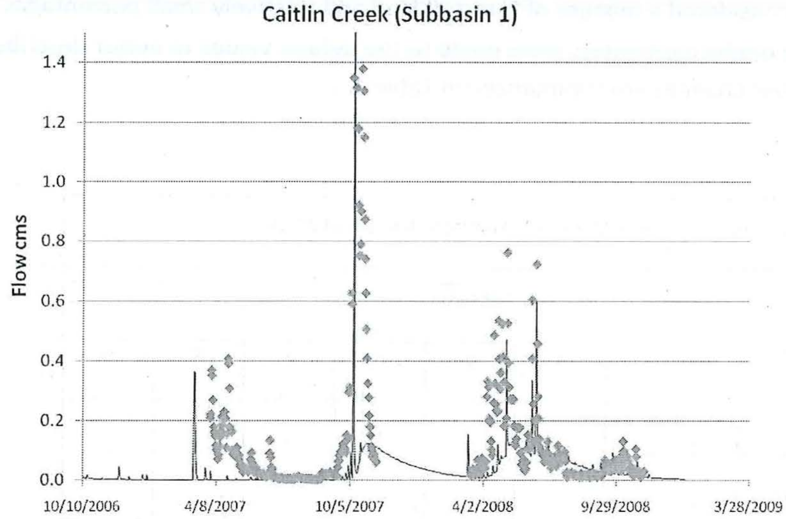
Dissolved oxygen measurements Upper St. Croix Lake (continued).

Collection Date	Depth ft	Dissolved Oxygen mg/L	Collection Date	Depth ft	Dissolved Oxygen mg/L	Collection Date	Depth ft	Dissolved Oxygen mg/L
10/7/2003	15	7	5/9/2005	12	7	3/21/2006	10	7.00
10/7/2003	18	7	5/9/2005	15	7	3/21/2006	11	7.01
5/10/2004	3	9	5/9/2005	18	7	3/21/2006	12	7.00
5/10/2004	6	9	6/22/2005	3	7	3/21/2006	13	6.94
5/10/2004	9	9	6/22/2005	6	7	3/21/2006	14	6.80
5/10/2004	12	9	6/22/2005	9	7	3/21/2006	15	6.65
5/10/2004	15	9	6/22/2005	12	7	3/21/2006	16	6.70
5/10/2004	18	9	6/22/2005	15	7	3/21/2006	17	5.00
6/22/2004	3	7	6/22/2005	18	7	3/21/2006	18	1.32
6/22/2004	6	7	7/20/2005	3	7	4/27/2007	2	10.77
6/22/2004	9	7	7/20/2005	6	7	4/28/2007	4	10.81
6/22/2004	12	7	7/20/2005	9	7	4/29/2007	6	11.03
6/22/2004	15	7	7/20/2005	12	7	4/30/2007	8	11.11
6/22/2004	18	7	7/20/2005	15	7	5/1/2007	10	10.93
7/20/2004	3	7	7/20/2005	18	6	5/2/2007	12	10.67
7/20/2004	6	7	9/6/2005	3	7	5/3/2007	14	10.50
7/20/2004	9	7	9/6/2005	6	7	5/4/2007	16	9.70
7/20/2004	12	7	9/6/2005	9	7	5/5/2007	18	8.72
7/20/2004	15	7	9/6/2005	12	7	5/6/2007	20	2.2
7/20/2004	18	7	9/6/2005	15	7	10/26/2007	1	8.18
8/29/2004	3	7	9/6/2005	18	7	10/27/2007	2	7.86
8/29/2004	6	7	10/23/2005	3	7	10/28/2007	3	7.82
8/29/2004	9	7	10/23/2005	6	7	10/29/2007	4	7.85
8/29/2004	12	7	10/23/2005	9	7	10/30/2007	5	7.75
8/29/2004	15	7	10/23/2005	12	7	10/31/2007	6	7.63
8/29/2004	18	7	10/23/2005	15	7	11/1/2007	7	7.65
10/11/2004	3	7	3/21/2006	1	8.10	11/2/2007	8	7.64
10/11/2004	6	7	3/21/2006	2	8.10	11/3/2007	9	7.59
10/11/2004	9	7	3/21/2006	3	7.20	11/4/2007	10	7.58
10/11/2004	12	7	3/21/2006	4	6.71	11/5/2007	11	7.67
10/11/2004	15	7	3/21/2006	5	6.50	11/6/2007	13	7.67
10/11/2004	18	7	3/21/2006	6	6.70	11/7/2007	15	7.67
5/9/2005	3	7	3/21/2006	7	6.80	11/8/2007	17	7.73
5/9/2005	6	7	3/21/2006	8	6.90	11/9/2007	19	7.66
5/9/2005	9	7	3/21/2006	9	6.90	11/10/2007	21	7.5

APPENDIX B

Dissolved oxygen measurements Upper St. Croix Lake.

Collection Date	Depth ft	Dissolved Oxygen mg/L	Collection Date	Depth ft	Dissolved Oxygen mg/L	Collection Date	Depth ft	Dissolved Oxygen mg/L
9/27/1999	3	8	8/15/2001	3	7	7/30/2002	18	3
9/27/1999	6	8	8/15/2001	6	7	9/11/2002	3	8
9/27/1999	9	8	8/15/2001	9	7	9/11/2002	6	8
9/27/1999	12	8	8/15/2001	12	7	9/11/2002	9	8
9/27/1999	15	8	8/15/2001	15	7	9/11/2002	12	8
9/27/1999	18	8	8/15/2001	18	7	9/11/2002	15	8
6/26/2000	3	10	9/12/2001	6	7	9/11/2002	18	8
6/26/2000	6	9	9/12/2001	9	7	10/27/2002	3	8
6/26/2000	9	9	9/12/2001	12	7	10/27/2002	6	8
6/26/2000	12	10	9/12/2001	15	7	10/27/2002	9	8
6/26/2000	15	8	9/12/2001	18	7	10/27/2002	12	8
6/26/2000	18	8	10/9/2001	3	7	10/27/2002	18	8
7/25/2000	3	7	10/9/2001	6	7	5/31/2003	3	7
7/25/2000	6	8	10/9/2001	9	7	5/31/2003	6	7
7/25/2000	9	7	10/9/2001	12	7	5/31/2003	9	7
7/25/2000	12	8	10/9/2001	15	7	5/31/2003	12	7
9/10/2000	3	9	10/9/2001	18	7	5/31/2003	15	7
9/10/2000	6	8	5/21/2002	3	12	5/31/2003	18	7
9/10/2000	9	9	5/21/2002	6	12	7/22/2003	3	7
9/10/2000	12	10	5/21/2002	9	12	7/22/2003	6	7
9/10/2000	15	12	5/21/2002	12	12	7/22/2003	9	7
9/10/2000	18	13	5/21/2002	15	12	7/22/2003	12	7
10/11/2000	3	11	5/21/2002	18	12	7/22/2003	15	7
10/11/2000	6	11	6/30/2002	3	7	7/22/2003	18	7
10/11/2000	9	16	6/30/2002	6	7	8/31/2003	3	7
10/11/2000	12	12	6/30/2002	9	7	8/31/2003	6	7
10/11/2000	15	12	6/30/2002	12	7	8/31/2003	9	7
10/11/2000	18	18	6/30/2002	15	7	8/31/2003	12	7
7/10/2001	3	9	6/30/2002	18	4	8/31/2003	15	7
7/10/2001	6	10	7/30/2002	3	7	8/31/2003	18	7
7/10/2001	9	14	7/30/2002	6	7	10/7/2003	3	7
7/10/2001	12	12	7/30/2002	9	7	10/7/2003	6	7
7/10/2001	15	9	7/30/2002	12	7	10/7/2003	9	7
7/10/2001	18	6	7/30/2002	15	6	10/7/2003	12	7



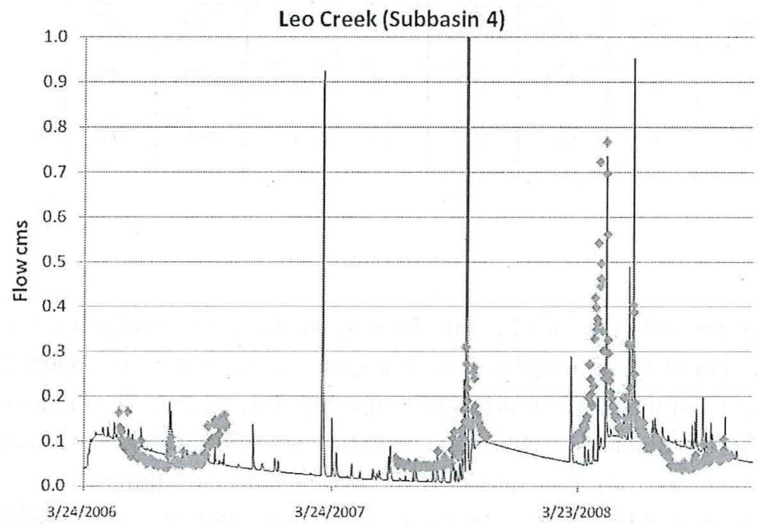


Figure 2. Comparison of SWAT simulated (solid line) and measured (diamonds) flows at two of the monitoring locations. Flow shown in cubic meters per second (cms).

The landuse in the watershed was considered a mixture of forested land and relatively small percentages of impervious area. Minor changes to model parameters were made to the default values to better describe the watershed and fit the data. Those changes are summarized in Table 1.

Table 1. Adjustments in Upper St. Croix Lake Watershed SWAT Model									
Parameter	Subbasin								
	1	2	3	4	5	6	7	8	9
% Impervious (Directly Connected)	2	2	2	2	2	2	2	2	2
NRCS CN	55	65	65	55	55	50	50	50	50
EPCO	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
K_{sat} (surface)	50	50	50	50	50	50	100	100	100
GW Delay (d)	60	60	60	200	200	200	200	200	200
Alpha BF	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Model Results

The SWAT model was used to simulate streamflow in the nine subbasins during the monitoring period. A nine year simulation was used to allow a model "warm-up" period prior to the monitored years. Figure 2 shows the hydrologic simulation of several of the monitoring locations for the study period. The model was generally able to simulate the observed variation in flow over time. For purposes of providing an estimate of the average daily flow from the watershed into Upper St. Croix Lake, this level of calibration was considered sufficient. The model was then used to develop a long-term simulation (1971 through 2008) for use in the hydrologic component of the lake P model. The daily streamflow was simulated by summing the results from the model reach file for the nine subwatersheds.

APPENDIX A

SWAT MODEL OF THE UPPER ST. CROIX WATERSHED - 2009

Introduction

The Soil and Water Assessment Tool (SWAT) is a simulation model that describes the movement of water within watersheds by simulating soil moisture, crop growth and runoff from land. It was used in the Upper St. Croix Lake water quality model to provide a daily runoff estimate that could be used to understand watershed loading contributions in the long-term simulations of lake water quality. This report provides an overview of the model and a discussion of its ability to simulate streamflow in the Upper St. Croix watershed.

Model Inputs

The Upper St. Croix Watershed SWAT Model (USC_SWAT) was designed with nine contributing subwatersheds as shown in the Figure 1 below. This is the topographically draining portion of the watershed and does not include the entire groundwater watershed for the lake. Those additional contributing areas were included separately as described in the hydrologic modeling report. In the USC_SWAT, the nine sub watersheds were simulated separately and the results from all were combined to represent the water moving from the watershed to Upper St. Croix Lake.

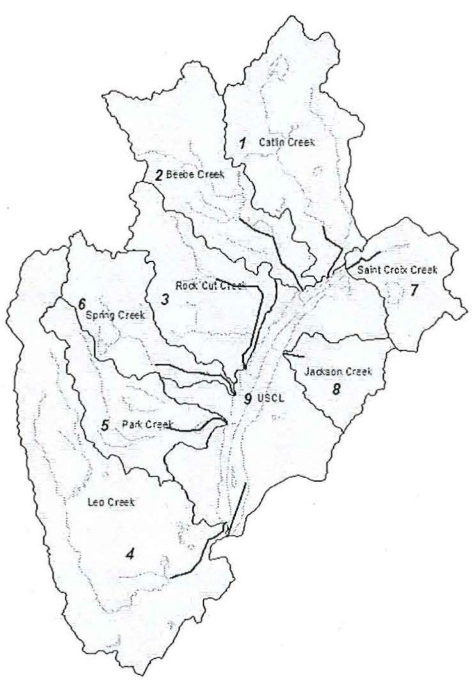


Figure 1. Subwatershed delineation of the Upper St. Croix lake watershed used in the SWAT model.

References

Chapra, S.C. and R.P. Canale. 1991. Long-term phenomenological model of phosphorus and oxygen for stratified lakes. Water Research 25:707-715.

Fisher, L.H. and T.M. Wood. 2004. Effect of water –column pH on sediment-phosphorus release rates in Upper Klamath Lake, Oregon, 2001. U.S.G.S. Water Resources Investigations Report 03-4271.

Hoverson, D. and P. McGinley. 2007. Internal phosphorus loading from sediment in Upper St. Croix Lake, Douglas County, WI. Report from the Center for Watershed Science and Education, University of Wisconsin Stevens Point.

Jensen, J.P., A.R. Pedersen, E. Jeppesen and M. Sondergaard. 2006. An empirical model describing the seasonal dynamics of phosphorus in 16 shallow eutrophic lakes after external loading reduction. Limnology and Oceanography 51:791-800.

Sondergaard, M., J.P. Jensen and E. Jeppesen. 2001. Retention and internal loading of phosphorus in shallow, eutrophic lakes. The Scientific World 1:427-442.

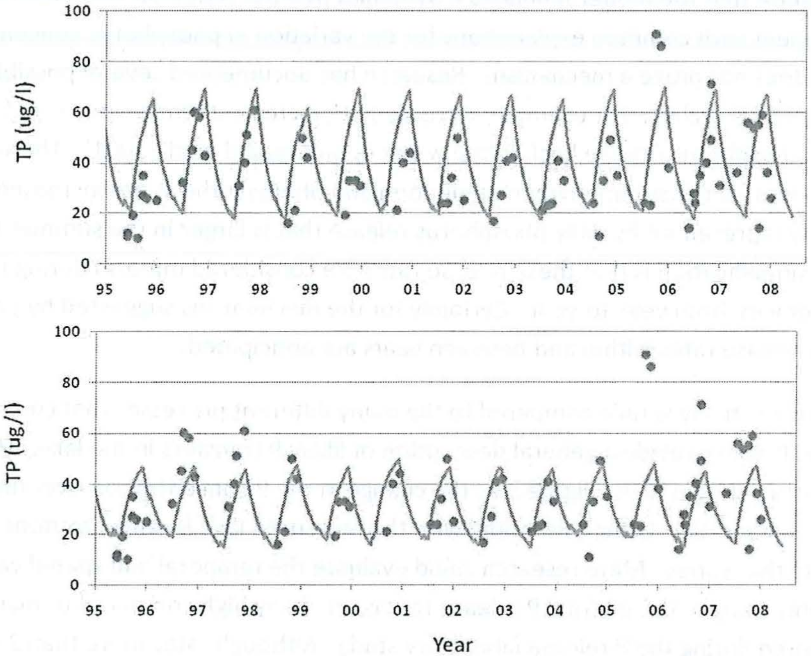


Figure 3. Example results from the P model shown as the concentration of P over time in Upper St. Croix Lake. Parameters used in this simulation are summarized in Table 3 with variation in summer (May through September) internal P release rate of 2.5 mg/m^2/day (upper) and 1.5 mg/m^2/day (lower).

The hydrology and P budget models were used to develop an average annual P budget for the lake. Table 4 shows the average annual (calendar year) P additions to the lake over the thirty-eight years from 1971 through 2008. In this model, the phosphorus that enters the lake either leaves the lake in the outflow or is settled in the lake. On an average annual basis, the quantity of P leaving in the outflow is approximately 511-676 kilograms and the quantity settling in the lake is 1052-1417 kilograms where the range represents results a summer sediment P release rate of 1.5 mg/m^2/d to 2.5 mg/m^2/d, respectively. This represents the average over the thirty eight year simulation, and there are year-to-year variations in external loading resulting from variations in precipitation and runoff.

The results of this simple modeling are consistent with a lake system that experiences significant internal turnover of phosphorus but a lower annual output from the lake. This cycle of release and settling leads to substantial inter-annual variation in phosphorus concentration, consistent with the observed range from 20 to 60 ug/l for growing season total phosphorus concentrations.

Table 4. Average Annual P Budget (1989-2008)

Source	P Quantity
Atmospheric Deposition	78
Streams and Groundwater	647
Internal Release	831-1361
Total Entering Lake	1563-2086
Total Leaving Lake in Outflow	507-673

It is important to recognize that the model simulates P dynamics (release based on lake area and a uniform settling velocity) consistent with common explanations for the variation in phosphorus concentration during the year, but it does not prove a mechanism. Research has documented several possible controls over the internal phosphorus cycling. For example, increased pH, increased temperature, and lower oxygen all lead to increases in phosphorus release back to the water (Sondergaard et al., 2001). These conditions are all likely more prevalent in the summer when respiration and photosynthesis are increased. In this model, these are simply represented by daily phosphorus release that is larger in the summer than in the winter. An important simplification is that these release rates are considered uniform during those time periods and they do not vary from year-to-year. Certainly for the mechanisms suggested by previous research, variations in release rates within and between years are anticipated.

Although the P model is relatively simple compared to the many different processes that control P behavior in Upper St. Croix Lake, it does provide a general description of likely P transfers in the lake. The results of the P model simulation are shown in the Figure 3 as the change in the P concentration over time for two different sediment P release rates. Using this model with the measured lake P concentrations suggests a sediment P release rate that varies. More research could evaluate the temporal and spatial variations of P release in the lake. Interestingly, the internal P release rate is relatively high compared to many of the sediment cores monitored during the P release laboratory study. Although rates more than 3 $mg/m^2/day$ were measured in several cores, most were less than 1 $mg/m^2/day$. The apparent sediment release rate of phosphorus in the lake is greater than those that were measured in the laboratory studies. This result is similar to that observed in Upper Klamath Lake where laboratory and field based measurements were compared (Fisher and Wood, 2004). In that study, the field-based estimates were almost ten times the release rate measured in the laboratory.

