Algal and Water Quality Assessment and Strategic Plan for Bear Lake, Forest County, Wisconsin

Final Report to the Town of Blackwell

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ACKNOWLEDGEMENTS

Many people were involved with this project and shared their time, insight, and funds. We appreciate their efforts and are grateful for their participation. We were honored to work with the dedicated volunteers that collected samples in good and poor weather, and Jenny Henkel and Sally Lewis for initiating this project and helping to coordinate this effort.

Our partners included:

- Bear Lake Shores Association
- Town of Blackwell
- US Forest Service (USFS)
- Forest County Land Conservation Dept.
- Wisconsin Dept. Natural Resources
- University of Wisconsin-Stevens Point

EXECUTIVE SUMMARY

During summer 2008, a health advisory was posted for Bear Lake in Forest County, Wisconsin by the US Forest Service for blue-green algae, which exceeded the World Health Organization's health standards. Since 2006, lake water had high concentrations of phosphorus (P), which likely contributed to the excess blue-green algae growth in Bear Lake. Drivers of the blue-green algal growth were unclear; aquatic plant biomass was minimal likely due to the aquatic invasive species *Orconectes rusticus*, and in addition, shoreland development had occurred in recent years, yet the watershed is located within primarily undisturbed National Forest land.

During this two-year study, which was conducted from April 2010 through May 2012, biological, physical, and chemical properties were evaluated in the groundwater, inflow/outflow streams, and Bear Lake. Blue-green algal growth in Bear Lake appears to be a result of a combination of factors. Sources of phosphorus to Bear Lake include Shabadock Creek, surface runoff, groundwater, and internal loading. Water entering Bear Lake from Shabadock Creek delivers the greatest amount of phosphorus; however, the phosphorus concentrations in the creek are typical for a watershed that is comprised of forests and wetlands. Phosphorus inputs from sediment contact with anoxic bottom water occurs when the lake is stratified; however, since Bear Lake appears to remain stratified throughout the summer this should be of little consequence to algal growth in the upper part of the water column. Some of the groundwater entering Bear Lake appears to be influenced by cultural sources such as septic systems, campground toilets, house construction, roads, and lawns. The newer septic systems that are located near areas of groundwater inflow will likely contribute phosphorus to the lake as the systems age. Shoreland runoff was not assessed, but where open soil exists, soil (with phosphorus) can erode and runoff the landscape into the lake.

Rusty crayfish appear to be having a large impact on the phosphorus and algal dynamics in Bear Lake. Because the rusty crayfish are removing most of the aquatic plants in Bear Lake, the phosphorus that would have been tied up in plant tissue is available for use by algae. They also generate substantial sediment perturbations, potentially leading to a surge in blue-green algal growth. To compound matters, rusty crayfish preferentially feed on filamentous green algae, like *Cladophora* (Dorn and Wodjak, 2004), leaving more blue-green algae to prosper. These combined effects result in greater and more frequent blue-green algae blooms.

Warmer temperatures and dry conditions existed prior to the start of this study. These conditions may have also played a role in the intense blue-green algal blooms that were observed and led to this study.

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Introduction and Background

This report presents the results of the Bear Lake water quality study in Forest County, WI. This study was a partnership between the citizens of the Bear Lake Shores Association, the Town of Blackwell, the Wisconsin Department of Natural Resources (WDNR), the US Forest Service (USFS), Forest County Land Conservation Department, and the University of Wisconsin Stevens Point's Center for Watershed Science and Education (CWSE).

Bear Lake is a 68-acre drainage lake located in east-central Forest County; much of it lies within Nicolet National Forest and near the Town of Blackwell. It has a maximum depth of 26 feet. It receives water from groundwater, stream inflow, surface runoff, and direct precipitation. Shabadock Creek feeds the lake from the north and Bear Creek drains the lake to the south (Figure 1). Water quality studies and the presence of blue-green algal blooms suggest that Bear Lake is experiencing water quality issues. The USFS website indicates a health advisory for the lake due to periodic blue-green algal blooms. This study was designed to help identify the sources of additional nutrients that are responsible for the blue-green algal blooms.

Although the lake is situated predominantly in the national forest, there is some near shore development by private landowners as well as a USFS campground. During the late 1800's and early 1900's the forests surrounding Bear Lake were virtually non-existent after being heavily logged. The cutover area was turned into farmland, which dominated in the area until the 1920s, and 1930s when the land became abandoned during the depression. In the mid to late 1930s the land around Bear Lake was purchased by private landowners and the USFS. The USFS first established a small campground, boat landing, and beach in the 1950s and have made subsequent improvements and expansions in the past half century. The campground currently has 27 sites that have averaged about 50 people a day during its summer season since 1975 (USFS). There are currently a handful of residences around the lake clustered mainly on the southern end of the lake.

Bear Lake's 4,472-acre watershed is located in the east-central/southeast portion of Forest County. It includes 10.4 miles of streams (Figure 2). It has gently sloping topography, which was greatly influenced by the last advance of the Langlade Lobe during the Pleistocene glaciation. The bedrock consists of basalt and rhyolite formations. The bedrock of Forest County is irregular in shape generally slopes to the east and southeast. The soils are primarily silt loam or organic in composition due to the flat topography. The soil ranges from well drained to very poorly drained; however, it is moderately permeable. Since the watershed is located within the Nicolet National Forest, most of the land use is limited to forestry and its associated practices.

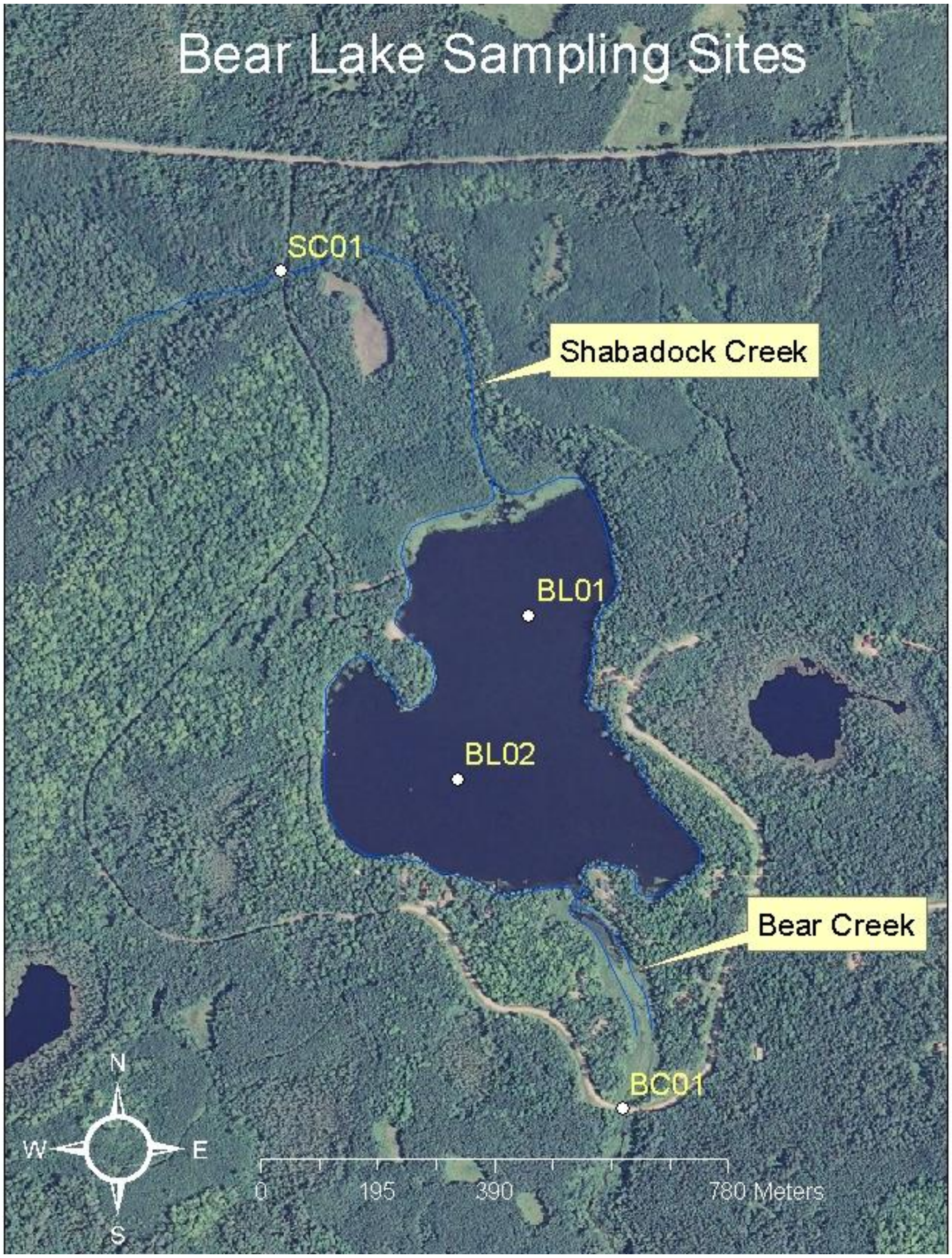


Figure 1. Location of sampling sites in Bear Lake (BL01, BL02) and inflow stream (SC01) and outflow stream (BC01).

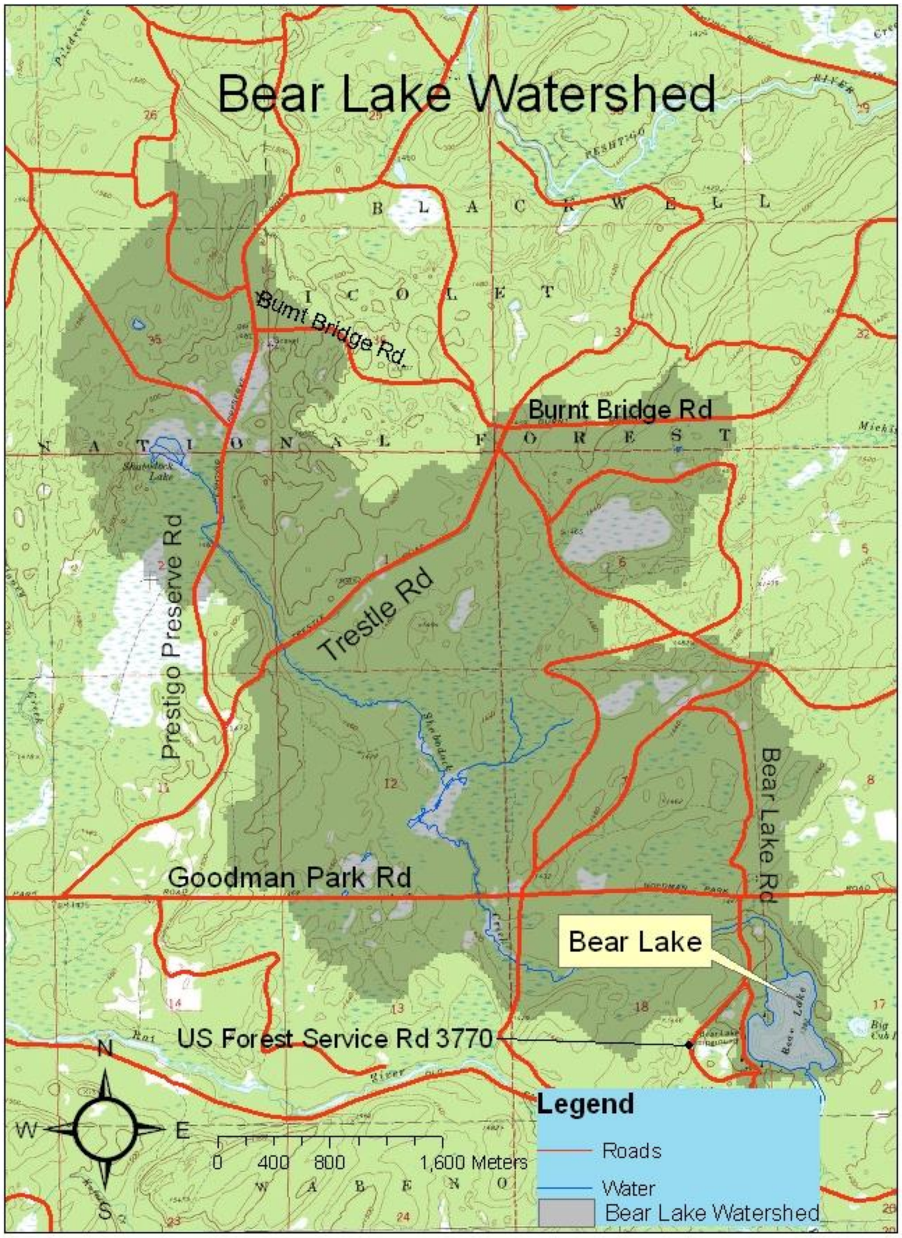


Figure 2. Map of the Bear Lake Watershed.

PURPOSE

In recent years, Bear Lake has experienced blooms of blue-green algae, which has raised concern for lake users and local residents. The thick blooms that occurred in 2008 were more extensive than locals recalled in the past. Residents report that a less dramatic bloom occurred in 2009. No major blue-green algal blooms were observed during summer 2010 and 2011. This study was initiated in response to citizens that were concerned about the unsightly and potentially toxic blooms pursuing answers about the cause of the blooms. Since the watershed is relatively undeveloped, it was not clear why the frequency and magnitude of blue-green algal growth appears to have increased in Bear Lake. Some of the questions that we sought to answer in this study included: 1) are the algal blooms related to an increase in nutrients from cultural sources, 2) are the invasive and non-native rusty crayfish changing the dynamics within the system, 3) is the water spending more time in the lake because of the increased vegetation in the outflow channel or are changes in weather patterns related to changes in the lake's dynamics. To address this uncertainty, we evaluated the phosphorus conditions in the watershed and lake along with a study of the algal community in Bear Lake. Ultimately, we developed hydrologic and phosphorus budgets for the lake. During this period, volunteers and WDNR professionals also surveyed the aquatic plant community to help in the understanding of their role in phosphorus use and release.

GOALS AND OBJECTIVES

This project took place in two phases. Data collection and summary took place in Phase One. Phase Two utilized the data in the development of a strategic plan. Distribution of information to the community occurred throughout the project and individuals and the community provided input about Bear Lake for consideration in the development of the lake management plan.

Goal 1: Develop an understanding of the dynamics involved with the algal community in Bear Lake.

1. Evaluate the algal community in Bear Lake throughout the ice-off periods in 2010 and 2011.
2. Develop hydrologic and phosphorus budgets for Bear Lake.
    a. Assess phosphorus concentrations and loads in Shabadock Creek, Bear Creek and Bear Lake.
    b. Evaluate dissolved oxygen conditions in Bear Lake.
    c. Monitor lake stratification/mixing.
    d. Evaluate data on historic forestry practices and logging in the Bear Lake watershed.

Goal 2: Evaluate current conditions and changes in the aquatic plant community.

1. Current conditions of the aquatic plant community will be assessed by trained citizens in July 2010 and 2012.
2. Historic aquatic plant data will be used to evaluate changes over time.

Goal 3: Monitor the rusty crayfish population in Bear Lake.

1. Use DNR Citizen Monitoring Protocol to monitor the rusty crayfish population in Bear Lake.
2. May use rusty crayfish exclosure in summer 2011.

Goal 4: Develop a strategic plan for Bear Lake.

METHODS

LAKE WATER QUALITY

Lake water quality data was collected at two in-lake sites on Bear Lake: one in the north deep hole (BL01) and one in the south deep hole (BL02). At both sampling sites a Secchi disc was used to measure water clarity, an integrated sampler was used to collect samples for chlorophyll *a* and total phosphorus (TP) analysis in the upper six feet of water, and an YSI temperature/dissolved oxygen probe was used to create depth profiles. In 2010 an alpha bottle was used to collect samples from the hypolimnion for TP analysis at the south deep hole (BL02a). The WDNR Citizen Lake Monitoring Network procedures were followed.

Throughout the 2010 and 2011 sampling periods, water clarity measurements were taken by Bear Lake Shores Association volunteers using a Secchi disc prior to sample collection. Lake samples were collected for lab analysis of TP and chlorophyll *a* (an indicator of algae. Volunteers recorded the time of collection and current weather conditions on a field sheet. The integrated sampler and collection bottle were rinsed with distilled water after use. In addition, a south deep-hole TP water sample was collected at a depth of approximately 10 feet using an alpha bottle. Immediately after the deep hole sample was collected, and using the alpha bottle spout, a 60 mL acid-preserved bottle was filled just below the top and placed in a cooler.

From the opposite side of the boat, a temperature and dissolved oxygen (DO) probe was used to record depth profiles at the north and south deep holes of Bear Lake. Prior to use, volunteers followed the manufacturer's instructions for calibrating the temp/DO probe. The probe was lowered to an initial depth of one foot and held in place while the readings stabilized. Temperature and DO were recorded on a field sheet and the probe was lowered two feet to a total depth of three feet. Measurements were taken and recorded at two foot increments past the one foot depth (for example, 3, 5, 7 feet, etc.) until no more measurements could be taken.

Once back on shore, the samples were prepared for lab analysis. Water collected in the 1L bottles at each site was gently mixed, then transferred into the 60 mL acid-preserved bottle to just below the top. Care was taken to avoid overflowing the bottles and spilling preservative. The TP bottles were 60 mL HDPE plastic screw-on-top with three drops of sulfuric acid (H_2SO_4) preservative in each bottle. Collection bottles were labeled for lab analysis.

The chlorophyll *a* filter was also prepared on shore with the remaining integrated water samples. Plastic tubing and a hand pump were attached to a 750 mL flask. Then a moistened stopper was inserted into the flask, and the filtering base was inserted into the stopper. The filter base was rinsed with distilled water before the membrane filter was placed. A tweezers was used to handle the membrane filter and place it centered on top of the filter base cup. The magnetic cup was placed on top of the filter base without moving or wrinkling the filter. Then the water collection bottle was gently mixed and a portion of it poured into a graduated cylinder to measure the volume of water being filtered. Some of the sample was poured into the upper cup of the filtering apparatus and the hand pump was squeezed repeatedly to move water through the filter. Additional water was then measured and added using the graduated cylinder. Volunteers attempted to filter 1000 mL of water using this technique, and recorded the exact total volume they were able to filter. The metal cup was carefully removed from the filtering apparatus after all water had passed through the base. Then the filter was carefully removed with a tweezers from the filtering apparatus, folded in half, and covered with tin foil. The foil was placed in a whirlpak bag and labeled for lab analysis. All water sample bottles were refrigerated until they were shipped on ice in a cooler to the UWSP Water and Environmental Analysis Lab (WEAL).

Lake depth profiles of pH, specific conductance, temperature, and dissolved oxygen, were measured by UWSP during spring and fall overturn and winter using a hydrolab prior to acquisition of samples for water quality analysis. An initial reading was taken with the hydrolab at one foot below the water surface after the instrument stabilized. Subsequent measurements were taken at two-foot increments past the one foot depth until no more measurements could be taken. Overturn lake samples were analyzed for alkalinity, nitrate (NO2+NO3-N), ammonium (NH4-N), total Kjeldahl nitrogen, reactive phosphorus (SRP), total phosphorus (TP), and chloride. Water chemistry analysis was performed at the state certified UWSP Water and Environmental Analysis Lab (WEAL).

To determine the extent of stratification and mixing throughout the summer, temperature was measured every four hours using programmed thermosters. Five thermosters were deployed in the south deep hole of the lake in early summer 2010 and 2011. The thermistors were attached to a chain at 3, 8, 13, 18, and 23 feet from the lake's surface. The chain was attached to an anchored buoy and was also anchored to prevent lateral movement of the thermistors. The thermistors were set to measure temperature every four hours.

Lake water quality can vary from year-to-year and seasonally, making it beneficial to examine data for seasonal and long-term water quality trends. Through the Wisconsin Department of Natural Resources (WDNR's) Citizen Lake Monitoring Network program, volunteers from the Bear Lake Shores Association have been collecting in-lake water quality measures since 2006. In addition to collecting water quality samples, temperature data was also collected at various depths in the south deep hole of Bear Lake. These data are available through the WDNR's webpage.

ALGAE

Samples for algae were collected from Bear Lake twelve times during the 2010 season (May 20 – November 1), and eleven times during the 2011 season (30 April - 05 November). On each date, lake volunteers collected volumetric samples from 3 foot and 10 foot depths at each deep hole. A horizontal plankton tow was pulled between the two deep holes, and floating/attached algae were collected by grab sampling. Samples were transported to UW-Stevens Point for analysis.

Algal samples were fractionated into fresh and iodine-preserved aliquots. Initial evaluations revealed sample homogeneity and consequently all samples were pooled for analysis. Fresh samples were surveyed immediately to provide the most accurate genus list. Preserved samples were stored, cold, until counting. For analysis, 1 ml aliquots of preserved material were placed into a Sedgewick-Rafter counting cell and allowed to settle for 1 hr. Random fields were counted at 400X under an Olympus ZH20 Inverted Microscope with long working distance lenses. Colonial and filamentous organisms were counted as a single unit if intact. Organisms were enumerated until the total reached 300 per date. Generic identification was from standard freshwater reference texts (Smith, 1950; Prescott, 1973; Wehr and Sheath, 2003).

GROUNDWATER MONITORING

In July 2010 and August 2011, groundwater flow conditions (inflow, outflow, or static) of Bear Lake were assessed using mini-piezometers (small, temporary wells) placed approximately every 200 feet around the western, eastern, and southern shores of Bear Lake. Well positions were marked using a handheld GPS and labeled on a map for future reference and investigation. Lab analyses were completed on 17 water samples for nitrate-nitrite (NO_2+NO_3-N), ammonium (NH_4-N), soluble reactive phosphorus (SRP), and chloride from sites exhibiting groundwater inflow and from groundwater spring locations.

