediment appears quite high relative to other southeast Wisconsin Lakes.

Sediment Volume

The amounts and distribution of soft sediments on Blue Spring Lake appear to be different from that found on other lakes. For example, soft sediments are often found to be thicker at the deeper parts of a lake, but this is not the case for Blue Spring Lake. Also, the average sediment thickness of 3.6 feet on Blue Spring Lake is not as large as on some other lakes in the region. Potters Lake has been measured at 4.3 feet[5] and George Lake at about 13 feet.[6] In other lakes, soft sediments have generally had thousands of years to accumulate. Blue Spring Lake has only existed for the last 65 years, although the site's earlier condition as a marsh must have contributed to sediment formation. The lake is also without a significant inlet which can typically carry large amounts of watershed sediment into a lake. While the high mineral content in the inflowing spring water can result in solid CaCO3 precipitating and adding to the sediment, this only calculates to

4 *Barko, J.W., Smart, R.M., "Sediment-Related Mechanisms of Growth Limitation in Submersed Macrophytes", Ecology, Vol. 67, p.1328-1340, 1986.*

5 *WDNR, Potters Lake, Walworth County, Feasibility Study Results: Management Alternatives, Office of Inland Lake Renewal, 1988*

6 *.George Lake, Watershed Evaluation Report, A Lake Management Planning Grant Report for the George Lake Rehabilitation District, Aron & Associates, June 1993.*

Table 5-6

SEDIMENT PROPERTIES OF BLUE SPRING LAKE AND OTHER LAKES

Property	Statistic	Blue Spring Lake	17 N. Amer. Lakes[a]	S.E. Wisconsin Lakes[b]
Moisture, (wt % of wet sediment)	Min	28	27	38
	Max	88	93	97
	Avg	67	67	84
Dry Sediment Density, (g/mL)	Min	0.12	0.07	--
	Max	1.39	1.29	--
	Avg	0.49	0.46	--
Organic Content, (wt % of dry sediment)	Min	1	2	--
	Max	47	63	--
	Avg	12	24	20
Nutrient Content, (mg/g dry)				
Total-P	Min	0.05	0.2	0.01
	Max	1.50	4.9	1.60
	Avg	0.52	1.8	0.65
NH_3-N	Min	0.002	--	0.002
	Max	0.18	--	0.31
	Avg	0.04	--	0.06
TKN	Min	--	0.3	3.1
	Max	--	24.1	7.2
	Avg	12.0	7.8	4.6
Interstitial Phosphorus, (mg/L)				
Total-P	Min	1.0	--	--
	Max	2.9	--	--
	Avg	1.7	--	--
PO_4-P	Min	--	0.04	--
	Max	--	9.36	--
	Avg	--	1.15	--

Notes

a – Averages of 40 samples from 17 N. American lakes including Florida, New York, Wisconsin, and Washington states (Barko, J. W. and Smart, R. M., *Ecology*, Vol 67, 1328, 1986).

b – Averages based on 46 samples from 4 lakes for wt% moisture; 2 samples from 1 lake for wt% organic; 61 samples from 5 lakes for Total–P; 64 samples from 7 lakes for NH3–N; and 9 samples from 3 lakes for TKN (Marshall, D., "Nutrient Levels in Littoral Zone Sediments from Lake Ripley and Fish Lake," WDNR Report, Southern District Water Resource Management, May, 1993; Southeast Wisconsin Regional Planning Commission, "A Management Plan for Wind Lake, Racine County, Wisconsin," Community Assistance Report No. 198, 1991; WDNR, "Potters Lake, Walworth County, Feasibility Study Results; Management Alternatives," Office of Inland Lake Renewal, 1988; Les, D., and Guntenspergen, G., "Laboratory Growth Experiments for Selected Aquatic Plants," Center for Great Lake Studies, UW–Milwaukee, June 20, 1990.)

less than 0.1 inch/yr (based on a loss of 85 mg/L of hardness from the spring waters and a dry sediment density of 0.20 g/mL).[7] The point is, given the unique history and character of Blue Spring Lake, it may not be too surprising that its soft sediment volumes and distribution differ from other lakes.

