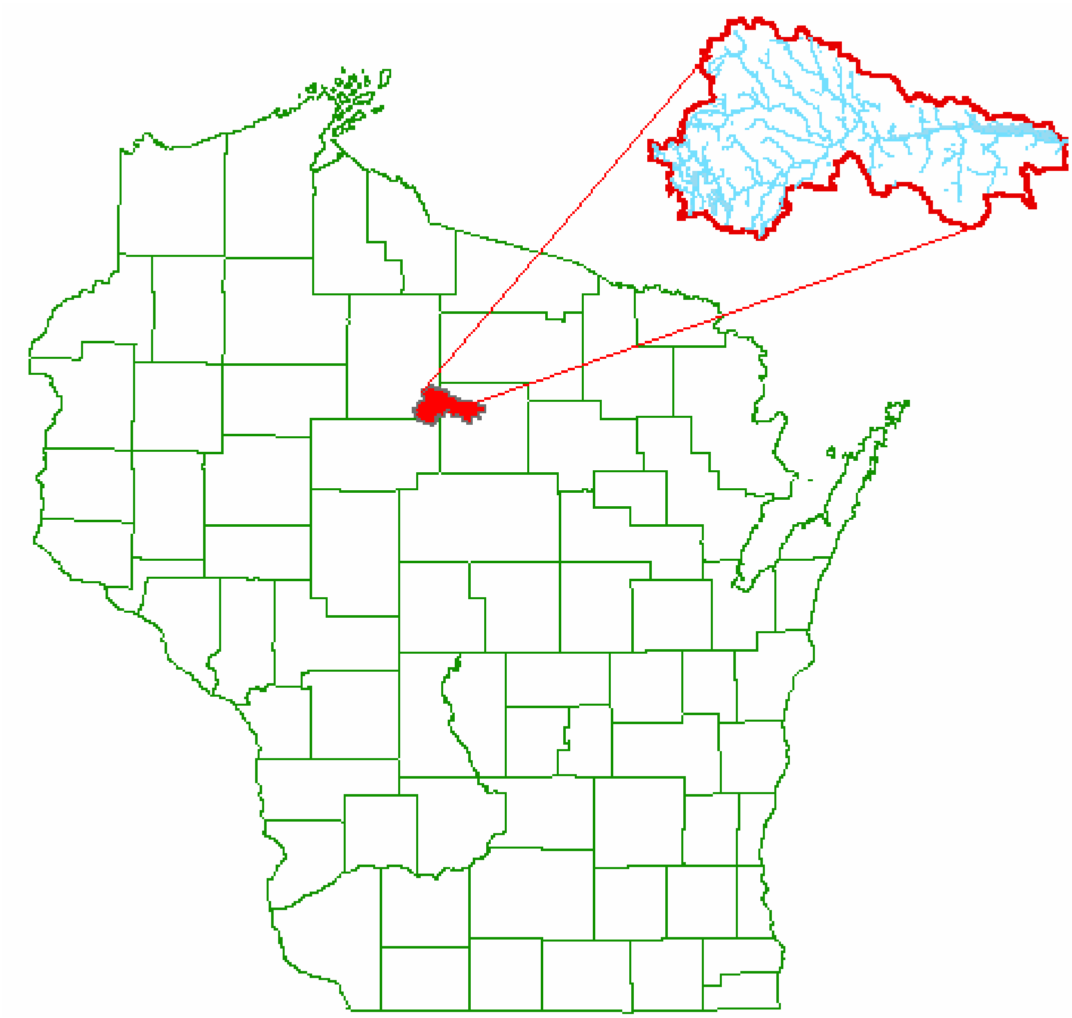
Spirit Reservoir Water Quality Assessment
Northern Wisconsin

December 2006



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ACKNOWLEDGEMENTS

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- Nancy Turyk, for her expertise on data analysis, report writing, editing, and lake sample scheduling which was crucial to completing this study.
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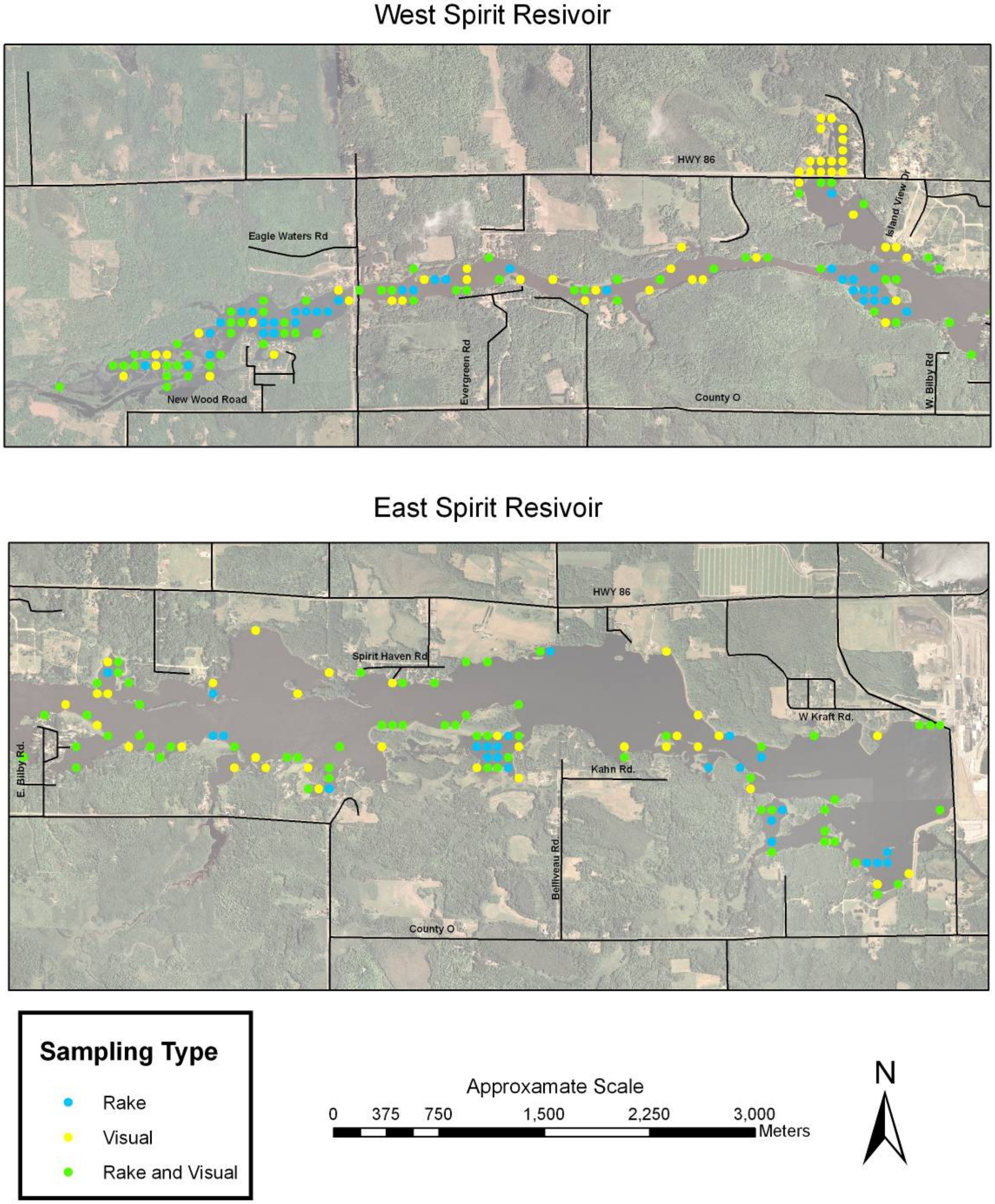

West Spirit Resivoir
HWY 86
Eagle Waters Rd
Island View Dr
Evergreen Rd
New Wood Road
County O
W. Bilby Rd
East Spirit Resivoir
HWY 86
Spirit Haven Rd
W Kraft Rd.
E. Bilby Rd.
Kahn Rd.
Belliveau Rd.
County O
Sampling Type
Rake
Visual
Rake and Visual
Approxamate Scale
0
375
750
1,500
2,250
3,000
Meters
N

List of Abbreviations

Chlor a	Chlorophyll a, a typical measure of algae populations.
Chlor a_{obs}	The reservoir area weighted mean chlorophyll a concentration in µg/L calculated by BATHTUB from observed data.
Chlor a_{pred}	The reservoir area weighted mean chlorophyll a concentration in µg/L predicted by BATHTUB.
CWSE	University of Wisconsin-Stevens Point Center for Watershed Science and Education
mg/L	Milligrams per liter, typical concentration used for water quality parameters other than total phosphorus and chlorophyll a, like nitrogen and chloride. Approximately equal to parts per million.
TP	Total phosphorus, the limiting nutrient in most aquatic systems.
TP_{obs}	The reservoir area weighted mean total phosphorus concentration in µg/L calculated by BATHTUB from observed data.
TP_{pred}	The reservoir area weighted mean total phosphorus concentration in µg/L predicted by BATHTUB.
WVIC	Wisconsin Valley Improvement Company
µg/L	Micrograms per liter, typical concentration units for total phosphorus and chlorophyll a. Equivalent to mg/m^3, and approximately equal to parts per billion.

Executive Summary

Water quality in the Spirit Reservoir and its tributaries were examined to evaluate sources of phosphorus leading to the pronounced algae blooms that are observed in the later part of the summer. Phosphorus is prevalent throughout the Spirit Reservoir watershed so therefore the reduction of phosphorus in the reservoir will be challenging. However, additional phosphorus inputs may result in the reservoir becoming algae dominated, resulting in a significant reduction of aquatic macrophytes and significantly altering the aquatic biota. The algal community is dominated by filamentous and colonial cyanobacteria, diatoms, and filamentous green algae. The filamentous cyanobacteria and green algae are typical of phosphorus-enriched waters and can become nuisance organisms. Once established these organisms are difficult to remove from the system due to internal recycling of nutrients. Not surprisingly because of the sub-watershed size and volume of water, the greatest load of total phosphorus entered the reservoir from the Spirit River, however on a pounds/acre basis the Armstrong Creek and New Wood Rd sub-watersheds had the highest loads of total phosphorus at 0.2 and 0.22 pounds/acre, respectively.

Additional inputs of phosphorus should be controlled by taking measures to control soil erosion throughout the watershed, restricting the use of phosphorus fertilizer, and minimizing the removal of native vegetation especially near the riparian areas around the lakes, streams, and river. The fishery should be closely examined to determine if bio-manipulation could be used to help control algae blooms and if it is not feasible, use of alum treatments could be considered. Installation of a sediment basin near the upper end of the Spirit Reservoir should also be explored.

An aquatic macrophytes survey was conducted in late July 2006 to evaluate the health of the plant community. A total of 785 sites were included in the survey but only 176 sites were accessible and had aquatic macrophytes present. The rooting depth of aquatic plants during the survey was estimated at 6.5 feet. Twenty-nine species of aquatic plants were identified throughout the reservoir with the highest species richness near the shoreline. The aquatic plant community in Spirit Reservoir is a relatively healthy community compared with other impoundments in Wisconsin. Coefficients of Conservancy for the aquatic plant species ranged from 1-9 and the floristic quality index for the reservoir was 33, however filamentous algae was one of the prominent aquatic plant species identified. The only invasive species identified in Spirit Reservoir was reed canary grass, however this plant was prevalent along the shoreline and therefore may eventually out compete some of the native aquatic vegetation that currently occupies the shoreline. A plan should be developed to keep other aquatic invasive species out of the Spirit Reservoir. Because of the reservoir size and its flow, once an aquatic invasive species becomes established it will be impossible to remove it.

Introduction

Physical characteristics and development

Setting

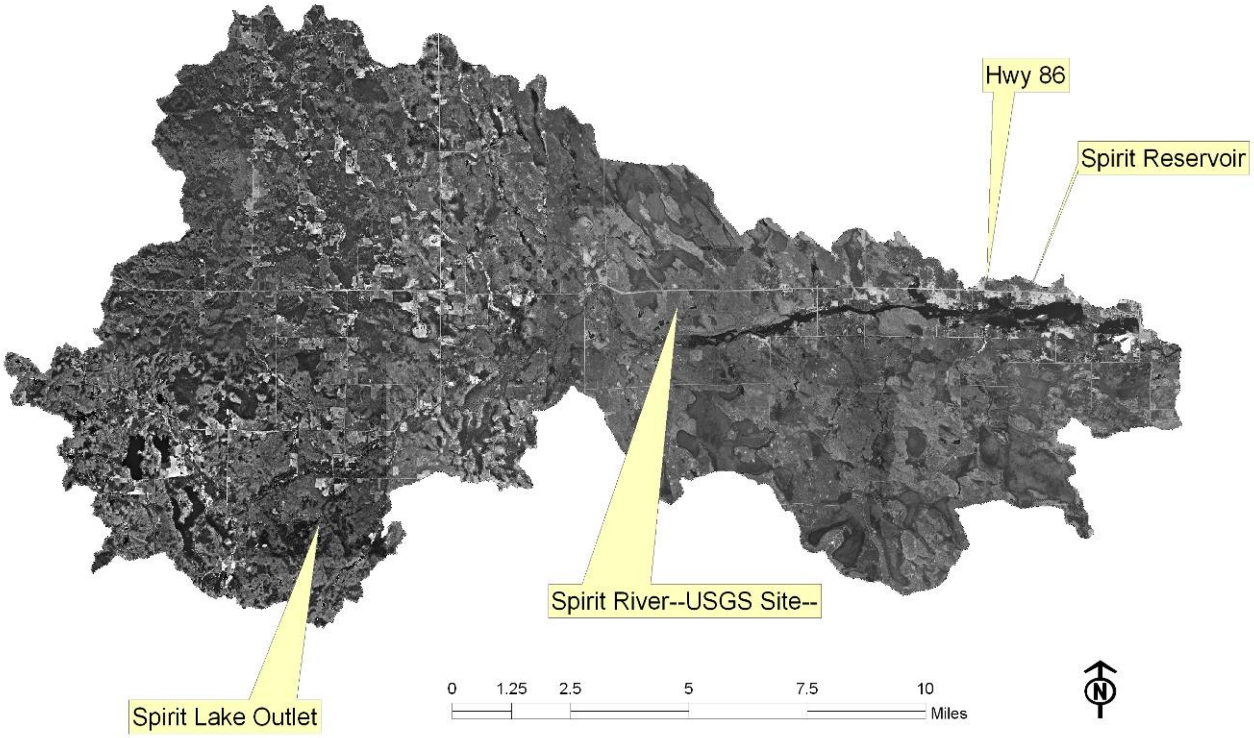
The Spirit Reservoir is located in Lincoln County and is the result of the impounded Spirit River. The Spirit Reservoir is fed by an extensive watershed of 108,174 acres (169 square miles) that lies within the Upper Wisconsin River Basin extending into Lincoln, Price, and Taylor Counties. An ortho-photo highlights the hilly topography throughout the western half of the watershed (Figure 1). Many of the tributaries that feed Squaw Creek, the Spirit River, and the Spirit Reservoir were sampled during this study. The corresponding sub-watersheds are shown in Figure 2 and Table 1 contains the name of each sub-watershed that corresponds with the numbers shown in Figure 2.

When filled, the lake encompasses 1,667 acres with a maximum depth of approximately 26 feet (WDNR, 2001). The impoundment that creates the Spirit Reservoir is operated by Wisconsin Valley Improvement Company (WVIC). The primary function of the Spirit Reservoir is to control water level fluctuations in the Wisconsin River (WVIC pamphlet). The water levels can change dramatically throughout the day and year. Levels may be drawn down 17 feet during winter months, affecting the aquatic biota including aquatic plants and fish. Fish entrapment has been documented by local residents and UWSP staff and students. However, a full assessment of fish mortality for the entire reservoir has never been conducted.

The Spirit Reservoir is used for recreation including boating, fishing, aesthetic appreciation and hunting. Most of the near-shore riparian vegetation is a healthy mixture of forbs, shrubs, and trees; very little is mowed or in lawn. Though some land is protected, there will likely be additional residential development. Many of the older homes have minimal impact to the water quality in Spirit Reservoir because of their limited impervious surfaces and naturally vegetated yards, however the newer developments often have increased impervious surfaces and frequently more mowed vegetation. Both of these attributes can accelerate runoff to the water, carrying sediments, nutrients, and other pollutants which may be used or spilled.

Residents and lake users are concerned about the water quality conditions in the reservoir during the summer, particularly algae growth which was the impetus for this study. The primary goal of this study was to assess water quality in the tributaries and reservoir and use the information to create water and nutrient models. In addition, surveys of algae and aquatic plants were conducted.

Figure 1. Ortho-photo showing Spirit Reservoir Watershed with Prominent Features.



Climate

The climate of the Spirit River Watershed is classified as continental. The winters are long, cold and relatively snowy with about 50 inches of snow falling annually. The summers are warm with cool nights and few days that are hot and humid. Overall the average temperature of the area is about 43º F and receives about 30 inches of rain and melted snow (Surface Water Resources of Lincoln County, 1977).

Topography, Geology, and Soil

The Spirit River Watershed contains gently rolling heavily wooded terrain. The topography is a result of the Chippewa Lobe of the last glaciation (Surface Water Resources of Lincoln County, 1977). Underlying the Spirit River Watershed is the Canadian Precambrian Shield consisting mostly of granite and undifferentiated igneous and metamorphic rock. There are basaltic to rhyolitic meta-volcanic rocks with some meta-sedimentary rocks as well. Above that are water barring rocks of drift and alluvial sand and gravel. The water is mostly found in the sand and gravel layer (where present) and the fractures of the rocks with groundwater plentiful in most of the Spirit Reservoir Watershed (Surface Water Resources of Lincoln County, 1977).

Figure 2. General overview of the Spirit Reservoir Watershed, its location within Wisconsin, and the locations of tributary monitoring points, sampled by the Center for Watershed Science (CWSE) in 2005.

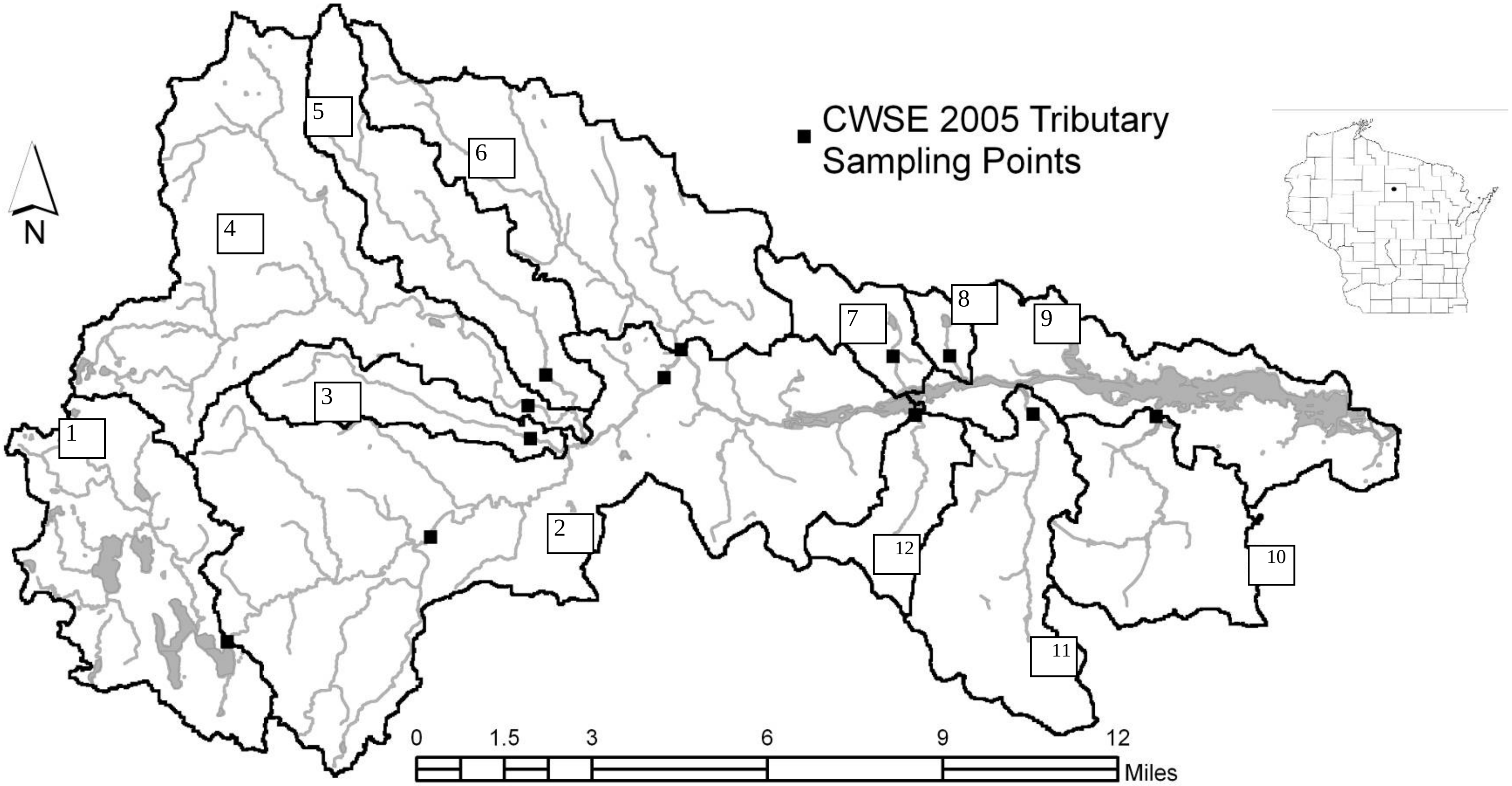
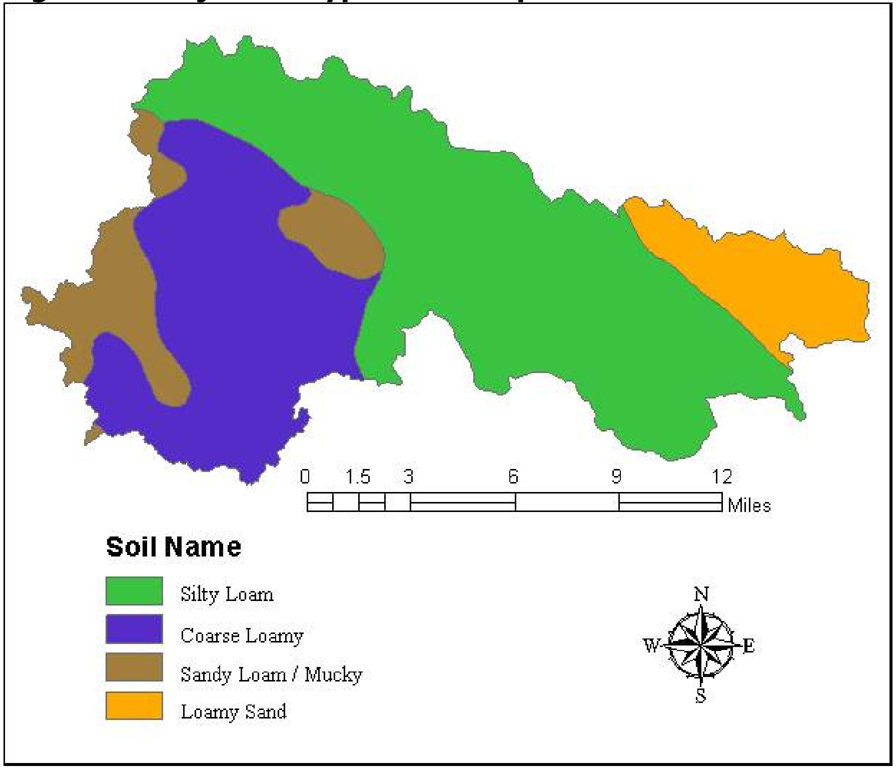


Table 1. Sub-watershed names associated with each sample site. Numbers correspond to Figure 2.

ID Number	Subwatershed Name	ID Number	Subwatershed Name	ID Number	Subwatershed Name
1	Spirit Lake	5	Ritchie Creek	9	Spirit Reservoir
2	Spirit River	6	Squaw Creek	10	Coffee Creek
3	Marheime Creek	7	Hwy 86 West	11	Armstrong Creek
4	North Fork Spirit River	8	Hwy 86 East	12	New Wood Road

The soil in the Spirit River Watershed is the result of weathering glacial deposits. The eastern part of the watershed is well-drained pitted sandy loam soil. The western part of the watershed contains mostly imperfectly drained silt loam soil and some level wet soil (Surface Water Resources of Lincoln County, 1977). General classification of these soils are found in Figure 3.

Figure 3. Major soil types in the Spirit Reservoir Watershed



Land Cover

The land cover within the Spirit Reservoir Watershed is mainly forested (Figure 4). Forest accounts for the majority of the land cover in most sub-watersheds, ranging from 46-72% of total land cover (Table 2). Wetlands are the second most abundant land cover within the watershed, ranging from about 4-49% of total land cover within each sub-watershed. Wetlands are most dominant within the Hwy 86 West, Coffee Creek, and New Wood Road sub-watersheds. Grassland is the third most frequently occurring land cover, although it accounts for much less of the total land cover than forest and wetlands, with values ranging from 5-15% of total land cover within the sub-watersheds. The other types of land cover within the watershed, such as agriculture, barren, and shrub land, are present but comprise only relatively small amount of the watershed. There is little developed land within the Spirit Reservoir watershed with most development in the Ritchie Creek, Squaw Creek, and Spirit Reservoir sub-watersheds.