The mini-piezometers were constructed from 5-foot lengths of 3/16 inch inside diameter polypropylene tubing with a point formed on the bottom end. A small diameter ballpoint-sewing needle was used to perforate the bottom 3.74 in of the tubing starting 2.75 in from the point. A 1 ml pipette tip was attached to the pointed end to protect the mini-piezometer tip during installation.

Researchers installed the mini piezometers to shallow depths (approximately 24 inches) in the lakebed in an average water depth of 18 inches. A metal rod was inserted into the mini-piezometer to ease the the well into the lake sediment. The rod and mini-piezometer were inserted into a tile probe that was manually pushed straight down into the sediment. After reaching an installation depth of approximately 24 inches, the metal rod and tile probe were removed and the well was developed to ensure communication with the groundwater. Well development was performed by injecting two to three 60cc syringes of water into the well and drawing four to five full syringes back out until clear water, assumed to be groundwater, was found. The site was abandoned if communication with groundwater could not be established.

At each sample site, measurements of water depth, installation depth, static head height, and slug height (length of tube above static head) were recorded. Static head identifies whether groundwater is entering the lake (inflow) or whether water is leaving the lake (outflow); a static head above the lake water indicates inflow and a static head below the lake water indicates outflow. A site where the head is level with the lake water is considered a no-flow or static site.

The velocity of groundwater inflow, or seepage rate, was estimated by conducting falling head tests to determine the hydraulic conductivity (Fetter, 2001). The test was performed by timing the fall of water from the top of the mini-piezometer to a black O-ring placed at 37% of the slug height above the static head. This procedure was repeated three times to determine an average falling head time. The hydraulic conductivity was calculated using the average falling head time and design specifications of the mini-piezometer. The groundwater seepage rate, or flux, was estimated by multiplying the hydraulic conductivity to the vertical hydraulic gradient (the difference in water levels between the mini-piezometer and surface water, divided by the depth from the sediment surface to the middle of the screened area).

Citizen volunteers mapped areas of open water and ice-melt on the lake in January 2011. This additional information contributed to a more complete understanding of the location and extent of groundwater inflow to Bear Lake.

Watershed Water Quality

Water quality samples from two streams, Shabadock Creek (inflow) and Bear Creek (outflow), were collected in 2010 and 2011. Samples were acquired using the grab method every two weeks and tested for TP and SRP, or a river package analysis. The TP and SRP sample bottles used were HDPE with sulfuric acid added as a preservative. The river package included lab analyses for TP, SRP, nitrate+nitrite (NO2+NO3-N), ammonium (NH4-N), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), and chloride. In addition to two HDPE H_2SO_4 preserved bottles, the river package required sample collection in one unpreserved HDPE bottle.

Volunteers grabbed stream samples using a 60 mL syringe on the upstream side of each sampling location at approximately half the depth from the water surface. The syringe and filtering equipment used to collect stream samples were rinsed with distilled water prior to use. The syringe was rinsed with stream water three times right before the sample was taken at the sample location. Total phosphorus samples were transferred into preserved, 60 mL, HDPE screw-top bottles until almost full. Samples collected for SRP were filtered on site with a clean filter cartridge that contained a new 0.45-micron filter. The filter cartridge was attached to a 60 mL syringe after the sample was grabbed from the stream and a small amount of initial water sent through the filter was discarded. Filtered water was then injected into a preserved, 60 mL, HDPE bottle until almost full. If a river package analyses were being conducted for the sampling date, volunteers also collected an unpreserved, unfiltered grab sample from the same location in a clean, 250 mL, HDPE collection bottle. All sample bottles were labeled and refrigerated until they were shipped on ice in a cooler to the WEAL lab.

In addition to water quality monitoring, stream flow was quantified using pressure transducers, staff gauges, and stream discharge measurements. Four locations (one outflow and three inflow sites) were measured for discharge using a flow meter and cross-sectional method. One inflow site and one outflow site was equipped with a staff gauge and pressure transducer. At the time water quality samples were collected, a staff gauge reading was recorded on a field sheet. In addition, volunteer observers recorded the date, time, and current weather conditions.

Two Solist pressure transducers were installed by the CWSE, one in Bear Creek and one in Shabadock Creek. Each transducer was placed in a lock box and chained to discourage tampering with the devices. Level surfaces were created in the streambeds and supports were placed around the lock boxes to prevent movement. The pressure transducers were placed in the stream May 20, 2010 and June 16, 2011 and were set to record pressure every 15 minutes. Approximately once per month, transducers were surveyed and removed for data download. Care was taken to make sure each transducer box was reinserted exactly where it was removed with the use of leveling and measuring devices or survey equipment.

A permanent staff gauge was installed at the Bear Creek location (outflow). A fence post was pounded into the streambed until a solid placement was achieved. A staff gauge was then firmly attached to the fencepost with U-bolts. The staff gauge was surveyed prior in the fall to measure any shift over the winter months.

Results and Discussion

Understanding why the blue-green algal blooms appear to have increased in Bear Lake in recent years requires an examination of water quality and potential sources of nutrients (food for algae) and other changes within the lake and its watershed. During this two-year study, water quality was evaluated in the inflow and outflow streams, Bear Lake, and the groundwater flowing into Bear Lake. The study also evaluated the in-lake vegetation and water volumes.

Lake Hydrology – Where the water is coming from

Understanding how water moves to and from a lake is critical in determining how to reduce nutrient inputs (primarily phosphorus and nitrogen) which will be necessary to reduce blue-green algal blooms in Bear Lake. The amount of water going into and out of the lake can greatly affect the amount of time water stays in a lake, which in turn affects its water quality, and the amount of algae and aquatic plants growth in a lake. During snowmelt or a rainstorm, water moves across the surface of the landscape (runoff) from higher to lower elevations such as wetlands, lakes, rivers, or internally drained areas (where water on the land's surface can soak in and recharge groundwater). The capacity of the landscape to hold water and filter particulates, such as dissolved nutrients, ultimately determines the water quality, habitat type, and amount of erosion that may occur. Essentially, landscapes with a greater capacity to hold water during and after rain events and snowmelt will deliver the water to the wetlands and streams at a slower rate, allowing the vegetation to filter the runoff; resulting in better water quality for the receiving water body. The Bear Lake watershed is primarily comprised of forests and wetlands so overall the landscape is well suited to handle rainstorm events; however, some of the near shore land management practices (such as compacted areas in campsites and yards, groomed lawns, hard-packed walking paths, and pavement) may increase surface water runoff that carries sediment and nutrients to the lake.

As water moves across the land's surface, dissolved and particulate matter is picked up and travels with the flow. Surface water runoff can be decreased when water has the ability to soak into the soil, which in turn filters out sediments and nutrients. Plants covering the ground can also divert water and slow its movement allowing some or all sediment and associated nutrients to be deposited or absorbed along the way. Near shore, the optimal plant communities (vegetated buffers) consist of a combination of trees, shrubs, and deeply rooted perennial vegetation with well-structured soil. Most of the area surrounding Bear Lake has this type of vegetated buffer. However, where the shoreline is disturbed, developed, and/or has impervious surfaces the runoff may be increased and land use practices to reduce runoff should be put into place. These practices may include the use of rain barrels to collect rainwater and landscaping that includes depressions and/or rain gardens to redirect surface water in a fashion that will allow it to soak into the ground.

Precipitation feeds lakes and their inflow rivers/streams directly via surface runoff and indirectly via groundwater inflow. Near Bear Lake, about one third of the precipitation that falls infiltrates into the ground to recharge groundwater. The rest of this precipitation is either lost through evaporation and transpiration (water loss from plants) or makes its way to wetlands, rivers and streams, or the lake as surface runoff. A combination of interactions between topography, geology, soil type, structures, natural and altered drainages, and land use practices influence the water chemistry and both regional and local surface water flow.

A water budget was calculated from flow measurements taken from Bear Lake, the inflow stream Shabadock Creek and the outflow stream Bear Creek. A little more than 50% of the water was estimated to be entering the lake by surface runoff. About 45% of the water was measured to be entering through the inflow stream, Shabadock Creek. The smallest portion, about 2 percent of water entering Bear Lake, is estimated to be coming from groundwater inflow (Figure 3). The water in Bear Lake leaves through groundwater and the outflow stream Bear Creek.

Table 1. Estimated water budget for Bear Lake, cubic feet.

Water Budget Bear Lake	Total (ft^3)
Shabadock Creek	54,171,000
Surface Runoff	64,944,000
Groundwater Inflow	1,997,000
Total	121,112,000

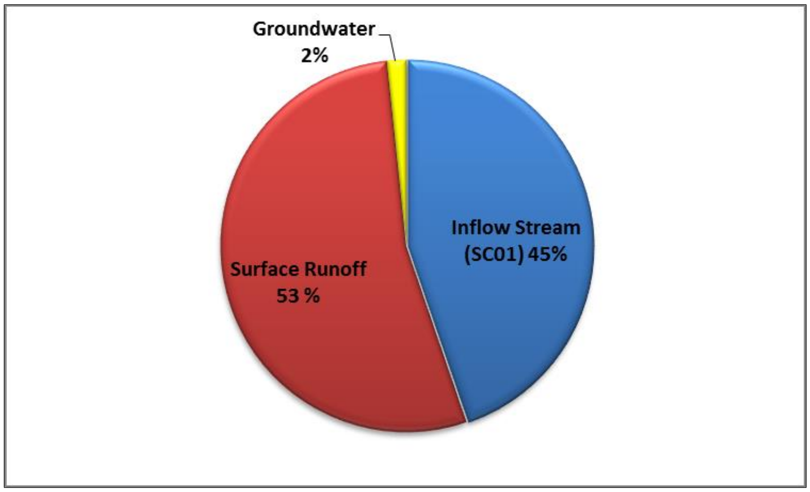


Figure 3. Estimated water budget for Bear Lake, percent.

RIVER WATER QUALITY DATA

Shabadock Creek accounts for about 45% of the water in Bear Lake so its water quality plays a large role in the lake's water quality. Except for some road crossings and towards the headwaters of Bear Lake, the watershed draining to Shabadock Creek is in a natural state with intact natural wetlands. This means the water quality in Shabadock Creek is good. The land management activities that would periodically change this condition would be large-scale and/or near shore logging. Typically, logging activities in the National Forest are done with attention to minimizing impacts to the creek; however, with the use of heavy equipment, development of roads, and felling of trees some impacts are inevitable.

During this study, samples were collected from Shabadock Creek (inflow site SC01) and Bear Creek (outflow site BC01) bi-weekly between June and November in 2010 and 2011. One sample was collected during the winter months in January 2011. At the time of sample collection, in-stream measurements included temperature and dissolved oxygen. All samples were analyzed in the WEAL lab for total phosphorus. In addition, 2010 samples were also analyzed for nitrogen, soluble and total phosphorus, total suspended solids, and chloride.

Flow measurements were taken monthly during the sampling periods by CWSE staff and some measures were made by USFS personnel. Citizen monitors took staff gauge readings when they were collecting samples. Continuous flow measures were recorded using pressure transducers. The staff gauge readings and instantaneous discharge measurements were used to develop rating curves (see Appendix). The rating curves were used to translate the data from pressure transducers into discharge that was used to analyze seasonal flow patterns and variability as well as an overall water budget for the watershed.

PHOSPHORUS

The median total phosphorus (TP) concentrations in both the inflow (Shabadock Creek-SC01) and the outflow (Bear Creek-BC01) are below the phosphorus standard of 75 µg/L for wadeable streams in Wisconsin (WDNR 2010). The median concentrations were 21 µg/L at SC01 and 31µg/L at BC01. There was little correlation between total and soluble reactive (SRP) phosphorus (Figure 4). Fluctuations in TP appeared to be related to precipitation events. TP showed higher concentrations in 2010 than during the same time period in 2011 at SC01 (Figure 5). The highest measured TP concentrations occurred during the summer 2010, while 2011 results were similar throughout the entire sampling period for both sites (Figures 5 and 6). Phosphorus loads were calculated using discharge measurements and are discussed at the end of this document.

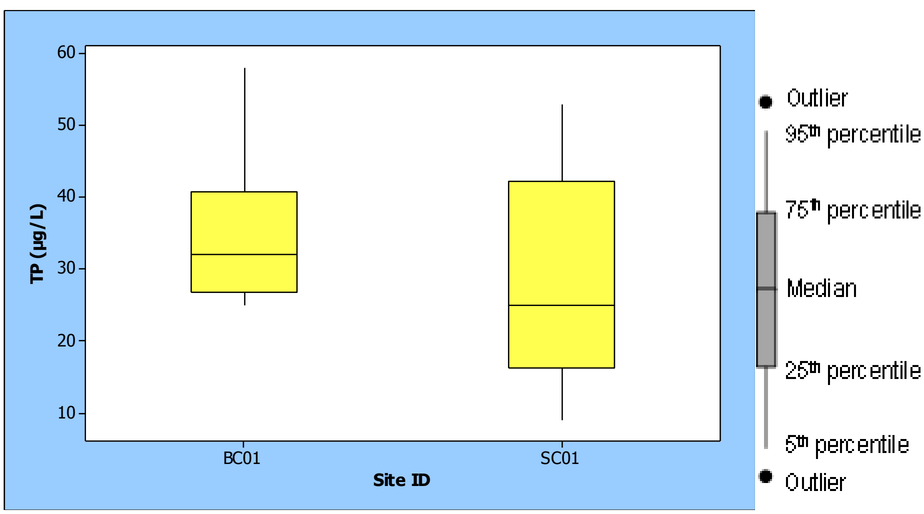


Figure 4. Boxplot of total phosphorus calculated in samples collected during the summer months [May 1st-October 31st] at sites SC01 and BC01, 2010 and 2011.

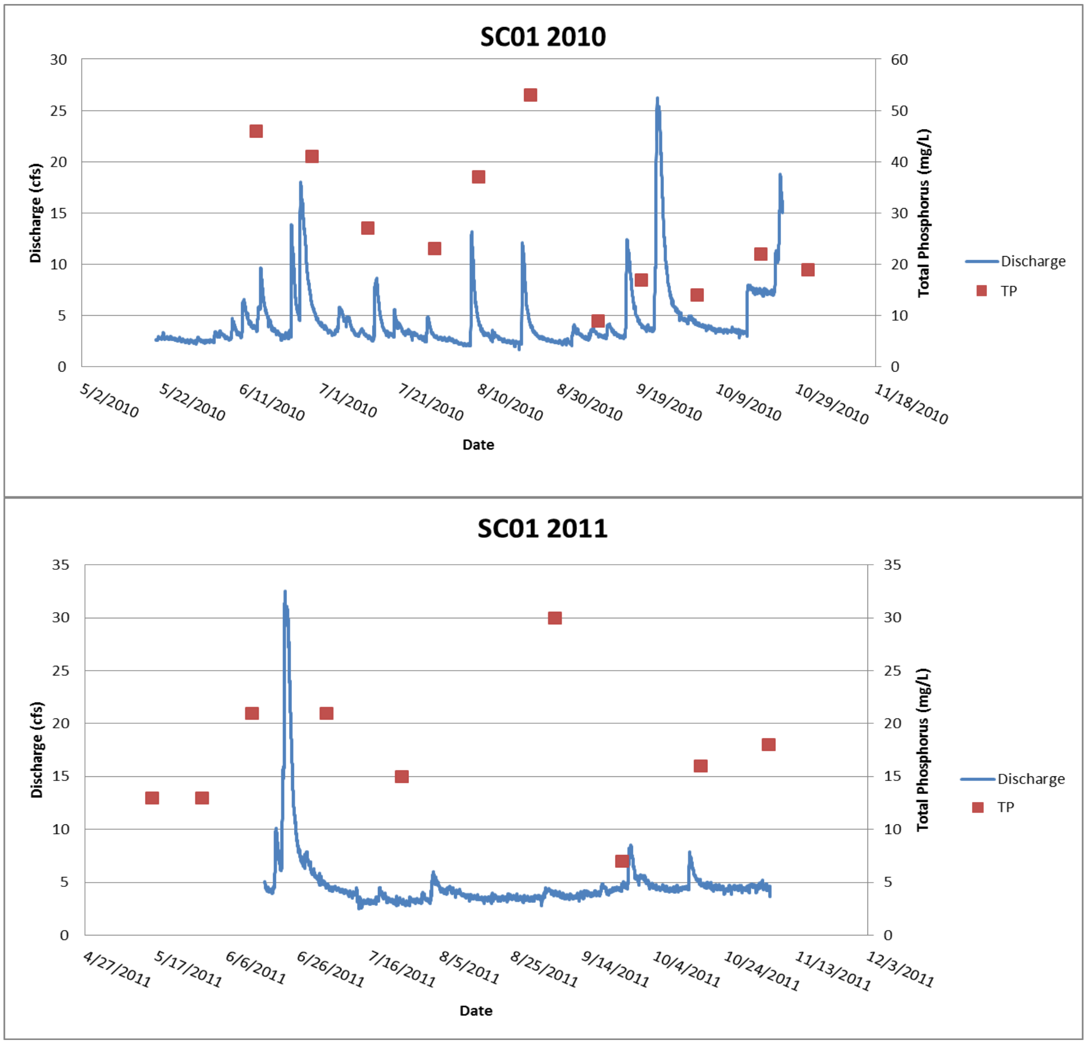


Figure 5. Discharge and TP over time at SC01 in 2010 and 2011.

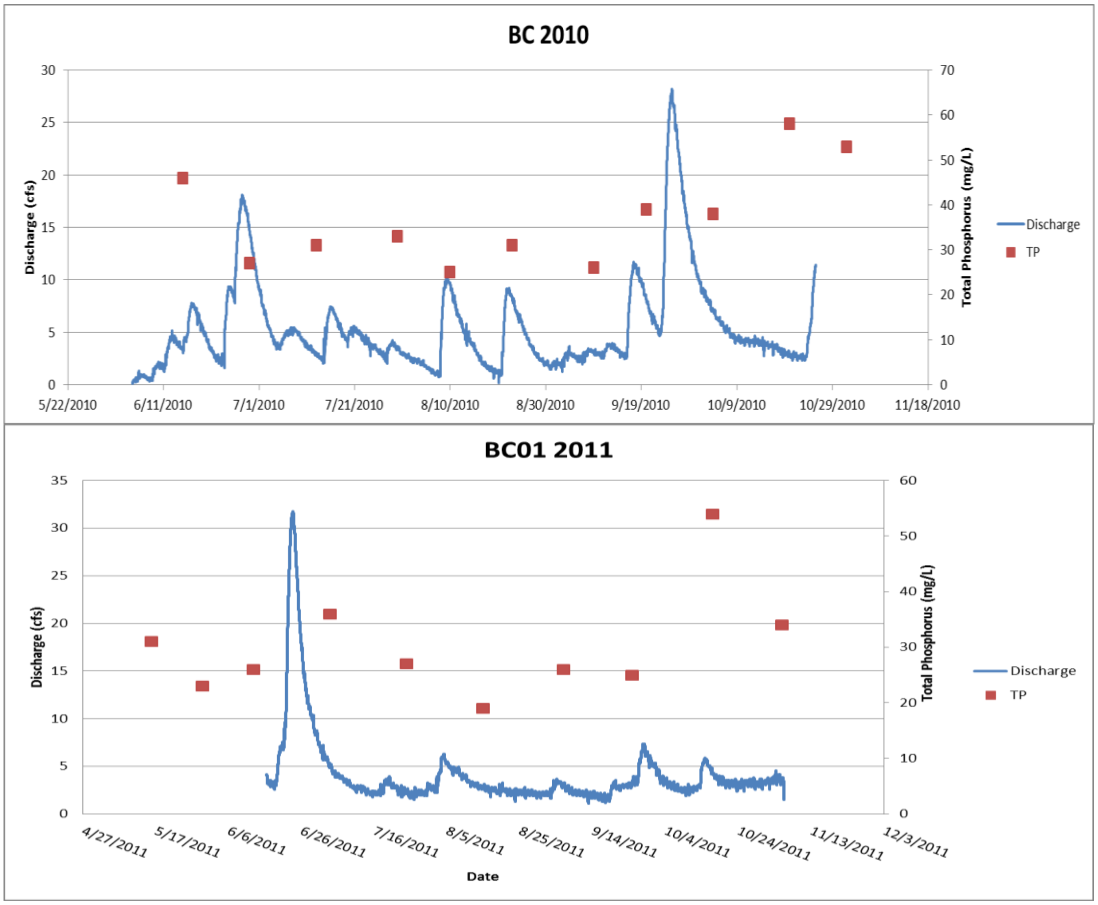


Figure 6. Discharge and TP at BC01 over time in 2010 and 2011.

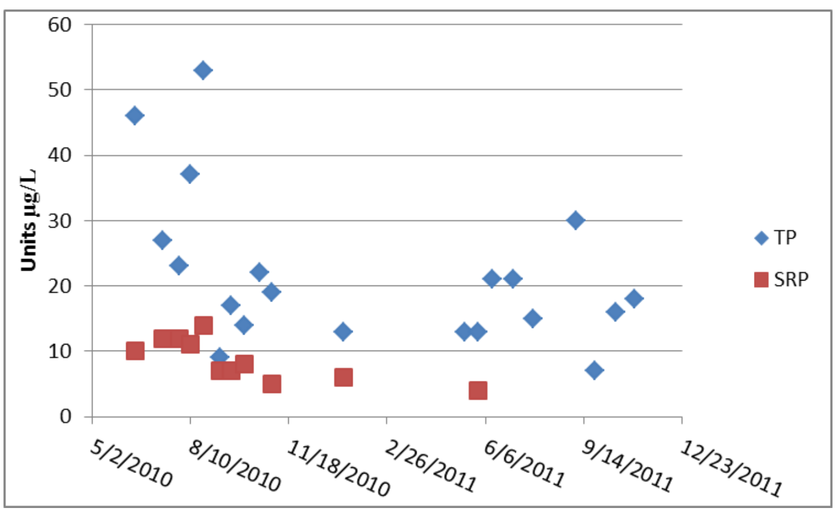


Figure 7. Total and soluble reactive phosphorus concentrations in samples collected at SC01 in 2010 and 2011.