Nonetheless, the volume of soft sediment in Blue Spring Lake still represents a considerable amount of material. The 3.6-foot average amounts to more than 400 acre-ft, or 700,000 cubic yards of soft sediment. These numbers can be useful for evaluating the frequent proposals for ridding the lake of its nutrient rich sediment by dredging. Hydraulic dredging cost can vary and a range of $4 to $10 per cubic yard is not unusual. For Blue Spring Lake, this would result in a $3,000,000 to $7,000,000 charge for total dredging. Partial dredging may reduce this cost, but considering the continuing presence of Total-P deep within the soft sediments, this approach may not succeed in reducing nuisance aquatic plant growth.

Sediment Nutrients

The organic content of the sediment appears to be the key to its nutrient content. As the organic content increases, so does NH_3-N and especially Total-P. While phosphorus can exist in mineral forms, the strong correlation shown in Figure 5-6 suggests most of the phosphorus is in an organic form. The intercept of this plot suggests an inorganic phosphorus content of only 170 mg/kg of dry sediment. Assigning the rest of the phosphorus to the organic solids results in a 0.2 to 0.4 wt% phosphorus concentration in the dry organic solids. This is a typical phosphorus concentration for aquatic biomass.[8]

Regardless of the form that the nutrients are in, which may be important to the immediate availability of the nutrients to growing vegetation, it is clear from this survey that Blue Spring Lake's soft sediments store huge quantities of both nitrogen and phosphorus compounds. Ultimately, these serve as a pool of nutrients for aquatic vegetation. Using averages of measured values, the total amount of phosphorus in the 700,000 cubic yards of sediments is over 300,000 lbs. Even if only the top four inches of sediment are considered, which is the primary layer for macrophyte support, this still amounts to over 28,000 lbs of phosphorus. Compared to the estimated annual loading of phosphorus to the lake from the watershed of less than 300 lbs (see Section IV), it seems obvious that methods for managing nutrients must concentrate on those already in the sediment and which are in intimate contact with the water and with the macrophyte roots.

Phosphorus removal in Blue Spring Lake's harvesting program has been estimated at about 1000 lbs/yr. (Based on 400 harvester loads/yr, 4 tons/load, 10 wt% dry biomass/load, and 0.3 wt% phosphorus in dry biomass.) At this rate, assuming no additional contributions of phosphorus to the sediment, the average phosphorus content in the top four-inch layer could be reduced by 75%, from 500 mg/kg to 125 mg/kg, in about 21 years. (A concentration of 125 mg/kg is being taken here as a desirable target that would still support macrophyte growth, but not at nuisance levels.) If the sediments deeper than four inches are actually contributing to macrophyte support because of either phosphorus diffusion or deeper root penetration, then the time to reach this targeted level through harvesting would be proportionately longer; e.g., 63 years for one foot of sediment. These calculations show that harvesting, while directionally beneficial in reducing sediment nutrients, is indeed a long term solution to excessive plant growth.

Sediment Effects on Algae

Sediment phosphorus can also contribute to excessive algal growth if the sediment is disturbed. Interstitial water, containing 30-100 times the concentration of phosphorus in the water column, mixes in the lake water and raises its nutrient levels. Algae can also use sediment nutrients for their growth even when they are in insoluble forms as solids or adsorbed on

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[7] *Brown, B.E., Cherkauer, D.S., Phosphate and Carbonate Mass Balances and Their Relationships to Groundwater Inputs at Beaver Lake, Waukesha County, Wisconsin, Wisconsin Water Resource Center Technical Report 91-01, 1991.*

[8] *Carpenter, S.R., "Enrichment of Lake Wingra, Wisconsin, by Submersed Macrophyte Decay", Ecology Vol. 61, p.1145-1155, 1980.*

solid particles.[9] Dispersing these particles into the water column increases the contact between algae and its nutrient source. Sediment disturbances include: power boating in shallow water (some would define all of Blue Spring Lake as shallow water); raking or dragging near shore areas to enhance swimming; harvesting in shallow water (big paddle wheels cause great turbulence); allowing the harvester blade to penetrate the sediment; and bottom-feeding ducks, geese, and fish. Prior to 1979, an abundance of bottom-feeding carp in Blue Spring Lake may have been the primary cause of the lake water's high Total-P content of about 60 mg/L compared to today's levels of less than 25 mg/L.