Figure 4. Land cover within each sub-watershed in the Spirit Reservoir Watershed.

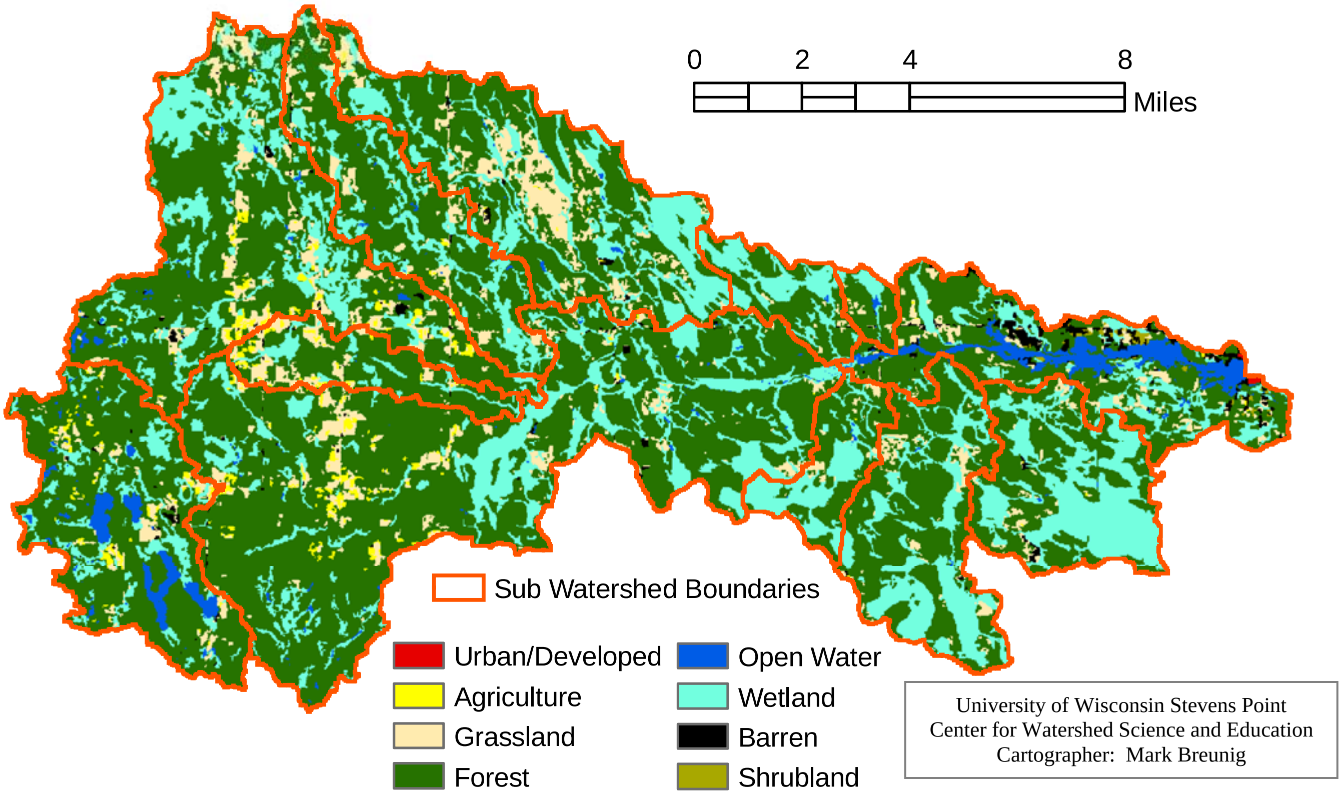
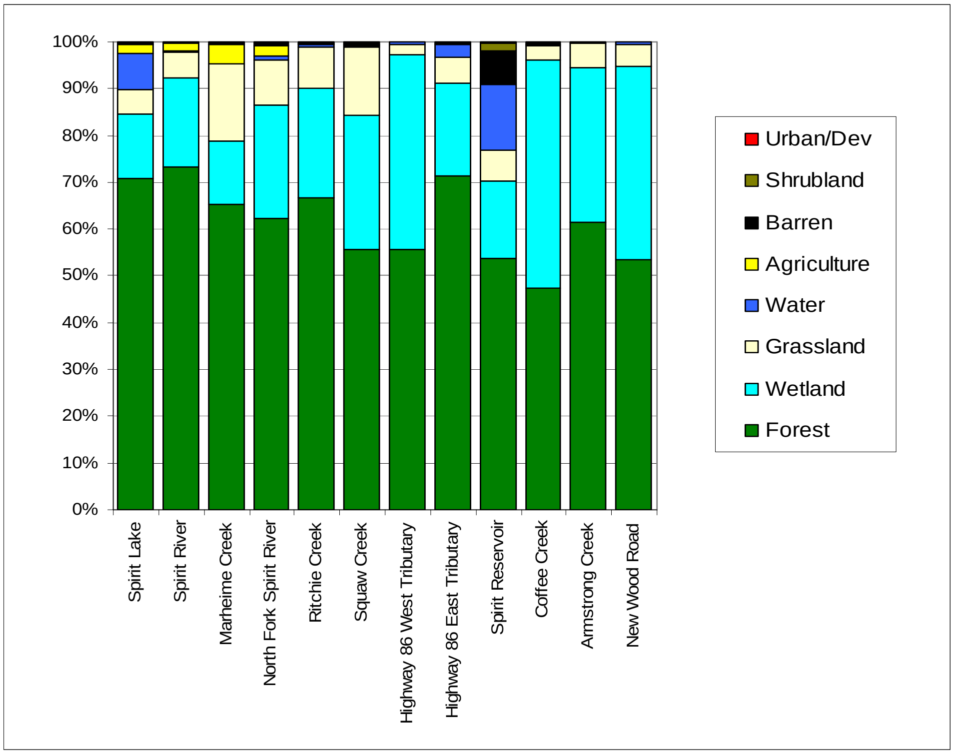


Table 2. Percent land use within each sub-watershed in the Spirit Reservoir Watershed.



METHODS

Field/Lab Procedures

The equipment and techniques used in the field and laboratory were selected because they are appropriate for water quality analysis and habitat assessment of the Spirit Reservoir. All information that was gathered was placed into the Center for Watershed Science and Education's (CWSE) computer database in programs such as Microsoft Excel and Arc GIS for analysis. Water samples were collected by University of Wisconsin Stevens Point (UWSP) staff unless otherwise mentioned. Training and guidance for sample collection was provided for the Spirit Reservoir Association by the UWSP staff.

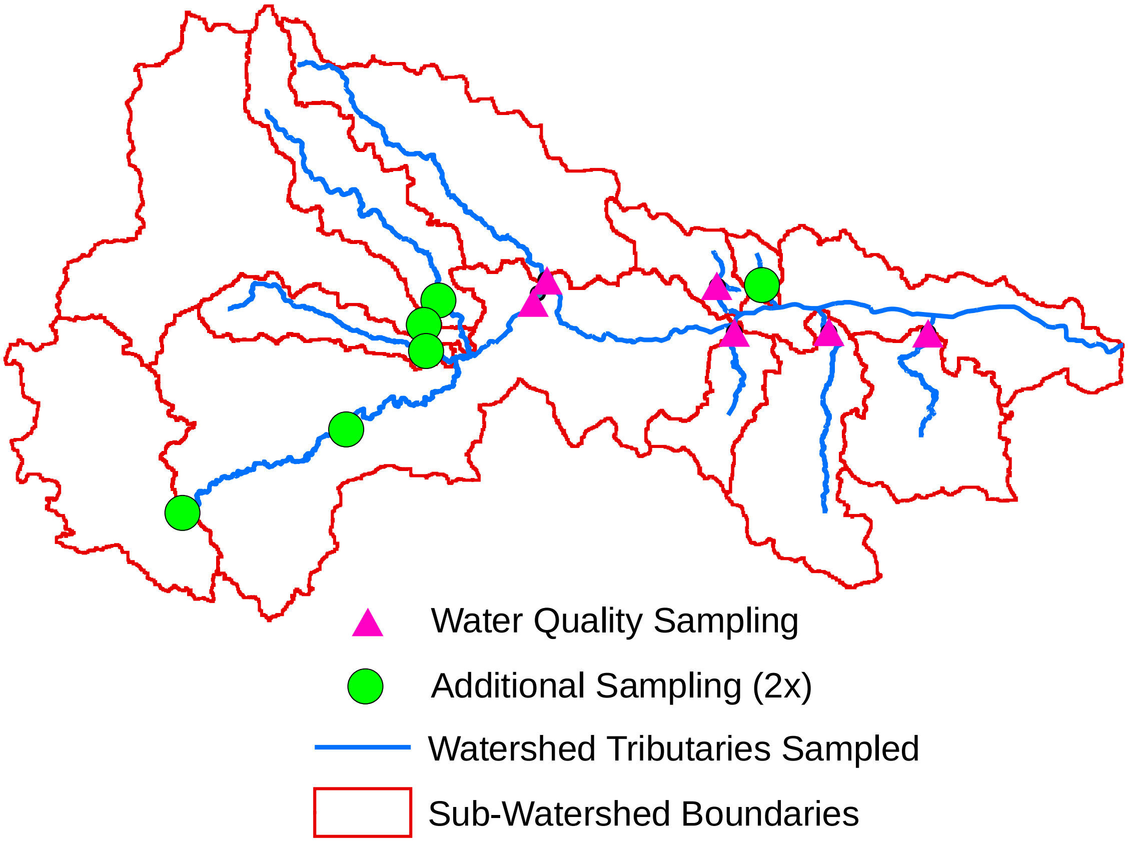
Tributary Sampling

Throughout much of the study water quality samples were collected at six sites including: Spirit River, Squaw Creek, Un-named Tributary at County Highway 86, Unnamed Tributary at County Highway O, Armstrong Creek, Coffee Creek at County Highway O, and twice during the study samples were collected at 12 sites during winter baseflow (Figure 5).

Samples were taken via the grab method and using siphon samplers at five of the six regular water quality sites. Siphon samplers were attached to a fence post that was installed in the central part of the river. The siphon samplers were positioned to sample an anticipated rise in the stream from an event. This height varied from site to site depending upon the morphology (size, shape) of the stream and location within watershed. When the water crested above the peak of the lower tube, the river water entered the bottom tube and filled the 500 mL polypropylene sample bottle.

Grab samples were gathered using three different polyethylene bottles: one 500 mL bottle which was unfiltered and unpreserved, one 125 mL bottle which was unfiltered and preserved with 1 molar H_2SO_4, and another 125 mL bottle which was filtered and preserved with 1 molar H_2SO_4. Grab samples were collected by lowering the capped bottle to the mid-depth of the river with the lid facing downstream and then opening it, allowing the bottle to fill with water. Additional sampling took place during storm events (April 2005, June 2005) using siphon samplers. Sample from this bottle was used to fill the unfiltered 125 mL preserved bottle. The second 125 mL bottle was filtered by filling a 60 mL syringe with sample and than screwing it onto a 47mm in-line filtering cassette. The in-line filter contained two filter papers: a 934/AH coarse glass filter paper and a fine 0.45 micron membrane filter. The water first passed through the coarse filter and then the finer filter. The sample preservation and filtering process took place within 24 hours of sample collection. After collection, the bottles were placed on ice and transported to UWSP's state certified Water and Environmental Analysis Lab (WEAL) for analysis. Water quality samples were analyzed for nitrate+nitrite-N ($NO_2 + NO_3$), ammonium-N (NH_4 - N), total Kjedahl nitrogen (TKN), total phosphorus (Total P), dissolved reactive phosphorus (Reactive P), chloride (Cl), and total suspended solids (TSS).

Figure 5. Location of water quality sample collection sites within the Spirit River Watershed



Stream Flow Measurements

Stream flow, the volume of water passing a location within a specific time period, was measured in the Spirit River multiple times throughout the project. Stream flow was measured by CWSE using a Marsh-McBirney Flo-Mate Model 2000 personal flowmeter to determine flow velocity and a 100’ tape and wading rod to measure stream area through which that flow passes. The total width of the stream was divided into even increments (segments). Velocity and depth measurements were collected at the mid-point of the segment. Stream flow (or discharge) was calculated by multiplying the total depth by the segment width by the average velocity. Total stream flow (discharge) was then calculated by summing up the stream flow for the individual segments [Total Discharge = Σ (Discharge 1, 2, 3, 4…20)].

Pressure Transducers

Pressure Transducers were installed at five stations in fall 2004 and at two stations in 2005 to obtain continuous measurements of stream height ("stage") which were used to estimate stream flow (Table 3). The pressure transducers were Solinst level loggers. They were installed within the river at a fixed height above the sediment. When pressure of the water increased more than 1% from the previous reading, the level logger collected pressure and temperature. The instruments were set to check for changes in stream height at 15 minute intervals. A rating curve was developed for each site by using discharge measurements that were made at varying water levels. The level logger data was corrected for changes in barometric pressure by using another logger ("baro logger") outside the stream. Data collected in Spirit River at the USGS gaging station was also used in this evaluation.

Table 3. Pressure transducer sites, 2004.

Pressure Transducers Installed at the Following Locations in 2004				
Armstrong Creek	Squaw Creek	New Wood Rd.—Unnamed Creek.	Spirit Rd.—Unnamed Creek.	Coffee Creek

Mid-Lake Water Quality

There were three locations in the reservoir that were sampled: an upper end location, a middle location and a lower end location, ML2, ML3 and ML4 respectively. The locations of these sites, the segment boundaries used in BATHTUB, and a bathymetric map, can be found in Figure 7. These sites were sampled throughout 2005 for total phosphorus and chlorophyll *a*. Each time samples were collected measures of water clarity, and profiles of temperature, dissolved oxygen, pH and conductivity were also taken. Historic data from WVIC was used to supplement these data.

Sample Analysis

After collection, all water samples were stored and transported on ice to the state-certified Water and Environmental Analysis Lab (WEAL) at the University of Wisconsin-Stevens Point. The analyses run in the Water and Environmental Analysis Lab followed the methodology in Table 4.

Sediment Samples (Internal Loading)

Field Techniques

Sediment sampling was conducted on the Spirit Reservoir during the winter of 2004-05. Sediment samples were collected on three different days; January 13, January 19, and February 12, 2005. Sampling sites were chosen at random from the headwaters to the dam and consisted of transects along the width of the lake. Each transect generally ran from north to south and consisted of two to five transect points, depending upon its length. At each

Table 4. Analytical methods and corresponding detection limits for water quality analyses run in the UWSP Water and Environmental Analysis Lab.

ANALYSES	METHOD	METHOD DETECTION LIMIT
Alkalinity	Titrimetric 2320 B	4 mg/L
Chloride	Automated Ferricyanide 4500 C1 E	0.5 mg/L
Chlorophyll *a*	Spectrometric 10200 H	0.1 mg/L
Conductivity (in lab)	Conductivity Bridge 2510 B	1 umho
Hardness, Calcium	Titrimetric 3500 Ca D	4 mg/L
Hardness, Total	Titrimetric 2340 C	4 mg/L
Nitrogen, Ammonium	Automated Salicylate 4500-NH_3 G	0.01 mg/L
Nitrogen, Nitrate + Nitrite	Automated Cadmium Reduction 4500 NO_3 F	0.021 mg/L
Nitrogen, Total Kjeldahl	Block Digester; Auto Salicylate 4500-NH3 G	0.08 mg/L
Phosphorus, Soluble Reactive	Automated Colorimetric 4500 P F	0.003 mg/L
Phosphorus, Total	Block Digester, Automated 4500 P F	0.012 mg/L
Potassium	ICP 3120B	270 ug/L
Sodium	ICP 3120B	0.2 mg/L
Sulfur (SO4)	ICP 3120B	26 ug/L
Total Suspended Solids	Glass Fiber 103-105C 2540D	2 mg/L

site one hole was drilled through the ice with an auger and an acrylic cylindrical coring device attached to approximately ten feet of metal piping was lowered to the lake bottom. The coring device consisted of a hollow acrylic tube that was 50 cm in length and 8.8 cm in diameter. The acrylic tube was threaded at one end and beveled at the other end creating a blade like surface that could be pushed into dense sediments. The threaded end of the acrylic tube was screwed on to a metal plate of the same diameter which was welded to a 5 foot steel pipe. The pipe was also threaded so that additional 5 foot lengths could be connected. The coring device was attached to the steel pipe so that it could be pushed into the soft sediment until a harder more compacted layer was contacted. This layer was generally dense enough to keep the sediment sample in the acrylic tube as it was lifted. The coring device was then retracted and plugged with a rubber stopper as soon as the acrylic tube reached the surface. The cores were preserved and taken back to the lab for analysis.

Twenty samples containing the top two inches of sediment from the lake bottom were also collected. These samples were collected following the same procedure as the whole core sample collection. The primary difference was that the sediment cores were not sealed into the acrylic tubes as the whole sediment cores were. Instead, the cores were slowly emptied out of the acrylic tubes on to the ice. The topmost layer of the sediment core was then scooped into a plastic bag which was brought back to the lab for analysis. Upon arrival to the lab, the bag samples were placed into the freezer and the whole core samples were sealed with parafilm and refrigerated until the analysis began.

Lab Techniques

Soon after the whole core sediment samples were collected, the lab analysis of sediment/water equilibrium study began. The first step was to remove any of the lake water that was trapped in the acrylic tube above the sediment. This was done by siphoning off the water using a small plastic pipette. Next, some of the bottom sediment in the acrylic tube was removed to leave 13 inches (33 cm) of space in the top of the acrylic tube. This generally left 5 to 6 inches of the sediment core in the bottom of the acrylic tube. The upper 13 inches of space in the acrylic tube was then filled with Spirit Reservoir water that was collected at one of the transect points. Once the acrylic tubes were filled with Spirit Reservoir water, air was pumped into the water through small diameter rubber tubing connected to glass pipettes. The glass pipettes were positioned so that the air entered the water 6.5 inches (16 cm) from the sediment surface (half the depth of the water). Air flow was adjusted so that there was good water circulation without re-suspending the sediments. The acrylic tubes were then covered with tinfoil to keep light from entering the tubes to limit algae growth. The top ends of the acrylic tubes were also covered with foil and a rubber stopper was placed gently on top to minimize evaporation. Water samples were taken approximately one hour after the start of this project and every 12 hours after that point for the next four days. After four days the sampling rate will be reduced to once every 24 hours for three additional days. Altogether, water samples were collected for 7 days yielding approximately 12 water samples per sediment core. Thirty mL water samples were collected from each of the sediment core samples, filtered through a 0.45 um filter and placed into a 15 ml H_2SO_4 preserved centrifuge tube. The samples were analyzed for total phosphorus by ICP-OES.

Metadata

ArcView GIS 3.2a and ArcMap GIS 9.1 software was used with land use, soil, hydrology, road, and topography coverages for data interpretation Land use coverages for Wisconsin were obtained from the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data (WISCLAND). Land cover data was derived from Landsat Thematic Mapper (TM) satellite imagery acquired from fly-overs from 1991-1993. On the map, each pixel represents a 30 by 30 meter square resolution on the ground. Statsgo was used for the soil coverage (WI general soils). DNRgeodisk3 coverages were used for hydrology (hydtopen) and watershed delineation (wsdnw924 – wsdrwats). Tiger coverages were used for the designation of roads.

Sub-Watershed Delineation

The sub watersheds were delineated using the ESRI ArcMap Geospatial Analyst and a 30 by 30 meter resolution DEM with the hydrology coverage. Sample sites were located with a GPS unit, which was then used to create a GIS coverage of the sample points. The sample sites were added as outlets for the final delineation of the Spirit River Watershed and associated sub-watersheds. The digitized watershed map was compared to the DNR watershed boundary and discrepancies were ground-truthed.

Aquatic Plant Survey

The aquatic macrophytes in Spirit Reservoir were sampled from July 18 to 22, and July 24, 2006. The Wisconsin Department of Natural Resources (WDNR) point-intercept method was utilized. WDNR provided a grid of Global Positioning System (GPS) points that evenly covered the lake's surface area. At each point a collection rake was used to gather a sample of the reservoir's aquatic macrophytes, if any were present. For a complete description of the methods refer to WDNR protocol entitled "Protocol for Aquatic Plant Survey Collecting, Mapping, Preserving and Data Entry" dated 3/16/06.

The maximum depth that plants were observed was 6.5 feet. The maximum Secchi disk measurement was 3.5 feet. To determine the maximum depth of growth, all points along several transects were analyzed. Sites past the maximum depth of growth where not routinely sampled, however, throughout the survey random rake samples where taken at depths deeper then the maximum depth of vegetation to confirm this observation.

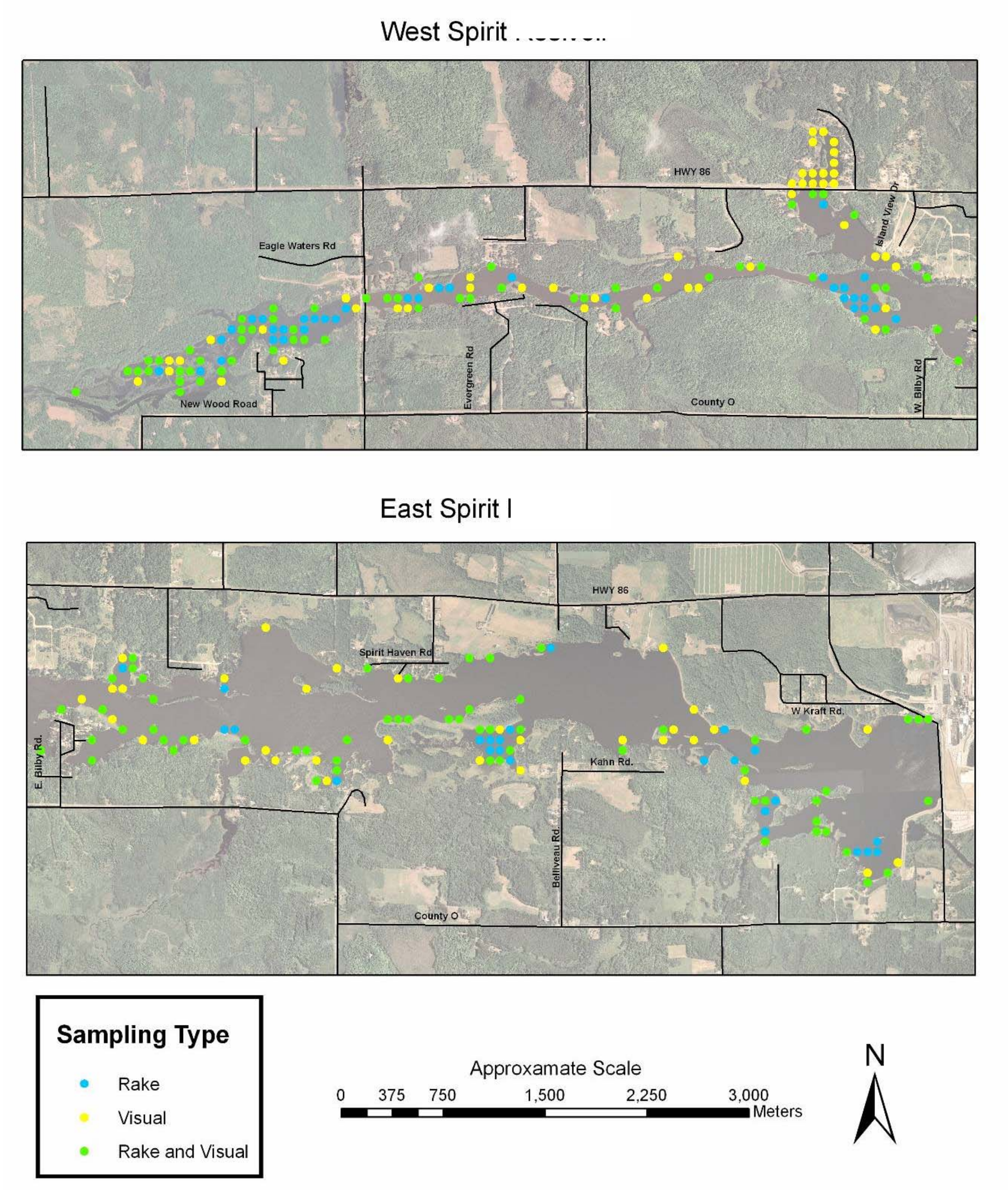
During the survey water levels were four feet below normal (WVIC), this made access to many of the predetermined GPS points difficult. If a point could not be reached without getting out of the boat, it was considered inaccessible. However, if the survey team could get close enough to an inaccessible point to identify species by sight, visual observations were made. Likewise, visual observations were recorded for sites on land if the point was close enough to be surveyed from the boat. Figure 6 shows the distribution of the sample points and the type of sampling over the entire reservoir.

Voucher samples of plants were collected, identified, and pressed. Identities were confirmed by UWSP faculty and are housed in the Robert Freckmann Herbarium on the UWSP campus.

