Blueberry Lake Water Quality Study

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Executive Summary

The study described by this report was initiated by the Lac Courte Oreilles (LCO) Conservation Department to provide information for the development of a lake management plan for Blueberry Lake. The study involved collection of data from Blueberry Lake and its watershed during 1999. Annualized hydrologic and phosphorus budgets were then modeled for existing watershed land use conditions.

The lake water quality data show that Blueberry Lake has good water quality. Total phosphorus, chlorophyll-a and Secchi disk data were generally within the mesotrophic (moderate algal growth, minimal or no recreational use impairment) category. Water clarity was better than expected based upon total phosphorus and chlorophyll-a concentrations.

The results of the phosphorus budget analysis for the lake estimated that the total annual load of phosphorus into Blueberry Lake is approximately 169 pounds per year based on 1998-1999 data. Based upon the modeling results, the data indicates that 33.9% of the load is contributed by forested land use, 5.2% from wetlands, 40.4% is contributed by atmospheric deposition, residential land use comprises 14.3% and septic systems make up the remaining 6.3%.

The impacts of cultural eutrophication on Blueberry Lake were evaluated in this study. Cultural eutrophication describes the acceleration of the natural eutrophication process caused by human activities. An assessment of the land uses within the Blueberry Lake watershed indicates that there is one type of land use as a result of human activity, which is residential and the associated septic systems. The residential land use and septic systems account for nearly 21% of the annual phosphorus load to the lake.

The impacts of cultural eutrophication on Blueberry Lake were estimated by modeling pre-development in-lake phosphorus concentrations and comparing the estimated pre-development phosphorus concentrations with current phosphorus concentrations (i.e. post-development conditions).

The modeling scenario completed for Blueberry Lake to assess the impacts of cultural eutrophication consisted of eliminating the septic loading and replacing the residential land use (i.e., current or post-development condition) with forested land use (i.e., pre-development condition) within the watershed.

The model indicates that the assumed conversion of forest land use to residential land use results in a 2 ug/L (15%) increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of 2.3 feet. This is based upon the regression relationship between total phosphorus and Secchi disk depth as determined in the trophic response module in the WILMS model (Panuska and Wilson, 1994). This predicted decrease in Secchi disk depth would be an overall reduction in water clarity of 16% based upon the 1998-99 average summer Secchi disk depth of 14.4 feet which was noted for Blueberry Lake.

The development of a comprehensive lake management plan for Blueberry Lake is recommended in order to prevent any further degradation of the water quality. This plan should include:

1. The development of a long-term water quality goal for the lake;
2. An evaluation of different watershed development scenarios to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options;
3. Recommendations for ultimate watershed development relative to achieving the lake's water quality goal (i.e. minimum lot size, maximum area of impervious surface, etc.);
4. Recommendations for watershed best management practices under future development conditions;
5. Recommendations for ordinances to control watershed development;
6. Recommendations for the riparian owner management practices;
7. Recommendations for best management plans to protect sensitive lands including wetlands, steep slopes, undeveloped land, shoreline, etc.;
8. Algal study to determine species abundance and distribution;
9. A macrophyte study to determine the spatial coverage, density, and species composition of the macrophyte community. A special area of concern would be identification of Eurasian Water Milfoil;
10. Volunteer monitoring program to establish a long-term water quality database.

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Introduction 1.0

Blueberry Lake located in Sawyer County, Wisconsin, is considered a unique and significant water resource by the Lac Courte Oreilles Band of Lake Superior Chippewa Indians (LCO) and the Blueberry Lake Association (BLA). The lake is a seepage lake which has no inlets or outlets. Blueberry Lake has a surface area of approximately 280 acres and a volume of approximately 4,610 acre-feet. The maximum depth is 29 feet. Approximately 53% of the lake is over 20 feet deep and about 11% is less than 3 feet deep. The total shoreline of the lake spans 4.2 miles. The watershed of Blueberry Lake consists of 1364 acres, which results in a drainage basin to lake area ratio of approximately 4:1. Therefore for every acre of water within the lake, 4 acres of land drains into it. See Figure 1 for a map of the Blueberry Lake watershed. The lake is noted for an excellent fisheries and has a wide variety of species including largemouth bass, walleye, and panfish. The lakeshore property owners, the LCO tribal members and the general public, via the public accesses, utilize the lake for a wide variety of activities including fishing, boating, skiing, swimming, snorkeling, SCUBA diving and viewing wildlife.

Over the past few years, complaints and concerns that the water quality of the lake may be degrading have become increasingly more numerous. Due to the cultural and economic significance of this lake to the LCO Reservation, the riparian owners, and Sawyer County, the LCO Conservation Department determined that a comprehensive monitoring program was necessary to assess the current water quality status of Blueberry Lake. Consequently, the LCO Conservation Department along with the Blueberry Lake Association initiated a project for a water quality study. This study will serve as the basis for developing a comprehensive lake management plan.

The study included a data collection phase, the completion of an annualized phosphorous and hydrologic budget along with a watershed evaluation for the lake.

1.1 Report Coverage

This report will answer the following questions that apply to properly managing a lake:

1. What is the general condition of the lake?
2. Are there problems associated with the lake?

To answer the first question, this report begins with a description of the Blueberry Lake watershed, the lake, methods of data collection and analysis. The results of the water quality monitoring are then summarized in tables, figures, and accompanying descriptions.