It is surprising that even though the lake experienced strong algal blooms during the summer of 1994, no significant increase in Total-P was found in summer water samples. It is also surprising that even though it is well known that sediment disturbances add nutrients to the water column, no significant correlation was found between boating intensity and water quality. What is clear is that more needs to be learned about Blue Spring Lake's algae.

Sediment Effects on Macrophyte Productivity

The relationship between sediment nutrients and macrophyte growth has been looked at many times, and often specifically for Eurasian water milfoil growth.[10] Generally, these studies indicate plants receive their nutrients primarily from the sediment and that their greatest growth occurs in fine sediments, of low organic content, and intermediate densities of 0.8 to 1.0 g/mL on a dry basis. Sediments with organic content greater than 20 wt% typically are less supportive of growth because they hold large percentages of water which slows the rate of nutrient transport to the roots. On the other extreme, coarse textured, higher density sediments, such as sand, simply have lower nutrient contents.

Generally, lower vegetation productivity would be expected from sediments of low nutrient content. Qualitatively, this appears to be the case for both Blue Spring Lake as well as some other lakes in southeast Wisconsin as evidenced by the data presented in Table 5-7. The table shows comparisons of high and low levels of productivity with sediment nutrient contents. The qualitative assessment of macrophyte productivity at specific sites in Blue Spring Lake was made by residents who frequently use the lake, including one of the harvester operators. Assessments on the other lakes were based on actual DNR macrophyte surveys, or on qualitative assessments by trained personnel.

The comparisons generally show lower productivity for sediments having less than 0.4 to 0.5 g/kg Total-P. The rough guidelines for polluted sediments published by the EPA and shown in the table, are also in line with these criteria. While the above values are, indeed, approximations, they do offer some feel for desirable levels of sediment nutrients; e.g., if Total-P in the average Blue Spring Lake sediment was reduced to 0.25 g/kg through many years of harvesting, we should hope to see a noticeable reduction in nuisance weeds. And at a level of 0.125 mg/kg, by Blue Spring Lake's own qualitative assessment, macrophyte growth at nuisance levels could cease to be a problem.

Importantly, reaching these goals, by harvesting or any other technique, will take place quicker if efforts are taken to minimize the unnecessary addition of phosphorus to the lake and its sediments.

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[9] *Asplund, T., Motor Boat Impacts on Water Clarity: Results of a 1994 Volunteer Monitoring Study, WDNR, Bureau of Research, Pre-Publication Draft Report, April 8, 1995; Wetzel, R.G., Limnology, Saunders College Publishing, Philadelphia, PA, P.265, 1983.*

[10] *Smith, D.S., Barko, J.W., "Ecology of Eurasian Water Milfoil," J. Aquatic Plant Management, Vol., 28, p.55-64, 1990; Barko, J.W., Smart, R.M., "Sediment-Related Mechanisms of Growth Limitation in Submersed Macrophytes," Ecology, Vol. 67, p.1328-1340, 1986; Marshall, D., Nutrient Levels in Littoral Zone Sediments from Lake Ripley and Fish Lake, WDNR Report, Southern District Water Resource Management, May 1993; SEWRPC, et al, A Management Plan for Wind Lake, Racine County, Wisconsin, Community Assistance Planning Report Number 198, 1991.*

Table 5-7

COMPARISONS OF MACROPHYTE GROWTH TO SEDIMENT NUTRIENT CONTENT

Lake	Avg. Total-P (g/kg) High Growth Area	Avg. Total-P (g/kg) Low Growth Area	Avg. NH_4-N (mg/kg) High Growth Area	Avg. NH_4-N (mg/kg) Low Growth Area	No. of Samples Analyzed	References
Blue Spring	0.52	0.12	29	12	11	This Study
Fish	1.14		128		13	1
Fish	0.56		49		9	1
Ripley		0.37		23	16	1
Rock	0.68	0.5	33	<7	6	1
Wind	0.52	0.27	97	32	?	2
EPA Pollution Guidelines	>0.65 Hi Polluted	<0.42 Lo Polluted	>200 Hi Polluted	<75 Lo Polluted	260	3

References

1 – Marshall, D., "Nutrient Levels in Littoral Zone Sediments from Lake Ripley and Fish Lake," WDNR Report, Southern District Water Resource Management, May, 1993.

2 – SEWRPC, et al, "A Management Plan for Wind Lake, Racine County, Wisconsin," Community Assistance Planning Report Number 198, 1991.