Table 3. Parameter Values Used in P Model

Parameter	Value
Groundwater P	20 ug/l
Stream P	50 ug/l
P Settling Velocity	10 m/year
Atmospheric Deposition	0.2 lb/acre/year
Summer Sediment P Release (June-Sept)	1.5 – 2.5 mg/m2/day
Non-Summer Sediment P Release	0.05 mg/m2/day

in the lake. The model adjusted the mass of P in the lake daily and used that and the daily lake volume to calculate the concentration in the lake.

The rate of P entering in streamflow and groundwater was estimated for each day by multiplying the flow and the concentration of P in that water:

Rate of P Entering in Water = Water Flow Rate x P Concentration

The water flow rate was based on the results of the hydrologic model, with daily streamflow volumes from the SWAT model and daily groundwater volumes from the estimated recharge on those additional groundwater contributing areas. The P concentration for streamflow was assumed constant at 0.05 mg/l. The P concentration for groundwater was estimated to be 0.02 mg/l.

The atmospheric deposition was assumed to be 0.05 kg/ha-year based on previous studies (WILMS).

The internal release of P was based on the results of the sediment P release experiment performed in the Center for Watershed Science and Education. That study found P release ranging from very low to 3 $mg/m^2/day$. Although multiple mechanisms could lead to internal release of P, they are combined within this internal release term. The release is expressed as mass per unit area per time in the model. The laboratory sediment P release appeared to be generally higher under anaerobic conditions, although there was considerable variability in the laboratory measurements. In Upper St. Croix Lake, sediment anoxia is likely at some locations and at some times during the summer. Because anoxia is linked to microbial respiration, it is also expected that it would be greater during warmer times of the year. In the model, the internal P release (sediment release) was included with separate release rates for the warmer growing season months (June-September) when warmer temperatures and some anoxia were likely to increase release rates.

The rate of P leaving the lake was based on the lake concentration on the previous day and the rate of water leaving calculated as described in the hydrologic budget:

Rate of P Leaving in Water = Water Flow Rate x P Concentration

The other removal mechanism for P is sedimentation in the lake. P in biomass and associated with particles will be settling in the lake. The approach used to describe P sedimentation is a settling velocity approach (Chapra, 1997):

Rate of P Settling = Settling Velocity x Lake Area x P Concentration in Water

Where the rate of P settling is proportional to the concentration of P and a settling velocity. Typical settling velocities are 5 to 20 meter/year, although these are frequently described as apparent or net settling velocities because they may also include P release from the sediment . This approach is frequently applied in annual simulations where the results represent an average for the year. The P budget model developed here was developed using a daily time-step using a constant settling velocity and a P concentration from the previous day. A recent study of sixteen shallow Danish lakes described by Jensen et al. (2006) also used a constant sedimentation rate (17 m/year).

increase in water stored during the summer is approximately 30 to 50 million cubic feet (0.3×10^8 to 0.5×10^8 ft^3). Assuming a constant lake area of 855 acres, this would lead to increased lake surface elevation of 10 to 16 inches.

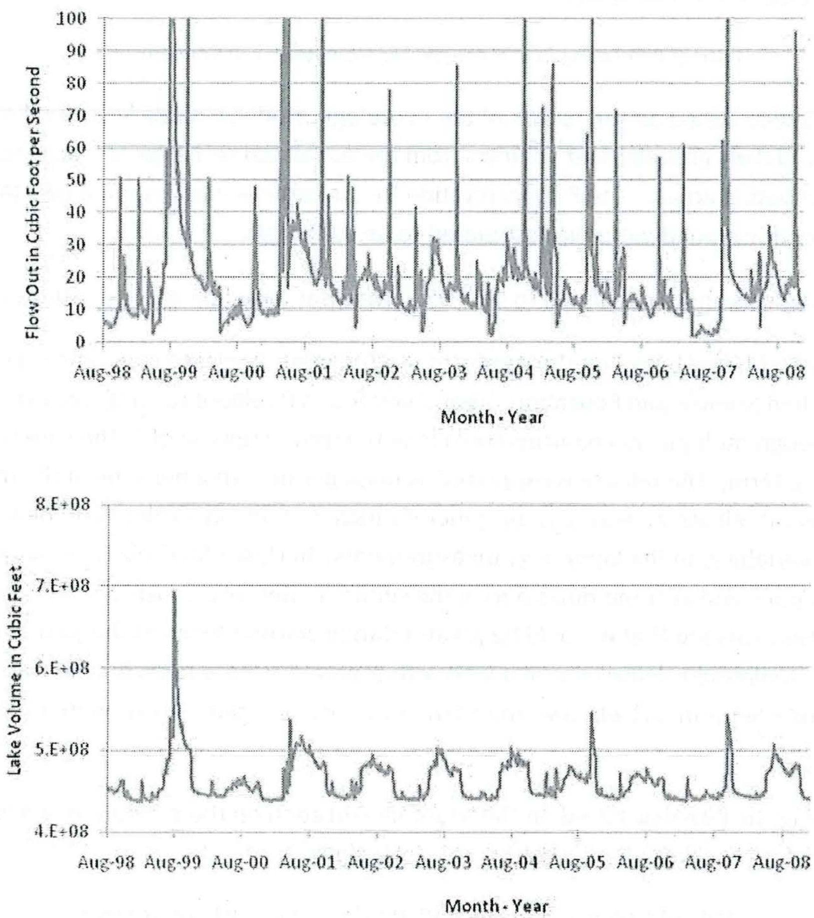


Figure 2. Variation in flow rate out of the lake (upper) and lake volume (lower) over time calculated using the hydrologic model. The lake outflow varied seasonally with a constant (A) of 12 for summer (June-September) and 58 the remainder of the year.

Phosphorus Model

The phosphorus (P) budget for the lake was also developed using a mass balance around the water in the lake for each time step:

Change in P Mass in Lake Water = Rate of P Entering – Rate of P Leaving

Sources of P to the lake include streamflow, groundwater, atmospheric deposition, and internal P release. The internal P release could have several sources, diffusion of P from sediment pore water, aquatic plant P release and decay, resuspension of high P sediments, and mixing of surface water with deeper, higher P water. Losses of P from the lake include transport of P in the water leaving the lake and sedimentation of P

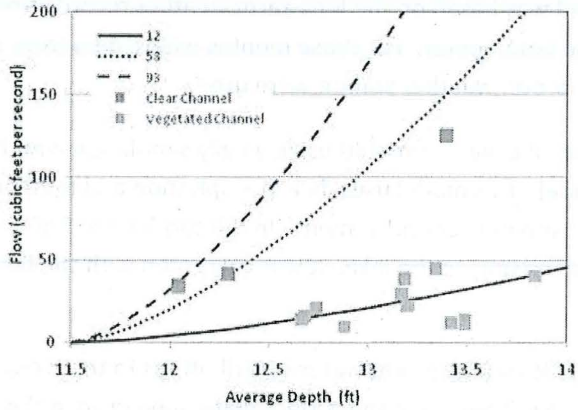


Figure 1. Variation in outflow from Upper St. Croix Lake as average lake depth increases for different values of the flow resistance constant A. Level logger readings at Cut Away Dam were adjusted to an assumed base (no-flow) lake elevation of 11.5 feet.

Evaporation from the lake was estimated assuming a uniform evaporation rate of 0.2 inches per day from May through September. The long-term average daily pan evaporation varies from 0.26 inches /day in July to 0.16 inches/day in September based on records collected in St. Paul Minnesota (climate.umn.edu/img/wxsta/pan-evaporation.htm), but it was assumed that a more refined estimate of daily variation in evaporation was not necessary in this model.

The hydrologic model was implemented in a spreadsheet where the inputs and outputs were used to adjust the lake volume from the previous day. Outflow from the lake was based on the mean depth (volume/area) from the previous day. In this simple model, the lake area was assumed constant and did not vary with lake depth. The long-term (1971-2008) water budget is summarized in Table 1.

Table 1. Long-Term Simulated Hydrologic Budget	
Source	**Average Flow (cfs)**
Precipitation	3.0
Groundwater & Streamflow	15.1
Evaporation	3.0

The average outflow from the lake would be the difference between inputs (precipitation, streamflow and groundwater) and other outputs (evaporation). The resulting average outflow is 15.1 cfs. The pattern of flow out of the lake as estimated by the simulation tool is shown in Figure 2. Based on the results, several years of relatively high flow (1999, 2001) preceded years of relatively low flow. Year 2007 in particular is predicted to have had little water leaving the lake.

The time-varying nature of streamflow, precipitation, evaporation and discharge from the lake lead to variations in water volume in the lake. Figure 2 below shows the results of these simulations and the variations in the water volume of the lake that result. The reduced lake outflow rate during the summer leads to an increase in water stored during that time. Based on the results from this simulation, a typical

Precipitation in the watershed was based on the long-term weather records from Solon Springs obtained through the National Climatic Data Center. For those months where data from Solon Springs was not available, records from the Gordon weather station were used.

Runoff from tributaries to the lake was estimated using a daily simulation with the Soil and Water Assessment Tool (SWAT) model. This model uses daily precipitation and temperature to simulate plant growth, hydrology, sediment and nutrient movement. In this model, the SWAT output was used to estimate the daily flow in the streams to the lake. It was calibrated with the flow data collected during the 2006-2008 research study.

The SWAT model output includes some groundwater contributions to the streams. Because the groundwater contributing area is larger than the surface watershed used in the SWAT simulation, an additional groundwater contributing area was included in the model. The daily contribution of groundwater from this additional area was assumed to be 1/365 of the annual groundwater recharge.

Water leaves Upper St. Croix Lake through the outlet at the southern end of the lake. The daily hydrologic budget requires an estimate of the flow rate out of the lake. A simple relationship between lake height and flow out of the lake was developed where the rate of water leaving the lake was:

$$\text{Discharge Rate} = A * H^{1.5}$$

H is the difference between the water elevation in the lake and a base elevation where no flow out of the lake would occur, and A is a constant representing the resistance to flow in the channel. A value of 11.5 feet was used as a base elevation where there would be no flow out of the lake, based on using an elevation just below the mean depth of 12 feet in the lake. The Figure below shows how the discharge changes with height of the lake for different values of the constant A. Comparison to measurements made at Cut Away dam suggest a value of 12 for vegetated conditions and 58 for clear conditions could provide a general approximation to the flow which was observed at different times of the year when H is expressed in feet and the discharge rate is given in cubic feet per second (cfs).

Appendix A

HYDROLOGY AND PHOSPHORUS MODEL
FOR UPPER ST. CROIX LAKE,
DOUGLAS COUNTY, WISCONSIN[1]

Background

This report describes the development and application of a water quality simulation model to better understand the hydrology and phosphorus in Upper St. Croix Lake in Douglas County, Wisconsin. A primary objective in developing the simulation tool was to be able to use the long-term water quality data record, both year-to-year and within-year phosphorus measurements, to more accurately separate internal and external controls over phosphorus concentrations in the lake.

This model was developed as part of a research study of the lake performed by the Center for Watershed Science and Education at the University of Wisconsin-Stevens Point.

Model Overview

Lake water quality modeling has usually relied on steady-state modeling of lakes based on an annual hydrologic and phosphorus budgets. This can be a very powerful tool to relate the nutrient loading to measured water quality. This approach does not, however, explain variations in phosphorus concentration during the year, and instead relates annual loading only an average phosphorus concentration. This may reduce the amount of information that can be obtained from the phosphorus concentration pattern during the year. In the Upper St. Croix Lake modeling effort described here, an alternative modeling strategy was attempted. A model was developed for the lake based on a daily hydrologic and phosphorus budget and combined with more than a decade of monthly summer phosphorus monitoring. The model includes relatively simple descriptions of the dynamics of phosphorus in the lake simulated on a daily time-step. The results were compared to the measured data, and long-term simulations were used to improve an estimate of the relative importance of internal and external phosphorus sources.

Hydrology Model

The hydrology model was developed using the concept of a mass balance. By accounting for the water entering and leaving the lake, the change in the water volume in the lake was calculated over time. The hydrologic or water budget for the lake can be expressed for each time step as:

Change in Water Volume in the Lake = Volume of Water Entering – Volume of Water Leaving

Sources of water to the lake that were included in the simulation were: 1) precipitation directly on the lake; 2) runoff into the lake and through the tributaries to the lake; and, 3) groundwater entering the lake. Water was assumed to leave the lake through: 1) the outlet from the lake; and, 2) evaporation from the lake.

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[1] *This technical report was prepared by the Center for Watershed Science and Education at the University of Wisconsin Stevens Point. Contact Paul McGinley at (715) 346-4501 or paul.mcginley@uwsp.edu with questions or comments.*

Works Cited

Garrison, P. 2004. Paleoecological Study of Upper St. Croix Lake. Wisconsin Department of Natural Resources.

Hlina, Paul et al. 1997. Non-Point Source Control Plan for the Upper St. Croix – Eau Claire Rivers Priority Watershed. Department of Natural Resources, Madison, Wisconsin.

Manners, N., J.Hansen, and J. Zaengle. 2001. Pilot Study of Fluctuating Lake Levels on the Upper St. Croix Lake, Southwestern Douglas County, Wisconsin. Department of Biology and Earth Science University of Wisconsin-Superior.

Shaw, B., C. Mechenich, and L. Klessig. 2004. Understanding Lake Data, University of Wisconsin Stevens Point, University of Wisconsin Extension.

chambers can be added to a septic system to remove phosphorus. Selecting household products that don't contain phosphorus (and other harmful chemicals) can also be beneficial.

- Internal sources of phosphorus are an important part of the lake's phosphorus budget. Minimize the amount of exposed sediment in the shallows by leaving aquatic plants in place. Motor boats (especially large boats) stir up exposed sediment. Operating motor boats in depths less than 4 feet should be minimized and start ups in this zone should be avoided.
- Exploration of pilot tests of treatments could be conducted although these approaches may only provide short term relief, are generally expensive, and won't solve the problem over the long term. These treatments include the application of alum to seal off the resuspension of nutrients from the sediments for several years. Removal of sediments may be another option but would significantly disturb the lake's ecosystem and runs a large risk for the establishment of invasive aquatic species.

Strategic Plan

The information provided in this report was presented and used to develop a strategic plan for the reduction of phosphorus in Upper St. Croix Lake. The planning process involved several meeting that were attended by community members including faculty and students from the School District of Solin Springs, and representatives of Village of Solin Springs, Town of Solin Springs, the County Board, the Wisconsin Department of Natural Resources, Upper St. Croix Lake Association, and Friends of the St. Croix Headwaters. Attendees of this process were provided a summary document of the results of this study and the results of the strategic planning process can be found in a document titled *Upper St. Croix Lake Strategic Plan, January 2010.*

Conclusions and Recommendations

Upper St. Croix Lake shows signs of moderate nutrient enrichment and a shift towards dominance by less desirable blue-green algae. Sources of nutrients are both natural and from human inputs from land management practices and other activities. Physical conditions such as drought, geological conditions, or the shape of the lake can't be controlled. Reducing phosphorus inputs to Upper St. Croix Lake will improve conditions over the long term, although these changes may be slow. *Taking no action to reduce phosphorus inputs to the lake will likely result in increased frequency and magnitude of algal blooms.* Allowing an increase in phosphorus additions to the lake *will* result in increased frequency and magnitude of algae blooms with the potential of fish kills due to oxygen depletion.

Water quality in a lake is a reflection of land use practices in its watershed and this is certainly the case with Upper St. Croix Lake. In the summer Upper St. Croix Lake has high concentrations of phosphorus. <u>Action should be taken to reduce phosphorus inputs to the lake and its tributaries.</u> Actions to consider:

- Disseminating information is an important part of helping people understand why land management practices need to be altered. Information can be exchanged in a variety of creative ways including the use of demonstration projects in public places (with signage). There are a number of sites around Solon Springs and Upper St. Croix Lake that could be used as demonstration sites. Workshops, brochures, and newsletters are other means that can be used to get the word out.
- Decrease direct runoff to Upper St. Croix Lake and its tributaries. This may include designing water conduits to direct runoff to retention basins and rain gardens and use of pervious pavement in parking lots. Road crossings over tributaries should direct water to depressions where water can infiltrate to groundwater or sediments can settle and be filtered by vegetation before flowing into surface water. Paths that provide access to the lake should be designed to minimize direct runoff to the lake; this can be accomplished by using a serpentine design and materials that are not easily eroded. Tall vegetation (grasses and forbs) should be established adjacent to the path to reduce direct runoff to the lake and to help filter runoff. Trees and shrubs reduce the direct impact of raindrops which results in greater erosive potential and should be used in landscape design.
- Erosion from construction, forestry practices, clearing below power lines, and other activities that make soil susceptible to erosion should be controlled. When soil is exposed water running off of these areas should be prevented and cover should be re-established as quickly as possible.
- Vegetative shoreland buffers should be protected where they are already established and restored where they have been removed. The buffers should be at least 35 feet deep, which is consistent with the state shoreland zoning ordinance. The County should implement policies to bring all properties into compliance with these standards.
- Fertilizers containing phosphorus should not be used. Most soils have sufficient phosphorus concentrations to maintain a vegetative cover. If a soil is deficient in phosphorus it may be applied according to recommendations based on soil test results.
- Septic systems should be sited as far from waterways as possible or tertiary treatment systems should be included on the systems. Septic system effluent is rich in phosphorus. Over time phosphorus will move from a septic system drainfield to groundwater which in turn discharges to surface water. Traditional septic systems do not remove phosphorus but additional treatment

Table 5. Parameters used in phosphorus model for Upper St. Croix Lake.