Algal Community Survey

The algal community in Spirit Reservoir was sampled seven times during 2005. All samples were returned to UWSP and analyzed using standard algal methods as summarized below. Volumetric samples were collected using a Kemmerer sampler and after return to UWSP the sample was resuspended and split into two equal volumes, one was fixed with Lugol's Iodine the other analyzed live as soon as possible. Both samples were concentrated using low-speed centrifugation, and dispersed into Sedgewick-Rafter counting cells. An Olympus Inverted Microscope was used to count the first 300 cells/sample in randomly-selected fields. All organisms were identified to phylum, class, and genus based on a variety of current algal taxonomic references. Additionally, two plankton tows were also conducted at the same sites as the volumetric samples using a 60-micron plankton net. Plankton tows are non-quantitative but collect and concentrate a much larger volume of water, thus they can provide a bigger picture of the types of algae present in the water column. These samples were concentrated by centrifugation and surveyed, qualitatively, to identify all genera present. Lastly, periphyton samples (algal attached to rocks and other surfaces) were scraped, concentrated, and surveyed, qualitatively, to identify all genera present.

Figure 6. Aquatic plant sampling locations and type of sample.



Results and Discussion

Lake Water Quality

The quality of water in a lake is dependent upon many features including the regional soil, geology, land cover and uses, lake type, shape, and the aquatic plant community. In addition many physical and chemical measures of the water can be made to assess the water quality within a lake including the temperature, dissolved oxygen, nutrients, algae, water clarity, and other chemicals.

Spirit Reservoir was created by damming the outlet of the Spirit River near its confluence with the Wisconsin River. Impoundments like the Spirit Reservoir tend to accumulate sediment that is carried into the system by rivers and tributaries. The dam results in a reduction in the velocity of the water, and consequently the sediment settles out of the water. This sediment contains nutrients and over time the nutrient-rich sediments build-up in the reservoir bottom providing an ideal substrate for aquatic plant growth. In the case of Spirit Reservoir, the aquatic plant beds are limited to areas where the water is less than 6 feet deep. However, since there are still abundant nutrients in the water, algae blooms can be significant, particularly in August.

Field measurements and sample collection occurred at three sites in the Spirit Reservoir. These sites are shown in Figure 7 along with the depth of the water and the segment boundaries used in BATHTUB, a model that was developed during this study to evaluate phosphorus in the Spirit Reservoir.

Temperature and Dissolved Oxygen

Thermal stratification and mixing progressions occur in many Wisconsin lakes, but conditions in and around some lakes may preclude full stratification from occurring. In the Spirit Reservoir gentle sloping banks around the reservoir, a relatively large surface area, and the relatively rapid flow of water moving through the reservoir are conducive to mixing and often prevents significant stratification from taking place.

Temperature was monitored with depth during every sample period. Sample data is displayed in Figure 8 which shows the water in the reservoir is usually mixed from top to bottom. The reservoir was stratified at all locations in May 2005, however this stratification was not stable and less than a month later the reservoir was mixed again.

Figure 7. Bathymetric map of the Spirit Reservoir (in feet) with CWSE 2005 mid-lake sampling locations and segment boundaries used in BATHTUB.

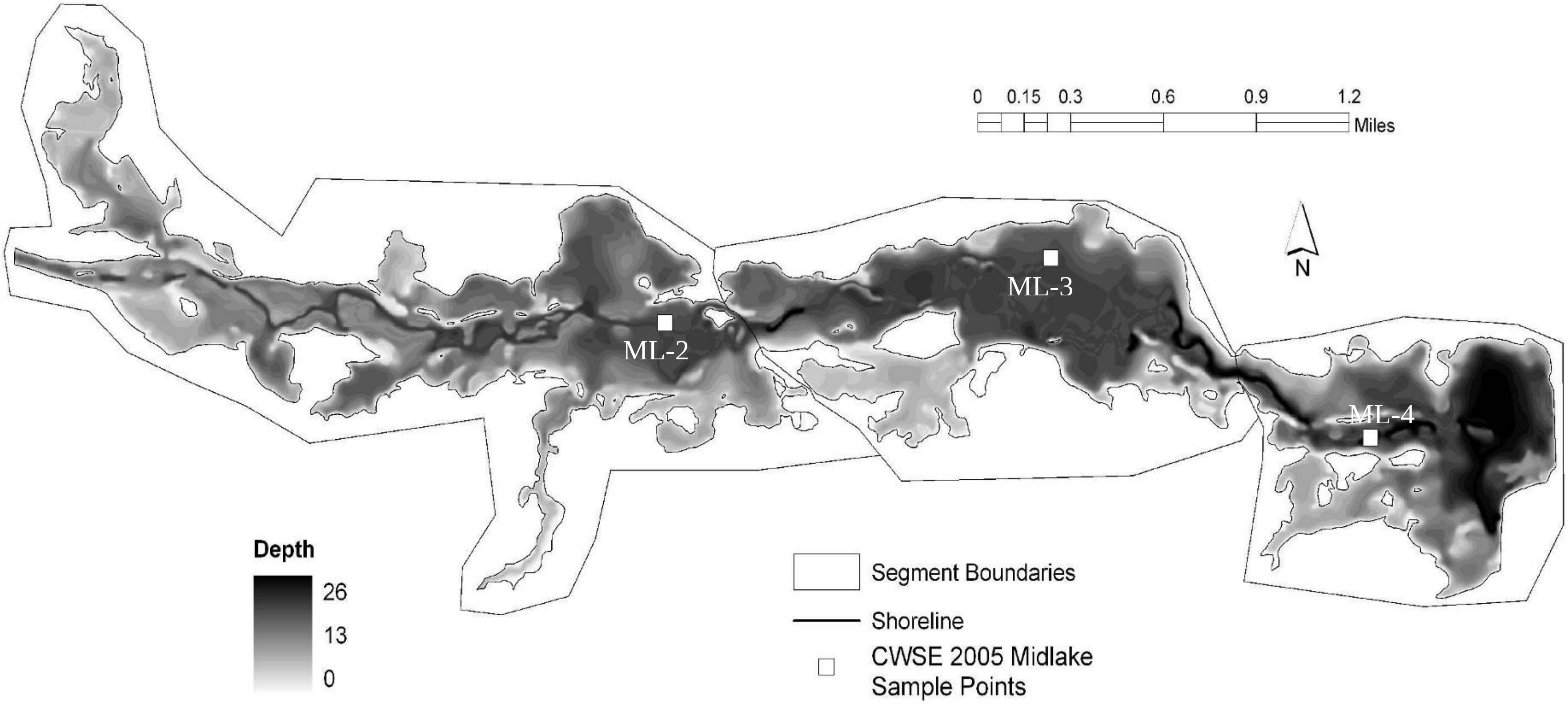
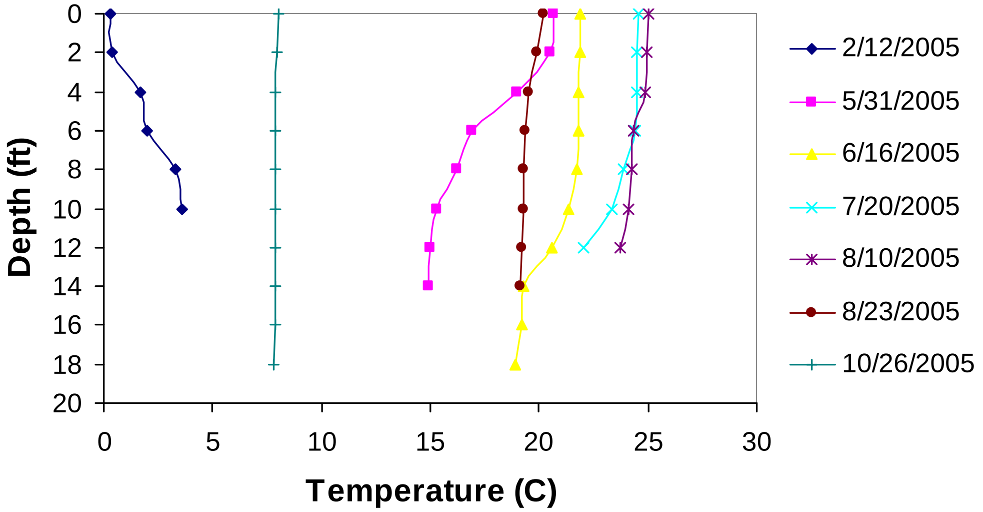
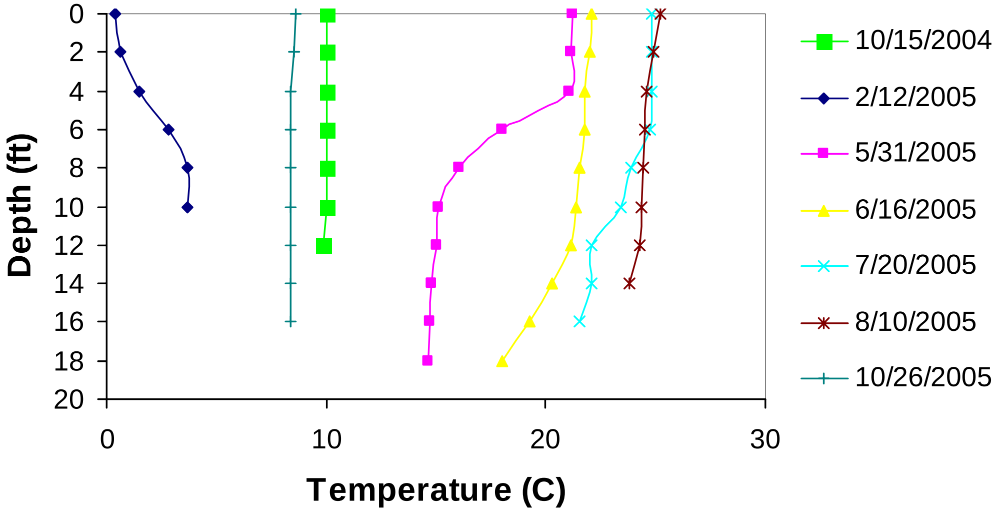


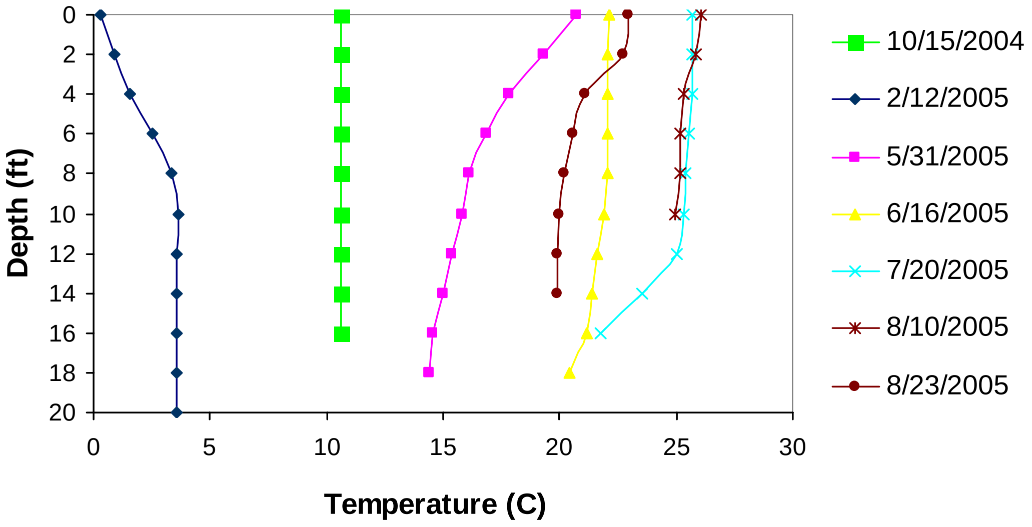
Figure 8. Temperature profiles at sample site ML-2 in the Spirit Reservoir.



Sample site ML-3

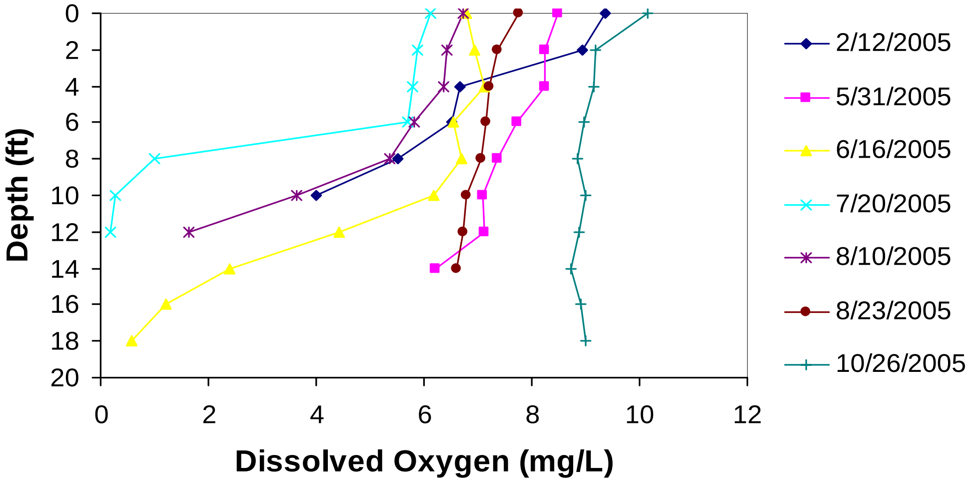


Sample site ML-4

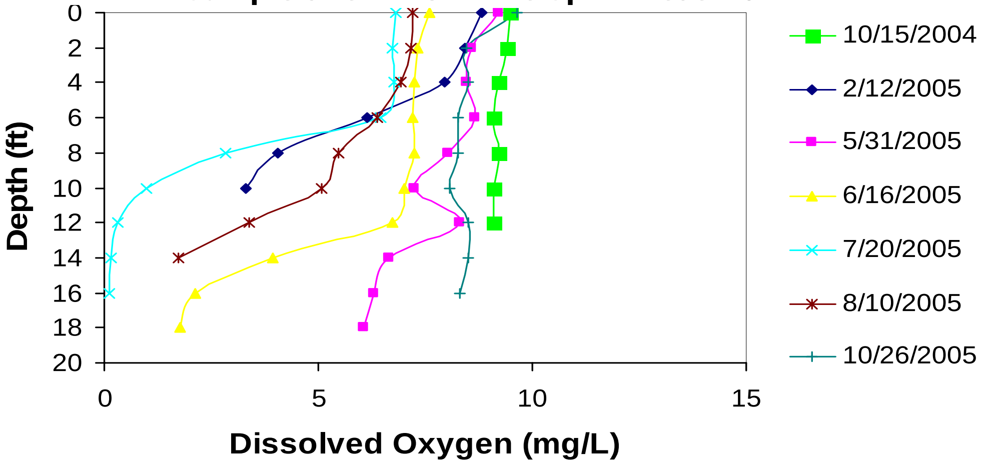


Dissolved oxygen concentrations were measured with depth at each sampling point in the reservoir. The oxygen content was not as uniform as temperature, and often was quite low near the bottom (Figure 9). Concentrations less than 5 mg/L may adversely affect many fish species.

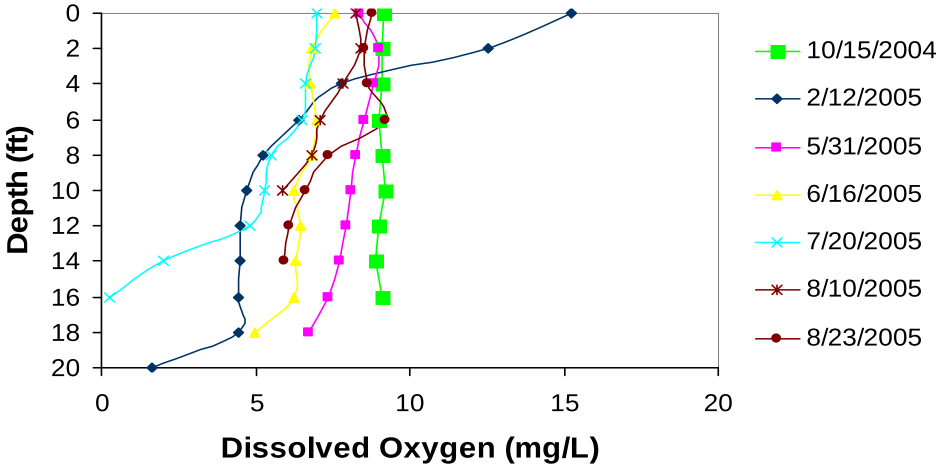
Figure 9. Dissolved oxygen profiles at sample site ML-2 in the Spirit Reservoir



Sample site ML-3 in the Spirit Reservoir



Sample site ML-4 in the Spirit Reservoir



pH

pH describes the lake water acid concentrations by measuring hydrogen ions (H^+) in solution. pH is measured on a scale ranging from 1 to 14 with lower values indicating acidic conditions and higher pH values indicating basic conditions. Lakes with low pH values often allow metals (aluminum, zinc, mercury), which can be located in the lake sediment, to become soluble. These metals can then make their way into the food chain (Shaw et al. 2000). The value of pH can change throughout the day, year, and depth because of chemical interaction with photosynthesizing biota, which can lower the pH by releasing carbon dioxide during respiration and increase the pH by using carbon dioxide during photosynthesis.

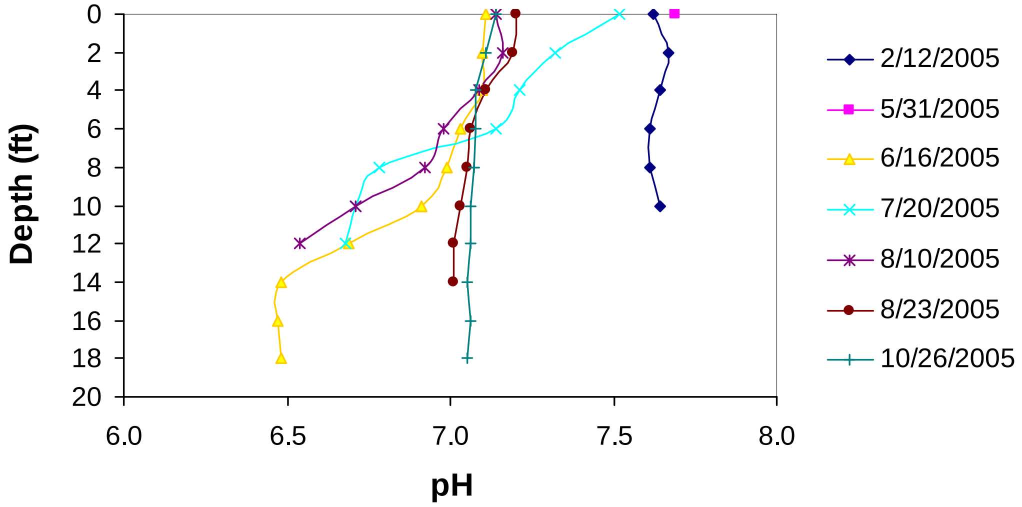
In Wisconsin lakes, the range of pH is ideally between 6 (neutral) to 9 (basic). The pH in the Spirit Reservoir are neutral to basic and the profiles with depth are quite similar except for the noticeably higher pH values at mid-lake sites ML-3 and ML-4 specifically on October 15, 2004 where the pH was 9 at ML-4 throughout the profile (Figure 10). High pH is often the result of aquatic plant photosynthesis. All samples were collected during the day, therefore, pH increases due to aquatic plant photosynthesis can be observed in the summer months. Also, note the decreasing pH levels lower in the water column where more carbon dioxide is present due to decomposition of organic matter and respiration. These patterns of pH shift and change throughout the water column are normal.

Alkalinity and Hardness

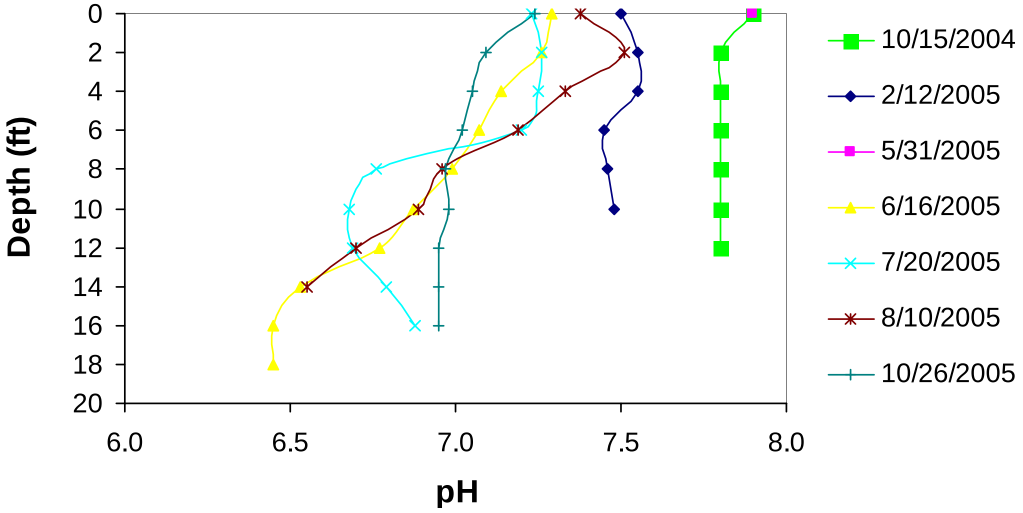
Alkalinity and hardness can have tremendous impacts on the biological life within an aquatic system because of the ability of some organisms to consume calcium in the development of bones, shells, and exoskeletons. A lake's hardness and alkalinity are affected by the type of minerals in the watershed soils and bedrock (Shaw et al., 2000). Lakes with high concentrations of calcium and magnesium are called hard water lakes and those with low concentrations are called soft water lakes. Soft water lakes tend to be overall less productive and produce fewer fish and aquatic plants than hard water lakes (Shaw et al.,2000).

The Spirit reservoir has relatively low alkalinity and hardness compared to many lakes in Wisconsin. Alkalinity ranged from 20 to 48 mg/L and total hardness ranged from 24 to 52 mg/L. Approximately half of the total hardness is calcium hardness (15 to 33 mg/L). Spirit Reservoir would be categorized as a soft water lake.

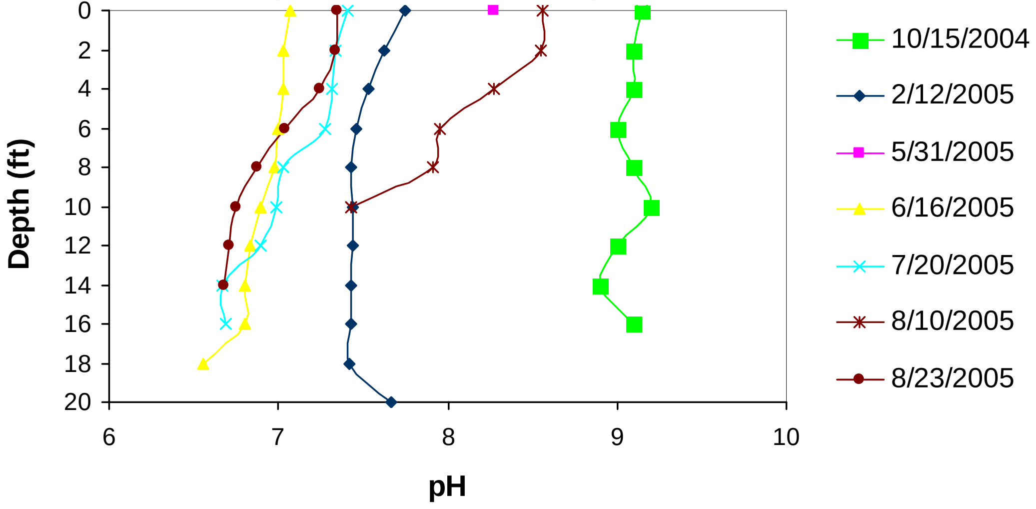
Figure 10. Profiles of pH at sample site ML-2 in the Spirit Reservoir



Sample site ML-3 in the Spirit Reservoir



Sample site ML-4 in the Spirit Reservoir



Conductivity

Conductivity is a measure of water's ability to conduct an electric current which is a direct measure of dissolved minerals and salts in water. Many of these compounds can result naturally from dissolution of local minerals or unnaturally by wastewater from septic systems, agricultural/lawn/garden fertilizers, animal waste, and road salt runoff. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans (Shaw et al. 2000).

The Spirit Reservoir's surface water conductivity ranged between 48 and 132 umhos. Depth profiles showed fairly linear patterns with consistent conductance measurements throughout the water column. On July 20, 2005 however, there was evidence of some stratification in regards to the conductivity. The conductance readings increased about 25 umhos from 10 feet to the bottom in both ML-2 and ML-3 (Figure 11). Conductance is normally higher near the bottom of a lake as increased decomposition and low pH conditions allow additional materials to become soluble. Conductance readings normally decrease throughout the summer in natural lakes; however, it is evident that the reverse happens in the Spirit Reservoir. This is likely due to higher conductivity groundwater providing more water to the system during dryer periods.

Chloride

Chloride is not commonly found in Wisconsin rocks and soils and is usually not harmful because of its low concentrations and low toxicity. Because of its naturally low concentrations, high concentrations of chloride usually indicate human inputs to water. Chloride is non-reactive in nature, and as a result, it is readily leached through the soil and into the groundwater from animal and human wastes, potash fertilizer, and road salt.