3 – Environmental Protection Agency, "Guidelines for the Pollutional Classification of Great Lakes Harbor Sediments," US–EPA Region V Report, Chicago, IL, April, 1977.

CONCLUSIONS

- The average thickness of Blue Spring Lake's soft sediment is 3.6 feet. It varied from 1.7 feet to more than 10 feet in a survey of 26 sites.

- Unlike many lakes, the soft sediments are not thickest at the greatest water depths, but, instead, vary throughout the lake.

- The total volume of soft sediment in Blue Spring Lake is about 700,000 cubic yards. Costs for removing all this sediment are estimated to range from three to seven million dollars.

- Organic content in dried sediment averages 12 wt% and varies from 1 to 47 wt%. As organic content in the dried sediment increases, its Total-P, NH_3-N, and wt% moisture also increase, and sediment density decreases.

- Organic content and nutrients tend to be higher in the sediments of deeper waters and along the eastern shore.

- Nutrients in the top four inches of Blue Spring Lake sediments have an average Total-P content of about 500 mg/kg and an average NH_3-N content of 38 mg/kg. These are not unlike those of many other southeast Wisconsin lakes.

- The total amount of phosphorus in the soft sediment is estimated at 300,000 lbs. While harvesting aquatic plants can remove much of this phosphorus, it will take decades, at the current rates, to have a noticeable effect.

- Interstitial water in the sediments contains 30-100 times more Total-P and 10-40 times more NH_3-N than lake water. Disturbing the sediments mixes this rich interstitial water into the lake water which can contribute to the growth of algae.

- Lower macrophyte productivity occurs on sediments with low nutrient content. The excessive growth of macrophytes to nuisance proportions on Blue Spring Lake would likely cease if sediment Total-P could be reduced to less than 125 mg/kg.

SECTION VI

MANAGEMENT RECOMMENDATIONS

The primary purpose of this inventory was to develop a better understanding of how Blue Spring Lake works in order to have that knowledge available for development of a lake management plan. This purpose has, for the most part, been fulfilled. The primary recommendation, then, is to now take that next step and initiate the development of a long-range plan for maintaining or improving the quality of the lake. Steps to be taken for developing that plan can be modeled after those presented in the UWEX publication, "A Model Lake Plan for a Local Community." In addition, there are other secondary recommendations, some applicable to the near-term and others to the long-term, that derive from this study:

NEAR-TERM RECOMMENDATIONS (1995-96)

Continued Monitoring

Good management of a lake is not an on-again, off-again activity. It requires continual and long-term monitoring of the lake's condition. Blue Spring Lake's participation in the DNR's Trophic State Index (TSI) Program, which monitors water clarity, phosphorus and chlorophyll-a content five times a season, is valuable and should definitely be continued. More frequent (two or more times per week) Secchi disc readings, along with dissolved oxygen and temperature, provide a good opportunity to pick up rapid changes in water quality which, if observed, might then be related to specific environmental events.

Monitoring the aquatic plant community is equally important, especially because it is the main concern of most lake users. Qualitative identification of species and plant densities should be done on weekly or bi-monthly tours of the lake and the information recorded in order to show trends. Such monitoring is especially important for the early detection of Eurasian water milfoil infestations. The early warning provides the time necessary for management action against the exotic nuisance plant before it spreads out of control. Harvester operators, who are on the water almost every day, are ideal candidates for training to identify different plant species and to monitor their presence. Alternatively, the work could be spread over a number of community volunteers, each assigned a section of the lake, and each knowledgeable on plant species. This latter approach has the added benefit of increasing the awareness of lake ecology by those who use the lake.

Monitoring the lake's plankton community should also be established in a planned program. These communities are important parts of the overall lake ecosystem, and imbalances in these can lead to severe algal blooms. Yet, little is known about the character of phytoplankton and zooplankton in Blue Spring Lake. A sampling program to identify species, populations, and their changes with seasons and events should increase our understanding of these communities and of the causes of algal blooms. Such a monitoring/sampling program should be guided by a professional biologist/phytologist.

Monitoring the fishery should continue as it is important to the balance of the biotic community. The DNR electroshocking surveys provide valuable information regarding the fish populations and their changes with time. Stocking activities should be based on these surveys and the needs for restoring a balance within the food chain.