Parameter	Value
Lake Area	855 acre
Additional Groundwater Area	5000 acre
Groundwater Recharge	10"/year
Groundwater P	20 ug/L
Stream P	50 ug/L
P Settling Velocity	10 m/year
Atmospheric Deposition	0.05 lb/acre/year
Summer Sediment P Release (June-Sept)	3.0 mg/m2/day
Non-Summer Sediment P Release	0.05 mg/m2/day

The hydrology and phosphorus budget models were used to develop an average annual phosphorus budget for Upper St. Croix Lake. Table 6 shows the average annual phosphorus additions to the lake over thirty-eight years from 1971 through 2008. The phosphorus that enters the lake either leaves the lake in the outflow or is settled in the lake. On an average annual basis, the quantity of phosphorus leaving in the outflow is approximately 1115-1481 pounds and the quantity settling in the lake is 2322-3108 pounds. Internal loading is clearly the primary source of phosphorus in Upper St. Croix Lake. This is phosphorus that is being released from sediments. A band-aid such as the use of alum could be used to temporarily control this phosphorus release; however, long term reductions of internal loading must be accomplished by reducing inputs of phosphorus to the lake from the surrounding landscape.

Table 6. Average annual phosphorus budget for Upper St. Croix Lake.

Source	P Quantity pounds/year
Atmospheric Deposition	172
Streams and Groundwater	1423
Internal Release	1828-2994
Total Entering Lake	3437-4589
Total Leaving Lake in Outflow	1115-1481

Table 5.

Several models were developed to evaluate the sources of water and phosphorus entering and exiting Upper St Croix Lake. Details of the estimates may be found in the paper *Hydrology and Phosphorus Model for Upper St. Croix Lake, Douglas County, Wisconsin* (McGinley, 2009). Excerpts from the report follow. The hydrology modeled was based on the concept of mass balance which involves accounting for the inputs and outputs of water. Sources of water to the lake included: precipitation directly on the lake, runoff into the lake and through the tributaries to the lake, and groundwater entering the lake. Water leaves the lake via the lake's outlet and evaporation from the lake. The resulting long-term water budget is displayed in Table 4.

Table 4. Long-term simulated hydrologic budget for Upper St. Croix Lake. McGinley, 2009.

Source	Average Flow (cfs)
Precipitation	3.0
Groundwater and Streamflow	15.1
Evaporation	3.0

The phosphorus model was also based on a mass balance and was developed using water quality, results of the hydrologic model, daily streamflow and volumes from a SWAT model, and daily groundwater volumes from the estimated recharge on additional groundwater contributing areas. Internal loading and settling velocities were also utilized in the phosphorus model (Table 6). Precipitation data from 1995 to 2008 was used to generate the model results shown in Figure 28.

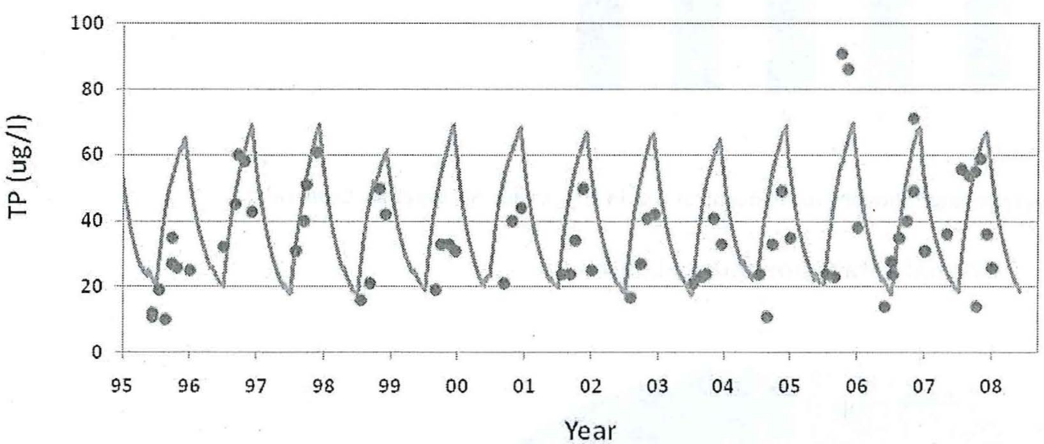

Figure 28. Results from the phosphorus model shown as the concentration of total phosphorus over time St. Croix Lake. Parameters used in this model are shown in

The total amount of phosphorus that is delivered to Upper St. Croix Lake from a tributary (mass) is calculated by multiplying the concentrations in the water by the volume of water moving through the stream each year. Some tributaries can have high concentrations of phosphorus but a low volume of water, ultimately delivering a lesser mass of phosphorus to the lake than other tributaries with lower concentrations and higher volumes. For example, although average TP concentrations in samples were similar in Leo and Rock Cut Creeks, the greater volume of water moving through Catlin and Leo Creeks resulted in a greater amount (mass) of TP delivery to Upper St. Croix Lake (Figure 26 and Figure 27). Looking at the mass of phosphorus loading from a given stream can provide insight into where funds and educational activities might be focused. We suggest emphasis on Leo Creek sub-watershed and the unmonitored part of the watershed. Although TP mass from Catlin Creek is large, other parameters and additional exploration during this study suggest that much of the TP in the system is of natural origin. The "unmonitored" areas of the watersheds are lands that drain directly to Upper St. Croix Lake. This includes the majority of residences around Upper St. Croix Lake and parts of Solin Springs.

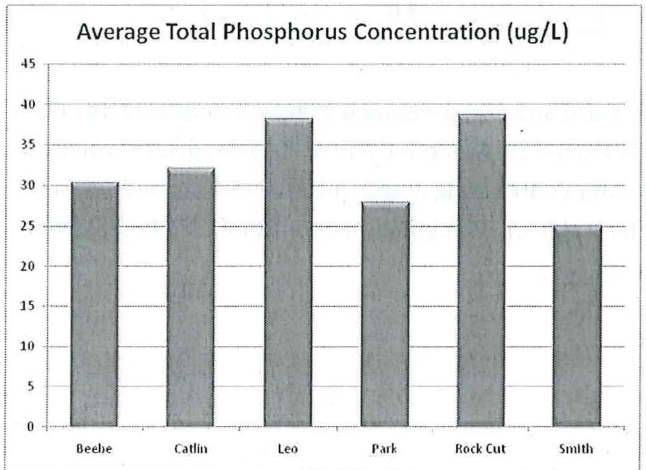

Figure 26. Average total phosphorus concentrations in tributaries of Upper St. Croix Lake.

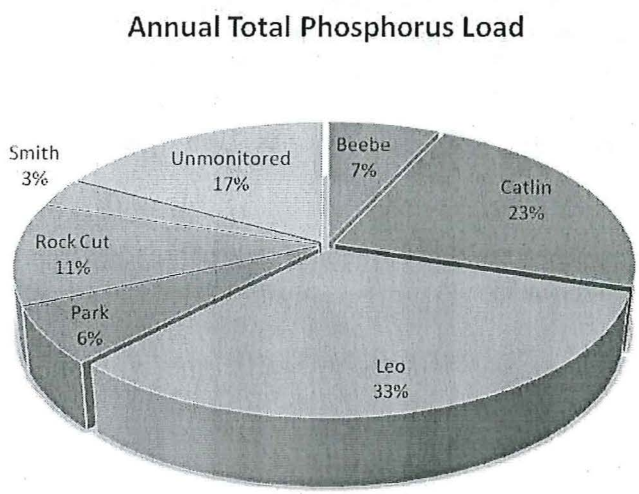

Figure 27. Estimated total phosphorous loads for the monitored tributaries of Upper St Croix Lake.

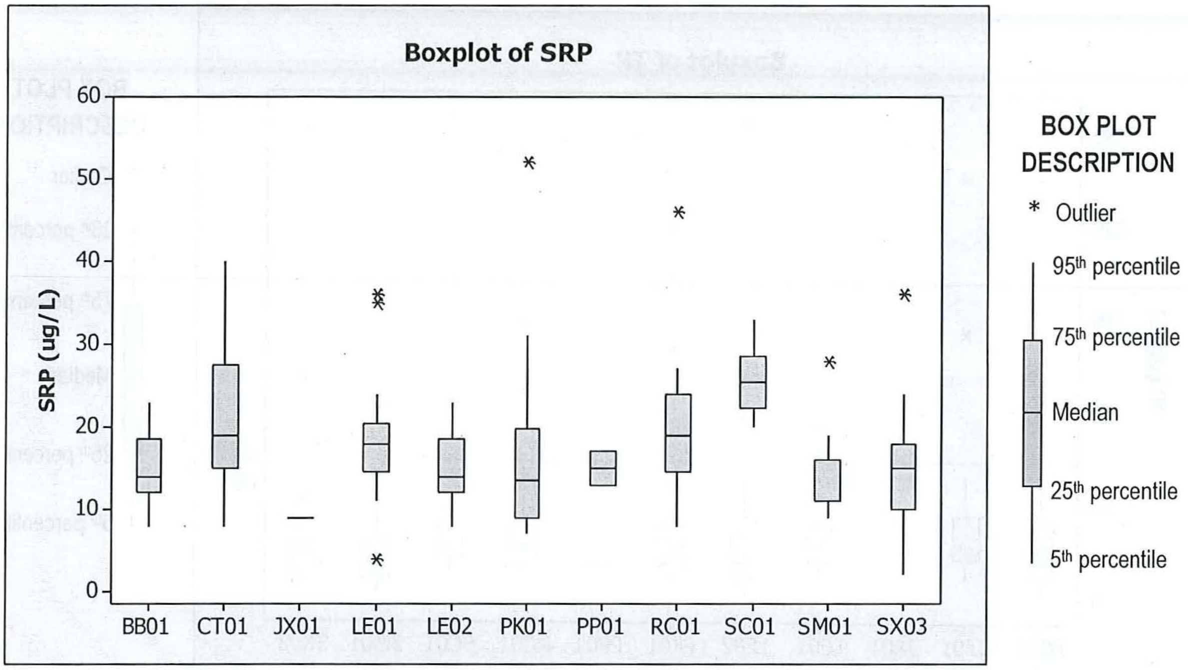

Figure 24. Ranges of soluble reactive phosphorus concentrations measured in USCL tributaries 2006-2009. The asterisks on the graph indicates outliers. An extreme value (186 µg/L on 8/27/2008) has been removed from Catlin Creek to allow for the resolution of the other samples.

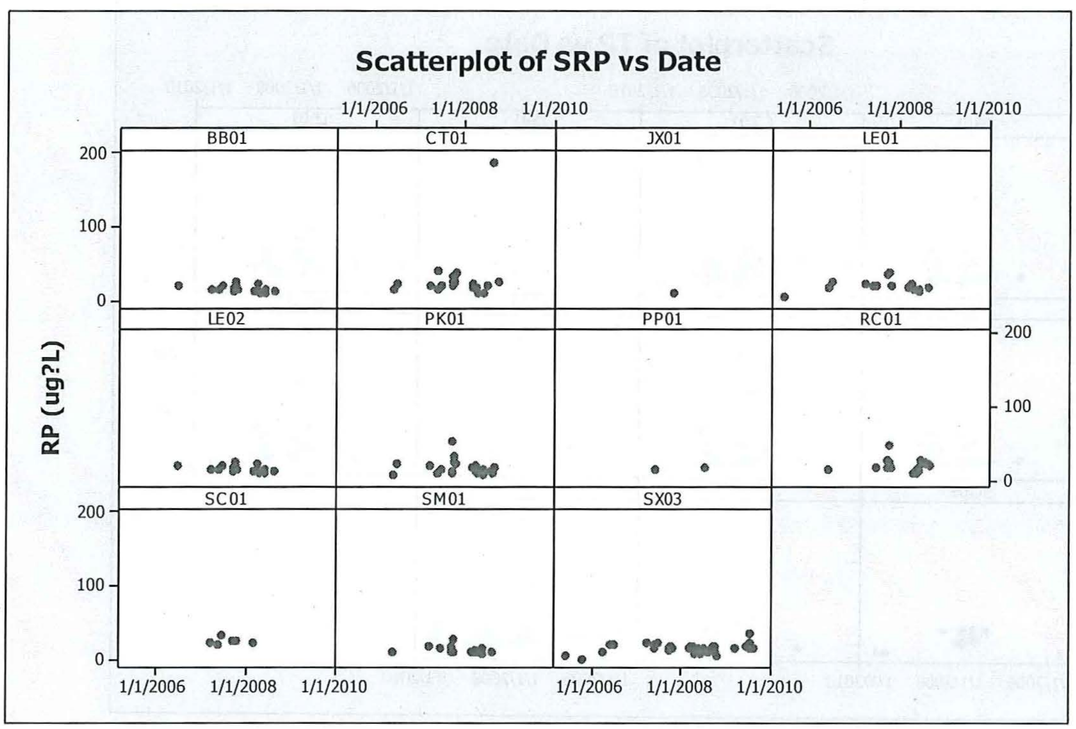

Figure 25. Soluble reactive phosphorus concentrations measured in USCL tributaries 2006-2009.

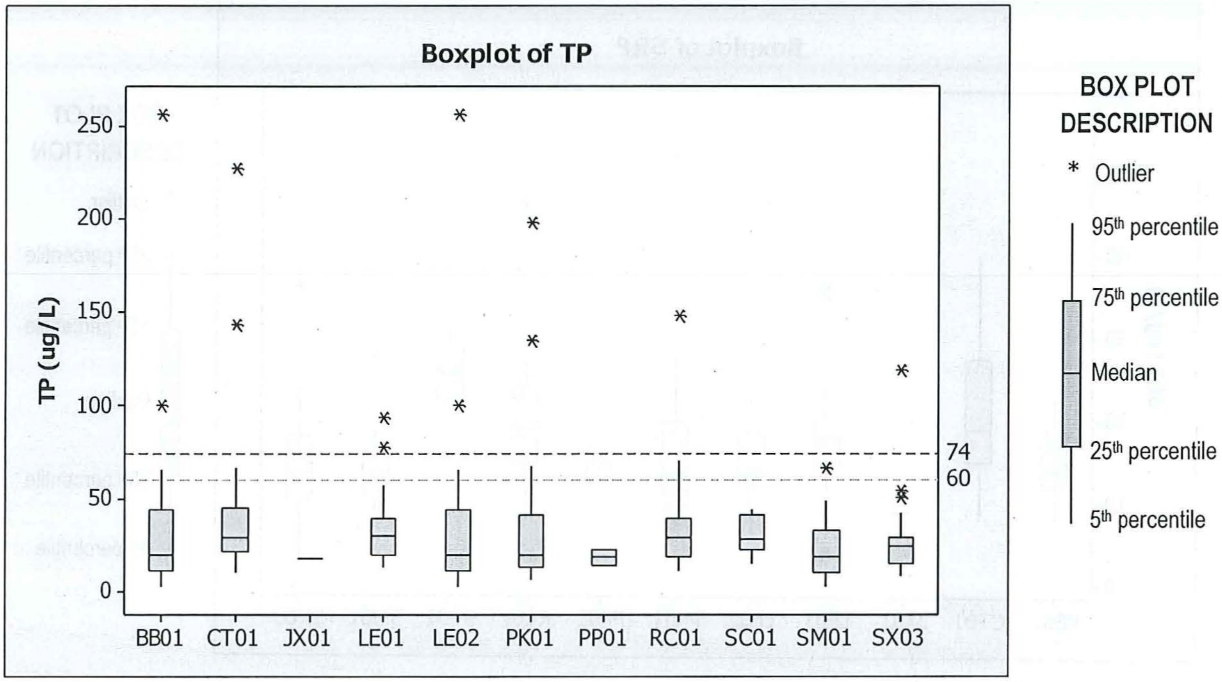

Figure 22. Ranges of total phosphorus concentrations measured in USCL tributaries 2006-2009. An extreme value (930 µg/L on 09/21/2007) has been removed from Leo Creek to allow for the resolution of the other samples. Asterisks indicate outliers.

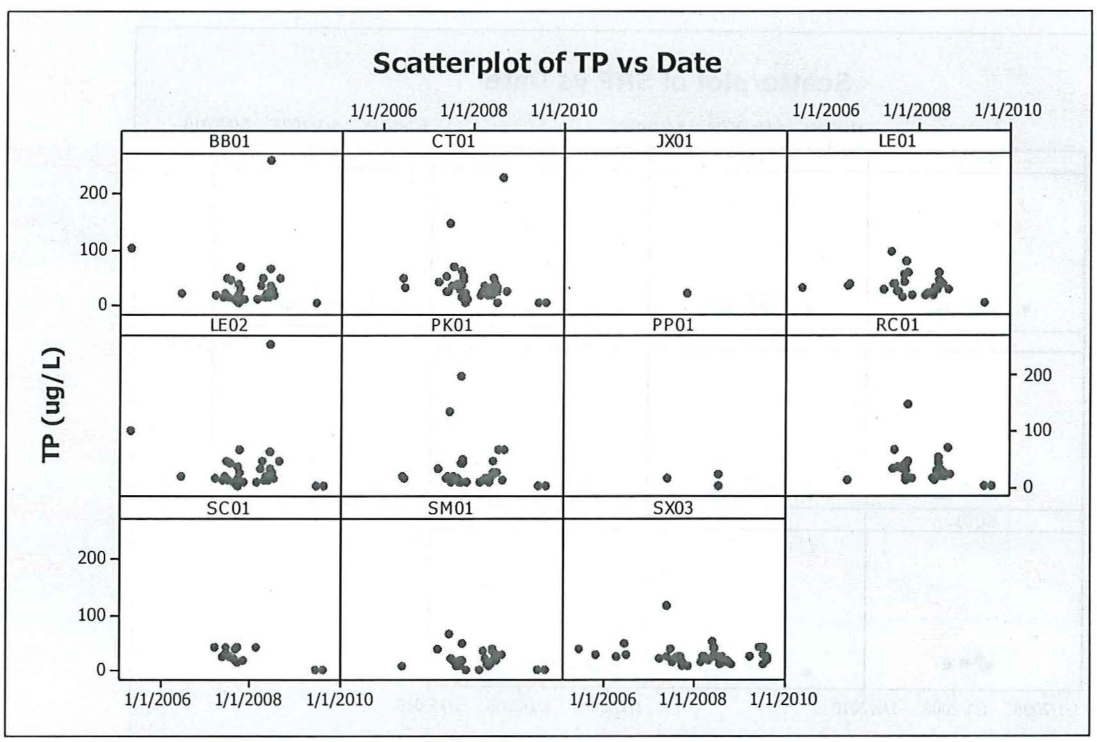

Figure 23. Total phosphorus concentrations measured in USCL tributaries 2006-2009. An extreme value (930 µg/L on 09/21/2007) has been removed from Leo Creek to allow for the resolution of the other samples.