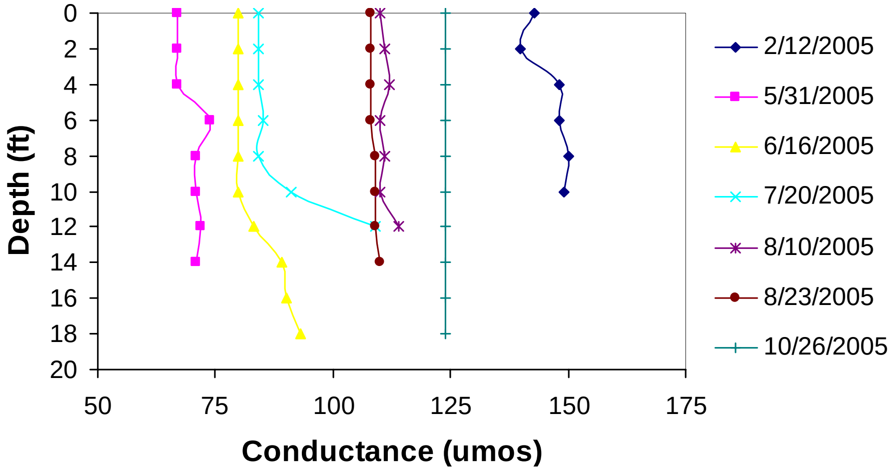
Chloride concentrations in the Spirit Reservoir ranged from 0.8 to 4.5 mg/L. According to Shaw et al., 2000, chloride concentrations are typically below 3.0 mg/L in this region of the state. A source of chloride to the Spirit Reservoir is likely the result of road salt being used on local roadways.

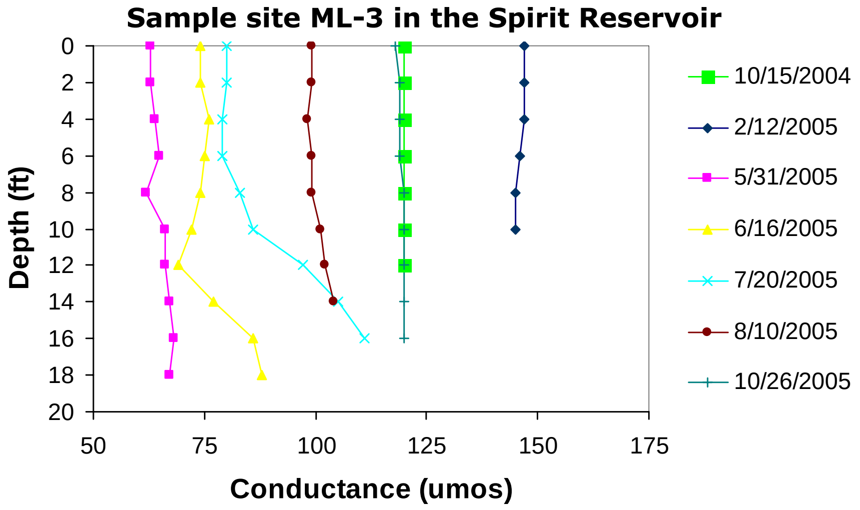
Potassium and Sodium

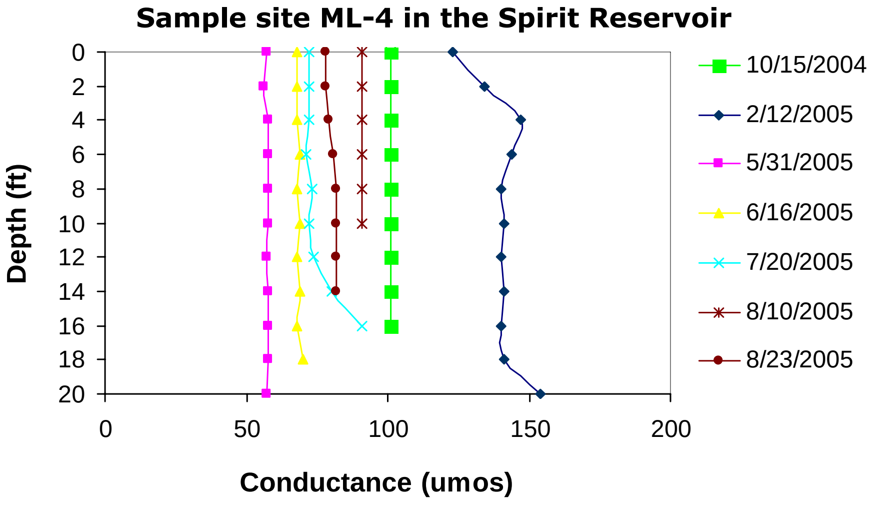
Concentrations of sodium and potassium are usually low in Wisconsin lake water. Therefore, when found in lakes, they often indicate human-related inputs. Sources of sodium include road salts, fertilizers, and human and animal wastes.

Potassium concentrations in the Spirit Reservoir ranged from 0.06 to 0.8 mg/L and sodium concentrations ranged from 1.8 to 3.5 mg/L. These concentrations are not high; although the sodium may be slightly elevated, most likely a result of the road salt.

Figure 11. Depth vs. Conductivity @ ML-2 in the Spirit Reservoir.







Sulfate

Sulfate naturally enters into Wisconsin lakes through geological solution in groundwater and from acid rain deposition caused by the burning of sulfur containing products such as coal. Under low oxygen conditions sulfate can be converted into sulfide, which can bind metal elements such as iron rendering them as insoluble sulfide precipitates. Sulfate concentrations in the Spirit Reservoir ranged from 3.5 to 4.5 mg/L. These concentrations are similar or below the expected 5 to 15 mg/L expected for this area of the state (Shaw et al., 2000).

Water Clarity

Water clarity is a measure of light transparency measured by an instrument called a Secchi disc. The depth to which light can penetrate is important because plants need light for growth. Aquatic plants grow in areas where light penetrates to the lake bottom. The depth of water clarity is affected by algae, dissolved minerals, organic acids, suspended solids (turbidity), and the color of water.

Fluctuations of water clarity throughout the year are normal as changes occur with available nutrients, temperature, algae and aquatic plant growth. Higher color readings in the spring are likely a result of the extensive wetland drainage system which feeds the Spirit Reservoir which often produces the coffee-stained color. The water clarity was consistently between 4 and 5 feet deep. Summer measures of clarity were less than during the spring and fall, likely due to increased concentrations of algae (**Figure 12**). Compared to other lakes, the measured water clarity in the Spirit Reservoir range between very poor and poor (Shaw et al., 2000).

Table 5. Measurements of turbidity, color, water clarity during Spring and Fall.

Date	Site	Turbidity (NTU)	Color (CU)	Water Clarity (ft)
5/31/2005	ML-2	1.6	106.8	5.0
10/15/2004	ML-3	5.6	46.0	5.1
5/31/2005	ML-3	1.7	111.8	5.0
10/15/2004	ML-4	3.6	54.0	6.0
5/31/2005	ML-4	1.5	103.1	4.5

Figure 12. Water clarity measures at 3 sites in the Spirit Reservoir

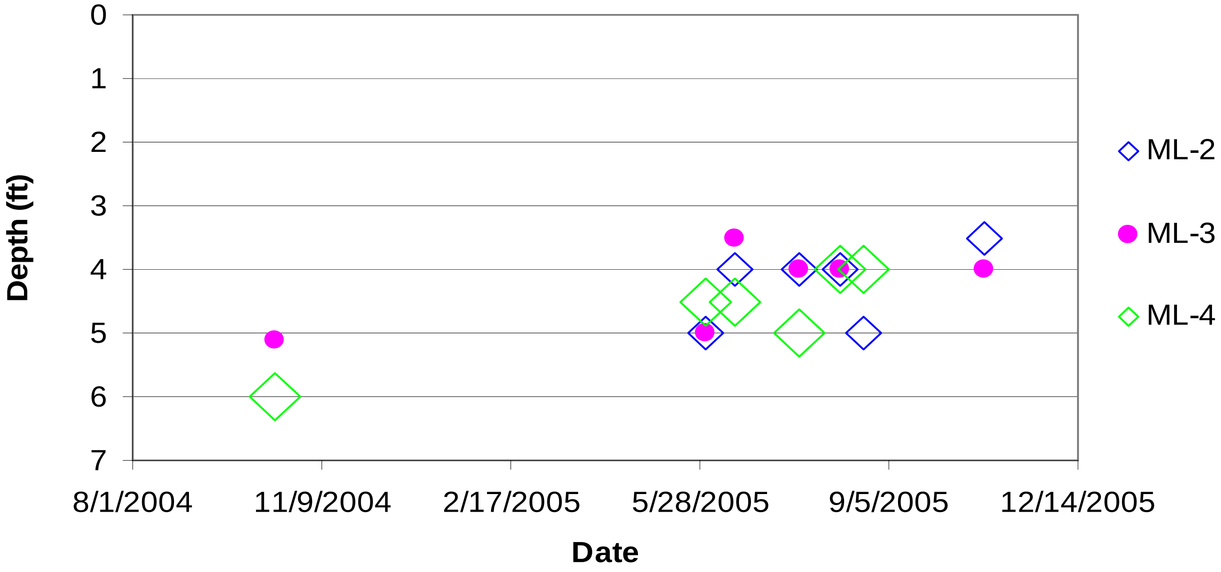
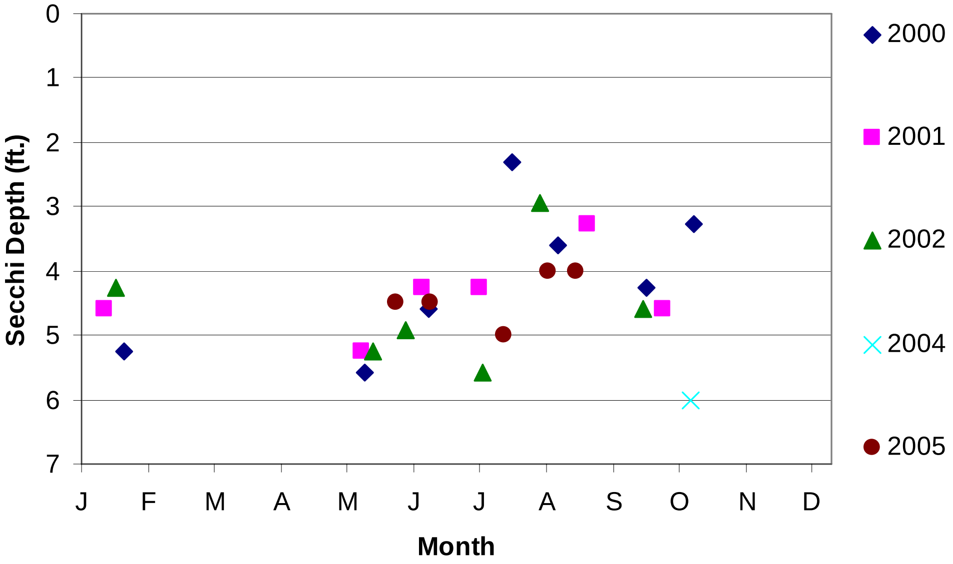


Figure 13. Water clarity measures by month at site ML-4 using combined UWSP and WVIC data. 2000-2005



Chlorophyll *a*

A good indicator of the amount of algae in the water column is chlorophyll *a*. Chlorophyll *a* concentrations are frequently inversely correlated with water clarity (the higher the chlorophyll *a* concentrations, the lower the water clarity). Algae and therefore chlorophyll *a* concentrations change throughout the growing season and from year to year depending on nutrient input and weather (Shaw et. al, 2000).

Spirit Reservoir chlorophyll *a* concentrations ranged from 9.4 to 22.03 mg/L. The highest concentrations were measured during July at sites ML-2 and ML-3 and in August at site ML-4. These concentrations are indicative of a mesotrophic (mid range) lake.

Table 6. Chlorophyll *a* concentrations in the Spirit Reservoir

Date	Site Name	Chlorophyll *a* (mg/L)
6/16/2005	ML-2	13.08
6/16/2005	ML-3	10.84
6/16/2005	ML-4	10.15
7/20/2005	ML-2	22.03
7/20/2005	ML-3	17.62
7/20/2005	ML-4	9.81
8/23/2005	ML-2	9.4
8/23/2005	ML-4	15.14

Nitrogen

Nitrogen is an important biological element. 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 all plant and animal tissue, and therefore organic matter. It is also found in rainfall and precipitation can be the primary nitrogen source in some seepage and drainage lakes. Nitrogen travels in groundwater and surface runoff. Nitrogen enters lakes in both soluble and particulate forms. Sources of nitrogen are often directly related to local land uses including agricultural fertilizers, septic systems, sewage treatment plants, lawn and garden fertilizers.

Nitrogen enters and exits lakes in a variety of forms. The most common inorganic forms include ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-) nitrogen. These forms summed with organic nitrogen yield total nitrogen. Aquatic plants and algae can use all inorganic forms of nitrogen; 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., 2000). Organic forms of nitrogen can also become available after biological conversion to ammonium.

In the samples collected from Spirit Reservoir nitrate and ammonium concentrations were low. Throughout the course of the year, organic nitrogen (which is the particulate form) may become more available for aquatic plant use; 0.56 mg/L in February, 2005 to 0.99 mg/L in October 2005, (Figure 14).

Figure 14. Concentrations of nitrogen in the Spirit Reservoir during different seasons.

Site Name	Date	NO2+NO3-N (mg/L)	NH4 (mg/L)	Total N (mg/L)	Organic N (mg/L)
Winter					
Spirit Mid-Lake #2	2/12/2005	0.02	0.14	0.72	0.56
Spirit Mid-Lake #3	2/12/2005	0.26	0.10	0.87	0.51
Spirit Mid-Lake #4	2/12/2005	0.25	0.07	0.93	0.61
Early Summer					
Spirit Mid-Lake #2	5/31/2005	0.01	0.02	0.79	0.76
Spirit Mid-Lake #3	5/31/2005	0.01	0.03	0.89	0.85
Spirit Mid-Lake #4	5/31/2005	0.09	0.06	0.91	0.76
Fall					
Spirit Mid-Lake #2	10/26/2005	0.07	0.04	1.09	0.98
Spirit Mid-Lake #3	10/26/2005	0.19	0.06	1.24	0.99
Spirit Mid-Lake #3	10/15/2004	0.08	0.04	0.60	0.48
Spirit Mid-Lake #4	10/15/2004	0.02	0.02	0.65	0.61

Total Nitrogen to Total Phosphorous Ratio

In Wisconsin lakes, either nitrogen or phosphorus concentrations control the amount of algae and aquatic plant growth where they are the nutrient most limiting to growth. In lakes that are limited by nitrogen the ratio of total nitrogen to total phosphorus is less than 10:1. (For every 10 nitrogen molecules there is 1 phosphorus molecule.) If limitation varies from year to year there is a ratio between 10:1 and 15:1. When lakes are limited by phosphorus the N:P ratios are above 15:1 (Wetzel, 2002).

Total nitrogen to total phosphorus ratios for the Spirit Reservoir are shown in Figure 15. Throughout most of the year phosphorus was the limiting element (indicated by ratios above 15:1).

Figure 15. Total nitrogen to phosphorous ratios in the Spirit Reservoir.

Site Name	Date	Spirit Reservoir TN:TP
Winter		
Spirit Mid-Lake #2	2/12/2005	14
Spirit Mid-Lake #3	2/12/2005	17
Spirit Mid-Lake #4	2/12/2005	20
Early Summer		
Spirit Mid-Lake #2	5/31/2005	28
Spirit Mid-Lake #3	5/31/2005	31
Spirit Mid-Lake #4	5/31/2005	83
Fall		
Spirit Mid-Lake #2	10/26/2005	20
Spirit Mid-Lake #3	10/26/2005	22
Spirit Mid-Lake #3	10/15/2004	8
Spirit Mid-Lake #4	10/15/2004	10

Phosphorus

In Spirit Reservoir, phosphorus is the most significant limiting nutrient. This is similar to most lakes where phosphorus is the primary element that leads to the development of nuisance algae (Wetzel 2002; Cogger 1988). Phosphorus is present naturally on the lake shore and in the watershed, found in the soil and plants. It transfers to the lake from the erosion of soil, animal waste, septic systems, fertilizers, inland recycling, and atmospheric deposition.

High concentrations of phosphorus are primarily transported to lakes in surface runoff. Phosphorus is reactive and adheres to soil/sediment particles. If those particles 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. Once in a lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue or sediments. The phosphorus continues to cycle within the system, and is very difficult to remove once it enters.

In this study, two forms of phosphorus were measured: soluble reactive phosphorus (SRP) and total phosphorus (TP). SRP is dissolved phosphorus in the water column that is readily available for plants and algae to utilize. It is usually present in low concentrations and when present it can quickly be taken up by plants and algae (Wetzel 2002). TP is a measure of the dissolved phosphorus plus organic and inorganic particulate phosphorus in the water. Examples of organic phosphorus would be decaying plant or animal matter or phosphorus that is bound to soil particles.

TP is used as a measure of overall lake phosphorus because its concentrations are more stable than SRP. Phosphorus availability can vary within a lake. For example, when the lake is stratified oxygen concentrations and pH can cause reducing conditions in the bottom layer (*hypolimnion*) of a lake. Reducing conditions can result in the release of soluble phosphorus from sediments. In the Spirit Reservoir dissolved oxygen concentrations were low enough to release phosphorus from the sediment during the summer and winter.

Generally, phosphorus concentrations above 30 ug/L are enough to stimulate algae blooms and excessive aquatic plant growth. It is not uncommon for phosphorus concentrations in Wisconsin impoundments to exceed 65 ug/L. Phosphorus concentrations in samples collected in the Spirit Reservoir are shown in Table 7. The concentrations of phosphorus in the July and August samples had concentrations around 60 ug/L at the ML2 and ML3 sites. During most sampling periods concentrations decreased moving downstream in the reservoir, with the lowest concentrations observed at the ML4 site. The highest observed concentration in the reservoir (85 ug/L) was measured at ML2 on 8/23/05.

Table 7. Results of total phosphorus sampling done by the UWSP CWSE in 2005.

Date	TP at ML2 (µg/L)	TP at ML3 (µg/L)	TP at ML4 (µg/L)
5/31/2005	28	29	11
6/16/2005	36	22	10
7/20/2005	60	67	35
8/10/2005	79	73	48
8/23/2005	85		84
10/26/2005	55	56	

Table 8 shows the median TP concentrations for a range of sampling years. A median is calculated by sorting all values in order and selecting the middle value or the average of the two middle values if the number of observations is even. All of the median concentrations are well above the 30 ug/L that leads to algae blooms.

Table 8. Median total phosphorus concentrations and associated data sources for 2001, 2002, and 2005.

Data Source	Year	Location	Median TP (µg/L)
CWSE	2005	ML2	58
CWSE	2005	ML3	56
CWSE	2005	ML4	35
WVIC	2002	ML4	49
WVIC	2001	ML4	49

Figure 26 shows the TP concentrations during the CWSE study period demonstrating a significant increase in concentrations from around 25 ug/L in June to around 80 ug/L in August which coincides temporally with the nuisance algal blooms on the Spirit Reservoir. Figure 30 includes additional WVIC data from 2000 which demonstrates the same pattern. Compounding the increased phosphorous concentration issue is the fact that there is less flow though in the system at this time or a longer retention time for the nutrient to concentrate and facilitate the algal blooms.

Algal Community Composition and Seasonal Succession

The algae are a diverse group of photosynthetic organisms (autotrophs) that are classified into nearly a dozen different phyla and include both bacteria-like cell types (prokaryotes) and more complex cell types (eukaryotes). The different groups possess different pigments, have different abilities to metabolize nutrients, have different nutritional requirements, and employ various reproductive strategies. Thus they cannot be discussed as a single entity, and knowing which algal groups are present during the growing season can provide insights into the trophic status of a lake. Certain groups of algae are associated with different water quality conditions and some are clearly associated with the nutrient-enriched condition found in many lakes. The algae that are found in and respond to eutrophic (nutrient enriched) environments can be thought of as bioindicators of pollution. Unfortunately once some of these nuisance species are present they are difficult to eradicate. Many are insensitive to copper treatments and herbicides. With each passing year their abundance increases and as they grow and die they drive an internal cycling of nutrients that fuels the next year of growth. As they accumulate in the water column and on surfaces (including macrophyte vegetation) they compete with macrophytes and can cause changes not only in plant community composition and abundance but they can also change the dynamics of the food web. Algae are a primary producer in the aquatic food web and many things eat algae or eat other things that eat algae. When the mix of genera shifts from "clean water" forms to "polluted water" forms it can cause significant shifts in higher trophic levels because different algae have different palatability, digestibility, and nutritional content. Therefore the effects of a shifting algal community can be far-reaching.

Algae in Spirit Reservoir during 2005 came from six algal phyla and were identified into 86 distinct genera (The algal community in Spirit Reservoir shifted during the growing season of 2005 (Figure 17and Figure 18). Over the course of the season the general trend was for cyanobacteria to increase to the most abundant forms in August and beyond while the green algae were the dominant community component from February to July with decreasing abundance beyond. The ochrophytes, mostly diatoms, waxed into near codominant position in August and beyond. The other represented phyla generally contributed less than 10% of cells counted and each group had a small pulse during the year with cryptophytes more abundant early and late, euglenophytes more common early, and the dinoflagellates (Dinophyta) surging briefly in June.

Figure 16), several genera were represented by several species. The majority of taxa (73 of 86 genera, 85%) came from three phyla (Cyanobacteria, Chlorophyta, Ochrophyta). Cyanobacteria (blue-green algae) are prokaryotic, bacteria-like organisms that thrive in extreme habitats and those that are nutrient enriched. There were 15 genera of Cyanobacteria identified in Spirit Reservoir (Table 9). The green algae are from the phylum Chlorophyta and they were the most abundant by genus over the season, 37 genera (43%) identified were green algae. The green algae represent a very successful group of algae, they are the ancestors of the land plants, and they are generally second only to the cyanobacteria in terms of tolerance ranges for various environmental factors. The Ochrophyta are a very large algal group composed of several major subgroups, the biggest of these subgroups is the class Bacillariophyceae or diatoms. Diatoms are very widespread on Earth and account for a significant fraction of photosynthesis or primary production in both freshwater and marine system. Some diatoms are indicators of nutrient-enriched waters.

The algal community in Spirit Reservoir shifted during the growing season of 2005 (Figure 17and Figure 18). Over the course of the season the general trend was for cyanobacteria to increase to the most abundant forms in August and beyond while the green algae were the dominant community component from February to July with decreasing abundance beyond. The ochrophytes, mostly diatoms, waxed into near codominant position in August and beyond. The other represented phyla generally contributed less than 10% of cells counted and each group had a small pulse during the year with cryptophytes more abundant early and late, euglenophytes more common early, and the dinoflagellates (Dinophyta) surging briefly in June.

Figure 16. Number of algal genera by phylum in the Spirit Reservoir.

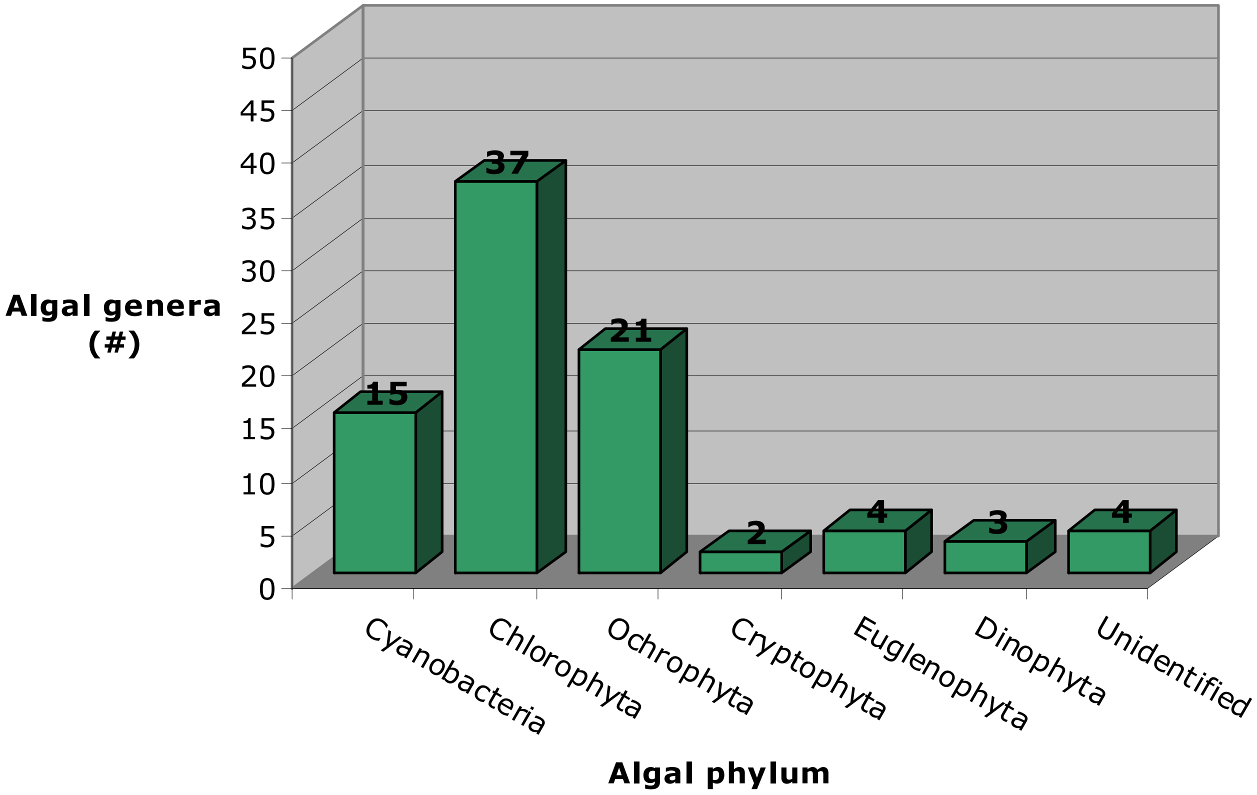


Table 9. List of all algal genera identified in Spirit Reservoir in 2005 by phylum.