To answer the second question, water quality data are analyzed and compared to established water quality standards for lakes.

A background information section is also included in this report. Section 2.0 covers general concepts in lake water quality.

2.0 General Concepts in Lake Water Quality

There are many concepts and terminology that are necessary to describe and evaluate the water quality of a lake. This section provides a brief discussion of the following topics:

- ♦ Eutrophication
- ♦ Trophic states
- ♦ Limiting nutrients
- ♦ Nutrient recycling and internal loading
- ♦ Stratification
- ♦ Riparian Zone
- ♦ Watershed

2.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in a lake. As a lake naturally ages and becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fills in the lake's basin. The process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process which is caused by human activities. Nutrient and sediment inputs from construction, houses, septic tanks, lawn fertilizers, and storm water runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants results in unpleasant consequences such as profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds.

The main cause of cultural eutrophication is uncontrolled development within a lakes watershed and/or development without the use of Best Management Practices (BMP's). Creating and implementing a lake management plan prior to the development of the lake's watershed is the best way to try to prevent and minimize the impacts from cultural eutrophication.

2.2 Trophic States

Not all lakes are in the same stage of eutrophication because of varying nutrient status. Criteria have been established to evaluate the existing nutrient "status" of a lake. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, chlorophyll-a concentrations, and Secchi disk transparencies. A TSI value can be obtained from any one of those parameters. TSI values range upward from zero, designating the condition of the lake in terms of its degree of fertility. The trophic status indicates the severity of a lake's algal growth problems and the degree of change needed to meet its recreational goals. Determining the trophic status of a lake is therefore an important step in diagnosing water quality problems. Carlson's Trophic State Index is often used in interpreting water quality data (see Figure 2). For a general guideline, Table 1 can also be referred to.

Table 1: Trophic Status and TSI Ranges

Trophic Status	TSI Range	
Oligotrophic	TSI 37	Clear, low productivity lakes with total phosphorus concentrations less than or equal 10 ug/L
Mesotrophic	38 TSI 50	Intermediate productivity lakes with total phosphorus concentrations greater than 10 ug/L, but less than 25 ug/L
Eutrophic	51 TSI 63	High productivity lakes generally having 25 to 57 ug/L of total phosphorus
Hypereutrophic	64 TSI	Extremely productive lakes that are highly eutrophic, disturbed and unstable (i.e., fluctuating in their water quality on a daily and seasonal scale, producing gases, off-flavor, and toxic substances, experiencing periodic anoxia and fish kills, etc.) With total phosphorus concentrations above 57 ug/L

Figure 2: Carlson's Trophic State Index

TSI < 30 Classic Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.

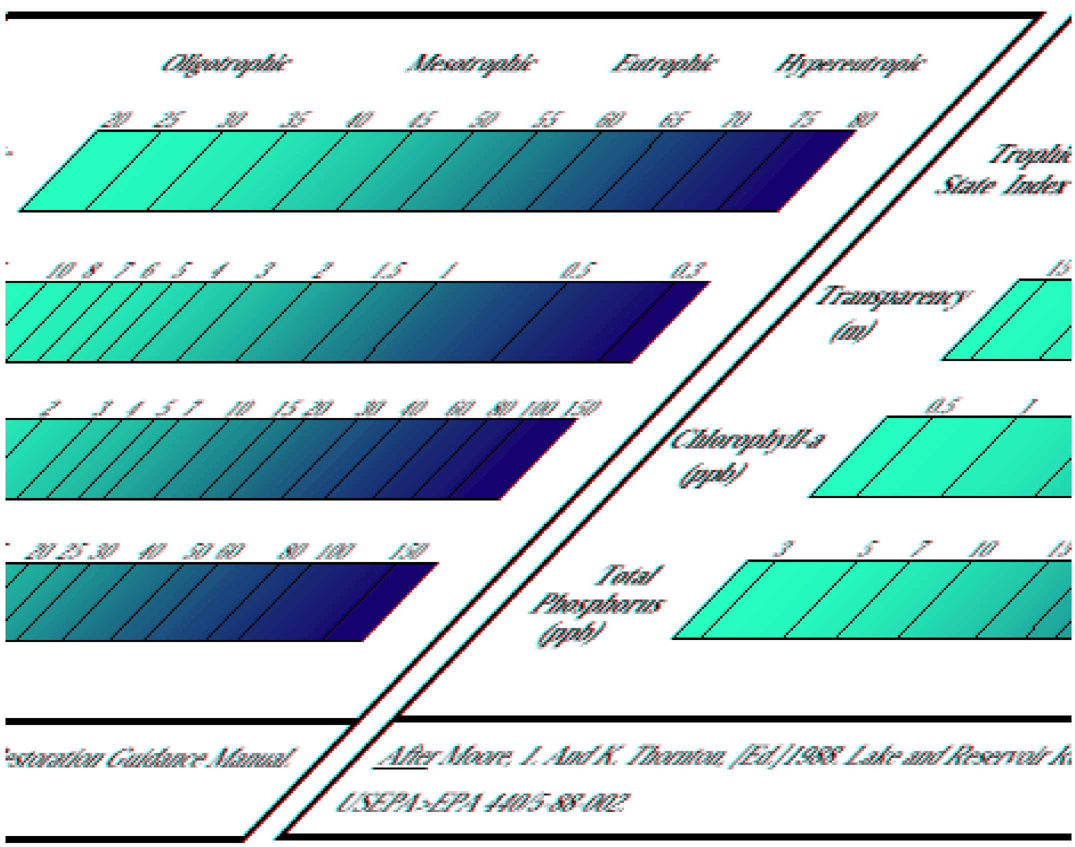
TSI 30 - 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 - 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 - 70 Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.