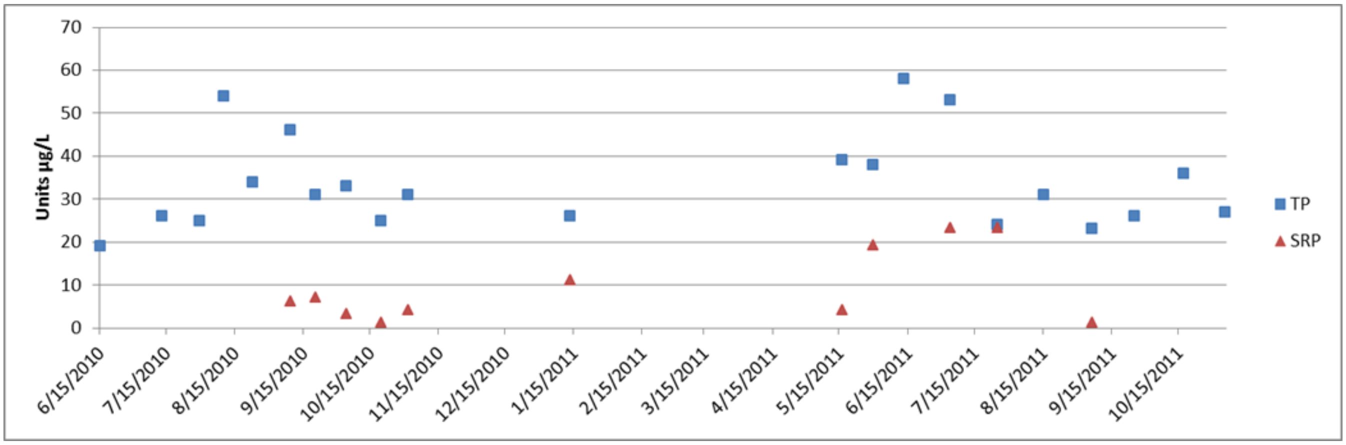


Figure 8. Total and soluble reactive phosphorus concentrations in samples collected at BC01 in 2010 and 2011.

NITROGEN

Nitrogen is another essential nutrient that is related to the growth of aquatic plants and algae (except for the blue-green species). It is second only to phosphorus as a key nutrient. Nitrogen is a major component of plant and animal tissue, and therefore organic matter and soil. Cultural sources of nitrogen are often directly related to land use practices including lawn and garden fertilizers, animal waste, and effluents from septic systems.

Nitrogen exists in minimal concentrations in Shabadock and Bear Creeks. The most common forms of nitrogen were measured in samples collected during 2010 which included ammonium (NH^{4+}), NO2+NO3-N, and organic nitrogen. Summing these forms yields total nitrogen (TN). Median concentrations of TN were 0.97 mg/L in BC01 and 0.93 mg/L in SC01 (Figure 9). Organic nitrogen was the most prevalent form of nitrogen measured at both sites. The median concentration at SC01 was 0.7 mg/L at and BC01 was .86 mg/L (Figure 10). Aquatic plants and algae can use all inorganic forms of nitrogen (NH^{4+}, NO_3^-, and NO_2^-). In a lake, if inorganic nitrogen exceeds 0.3 mg/L in spring, there is sufficient nitrogen to support algae blooms throughout the summer (Shaw et al., 2002). In Bear Lake, median concentrations of inorganic nitrogen were 0.17 and 0.11 for SC01 and BC01, respectively (Figure 11). Though not readily available for uptake by algae and aquatic plants, organic forms of nitrogen can become available to algae and plants following microbial decomposition.

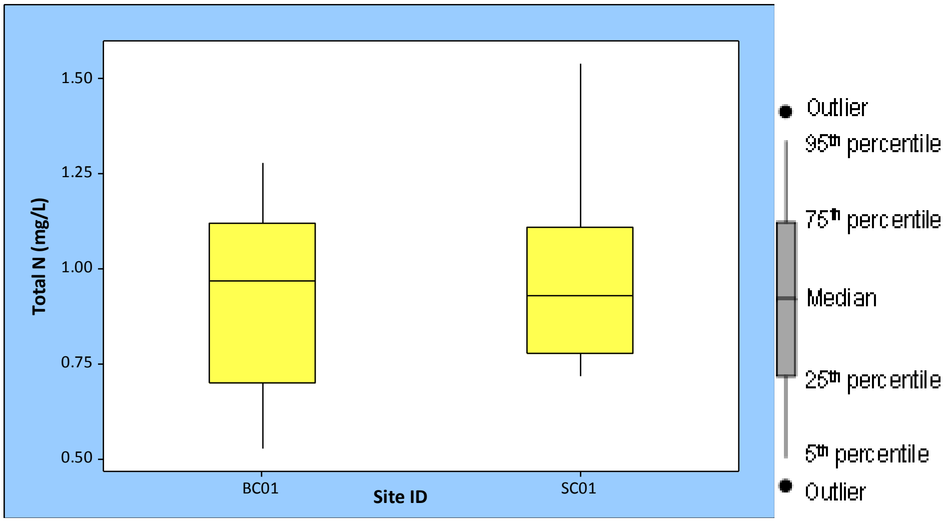


Figure 9. A box plot displaying the range in total nitrogen concentrations in BC01 and SC01 (May-Nov 2010 and 2011).

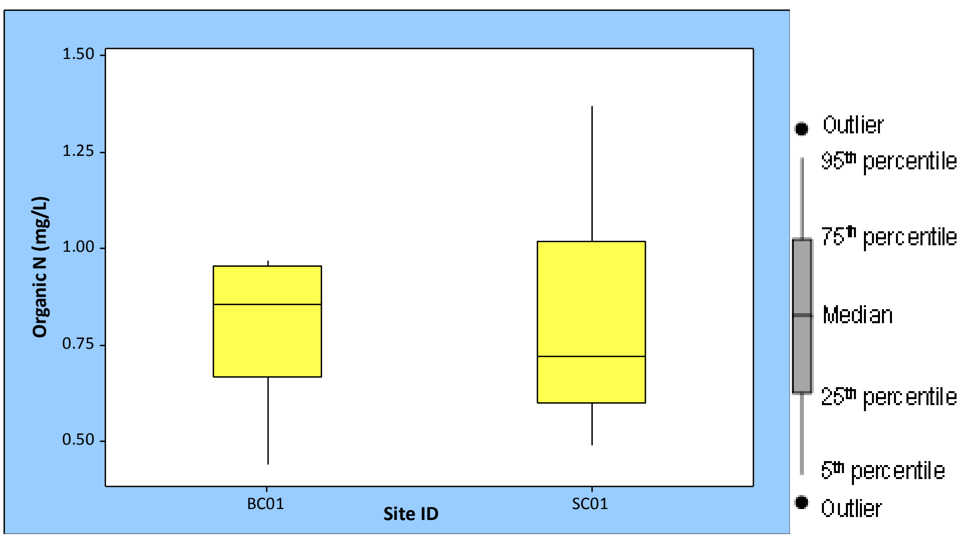
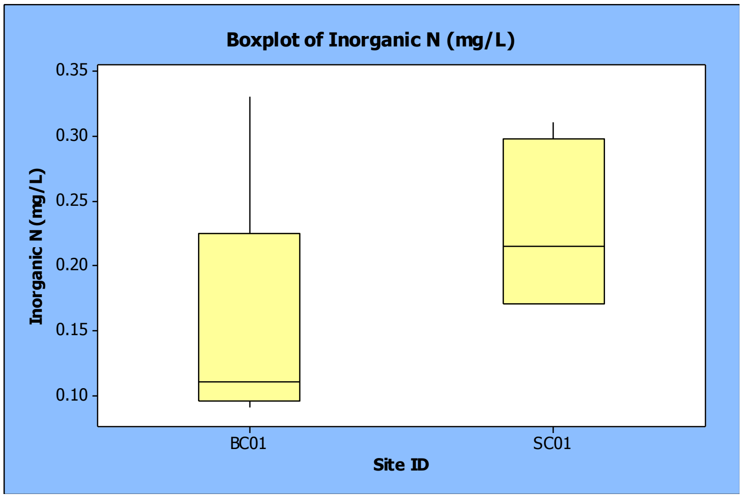


Figure 10. Box plot displaying the range of organic nitrogen concentrations measured in samples collected from BC01 and SC01 (May-Nov 2010 and 2011).



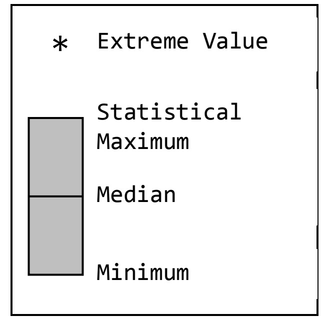


Figure 11. A box plot displaying the range in concentrations of inorganic nitrogen (mg/L) in samples collected from BC01 and SC01 (May-Nov 2010 and 2011).

Chloride

Although we are most interested in the movement of phosphorus to and from Bear Lake and its inflow and outflow streams, phosphorus has both natural and cultural sources so we often use other chemical analyses to help interpret the of phosphorus as it moves throughout the system. In Wisconsin, chloride is naturally found in low concentrations. Chloride is soluble and readily moves through the environment because it is not utilized by biota so therefore; elevated concentrations of chloride suggest an influence on water quality from human activities. In the Bear Lake watershed, the most common sources of chloride are road salts but septic systems and fertilizers may also be sources.

In Shabadock and Bear Creeks, all chloride concentrations were within normal background concentrations found in Forest County which is <3 mg/l (Shaw 2002). The maximum chloride concentration measured at any site was 1.6 mg/l at BC01 (Figure 12). (It should be noted that chloride data from 6/15/2010 was removed from the data set because it was determined that sampling error caused an unusually high measure of chloride and was therefore not representative of the water quality at SC01).

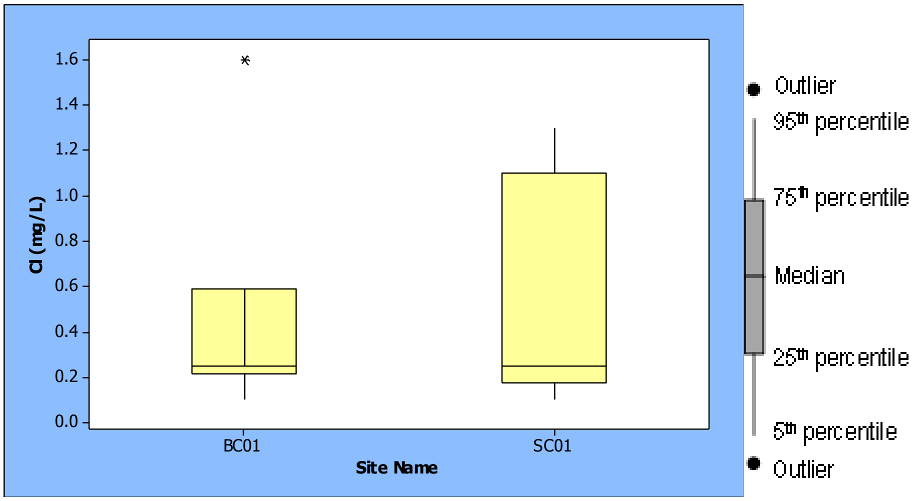


Figure 12. A box plot displaying the range in chloride concentrations (mg/L) measured in water samples collected at BC01 and SC01, 2010 and 2011.

Dissolved Oxygen and Temperature

Dissolved Oxygen (DO) and temperature concentrations were measured at the time of sample collection. The primary sources of DO to water include contact with the atmosphere and respiration of aquatic plants. Normally, DO concentrations increase with a decrease in water temperature because cooler water holds more oxygen. Water temperatures were generally much cooler at the inflow (3.5-19.0 C®) than the outflow (4.9-26.3 C®) (Figure 13). Conversely, DO concentrations were higher at the inflow (6.9-11.4 mg/L) than the outflow (2.27-10.89 mg/L) (Figure 14). In addition, the median DO concentrations at BC01 were lower than those at SC01. In addition to higher water temperatures, the outflow site also mixes with oxygen-reduced water from a wetland on the southern end of the lake. Wetlands have naturally low DO concentrations because of the large amount of decaying plant and animal materials and use of oxygen by bacteria to process these materials.

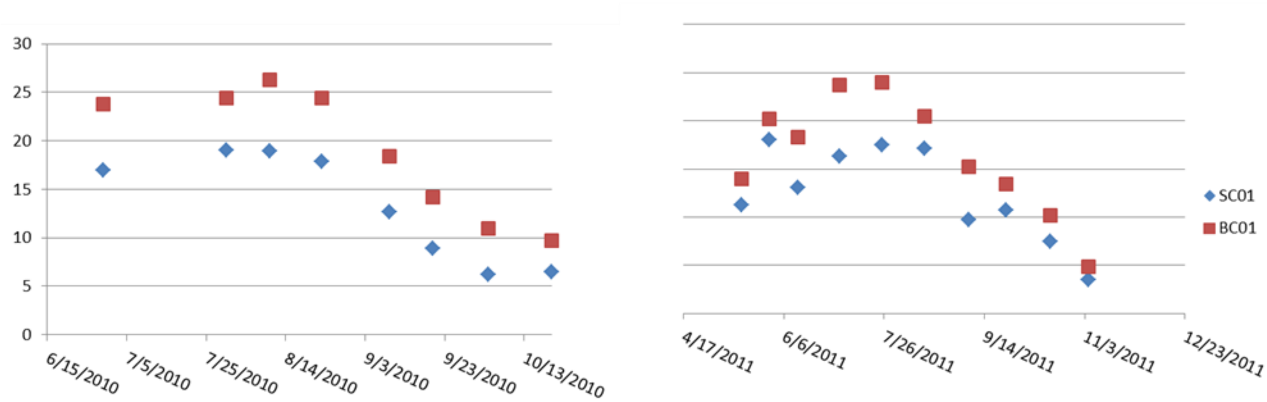


Figure 13. Temperature(C) measured at SC01 and BC01, 2010-11.

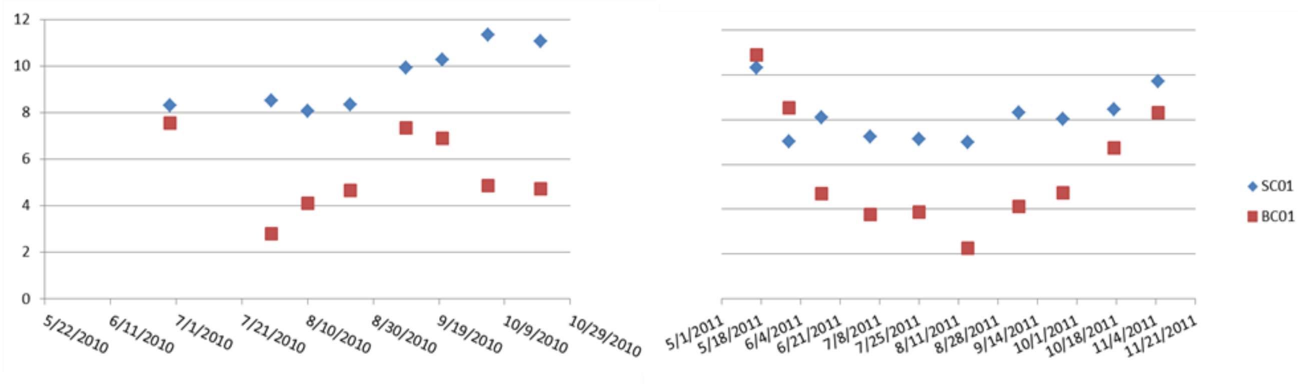


Figure 14. Dissolved oxygen concentrations (mg/L) measured at SC01 and BC01, 2010-11.

DISCHARGE AND STAGE DATA

Discharge (stream flow) and staff gauge measures (stream height) were collected beginning in spring 2010 through fall 2011 to develop rating curves. In total, eight measurements were taken at SC01 and 11 were taken at BC01. At SC01, flow volume ranged from 3.2-14.9 cfs. At BC01 flow volume ranged from 0.7-14.53 cfs. The rating curves were applied to the data from the pressure transducers that were deployed at SC01 and BC01 from June through November 2010 and 2011 to estimate discharge during this period (Appendix). This information was combined with water quality data to estimate nutrient loads entering Bear Lake from Shabadock Creek and leaving the lake through Bear Creek. These results are displayed and discussed at the end of this document.

GROUNDWATER DATA

Groundwater can be an integral part of the water budget in a lake (the amount of water entering and leaving a lake). This is the primary source of water to Shabadock Creek and Bear Lake during dry periods. In the summers of 2010 and 2011, temporary mini piezometers (small wells) were installed in the lakebed of Bear Lake to determine where groundwater enters and leaves the lake, and to acquire water samples for analysis. In 2010, a preliminary survey was conducted and four sites were sampled on the western and southern shores. A more complete survey was conducted in 2011 with 14 sites sampled on the eastern and western shores (Figure 15). Groundwater was entering the lake (upwelling) at 56% of the sites and no groundwater connection (no welling) was observed at 44% of the sites. No groundwater outflow was observed at any of the sites; most of the water is leaving Bear Lake through the Bear Creek outflow. Groundwater samples taken from the upwelling sites were tested in the field for pH, specific conductance, and temperature. Samples were analyzed in the WEAL lab for soluble reactive phosphorus (SRP), chloride (Cl), nitrate-nitrite (NO_2+NO_3-N), and ammonium (NH_4-N).

Variation in chemistry was observed for pH (ranging from 6.83 – 8.40). Less variation was observed for NO2+NO_3-N concentrations (ranging from 0.01 – 0.08mg/L), and ammonium (ranging from 0.01 – 0.74mg/L). Groundwater temperatures were similar to Bear Lake surface water temperatures, which suggest that the groundwater originates nearby. The close proximity to the origin of groundwater feeding Bear Lake requires special attention to shoreline practices that may affect groundwater, e.g. the use of fertilizers and location of septic systems, particularly on land adjacent to the upwelling sites.

Phosphorus concentrations were quite variable (ranging from 19 – 560 µg/L). Seventeen percent of the upwelling sites had phosphorus concentrations less than 25 µg/L. This would be considered background concentrations for the groundwater near Bear Lake. Half of the sampling sites had slightly elevated phosphorus concentrations (25 to 45 µg/L), and 22% had elevated concentrations greater than 45 µg/L. Two sites (2% of upwelling sites) had unusually high concentrations that were greater than 200 µg/L (Figure 16). The six sites with the high phosphorus concentrations (above 45 µg/L) are located near areas of development around Bear Lake. A few sites with elevated phosphorus concentrations were also located down gradient of the Bear Lake campground privies (Figure 17).

Chloride concentrations are naturally low in lakes in Forest County, making chloride in groundwater a good indicator of cultural influences such as road salt and septic systems. Sixty-one percent of upwelling sites tested for chloride had concentrations less than 1 mg/L, 33% had slightly elevated concentrations ranging from 1 -3 mg/L, and one site had an elevated chloride concentration of greater than 3 mg/L. Many of the sites with elevated phosphorus also had elevated chloride.

The USFS has installed new toilets that do not discharge to groundwater, but existing septic systems in areas upgradient of inflow sites will likely eventually discharge phosphorus to the lake. Septic systems remove some phosphorus, but unless specially designed, do not remove phosphorus. Siting septic drainfields further from the lake would reduce inputs to the lake. Other ways to reduce the phosphorus discharged through the septic systems would be to use laundry and dishwashing soaps that do not contain phosphorus.

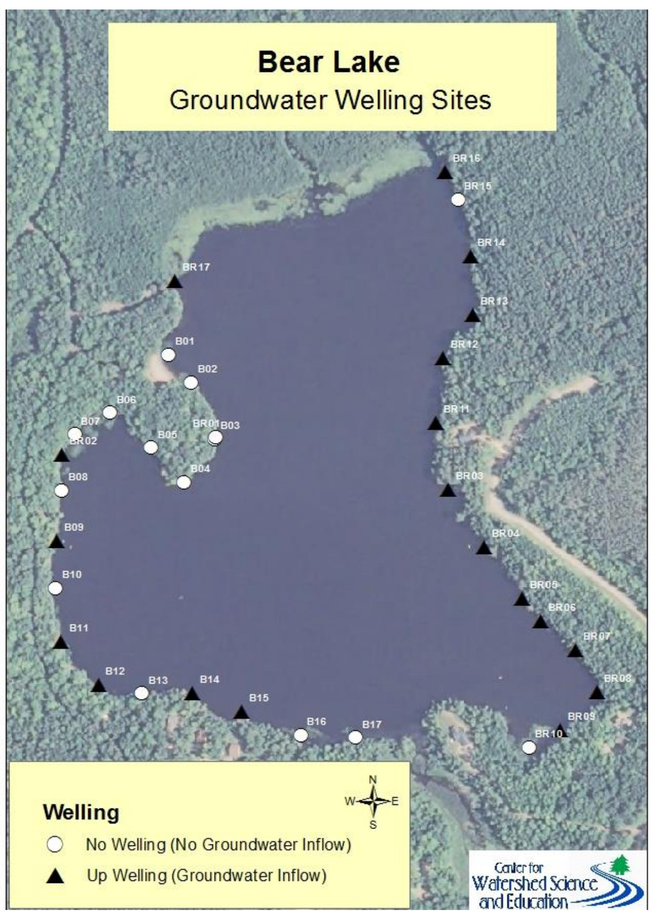


Figure 15. Location of groundwater welling sites at Bear Lake.