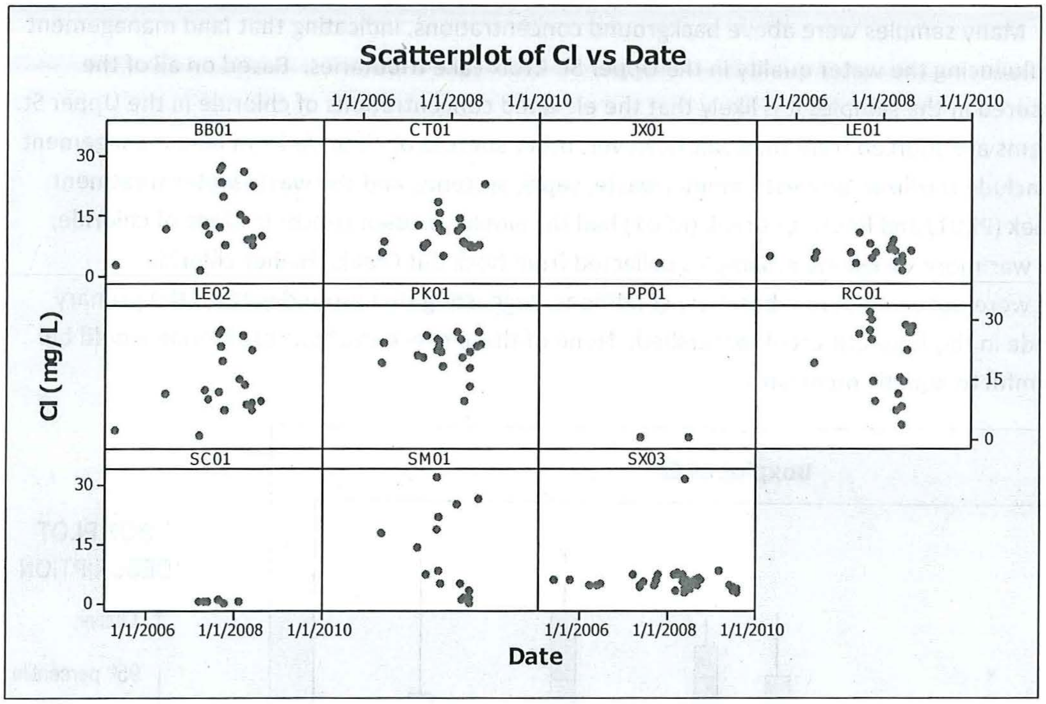

Figure 21. Chloride concentrations measured in USCL tributaries 2006-2009.

Phosphorus was measured in two forms, total and reactive. Soluble reactive phosphorus (SRP) is a dissolved form that is readily available for use by aquatic plants and algae. Total phosphorus (TP) includes soluble reactive phosphorus plus forms that are associated with organic material, sediment, and metals. During certain conditions this phosphorus may become more available for use by aquatic plants and algae. Sources of phosphorus can be natural and cultural.

When evaluating water quality in Upper St. Croix Lake streams, phosphorus was evaluated in terms of concentration of phosphorus in a sample and as a mass. The mass of phosphorus is used to describe the total amount of phosphorus that the stream delivers to the lake each year. This is calculated using the concentration and the estimated amount of water moving in the stream over the year. As would be anticipated, TP and SRP concentrations were variable in each stream. Lower phosphorus concentrations were measured during baseflow conditions and higher concentrations were measured during runoff events. During storms, surface runoff carries particles and debris to the tributaries and lakes, bottom sediments are disturbed, and wetlands are flushed. These are all sources of phosphorus and this pattern is typical of many streams in Wisconsin. Use of land management practices that reduce runoff and/or reduction of the amount of exposed soil help to reduce movement of particles to streams and the lake. Additional care should be taken in hilly areas which are even more prone to erosion. Some of the measured concentrations of TP were quite high during runoff events; however, the median concentrations of TP were well below the DNR's proposed levels of concern. DNR has proposed statewide criteria for wadable streams which suggest TP concentrations of 74 ug/L or 60 ug/L for ERW (excellent resource waters). Phosphorus concentration data are displayed in Figure 22 through Figure 25.

and Figure 21). Many samples were above background concentrations, indicating that land management activities are influencing the water quality in the Upper St. Croix Lake tributaries. Based on all of the chemistry measured in the samples it is likely that the elevated concentrations of chloride in the Upper St. Croix Lake streams are sourced from road salt however, other sources of chloride from land management activities may include fertilizer, domestic animal waste, septic systems, and the waste water treatment plant. Park Creek (PK01) and Rock Cut Creek (RC01) had the similar median concentrations of chloride, although there was more variability in samples collected from Rock Cut Creek. Higher chloride concentrations were observed during baseflow conditions, suggesting that groundwater is the primary route for chloride in the Rock Cut Creek watershed. None of these concentrations of chloride would be considered harmful to aquatic organisms.

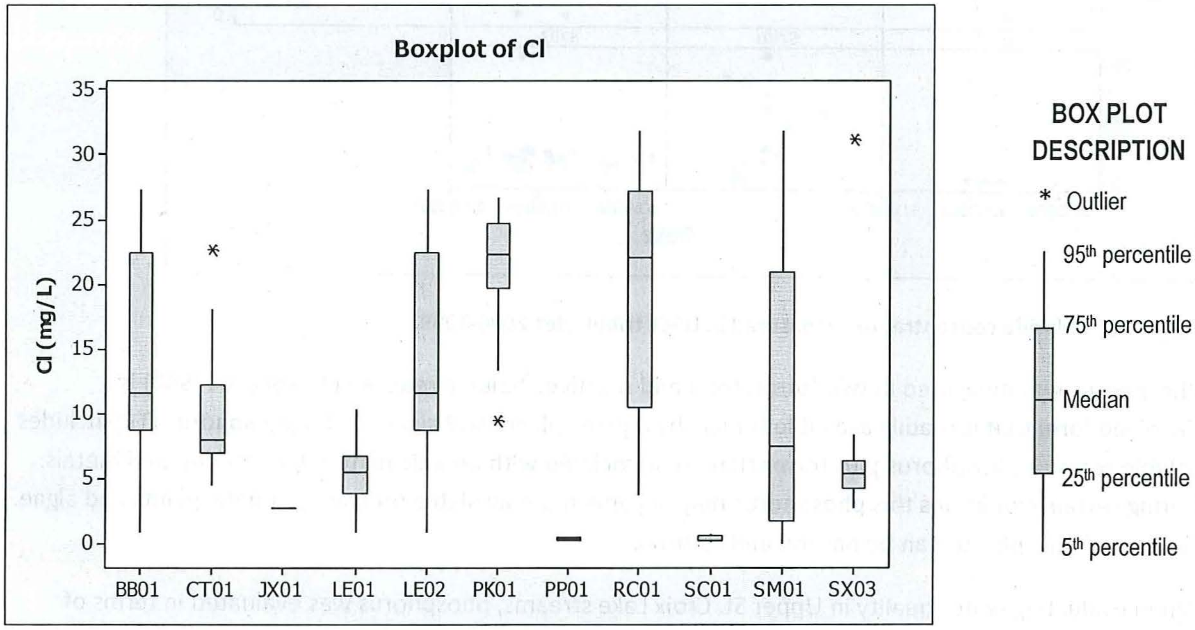

Figure 20 Range of chloride concentrations measured in USCL tributaries 2006-2009.

- Upstream diversion of water into the constructed/natural wetlands to reduce sediment and nutrient load prior to water entering Upper St. Croix Lake.
- Planting of vegetation buffer strips along the shoreline and the reduction/elimination of excessive fertilizer use in the residential landscapes around Upper St. Croix Lake.
- Alum treatment of the sediments to seal off the resuspension of nutrients for several years.
- Removal of sediments.

In closing, Upper St. Croix Lake shows signs of moderate nutrient enrichment and a movement towards dominance by less desirable blue-green algae. You can't control drought, geological conditions, or basin morphology. Urban land use practices and local anthropomorphic inputs can be improved but will be slow to show significant visual improvements and could therefore be hard to initiate and sustain. Each of these drivers contributes to the problem and some by themselves might be overcome but in the aggregate the problem of algal blooms and the potential of fish-killing oxygen depletion will likely continue to increase.

Tributary Water Quality

To begin to understand how the watershed influences water quality in Upper St. Croix Lake, water monitoring has been performed at all of the lake's tributaries (Beebe, Catlin, Jackson, Leo, Park, Rock Cut, Spring/Smith, and St. Croix Creeks). Tributary nutrient concentrations and water flow rates were measured between 2006 and 2009. A delineation of the tributary sub-watersheds was used to determine the area of land that is draining to each tributary (Figure 3).

Water quality in streams can vary from season to season. Water quality can also change quite a bit throughout a rainstorm or snowmelt (or series of rainstorms) and it is often different during low flow (baseflow). When it hasn't rained for awhile much of the water in a stream comes from groundwater that is feeding the stream and drainage from adjacent wetlands. Water samples were collected for lab analysis during different flow conditions. Samples were collected during low flow using the grab method and during high flow samples using the grab method and/or siphon samplers. The discharge (amount of flow) was estimated using continuous flow records along with flow rate measures which were taken at the tributary monitoring locations multiple times over the years.

Although we are most interested in the movement of phosphorus to/from Upper St. Croix Lake and its tributaries, phosphorus has both natural and cultural sources so we often use other chemical analyses to help interpret the sources and forms of phosphorus as it moves throughout the system. In Wisconsin, chloride is naturally found in low concentrations; it readily moves through the environment because it is not utilized by biota. The most common source of chloride in the Upper St. Croix Lake watershed is road salt, but other common sources can include septic system and wastewater treatment plant effluent, and some fertilizers.

Low chloride concentrations were exhibited in water quality samples acquired from St. Croix Creek (SC01) where chloride concentrations remained below 2 mg/L; these concentrations represent background concentrations for the Upper St. Croix Lake watershed. Low concentrations of chloride were also measured in the several samples that were collected from Jackson Creek (JX01) and Porcupine Creek (PP01) (Figure 20 blue-green taxa should be monitored in the future, especially in light of the significant component of Nodularia and other cyanobacteria in the 2008 sampling season.

The circumstances that pushed the algal community in Upper St. Croix Lake towards blue-green algae is an unfortunate, and largely unavoidable combination of several things –drought, urban land use nutrient inputs, local geological conditions (leaching of naturally occurring nutrients from the basal material), shoreline and near-shoreline anthropomorphic inputs (fertilizing of lawns, septic systems, surface runoff), and perhaps most important of all – basin morphology.

First, it's important to remember that all bodies of water, no matter how pristine or protected, will eventually support the growth of algae. Once a body of nutrients is introduced to a lake system it is very difficult to manage or eliminate. These nutrients undergo a season change in location and form. The spring overturn of the lake re-suspends available inorganic nutrients from the sediments. The algae assimilate these nutrients and consequently they are incorporated into organic molecules (DNA, protein) or are stored ("luxury storage") in excess of their current need. As algae are eaten their organic and inorganic matter is echoed through the food web and becomes organic material within the various levels of consumers. Consumer waste, consumer death, and algal death all contribute abundant inorganic and organic matter to the sediments throughout the year but particularly in the fall/winter when most algae and aquatic plants die back. In the fall and winter the decomposing bacteria in the sediments metabolize these mostly organic forms of nitrogen and phosphorus back to inorganic forms that are once again available in the following spring during lake overturn.

The soft-water nature of Upper St. Croix Lake also seems to contribute to its sensitivity to inputs of phosphorus. The algae need phosphorus in much smaller amounts than nitrogen (the other potentially limiting nutrient). If sufficient amounts of other nutrients are available then adding even small amounts of phosphorus is like stepping on the algal growth accelerator.

Over time nutrients accumulate ("run up to tipping point"), this alters the water chemistry and eventually nuisance organisms get established that outcompete other organisms for the available nutrients ("tipping point"). Since the algae are microscopic they can be accumulating over time for quite a while but at levels not perceived by the naked eye. Then, as the nuisance organisms really take hold and begin to reach higher densities earlier in the season, humans begin to notice. This is what seems to be happening in Upper St. Croix Lake.

Upper St. Croix Lake is basically a flattened, horizontal cylinder – long and narrow, flattened on one side. Of all the basic geometric shapes the cylinder has the greatest surface area to volume ratio. It's also fairly shallow and the long expanses of cylinder sidewall (shoreline) with shallow depths makes for a very high proportion of the lake being euphotic (the fancy word for getting enough light to make algae happy). A lake basin that is circular with steep sides (essentially the opposite of Upper St. Croix Lake) provides the smallest surface area to volume ratio. These bodies present much less surface area for algal growth and are generally beset with much less algae. Additionally, Upper St. Croix Lake runs largely north-south, this allows the prevailing westerly winds to stir up internal nutrient pools and drive algal material to the very long eastern shore of the lake where it finds lots of shallow, nutrient-rich, well-lit habitats.

These problems took a long time to develop and the solutions will be equally slow to take effect. Various nutrient abatement strategies are possible. They vary widely in effectiveness and cost. They include, in no particular order, but are not limited to:

make for formidable nuisance organisms that are very difficult to control and even more difficult to eradicate.

Of the 71 total genera found over the sampling season there were 22 cyanobacterial (blue-green algae) genera. Ten genera of the 71 (14%) were present in all six cell counting samples. Four of these ten genera were cyanobacterial taxa. The filamentous blue-green genera Gloeotrichia and Nodularia were present in all sampling periods and Gloeotrichia was the most common organism in the cell counts of 10/03 and 10/31 (late season). Nodularia was one of the three most common organisms in the final three periods sampled. The colonial genera, Coelosphaerium and Woronichinia were also present in every sample. They both produce significant sheaths that render them basically inedible. All four of these taxa are cosmopolitan and their abundance is generally associated with nitrogen and especially phosphorus-enriched waters.

In addition to the general metabolic and ecological advantages of blue-green algae discussed above, Gloeotrichia and Nodularia have another metabolic advantage that makes them more of a nuisance, harder to control, and even harder to eradicate. These organisms can produce specialized cells called heterocysts (or heterocytes) that enable them to enzymatically fix atmospheric nitrogen gas into inorganic and useable forms of nitrate or ammonium. Thus, even if you can limit nitrogen availability in the water column they can make their own!

The colonial blue-green genus Microcystis was present in five of the six sample counts. This organism forms large amorphous colonies with substantial and diffuse sheaths. The only other cyanobacterial genus found in more than half the samples was the filamentous and heterocyst-producing genus Anabaena. The 16 remaining blue-green algal genera were found in at most half the samples (6 genera) or less (6 genera found in two samples, 4 genera found in only one sample).

Some blue-green algae are capable of "blooming" (massive population explosions) and in the bloom state may produce toxins that can harm aquatic life, pets, and potentially humans. Recent research has hinted at the possibility of these organisms producing toxins at sub-bloom densities as well. There are three basic types of toxins produced by blue-green algae: cytotoxins (or endotoxins), hepatotoxins, and neurotoxins.

The cytotoxins are various lipopolysaccharides (polymers of sugar-backbones with fatty acid side chains) that can kill cells in a fashion similar to pathogenic bacteria like Salmonella but with less toxic effects. Some strains of both Anabaena and Microcystis have been shown to produce cytotoxins.

Hepatotoxins are cyclic peptides that irreversibly inhibit liver-cell protein phosphatase enzymes. Their effects on the liver vary based on the amount of exposure. Strains of some common blue-green algal genera from Upper St. Croix Lake have been associated with hepatotoxin production including Microcystis, Anabaena, Nodularia, and Oscillatoria.

Neurotoxins are potent membrane sodium-channel blockers that disrupt neuromuscular activity. These very rapid-acting and high-potency toxins have been associated with the most critical animal and human pathologies including several documented human fatalities. The only blue-green genus from Upper St, Croix Lake that has been documented to have strains capable of producing neurotoxins is Anabaena.

Of all the known toxin-producing taxa found in Upper St. Croix Lake only Nodularia approached bloom conditions (9 -12% of all cells counted) in the 08/31, 10/03, and 10/31 samples. At present this blue-green algae does not appear to be a toxin-producing threat but it and other seasonally-dominant

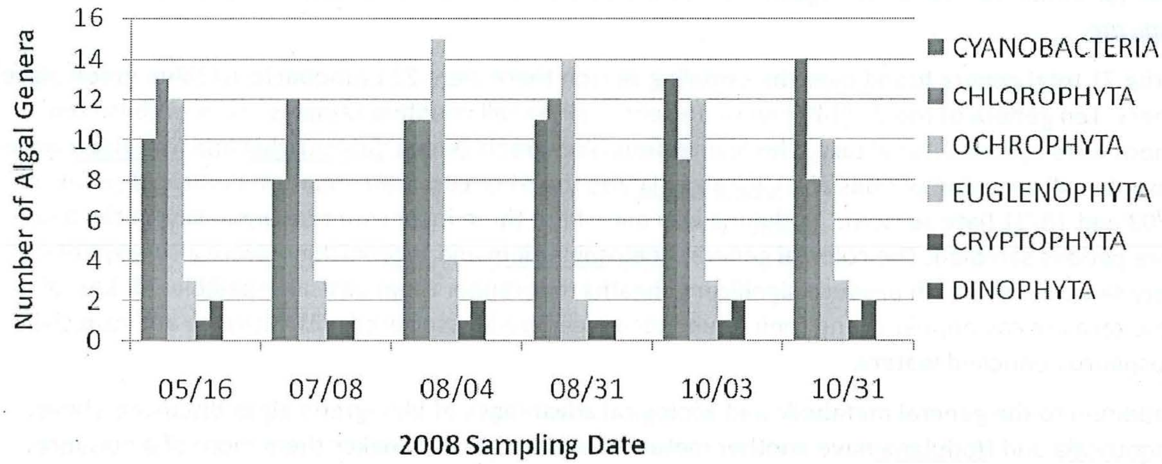

Figure 19. Number of Planktonic Algal Genera in Upper St. Croix Lake, Douglas County, WI, 2008 by Phylum and Sampling Date.