Phylum	Genus
Cyanobacteria	*Anabaena*
	Aphanizomenon
	Chroococcus
	Coelosphaerium
	Cylindrospermum
	Gloeocapsa
	Merismopedia
	Microcystis
	Nostoc
	Oscillatoria
	Phormidum
	Rivularia
	Scytonema
	Snowella
	Spirulina
Chlorophyta	*Ankistrodesmus*
	Botryococcus
	Bulbochaete
	Carteria
	Chlamydomonas
	Chlorella
	Cladophora
	Closteriopsis
	Closterium
	Coelastrum
	Coleochaete
	Cosmarium
	Desmidium
	Dictyosphaerium
	Euastrum
	Eudorina
	Gonium
	Haematococcus
	Hydrodictyon
	Mesotaenium
	Micrasterias
	Microspora
	Mougeotia
	Netrium
	Oedogonium
	Oocystis
Ochrophyta	*Achnathes*
	Asterionella
	Botrydiopsis
	Cyclotella
	Cymbella
	Diatoma
	Dinobryon
	Fragilaria 1
	Fragilaria 2
	Gomphoneis
	Gomphonema
	Gyrosigma
	Mallomonas
	Melosira
	Navicula 1
	Navicula 2
	Navicula 3
	Navicula 4
	Ochromonas
	Pinnularia
	Stephanodiscus
	Synedra 1
	Synedra 2
	Synura
	Tabellaria
	Vaucheria
Euglenophyta	*Astasia*
	Euglena 1
	Euglena 2
	Euglena 3
	Phacus 1
	Phacus 2
	Phacus 3
	Trachelomonas 1
	Trachelomonas 2
Dinophyta	*Amphidinium*
	Ceratium 1
	Ceratium 2
	Peridinium 1
	Peridinium 2

Phylum	**Genus**		
Chlorophyta	***Pandorina***		
	Pediastrum	**Cryptophyta**	***Chroomonas***
	Rhizoclonium		***Cryptomonas***
	Scenedesmus		
	Selenastrum	**Unidentifiable**	**3-5 unidentifiable genera**
	Spirogyra		
	Spirotaenium		
	Staurastrum		
	Tetraselmis		
	Ulothrix		
	Zygnema		

Figure 17. Algal community as percent composition by phylum in Spirit Reservoir by date.

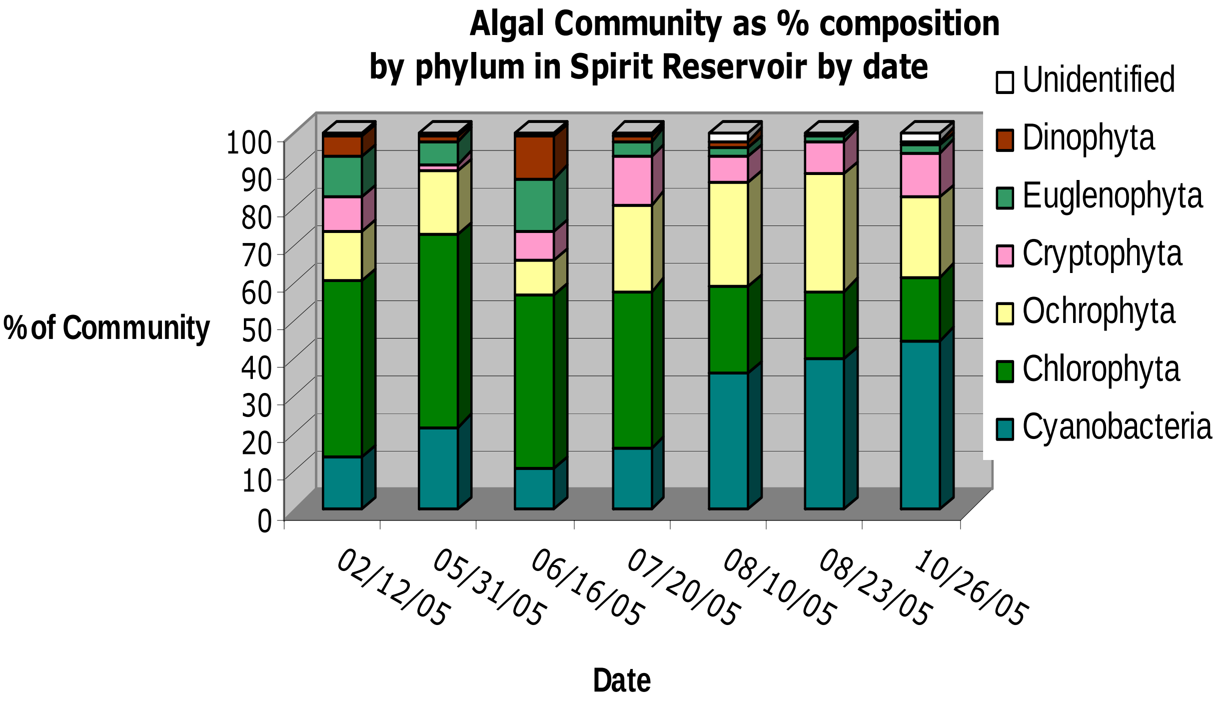
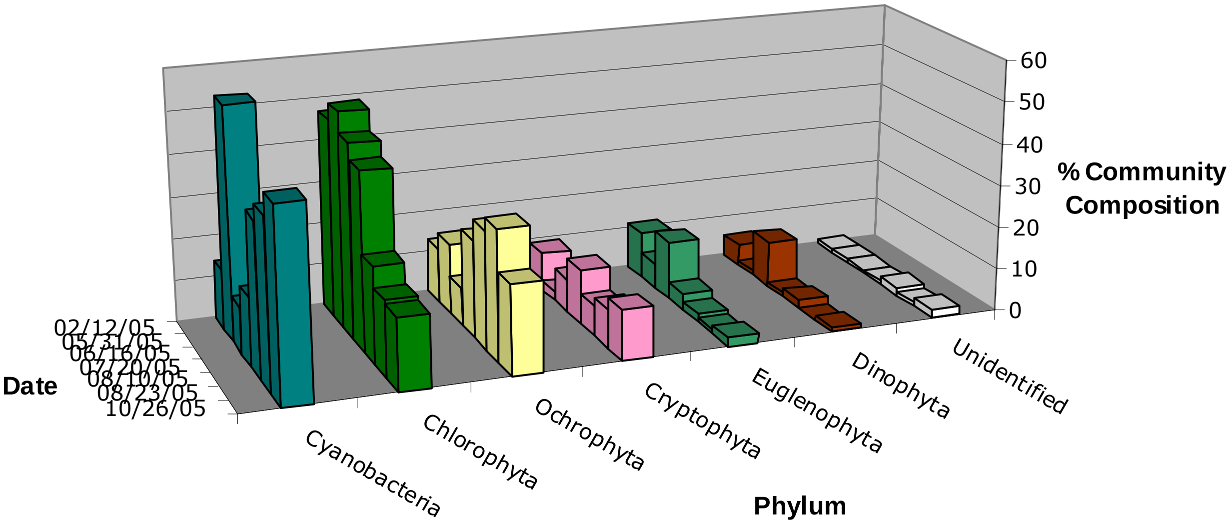
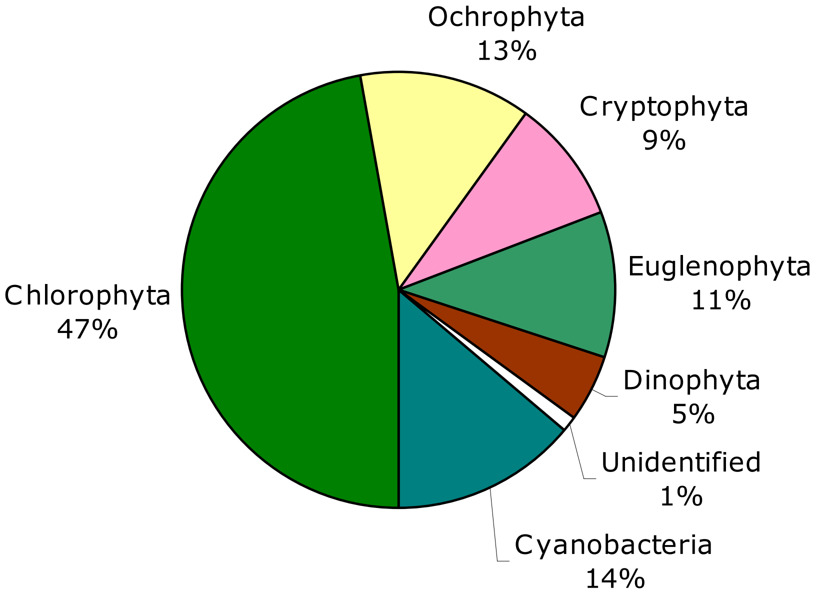


Figure 18. Algal community in Spirit Reservoir by date and percent composition.



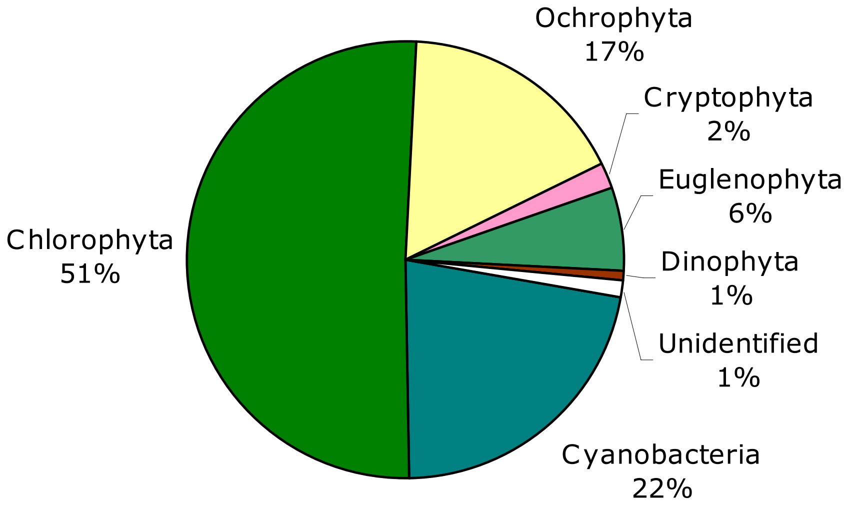
Under the ice in February the community was dominated by overwintering forms of green algae (47% of cells counted) with much smaller cohorts (9-14%) of cyanobacteria, ochrophytes, euglenophytes (phylum Euglenophyta), and cryptophytes (phylum Cryptophyta) also present Figure 19). The dominant overwintering taxa were primarily unicellular forms, mostly motile by means of flagella. These taxa included *Chlamydomonas*, *Astasia*, *Euglena*, *Cryptomonas* (all unicellular and motile), and *Ankistrodesmus* (unicellular, nonmotile). The three major phyla (Cyanobacteria, Chlorophyta, Ochrophyta) accounted for 74% of cells counted in February.

Figure 19. Algal community in Spirit Reservoir on 2/12/2005 by phylum.



Samples from Spirit Reservoir in late May showed very little numeric change from winter conditions but a significant change in taxonomic composition. The three major phyla contributed 90% of all cells counted (Figure 20). The green algae (51% of cells counted) were most represented by filamentous forms such as *Mougeotia* and *Oedogonium* – both common in enriched waters; other common greens in May were the unicellular pollution-tolerant genera *Oocystis* and *Scenedesmus*. Cyanobacteria were 50% more abundant (from 14% in February to 22% in May) and dominated by pollution-tolerant colonial forms (*Microcystis*, *Snowella*) with low palatability and digestibility. Two diatoms – *Asterionella* and *Fragilaria*, were the dominant Ochrophytes in May samples. Both are quite pollution-tolerant.

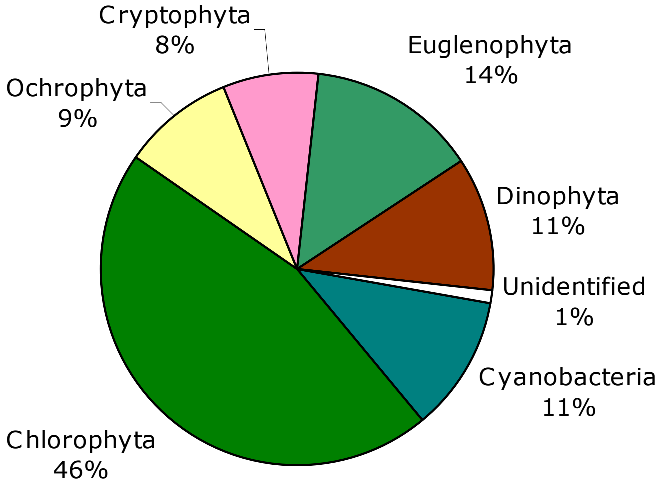
Figure 20. Algal community in Spirit Reservoir on 5/31/2005 by phylum.



Spirit Reservoir algal samples from mid-June showed a continued dominance by green algae (46% of all cells counted) with a sharp drop in Cyanobacteria (from 22% to 11%) and Ochrophyta (from 17% to 9%). These three phyla accounted for only 66% of all cells counted in June samples (Figure 21). The second most common group in June was the Euglenophyta, these organisms often reflect some type of organic enrichment and this was likely a seasonal pulse driven by some external event such as rainfall flushing organic matter into the watershed. The other minor groups – cryptophytes and dinophytes also pulsed during this period and these groups also respond to organic enrichment.

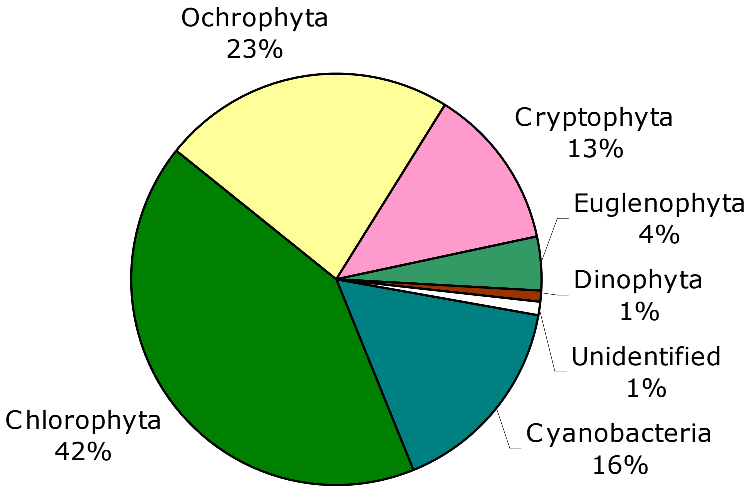
The chlorophytes were again dominated by the filamentous forms (now including *Zygnema* along with *Mougeotia* and *Oedogonium*) as well as *Oocystis* and *Scenedesmus*. The dominant cyanobacterium was the colonial *Snowella*, while the other most abundant taxa included the euglenophyte *Phacus* and the cryptophyte *Cryptomonas*.

Figure 21. Algal community in Spirit Reservoir on 6/16/2005 by phylum.



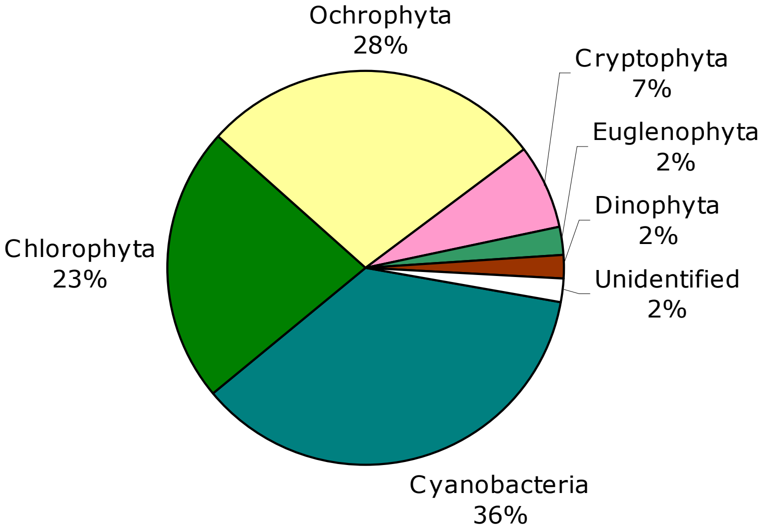
July samples from the Spirit Reservoir were again dominated by the cyanobacteria, greens, and diatoms (81% of cells counted). Green algae accounted for 42% of cells counted and the filamentous genera – *Mougeotia* and *Oedogonium*, were significant dominants (31% of all cells counted), all other green algal taxa were counted in very low numbers (Figure XX). The ochrophytes rebounded from their June low to levels (23% of cells counted) that would remain above 20% for the rest of the season. The colonial diatom ***Asterionella*** and the filamentous diatom ***Melosira*** were the most common ochrophyte taxa. The cyanobacteria were again dominated by *Snowella* (13% of cells counted) and the cryptophytes (*Cryptomonas*) reached their peak abundance in cell counts at 13% of cells counted.

Figure 22. Algal community in Spirit Reservoir on 7/20/2005 by phylum.



Algal samples from early August showed a distinct shift from green algal dominance to cyanobacterial and ochrophyte dominance (Figure 23). The blue-green algae rose from 16% in July to 36% in early August and the ochrophytes rose from 23% to 28% while green algal abundance dropped from 42% to 23% and never again rose above 20% for the season. These three major phyla contributed 87% of all cells counted. The cyanobacterial dominants were the colonial genera – *Snowella*, *Coelosphaerium*, and *Microcystis*; and the filamentous *Anabaena*. The most common diatoms were *Asterionella*, *Fragilaria*, and *Navicula*.   The filamentous green algal taxa *Mougeotia* and *Oedogonium* were the only significant representatives of this group in early August.

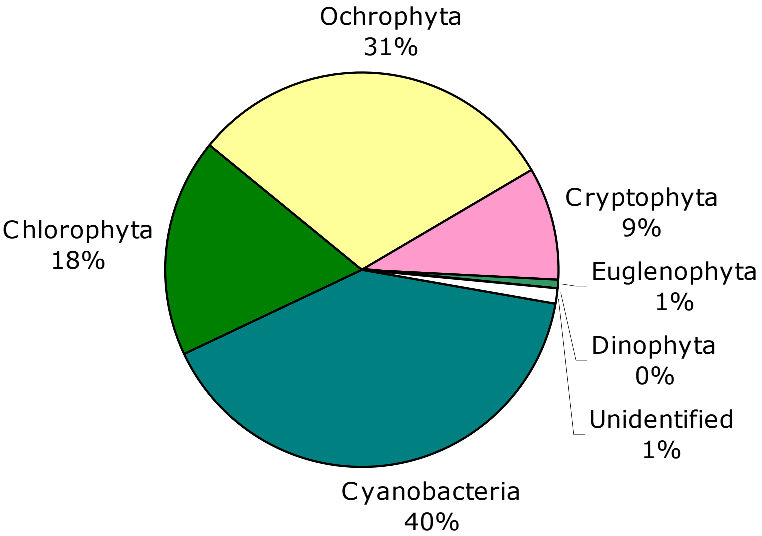
Figure 23. Algal community in Spirit Reservoir on 8/10/2005 by phylum.



Spirit Reservoir samples from late August mirrored and extended the shift in dominance seen in early August (

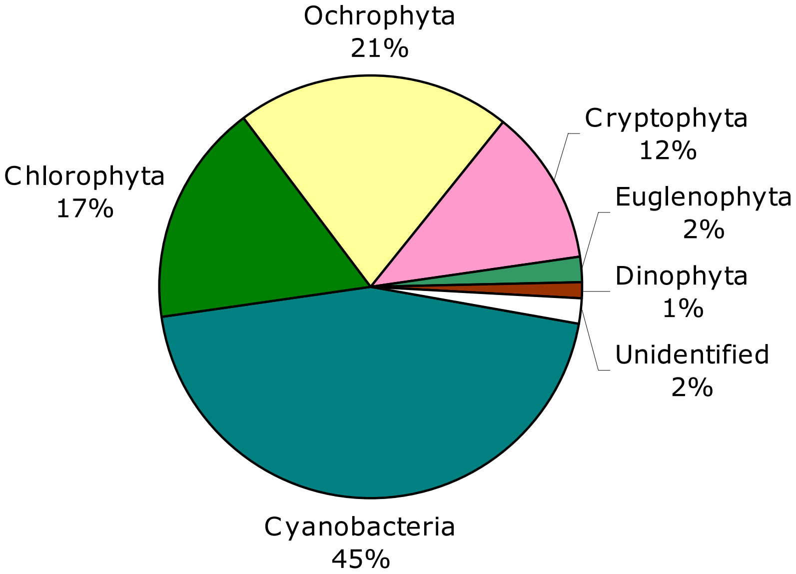
Figure 24). Cyanobacterial and ochrophyte dominance continued to increase (from 36% to 40% and from 28% to 31% respectively) while green algal abundance continued to drop from 23% to 18%. The three major phyla contributed 89% of all cells counted. Dominant cyanobacteria continued to include the genera *Snowella*, *Microcystis*, and *Anabaena*, with the addition of another filamentous genus *Aphanizomenon*. The diatom *Asterionella* was the clear dominant (12% of all cells counted) and to a lesser extent *Fragilaria* and the unicellular *Gomphonema* were also common. While overall green algal abundance declined the same two filamentous taxa – *Mougeotia* and *Oedogonium* were still common.

Figure 24. Algal community in Spirit Reservoir on 8/23/2005 by phylum.



The algal community in Spirit Reservoir in the final sampling period (October) continued the trend seen in the previous two sample periods (Figure 25). The major three phyla accounted for 83% of the cells counted. The cyanobacteria expanded their late season domination contributing 45% of all cells counted while the ochrophytes and green algae made up 21% and 17% of the total cell counts, respectively. The cryptophytes contributed 12% of cells counted.

Figure 25. Algal community in Spirit Reservoir on 10/26/2005 by phylum.



The filamentous genera *Anabaena*, *Nostoc*, and *Aphanizomenon* and the colonial genera *Coelosphaerium*, *Snowella*, and *Microcystis* were the dominant taxa of cyanobacteria during October. These are all generally considered nuisance organisms and are capable of generating population explosions called "blooms" that can reduce aesthetic and recreational use of a lake. The dominant ochrophyte taxon was *Fragilaria*, it accounted for 12% of total cells counted. This genus is a very common pollution-tolerant organism. The cryptophyte genus *Cryptomonas* accounted for nearly all cells from that phylum (31 of 36) and represented 12% of total cells counted. Cryptomonas is a high quality food item, is very digestible, and a preferred prey item for most zooplankton and planktivorous fish. The only green algal taxa of any consequence in the October cells counts was *Mougeotia*. The widespread filamentous cloud of this organism was breaking up at this time of the year.

A review of the frequency-of-occurrence data reveals that the ten most common algal genera in Spirit Reservoir during 2005 accounted for 56.1% of all cells counted (Table XX). The top ten genera included four cyanobacteria, three green algae, two ochrophytes and one cryptophyte. The four dominant cyanobacteria – *Snowella*, *Microcystis*, *Anabaena*, and *Coelosphaerium* were ranked 2, 7, 8, and 10 respectively. This could be considered good news since they are not the most dominant group at this time. Also, the most common cyanobacteria, *Snowella*, is the least annoying of this group and not presently known to produce any cyanotoxins like those that have been found in some species of *Microcystis* and *Anabaena*.

Table 10. Ten most common algal genera in Spirit Reservoir in 2005.

Phylum	Class	Genus	Total Counts[a]	Total %[b]	Cumulative %[c]	Total Occurrences[d]
Chlorophyta	Charophyceae	*Mougeotia*	199	9.5	9.5	7
Cyanobacteria	Cyanophyceae	*Snowella*	173	8.2	17.7	7
Cryptophyta	Chloromonadophyceae	*Cryptomonas*	140	6.7	24.4	7
Chlorophyta	Chlorophyceae	*Oedogonium*	126	6.0	30.4	7
Ochrophyta	Bacillariophyceae	*Asterionella*	106	5.0	35.4	7
Ochrophyta	Bacillariophyceae	*Fragilaria 1*	101	4.8	40.2	7
Cyanobacteria	Cyanophyceae	*Microcystis*	96	4.6	44.8	7
Cyanobacteria	Cyanophyceae	*Anabaena*	89	4.2	49.0	6
Chlorophyta	Chlorophyceae	*Oocystis*	80	3.8	52.9	5
Cyanobacteria	Cyanophyceae	*Coelosphaerium*	68	3.2	56.1	7

[a] Total Counts equals sum of taxon counted during 7 sampling periods.

[b] Total Percent (%) equals taxon counts/total cells counted (n=2100).

[c] Cumulative Percent (%) equals sum of taxon and all taxa above it.

[d] Total Occurrences equals number of samples a taxon was found in (of 7 possible)

The green alga *Mougeotia* was the most commonly counted organism in the study period, this genus was tallied nearly 10% of the time with 199 occurrences in 2100 cells counted. The other common green algal filament was the genus *Oedogonium* and it ranked 4, representing 6% of all cells counted. Both these genera are persistent filaments that can tolerate many environmental conditions and they capable of significant growth rates. They particularly like shorelines and shallow water and Spirit Reservoir certainly has lots of shallow shore relative to its volume. The third abundant green algal genus (ranked 9) was *Oocystis* a small unicellular organism that is easy to ingest and digest and rarely develops into bloom densities.