TSI 70 - 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.



TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

2.3 Limiting Nutrients

The quantity of algae in a lake is usually limited by the water's concentration of an essential element or nutrient. This is the "limiting nutrient." The limiting nutrient concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the plant or algae, will limit it's growth.

Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content in lake water provides ratios of N:P. By comparing the ratio, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with a N:P ratio greater than 15 (Byron, et. al. 1997). It has been amply demonstrated that phosphorus is usually the nutrient in limited supply in fresh waters. Therefore, reducing phosphorus in the lake is required to reduce algal abundance and improve water transparency. The failure to reduce the phosphorus concentrations entering the lake will allow the process of accelerated eutrophication to continue.

2.4 Nutrient Recycling and Internal Loading

Watershed runoff, which includes overland flow and groundwater infiltration, and direct atmospheric deposition are the two ways in which phosphorus can enter a lake. It would therefore seem reasonable that phosphorus in a lake can be decreased by reducing these external loads of phosphorus to the lake. However, all lakes accumulate phosphorus, along with other nutrients, in the sediments from the settling of particles and dead organisms. In some lakes this stored phosphorous can be reintroduced into the lake water and become available again for plant uptake. This release of the nutrients from the sediments to the lake water is known as "internal loading." The amount of phosphorus coming from internal and external loads vary with each lake. Internal loading can be estimated from depth profiles of dissolved oxygen and phosphorus concentrations.

2.5 Stratification

The process of internal loading is dependent on the amount of organic material in the sediments and the depth-temperature pattern, or "thermal stratification," of a lake. Thermal stratification has a profound influence on a lake's chemistry and biology. As the ice melts and the air temperature warms in the spring, lakes generally progress from being completely mixed to stratified with only an upper warm well-mixed layer of water (epilimnion), and cold temperatures in a bottom layer (hypolimnion). Because of the density differences between the lighter warm water and the heavier cold water, stratification in a lake can become very resistant to mixing. When this occurs, generally in mid to late summer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic). Complete loss of oxygen changes the chemical conditions in the water and allows phosphorus that had remained bound to sediments to reenter the lake water.

Phosphorus concentrations in the hypolimnion can continue to rise as the summer progresses until oxygen is once again reintroduced. The dissolved oxygen concentration will increase if the lake sufficiently mixes to disrupt the thermal stratification. Phosphorus in the hypolimnion is generally not available for plant uptake because there is not sufficient light penetration into the hypolimnion to allow for the growth of algae. The phosphorus, therefore, remains trapped and unavailable to the plants until the lake is completely mixed again. In shallow lakes mixing can occur frequently throughout the summer with sufficient wind energy. In deeper lakes only extremely high wind energy is sufficient to destratify a lake during the summer and complete mixing only occurs in the spring and fall. The cooling air temperature in the fall reduces the epilimnion water temperature and consequently increases the density of water in the epilimnion. As the epilimnion water density approaches the density of the hypolimnion water, very little energy is needed to cause complete mixing of the lake. When this fall mixing occurs, phosphorus that has built up in the hypolimnion is mixed with the epilimnetic water and some of it becomes available for algal growth, while the remainder combines with iron in the water to form an amorphous ferric-hydroxy-phosphate complex that re-precipitates to the lake's bottom sediments.

2.6 Riparian Zone

The riparian zone is extremely important to the lake and to the plants living there. Riparian vegetation is that which is growing close to the lake and may be different from the terrestrial or upland vegetation. The width of the riparian zone varies depending on many factors, including soils, vegetation, slopes, soil moisture, depth of the water table, and even by location on the lake. For instance, the north shore vegetation may provide little or no shade, while vegetation on the southern shore may offer shade and cover well into the lake.

The riparian zone is important for the following reasons:

- Acts as a filter from outside impacts
- Stabilizes the bank with an extensive root system
- Helps control or filter erosion and nutrients
- Provides screening to protect visual quality and hides man's activities and buildings
- Provides the natural visual backdrop as seen from the lake

- Provides organic material to the lake's food web.
- Offers cover and shade for fish and other aquatic life
- Provides valuable wildlife habitat

The riparian zone is the area most often impacted and riparian vegetation is lost when man enters the scene. Driveways, cabins, homes, lawns, or other structures replace native riparian vegetation. Additional riparian vegetation may be eliminated to provide a larger view from the house or it may be mowed and its value to the lake is lost.

The loss of riparian vegetation results in the deterioration of many lake values besides water quality. Wildlife habitat is lost, the scenic quality suffers, fish habitat is impacted, bank stability may be weakened and the potential for erosion increases. The vegetation in the riparian zone filters phosphorus and sediments from runoff water, which in turn protects the water quality of the lake.