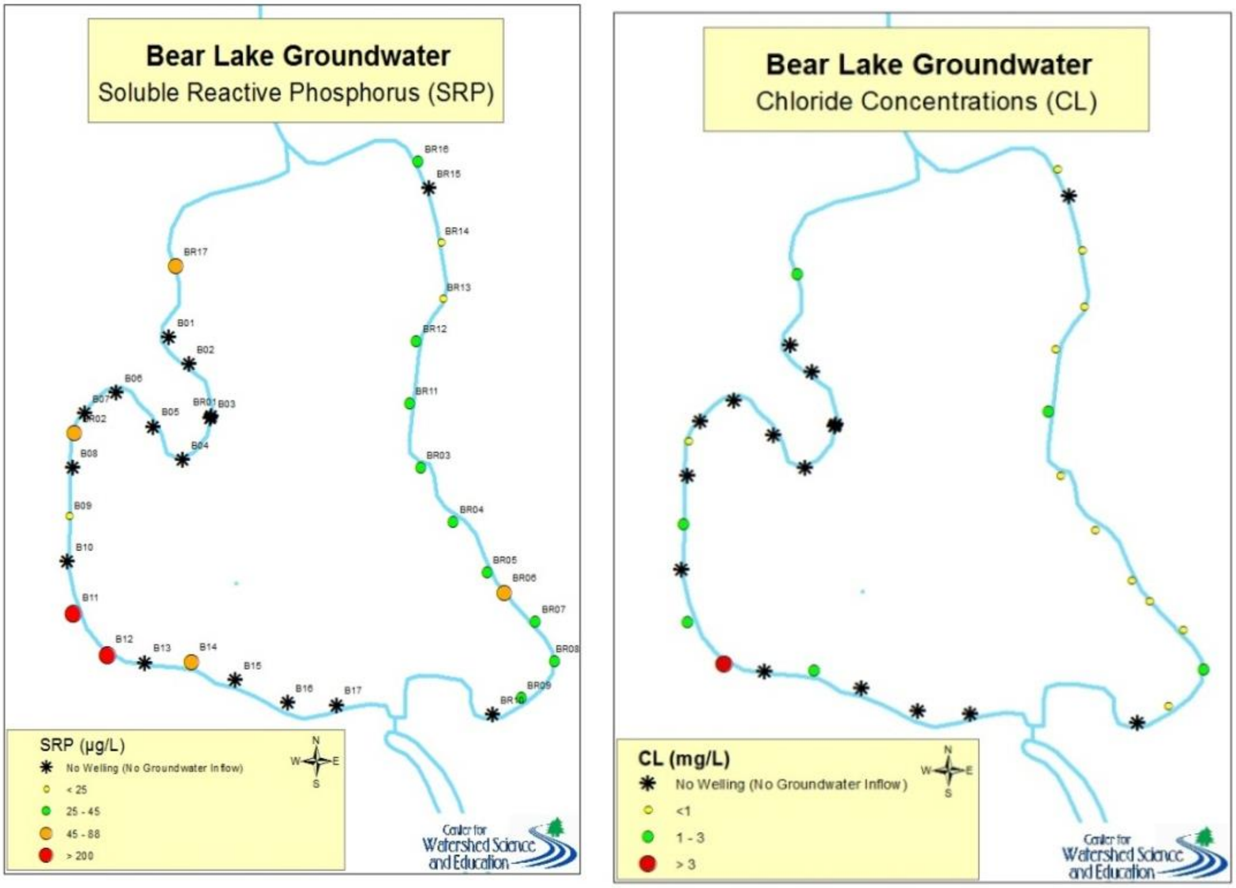


Figure 16. Soluble reactive phosphorus and chloride concentrations in groundwater samples collected from upwelling sites in Bear Lake.

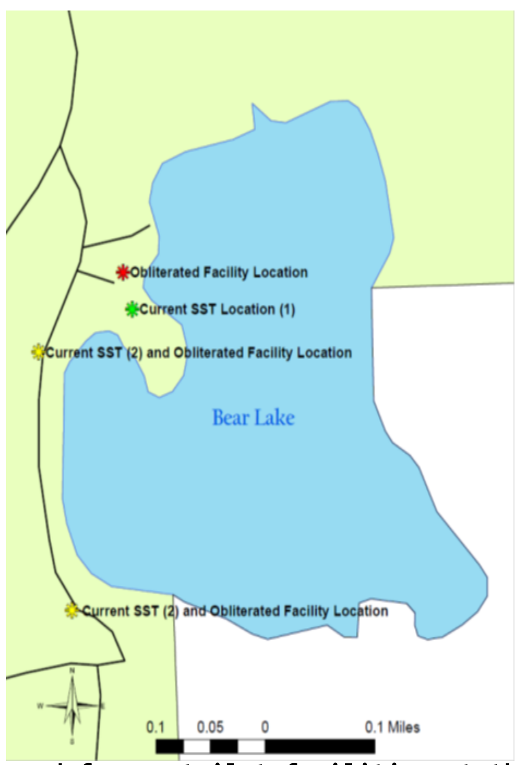


Figure 17. Location of current and former toilet facilities at the USFS campground.

LAKE WATER QUALITY

WATER CLARITY AND CHLOROPHYLL A

Water clarity is a measure of light penetration that is affected by algal growth, turbidity, and water color. These measurements can vary from month-to-month or day-to-day and sometimes even hourly. Variations can result from storms and wind, season, abundance of algae, sun angle, motor boat traffic, and some variability may be introduced by different people making the measurement. The south hole showed seasonal variability during both study years. The data show lower visibility during peak summer months, but higher clarity in earlier summer and fall. During the 2010 and 2011 sampling season, the median depth of water clarity was 3 feet (Figure 18). The north deep hole, only sampled during the 2010 season, had a median depth of 2.9 feet (Figure 19). Although both median measures indicate very poor clarity according to the water clarity index (Shaw 2002), brown staining from higher iron concentrations in Bear Lake are likely responsible for some of the reduced water clarity.

Chlorophyll *a* is related to algal concentrations therefore it varies seasonally and from year-to-year depending on the growing conditions for algae. Chlorophyll *a* is a substance produced by algae and when measured gives an idea of relative abundance of algal species within the lake (including blue- green algae). Consistent with elevated TP concentrations and decreased water clarity, chlorophyll *a* concentrations are typically highest in the month of August because temperatures and conditions are most favorable for algal growth. Plentiful phosphorus allows algae to increase in abundance.

Median chlorophyll *a* (chlor *a*) concentrations were 11 µg/L, the threshold necessary to classify the lake as eutrophic (Shaw et al. 2002). In 2010, the median concentration at BL01 was slightly below the threshold at 10.5 µg/L. For both years, BL02 had a median concentration slightly above the threshold at 11.5 µg/L (Figure 20).

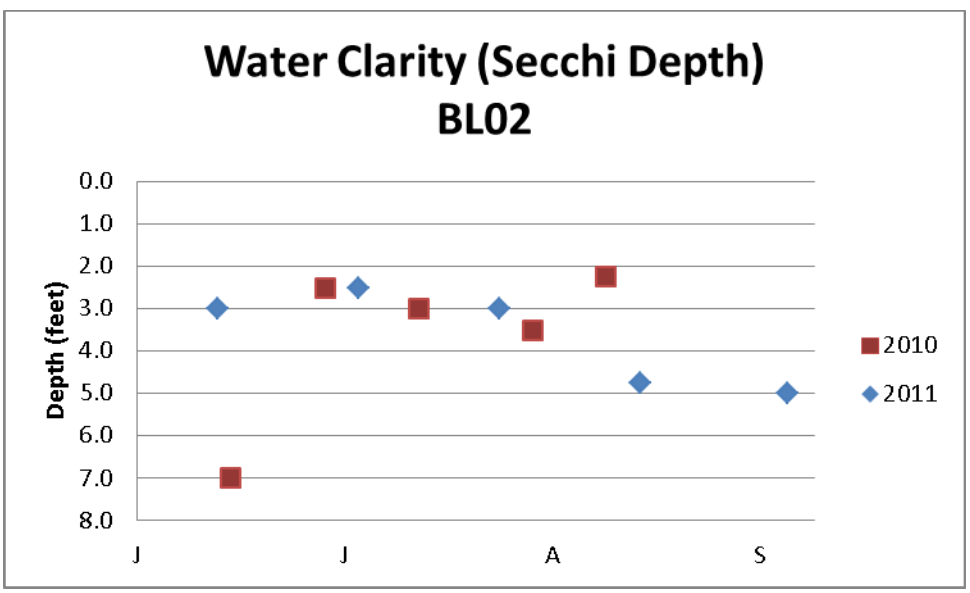


Figure 18. Secchi disc measurements (ft) at BL02, June – Sept. 2010 and 2011.

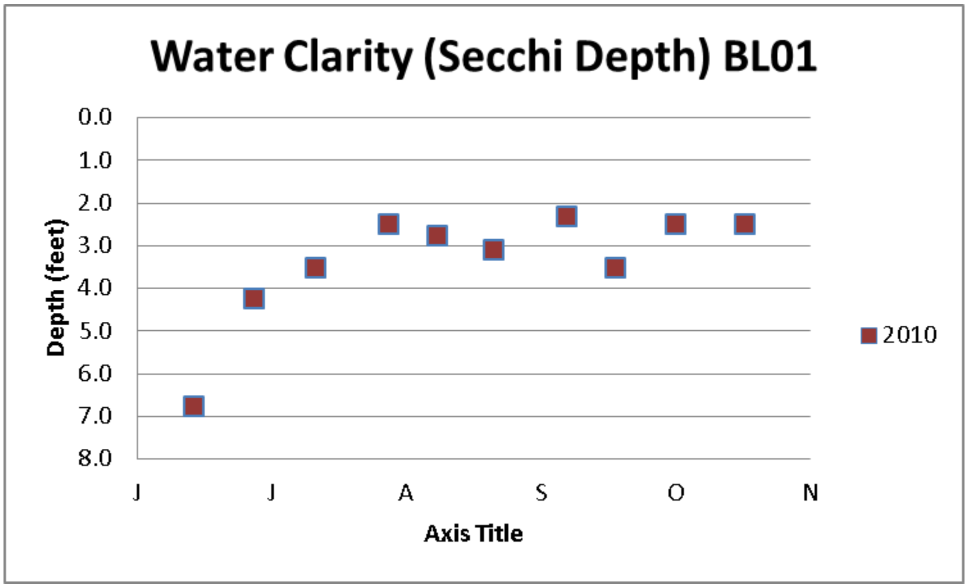


Figure 19. Secchi disc measurements at BL01, 2010.

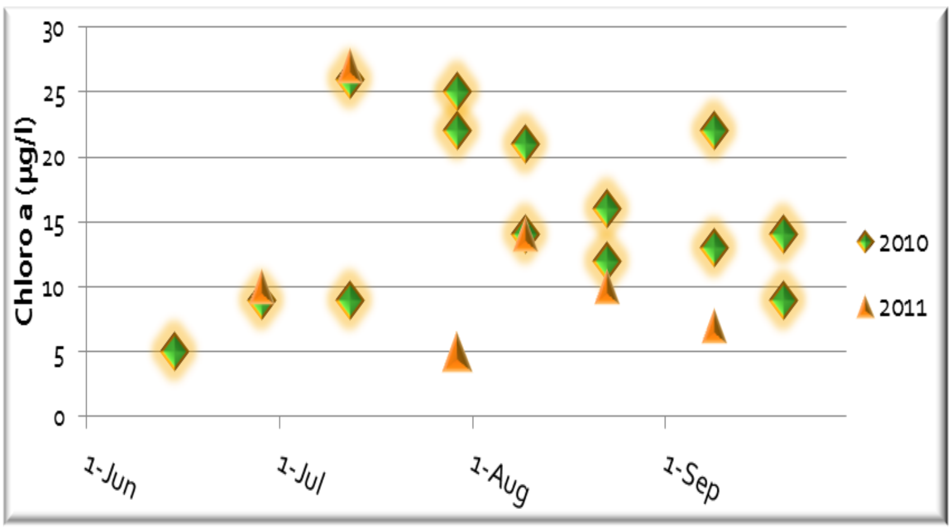


Figure 20. Chlorophyll a concentrations measured in samples collected from Bear Lake in 2010 and 2011.

Temperature and Dissolved Oxygen

Dissolved oxygen (DO) is an important measure in aquatic ecosystems because a majority of organisms in the water depends on oxygen to survive. Oxygen is dissolved into the water through diffusion from the air, which is increased by wind and wave action. During the summer, algae and aquatic plants also produce oxygen through photosynthesis. Typically, the predominant mechanism that removes dissolved oxygen from lake water is bacterial use in the decomposition of plants, animals, and sediment. Heavy nutrient loads to the lake can lead to increases in algae and aquatic plants. The algae and aquatic plants produce oxygen while photosynthesizing, but as these plants and algae die, they begin to decay and oxygen is consumed by bacteria processing this dead material. Some forms of iron, copper, and other reduced metals carried by groundwater can also consume oxygen when the groundwater discharges to the lake and mixes with the oxygen-rich lake water.

Dissolved oxygen concentrations are also affected by temperature; water can dissolve greater amounts of oxygen and other gases at colder temperatures than at warmer temperatures. In a lake, the water temperature changes throughout the year and may vary with depth. During winter and summer when lakes stratify, the amount of dissolved oxygen at a particular depth is often finite because it is not replaced by shallower oxygen-rich water near the surface. This can limit the amount of oxygen available to aquatic animals. During periods where the oxygen concentrations are low near the sediment, phosphorus can be released into the water column, providing food for algae. Bear Lake typically mixes twice a year in spring and fall and stratifies over the summer (Figures 21 and 22).

In 2010 at BL01 and BL02, temperature readings indicate fairly strong stratification through the summer months with temperatures steadily decreasing with depth. As fall approached, the water temperatures cooled causing mixing of the lake water from top to bottom, resulting in uniform temperatures throughout the lake.

In 2011 at BL02, the temperature readings indicate a strong stratification as well (Figure 23). The temperature profiles show that the lake was stratified by the first sample period, June 13 and was still stratified at the last 2011 temperature profile sample, September 6.

Instruments were placed in the lake near the deep hole and were set to record temperatures on a routine basis at depths of approximately 3, 8, 13, 18, and 21 feet (
Figure 24). These thermistors suggested very little mixing during the summer months but as fall approached a break in stratification was measured as the temperatures at BL02 became uniform (Figure 25, Figure 26).

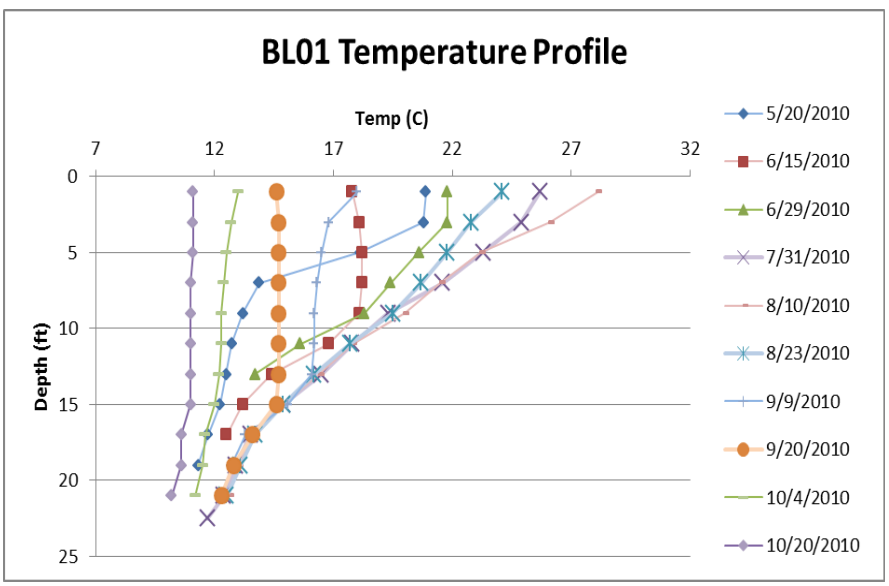


Figure 21. Bear Lake Temperature (C) profiles from 5/20/2010-10/20/2010 at BL01.

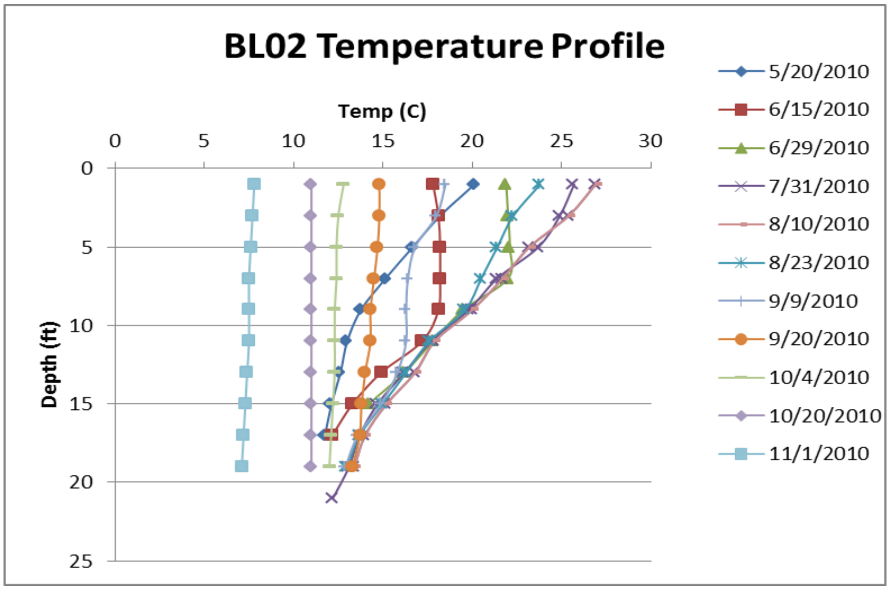


Figure 22. Bear Lake Temperature profiles from 5/20/2010-10/20/2010 at BL02.

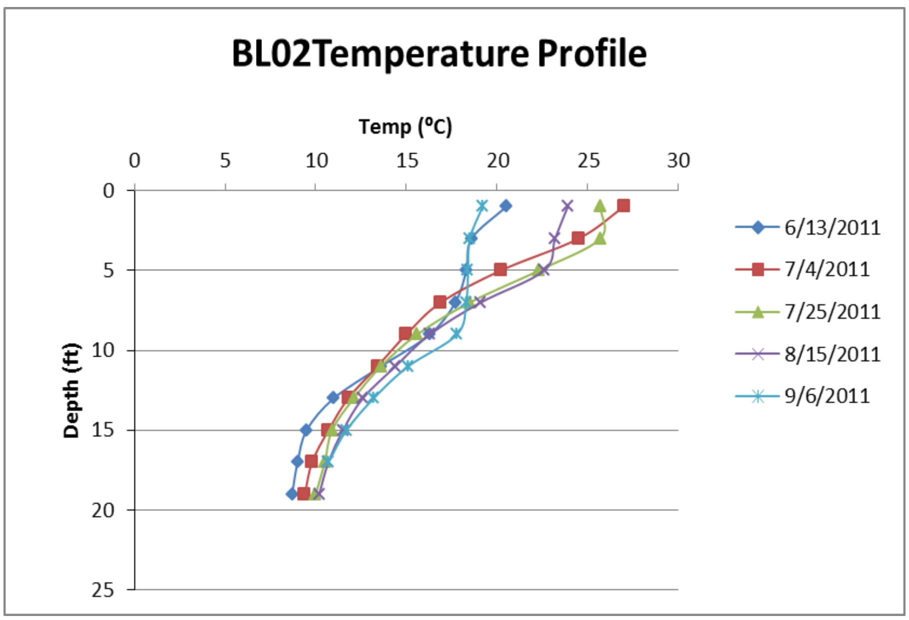


Figure 23. Bear Lake Temperature (C) profiles from 6/13/2011-9/6/2011 at BL02.

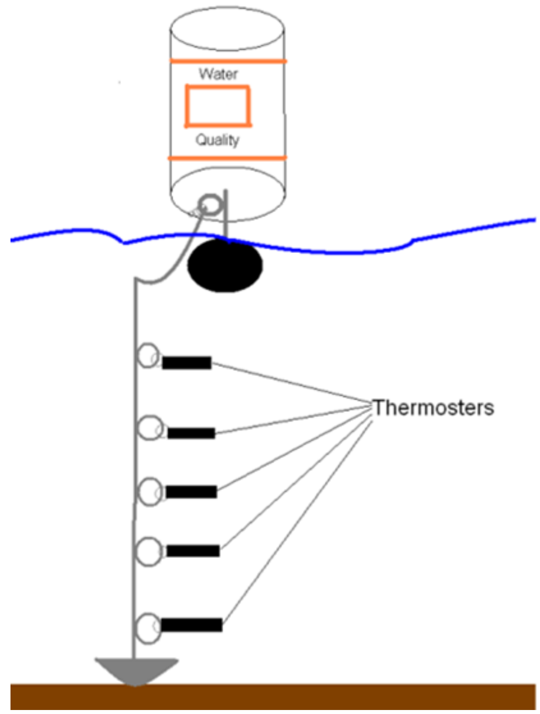


Figure 24. Diagram depicting how the thermistors were deployed at BL02 (diagram is not to scale).

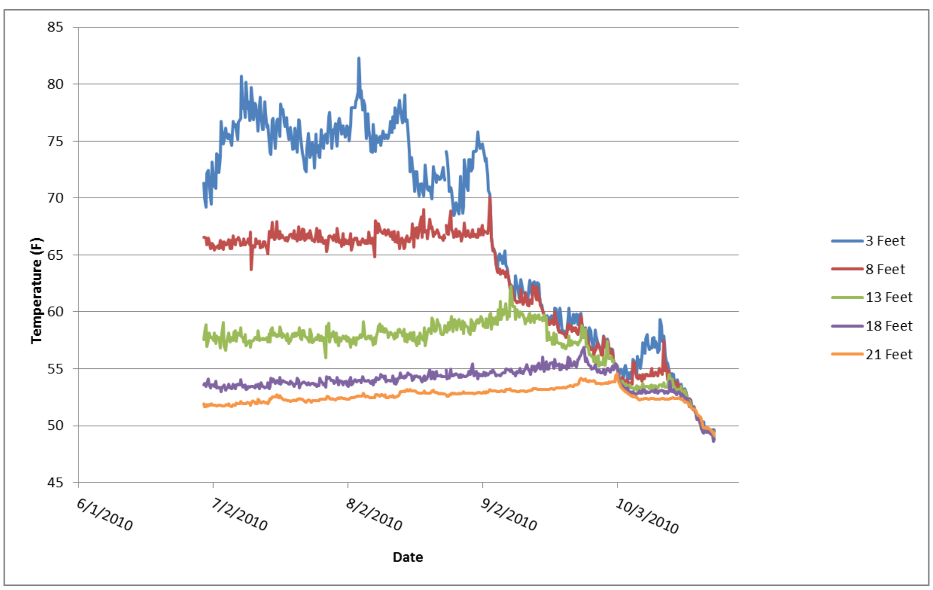


Figure 25. BL02 Temperature (F) collected by thermistors at various depths over time in 2010.