Phytoplankton (floating algae) community dynamics is controlled by three broad categories of factors – the physical environment, nutrients, and biotic factors. The physical environment included such things as temperature, light, turbulence, stratification, and other hydrodynamic factors. Nutrients, from internal and external sources, determine community structure and can limit physiological responses in some taxa. Together, hydrodynamic/physical factors and nutrient factors are considered "bottom-up" controls of algal communities. Biotic factors like competition, toxic inhibition, parasitism, disease, and predation are typically considered to be "top-down" mechanisms that exert their influence down through a food web. Each algal phylum, genus, and species fits into this continuum of characteristics at some specific spot but that spot can change as the combination of characteristics changes. The dynamic nature of climate, season, and microhabitats in the continuously-changing water column make predictions very difficult.

The following sections present expanded discussions of the algal community components and the development of algal communities.

The **blue-green algae** (Cyanobacteria) are prokaryotic (bacteria-like) organisms with very wide metabolic and ecological tolerances coupled with potentially high growth rates under good conditions. This confers on them the ability to withstand conditions that are harmful to other types of algae. They can quickly respond to changes in their environment and take advantage of any available excess nutrients. All blue-green algae store nutrients beyond their immediate metabolic needs when such nutrients are present. Particularly, they generate intracellular storage granules of nitrogen and phosphate. These substantial cell-storage reservoirs allow the blue-greens to continue to grow during periods of nutrient deprivation in the water column.

Blue-green algae are also largely indigestible due to their cell wall. Nearly every genus of blue-green identified in Upper St. Croix Lake also has an outer mucilage layer called the sheath. The sheath is a sticky and difficult-to-digest matrix that can be quite extensive. The cell wall and sheath make the blue-green algae hard to both ingest and digest; as a result they are generally avoided by consumers like zooplankton (microscopic animals) and planktivorous fishes. *The unfortunate combination of versatile metabolism, ecological tolerance, luxury nutrient storage, high growth rate, and indigestibility*

Blue-green algae or Cyanobacteria were only 9% of cells counted in the first sample period (05/16) but their abundance ramped up steadily and at times quickly over the sampling season (Figure 19). In the first sample this phylum was the fourth most common group, it rose to third most common in the next two periods, 07/08 (23%) and 08/04 (17%). In less than four weeks, the population more than doubled to 36% of cells counted (08/31) and was twice as common as either the green algae or ochrophytes. A month later (10/03) cyanobacterial cells counts were up another 50% and representing 49% of all cells counted. By the final sample period (10/31) the blue-green algae made up 62% of all 8 cells counted, more than four times more abundant than either of the other two most common phyla. Averaged over the six samples, the cyanobacteria represented a third of all cells counted (Table 3).

The euglenoids, cryptophytes, and dinoflagellates combined to represent 23% of all cells counted over the entire sampling period (Table 3). In the first sample period (05/16) these phyla comprised 33% of all cells counted (Figure 19) before dropping to 18-26% of cells counted for the next four sample periods (07/08, 08/04, 08/31, 10/03) and reaching a seasonal low of 11% of cells counted in the final sample (10/31). The euglenoids were the third most abundant group (18%) in the first sample (05/16) and the cryptophytes were the third most abundant group (19%) in the fourth sample (08/31). Individually, these three phyla only reached a 10% or greater level of abundance in the cell counts in 5 of 18 samples.

The dominance of the cyanobacteria, green algae, and ochrophytes is seen in the number of genera present in each sample. Over the sampling period there were from 33 to 44 genera per sample, averaging 40 genera per sample. There was no significant difference among the three dominant phyla, on average, during the growing season with each averaging 11-12 genera per sample period.

Table 3. Planktonic algal genera from Upper St. Croix Lake, Douglas County, WI, 2008 by phylum and sampling date.

PHYLUM	05/16	07/08	08/04	08/31	10/03	10/31	MEAN
Cyanobacteria	10	8	11	11	13	14	11.2
Chlorophyta	13	12	11	12	9	8	10.8
Ochrophyta	12	8	15	14	12	10	11.8
Euglenophyta	3	3	4	2	3	3	3.0
Cryptophyta	1	1	1	1	1	1	1.0
Dinophyta	2	1	2	1	2	2	1.7
TOTAL	**41**	**33**	**44**	**41**	**40**	**38**	**39.5**

Community Composition and Successional Trends Upper St. Croix Lake Wisconsin, Dr. R. Bell, 2008. The following are excerpts from this report.

Algae need carbon dioxide, water, sunlight, and a variety of inorganic nutrients, all in adequate amounts. The term algae is very general, this group of organisms encompasses both prokaryotic (like bacteria) and eukaryotic (like us) cell types. The algae range from single-celled to many meters long, some swim with flagella while others float or alter their buoyancy via physiological alterations. These organisms can be motile or non-motile unicells, unbranched or branched filamentous, motile or non-motile colonies, tubular, sheet-like, and about every shape in between. They can be blue-green, green, yellow, black, brown, gold, pink, red, or orange.

The dominant phyla showed different seasonal abundance patterns (Figure 18). The green algae were early season dominants, representing more than a third of cells counted in the first two samples (05/16, 07/08). This group underwent a steady reduction over the next four samples to finish the growing season as 13% of the total cells counted. For all samples the green algae comprised about 23% of cells counted.

The Ochrophyta, mostly diatom taxa, was the second most abundant phylum during in the first two samples and then reached peak abundance in the early August sample (08/04) at 34% of cells counted. They declined in all later sample periods (08/31, 10/03, 10/31) but were the second most common phylum in the cell counts for those periods (Figure 19). The ochrophytes represented 14% of cells counted at the end of the season and averaged 22% of cells counted for the entire sampling period (Table 3).

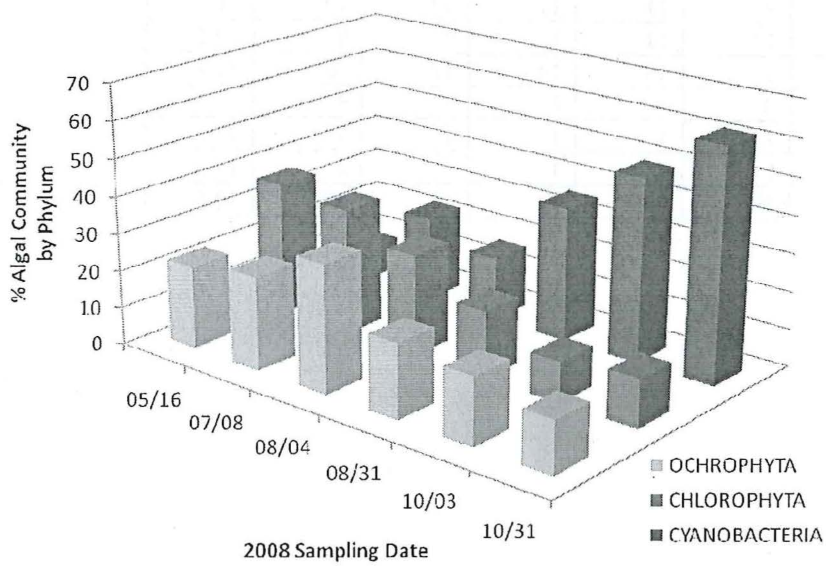

Figure 18. Algal Community Composition (%) in Upper St. Croix Lake, Douglas County, WI, 2008 by Three Most Common Phyla and Sampling Date.

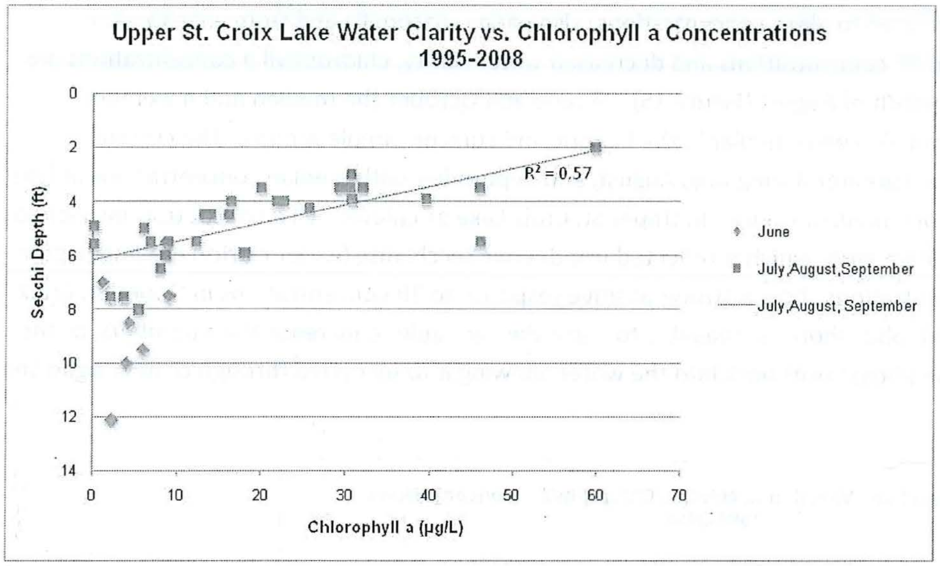

Figure 16. Water Clarity vs. Chlorophyll *a* concentrations in USCL, as chlorophyll a concentrations rise there is a decrease in the clarity of the water reflected in a lower Secchi measurement.

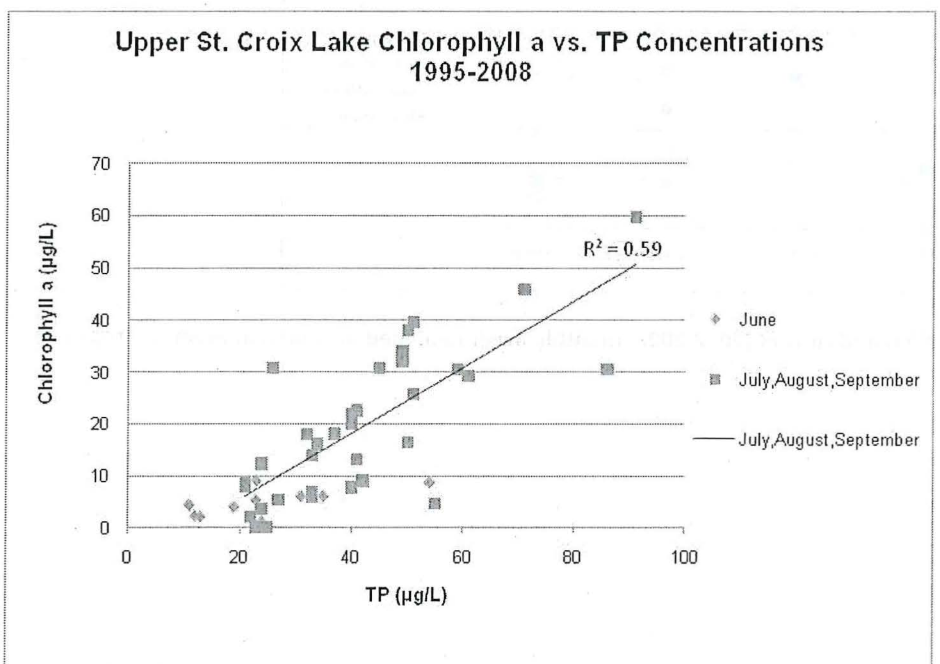

Figure 17. Chlorophyll a vs. total phosphorus concentrations in USCL.

The Algal Community

During the second year of this study Dr. Robert Bell, Professor of Biology at UW-Stevens Point evaluated the algal community from samples collected when water quality samples were collected from Upper St. Croix Lake during the growing season. The details of the study can be found in *Algal*

Chlorophyll *a*, which is related to algae concentrations, also varies seasonally and from year-to-year. Consistent with elevated TP concentrations and decreased water clarity, chlorophyll *a* concentrations are typically highest in the month of August (Figure 15). In June and October the median and maximum concentrations of chlorophyll *a* were similar in the historic and current sample groups. The current concentrations were much greater during July, August, and September with median concentrations at least 10 ug/L higher than historic median values. In Upper St. Croix Lake as chlorophyll *a* concentrations increase there is a decrease in water clarity which is reflected in a deeper Secchi disc (water clarity) reading (Figure 16). Chlorophyll *a* concentrations show a strong positive response to TP concentrations in Upper St. Croix Lake (Figure 17). As more phosphorus is available to algae they are able to increase their numbers, as the algae die off they release phosphorus back into the water allowing it to be cycled through to new algae and plants.

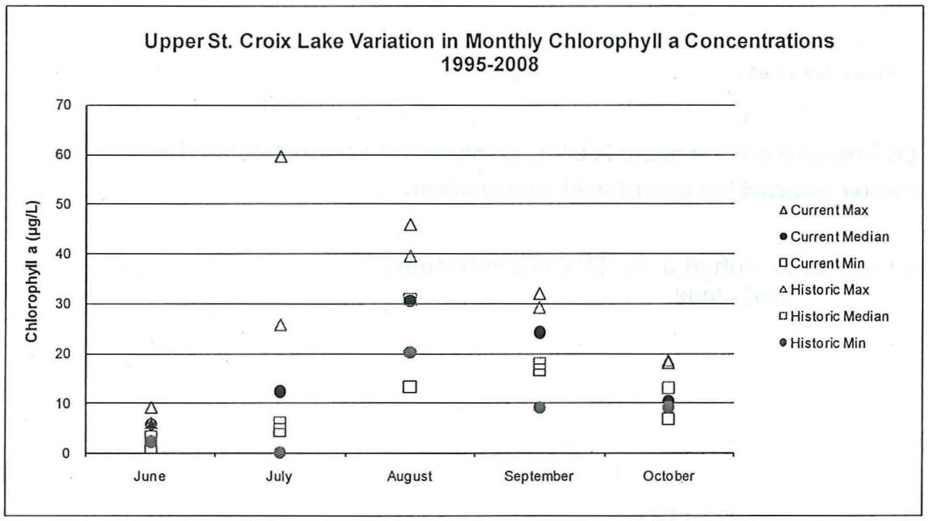

Figure 15. Historic (1996-2001) and current (2002-2008) monthly maximum, median, and minimum chlorophyll *a* concentrations in USCL.

Color in Upper St. Croix Lake ranged from 34-41 CU; these values show slight staining in the water from organic compounds originating from wetlands in the watershed and will reduce water clarity in the lake. Water clarity measurements have been taken in Upper St. Croix Lake since 1973 and are summarized in Figure 13. The number and timing of measurements were not consistent from year to year which can increase the variability in the annual minimum and maximum observations, however, the median values show less variability ranging from a low of 5.2 in 2000 and a high of 8.4 in 1998. Monthly data show decreasing Secchi depths which coincide with the months of greatest potential algal growth and highest recreational use. Median monthly clarity measures were similar for current and historic data for all months except June and September; current measures were lower during these months (Figure 14).

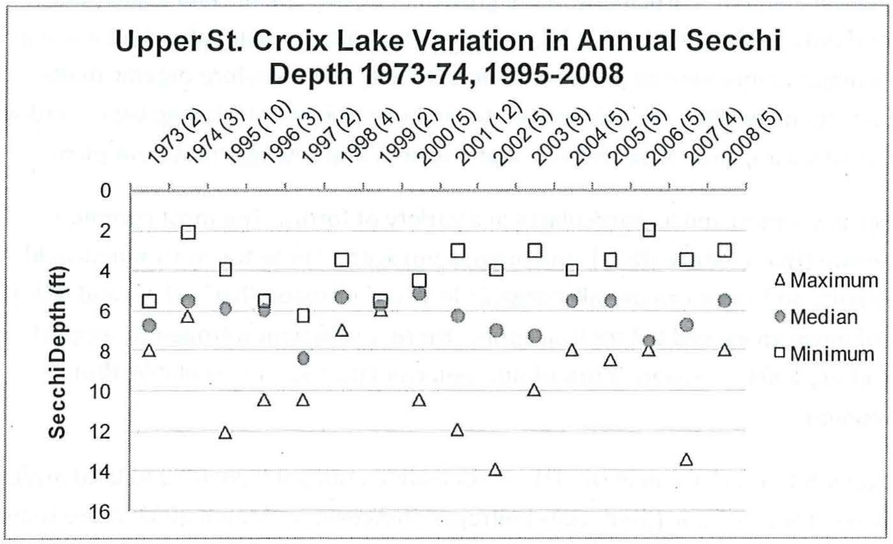

Figure 13. Minimum, median, and maximum water clarity measurements in Upper St. Croix Lake 1973-2008. The number of observation made in each year is in parentheses following the year.

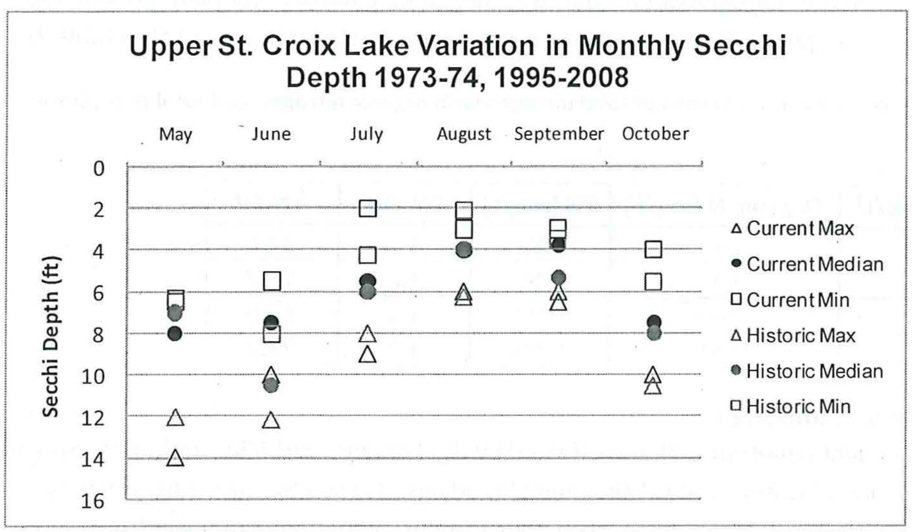

Figure 14. Average monthly water clarity measurements in Upper St. Croix Lake. Historic values 1973-2001; current values 2002-2008.