2.7 Watershed

The area of land that drains to the lake is called the lake's watershed. This area may be small, as is the case of small seepage lakes such as Blueberry. Seepage lakes have no stream inlet or outlet and their watersheds include only the land draining directly to the lake. Water draining to a lake may carry pollutants that affect the lake's water quality. Therefore, water quality conditions of the lake are a direct result of the land use practices within the entire watershed. Poor water quality may reflect poor land use practices or pollution problems within the watershed. Good water quality conditions suggest that proper land uses are occurring in the watershed or there is minimal development within the watershed.

All land use practices within a lake's watershed impact the lake and determine its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby, affecting the lake's water quality differently. An understanding of a lake's watershed, phosphorus exported from the watershed, and the relationship between the lake's water quality and its's watershed must be understood.

2.7.1 Water Quality Impacts of Various Land Uses In the Tributary Watershed

The impacts of various land uses on the water quality of Blueberry Lake will be estimated by modeling the water quality which would result from removing from the lake's phosphorus load the estimated annual phosphorus loading from various land uses. The estimated impacts of various land uses to the water quality of Blueberry Lake may be used by the LCO Conservation Department and other agencies to estimate the potential water quality improvements which could result from the implementation of Best Management Practices (BMP's) in the watershed.

3.1 Lake Water Quality Data Collection

The 1999 sampling program involved the collection of water samples from the deepest hole in Blueberry Lake. See Figure 3 for the location of the sampling point. The samples were collected monthly through the period of May through September. These dates spanned the lake's period of elevated biological activity throughout the summer months. The sampling depths are summarized in Table 2.

Table 2: Blueberry Lake Sampling Depths

Sampling Station	Maximum Depth (meters)	Sampling Depths (Meters)		
Deep Hole (1)	8.8	0-2*	5	NB

**0 -2 meter sample is a composite sample*
***NB indicates sample taken 0.5 meter from the bottom (Near Bottom)*

Table 3 indicates the water quality parameters that were measured at each station, and specifies at what depth and how frequent the samples or measurements were collected. The dissolved oxygen, temperature, specific conductance, total dissolved solids, pH, and Secchi disk transparency were measured in the field; whereas the water samples were analyzed in the laboratory for total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, chlorophyll *a*, and alkalinity.

Table 3: Blueberry Lake Water Quality Parameters

Parameters	Depth (Meters)	Sample Frequency			
		Approximately weekly	Approximately Biweekly	Approximately Monthly	Quarterly
Dissolved Oxygen	Surface to bottom Profile		**X**		
Temperature	Surface to bottom Profile		**X**		
Specific Conductance	Surface to bottom Profile		**X**		
Total Dissolved Solids	Surface to bottom Profile		**X**		
pH	Surface to bottom Profile		**X**		
Chlorophyll *a*	0 - 2			**X**	
Secchi Disk	--	**X**			
Total Phosphorus	See Table 2			**X**	
Soluble Reactive Phosphorus	0 - 2			**X**	
Total Kjeldahl, Ammonia, and Nitrate+Nitrite Nitrogen	0 - 2			**X**	
Alkalinity	0 - 2				**X**

3.2 Lake Level Monitoring

One staff gauge was installed in Blueberry Lake shortly after ice-out. The gauge was read on a daily basis from May through mid-November by a Blueberry Lake Association volunteer. The lake level data will be used to determine the daily lake volume changes.

3.3 Precipitation Monitoring

One rain gauge accurate to within 1/100th-of-an-inch was installed near the lake and read daily by a Blueberry Lake Association volunteer from May through mid-November. Precipitation recorded at the Hayward Ranger Station was obtained for the time period not recorded by the volunteer.

3.4 Evaluation of the Watershed

The Blueberry Lake Watershed, including the lake, encompasses 1,364 acres or 2.13 miles^2 (refer to Figure 1). The various land uses and their corresponding acreage within the watershed are indicated in Table 4.

Table 4: Blueberry Lake Watershed Land Uses and Acreage

Land Use	Acres
Medium Density Residential	55
Wetlands	95
Forest	934
Lake Surface Area	280

3.5 Phosphorus and Hydrologic Budgets

The nutrient balance of a lake is defined by the quantities of nutrients contributed to or removed from the lake by various inflow and outflow routes and is analogous to and dependent upon the hydrologic balance for the lake. It has been amply demonstrated that most often phosphorus is the nutrient that limits algal growth in lakes. To develop an understanding of the pattern of phosphorus transport through Blueberry Lake, monitoring data was combined with the results of the hydrologic monitoring to develop an annualized hydrologic and phosphorus budget for the lake.