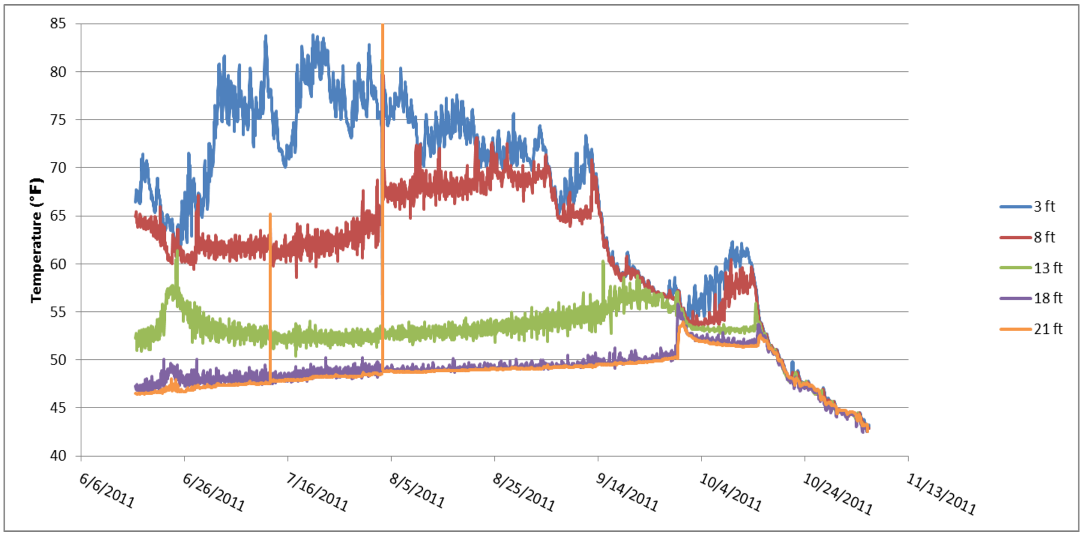


Figure 26. BL02 Temperature (F) collected at various depths over time in 2011.

Dissolved oxygen concentrations followed a pattern similar to temperature in the summer months at both sites in 2010, and at BL02 in 2011 (Figures 27-29). In 2010, both Bear Lake sites had a relatively high DO concentration near the surface and a steady decrease with depth. However, with the cooling temperatures and mixing (overturn) in the fall the DO concentrations became rather uniform in October and November. The DO profile concentrations do not appear to become uniform (mixed) in 2011 but that is likely a function of the collecting times. At the time of the last collection, September 6, the lake was stratified so mixing had not yet occurred. However, a review of Figure 26 shows that the lake did become mixed later in the fall (early October), and this likely helped mix the oxygen concentrations by depth in a manner similar to that seen in 2010.

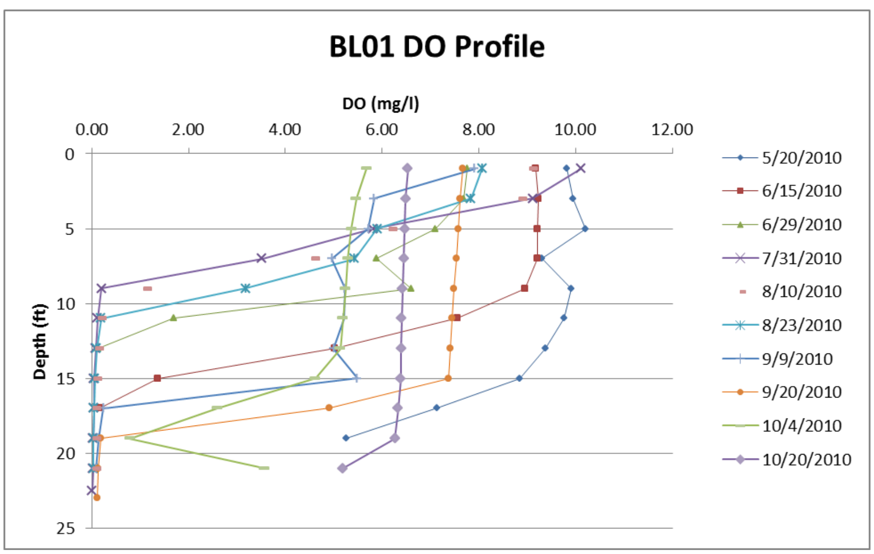


Figure 27. Dissolved oxygen(mg/L)with depth in Bear Lake, Site BL01, 5/20/2010-10/20/2010.

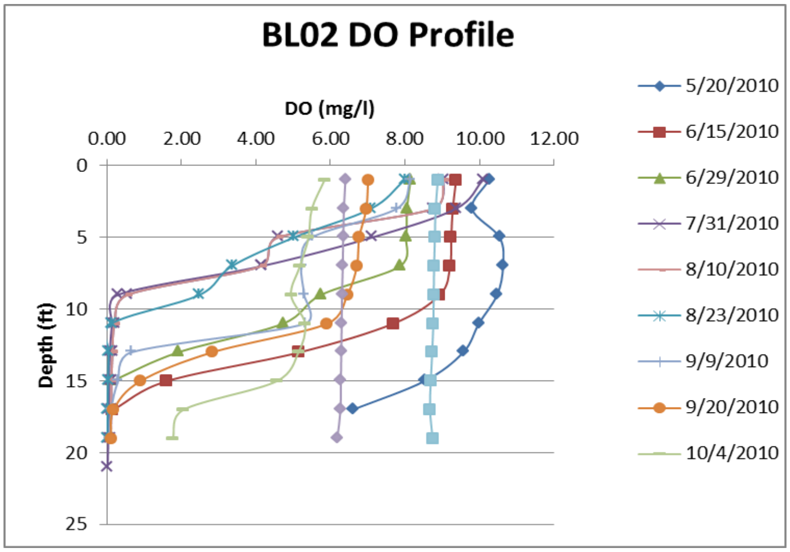


Figure 28. Dissolved oxygen (mg/L) with depth in Bear Lake, Site BL02, 5/20/2010-11/1/2010.

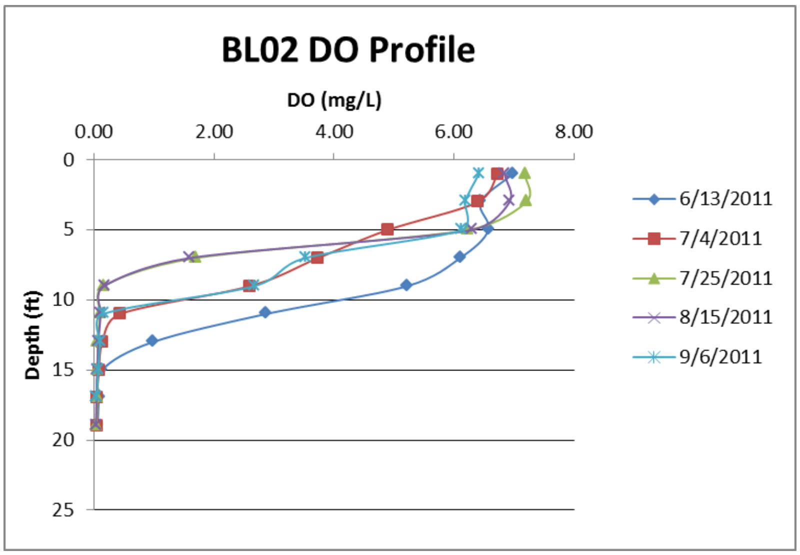


Figure 29. Dissolved oxygen (mg/L) in Bear Lake, Site BL02, 6/13/2011-9/6/2011.

Phosphorus Loading to Bear Lake

Nutrients are the primary fuel for algae and aquatic plant growth in lakes. As an essential nutrient, phosphorus is present naturally throughout the watershed in soil, plants, and animals. It is transferred to the lake by the erosion of soil and runoff from sources such as animal waste, fertilizers, effluent from septic systems, and wetlands.

The most common mechanism for the transport of phosphorus from the land to the water is through surface runoff of phosphorus attached to soil/sediment particles. Phosphorus can also travel to Bear Lake in a dissolved form with inflow from Shabadock Creek or groundwater. Once in Bear Lake, a portion of the phosphorus becomes part of the aquatic system in the form of plant and animal tissue, and sediment. The phosphorus continues to cycle within the system, and although some may leave with the outflowing water, after sources in the watershed are reduced it can take time to reduce it in the lake.

Phosphorus also travels to Bear Lake via groundwater. In the Bear Lake watershed, the natural phosphorus sources to groundwater may include contact with wetlands. In situations where there is a continuous phosphorus source (e.g. septic systems), it can infiltrate into the groundwater. Once the soil's capacity to hold phosphorus is exceeded, phosphorus movement to groundwater can readily occur so as septic drain-fields age, the systems can deliver more phosphorus to the groundwater.

Higher phosphorus concentrations can lead to increased aquatic plant and algal production, lowered water clarity, and oxygen reduction from decomposition of plants and algae. Phosphorus concentrations vary over time and seasonally. The WDNR standard for total phosphorus in deep drainage lakes like Bear Lake is 30 µg/L (NR102, 2010). Above these concentrations, deep drainage lakes experience a shift in biota and tend to have more frequent algae blooms and/ or increased aquatic plant growth (Shaw et al., 2002). In Bear Lake, the median total phosphorus (TP) concentrations were near 30µg/L during 2010 and 2011 . BL01 and BL02 slightly exceeded this threshold with median concentrations of 32 and 30 µg/l, respectively (Figure 30). BL02a exhibited a higher median TP concentration of 116 µg/L but is not held to the same standard because it was collected near the bottom of the lake (Table 2). This measure was taken to observe the sediment release of phosphorus during the summer when the lake was stratified.

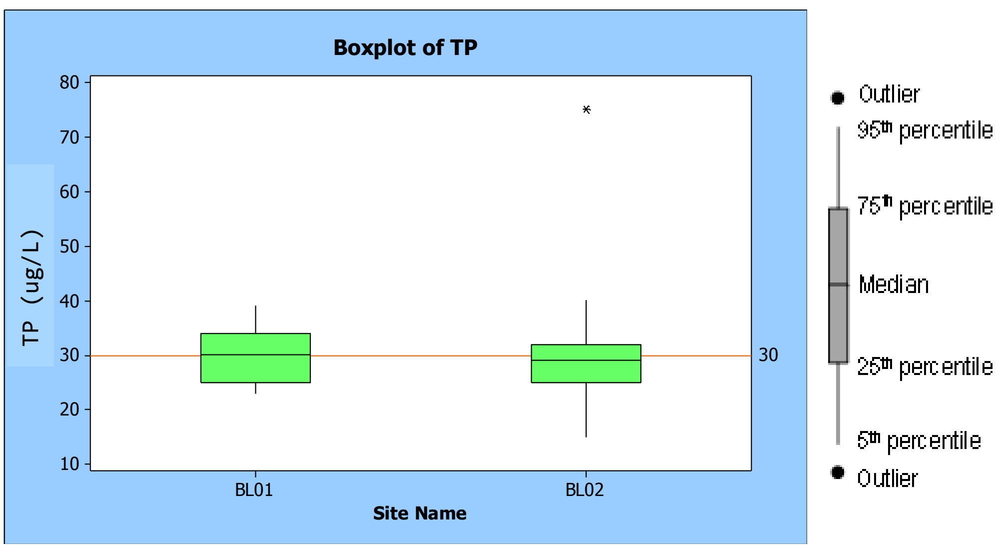


Figure 30. Boxplots showing the range of total phosphorus concentrations (ug/L) measured at the lake sampling sites during summer months [June-September 15th] in 2010 and 2011. The horizontal line represents the WDNR standard of 30µg/l.

Table 2. Total Phosphorus Data by season for Bear Lake (2010 and 2011).

Total Phosphorus Concentrations (µg/L)				
	Spring and Fall Overturn (2010 and 2011)	Summer 2010	Summer 2011	Deep Hole Hypolimnetic (Summer 2010)
Min	47	25	15	27
Median	57.5	30	25	116
Max	67	75	30	282

The phosphorus data collected from the various sources were estimated as loads so that they could be compared to one another. These loads were calculated by multiplying median phosphorus concentrations by estimated annual volume of water. The greatest phosphorus load to Bear Lake was from Shabadock Creek. Because the watershed upstream of the Shabadock Creek sampling site is predominantly forested, these sources of phosphorus would be considered natural and there is little that can be done to reduce them. Near shore runoff and internal load also contribute to the phosphorus budget for Bear Lake. A portion of these contributions may be controlled through alterations of near shore land management practices. Groundwater contributes approximately 10% of the phosphorus load to the lake. The groundwater chemistry suggested that some of this phosphorus is natural but some may reflect impacts from septic systems (Table 3, Figure 31). Based on the phosphorus budget, Bear Lake does not appear to be a phosphorus sink.

Table 3. Estimated annual total phosphorus loads to and from Bear Lake.

Total Phosphorus (pounds per year)	
Phosphorus Inputs to Bear Lake	
Shabadock Creek	63,900
Runoff/Internal Load	33,500
Groundwater	10,350
Phosphorus Export from Bear Lake	
Bear Creek	107,760

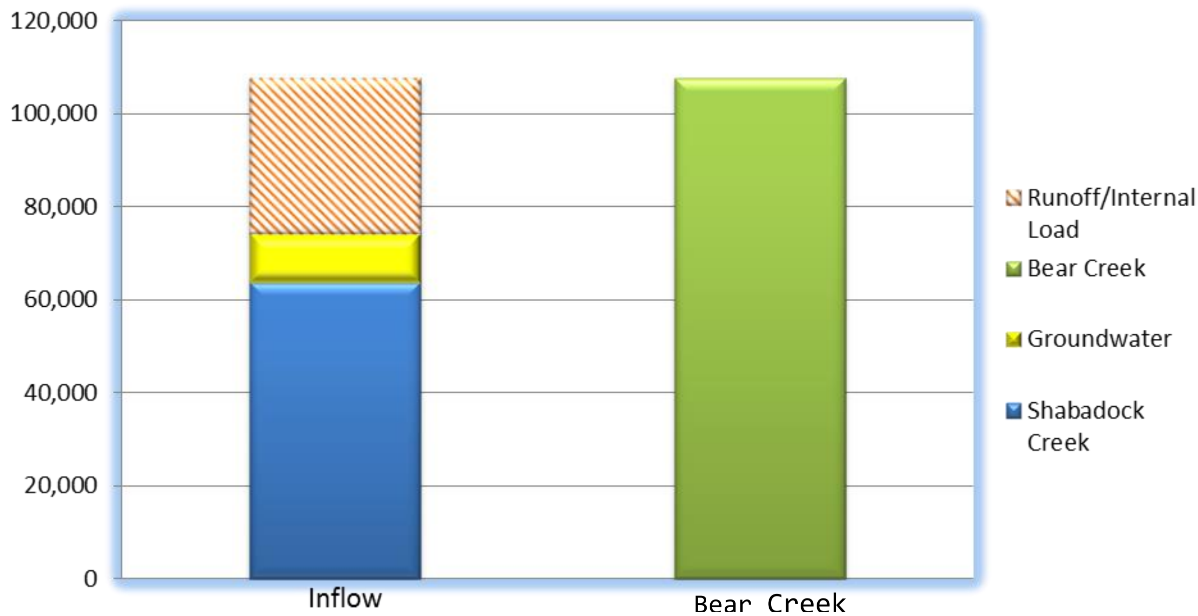


Figure 31. Estimated loads of total phosphorus (pounds).

ROLE OF RUSTY CRAYFISH

Crayfish are common to Wisconsin's aquatic ecosystems. Native crayfish tend to be smaller in size and have different feeding habits than their larger introduced cousin, the rusty crayfish. The invasive species rusty crayfish (*Orconectes rusticus)* was abundant in Bear Lake during 2010 and 2011 (date of introduction is not known). The size of the population has had a profound impact on the lake's ecosystem and particularly the aquatic plant community. The crayfish destroy native aquatic plants when feeding; the nutrients that would normally be tied up in plant tissue are then available for phytoplankton (algal species) to use. In addition, rusty crayfish preferentially feed on filamentous green algae species rather than blue-green species; this leads to more abundant blue green algae (Dorn and Wojdak 2004). During 2011, shoreland residents trapped and removed rusty crayfish using minnow traps.

The lack of aquatic plants in Bear Lake was observed in an aquatic plant survey conducted by the Wisconsin Department of Natural Resources with assistance by members of the Bear Lake Homeowners Association. For the most part, the lakebed lacked plants and only three submergent species were observed. They included coontail (*Ceratophyllum demersum*), common waterweed (*Elodea Canadensis*), and large leaf pondweed (*Potamogeton amplifolius*).

A fishery survey conducted in 2010 by the Wisconsin Department of Natural Resources fishery biologists revealed a fishery that was well balanced and comparable to earlier surveys. The most abundant game fish were largemouth bass, with some northern pike and walleyes. The most abundant pinfish were bluegill, crappie, perch, and rock bass. Many of these species consume crayfish and are often used as biological controls for rusty crayfish.

The Algal Community

Different groups and individual taxa of algae respond differently to seasonal fluxes in temperature, oxygen, and nutrients. The types of algae present, their relative abundance, and the dynamics of the algal community over time can provide insights into trophic status and might suggest possible remediation strategies or might provide evidence that watershed-level control of nutrient inputs is having some effect. Most aquatic algal communities are limited by phosphorus and the timing and point of origin around phosphorus availability usually determines when, and what algae will bloom.

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

There are nine or more major groups or phyla of algae. Each group produces its own unique set of photosynthetic pigments and each group responds differently to changing environmental conditions. Seasonal changes in the composition of the algal community in Bear Lake were traced via changes in the relative abundance of algae at the genus and phylum level. Samples were collected at the same time other water quality measurements were taken in Bear Lake.

Algae, being photosynthetic, are considered primary producers in aquatic food webs (along with macrophyte vegetation). They are responsible for capturing solar energy via their photosynthetic pigments and using that trapped energy to convert inorganic carbon dioxide into organic sugars. These sugars store some of the captured solar energy in their chemical bonds. The algae use the sugars to make other new organic matter (proteins, carbohydrates, nucleic acids, lipids) as they grow and divide. Consumers and decomposers also use these sugars for energy and recycle much of the other organic matter as well. Algae are important components of the aquatic food web since many zooplankton (microscopic animals) as well as many larger consumers (snails, planktivorous fishes) have a diet based largely on algae.

The algal community composition in Bear Lake was typical of similar regional lakes and largely unremarkable except for a somewhat heavier presence of blue-green algae (phylum Cyanobacteria). The algal community also displayed a seasonal pattern of algal composition that is more common in moderately to heavily eutrophied (nutrient-enriched) lakes than less nutrient-enriched waters. In 2010, there were 40 algal genera from six algal phyla identified during the counting process in Bear Lake (Table 4). Thirty-four of the 40 taxa from Bear Lake in 2010 were from three phyla (8-Cyanobacteria, 17-Chlorophyta, and 9-Ochrophyta) (Figures 32, 34, and 35). The Bear Lake algal community counts in 2011 showed 35 genera from the same six phyla, most of them (>80%) were found in both years Tables4 and 5). Thirty of the 35 taxa from Bear Lake in 2011 were from the three dominant phyla (6-Cyanobacteria, 13-Chlorophyta, and 11-Ochrophyta (Figure 33, 34, and). These are the dominant groups in most temperate zone lakes, especially those with moderate eutrophication, and they accounted for ca. 85% of all cells counted, regardless of sample date in 2010 (Table 4). In 2011, these three groups were even more dominant, accounting for ca. 95% of all cells counted, regardless of sample date (Table 5).

An often-misunderstood aspect of aquatic biology is the concept of net growth rate. Net growth rates of algae are determined by the difference between growth (production of new algae via asexual and sexual reproduction) and death (consumption, parasitism, natural death). Algae differ in their digestibility (shape, size, production of sticky mucilage) and nutrient value (proteins, lipids, carbohydrates) to consumers. Consequently, some genera are preferentially removed from the community by predation while others are largely ignored by consumers and continue to expand their biomass during the growing season. The algae present at any point in time are frequently based more on what hasn't been eaten than what is growing the fastest. It's often these "not eaten" algal taxa, especially the blue-green algae (phylum Cyanobacteria) that become persistence bloom formers in ever earlier and longer cycles.

The microbial decomposition loop (detritivorous) is driven largely by the algae. It is in the sediments that bacterial consumption of the dead algae can reduce oxygen content to anoxic levels setting the stage for fish kills. The seasonal pattern typical of lakes like Bear Lake is one of spring and summer algal growth (fed by nutrients either input or re-suspended from the sediments); fall and winter decomposition in the sediments (converting organic matter to inorganic nutrients again); and re-suspension of nutrients into the water column during spring and fall overturn. If there is a flux of nutrients in the fall, it's possible that more algae will survive beneath the ice. This can lead to increasing larger standing crops of undesirable algal taxa.

Table 4. Algal Phyla (%) from Bear Lake, Forest County, WI, 2010, by date.