Table 1. Average annual phosphorus budget for Upper St. Croix Lake (1998-2008).

Source	P Quantity pounds/year
Atmospheric Deposition	172
Streams and Groundwater	1423
Internal Release	1828-2994
Total Entering Lake	3437-4589
Total Leaving Lake in Outflow	1115-1481

Nitrogen is an important biological element, particularly in the growth of aquatic plants and algae (non-bluegreen species). It is second only to phosphorus as a key nutrient that influences aquatic plant and algal growth in lakes. Nitrogen is a major component of plant and animal tissue, and therefore organic matter and soil. Cultural sources of nitrogen are often directly related to land use practices including lawn, garden, and agricultural fertilizers, animal waste, and effluents from septic system and sewage treatment plants.

Nitrogen enters and exits lakes in solution and as particulates in a variety of forms. The most common include ammonium (NH^{4+}), nitrate (NO_{3-}), nitrite (NO_{2-}), and organic nitrogen. These forms summed yield total nitrogen (TN). Aquatic plants and algae can use all inorganic forms of nitrogen (NH^{4+}, NO_{3-}, and NO_{2-}) and if these inorganic forms of nitrogen exceed 0.3 mg/L in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2004). Organic forms of nitrogen can also become available after biological conversion to ammonium.

During sampling periods in Upper St. Croix Lake in 2007, TN concentrations ranged from 0.69 to 0.80 mg/L (Table 2). The majority of nitrogen was organic (particulate) nitrogen; however, in March 2007, more than half of the TN was NO_2+NO_3 –N which is readily available for uptake by algae. These concentrations were sufficient to enhance algal blooms during the upcoming growing season.

The TN to TP ratio indicates whether nitrogen or phosphorus is the limiting nutrient for plant growth; lakes with a ratio of 15:1 and above are phosphorus limited which is the case for Upper St. Croix Lake (Table 2).

Table 2. Nitrogen average concentrations and ratios of total nitrogen with organic nitrogen and total phosphorus, USCL 2007/08.

Season	NO_2+NO_3 (mg/L)	Organic N (mg/L)	TN (mg/L)	TN:ON	TN:TP
Winter	0.33	0.52	0.87	1.7	34.8
Spring	0.06	0.47	0.55	1.2	15.7
Summer	0.16	0.69	0.93	1.3	17.5
Fall	0.11	0.51	0.66	1.3	21.3

Water Clarity, Chlorophyll *a*, and Algae

Water clarity is a measure of light penetration that is affected by algal growth, turbidity, and color. Secchi disk measurements give a value of water clarity at the time of readings. These measurements can vary from month to month or day-to-day and sometimes even hour-to-hour. Variations can result from storms and wind, season, abundance of algae, boat traffic and some variability may be introduced by different people making the measurement.

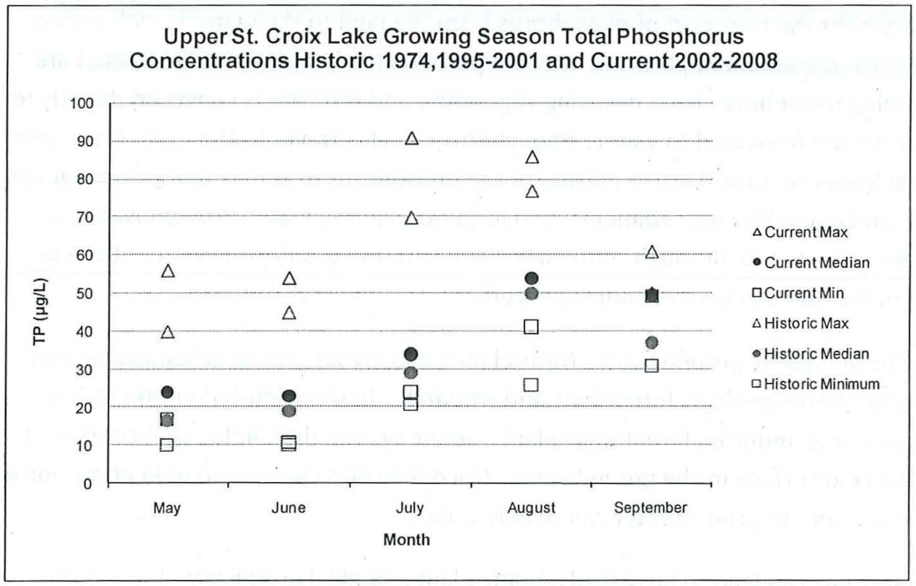

Figure 11. Historic (1996-2001) and current (2002-2007) monthly maximum, median, and minimum chlorophyll a concentrations in USCL typically peaking in August.

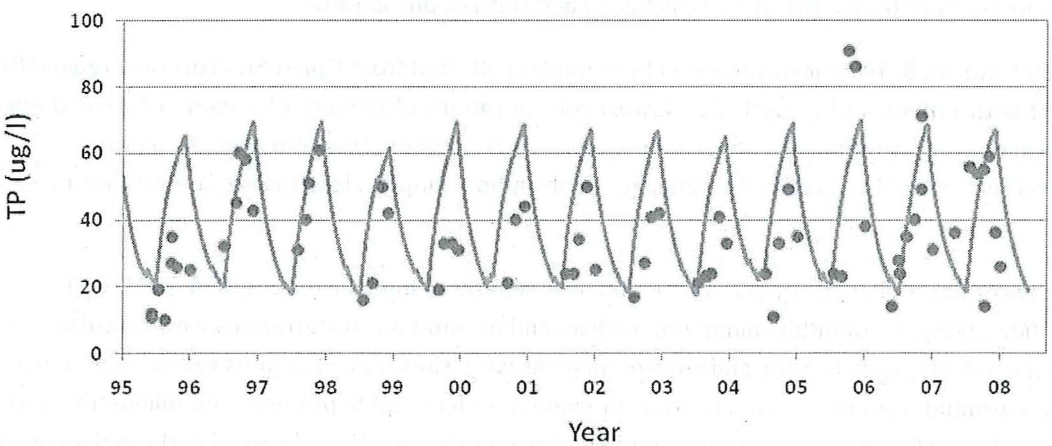

Figure 12. SWAT model results showing the seasonal nature of the water quality data measured in Upper St. Croix Lake. (Red points are TP samples collected from Upper St. Croix Lake, Blue line is model simulation).

The adjusted SWAT model was also used in the development of an average annual phosphorus budget for Upper St. Croix Lake. This budget identifies major sources of phosphorus entering and leaving the lake. Model results suggest that each year the largest source of phosphorus to the lake originates from internal release and the total amount of phosphorus entering the lake is much greater than what is leaving the lake. When phosphorus enters the lake it is cycled within the lake for many years which highlights the importance of preventing excess phosphorus from getting into Upper St. Croix Lake.

The most common mechanism for the transport of phosphorus from the land to the water is with surface runoff. Phosphorus adheres to soil/sediment particles. If those particles (soil, organic material, etc.) are disturbed or if water containing phosphorus from decaying vegetation and fertilizer is conveyed directly to the lake, phosphorus is transferred from land to water. Phosphorus can also travel to Upper St. Croix Lake in a dissolved form. Once in Upper St. Croix Lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue, sediments, and in solution in the water. The phosphorus continues to cycle within the system, and although some may leave with the out flowing water, it can be very difficult to remove from the lake's ecosystem once it enters.

Phosphorus can also travel to the lake in groundwater. Natural phosphorus sources to groundwater may include contact with high phosphorus geologic formations and wetlands. In situations where there is a continuous phosphorus source (e.g. municipal treatment plants, septic system drainfields, golf courses) it may migrate slowly from the land surface to the groundwater. Once the soil's capacity to hold phosphorus is exceeded, phosphorus movement to groundwater can readily occur.

Higher phosphorus concentrations can lead to increased aquatic plant and algal production, lowered water clarity, and oxygen reduction from decomposition of plants and algae. Phosphorus concentrations vary over time and seasonally. Lakes with more than 30 µg/L TP tend to have more frequent algae blooms or increased aquatic plant growth (Shaw et al., 2004). Soft water lakes with low calcium concentrations like Upper St. Croix Lake are frequently more sensitive to additions of phosphorus.

Between 2007 and 2008, TP concentrations in the samples collected from Upper St. Croix Lake ranged from 14 to 71 µg/L with a median of 36 µg/L. The lowest concentrations of TP were observed in April and August 2008; the highest concentration was observed in August 2007. Seasonal variations in phosphorus concentrations are normal and can reflect changes in phosphorus inputs, lake mixing, and settling of particles.

To evaluate phosphorus changes by season, TP data was separated into "historic" (1974-2001) and "current" (2002-2008) and monthly minimum, median, and maximum concentrations were calculated for each group (Figure 11). Both historic and current medians were similar in all months except September. The current maximum was greater than historic for every month except September and minimums were lower historically for all months except June and July. Some of the variation observed in these data are due to differences in the amount of data collected each month, the timing of data collection (before or after a storm), and differences in climatic conditions (wet versus dry years, early versus late ice off, etc).

A model was developed to estimate phosphorus in Upper St. Croix Lake over time. The model used precipitation records and TP data that had been collected from Upper St. Croix Lake. Additional data used to build the model included TP estimates from groundwater, sediment release, and atmospheric deposition. A thorough description of the SWAT model can be found in the Appendix. The average TP concentrations in Upper St. Croix Lake in spring are generally around 20 ug/L and slowly increase throughout the summer to an average of 54 ug/L. This increase is due to internal phosphorus release from sediments, mixing of phosphorus rich bottom waters with upper waters, etc. Much of the year-to-year variability can be accounted for by variation in precipitation (wet versus dry years).

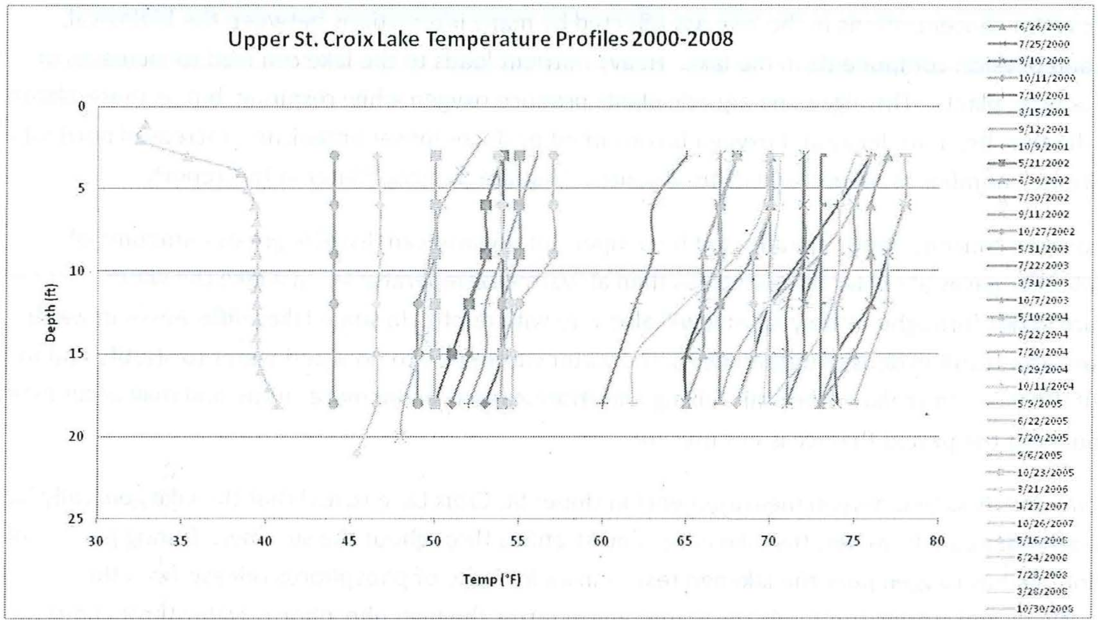

Figure 9. Temperature profiles in Upper St. Croix Lake exhibiting weak or no stratification (1996-2008).

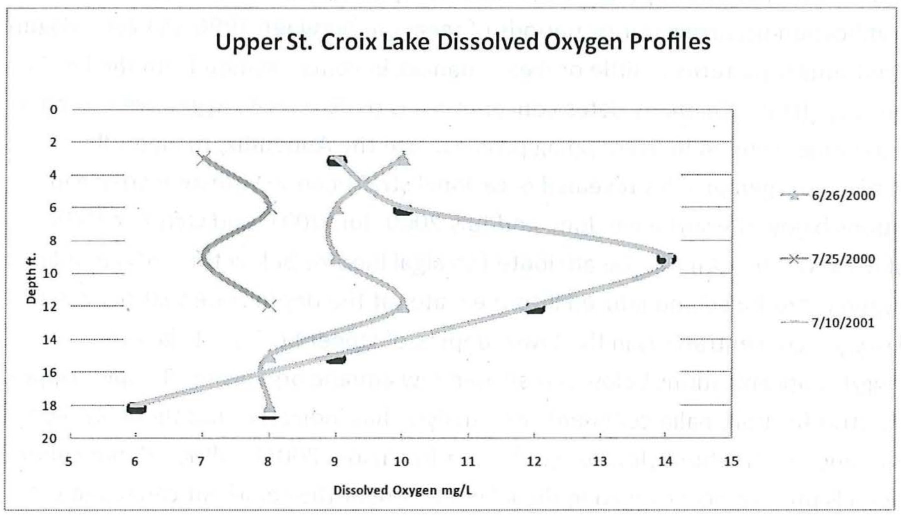

Figure 10. Stratified dissolved oxygen profiles from the South Site DNR Self Help Data.

Nutrients (Phosphorus and Nitrogen)

Nutrients are the primary fuel for algae and aquatic plants in lakes. Phosphorus is present naturally throughout the watershed in soil, plants, and animals. It is transferred to the lake with the erosion of soil and via runoff from sources including animal waste and fertilizers, effluent from septic systems, dissolved nutrients and sediments released from wetlands and shoreland plants, groundwater, and atmospheric deposition.

Dissolved oxygen concentrations in the lake are affected by many interactions between the biological, chemical, and physical components in the lake. Heavy nutrient loads to the lake can lead to increases in algae and aquatic plants. The algae and aquatic plants produce oxygen while respiring, but as these plants and algae die they begin to decay and oxygen is consumed by decomposer organisms. Increased nutrients can come from a number of natural and cultural sources that are discussed later in this report.

Dissolved oxygen concentrations are affected by temperature; water can dissolve greater amounts of oxygen and other gases at colder temperatures than at warmer temperatures. In a lake the water temperature varies throughout the year and will also vary with depth. In some lakes differences in water temperature also result in density differences in the water causing ice to float and water to stratify and mix throughout the year. In shallow lakes this mixing and stratification can be more subtle and may occur many times throughout the period that ice is not present.

Temperature and dissolved oxygen measurements in Upper St. Croix Lake reveal that the lake generally has little or no stratification; however, the lake mixes and stratifies throughout the summer. During periods of stratification the low oxygen near the lakebed results in an increase of phosphorus release from the sediment. Winds and storms can remix the water, which mixes the high phosphorus water throughout the water column. In addition, Upper St. Croix Lake is a relatively shallow lake with depths rarely exceeding 20 ft. This allows winds to mix the water periodically (Figure 9). Most temperature profiles in Upper St. Croix Lake showed weak or no stratification occurring during periods of measure between 1996 and 2005 (Figure 9). Dissolved oxygen exhibited similar patterns of little or weak changes in concentration from the lake's surface to the bottom (Figure 10). (Note: On many dates concentrations of dissolved oxygen were similar throughout the profile and graphing resulted in overlapping profiles. See the Appendix, to view all dissolved oxygen data.) Dissolved oxygen profiles revealed occasional stratification with an increase in dissolved oxygen concentrations below the surface in June and July 2000, July 2001, and October 2005 (Figure 10). This increase of dissolved oxygen may be attributed to algal blooms below the surface of lake; through photosynthesis, oxygen is produced and infused into the water at the depth zone that the algal bloom occupies. Dissolved oxygen concentrations in the lower depths of Upper St. Croix Lake rarely dropped below a level of 5 mg/L; concentrations below this sustain few aquatic organisms. Despite Upper St. Croix Lake exhibiting little stratification, palio-sediment core analysis has indicated that there has been increase in the frequency that anoxic conditions (low oxygen) occur (Garrison, 2004). Although phosphorus release can occur when oxygen is present, low oxygen in the lake water near the sediment can result in increased phosphorus release from sediments.