3.5.1 Annualized Hydrologic Budget Calculations

The hydrologic budget for Blueberry Lake based on the 1998-99 water year (October 1, 1998 through September 30, 1999) was calculated by measuring or estimating the important components of the budget. The important components of the budget for Blueberry Lake include:

- Precipitation
- Runoff (Overland and Groundwater Flow)
- Evaporation
- Groundwater seepage
- Change in lake storage

A mass balance approach was used to determine the annualized hydrologic budget for Blueberry Lake. The general water balance equation used was:

$$\Delta S = E - P - R + \Delta GW$$

Where:

ΔS = change in lake storage volume
E = evaporation from the lake surface
P = direct precipitation on the lake surface
R = runoff from the watershed
ΔGW = Net Groundwater Flow (Groundwater inflow - Groundwater outflow)

Evaporation from the surface of Blueberry Lake was estimated from pan evaporation rates obtained from the Marshfield Agricultural Research Center. An evaporation coefficient of 0.7 was used to convert the pan evaporation to actual field evaporation. Evaporation for the winter months (November - April) were assumed to be similar to the evaporation rates over the winter months computed for a study on Lac Courte Oreilles Lake by Barr Engineering during 1995-96 (Barr Engineering, 1998).

The average runoff rate for Sawyer County Wisconsin was used as a basis for determining the runoff rate for the Blueberry Lake watershed. This value was adjusted to reflect the higher than normal amount of precipitation during the 1998 - 1999 water year. The precipitation was approximately 36.5% above the average precipitation, therefore the runoff was adjusted to be 36.5% greater than average also.

The net groundwater flow (inflow minus outflow) was estimated for the period from June through September since the precipitation, change in storage, inflow, outflow, and the other parameters were either known or estimated for that period using generally accepted practices. An average daily groundwater flow was determined for that period. The average daily flow was then used to compute an annual groundwater flow contribution.

The annual yield of surface water runoff from the Blueberry Lake watershed was determined by dividing the predicted watershed runoff volume by the watershed area to compute an annual areal yield expressed in inches of water. The runoff yield was divided by the total precipitation to determine the estimated runoff coefficient for the watershed.

3.5.2 Annualized Phosphorus Budget

The annualized phosphorus budget for Blueberry Lake under existing land use conditions was estimated with the assistance of a phosphorus mass balance model. The mathematical equations within the model help to interpret the relationship between phosphorus loads, water loads and lake basin characteristics to the observed in-lake total phosphorus concentration. The model used in this study was the Wisconsin Lake Model Spreadsheet "WILMS" developed by the WI Department of Natural Resources (Panuska and Wilson, 1994). The equation used within the "WILMS" model for the Blueberry Lake study was one developed by Walker (Walker, 1977). The Walker 1977 General Lake Model has the form of:

$$P = \frac{LT_w}{z}\left[\frac{1}{1+0.824\,T_w^{0.454}}\right]$$

Where:

P = Predicted mixed lake total phosphorus concentration (mg/m^3 or ug/L)
L = Areal total phosphorus load (mg/m^2 of lake area/year)
T_w = Lake hydraulic retention time (years)
z = Lake mean depth (meters)

The important components of the phosphorus budget for Blueberry Lake include:

- Watershed surface runoff from forested, residential, and wetlands land uses
- Atmospheric wet and dry deposition on the lake surface
- Septic system loading

Internal phosphorus loading was not considered to be significant due to the very short and minor stratification of the lake during the summer months. No anoxic conditions were observed either.
The watershed surface runoff components of the phosphorus budget were estimated using

an assumed phosphorus export coefficient for each land use type within the watershed of Blueberry Lake. Table 5 lists the land use along with its corresponding export coefficient.

Table 5: Blueberry Lake Land Use Phosphorus Export Coefficients

Land Use	Export Coefficient (lbs/acre-year)
Medium Density Urban Residential	0.45
Wetlands	0.09
Forest	0.06
Lake Surface (atmospheric deposition)	0.24

All of the phosphorus export coefficient values are within the ranges suggested by the WILMS model and generally agree with the most likely default value suggested by the model (Panuska and Lilly, 1995).

The phosphorus export rate computations used in the WILMS model were used to estimate an annual load from the septic systems along Blueberry Lake. The equation used to estimate this load was:

Total Septic System Load (Kg/yr) = E_{st} * # of capita-yrs * (1-SR)

Where:

E_{st} = export coefficient to septic tank systems (0.5 Kg/capita/yr)
capita-yrs = # of people occupying a dwelling each year
= (# of permanent residents/dwelling)*(# of permanent dwellings) + (# of seasonal residents/dwelling)*(days/yr)*(# of seasonal dwellings)
SR = weighted soil retention coefficient (.9 for most likely value used in model)

Aerial photos and the USGS quadrangle maps were used to determine the number of septic systems (dwellings) within the watershed of Blueberry Lake. The following assumptions were used in determining the loading from septic systems:

- Groundwater flows easterly; therefore dwellings along east shore do not contribute septic load

- 90 dwellings along lakeshore-60 contribute to septic load (30 along east shore do not contribute load to lake)
- 35% of residences are year round; 65% seasonal
- 2 persons/year-round residence; 5 persons/seasonal residence
- Seasonal dwellings occupied 100 days/yr
- all systems functioning properly as result of comprehensive septic system survey around the lake

The accuracy of the phosphorus export coefficients to predict the phosphorus loading to the lake was evaluated by comparing the predicted in-lake phosphorus concentration with the observed concentrations of the samples which were collected. The modeled predicted total phosphorus concentration was the same as the observed average epilimnetic (i.e. surface water or upper 6 feet) total phosphorus concentration. The data therefore supports the annual phosphorus export coefficients selected for the model.