The two dominant ochrophytes, both diatoms, were the colonial *Asterionella* and the filamentous *Fragilaria*, ranked 5 and 6, together they accounted for nearly 10% of all cells counted. Both are common, capable of high growth rates, and tolerant of pollution and nutrient enrichment.

The unicellular cryptophyte, *Cryptomonas*, was the third most common genus, totaling almost 7% of all cells counted. As mentioned above this genus is a good news organism since it doesn't bloom, it doesn't smell or taste bad, it doesn't produce toxins, and it's a beneficial and positive component of a healthy aquatic food web.

In summary, the algal community in Spirit Reservoir exhibits fairly high diversity and a fairly typical seasonal succession pattern for slightly to moderately mesotrophic waters. Major parts of this pattern include the early to mid-season dominance of green algae being replaced from mid-season on by cyanobacteria; and very early and very late season periods being dominated by small, motile, unicellular taxa like *Chlamydomonas*, *Euglena*, *Astasia*, and *Cryptomonas*. Blooms that occur in August consist of a mixture of several filamentous algal genera and these contribute to the poor clarity of Spirit Reservoir.

Phosphorus-limited lakes, like Spirit Reservoir, can be subject to wide annual swings in algal community dynamics because of how sensitive these organisms are to this limiting nutrient. While there may be a swing from one year to the next a continued input of phosphorus from the watershed will eventually provide enough internal phosphorus for recycling that blooms will increase and community composition will shift to one dominated by cyanobacterial colonies and filaments.

One element of this scenario that is a bit different is the timing of the diatom pulse. In many cases the diatoms flourish early with the spring overturn of the lake and the resuspension of nutrients including the silica needed for their cell covering; and after a mid-season maximum the group tends to decline as silica becomes limiting and there may be a small peak late in the season because of the fall lake overturn of nutrients. In Spirit Reservoir the diatoms started slowly and their pulse was delayed. It didn't really begin until mid-season and stayed fairly strong into the fall but dropped steadily on the way. There is no obvious explanation for this other than natural variation and, perhaps, the nature of the Spirit Reservoir morphology (long and narrow).

Inputs to Spirit Reservoir - Tributary Water Quality

The source of water and path it takes to the lake is important to the in-lake water quality. Understanding how water is moving to lakes and the quality of the water helps to determine management strategies for a lake. Water enters the Spirit Reservoir via direct precipitation, groundwater, surface water runoff, and several direct inflows to the Reservoir including the Spirit River, Squaw Creek and additional tributaries.

In developed settings, the amount of water and speed at which the water reaches the lake via surface runoff is frequently increased because of reduced amounts of tree, shrub, and tall vegetation, which increases the amount of precipitation that reaches the ground. In a forested setting, like much of the Spirit Reservoir watershed, leaves and stems intercept some of the precipitation traveling to the ground. Some precipitation may be used by the vegetation, evaporate from the vegetation, or simply be slowed by the vegetation decreasing the rate at which water is hitting the ground as water slowly drips off leaves long after a storm has ended. The amount of

Figure 26. Concentrations of TP in mid-reservoir samples from the Spirit Reservoir.

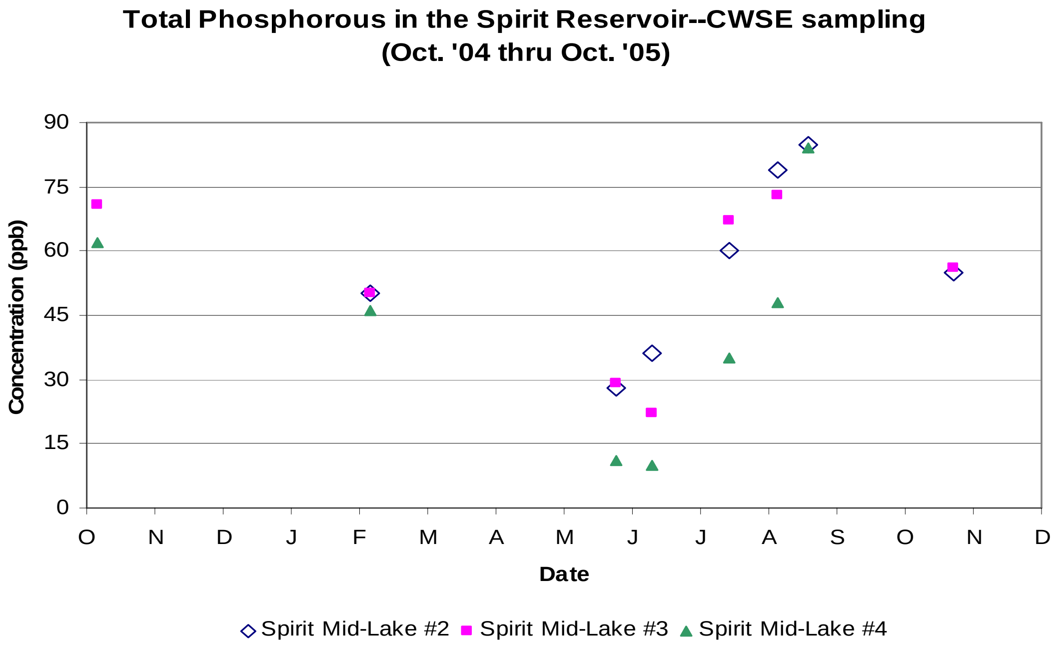
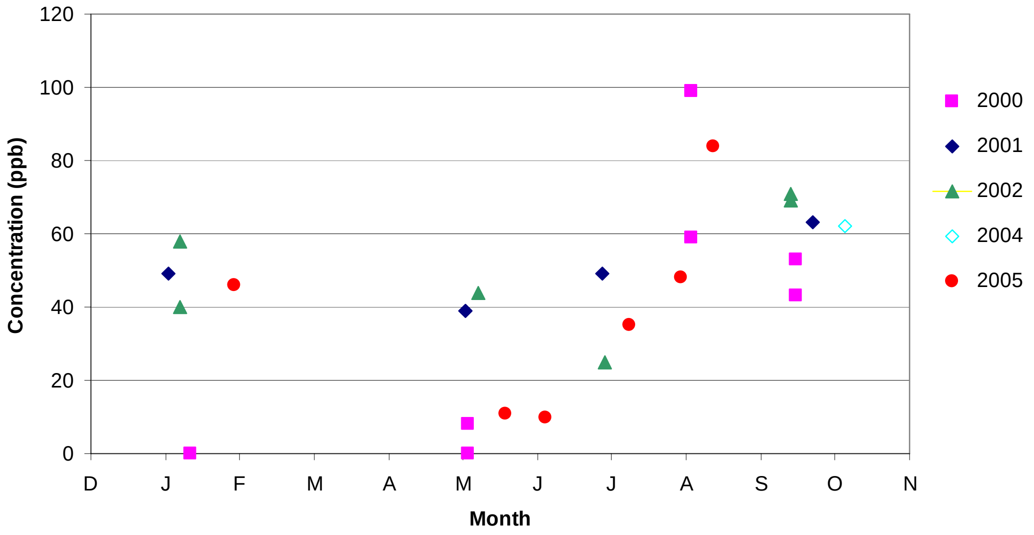


Figure 27. Concentrations of TP in the Spirit Reservoir (WVIC and UWSP 2000-2005).



impervious surface also effects water movement. Impervious surfaces (roofs, streets, sidewalks, and compacted soil) do not allow water to soak into the ground and results in more runoff. Water on impervious surfaces moves swiftly and is not filtered as it would be with vegetation. Swiftly moving water carries particles and nutrients from the land surface and deposits them into the Reservoir. Currently the percent impervious surface in the Spirit Reservoir is low, but new developments around the reservoir will increase the amount of impervious surfaces. Addressing how to reduce additional runoff from future developments is highly recommended.

In this study, streams flowing into the Spirit Reservoir were measured during baseflow and event flow periods. Baseflow is the water flowing in a stream at low flow when primarily groundwater is contributing to it. Event flow is the flow that occurs during storms or snowmelt.

The tributaries of the Spirit Reservoir were sampled and flow was measured to supplement rating curves. However, the extremely slow flow, soft mucky bottoms, and weed growth made estimation of the channel yields (total quantity of nutrients) challenging. Small errors in velocity that occur with little flow, lead to over or underestimations when multiplied over the channels larger areas. Reformulated trend lines were used when modeling to offer a better sense of the stream hydrology within the watershed.

Total Suspended Solids

Total suspended solids (TSS) are a measure of the particles suspended in water. TSS enters reservoirs through streams or runoff. In the Spirit Reservoir the primary sources of TSS entering the reservoir include eroding soil, runoff from streambanks, and vegetation from wetlands and streams. TSS can also be formed in the lake as algae, decaying plant and animal tissue and waste, microscopic animals, or by re-suspension of bottom sediments.

Rain can cause increases in TSS by washing deposited material from the watershed into the streams. Also, during the growing season the adjacent wetlands grow algae and plants that can be released to the lake. Additionally, in-lake sediments that have settled can be re-suspended with agitation created by wind or motorboats in shallow water.

Rivers carry a lot of TSS and in the case of an impounded river the TSS settles in the reservoir and builds up as sediment over time. Excessive TSS loading can adversely affect a reservoir. TSS can reduce water clarity, increase water temperature by absorbing heat from the sun, and increase the nutrient load to the reservoir since nutrients are attached to TSS particles. Increased TSS often blocks light used by submerged vegetation, which decreases photosynthetic activity and oxygen production. Furthermore, TSS that deposits on lake bottoms may alter aquatic habitat and increase nutrient and organic matter leading to accelerated aging of the lake (*eutrophication*) and oxygen depletion.

TSS concentrations in rivers naturally fluctuate throughout the year. This variability was noticed in the Spirit Reservoir tributaries. TSS concentrations ranged from below 2.0 mg/L to 258 mg/L at the New Wood Road tributary during a storm event on June 5, 2005. Rains during June and July 2005 had the highest concentrations of TSS (Table 11). Although sources of these sediments can come from natural sources, some may be a result of land use practices near the streams. It is important that measures are taken to minimize erosion in the watershed.

Table 11. Average concentrations of water chemistry measures in the Spirit Reservoir Tributaries.

Tributary	NO2+NO3 mg/L	NH4 mg/L	Total N mg/L	Organic N mg/L	Reactive P ug/L	TP ug/L	Cl- mg/L	TSS mg/L
Armstrong Creek	0.15	0.13	1.7	1.5	38.3	153.6	3.1	18.2
Coffee Creek	0.27	0.15	1.3	1.0	15.6	38.4	1.2	8.2
Hwy 86 W - Trib	0.13	0.19	1.4	1.0	13.0	32.7	1.4	5.7
New Wood Road - Trib	0.17	0.24	1.5	1.1	28.2	84.8	0.7	66.6
Squaw Creek	0.13	0.1	0.8	0.6	26.3	41.7	1.7	10.6
Spirit River - USGS Site	0.10	0.06	0.8	0.7	38.3	66.8	4.1	2.8

Chloride

Chloride concentrations in the tributaries ranged between below 0.5 mg/L and 15.0 mg/L at Marheime Creek in March 2005. Chloride concentrations were consistently low in samples collected at Coffee Creek, the tributary off Highway 86, and New Wood Rd tributary. Where concentrations are above 3 mg/L it is a good indication that cultural influences are affecting the Spirit Reservoir water quality and may often coincide with other inputs such as nitrogen and phosphorus.

Nitrogen

Major forms of nitrogen were analyzed and are shown in Table 11. (The forms of nitrogen were described earlier in the surface water section.) Throughout most of the sample period, nitrate and ammonium concentrations were low, as much of the nitrogen moving to the system was in the organic form (associated with particles). These concentrations are typical for the soil types and wetlands around Spirit Reservoir. Concentrations of nitrogen in the event samples were not much higher than baseflow concentrations.

Phosphorus

Phosphorus concentrations varied between the tributaries but all had relatively high concentrations (Table 11). Samples collected in June 2005 had some of the highest concentrations measured, 880, 105, 66, 60, 55, and 51 ug/L TP in Armstrong Creek, New Wood Rd tributary, Squaw Creek, Spirit River, Coffee Creek, and the Highway 86W tributaries, respectively. Although concentrations at Squaw Creek and Spirit River were not the highest, they clearly delivered a much greater mass of phosphorus to the system. This is because of the large volume of water that they deliver to the Spirit Reservoir. In addition, groundwater with apparently naturally occurring phosphorus concentrations has been found in Taylor County so groundwater flow to the tributaries and Spirit Reservoir may also be contributing TP. Additional discussion of phosphorus contributions from the tributaries can be found in the modeling section.

Water quality sampling was conducted at sites throughout the Spirit River watershed in the winters of 2005 and 2006 to obtain a few more detailed snapshots of water quality in the watershed. TP concentrations were high in samples collected throughout the watershed in March 2005 and elevated at the majority of sites in January 2006 (Figure 28). TSS was low in most of the tributaries with the exception of Marheime Creek in 2006 with a concentration of 57 mg/L (Figure 29

Figure 29).

Figure 28. TP concentrations in samples collected throughout the Spirit Reservoir Watershed in 2005 and 2006.

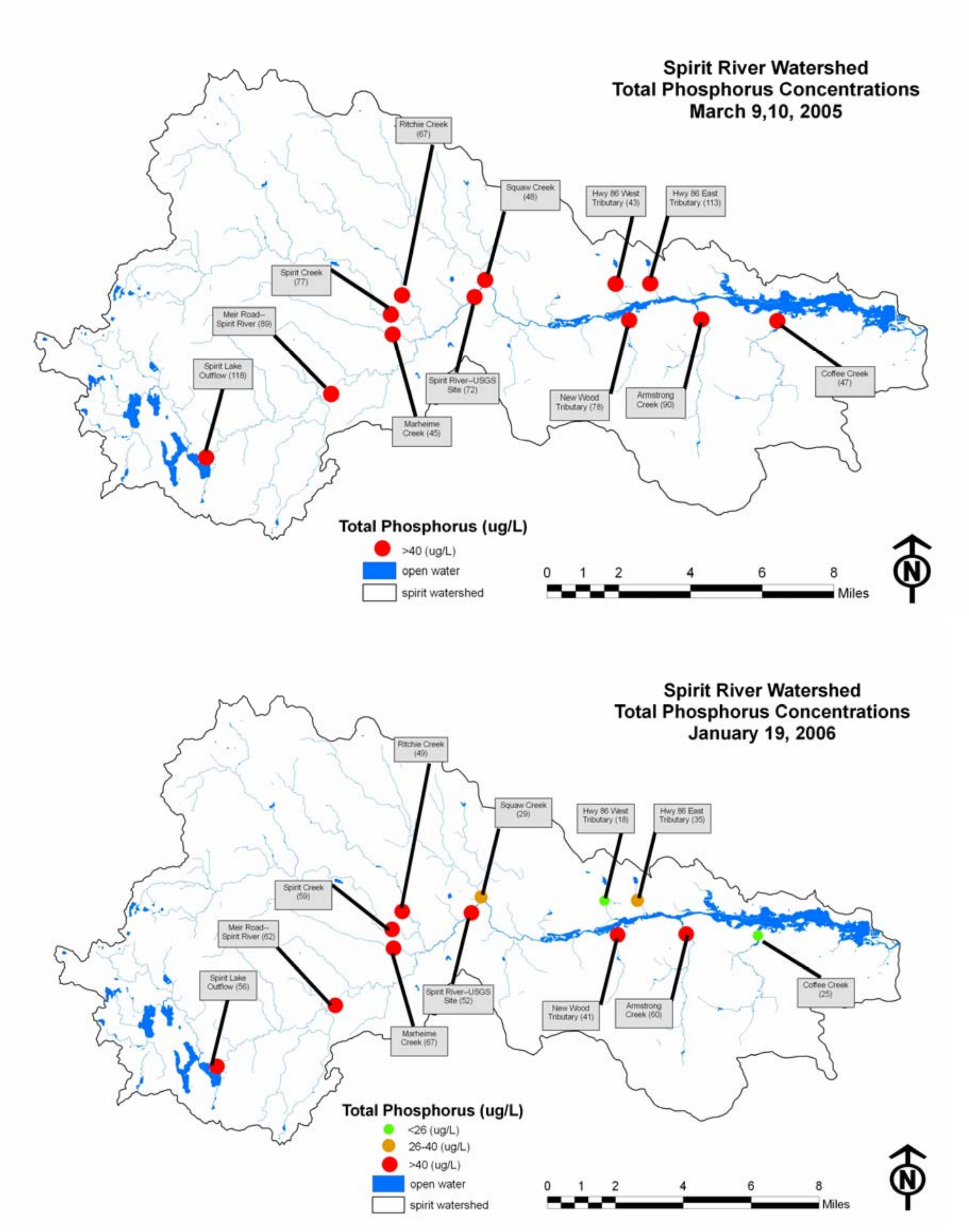
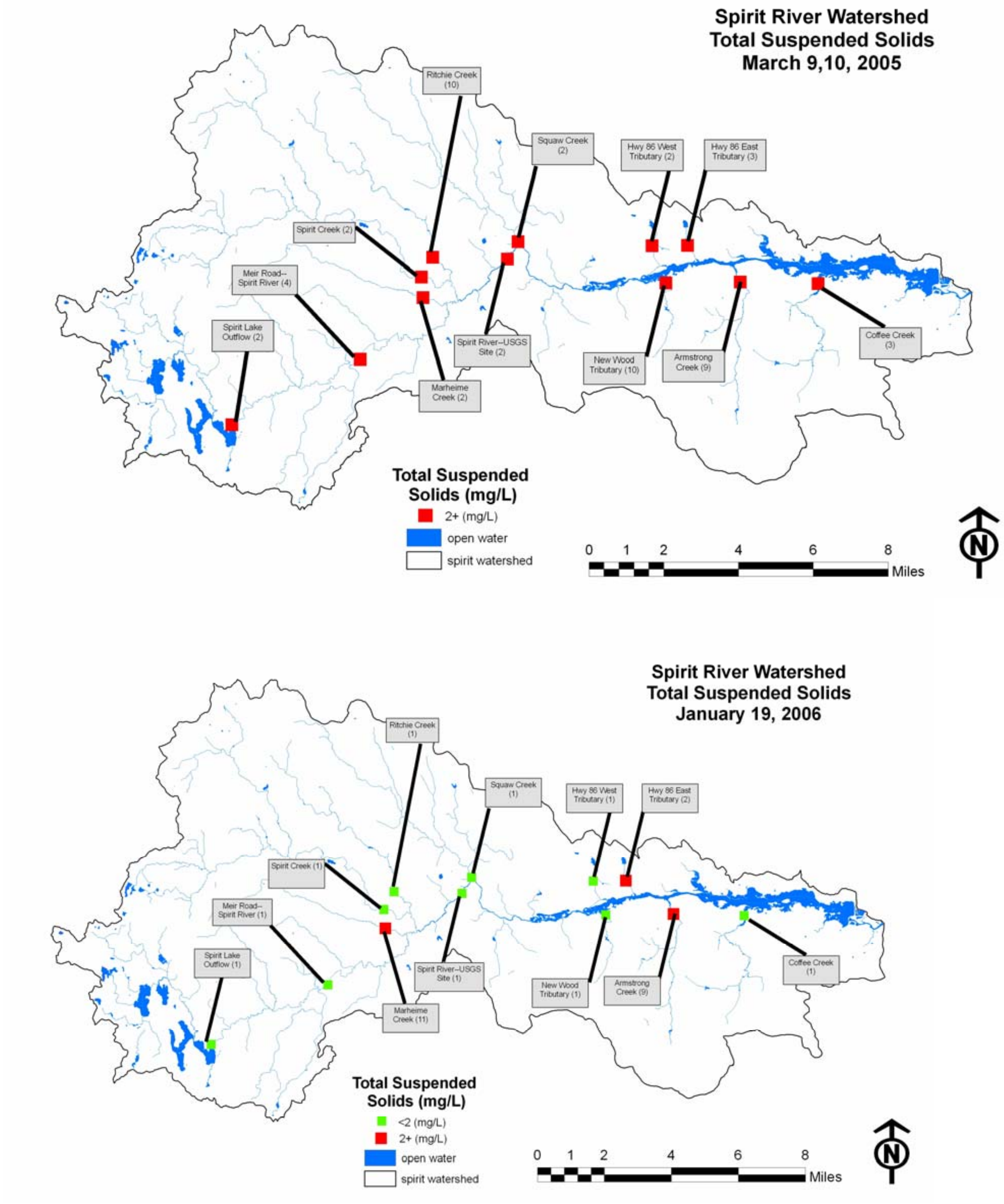


Figure 29. TSS concentrations in samples collected throughout the Spirit Reservoir Watershed in 2005 and 2006.



Water Quality - The Big Picture
Modeling with BATHTUB

Introduction

Eutrophication results when a water body receives excessive dissolved nutrients like phosphorus and nitrogen, naturally or as a result of human activity. This causes significant increases in algae and aquatic macrophyte (plants that grow in water) populations, which may in turn result in low dissolved oxygen concentrations due to aerobic decomposition. We used the BATHTUB model, developed by William Walker Jr., which is designed to apply empirical eutrophication models to reservoirs and lakes to model how phosphorus was moving to Spirit Reservoir and predict the resulting algae growth (chlorophyll *a*).

BATHTUB can be used as both a descriptive and predictive tool. By calibrating the model to observed data, one can than predict how changes in the watershed could impact water quality conditions in the reservoir. The main concern of this study is the relationship between phosphorus and algae (chlorophyll *a*).

The BATHTUB model consists of four main parts. The first component allows the user to choose from a variety of empirical models that predict phosphorus, chlorophyll *a*, and other concentrations based on inputs to the lake. Since the user can choose from several models, the model with the "best fit" can be selected. The second component involves defining "global variables", which are applied to the entire model. These parameters include precipitation, evaporation, and atmospheric nutrient loads. The third component of BATHTUB allows the user to define the model segments. The user may define specific attributes for several different tributaries, and even divide a reservoir into different segments. Average depth, surface area, sediment P, in addition to other information, is required for each segment. The fourth component of BATHTUB involves defining water quality information for tributaries. This can be done in two ways, either by entering in actual observed data, or by using theoretical runoff coefficients based on land use. Information about how much flow the tributary has and its watershed area is also needed.

Model Structure

Overall, six BATHTUB models were created. Three of the models, the 2001, 2002 and 2005, were designed to be calibrated to field data. The most accurate model, the 2005 model, was than used to predict how water quality in the reservoir would react to potential changes in phosphorus from the watershed. A summary of the data sources used for the six different models can be found below in Table 12.

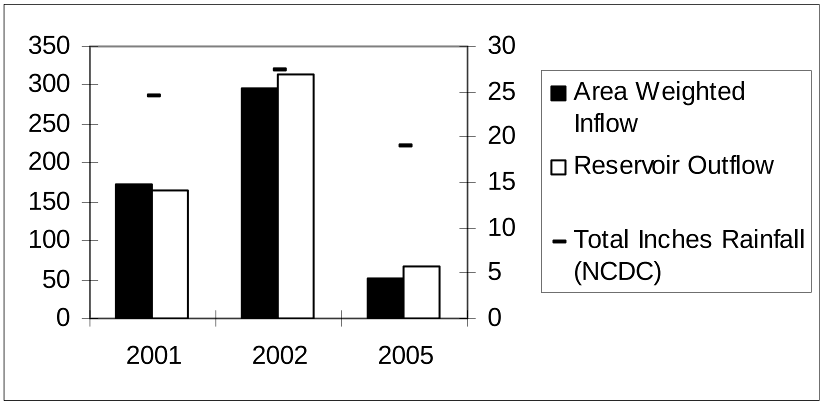
The hydrologic inputs for the model were based on extrapolating data collected from some locations to the entire watershed. This was necessary because detailed field gathered flow measurements throughout the entire watershed were beyond the scope of this project. When compared to the observed monthly mean reservoir outflows measured by the WVIC, the extrapolated flow was very similar, which can be seen in Figure 30.

Table 12. Water quality data sources used for each BATHTUB model.

Model	Observed Water Quality Data Source
2001	WVIC
2002	WVIC
2005	CWSE
$TP_{-20\%}$	modified from 2005 CWSE data
$TP_{+20\%}$	modified from 2005 CWSE data
$TP_{+40\%}$	modified from 2005 CWSE data

The flow data that was collected showed a strong similarity with the flow data from the USGS gauging station located on the Spirit River at Bridge Rd above the reservoir. Based on this comparison, and the fact that the land cover within the watershed is relatively uniform, we assumed that each sub-watershed produced similar amounts of runoff per sub-watershed area as the area draining to the USGS gauge station. The USGS data is available for a very extensive time period, providing a continuous record of flow that could be applied to most of the watershed.

Figure 30. Comparison of total estimated area weighted inflow (extrapolated from USGS data and sub-watershed areas), WVIC mean daily Spirit Reservoir outflow data, and total inches of rainfall. Units of flow are mean hm^3/200 days.