Monitoring unusual events also is recommended as these often represent opportunities to learn more about the lake and how it is impacted by external forces. Measuring flow rates of inlet and outlet streams during periods surrounding heavy rain storms, and analyzing the nutrient content of surface runoff samples can firm-up estimates made in this inventory. Monitoring water quality and boating activities around heavy use holiday weekends should help in the development of a better understanding of the relationship between these variables.

Aquatic Plant Management

Rooted Plants - Blue Spring Lake should continue its current strategy of fostering the growth of native aquatic plants while eliminating Eurasian water milfoil infestations. This inventory has shown the lake will have a high productivity of aquatic plants because it is a shallow lake, allowing sunlight to penetrate to all depths, and because it has a nutrient rich, fine textured sediment that readily supports rooted aquatic plants. The concept of a "weed free" lake is not compatible with these lake characteristics, nor is it compatible with the quality goal of a healthy, balanced biotic community. The best approach for relief from nuisance levels of plant growth is to replace the fast-growing, mat-forming Eurasian watermilfoil with a variety of less dense, or lower, slower growing species, such as chara and wild celery. This approach appears to have worked successfully over the last two years following the fortunate, but unexplained, near eradication of Eurasian water milfoil by a 2,4-D herbicide treatment. This was also accompanied by an increase in many native plant species, a great reduction in the need for harvesting (which resulted in considerable cost savings), and greatly improved conditions for recreation.

While low-growing plant species may be desirable from a recreational viewpoint, this requirement alone restricts plant diversity which is desirable in most ecosystems. The healthiest systems, be they terrestrial or aquatic, are ones that have the greatest diversity. Diversity builds in its own sets of checks and balances and is most capable of withstanding stresses placed on the ecosystem. Consequently, one of the bigger management challenges will be to recognize and effectively deal with the tradeoffs between the lake's ecological health and its recreational uses.

The growth of native species can be encouraged by not removing entire plants by such methods as raking, dragging, or harvesting with the cutting blade at or below the sediment surface. These methods not only remove desirable plants, but also create bare sediment that can easily be invaded by aggressive, exotic species such as Eurasian water milfoil. These problems can be particularly acute when operating the harvester in very shallow water. The practice of using the large harvester around piers and for backwashing shorelines to pick up floating plants should be re-examined to determine if other methods can be used that are less disruptive to native plant communities.

Disturbed plant communities may also result from operating power boats in very shallow waters. This is particularly likely when powering up the boat from idle speeds, which generally directs the prop wash downward. Boaters should be encouraged to power up only in deeper waters, especially when pulling up skiers.

Elimination of Eurasian water milfoil is important to the growth of other species because the milfoil tends to form canopies that dominate other plants. While these canopies can be cropped by harvesting, this can cause spreading of the plant by fragmentation. It also leaves the base of the plant intact for continued growth. The best approach for eliminating Eurasian water milfoil is the use of 2,4-D herbicide which specifically and systemically eliminates the milfoil but not other native species. The treatment should be applied primarily as spot treatments of small, dense, infestations. Scattered Eurasian water milfoil plants, lying amongst other native species, need not be treated as they often will not become dominant. These stands, however, should be monitored for indications of spreading growth.

Selective harvesting is recommended for those stands of native species that grow to nuisance proportions creating widespread loss of boating and swimming uses. Only the tops of these plants should be harvested and only in areas needed for recreational use. Harvesting of Eurasian water milfoil is also recommended as a short-term measure should this plant return to widespread domination of the lake as it did prior to 1993.

Algae - A better understanding of the species, populations, and their seasonal changes should be developed. This is particularly true in light of the severe algal blooms that occurred on the lake in 1994 and affected both aesthetic and recreational uses of the lake. This imbalance should be examined with the knowledge that the algae, the zooplankton that graze on the algae, and the fish that feed on the zooplankton are all part of the ecological balance of the lake and its food chains. To manage this balance, it is important to understand these species and their interrelationships. An inventory and monitoring of the lake's planktonic community is recommended, using professional help and a Lake Management Planning Grant to support the work.

Undesirable algal blooms can generally be avoided by preventing excessive nutrients from entering the water column. This inventory has shown that disturbed sediments are the most likely source of excessive nutrients. Thus, most of the above recommendations for not disturbing sediments as they relate to rooted plant growth, also apply to minimizing algal blooms. In addition, as rooted plant coverage increases in the lake, more bottom sediments will be shielded from the turbulent actions of wind, waves, and boating.