	SAMPLE DATE												
PHYLUM	05/20	06/15	06/29	07/13	07/30	08/10	08/23	09/09	09/20	10/04	10/20	11/01	AVG.
Cyanobacteria	22	26	19	34	52	46	38	31	41	53	29	31	**35**
Chlorophyta	31	41	57	26	17	33	48	28	21	32	48	50	**36**
Ochrophyta	13	22	11	27	9	10	7	15	8	14	18	11	**14**
Dinophyta	7	5	3	10	3	6	2	4	9	1	2	3	**5**
Euglenophyta	9	3	5	2	7	2	0	6	11	0	0	2	**4**
Cryptophyta	18	3	5	1	12	3	5	16	10	0	3	3	**7**
	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 5. Algal Phyla (%) from Bear Lake, Forest County, WI, 2011, by date.

	SAMPLE DATE											
PHYLUM	04/30	05/16	05/30	06/13	07/04	07/25	08/15	09/07	09/25	10/17	11/05	AVG.
Cyanobacteria	29	22	35	42	48	47	40	49	52	47	55	**42.4**
Chlorophyta	36	44	48	37	32	36	30	31	27	20	14	**32.3**
Ochrophyta	31	29	15	18	15	15	21	16	19	26	25	**20.9**
Dinophyta	1	0	1	0	0	0	2	0	0	2	1	**0.6**
Euglenophyta	1	2	0	0	2	0	5	2	1	0	1	**1.3**
Cryptophyta	2	3	1	3	3	2	2	2	1	5	4	**2.5**
	100	100	100	100	100	100	100	100	100	100	100	100.0

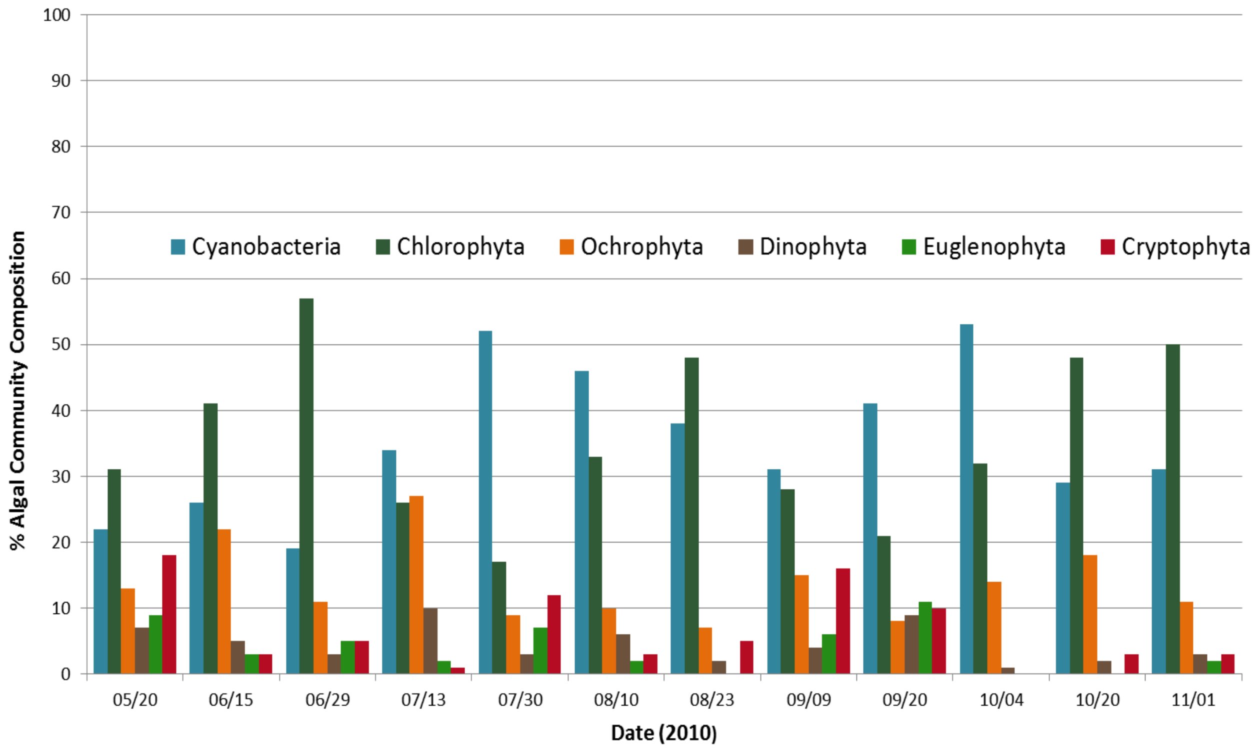


Figure 32. Abundance (%) of algal phyla, Bear Lake, Forest County, 2010, by date.

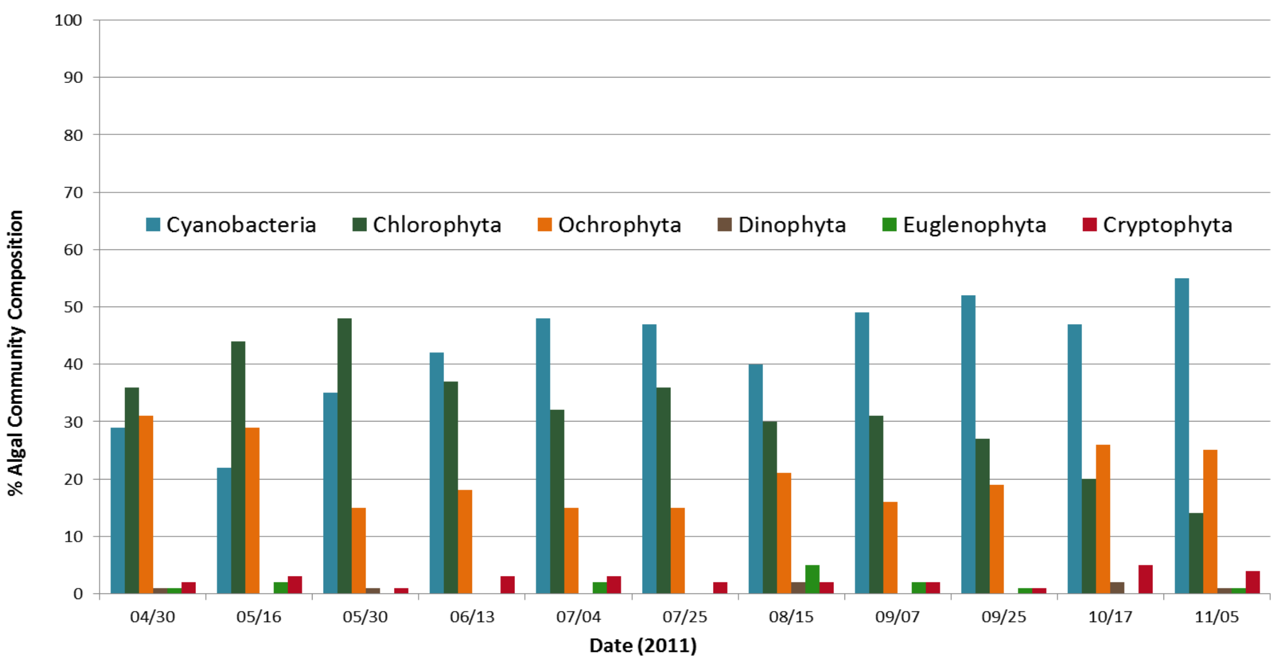


Figure 33. Abundance (%) of algal phyla, Bear Lake, Forest County, 2011, by date.

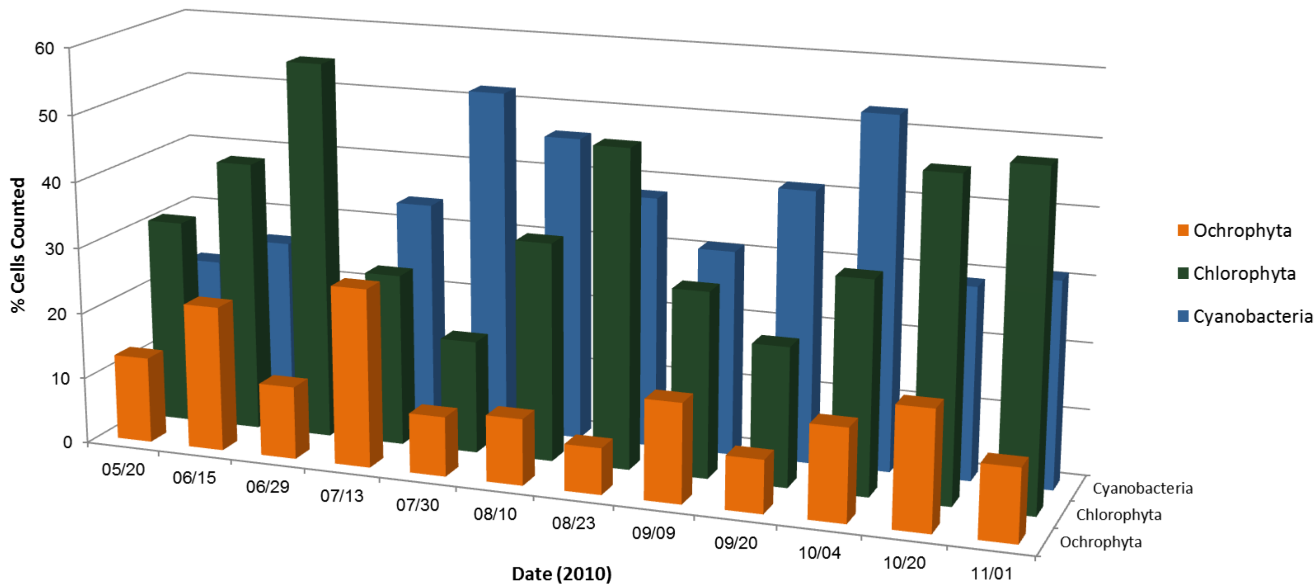


Figure 34. Three most common algae phyla (%), Bear Lake, Forest County, 2010, by date.

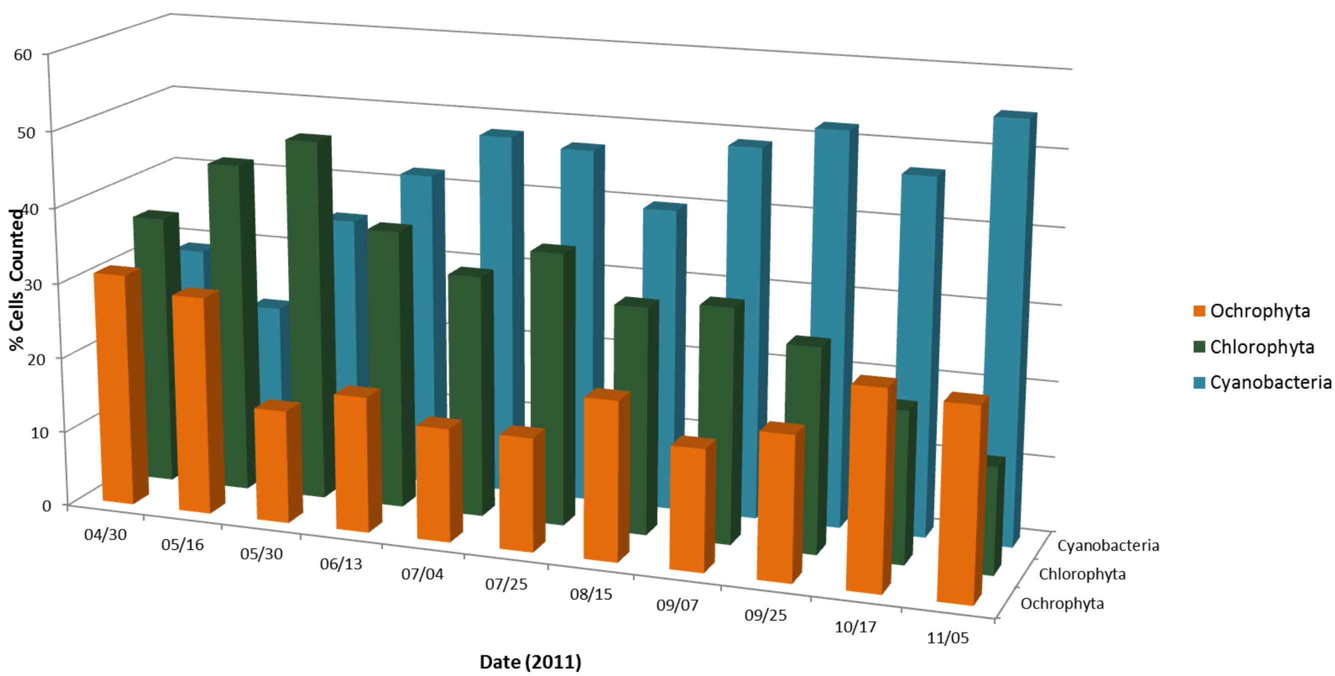


Figure 35. Three most common algae phyla (%), Bear Lake, Forest County, 2011, by date.

Cyanobacteria

The Cyanobacteria (or Blue-Green Algae) are prokaryotic (bacteria-like) organisms with wide metabolic and ecological tolerances. They are also largely unpalatable and generally avoided by consumers like zooplankton and planktivorous fishes.

There were eight cyanobacterial taxa present in 2010 (Table 4), and six were common or dominant. *Oscillatoria* (filamentous) and *Woronichinia* (gelatinous colony) were present in every sample and were dominant organisms throughout the sampling period. Four other blue-greens: *Anabaena* (filamentous), *Lyngbya* (filamentous with a sheath), *Microcystis* (gelatinous colony), and *Gloeotrichia* (filamentous with a sheath) were present in nine of twelve samples.

Table 6. Most Common Algal Genera from Bear Lake, Forest County, WI, 2010 and 2011, matched by same approximate collecting date.

Most Common Algal Genera-2010				Most Common Algal Genera-2011			
DATE	GENUS	PHYLUM	%	DATE	GENUS	PHYLUM	%
				04/30	*Oocystis*	Chlorophyta	10
					Scenedesmus	Chlorophyta	10
					Woronichinia	Cyanobacteria	9
					Synedra	Ochrophyta	8
					Fragilaria	Ochrophyta	7
					% of total		44
5/20	*Cryptomonas*	Cryptophyta	18	05/16	*Oocystis*	Chlorophyta	12
	Scenedesmus	Chlorophyta	9		*Ankistrodesmus*	Chlorophyta	8
	Oscillatoria	Cyanobacteria	8		*Fragilaria*	Ochrophyta	8
	Chlamydomonas	Chlorophyta	7		*Scenedesmus*	Chlorophyta	7
	Euglena	Euglenophyta	7		*Woronichinia*	Cyanobacteria	6
	% of total		49		% of total		41
				05/30	*Microcystis*	Cyanobacteria	10
					Cosmarium	Chlorophyta	10
					Scenedesmus	Chlorophyta	9
					Anabaena	Cyanobacteria	9
					Woronichinia	Cyanobacteria	8
					% of total		46
6/15	*Clamydomonas*	Chlorophyta	13	06/13	*Woronichinia*	Cyanobacteria	17
	Gloeotrichia	Cyanobacteria	9		*Oscillatoria*	Cyanobacteria	10
	Oscillatoria	Cyanobacteria	9		*Microcystis*	Cyanobacteria	10
	Oocystis	Chlorophyta	9		*Scenedesmus*	Chlorophyta	9
	Aulacoseira	Ochrophyta	8		*Pediastrum*	Chlorophyta	8
	% of total		48		% of total		54
6/29	*Clamydomonas*	Chlorophyta	14	07/04	*Oocystis*	Chlorophyta	10
	Oocystis	Chlorophyta	13		*Scenedesmus*	Chlorophyta	10
	Oscillatoria	Cyanobacteria	12		*Woronichinia*	Cyanobacteria	9
	Scenedesmus	Chlorophyta	7		*Synedra*	Ochrophyta	8
	Ankistrodesmus	Chlorophyta	7		*Fragilaria*	Ochrophyta	7
	% of total		53		% of total		44
7/13	*Aulacoseira*	Ochrophyta	15				
	Oocystis	Chlorophyta	11				
	Lyngbya	Cyanobacteria	9				
	Microcystis	Cyanobacteria	8				
	Amphidinium	Dinophyta	6				
	% of total		49				
7/30	*Oscillatoria*	Cyanobacteria	18	07/25	*Oocystis*	Chlorophyta	12
	Woronichinia	Cyanobacteria	17		*Ankistrodesmus*	Chlorophyta	8
	Cryptomonas	Cryptophyta	12		*Fragilaria*	Ochrophyta	8
	Oocystis	Chlorophyta	9		*Scenedesmus*	Chlorophyta	7
	Lyngbya	Cyanobacteria	7		*Woronichinia*	Cyanobacteria	6
	% of total		63		% of total		41

8/10	Oocystis	Chlorophyta	16
	Woronichinia	Cyanobacteria	16
	Oscillatoria	Cyanobacteria	14
	Anabaena	Cyanobacteria	6
	Lyngbya	Cyanobacteria	6
	% of total		58

8/23	*Woronichinia*	Cyanobacteria	12
	Scenedesmus	Chlorophyta	12
	Pediastrum	Chlorophyta	10
	Oocystis	Chlorophyta	10
	Oscillatoria	Cyanobacteria	9
	% of total		53

9/9	*Oscillatoria*	Cyanobacteria	19
	Cryptomonas	Cryptophyta	16
	Scenedesmus	Chlorophyta	10
	Woronichinia	Cyanobacteria	9
	Oocystis	Chlorophyta	6
	% of total		60

9/20	*Oscillatoria*	Cyanobacteria	21
	Lyngbya	Cyanobacteria	13
	Euglena	Euglenophyta	10
	Cryptomonas	Cryptophyta	10
	Oocystis	Chlorophyta	8
	% of total		62

10/4	*Oscillatoria*	Cyanobacteria	17
	Lyngbya	Cyanobacteria	13
	Oocystis	Chlorophyta	11
	Woronichinia	Cyanobacteria	9
	Microcystis	Cyanobacteria	9
	% of total		59

10/20	*Pediastrum*	Chlorophyta	14
	Scenedesmus	Chlorophyta	13
	Woronichinia	Cyanobacteria	12
	Oocystis	Chlorophyta	9
	Lyngbya	Cyanobacteria	6
	% of total		54

11/1	*Oscillatoria*	Cyanobacteria	17
	Chlamydomonas	Chlorophyta	15
	Oocystis	Chlorophyta	10
	Pediastrum	Chlorophyta	9
	Aulacoseira	Ochrophyta	8
	% of total		59

08/15	*Microcystis*	Cyanobacteria	10
	Cosmarium	Chlorophyta	10
	Scenedesmus	Chlorophyta	9
	Anabaena	Cyanobacteria	9
	Woronichinia	Cyanobacteria	8
	% of total		46

09/07	*Woronichinia*	Cyanobacteria	17
	Oscillatoria	Cyanobacteria	10
	Microcystis	Cyanobacteria	10
	Scenedesmus	Chlorophyta	9
	Pediastrum	Chlorophyta	8
	% of total		54

09/25	*Woronichinia*	Cyanobacteria	13
	Anabaena	Cyanobacteria	11
	Oscillatoria	Cyanobacteria	10
	Synedra	Ochrophyta	10
	Microcystis	Cyanobacteria	10
	% of total		54

10/17	*Oscillatoria*	Cyanobacteria	18
	Microcystis	Cyanobacteria	9
	Woronichinia	Cyanobacteria	8
	Oocystis	Chlorophyta	8
	Synedra	Ochrophyta	5
	% of total		48

11/05	*Woronichinia*	Cyanobacteria	20
	Microcystis	Cyanobacteria	10
	Aulacoseira	Ochrophyta	7
	Anabaena	Cyanobacteria	7
	Oscillatoria	Cyanobacteria	7
	% of total		51

The dominant cyanobacteria are colonial with a sheath, or filamentous (usually with a sheath) and large enough that they are hard to ingest (Figure 35, top row). The lipopolysaccharide cell walls and polysaccharide sheaths make them even harder to digest. Zooplankton organisms often avoid ingesting them, and even if ingested cyanobacterial cells are rarely digested. If not passed, intact and viable, in fecal material, the organisms can clog zooplankton digestive systems and cause death.

As a group, the 2010 Bear Lake Cyanobacteria generally increased in abundance across the sampling season rising from ca. 25% of cells counted early in the season (May, June) to levels generally above 35% for the rest of the season with three samples at or near 50% of all cells counted (Figure 36). For the entire 2010, collecting season the Cyanobacteria represented 35% of all cell counted, making them the co-dominant phyla with the green algae. There appeared to be two significant peaks in cyanobacterial abundance during 2010, late July – early August, and late September – early October (Figure 32). Cyanobacterial taxa, in 2010, were in the top five most common genera (according to cells counted) 26 out of 60 (43%) possible times (Table 6).

For 2011, the five ubiquitous blue-green genera (*Anabaena*, *Microcystis*, *Oscillatoria*, *Phormidium*, and *Woronichinia*) occupied 32 of 55 possible top 5 most counted positions (58%), a significant increase over 2010.These taxa are cosmopolitan and their abundance is generally associated with inorganically enriched (especially phosphorus) waters. During 2010, there was at least one cyanobacterial taxon in the top five most common taxa in every sample period, and during two periods (8/10, 10/04) there were four cyanobacterial taxa in the five most genera. *Oscillatoria* was the most common organism in five of twelve samples (15-20% of all cells counted) and it was in the top five most common taxa in 10 of 12 sample periods. *Woronichinia* was the dominant taxon in one sample, and this organism was in the top five most common taxa in half the sample periods, as was *Lyngbya*. None of the other most common cyanobacterial taxa was present in the top five most common taxa more than twice (Table 6).

The 2011 Bear Lake cyanobacterial community was dominated by *Woronichinia*; this genus was present in all 11 samples and in the top 5 most counted taxa in 10 of the 11 samples. The genera *Anabaena*, *Microcystis*, *Oscillatoria*, *Phormidium*, and *Woronichinia* were present in all 11 samples from 2011 (Table 6, Table 8). In all, five of the six cyanobacterial genera were present in all 11 samples. *Woronichinia*, *Oscillatoria,* and *Microcystis* are three of the most widespread, problematic, bloom-forming taxa encountered in the Upper Midwest lake environment.