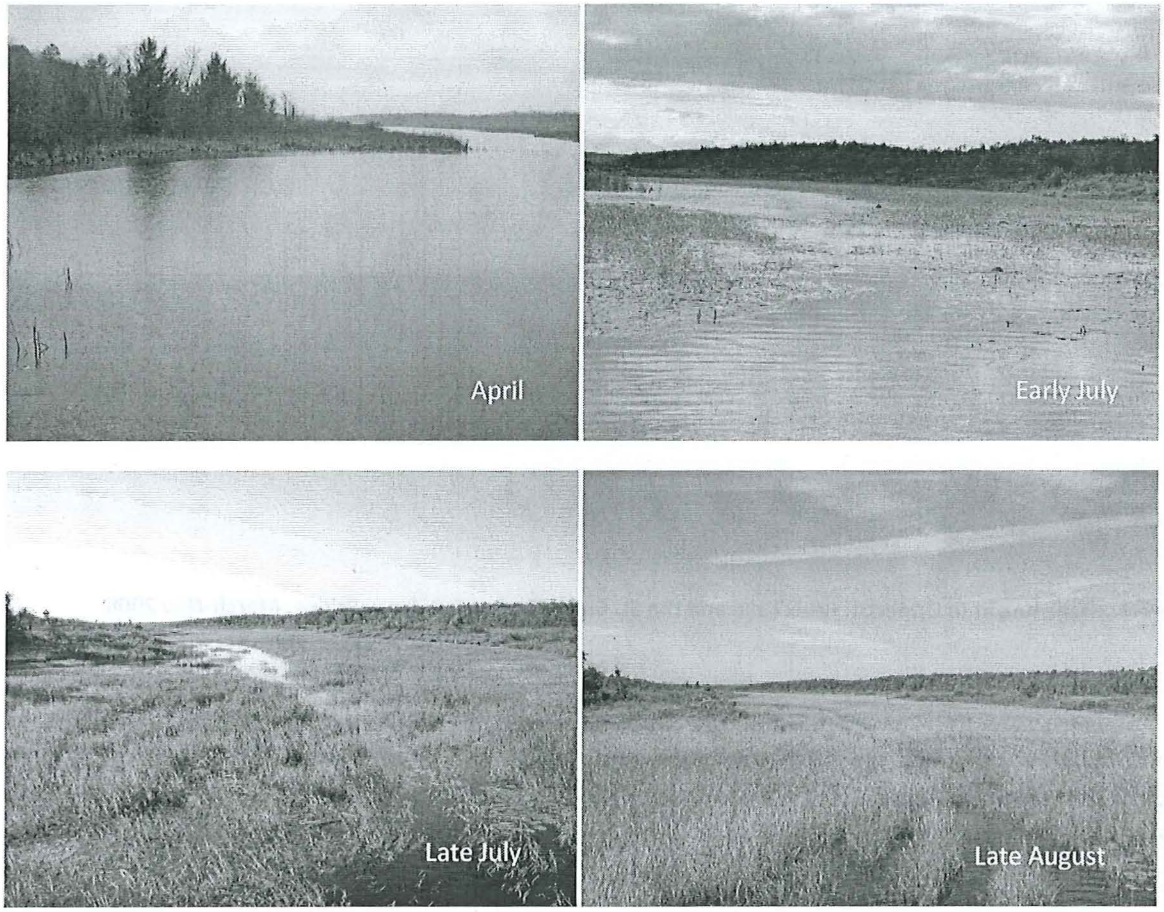

Figure 8. Photos of the St. Croix River at Cut Away Bridge showing a decrease in channel size throughout the spring and summer 2008 and 2009.

Lake Water Quality

Since 2006, UWSP, USCLA, and FOTSCH have been collecting water quality measurements including temperature, dissolved oxygen, water clarity, pH. Water samples were also collected for lab analysis of nutrients (phosphorus and nitrogen), total hardness, alkalinity, chloride, color, turbidity, sulfate, magnesium, sodium, potassium, and chlorophyll *a*. Additional data have been collected by USCLA volunteers and others since 1996.

Dissolved Oxygen and Temperature

Dissolved oxygen is an important measure in aquatic ecosystems because a majority of organisms in the water depend on oxygen to survive. Oxygen is dissolved into the water through diffusion from the air which is increased by wind and wave action. During the summer, algae and aquatic plants produce oxygen through photosynthesis which is also diffuses into the water. Typically, the predominant mechanism that removes dissolved oxygen from lake water is by bacterial use in the decomposition of plants, animals, and sediment. Some forms of iron, copper, and other reduced metals carried by groundwater can consume oxygen when the groundwater discharges to the lake and mixes with the oxygen-rich lake water.

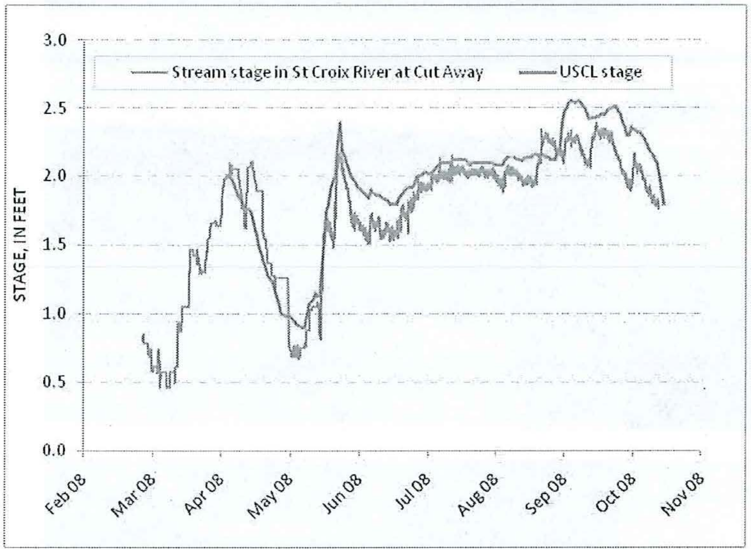

Figure 6. Stage height in Upper St. Croix Lake and the St. Croix River at Cut Away Bridge, March-Nov 2008.

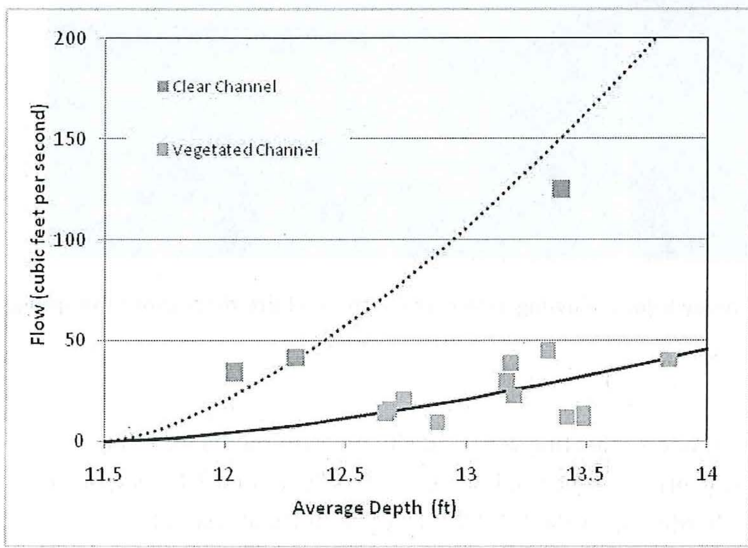

Figure 7. Flow volume at Cut Away Bridge versus estimated lake depth. Note that when the channel is clear an increase in flow volume results in only a small increase of water depth in Upper St. Croix Lake.

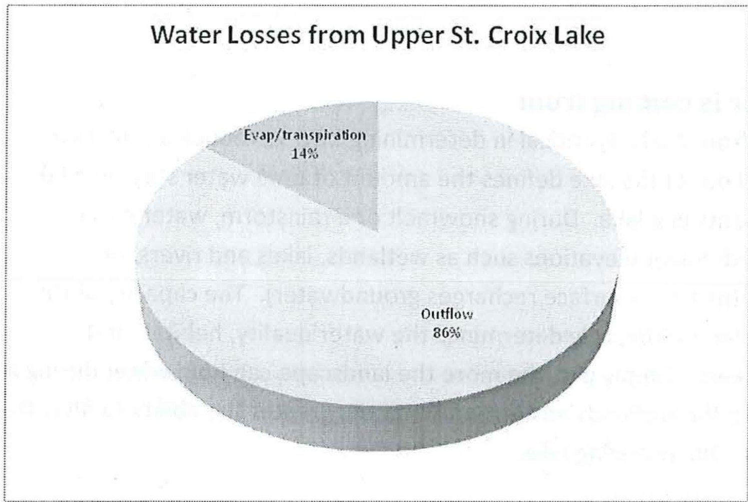

Figure 5. Water losses from Upper St. Croix Lake.

Precipitation feeds lakes and their tributaries directly via surface runoff and groundwater inflow. Near Upper St. Croix Lake, about one third of the precipitation that falls infiltrates into the ground to recharge groundwater. The rest of this precipitation is either lost through evaporation/transpiration or makes its way to wetlands, tributaries, or the lake as surface runoff. A combination of interactions between topography, geology, soil, man-made structures, natural and altered drainages, and land use practices influence the water chemistry and both regional and local surface water flow.

Observations of water level (stage) in Upper St. Croix Lake and the St. Croix River at Cut Away Bridge show that they are closely related (Figure 6). During this study we have observed dramatic differences in the volume of water in the St. Croix River near Cut Away Bridge during different seasons. Of course, changes in volume are related to the amount of precipitation but they are also related to the size of the channel (Figure 7). The channel remained open until early July when vegetation (predominantly wild rice) began to fill the channel. By August the channel was filled with wild rice and backed up the water into Upper St. Croix Lake (Figure 8).

Results and Discussion

Lake Hydrology – Where the water is coming from

Understanding how water moves to and from a lake is critical in determining how to reduce inputs to a lake. The amount of water going into and out of the lake defines the amount of time water stays in a lake, its water quality, the algae and aquatic plants in a lake. During snowmelt or a rainstorm, water moves across the surface of the landscape towards lower elevations such as wetlands, lakes and rivers, or internally drained areas (where water on the land's surface recharges groundwater). The capacity of this landscape to hold water and filter particulates ultimately determines the water quality, habitat, and amount of erosion into and out of the stream. Simply put, the more the landscape can hold water during a storm, the slower the water is delivered to the wetlands and streams and the greater the ability to filter the runoff; resulting in better water quality for the receiving lake.

As water moves across the land's surface, soluble and particulate matter is picked up and travels with the flow. Less surface runoff is generated and runoff is partially filtered when water is infiltrated and plants divert and slow water movement causing sediment and associated nutrients to be deposited or absorbed. The best plant filters (vegetated buffers) consist of a combination of trees, shrubs, and deeply rooted perennial vegetation with well structured soil. Although some of the land around Upper St. Croix Lake and its tributaries have this type of vegetated buffer, one aspect or another is missing from parts of the landscape.

Upper St. Croix Lake receives its water from tributaries, precipitation on the lake, surface runoff during rainstorms and snowmelt (unmonitored), and groundwater inflow (included in unmonitored and tributaries) (Figure 4). Most of the water leaves Upper St Croix Lake through its outflow (the St. Croix River), though some water is lost to groundwater (included in outflow) and evaporation (Figure 5).

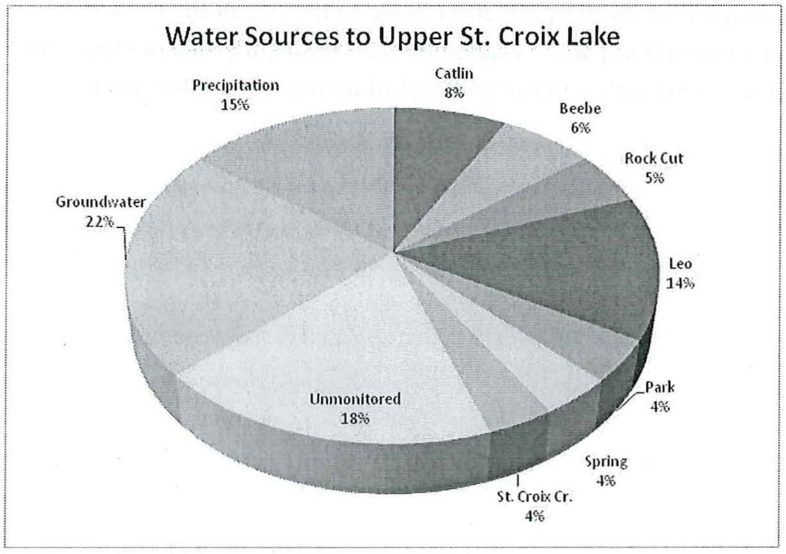

Figure 4. Sources of water to Upper St. Croix Lake.

Watershed Water Quality

UWSP conducted tributary monitoring during part of this study along with trained volunteers from USCLA and Friends of the St. Croix Headwaters (FOTSCH). Samples from four tributaries (Leo, Park, Beebe, and Catlin Creeks) were collected routinely during 2007 and 2008 (Figure 3). St. Croix Creek was monitored routinely in 2007 and Spring and Rock Cut Creeks were routinely monitored in 2008. In addition, samples were also collected from Porcupine and Jackson Creeks. Samples were acquired using grab method and with the use of siphon samplers. Siphon samplers were set at each location to obtain water samples during storm events. When samples were collected by grab method field measures included pH, temperature, dissolved oxygen, and specific conductance. Samples were placed on ice, then prepared according to protocol. Lab analyses included total suspended solids (TSS), chloride (Cl), and major nutrients (phosphorus and nitrogen).

Streamflow was quantified with the use of pressure transducers, staff gauges, and stream discharge measurements. The flow and water quality data were used to evaluate contributions from each sampled sub-watershed as well as nutrient and water budgets. The nutrient and water budget data were used to evaluate nutrient and sediment inputs to Upper St. Croix Lake from the watershed tributaries.

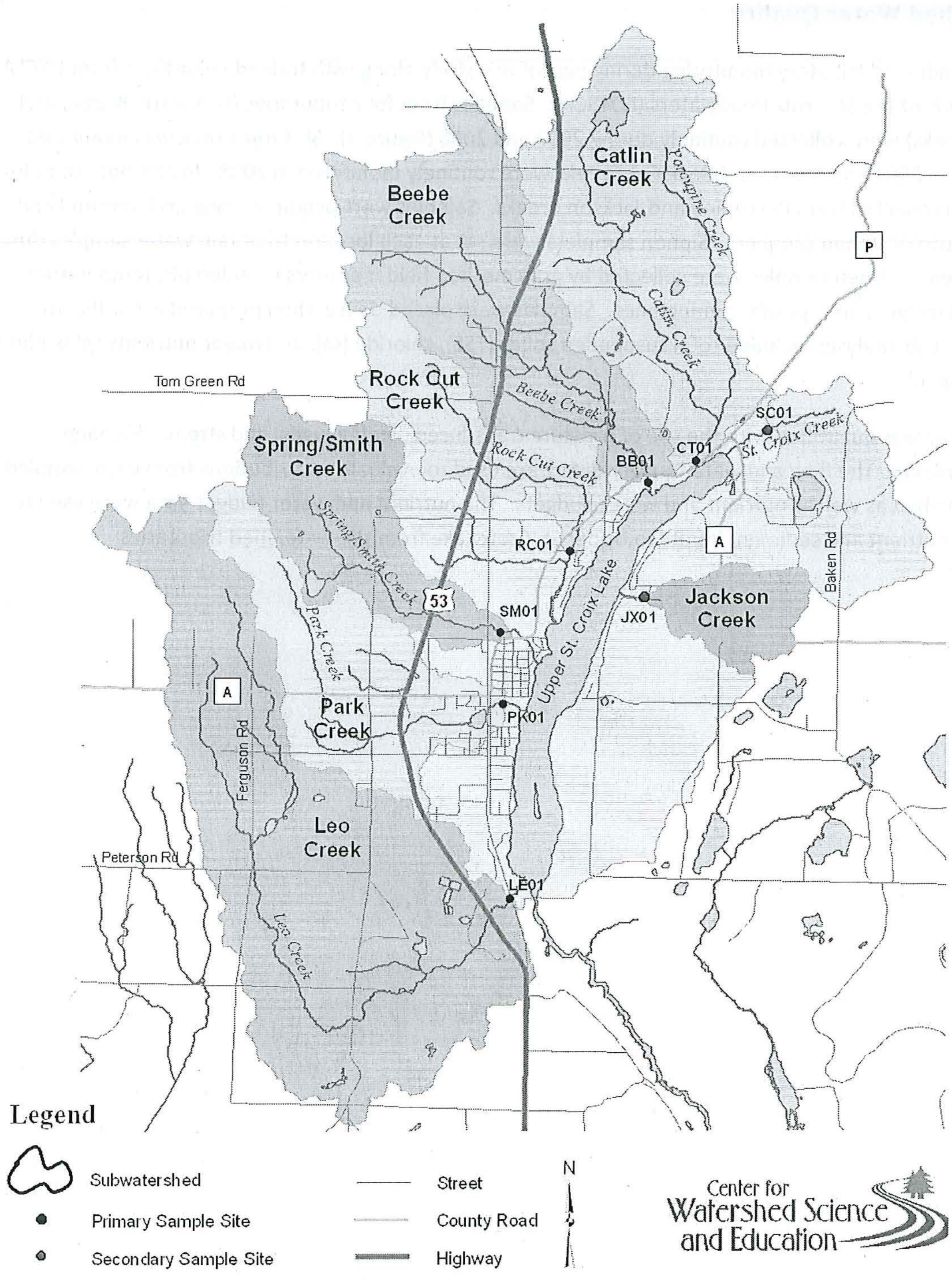

Figure 3 Tributaries, sub-watersheds, and river water quality sampling sites in the Upper St Croix Lake Watershed.

Methods

Lake Water Quality

Variability in lake water quality can occur from year-to-year and seasonally, so it is beneficial to examine data for seasonal and long-term water quality trends. Through the WDNR's Self Help Monitoring Program, volunteers from the USCLA have been collecting in-lake water quality measures since 1996; UWSP has been working with the USCLA since 2006. All of these data have been compiled in this report.

Lake water quality data have been collected at two in-lake sites: one north basin location and one south basin location (Figure 3). During the summer, water clarity measurements were taken by USCLA volunteers prior to sample collection for water quality analysis. Lake samples were analyzed in the lab for phosphorus and chlorophyll *a* (an indicator of algae) during the summer. Profiles of pH, specific conductance, temperature, and dissolved oxygen were measured by UWSP during spring and fall overturn, and winter at the time that lake samples were acquired for water quality analysis. Overturn samples were analyzed for alkalinity, nitrate (NO_2+NO_3-N), ammonium (NH4-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), and chloride. Water chemistry analysis was performed at the State Lab of Hygiene (DNR citizen volunteer monitoring samples) and the DNR-certified Water and Environmental Analysis Lab (WEAL) at UWSP.