4.0 Results and Discussion

4.1 Compiled Data

Water quality data acquired during the 1999 monitoring program are compiled in Appendices A through D. Appendix A presents the tabulated in-lake water quality. Appendix B contains the profiling data. Appendix C contains the lake level data used to determine changes in lake volume. Appendix D contains the precipitation data which was collected by the Blueberry Lake Association volunteer. Appendix E provides the calibrated model output for the WILMS simulation run.

4.2 1999 Lake Water Quality Conditions

4.2.1 Phosphorus

Phosphorus is the plant nutrient that most often limits the growth of algae. Phosphorus-rich lake water indicates a lake has the potential for abundant algal growth, which can lead to lower water transparency and a decline in hypolimnetic oxygen levels in a lake.

While nitrogen can limit algal growth, it can be obtained from the atmosphere by certain algal species. This is termed nitrogen fixation. Thus, phosphorus is the only essential nutrient that can be effectively managed to limit algal growth.

Lakes with nitrogen (N) to phosphorus (P) ratios greater than 15:1 are considered to be phosphorus limited. Values between 10:1 and 15:1 are to be considered transitional lakes, while lakes with a ratio below 10:1 are to be considered nitrogen limited (Byron, et. al. 1997). To determine the nutrient limiting the algal growth in Blueberry Lake, the May average N:P ratio was determined. The ratio for Blueberry Lake was 13, thus indicating the lake to be transitional.

Total phosphorus data collected from Blueberry Lake during 1999 were within the mesotrophic (i.e. moderate amounts of nutrients) category during May and August through September. During June and July, the total phosphorus was in the oligotrophic (i.e. few nutrients or nutrient-poor) category. The average summer (i.e. June through August) total phosphorus concentration was within the mesotrophic range (see Figure 4).

4.2.2 Chlorophyll-*a*

Chlorophyll-a is a measure of algal abundance within a lake. High chlorophyll-a concentrations indicate excessive algal abundance (i.e. algal blooms), which can lead to recreational use impairment.

The 1999 Blueberry Lake chlorophyll-a data were within the mesotrophic range during the spring and fall (May and September). During June the concentration was in the oligotrophic category. However, during August the concentration was in the eutrophic category (i.e. nutrient rich or well fertilized) category (Figure 5). The summer average was within the mesotrophic category approaching eutrophic. The seasonal pattern of chlorophyll-a was similar to the total phosphorus concentrations suggesting that the lake's algal growth is directly related the phosphorus levels in the lake.

4.2.3 Secchi Disk Transparency

Secchi disk transparency is a measure of water clarity. Perceptions and expectations of people using a lake are generally correlated with water clarity. The results of a survey completed by the Metropolitan Council (Osgood, 1989) indicated that the following relationships can generally be perceived between a lake's recreational use impairment and Secchi disk transparencies:

- *No impairment occurs at Secchi disk transparencies greater than 4 meters.*
- *Minimal impairment occurs at Secchi disk transparencies of 2 to 4 meters.*
- *Moderate impairment occurs at Secchi disk transparencies of 1 to 2 meters.*
- *Moderate to severe use-impairment occurs at Secchi disk transparencies less than 1 meter (3.3 feet).*

The Secchi disk measurements in Blueberry lake generally mirrored the total phosphorus and chlorophyll-a concentrations (Figure 6). During spring, early summer and fall the Secchi disk measurements were in the oligotrophic range. During the late summer, the values decreased to the mesotrophic range. The seasonal patterns suggest that the lake's water transparency is largely determined by the algal abundance. The summer average Secchi disk depth was 4.4 meters or 14.4 feet, which is in the mesotrophic category.

4.2.4 Temperature, Dissolved Oxygen, total Dissolved Solids, and Specific Conductance Isopleth Diagrams

Isopleth diagrams represent the change in a parameter relative to depth and time. For a given time period, vertical isopleths indicate complete mixing and horizontal isopleths indicate stratification.

Isopleth diagrams are useful for showing patterns with depth and time when sufficient depth profile data are available. Isopleth diagrams of temperature, dissolved oxygen, total dissolved solids and specific conductance were prepared for Blueberry Lake. The temperature isopleth diagram (Figure 7) shows that Blueberry Lake mixed completely during the spring and fall (i.e. same temperature from top to bottom) and was weakly stratified from late June through early August.

The dissolved oxygen isopleth diagram (Figure 8) indicates that most of the lake had stratified dissolved oxygen concentrations during the monitoring period. Low dissolved oxygen concentrations were observed from June through mid-July and for a brief period during the middle of August. Oxygen depletion of the bottom waters reduces the available habitat for organisms (i.e. fish and zooplankton). A dissolved oxygen concentration of 5.0 mg/L is considered the minimum desirable level for fish. Oxygen concentrations of at least 5.0 mg/L were noted throughout the entire monitoring period down to a depth of 6 meters or 20 feet. If dissolved oxygen concentrations fall below 0.5 mg/L, the water is considered anoxic (i.e. without oxygen) and phosphorus can redissolve into the anoxic waters from the sediment. This is termed internal loading. Internal loading within Blueberry Lake was considered to be insignificant since the bottom waters did not become anoxic.