In 2011, cyanobacterial dominance was more pronounced with higher highs and higher lows (Figure 35). The blue-greens proliferated earlier (35% of cells counted by 05/30,) and stayed abundant longer resulting in an across the season average of 42% of all cells counted. This made them the dominant group by a wide margin (>10%) over the Chlorophyta (32% of all cells counted across the season) and Ochrophyta (21% of all cells counted across the season. The cyanobacterial abundance was near or above 50% of all cells counted in six of the 11 samples from 2011. The large fall populations of cyanobacteria means a greater likelihood of survival over the winter and the possibility of earlier and more extensive blooms in the future.

For 2011, *Woronichinia* was clearly the dominant taxon. This small colonial organism, with a sheath (Figure 41, top right), was present in all 11 samples. It was in the top 5 most counted taxa in 10 of 11 samples, and it was the most counted organism in 4 of the 11 samples (Table 6). The filamentous genus *Oscillatoria* (Figure 41, top center) was in the top 5 most counted taxa in 8 of 11 samples and was the most counted genus in 1 of the 11 samples (10/17) during 2011. The large colonial organism, *Microcystis* (Figure 41, top left), was in the top 5 most counted taxa in 7 of the 11 samples from 2011, and it was twice the most counted genus (05/30, 08/15) (Table 6). There were 7 sample periods in 2011 where at least 3 cyanobacterial taxa were in the top 5 most counted genera, and in 5 of the 11 samples, the blue-greens were the top 3 most counted taxa (Table 6).

This pattern of slowly increasing cyanobacterial domination is typically caused by a combination of not being eaten, a fall surge in nutrients, and an extended temperature tolerance. *Microcystis*, *Oscillatoria*, and *Woronichinia* are capable of "blooming" to massive levels, and in the bloom state, they may produce toxins that can harm aquatic life, pets, and potentially humans. In both the 2010 and 2011 Bear Lake samples, they were not near bloom proportions and did not appear to be a toxin-producing threat but should be monitored in the future. Two years is a very small snapshot of the algal community in Bear Lake but the seasonal trend lines were going up in both years and 2011 blue-green abundance was greater at the start of the season, during the season, and at the end of the season than during 2010 (Figure 36).

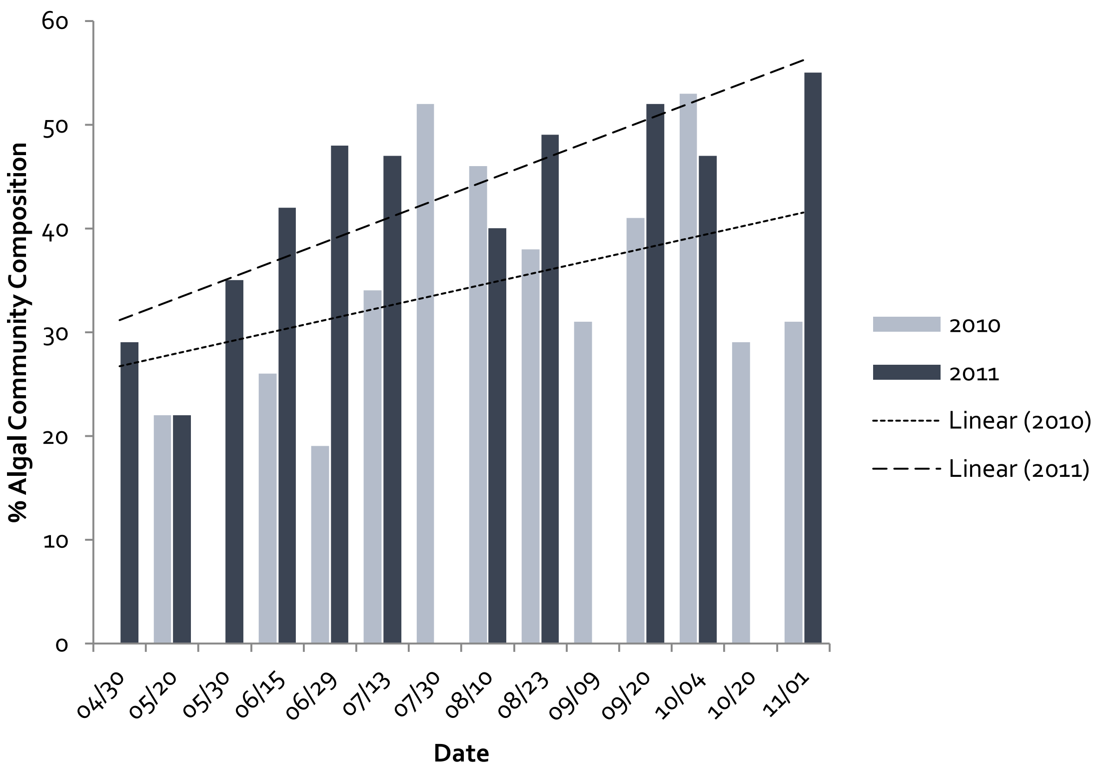


Figure 36. Linear regression trend lines for Cyanobacteria in Bear Lake, 2010 and 2011.

CHLOROPHYTA

Green algae were represented by 17 genera in 2010 (Table 6) and 13 genera in 2011(Table 8). *Ankistrodesmus*, *Chlamydomonas*, *Oocystis*, *Scenedesmus*, and *Pediastrum* were the most common and abundant taxa during the 2010 sampling season. These five genera were in the top five dominant taxa 24 times out of a possible 60 times (40% -Table 6). The chlorophytes are quite variable in size (unicellular, filamentous, colonial) and habit (motile, floating, attached) but all are fairly digestible and nutritious, and are often eaten. *Chlamydomonas*, *Ankistrodesmus*, and *Oocystis* are unicellular and are preferred food items (Figure 41, middle row center). *Scenedesmus* and *Pediastrum* are small colonial organisms (Figure 41, middle row left and right ends) that can be fragmented into easily ingested single cells, but entire colonies, depending on size, are often eaten by *Daphnia* and other zooplankters.

The only green alga present in more than half the common taxa lists in 2010 was *Oocystis* (11 of 12). *Scenedesmus* (5 of 12) and *Chlamydomonas* (4 of 12) were present in more than a third of the most counted taxa (Table 6). None of the other green algal taxa was present in more than four of the top five most common taxa lists. A green alga was the most common taxon in four of twelve periods, *Chlamydomonas* was twice the most common genus (06/15 and 06/29), with *Oocystis* (08/10) and *Pediastrum* (10/20) each most common in one sample.

The chlorophytes were the co-dominant phylum with the Cyanobacteria in the 2010 season, representing 36% of all cells counted (Figure 37). Together these two phyla comprised 71% of all cells counted during the 2010 season. Green algae never represented less than about 20% of all cells counted (17% - (07/30) and four times the group comprised ca. 50% of all cells counted. This phylum seemed to have three dominant growth periods during the 2010 collecting season. The group was dominant in June, late August, and late October into November. It appears that the greens and cyanobacteria waxed and waned as dominant phyla during the 2010 season (Figure 32).

During 2011, the green algae were less diverse and less abundant overall when compared to 2010. The most commonly counted taxa, in 2011, were *Oocystis* and *Scenedesmus*, present in all 11 sample periods. *Scenedesmus* was the most common green alga; it was in the top 5 most counted taxa in 7 of 11 sample periods. *Oocystis* was in the top 5 most counted taxa in 7 of the 11 2011 samples. Five other taxa were common, in 10 of 11 samples (*Ankistrodesmus*, *Closterium*, *Cosmarium*, *Pediastrum*, and *Staurastrum*) but none of these taxa was in the top 5 most counted taxa in more than 4 of the 11 sample periods.

The Chlorophyta was the second most common phylum (32% across the sampling season), after the Cyanobacteria, in 2011 (Figure 33). They were the clear dominants during the first third of the sampling season (04/30, 05/16, 05/30) before giving way to the burgeoning blue-green community. Green algal abundance waned steadily across the sampling season reaching a season low in the final sample (11/05). The trend lines for green algal % community composition differ significantly between 2010 and 2011 (Figure 37). The linear regression line was slightly positive in 2010 and sharply negative in 2011. This is not something one would hope to see given the important positive role the greens have in ecosystem function.

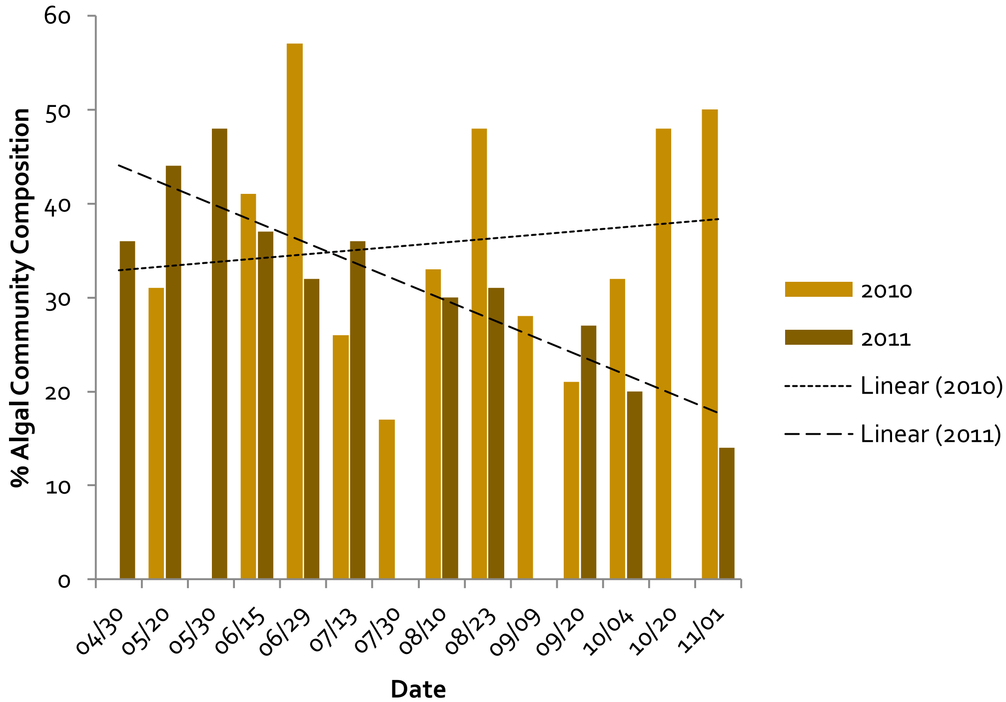


Figure 37. Linear regression trend lines for Chlorophyta in Bear Lake, 2010 and 2011.

Many green algal taxa were of only minor importance or abundance. Many were only seen in one or two of the sampling periods in 2010 and 2011 (Table 8). These organisms may have simply not been abundant or they may have been preferentially selected food items for the zooplankton and planktivorous fishes. This level of analysis cannot distinguish between these two possibilities.

OCHROPHYTA

Diatoms (Class Bacillariophyceae) are the most common and successful group of organisms within the phylum Ochrophyta. These unique organisms collect silica from the water and polymerize it into intricate glass cases called frustules that they use in place of a more traditional, organic cell covering. These organisms are common food items and are easily ingested and digested. There were nine genera of diatoms identified in the 2010 Bear Lake samples and 11 genera identified in the 2011 Bear Lake samples (Table 8).

Aulacoseira, *Navicula*, and *Fragilaria* (Figure 41, bottom row left to right) were the most common diatoms in 2010 (Table 6), all present in eight or more of the 12 samples. *Aulacoseira* was present in all samples and was the only diatom to make the top 5 most counted taxa list. This genus, a filamentous diatom, is very common in the region's lakes and it was the most common taxon in the 13 July sample.

In temperate lakes, the diatoms (and other ochrophytes) generally start low before rising in abundance early in the year (as lake nutrients, especially silica, are turned over and resuspended) and then showing a marked reduction in abundance in late summer due to silica depletion. Fall turnover often leads to a late season diatom spike. This was generally true in Bear Lake during 2010 as the diatoms rose to 20% of cells counted in June and July before dropping to ca. 10% of cells counted from late July to early October. Cell counts rose to ca. 15% of cells counted late in the sample season. For the entire 2010, sampling season the diatoms average 14% of all cells counted (Figure 38). Ecologically, the more diatoms the better for the food web in a lake. From 2010 to

2011, the overall abundance of diatoms increased both at the beginning and the end of the sampling seasons (Figure 38).

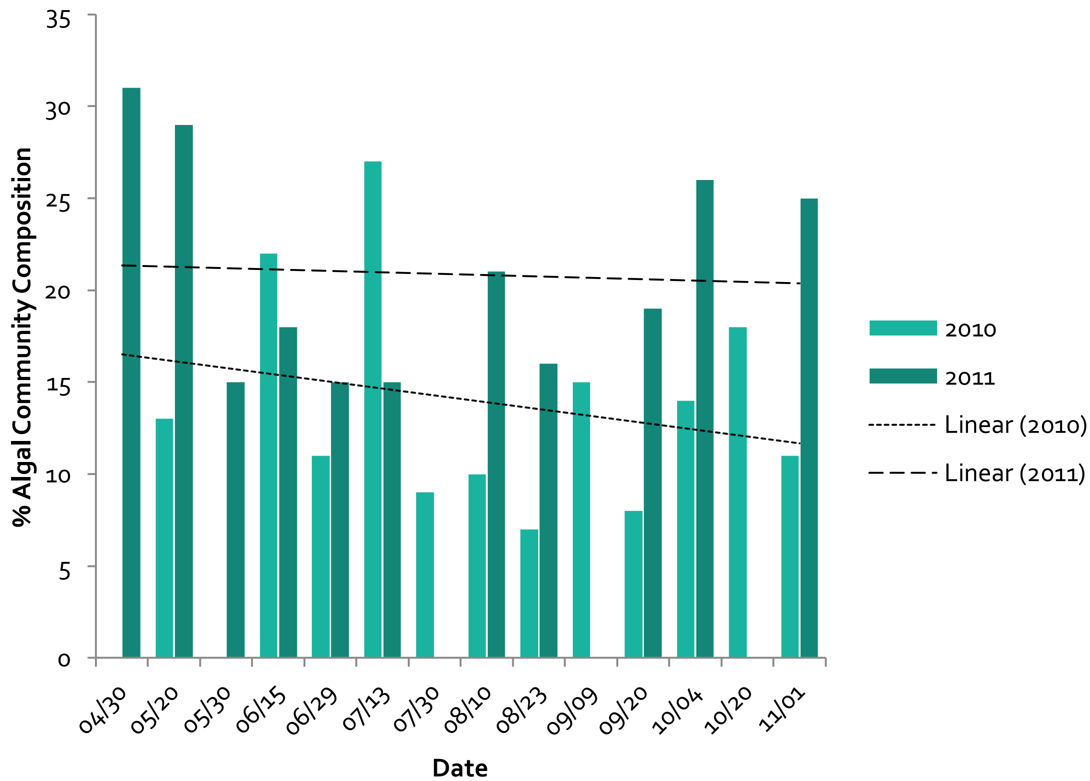


Figure 38. Linear regression trend lines for diatoms in Bear Lake, 2010 and 2011.

During 2011, the same three taxa (*Aulacoseira*, *Navicula*, and *Fragilaria*) plus the large and long taxon *Synedra* were the dominant diatom genera (Table 8). These four genera were present in all 11 samples but were rarely dominant, relative to the entire algal community. *Synedra* was in the top 5 most counted taxa on three occasions while *Fragilaria* and *Aulacoseira* were in the top 5 most counted taxa twice and once, respectively (Table 6).

For the 2011, sampling season the diatoms averaged 21% of all cells counted. The peaks were early and late (associated with lake turnover that resuspended silica). There were ca. 30% diatoms in the first two samples (04/30, 05/16) and ca. 25% diatoms in the last two samples (10/17, 11/05), and generally less than 20% diatoms in the other 7 sampling periods of 2011.

Other Phyla

The other three phyla (Dinophyta-dinoflagellates, Euglenophyta-euglenoids, and Cryptophyta-cryptophytes) were of varying significance across the 2010 and 2011sampling periods. These phyla comprised from 0 - 18% of all cells counted and averaged 16% of all cells counted across the 2010 study period. During 2011 the abundance of these three phyla was greatly reduced. They comprised from 0 - 5% of all cells counted and averaged just 4 - 5% of all cells counted across the 2011 study period. Diversity is generally considered a good thing and the presence of these groups, especially the cryptophytes is a positive indication of a healthy and somewhat balanced aquatic system.

The dinoflagellates are unicellular and can be a preferred food item for invertebrates and planktivorous fishes, both larval and adult stages (Gifford, 1991; Moore, et al., 1994). The dinophyte taxa – *Amphidinium* and *Peridinium* were very common in 2010, present in 11 and 12 of 12 samples, respectively (Table 8). Only *Amphidinium* was present in the top 5 most commonly counted taxa, it was the fifth most common genus on 13 July (Table 6). For the 2011 sampling periods only *Peridinium* was found and it was present in only 5 of 11 samples.

Euglenophytes are unicellular flagellates that are nutritious. Their flexible protein cell covering is easily disrupted and these organisms are often preferred food items. These organisms typically increase in abundance when there is a lot of organic matter being decomposed. Only *Euglena* was common in 2010, it was present in eight of 12 sample periods, and was in the top five most common taxa twice (Table 6). There were no euglenophytes in more than 6 of 11 samples from 2011 and none was ever in the top 5 most counted taxa.

One of the most easily ingested, digested, and nutritious groups of algae are the unicellular Cryptophyta. They usually have a high growth rate but it is balanced by a very high herbivory rate, resulting in a depressed appearance in the cell counts. The type genus, *Cryptomonas*, was present in 11 of 12 samples during the 2010 sampling season. This genus was the most common organism counted in the first sample (05/20), and was in the top five most common taxa list four times (Table 6). In 2011, Cryptomonas was present in all 11 sample periods but was never in the top 5 most counted taxa.

DISCUSSION

The relative abundance of all algal phyla over the two-year sampling period (2010-11) is shown in Table 6. The data indicate a moderately enriched (eutrophic) lake. It is likely that the onset, density, and extent of the cyanobacterial blooms of *Oscillatoria*, *Woronichinia*, and *Microcystis* will continue to expand.

The factors that contribute to this slowly expanding cyanobacterial dominance cannot easily be determined with surety. I (Dr. Bell) suspect two unrelated drivers are combining to push the change in the algal community in Bear Lake from more desirable organisms (green algae, diatoms, and the lesser three phyla) to less desirable organisms (Cyanobacteria). These drivers are a slowly increasing internal phosphorus load and ecosystem disruption by rusty crayfish (*Orconectes*).

Many years of small phosphorus accumulation have led to a sizeable internal load (30% of phosphorus (Table 3), and the algae, particularly the blue-green algae, have several physiological adaptations that contribute to what is termed "luxury accumulation". This term refers to algal cells that can take up excess nutrients, in excess of their contemporary needs, for storage to fuel future growth. Phosphorus might have come from upstream watershed inputs via Shabadock Creek, local anthropomorphic inputs (fertilizing of lawns, septic systems, surface runoff), and local geological conditions (leaching of naturally occurring nutrients from the basal material).

The rusty crayfish prey upon the rooted macrophytes, clipping them and reducing their percent cover. The disruption of the sediments by the crayfish reduces water column clarity and releases phosphorus into the water column for algal uptake. The algae are quicker to take up the excess nutrients and they can grow faster than aquatic macrophyte vegetation. The combination of reduced light and nutrients makes it harder for the submerged macrophytes to regrow, tipping the balance toward the algae. The rusty crayfish biomass produces lots of waste product that is like algae fertilizer and their decomposition in the detritus releases additional amounts of nutrients during lake overturn events.

Once nutrients are introduced to a lake system, it is very difficult to manage or eliminate them. These nutrients undergo a seasonal change in location and form. The spring overturn of the lake resuspends available inorganic nutrients from the sediments. The algae assimilate these nutrients and consequently they are incorporated into organic molecules (DNA, protein) or are stored ("luxury accumulation") in excess of their current need. As algae are eaten, their organic and inorganic matter is echoed through the food web and becomes organic material within the various levels of consumers. Consumer waste, consumer death, and algal death all contribute abundant inorganic and organic matter to the sediments throughout the year but particularly in the fall/winter as most algae and aquatic plants die back. In the winter, the bacteria in the sediments metabolize these mostly organic forms of nitrogen and phosphorus back to inorganic forms that are once again available in the following spring during lake overturn.

In closing, Bear Lake is a typical temperate zone lake that shows signs of moderate nutrient accumulation. If no actions are taken the problem of algal blooms, and the potential of fish-killing oxygen depletion will continue to increase, perhaps slowly and barely visible some years, overtly obvious in other years. Such is how large aquatic ecosystems wobble over long time scales, far beyond our two-year view. We are often measuring results in one year that are being driven by events of the previous year or even further back in the nutrient budget of the watershed making predictions difficult. The problems likely took a long time to develop and the solutions will be equally slow to take effect. Various nutrient abatement strategies are possible. They vary widely in effectiveness and cost. They include, in no particular order, but are not limited to:

- Planting of vegetation buffer strips along the shoreline and the reduction of fertilizer use in the residential and campground landscapes around Bear Lake
- Use of best practices in siting, installation, and maintenance of septic systems within the groundwater input zone
- Remove/reduce rusty crayfish (*Orconectes rusticus*) to enhance the growth of aquatic macrophytes and improve water clarity

Conclusions and Recommendations

Algal growth in Bear Lake appears to be a result of a combination of factors. Sources of phosphorus to Bear Lake include Shabadock Creek, surface runoff, groundwater, and internal loading.

Water entering Bear Lake from Shabadock Creek delivers the greatest amount of phosphorus; however, the phosphorus concentrations are typical for a watershed that is comprised of forests and wetlands.