Water Quality

The above recommendation for not disturbing bottom sediments and for minimizing algal blooms should also help improve the clarity of Blue Spring Lake's water. However, a better understanding is still needed to explain the dramatic drop in clarity that occurred in the spring of both 1993 and 1994. A study is recommended for relatively intense monitoring of water clarity during spring and the identification of matter that enters the water column causing a drop in clarity. Such matter may include suspended sediments, algae, colloids, or precipitates. This investigation can be part of the plankton inventory and may be supported by a Lake Management Planning Grant.

The present inventory showed Blue Spring Lake receives little in the way of nutrients and pollution from runoff and from non-point sources in the watershed, and that the major source of phosphorus is in the lake's sediment. While this information suggests management efforts be primarily focused on the lake's sediment, management should also not ignore land uses and practices in the watershed as these could become problems in the future. Before that happens, and to foster a "lake protection" attitude in the community, the following recommendations are made:

- Homeowners should be encouraged to test soils for nutrient needs before adding fertilizers. Healthy vegetation, whether lawns or natural grasses and plants, are effective at absorbing rainwater and preventing erosion. This vegetation should be cultivated and, if necessary, fertilizers added. However, excess fertilizer ends up in the lake and should be avoided. The only way to know is through soil testing. If testing seems too bothersome, don't fertilize, because chances are very high that it is not needed. Management could implement a program to test homeowner soils if desired and/or defray part of the testing cost (about $7 per sample).

- Runoff from construction sites around the lake should be prevented by using well-known construction practices, such as silt fences. (Some lake communities require double fencing.) Town ordinances should be enacted that require such practices as part of the permitting process. Local contractors should be invited to participate in drafting the ordinance. Planning grant moneys have been available in the past for the cost of developing such ordinances.

LONGER-TERM RECOMMENDATIONS (1995-2020)

Aquatic Plant and Algae Management

To the extent that a continuation of the above near-term recommendations are successful in improving the quality of Blue Spring Lake, very few long-term recommendations may be necessary. The lake does not appear to be suffering from any major pollutional problem that will require years of long-term effort to correct. The current problems with nuisance growths of plants and periodic algal blooms is the result of the lake being shallow, having a nutrient rich, fine textured sediment, and occasions of sediment disturbances. If the above recommendations lead to the control of Eurasian water milfoil and greater coverage of the sediments with low-growing, slow-growing, native species that, along with modifications in boating and harvesting practices, result in minimal sediment disturbances, then the problems with nuisance plants and algae will disappear.

However, if these efforts are not successful, then other longer term solutions should be sought. One alternative, brought up many times by residents, and deserving of careful consideration, is that of dredging. While this study has provided an estimate of the amount of material that could be dredged and a rough estimate of the high costs involved, a more thorough exploration of the idea is recommended. Removal of the soft sediments would deepen the lake, reducing both light penetration and its accompanying macrophyte growth in some parts. It would also distance the remaining bottom sediments from wind, wave, and boating turbulence, resulting in less disturbance of plant communities and of the sediment itself. Most importantly, the large nutrient pool existing in the sediment that supports excessive plant growth could be greatly reduced.

Among the many considerations to be addressed in a dredging feasibility study are: identification of permitting requirements; identification of appropriate disposal sites; presence of toxic materials in the sediment that would preclude its removal; how to maintain healthy, balanced biotic communities during and after dredging; the time period from start to finish and its impact on lake user needs; what dredging technology to use; who should do the work; costs of various options; and who should, can, or will pay for it.

Community Attitudes

One monitoring activity that should continue to be done on a two-year cycle, is a survey of lake user attitudes and practices. This information is important for establishing lake and water quality goals as these are dependent on the needs of the lake users. In addition, information on frequency of lake use and type of use helps assess user impacts on lake quality.

The community of people immediately surrounding the lake are not the only ones who impact the lake's quality. Residents outside the immediate community frequently use the lake, primarily for fishing, in both the summer and winter. Also, use of the wetlands and agricultural lands in the watershed, east of the lake, can impact the lake. Relationships should be sought with these users and land owners in order to ensure mutual understanding and respect for each other's needs and values.