Specific conductance is directly related to the amount of dissolved inorganic chemicals (minerals, nutrients, metals, and other inorganic chemicals) in the water. Total dissolved solids provides another measurement of materials dissolved in the lake. They both are a reflection of the soils and bedrock in the lake's watershed and they also indicate the level of internal loading occurring within the lake. The total dissolved solids and specific conductance isopleths show an increase for a brief period during late August (Figures 9 and 10). Lakes with higher specific conductance and total dissolved solids are more productive waters, capable of supporting more aquatic plants and animals. Higher levels can also indicate a poorer water quality among lakes.

Reserved for Figure 7: Blueberry Lake Temperature Isopleths

Reserved for Figure 8: Blueberry Lake Dissolved Oxygen Isopleths

Reserved for Figure 9: Blueberry Lake Total Dissolved Solids Isopleths

Reserved for Figure 10: Blueberry Lake Specific Conductance Isopleths

4.2.5 pH Isopleth Diagrams

pH defines the acid or alkaline status of the water. A pH of 7.0 is neutral, while waters above 7.0 are alkaline, and waters below 7.0 are acidic. Rainwater is naturally slightly acidic. Lakes that receive most of their water from precipitation, such as seepage lakes, will be acidic. Drainage lakes receive most of their water from streams and rivers and will tend to be more alkaline.

The acidity or alkalinity of a lake directly influences the aquatic life in the lake. For example, if a lake has a pH of 6.5 or lower (acidic), walleye spawning is inhibited. At a pH of 5.2 or lower, walleyes cannot survive. Acidic conditions may result in higher mercury levels and may pose health problems to wildlife and humans consuming fish.

The pH isopleth diagram for Blueberry Lake indicates that alkaline conditions generally occurred throughout the lake (Figure 11). An exception occurred during late June and early July when the bottom meter was slightly acidic. The lake's surface waters tended to be more alkaline than the deeper water, as is indicated by the higher pH levels. Photosynthesis causes the addition of hydroxide ions to the water, resulting in higher pH levels. Photosynthesis by algae in the lake's surface waters likely caused increased pH levels, thereby resulting in higher levels than the lake's bottom waters. All of the pH levels measured in Blueberry Lake are within the range of values considered safe for fish and aquatic animals. The pH values in Blueberry Lake ranged from a high of 8.8 to a low of 6.8.

Reserved for Figure 11: Blueberry Lake pH Isopleths

4.2.6 Alkalinity Data

Alkalinity is associated with the carbon system in the lake. Another term used to indicate a lake's alkalinity is hardness. Hard water lakes (greater than 60 mg/L calcium carbonate) tend to be better producers of aquatic life, including both plants and animals. Soft water lakes (less than 60 mg/L calcium carbonate) are not as productive. Extremely low alkalinities (less than 5 mg/L calcium carbonate) are more likely to be impacted by acidification resulting from acid rain. Alkalinities above 5 mg/L calcium carbonate have enough buffering to counteract the effects of acid rain.

The alkalinity measurement for Blueberry lake during 1999 was 18 mg/L calcium carbonate. The lake would therefore be classified as a soft water lake.

4.2.7 Current Trophic State Indices

Table 6 indicates the trophic state index (TSI) based on the given parameter.

Table 6: Blueberry Lake Trophic State Indices

Parameter	Value	Trophic State Index
Total Phosphorus	14.1 ug/L	49
Chlorophyll-a-	6.66 ug/L	49
Secchi disk depth	4.43 meters	39

The TSI values used for Blueberry Lake correspond to the parameter readings taken between Memorial Day and Labor Day, or the dates closest to these when samples were taken. The span of these dates corresponds with typical summer conditions and peak recreational use of the lake and therefore should most closely correlate with user perceptions of the lake. The TSI values indicate that Blueberry Lake is generally Mesotrophic (refer to Figure 2 and Table 1).

The TSI values indicate that water clarity is better than what would be expected based upon the total phosphorus and chlorophyll-a readings.

4.3 Rainfall, Evaporation and Lake Level Data

As was previously mentioned, a rain gauge was installed within the Blueberry Lake Watershed and read on a daily basis by a volunteer throughout the ice-free period to determine daily precipitation amounts. The total average precipitation during the 1998-1999 water year was 41.64 inches.

Pan evaporation rates from the Marshfield Agricultural Experimental Research Station were used to determine the surface evaporation from Blueberry Lake. Since pan evaporation rates are higher than actual lake evaporation, they must be adjusted to account for variances such as radiation and heat exchange effects. The adjustment factor, termed the pan coefficient, ranges from 0.64 to 0.81 and averages 0.70 for the United States (Bedient and Huber, 1992). A pan coefficient of 0.7 was used for this study. The pan evaporation data did not cover the winter months i.e. (November - April). Therefore, winter evaporation rates used by Barr Engineering for a similar study on Lac Courte Oreilles Lake were used (Barr, 1998). Evaporation ranged from a high of 6.48 inches in July to a low of 0.12 inches for each month in December, January and February. The total estimated lake surface evaporation during 1998-99 was 29.52 inches. The average annual evaporation rate for northwestern Wisconsin is 28 inches (Linsley, Jr. et al., 1982). The annual evaporation rate for 1998-99 was 5% above normal.