Groundwater Survey

Groundwater inputs to Upper St. Croix Lake were evaluated using several techniques. During winter 2006/07 USCLA volunteers mapped areas of open water. These areas were tested in greater detail by UWSP in summer 2007 using mini-piezometers (small wells inserted into the lake bed). The mini-piezometers allowed for the quantification of groundwater flowing into or out of Upper St. Croix Lake; samples for water quality analysis were collected from the inflowing groundwater. Field measures included pH, specific conductance, and temperature; nutrients, and chloride were analyzed in the WEAL lab. Groundwater flow from springs was estimated by either measuring flow with a Marsh-McBirney Flow Meter or timing flow into a container and measuring the volume. The survey of groundwater was used to identify areas with the greatest groundwater inflow, determine the quality of groundwater flowing into Upper St. Croix Lake, and estimating the groundwater contribution to the lake water and nutrient budgets. Details of this survey can be found in *Groundwater Assessment of Upper St Croix Lake, Douglas County, WI,* 2007.

Upper St. Croix Lake Project Content and Approach

Project Goals and Objectives

Many processes affect the water quality, algae, and aquatic plant conditions in Upper St. Croix Lake; therefore, a variety of sub-studies were conducted to provide a broad picture of the Upper St. Croix Lake system. The goals of this two year study included an examination of the water quality conditions in Upper St. Croix Lake and in its watershed, enhancing citizen understanding of the lake/watershed, and development of a management plan that highlights scientifically-based sustainable management options. Objectives included:

- Assessing lake chemistry and overall water quality of the lake, groundwater entering the lake, and its tributaries.
- Estimating overall nutrient and water budgets through modeling.
- Developing predictive models of nutrient and hydraulic loads to the lake.
- Developing science-based management recommendations.
- Aiding in development of strategic plan for the lake in coordination with members of the community.

The study involved the collection of water quality and quantity data from Upper St. Croix Lake, its tributaries, and groundwater. Sediment samples were also evaluated for phosphorus release during oxic and anoxic (lacking oxygen) conditions. Detailed results of the groundwater assessment, sediment release, and the development of the SWAT model, and the algal assessment can be found in reports titled *Groundwater Assessment of Upper St Croix Lake, Douglas County, WI,* 2007; *Internal Phosphorus Loading from Sediment under Controlled Conditions in Upper St. Croix Lake, Douglas County, WI,* 2008; *Hydrology and Phosphorus Model for Upper St. Croix Lake, Douglas County, WI, 2009;* and *Algal Community Composition and Successional Trends Upper St. Croix Lake, Douglas County, WI, 2009.* A summary of this report was created in a document titled *Water Quality and Algae in Upper St. Croix Lake - Summary Report.* A strategic plan was developed to guide the implementation steps needed to correct phosphorus issues related to algal blooms in Upper St. Croix Lake. This document is titled *Strategic Plan for Upper St. Croix Lake, Douglas County, WI, 2010.*

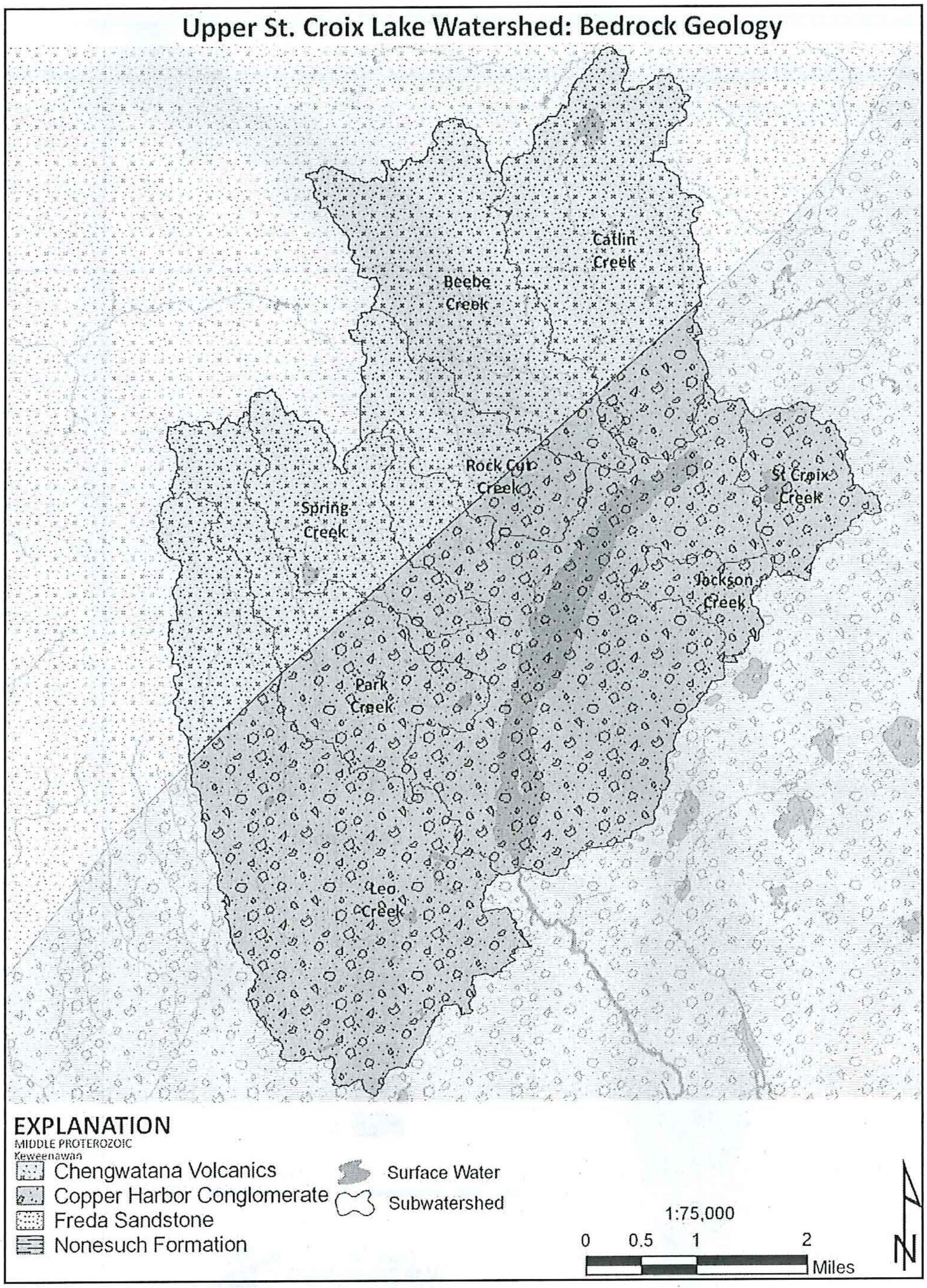

Figure 2. Local geology of the Upper St. Croix Lake watershed. Note: the Copper Harbor Conglomerate is the dominant bedrock.

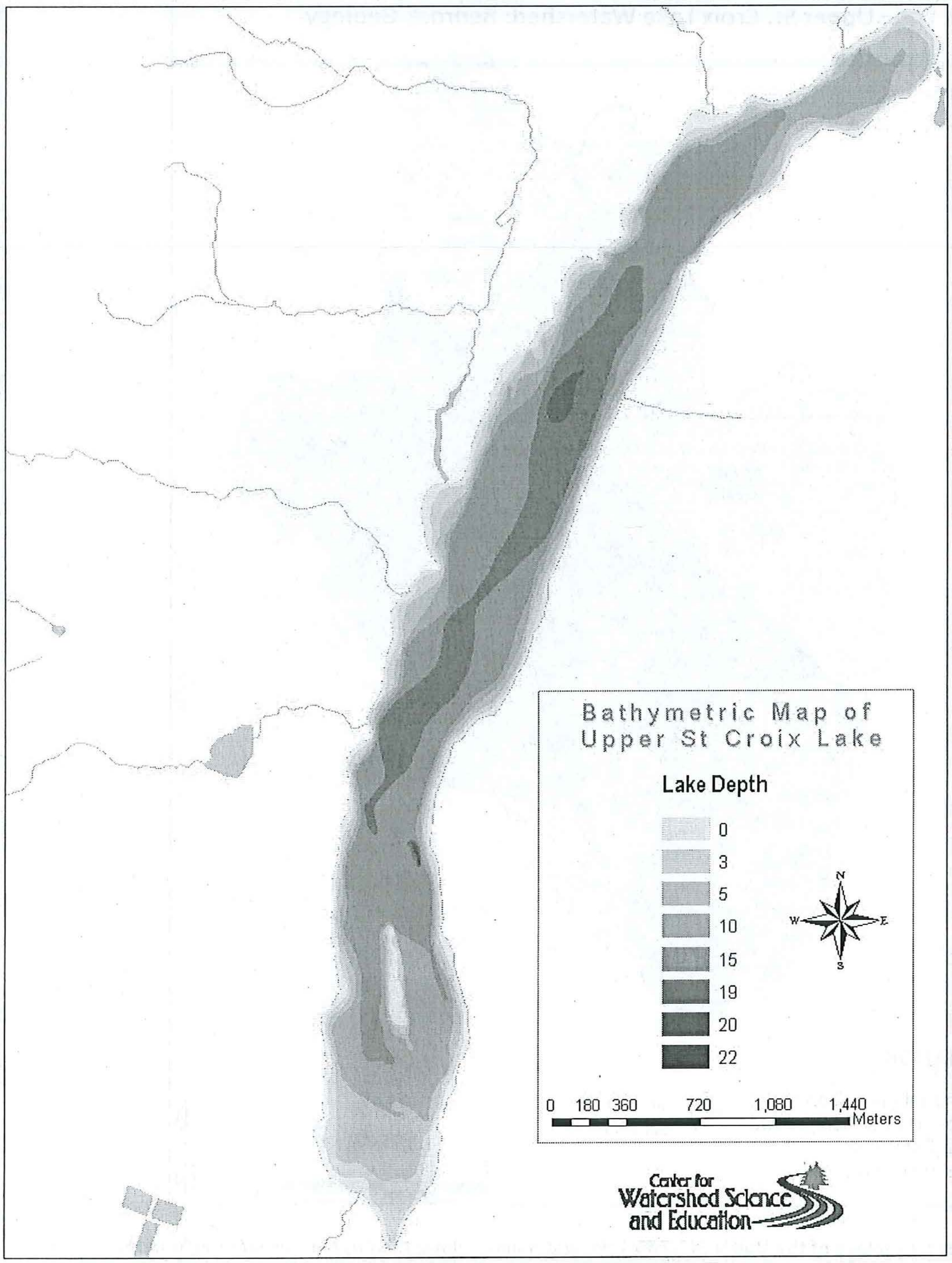

Figure 1. Bathymeteric map of Upper St Croix Lake.

Introduction and Background

This study was an effort between the Upper St. Croix Lake Association (USCLA), the University of Wisconsin Stevens Point (UWSP) Center for Watershed Science and Education (CSWE), the volunteers and citizens of the Upper St. Croix Lake Association (USCLA), and the Wisconsin Department of Natural Resources (WDNR).

Upper St. Croix Lake is a naturally impounded drainage lake located in the headwaters of the St. Croix River in Douglas County. Upper St. Croix Lake basin was formed of glacial origin. The basin which the lake occupies acted as a spillway for glacial outwash about 11,000 years ago during the retreat of glaciers at the end of the last ice age (Manners et al., 2001). Local geology of the area consists of a thick covering a glacial drift in excess of 200 ft in some areas with underlying sandstone, basalt, conglomerate, shale, and metamorphic rocks (Figure 2) (Manners et al., 2001). The soil in this area is primarily sandy loams, loamy sands, and organic soils in low lying areas.

The Upper St. Croix Lake Watershed encompasses 28 square miles and lies within Upper St. Croix–Eau Claire River Watershed reflecting the glacial drift parent material (Figure 2). The Upper St. Croix–Eau Claire River Priority Watershed project has been working to improve the quality of lake and watershed since 1997 in an effort to provide for the future a resource that can be enjoyed by the surrounding community and visitors to the area. Almost 67% of the 9.5 mile shoreline is developed (DNR, 1997). Some of the developed shoreline has significant vegetative buffers that provide habitat and reduce/filter runoff to the lake but much of the shoreline lacks these buffers and likely impacts the water quality of Upper St. Croix Lake. The lake is used by residents and visitors and because of the proximity to the Village of Solon Springs it is very much connected to the community and the local businesses.

Upper St. Croix Lake has a surface area of 855 acres and a maximum depth of 22 feet (Figure 1). It receives water from groundwater, seven tributaries, surface runoff, and direct precipitation. Upper St. Croix Lake's littoral zone (the area of the lake that sufficient light penetrates to allow the growth of aquatic plants) includes areas of the lake to a depth of 15 feet comprising 84.5% of the lake. The average residence time is relatively short at approximately 0.45 years; however, during low flow periods in later summer when the downstream vegetation impounds the river the retention time in Upper St. Croix Lake increases.

Water quality monitoring and presence of significant blue green algae blooms suggest that Upper St. Croix Lake is eutrophic during the later part of summer. The source of this eutrophication is thought to be an increase in soil erosion in the watershed beginning around 1940 (Garrison, 2004). The result of the soil erosion is an elevated sedimentation rate that increases nutrients entering the lake (Garrison, 2004). In the fall of 2005, algae samples were collected in the Upper St. Croix for identification of blue-green algae species; Aphanizomenon sp. (at 119,400 filaments/mL) and Anabaena sp. (at 45,800 filaments/mL) were identified in the sample. These concentrations are above the World Health Organization standards, indicating that the eutrophic conditions are not just affecting aesthetics and the lake ecology, but also pose a potential health concern.

Executive Summary

This study was initiated to gain insight into the growth of blue-green algae for use in the development of a plan outlining steps that need to be taken to reduce the algal bloom magnitude and/or frequency in Upper St. Croix Lake. The study was designed to evaluate phosphorus inputs from tributaries of Upper St. Croix Lake, the quality of groundwater feeding the lake and its tributaries, internal loading, and inputs from land use practices in the surface and groundwater watersheds. Water quality and hydrologic data were collected between 2007 and 2008 and to evaluate historical patterns, the data set used in our analysis ranged from 1996 to 2008. The algal community was also evaluated during the open water period in the second year of the study.

Upper St. Croix Lake shows signs of moderate nutrient enrichment and a shift towards dominance by less desirable blue-green algae. Sources of nutrients are both natural and from cultural inputs from land management practices and other activities. Each spring the phosphorus in Upper St. Croix Lake is about 20 ppb and as summer progresses the phosphorus increases to 60 ppb or more. Several mechanisms are likely to be associated with this increase including internal loading from sediment and biota and a longer retention time due to water that is impounded by wild rice downstream near Cut Away Bridge.

Many natural factors make this situation difficult to address. Upper St. Croix Lake is a soft water lake which results in increasing algal growth with the addition of phosphorus. The shape of Upper St. Croix Lake provides ideal conditions to grow algae and there is little that can be done to alter the natural internal loading of phosphorus; however, it is possible to reduce some of the sources of phosphorus that are related to land management practices and reductions should reduce algal bloom frequency and magnitude over the long term.

Water quality in a lake is a reflection of land use practices in its watershed and this is certainly the case with Upper St. Croix Lake. Physical conditions such as drought, geological conditions, or the shape of the lake can't be controlled. However; numerous changes in the way land is managed can reduce phosphorus inputs to Upper St. Croix Lake and will improve conditions over the long term, although these changes may be slow. Taking no action to reduce phosphorus inputs to the lake will likely result in increased frequency and magnitude of algal blooms. Allowing an increase in phosphorus additions to the lake *will* result in increased frequency and magnitude of algae blooms with the potential of fish kills due to oxygen depletion.

Members of the community gathered on several occasions in winter 2009/10 to identify steps that could be taken to reduce phosphorus inputs to Upper St. Croix Lake from the Upper St. Croix Lake watershed. Implementation of these steps by citizens, local municipalities, and County and State staff is essential to improve water quality and other goals identified in the strategic plan.

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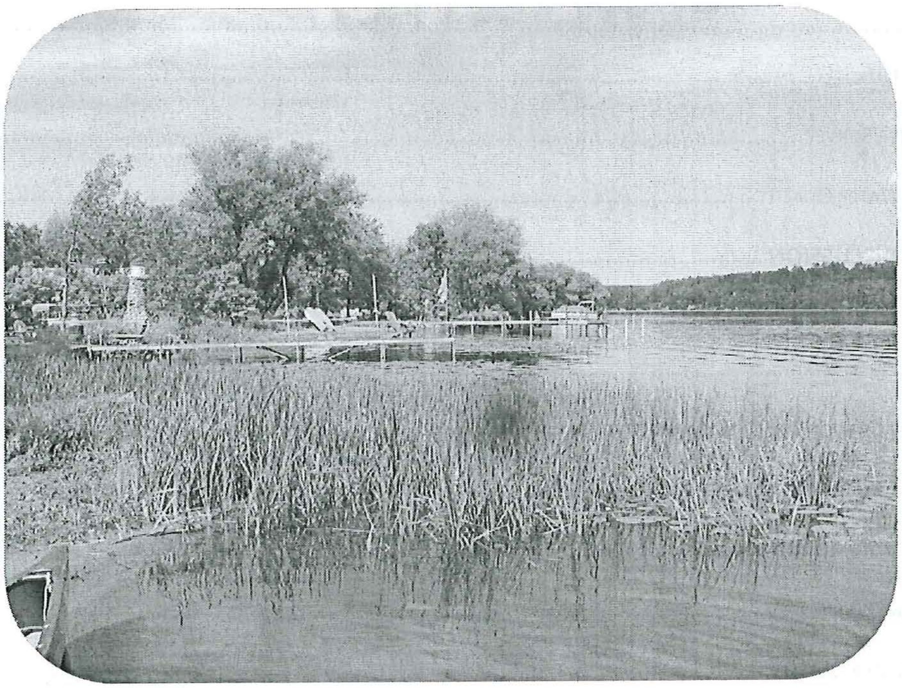

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