All the models used the three same reservoir segments, which can be seen in Figure 30. There were two major tributary model structures used in all the models. The first was a simplified model, which was used for the 2001 and 2002 periods. This involved using only one input tributary into the reservoir, since data was limited and was only available at one sampling location near the beginning of the reservoir. It was assumed that this single sample point on the Spirit River represented the entire watershed. Within the reservoir, observed data was only available at the ML4 site, which still provided a comparison of observed data and the predictions made by BATHTUB. In contrast to this simplified model, the 2005 model included eight tributaries, since water quality data was available during this time period. Since this model contained the most observed data and is more similar to actual conditions in the reservoir, it was also used as a predictive model once it was calibrated.

Empirical Model Selection

A summary of the empirical models used in each BATHTUB model are found in Table 13. All versions of the model used a linear model based only on TP to estimate chlorophyll *a* concentrations. Interestingly, it was observed that the relationship between TP and chlorophyll *a* varied from year to year. For some years chlorophyll *a* increased significantly with increasing TP, and during others it only increased slightly. In the 2001 and 2002 models, TP was most accurately simulated using a first order equation, while in 2005 a 2nd order decay equation was best. The best fitting empirical model was determined by comparing the values of all empirical models to the observed data.

Table 13. Empirical total phosphorus and chlorophyll a models used for each BATHTUB model.

Model	TP$_{model}$	Chlor a$_{model}$
2001	*First Order*	*P, Linear*
2002	*First Order*	*P, Linear*
2005	*2nd Order Decay*	*P, Linear*

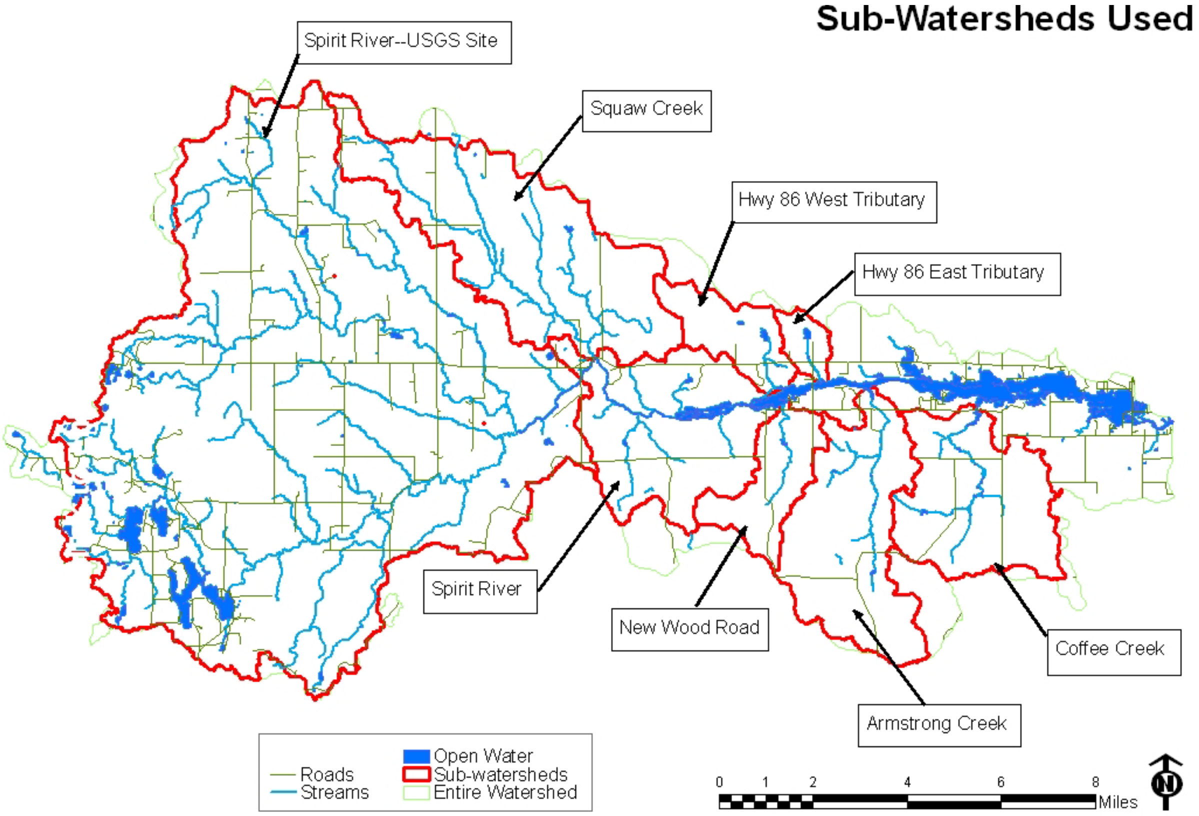
Internal Loading

Internal phosphorus loading is the amount of phosphorus that is re-released from sediment in a body of water. A study was conducted to establish an average value for the Spirit Reservoir, which involved collecting several sediment cores, which were than monitored for phosphorus release under aerobic conditions (oxygen present) in the UWSP WEAL. The ranges of values found in these experiments were than input into BATHTUB, and it was found that a loading value of 1 mg/m^2 per day most accurately modeled conditions within the reservoir. This loading value was used for all models.

Tributary Loading

Tributary loads were calculated for Armstrong, Coffee, Un-named at Hwy 86 East, Un-named at Hwy 86 West, Squaw Creek, using water quality data along with sub-watershed size, land use and topography. The associated sub-watersheds are shown in Figure 31. These loading estimates were used as tributary inputs to the BATHTUB model. Overall the Spirit River sub-watershed contributes the greatest amount of TP to the Spirit Reservoir. The sub-watershed comprised the largest area draining to the Spirit Reservoir, but on a per acre basis it did not contribute the greatest amount of TP, but had the second highest SRP load (Figure 33). Armstrong Creek and New Wood Rd sub-watersheds contributed the greatest per acre loads of TP, while Hwy 86 West had the least load/acre of both TP and SRP.

Figure 31. Sub-watersheds used for tributary inputs in the BATHTUB model and associated sub-watershed areas.



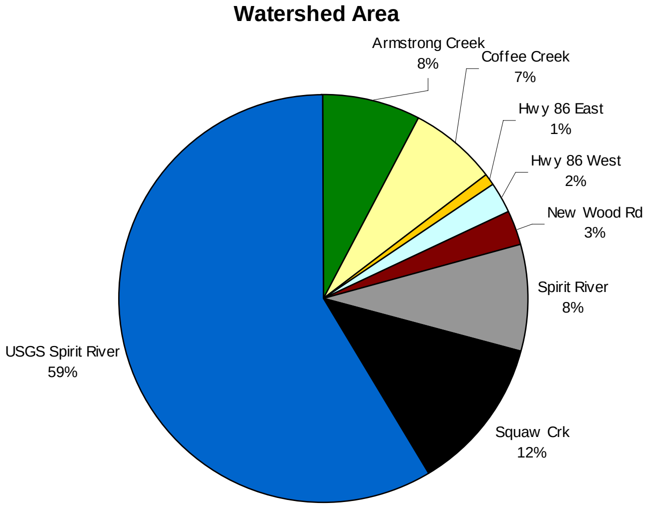


Figure 32. Estimated TP load to Spirit Reservoir from each sub-watershed.

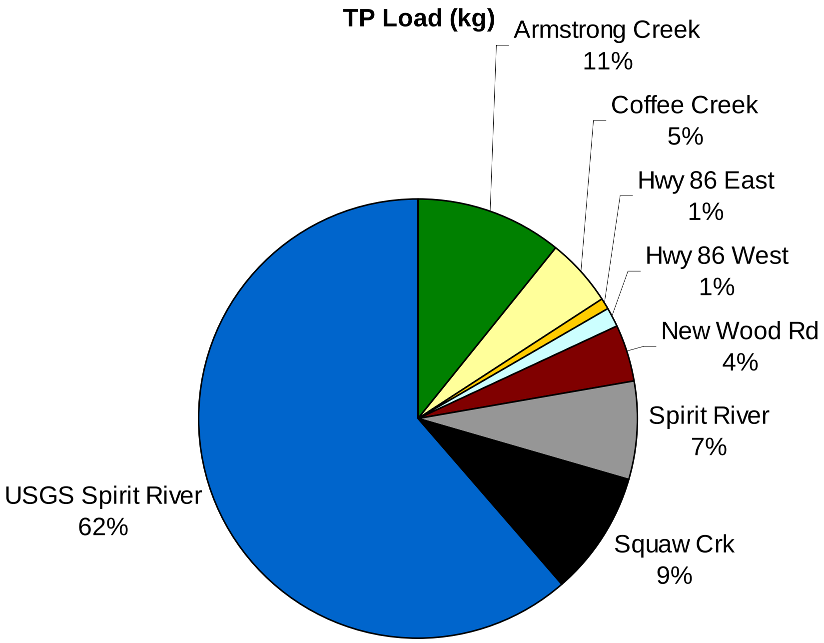


Figure 33. Estimated TP loads (lbs/acre) for the Spirit Reservoir sub-watersheds.

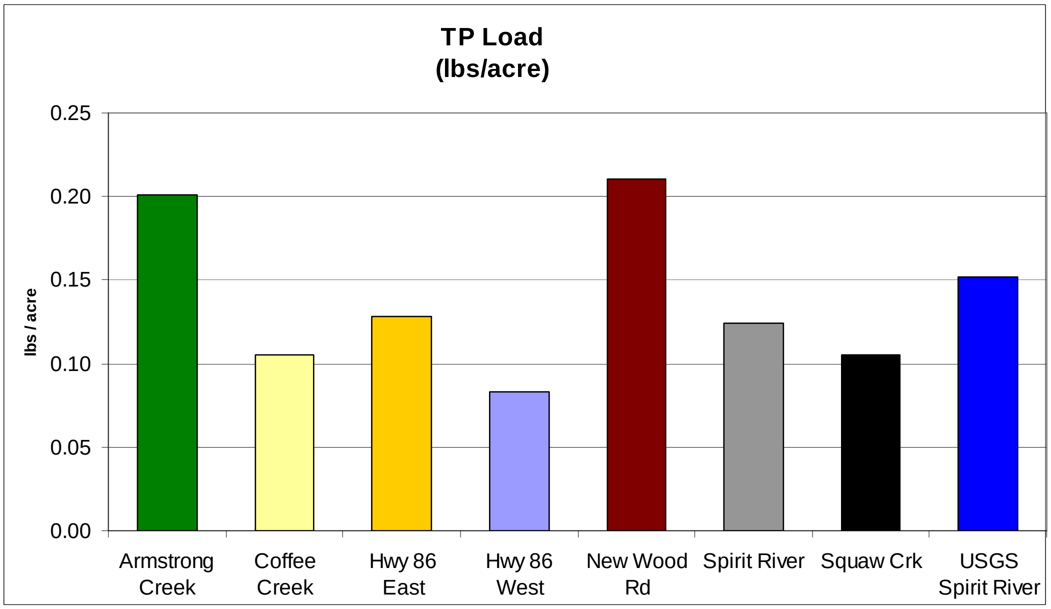
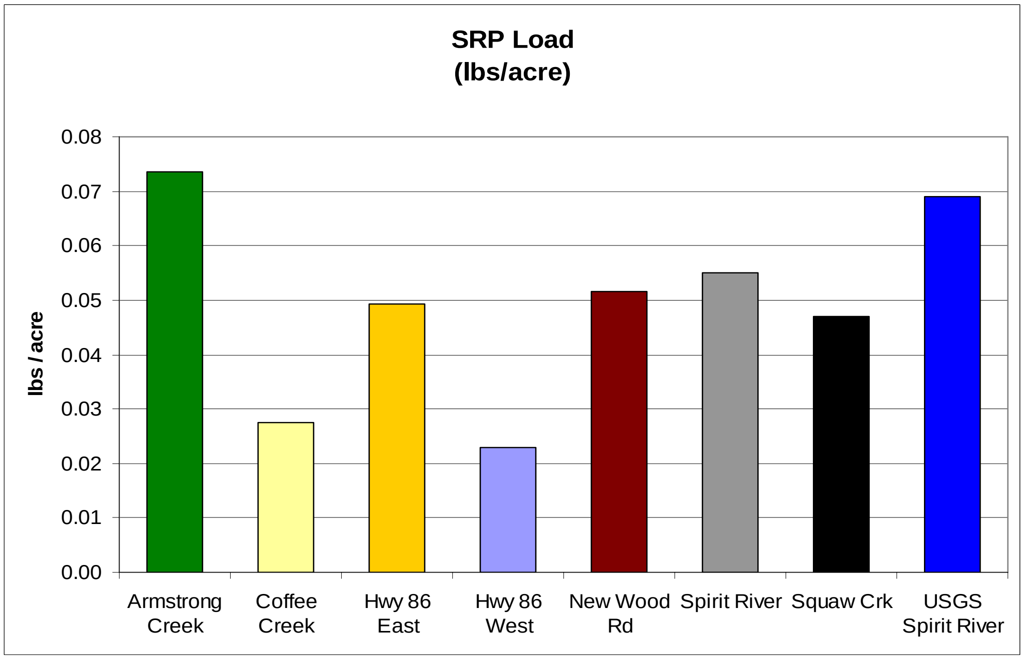


Figure 34. Estimated SRP loads (lbs/acre) for the Spirit Reservoir sub-watersheds.



Summary of Modeling Results

It is estimated that about 25% of the TP load is from internal loading, and the remaining 75% is from external loads entering the reservoir via runoff and its many tributaries. BATHTUB was used to model TP and chlorophyll *a* concentrations. A comparison of the mean area weighted concentrations for the entire Spirit Reservoir is located in Table 14 below. Most of the estimations produced by BATHTUB are very similar to the values derived from field data. The area weighted mean that was calculated from the 2002 field data may have been low because of one very low measurement.

Table 14. Summary of observed and predicted mean area weighted TP and chlorophyll a concentrations (µg/L) for the entire Spirit Reservoir, with the associated models used for prediction in BATHTUB.

Model	TP_{pred}	TP_{obs}	Chlor a_{pred}	Chlor a_{obs}
2001	50.7	49.0	14.2	15.0
2002	51.1	49.0	14.3	10.1
2005	49.2	51.9	13.8	13.9

As mentioned in the "Model Structure" section, once the 2005 model was accurately calibrated to predict values that were very similar to field data, it was than used as a predictive tool. The influences of changes in tributary phosphorus loads on reservoir TP and chlorophyll *a* concentrations were explored by comparing three scenarios. These scenarios involved reducing TP loads within the entire watershed by 20%, and increasing them by 20% and

40%. This predictive modeling can be used to estimate how the water quality of the reservoir will react to land use changes in the watershed.

The relationship between changes in the 2005 TP external load, predicted area weighted mean reservoir concentrations, and chlorophyll *a* are found in Figure 35. A very strong linear correlation exists between sets of data points. Examining the gentle slope of the chlorophyll *a* regression line, it can be seen that area weighted mean reservoir chlorophyll *a* concentrations are influenced but do not change proportionally to changes in external TP loads.

The relationship between changes in TP, the amount of chlorophyll *a*, and how frequent algae blooms occur is shown in Figure 36. This relationship becomes very important when assessing potential for nuisance algal blooms, which in this area are usually between 25 and 30 mg/m^3. According to the modeling predictions, bloom frequency is not directly proportional to TP load, but is affected by changes in loading to some degree. It is important to note that in high flow years the TP load will be considerably increased (as much 3 times the load used in Figure 36).

Within each category of change in percent TP external load, each chlorophyll *a* concentration has an associated bloom frequency percent exceedance value. This value indicates the percent of time the associated chlorophyll *a* concentration will occur in the reservoir between April and October. For example, currently chlorophyll *a* concentrations of 20mg/m^3 or more (1 mg/m^3=1µg/L) occurs about 17% of the growing season (approx. 31 days). For the 20% reduction model, a chlorophyll *a* concentration of 20mg/m^3 or more would be reduced to occur only 14% of the growing season (approx 26 days).

Figure 35. Relationship between changes in the 2005 external TP load and predicted area weighted mean reservoir TP and chlorophyll *a* concentrations.

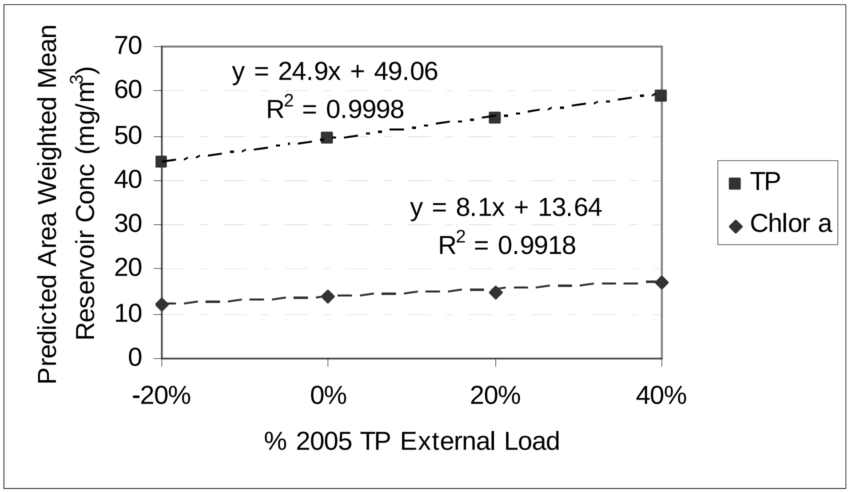
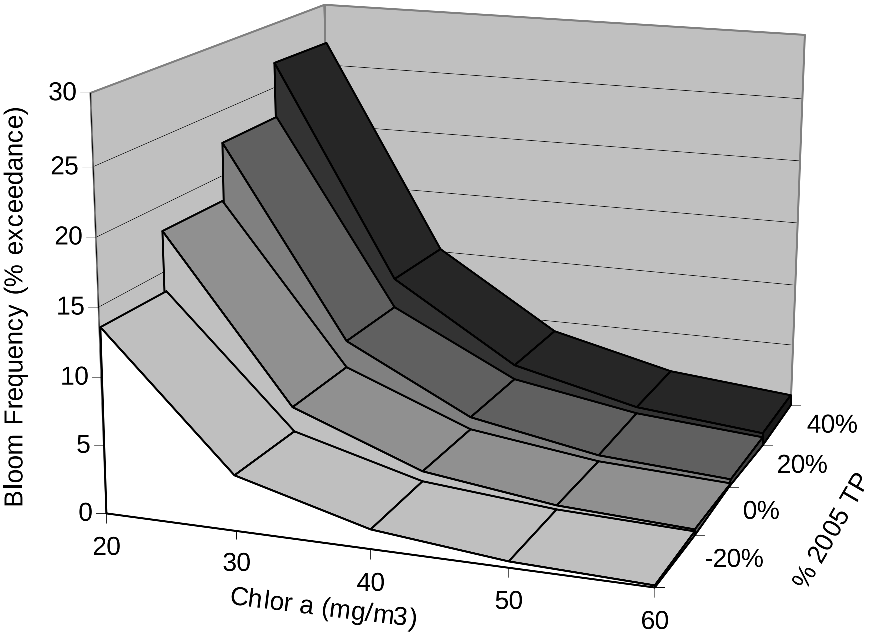


Figure 36. Various percent exceedance bloom frequencies and associated chlorophyll *a* concentrations predicted based on a 20% reduction, 20% increase, and 40% increase from the estimated 2005 TP external loading.



Plants have the potential to tie up available phosphorous, making less available to algae. In the Spirit Reservoir, about 34% of the lake is littoral zone, which is defined as the area of a lake that light penetrates deep enough for rooted plants to grow. Based on Secchi depth readings, during the summer the most likely littoral zone depth in the Spirit Reservoir, is approximately 6.5 feet. (The percent littoral zone was determined by creating a digital elevation model (DEM) from paper bathymetric maps produced by the WVIC and DNR. This DEM can be found earlier in the report in Figure 7**.**) If a typical amount of aquatic plants (for example *Myriophyllum*, a.k.a. Northern water milfoil) grew in the reservoir, their tissue would tie up approximately of 6% of the TP load to the reservoir (based on 2005 data). This value includes an area associated with a depth of 10 feet, which would be suitable for plant growth in years of low water levels due to drawdown and/or dry years. More likely estimations indicate macrophytes could only uptake 0.92% to 3.67% of the total phosphorous load, which would result in virtually no noticeable impact (

Table 15). Although a 6% change in TP loading would have little direct impact on resulting chlorophyll *a* concentrations, an increase in plants may have additional impact by holding sediments in place and filtering sediment and nutrient rich water entering the reservoir.

Table 15. Macrophyte percent total phosphorus estimations used to predict the percent of the total load that could potentially be tied up in biomass, based on a littoral zone of 6 feet (most practical) and 10 feet (unlikely-high range).

Ranges of TP in Biomass		
low	high	
100	200	Annual Production (g/m^2)
0.2%	0.4%	Tissue %TP
Vallisneria	*Myriophyllum*	Species
0.92%	3.67%	% 2005 Total Load*, littoral zone = 6 feet
1.54%	6.17%	% 2005 Total Load*, littoral zone = 10 feet

**Includes all loading estimated by BATHTUB, both internal and external*

Survey of Aquatic Macrophytes in Spirit Reservoir

Aquatic plants play a large role in a reservoir's ecosystem. They provide habitat for the fishery and other aquatic organisms, stabilize the sediment, reduce erosion, buffer temperature changes, infuse oxygen into the water, and utilize nutrients that would otherwise be used by algae.

The species of plants that comprise an aquatic plant community can provide insight into the health of the aquatic ecosystem as some species are present only in specific conditions and may not be tolerant of disturbance whereas other species are very disturbance tolerant. Aquatic invasive species of plants (such as Eurasian watermilfoil and curly-leaf pondweed) can significantly alter the aquatic plant and fish communities in a lake. In Wisconsin the spread of these species is occurring at an alarming rate as they are transported from lake to lake by boats, trailers, and fishing equipment.

The aquatic macrophytes (plants) in Spirit Reservoir were sampled from July 18 to 22 and July 24, 2006, using the WDNR point-intercept method. A total of 785 sites were sampled. During this survey the maximum Secchi disk measurement was 3.5 feet so the calculated maximum depth of water that plants would grow was in 6.5 feet. Although there were 355 sites shallower than 6.5 feet, only 176 sites had vegetation. Some of the lack of vegetation was due to the water levels being about four feet below the filled reservoir level (WVIC website, 2006). This meant that samples sites measured at 6.5 feet during the survey were actually up to 10.5 feet deep several weeks earlier and hence well beyond the depth that light would penetrate. Figure 37 shows the distribution of the 176 vegetated sample points and the type of sampling employed at each site.

Twenty-nine species of plants were identified in this survey (including sampled and visual observations); 19 species were identified from rake samples. Figure 39 shows this species richness (SR) by sample site. The areas of high SR were exclusively along shorelines, especially back bays and islands. On average there were 2.4 species per site. A complete list of aquatic macrophytes found in Spirit Reservoir is shown in Table 16. No submerged aquatic invasive species were identified in this survey; reed canary grass was the only invasive species of plant identified in this survey.

Figure 37. Location and type of sampling sites in Spirit Reservoir.

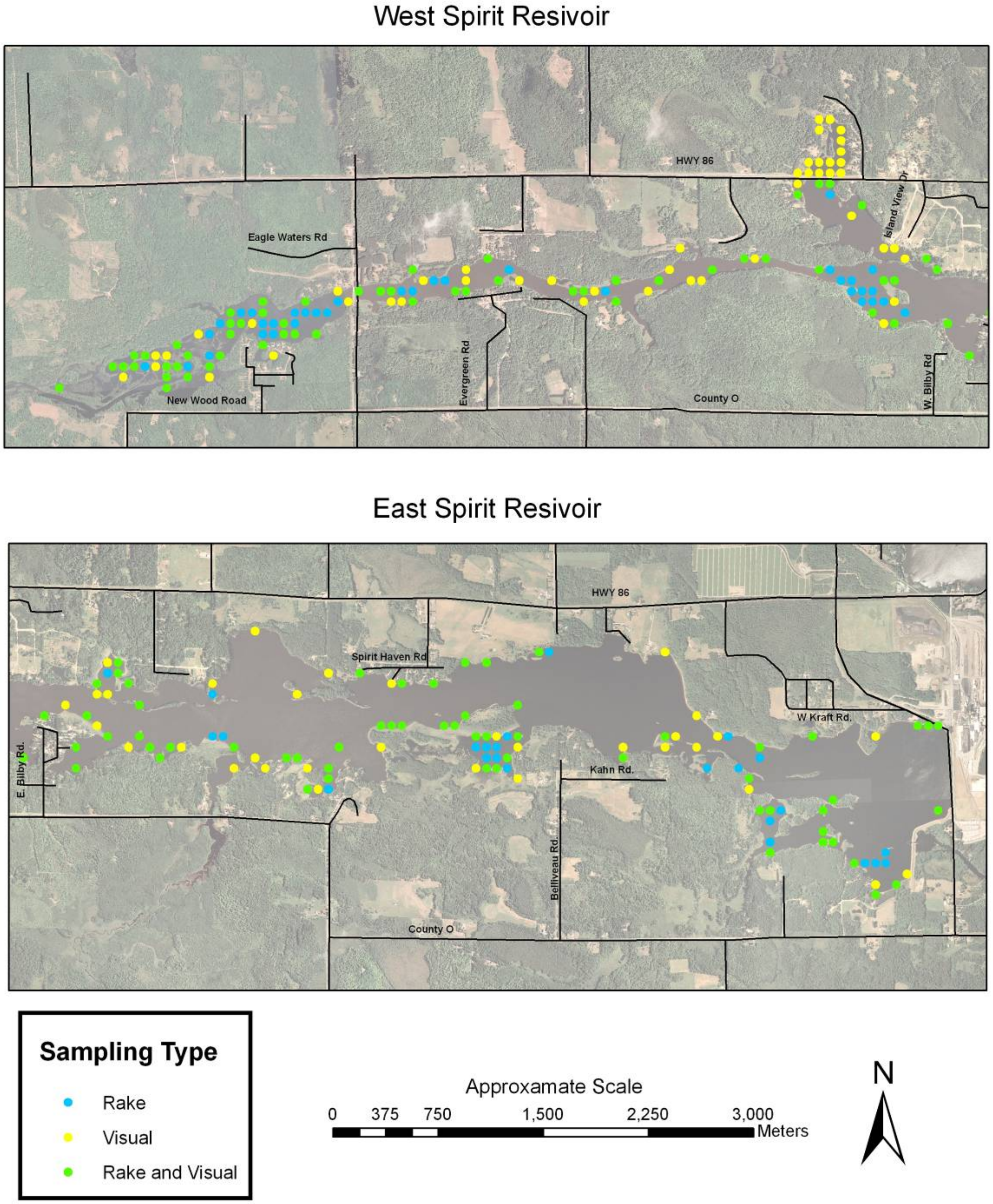


Table 16. List of aquatic plant species identified in Spirit Reservoir in 2006.