A staff gauge was installed in the lake to determine changes in storage. The gauge was read on a daily basis from May 5, 1999 through November 29, 1999. The monitored lake surface elevations had a range of approximately 10 inches throughout the monitoring period.

4.4 Hydrologic Budget Calculations

The 1998-99 water year (October 1, 1998 through September 30, 1999) estimated hydrologic budget for Blueberry Lake is presented in Figure 12. As the budget indicates, over 60% of the estimated annual water load to the lake came from rainfall runoff from the lake's watershed. Runoff consists of both overland and groundwater flow. Direct precipitation on the lake's surface and snowmelt runoff comprised the remainder of the estimated annual water load. The watershed runoff volume represents an annual water yield of approximately 16.7 inches from the Blueberry Lake watershed. This runoff yield divided by the 41.64 inches of total precipitation for the water year results in a runoff coefficient of 0.4 (40% of the total precipitation is estimated to runoff the watershed and reach the lake). The large amount of watershed runoff to reach the lake indicates that watershed runoff can have a significant impact on the water quality of Blueberry Lake.

The majority of the water, over 70%, exits Blueberry Lake through groundwater seepage. Evaporation from the lake surface comprises the remainder of the outflow budget.

Reserved for Figure 12: Estimated Blueberry Lake Hydrologic Budget

4.5 Phosphorus Budget and Lake Water Quality Mass Balance Model

The phosphorus budget modeling indicated that the total annual phosphorus loading to Blueberry Lake was 169 pounds, based on 1998-99 data. The results of the phosphorus loading budget are presented in Figures 13 and 14. The computations reveal that septic systems and residential use comprise 6.3% and 14.3% of the annual load respectively. By applying a wet and dry atmospheric deposition rate of 0.24 lbs/acre/yr to the surface of Blueberry Lake, the atmospheric component of the phosphorus loading is computed to be 40.4%. Wetlands are estimated to comprise 5.2%and the forested portion of the watershed contributes the remaining 33.9% of the loading.

Reserved for Figure 13: Blueberry Lake Estimated Annual Phosphorus Inputs (lbs)

Reserved for Figure 14: Blueberry Lake Estimated Annual Phosphorus Inputs (%)

4.6 Cultural Eutrophication Impacts on Blueberry Lake

All land use practices within a lake's watershed impact a lake and determine its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby, impacting the lake's water quality differently. Land uses resulting from human activity generally accelerate the natural eutrophication process of a lake. These land uses generally contribute larger quantities of phosphorus to a lake than the natural land uses occurring prior to development. Cultural eutrophication describes the acceleration of the natural eutrophication process caused by human activities. The impacts of cultural eutrophication on Blueberry Lake were evaluated in this study. An assessment of the land uses within the Blueberry Lake watershed indicates that there is one type of land use as a result of human activity, which is residential and the associated septic systems. The residential land use and septic systems account for nearly 21% of the annual phosphorus load to the lake.

The impacts of cultural eutrophication on Blueberry Lake were estimated by modeling pre-development in-lake phosphorus concentrations and comparing the estimated pre-development phosphorus concentrations with current phosphorus concentrations (i.e. post-development conditions).

The modeling scenario completed for Blueberry Lake to assess the impacts of cultural eutrophication consisted of eliminating the septic loading and replacing the residential land use (i.e., current or post-development condition) with forested land use (i.e., pre-development condition) within the watershed.

The model indicates that the assumed conversion of forest land use to residential land use results in a 2 ug/L (15%) increase in the total in-lake phosphorus concentration. This increase in phosphorus results in a noticeable water quality change. The estimated 2 ug/L increase in total phosphorus concentrations results in an estimated decrease in the average annual Secchi disc transparency of 2.3 feet. This is based upon the regression relationship between total phosphorus and Secchi disk depth as determined in the trophic response module in the WILMS model (Panuska and Wilson, 1994). This predicted decrease in Secchi disk depth would be an overall reduction in water clarity of 16% based upon the 1998-99 average summer Secchi disk depth of 14.4 feet which was noted for Blueberry Lake.

5.0 Recommendations and Management Actions

The development of a comprehensive lake management plan for Blueberry Lake is recommended in order to prevent any further degradation of the water quality. This plan should include:

1. The development of a long-term water quality goal for the lake;
2. An evaluation of different watershed development scenarios to determine acceptable (i.e., the water quality of the lake is within the established goal) and unacceptable (i.e., the water quality of the lake fails to meet its goal) development options;
3. Recommendations for ultimate watershed development relative to achieving the lake's water quality goal (i.e. minimum lot size, maximum area of impervious surface, etc.);
4. Recommendations for watershed best management practices under future development conditions;
5. Recommendations for ordinances to control watershed development;
6. Recommendations for the riparian owner management practices;
7. Recommendations for best management plans to protect sensitive lands including wetlands, steep slopes, undeveloped land, shoreline, etc.;
8. Algal study to determine species abundance and distribution;
9. A macrophyte study to determine the spatial coverage, density, and species composition of the macrophyte community. A special area of concern would be identification of Eurasian Water Milfoil;
10. Volunteer monitoring program to establish a long-term water quality database.

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