Scientific Name	Common Name	I.D. Code	Coefficient of Conservativism (C)
Emergent Species			
Alisma triviale	Water Plantain	ALITI	4
Carex sp.	Sedge	CARSP	5*
Eleocharis acicularis	Needle Spikerush	ELEAC	5
Eleocharis palustris	Creeping Spikerush	ELEPAL	6
Galium sp.	Bedstraw	GALSP	5*
Glyceria borealis	Northern Manna Grass	GLYBO	8
Hypericum boreale	St. John's Wort	HYPBO	6
Juncus balticus	Baltic Rush	JUNBA	5
Juncus effusus	Soft Rush	JUNEF	4
Juncus sp.	Rush	JUNSP	4*
Moss	Moss	MOSS	N/A
Mimulus ringens	Monkey Flower	MINRI	6
Ludwigia palustris	Water Purselane	LUDPA	4
Phalaris arundinacea	Reed Canary Grass	PHAAR	N/A
Pontederia cordata	Pickerelweed	PONCO	9
Sagittaria latifolia	Common Arrowhead	SAGLA	3
Sagittaria rigida	Sessilefruit Arrowhead	SAGRI	8
Sagittaria sp.	Arrowhead	SAGSP	3*
Sparganium chlorocarpum	Short Stemmed Bur-reed	SPACH	8
Sparganium angustifolium	Narrow-leaved Bur-reed	SPAAN	9
Sparganium sp.	Bur-reed	SPASP	8*
Scirpus atrocinctus	Black Girdled Wool-grass	SCIAT	7
Sium sauve	Water Hemlock	SIUSA	5
Typha sp.	Cattail	TYPSP	1*
Floating leaf Species			
Lemna minor	Small Duckweed	LEMMI	5
Nuphar variegata	Spatterdock	NUPVA	6
Polygonum amphibium	Water Smartweed	POLAM	5
Submergent Species			
Cardamine penslyvanica	Pennsylvania Bittercress	CARPE	3
Elodea nuttallii	Slender Waterweed	ELONU	7
Epilobium sp	Willowweed	EPISP	3*
Filamentous Algae	Filamentous Algae	FILAL	N/A
Potamogeton gramineus	Variable Pondweed	POTGR	7
Potamogeton pusillus	Small Pondweed	POTPUS	7
Najas flexilis	Bushy Pondweed	NAJFL	6
Nitella sp.	Nitella	NITSP	7
Schoenoplectus subterminalis	Water Bulrush	SCHSU	9
Schoenoplectus tabernaemontani	Softstem Bulrush	SCHTA	4
Rorippa palustris	Northern Marsh Yellowcress	RORIL	3

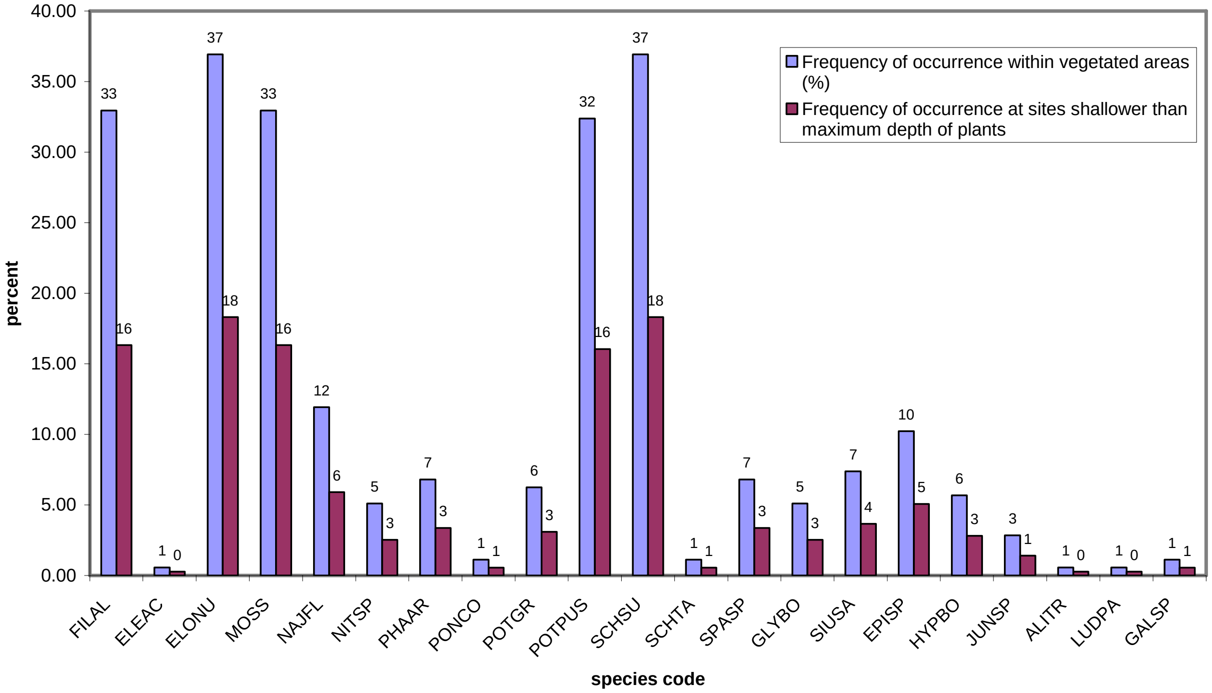
reference: Freckmann and Nichols 1998

* indicate C values not published but interpreted by author of this report

Frequency of occurrence

The frequency of occurrence (FO) percentage compares vegetated sites and sites shallower than the maximum water depth where plants were found, 6.5 feet. Approximately half (49.6%) of surveyed sites shallower then 6.5 feet had plants. Figure 38 shows the relative frequency of the individual species found in vegetated sites and the relative frequency of individual species found at sites less then maximum depth of plants. This graph shows a consistent ratio between each species between the two frequency classes. This indicates that the aquatic plant species are similar in different depths.

Figure 38. Frequency of occurrence in vegetated sites compared to frequency of occurrence in sites shallower than the maximum depth of vegetation.



Simpson Diversity Index

The Simpson diversity index (SDI) quantifies biodiversity as a percent using a formula containing the number of species surveyed and the number of individuals found per species. The closer the SDI is to one, the more diverse the plant community. The SDI for Spirit Lake is 0.89. Spirit Reservoir ranks among the top five reservoirs in a 1999 survey of nine other northern Wisconsin reservoirs as shown in Table 17.

Figure 39. Number of species (Species Richness) at each sampling site.

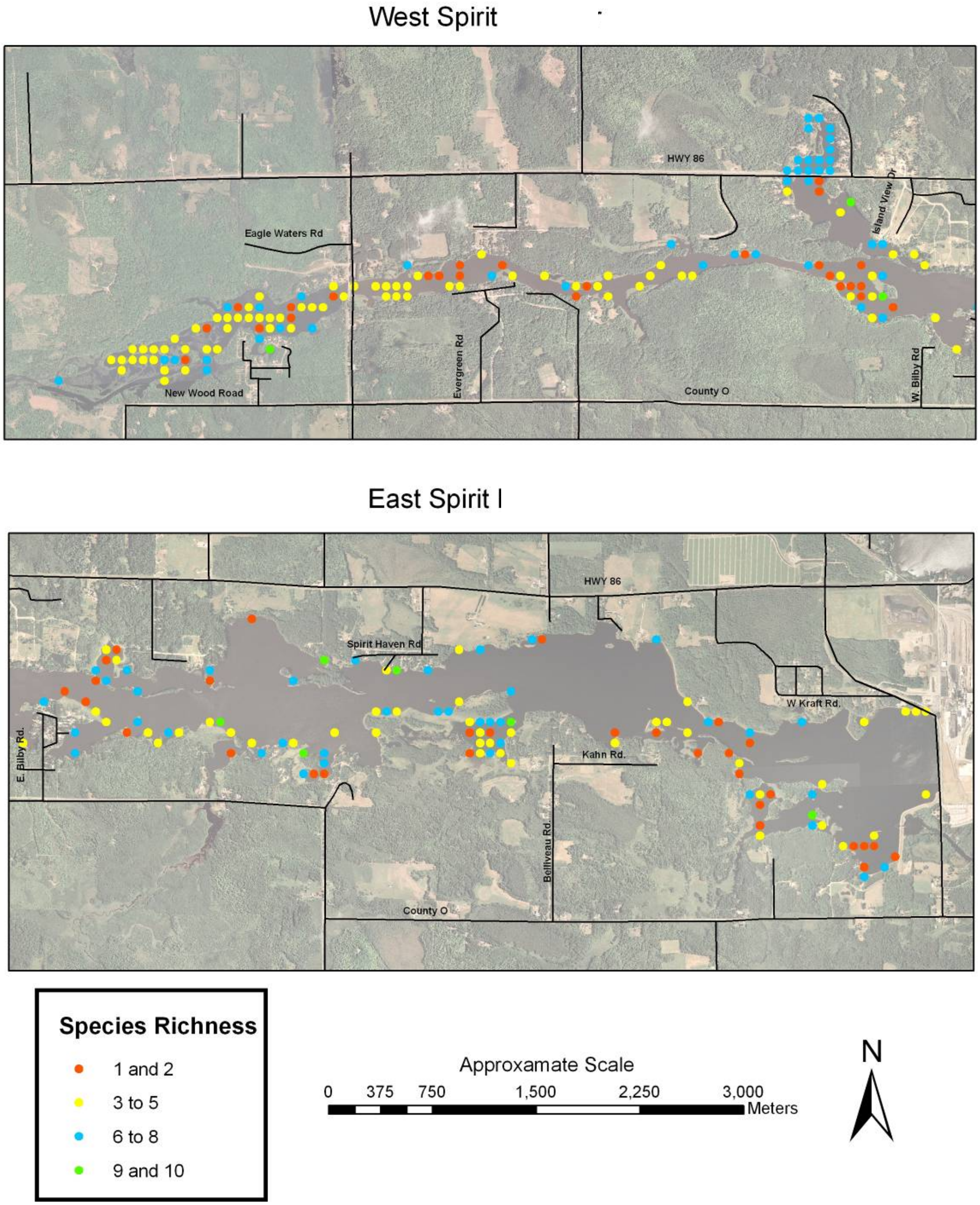


Table 17. Species diversity index of some northern Wisconsin reservoirs (Weber, 1999).

Reservoir	SDI
St. Croix	.92
Willow*	.90
Caldron Falls	.90
Spirit Reservoir*	.89
Minong	.87
Wissota	.82
Brule	.69
Rainbow*	.67
Gile*	.39
Big Eau Pleine*	.02
* reservoir is subject to fluctuating water levels	

Floristic Quality Index

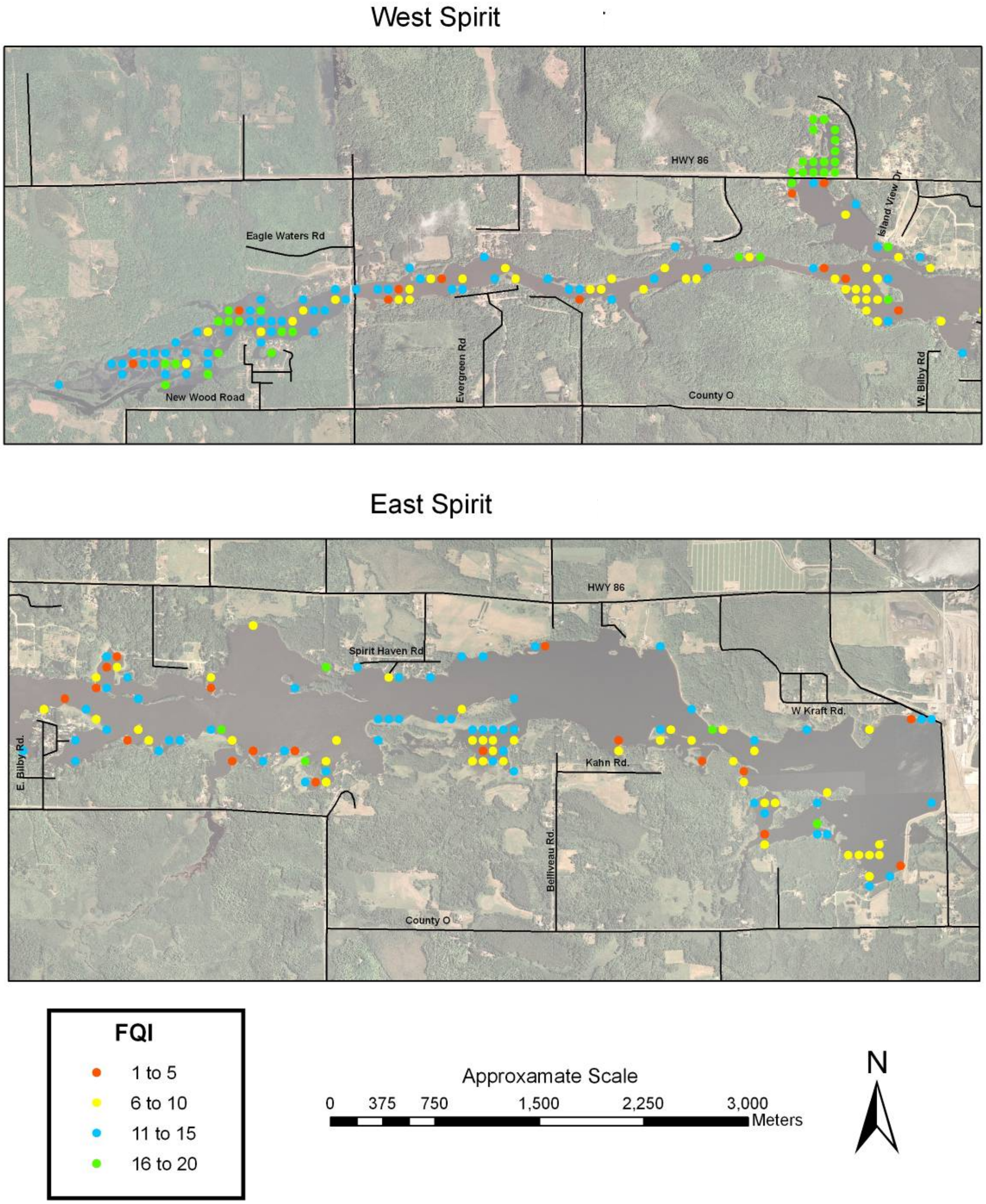
The Floristic Quality Index (FQI) evaluates the closeness of a plant community to undisturbed conditions. Each plant is assigned a coefficient of conservatism (C) that reflects its sensitivity to disturbance and these numbers are used to calculate the FQI. C values range from 1 to 10, the higher the number, the more intolerant of disturbance. A zero C value is assigned to exotic and most nonvascular species, and therefore these species are not included in the calculation. In Spirit Reservoir the C ranged was from 1 to 9 (Table 16). The FQI for Spirit Reservoir was 33. Table 18 compares FQI data calculated in this survey with data from lakes and reservoirs statewide and northern lakes and forest flowages (NLFF). The median FQI for Spirit Reservoir is above the statewide and NLFF median FQI, but the median average C value in Spirit Reservoir is slightly less than the statewide and NLFF median.

Table 18. Median floristic quality indices for Spirit Reservoir, statewide, and for Northern Lakes Forest Flowages.

	Median species #	Median average C value	Median FQI
Spirit Reservoir	35	5.6	33.0
Statewide	13	6	22.2
NLFF	23.5	6.2	28.3
Nichols, 1998			

Figure 40 shows the FQI value for each sample point. Sites with high FQI values mirror those with the highest SR. On the west end of the reservoir, high FQI number are found almost exclusively on the shore lines, especially in back bays and islands. The east end of the reservoir follows a similar pattern except for the area of high FQI concentrated in the shallow backwater near the headwaters.

Figure 40. Floristic quality index by sample site.



Statistics by Species

The most prominent aquatic plant species sampled on Spirit Lake were filamentous algae (FILAL), *Elodea nuttallii* (ELONU, slender waterweed), moss, *Potamogeton pusillus* (POTPUS, small leaved pondweed), and *Schoenoplectus* *subterminalis* (SCHSU, submerged bulrush). Excluding filamentous algae, these species had C values of 7 or greater. Figure 41 illustrates the number sites where each species occurred (excluding visuals).

When visual identifications are included in the statistics, the most prominent species change. Figure 42 shows the number of visual observations for each species. The most prominent species with visuals are Phalaris arundinacea (PHAAR, reed canary grass), Sium sauve (SIUSA, water hemlock), Glyceria borealis (GLYBO, northern manna grass), and Potamogeton gramineus (POTGR, variable leaved pondweed). Excluding reed canary grass C values for the prominent species ranged from 5 to 8.

Figure 41. Occurrence of species by site (excluding visuals).

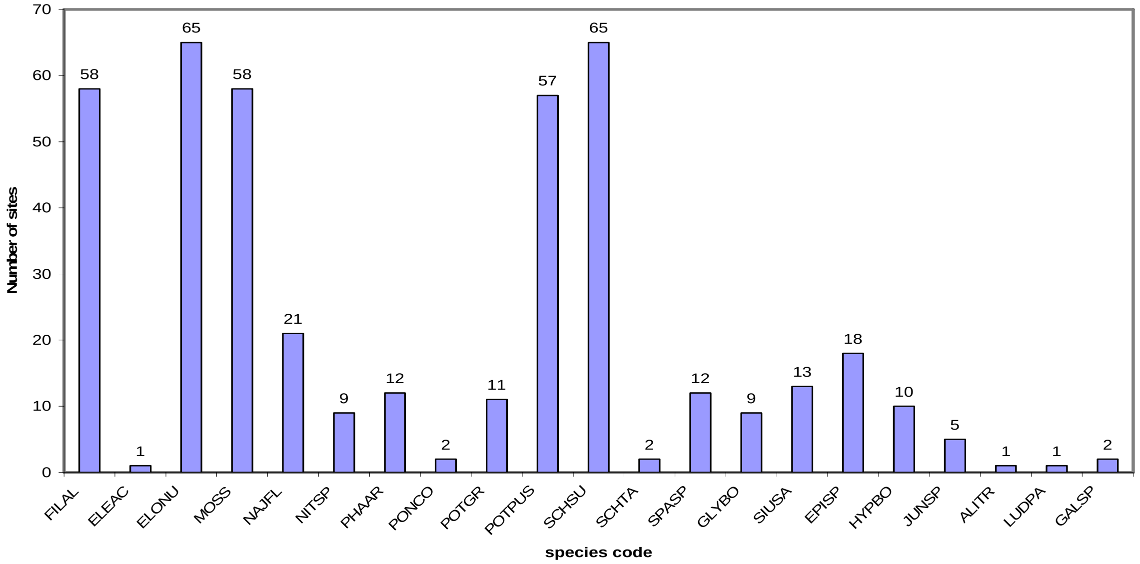
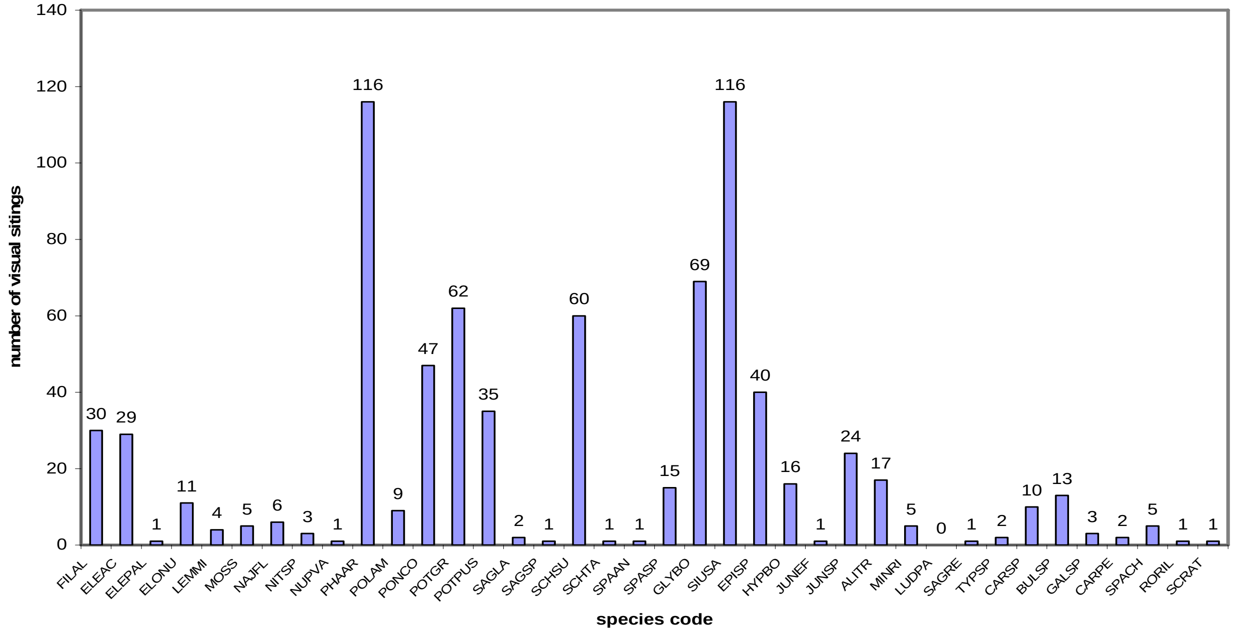


Figure 42. Occurrence of species by site including visuals.



Conclusions and Recommendations

- Overall, most water quality measures in the Spirit Reservoir and tributaries were good however, phosphorus concentrations in the inflowing Spirit River and tributaries were high throughout the year during low and high flow conditions.

- The algal community was diverse but included several taxa of cyanobacteria and green algae that are capable of continued bloom production.

- The overall mix of algal genera was good with only a few problematic taxa present and these taxa were not, as yet, the most dominant organisms in the community. They could become dominant, nuisance organisms if phosphorus reductions in the watershed do not occur AND possibly even if phosphorus reductions do occur. Once sufficient internal nutrient cycling is established (more than the 25% currently estimated) then these organisms will likely increase their abundance in the algal community.

- Water clarity measures range from 2.2 to 5.8 feet throughout the year. The most reduced measures occurred between mid July and August.

- It is estimated that about 25% of the total phosphorus load is from internal loading, and the remaining 75% is from external loads entering the reservoir via runoff and its many tributaries and possibly groundwater.

- Chlorophyll *a* concentrations of $20 mg/m^3$ or more ($1 mg/m^3$=1μg/L) occurs about 17% of the growing season. For the 20% reduction model, these same chlorophyll *a* concentrations would be reduced to occur only 14% of the growing season which equates to a difference of 5 days.

- Citizens should continue collecting water quality monitoring data at least 3 points in the Reservoir through the WDNR self-help monitoring program.

- Explore the use of bio-manipulation or alum to reduce algae blooms.

- The majority of phosphorus and sediment is entering the Spirit Reservoir from Spirit River. Keep erosion in the watershed to a minimum and consider collection of some of the sediment by installing a sediment basin near the upper end of the flowage.

- Based on the aquatic plant Species Diversity Index and Floristic Quality Index, Spirit Reservoir is average or above average when compared to similar reservoirs. Biodiversity in Spirit Reservoir is concentrated along shorelines and back bays.

- Reed-canary Grass (*Phalaris arundinaceae*) was the only invasive aquatic plant found is Spirit Reservoir. Reed-canary has both terrestrial and aquatic forms that rapidly spread in disturbed areas; this grass species is prevalent along the entire shoreline. Because the aquatic macrophytes of Spirit Reservoir are concentrated along shorelines, they are in competition with Reed-canary grass.

- Fish habitat and important aquatic ecosystems occur in and around vegetation. Because vegetated areas are concentrated close to shore, fish habitat and aquatic ecosystems are also threatened by fluctuating water conditions and invading reed-canary grass. Although the reservoir does not have abundant broad leaf plants associated with game fish habitat, the existing vegetation provides abundant food and cover for microorganisms, invertebrates, forage species and game fish fry.

- Develop a monitoring and proactive approach to keeping aquatic invasive species out of the Spirit River and Reservoir.

- Ensure shoreland zoning rules are in place and enforced with new and existing development.

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WVIC. Wisconsin Valley Improvement Company. www.wvic.com

APPENDICES