Phosphorus inputs from sediment contact with anoxic water occurs, but since Bear Lake does not appear to mix throughout the summer this may be of little consequence to algal growth in the upper part of the water column.

Some of the groundwater entering Bear Lake appears to be influenced by cultural sources such as septic systems. Most septic systems are designed to discharge their effluent to the groundwater, therefore, the newer septic systems that are located near areas of groundwater inflow will likely contribute phosphorus to the lake as the systems age.

Rusty crayfish appear to be having a large impact on the phosphorus and algal dynamics in Bear Lake. Because the rusty crayfish are removing most of the aquatic plants in Bear Lake, the phosphorus that would have be tied up in plant tissue is available for use by algae. To compound matters, rusty crayfish preferentially feed on green algae, leaving more blue-green algae to prosper. This can result in greater and more frequent blue-green algae blooms.

Dry conditions existed in northeast Wisconsin prior to the start of this study. These conditions may have played a role in the intense blue-green algal blooms that were observed and led to this study. Significantly noticeable blue-green algal blooms were not observed during this study.

Since the Bear Lake watershed has limited impacts to the lake, only a handful of options are available to reduce the magnitude and frequency of blue-green algal blooms in Bear Lake.

1. Make efforts to control additional phosphorus inputs to Bear Lake by minimizing soil disturbance, setting back septic systems from lake, controlling runoff from roofs and other impervious surfaces, and minimizing the disturbance of natural shoreland vegetation. When possible, locate septic system drainfields a greater distance from the lake, particularly in areas of groundwater inflow.

2. Reduce the rusty crayfish population through trapping and/or biomanipulation.

3. Put measures into place to prevent the introduction of other exotic aquatic plants and animals. These measures should include prevention and early detection.

4. Continue monitoring the water quality and routine or annual aquatic plant surveys in Bear Lake to ensure data are available to determine if efforts are resulting in improvements or if re-direction of efforts is warranted. Following the WDNR's Citizen Lake Monitoring Network protocol helps to ensure continuity of the data from year to year. Water quality parameters should include phosphorus and chlorophyll a and temperature and dissolved oxygen profiles.

Note: These and additional recommendations were considered in the development of the Bear Lake Management Plan. Please refer to the plan for details.

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APPENDICES

Bear Lake Campground History and Use
T35N, R16E, sections 17 and 18
Forest County, Wisconsin

RECREATION/CAMPGROUND HISTORY

A review of District files provides a reasonable history of the recreation use and development of facilities on National Forest System Land that is located on the west side of Bear Lake.

1930's – Land where the existing campground is located was purchased from the Menominee Bay Shore Lumber Company in several purchases from 1934 – 1936.

1950's – The first recreation developments likely occurred on National Forest System Land in the mid-1950's. Records would indicate that the first developments consisted of a boat landing, several campsites, and a pit toilet. The first developments were likely located near the existing boat landing, beach, and campsites 23 -27.

One cannot be certain, but it is likely that recreation use was occurring before the establishment of the first recreation developments. A review of aerial photographs from 1938 indicates that the road into the existing campground was in existence in the 1930's.

1960's – The existing campground was developed in the mid-1960's. The campground today is basically the same as the original design and construction.

1970's -1990's – There are no records to indicate that any major alterations or renovations took place within the campground within this time period. Routine maintenance such as cleaning of campsites and toilet facilities, hazard tree removal, well maintenance, and vault toilet pumping would have occurred annually. Other maintenance activities would have occurred on an as need basis such as refinishing of buildings and tables, resurfacing of campsites and trails, and replenishing sand for the beach.

One well was abandoned and another well established in the late 1980's. The abandoned well was located between the beach and beach parking area. The new well was established along the main campground road between the access roads to the boat landing and beach area.

With the age of the existing toilet facilities and direction to provide for universal accessibility, replacement of existing toilet facilities began in 1999. Existing vault toilets were replaced with larger vault toilets to meet universal accessibility standards. The first two toilets replaced were across from site 17. New toilets were placed in close proximity to the old toilets.

2000's – Replacement of the existing toilet facilities continued. In 2002, the toilet facilities across from site 5 were replaced. The new toilets were placed in the same general vicinity of the old toilets. In 2003, the toilet that served the boat landing/beach/picnic area was replaced. The old toilet was located in an area between the existing beach and boat landing. The new toilet was placed near the beach/walk-in campsites parking area to better serve those users.

Bear Lake 2010 Fish Summary: compiled by Skip Sommerfeldt, WDNR senior Fish Biologist for a Forest Service meeting at the laona office on 3/17/11. (Summary was scanned from a hardcopy sheet)

Bear Lake, Forest Co.: 68-acre drainage lake, ~8 miles southeast of Wabeno, off FR 2136. Survey of the fishery following water quality issues in previous years. Survey entailed winter DO's, spring shocker run (mid-May), June panfish netting, and fall shocker run. **Survey highlights:** Winter DO monitoring in early March 2010 showed good levels down to 15 feet, then < 1 mg/L from 16' to 25'– very low chance of winterkill. Spring shocking (5/12/10) – got fair catch of gamefish and good sample of panfish. Largemouth bass were just starting to nest, and collected 53 largemouth that ranged from 9.6" to 18.3 inches in length. Large modal peak near 14 inches, and RSD14 was 38%. Also sampled 2 northern pike (11.2" & 22.3"); and saw/missed 1 walleye (in 22"–24" size). Bluegill were the main panfish (330 /hr); followed by crappie (97 /hour) and perch (60 /hr); with much fewer rock bass, bullhead and pumpkinseed. Size structure was good for both bluegill (PSD6 = 41%; RSD8 = 10%) and crappie (PSD8 = 72%); but most perch were in the 3" to 4" size. Noted a diverse forage base with fair abundances of white sucker, golden shiner and common shiner. Rusty crayfish were considered to be 'common to abundant'. Summer panfish netting (June 2010, 12 net-days) produced a rather low catch of panfish – with crappie being the most common species; followed by bluegill, rock bass, perch, bullhead, and pumpkinseed. A total of 116 crappie were measured (9.7 /net-day), with a length range of 3.6" to 10.9" and a PSD8 of 64% (most were 8.5" to 10" long). The bluegill CPE was just 4.0 /net-day, most were in the 5.5" to 7.9" size and RSD7 was 29%. Others species were much lower in abundance – but all had some quality-size fish present (rock bass to 9.8", perch to 10.6", bullhead to 13"). Gamefish were lightly represented in the June netting – handled 11 northern pike (6 that were 28" to 35" long); 2 walleye (23" to 24"); and 3 largemouth collected by angling (13" to 14").
Fall shocking (Sept. 30, 2010) – water level was a couple inches low, and water was dark-stained from the large amount of rainfall/runoff from throughout the summer. The shoreline circuit produced a pretty good catch of all species. Measured 60 largemouth bass (75 /hour) that ranged from 2.4" to 19.3" long. Had good natural reproduction in 2010, and the RSD14 was 72%. A total of 11 northern pike were sampled (10.7" to 26.4"), as well as 1 smallmouth bass (7.2") and one small walleye (10" – naturally produced? Or bucket transfer??). White sucker were also fairly abundant (130 /hour), and ranged from 7" to 18" in length. The panfish were primarily bluegill, followed by perch, crappie, rock bass and pumpkinseed. Bluegill were considered moderate in abundance (345 /hour), and most were in the 3" to 5" size (PSD6 was just 13%). Most of the crappie sampled were YOY fish (~3.2") and the perch were a combination of YOY and yearlings (~3.1" and 5.4" respectively). Also collected fish for mercury contaminant analysis (5 largemouth bass, 3 northern pike, 6 panfish).
Summary → Overall, the 2010 survey indicated little change in last 12 years and the lake continues to have a fairly well-balanced fishery (very close to objectives from 1998 survey). Largemouth bass remain the primary gamefish, with a low to moderate population of northern pike, and a few walleye and smb. All species were sustained by natural reproduction, and preferred- and trophy-size fish were available to the angler. Bluegill were the predominant member of the panfish community, with somewhat lesser abundances of crappie, perch and rock bass. Growth rates appeared to be near average, and size structures were generally good for all 4 species. Despite the nuisance algae blooms during summer, the lake had no other major management issues. Shoreline and littoral habitat were adequate and the lake had a good mix of aquatic vegetation, woody structure and rock/gravel substrate.
Mgmt Recs – **1)** Continue to manage primarily as a largemouth bass and panfish fishery, with secondary emphasis on northern pike. All species had self-sustaining populations, and no stocking or regulation changes are recommended; **2)** practice proper riparian management to ensure future natural tree-falls into the lake; **3)** monitor the status of the fishery with a spring (or fall) shocker run every 3 years (especially watch lmb abundance and size structure of the panfish species).

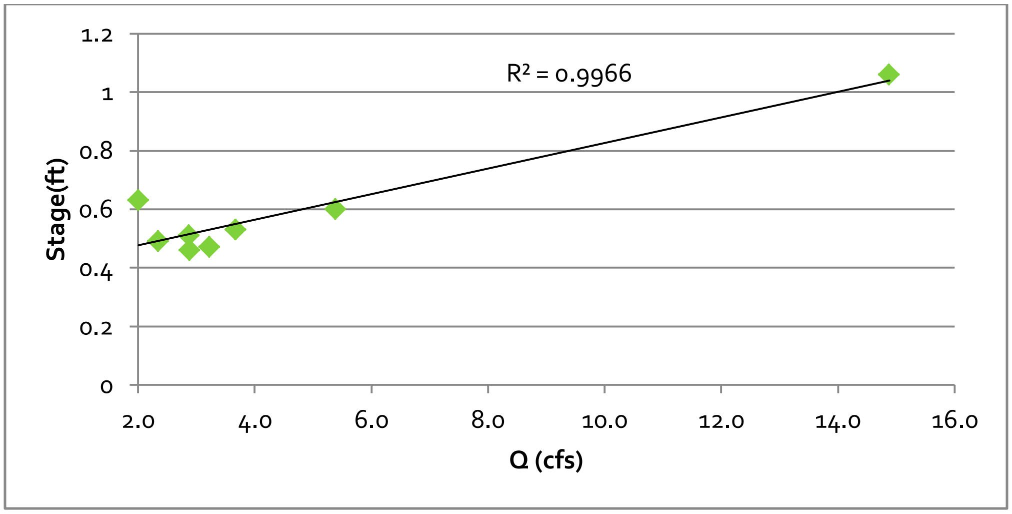

Figure 39. Rating curve for SC01,2010-11.

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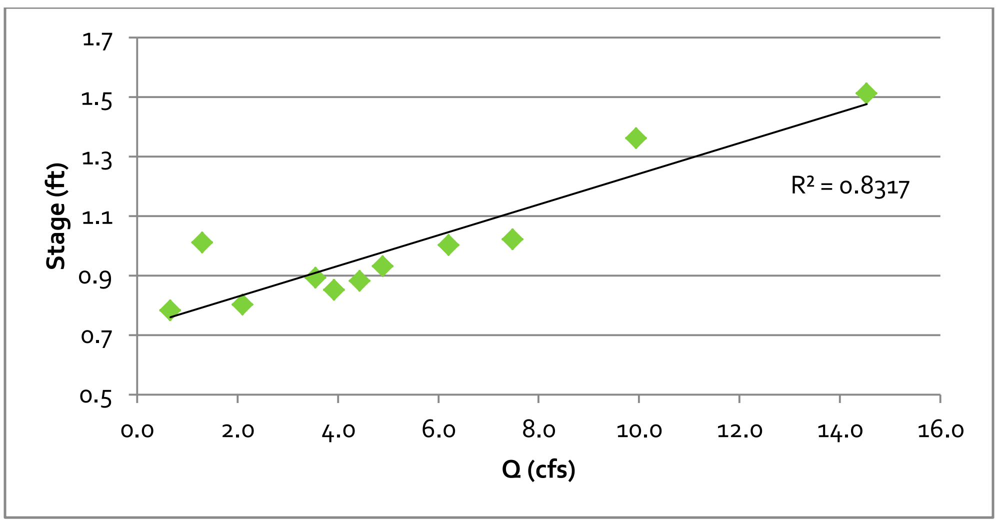


Figure 40. Rating curve for BC01, 2010-11.

Table 7. Algal Genera from Bear Lake, Forest County, WI, 2010, by date.

PHYLUM	GENUS	2010: TOTAL CELLS COUNTED & PERCENTAGE OF TOTAL, COUNTS UNTIL N=300																								
		05/20		06/15		06/29		07/13		07/30		08/10		08/23		09/09		09/20		10/04		10/20		11/01		Samples Present	Times in top 5 taxa	
Cyanobacteria	Anabaena	6	2	2	1		0		0	8	3	19	6	11	4	2	1	13	4	14	5	10	3		0	9	1	
	Cylindrospermum		0		0		0		0	3	1	2	1		0		0	1	0	3	1		0	4	1	5		
	Gloeotrichia	11	4	28	9	4	1	18	6	2	1	9	3	5	2	4	1		0		0	9	3		0	9	1	
	Lyngbya		0		0		0	27	9	22	7	17	6	14	5	3	1	38	13	40	13	18	6	14	5	9	6	
	Microcystis	17	6	8	3	3	1	23	8	9	3		0	19	6		0	5	2	26	9		0	7	2	9	2	
	Oscillatoria	24	8	27	9	36	12	18	6	55	18	41	14	27	9	58	19	62	21	51	17	13	4	52	17	12	10	
	Phormidium		0		0		0		0	8	3		0	1	0		0		0		0		0		0	2		
	Woronichinia	9	3	14	5	15	5	16	5	50	17	49	16	36	12	27	9	3	1	26	9	37	12	16	5	12	6	
8	**TOTAL**		**22**		**26**		**19**		**34**		**52**		**46**		**38**		**31**		**41**		**53**		**29**		**31**			# taxa, top 5
																												6
Chlorophyta	Actinastrum		0		0	11	4		0	2	1		0	10	3		0	3	1		0	6	2		0	5		
	Ankistrodesmus	2	1	12	4	21	7	6	2		0		0	4	1	17	6	5	2	6	2	8	3	18	6	10	1	
	Carteria		0		0		0		0		0	3	1		0		0		0		0		0		0	1		
	Chaetonema	2	1		0		0		0		0		0		0		0		0	1	0		0		0	2		
	Chlamydomonas	22	7	38	13	41	14	9	3	6	2	11	4	21	7	9	3	3	1	8	3	5	2	45	15	12	4	
	Cladophora		0		0		0		0		0		0		0		0		0		0		0	3	1	1		
	Closterium		0	1	0	4	1		0		0	2	1		0		0	2	1	8	3		0		0	5		
	Coelastrum	3	1		0	7	2		0		0		0	5	2	2	1		0	7	2	7	2		0	6		
	Cosmarium		0	3	1	5	2		0		0		0	2	1		0		0	2	1		0	8	3	5		
	Klebsormidium		0		0		0		0		0		0		0	6	2		0		0	2	1	6	2	3		
	Monoraphidium	2	1		0	3	1		0		0	6	2		0		0	7	2	21	7		0		0	5		
	Oedogonium		0		0		0		0		0		0		0		0	2	1	1	0	1	0	2	1	4		
	Oocystis	17	6	26	9	40	13	32	11	26	9	49	16	29	10	19	6	23	8	33	11	28	9	30	10	12	11	
	Pediastrum	10	3	21	7	13	4	15	5	17	6		0	30	10		0	11	4	2	1	41	14	27	9	10	3	
	Scenedesmus	28	9	17	6	22	7	11	4		0	16	5	36	12	31	10	8	3	7	2	40	13	6	2	11	5	
	Spirogyra		0		0		0	2	1		0	8	3		0		0		0		0	6	2	5	2	4		
	Staurastrum	7	2	6	2	4	1	2	1		0	5	2	6	2		0		0		0		0		0	6		
17	**TOTAL**		**31**		**41**		**57**		**26**		**17**		**33**		**48**		**28**		**21**		**32**		**48**		**50**			# taxa, top 5
																												5
Ochrophyta	Asterionella		0	3	1		0		0		0		0		0		0		0		0	5	2		0	2		
	Aulacoseira	18	6	24	8	8	3	44	15	5	2	8	3	12	4	16	5	9	3	15	5	9	3	24	8	12	3	
	Cocconeis		0	1	0		0		0		0		0		0		0	6	2		0	9	3		0	3		
	Cyclotella	8	3	7	2	11	4	18	6	7	2		0		0	2	1		0		0		0		0	6		
	Cymbella		0		0		0		0		0	3	1		0		0	2	1	3	1	5	2	2	1	5		
	Fragilaria	7	2	11	4	3	1	9	3		0	5	2	2	1	1	0		0	9	3	12	4		0	9		
	Gomphonema		0		0		0		0		0		0	4	1		0		0	4	1		0		0	2		
	Navicula	5	2	15	5	8	3	8	3	14	5	8	3	3	1	11	4	3	1		0	8	3	6	2	11		
	Synedra		0	4	1	3	1	3	1		0	5	2		0	15	5	4	1	11	4	6	2		0	8		
9	**TOTAL**		**13**		**22**		**11**		**27**		**9**		**10**		**7**		**15**		**8**		**14**		**18**		**11**			# taxa, top 5
																												1
Dinophyta	Amphidinium	4	1	3	1	1	0	19	6	4	1	9	3		0	9	3	21	7		0	7	2	6	2	10	1	
	Peridinium	16	5	11	4	8	3	11	4	6	2	10	3	7	2	4	1	6	2	2	1		0	2	1	11		
2	**TOTAL**		**7**		**5**		**3**		**10**		**3**		**6**		**2**		**4**		**9**		**1**		**2**		**3**			# taxa, top 5
																												1
Euglenophyta	Euglena	21	7	2	1	5	2	5	2	4	1	1	0		0	13	4	30	10		0		0	7	2	9	2	
	Phacus	6	2	7	2	2	1		0	2	1		0		0	1	0		0		0		0		0	5		
	Trachelomonas		0		0	8	3	2	1	15	5	4	1		0	3	1	4	1		0		0		0	6		
3	**TOTAL**		**9**		**3**		**5**		**2**		**7**		**2**		**0**		**6**		**11**		**0**		**0**		**2**			# taxa, top 5
																												1
Cryptophyta	Cryptomonas	55	18	9	3	14	5	2	1	35	12	10	3	16	5	47	16	29	10		0	8	3	10	3	11	4	
1	**TOTAL**		**18**		**3**		**5**		**1**		**12**		**3**		**5**		**16**		**10**		**0**		**3**		**3**			# taxa, top 5
																												1
		300		300		300		300		300		300		300		300		300		300		300		300				
40		300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**	300	**100**		60	15

Table 8. Algal Genera from Bear Lake, Forest County, WI, 2011, by date.

		SAMPLE DATE																					
PHYLUM		04/30		05/16		05/30		06/13		07/04		07/25		08/15		09/07		09/25		10/17		11/05	
Cyanobacteria	*Anabaena*	7	2	11	4	**27**	9	10	3	**23**	8	5	2	2	1	10	3	**33**	11	14	5	**20**	7
	Gloeotrichia		0	1	0		0		0	8	3	2	1		0	6	2	2	1	11	4	17	6
	Microcystis	20	7	16	5	**31**	10	**29**	10	14	5	**29**	10	9	3	**40**	13	**30**	10	**28**	9	**31**	10
	Oscillatoria	18	6	11	4	20	7	**30**	10	**39**	13	**35**	12	**31**	10	**25**	8	**31**	10	**55**	18	**20**	7
	Phormidium	13	4	8	3	3	1	7	2	13	4	**30**	10	**22**	7	18	6	**38**	13	10	3	16	5
	Woronichinia	**28**	9	**19**	6	**24**	8	**50**	17	**48**	16	**41**	14	**57**	19	**47**	16	21	7	**24**	8	**60**	20
	6 TOTAL		**29**		**22**		**35**		**42**		**48**		**47**		**40**		**49**		**52**		**47**		**55**
Chlorophyta	*Ankistrodesmus*	9	3	**24**	8	13	4	5	2	8	3	10	3		0	3	1	6	2	9	3	6	2
	Chlamydomonas	18	6	12	4	8	3		0		0		0		0		0	7	2		0	2	1
	Cladophora		0		0		0	3	1	5	2	1	0		0		0		0		0	3	1
	Closterium	3	1	8	3		0	4	1	12	4	5	2	5	2	7	2	10	3	2	1	5	2
	Cosmarium	7	2	14	5	**30**	10	11	4	14	5	23	8	**28**	9	11	4	9	3	5	2		0
	Hydrodictyon		0		0		0		0	1	0		0	1	0	5	2		0	6	2		0
	Oedogonium		0		0	4	1	5	2		0	7	2	3	1		0	8	3	1	0	2	1
	Oocystis	**30**	10	**36**	12	20	7	7	2	3	1	14	5	19	6	**26**	9	13	4	**24**	8	12	4
	Pediastrum	3	1	8	3	15	5	**25**	8	10	3	3	1		0	4	1	7	2	3	1	2	1
	Scenedesmus	**29**	10	**20**	7	**28**	9	**28**	9	**18**	6	**28**	9	13	4	**31**	10	15	5	8	3	2	1
	Spirogyra	5	2	8	3	21	7	8	3	4	1	6	2		0	2	1	3	1		0		0
	Staurastrum	4	1	2	1	5	2	16	5	**22**	7	10	3	**20**	7	3	1	2	1		0	3	1
	Stigeoclonium		0		0		0		0		0		0		0		0		0	3	1	4	1
	13 TOTAL		**36**		**44**		**48**		**37**		**32**		**36**		**30**		**31**		**27**		**20**		**14**
Ochrophyta	*Asterionella*		0		0	3	1	1	0	9	3	3	1	15	5	3	1	6	2	13	4	2	1
	Aulacoseira	12	4	18	6	2	1	3	1	8	3	14	5	7	2	8	3	7	2	13	4	**22**	7
	Cocconeis	3	1	5	2		0	3	1		0	2	1	5	2		0	2	1	4	1	5	2
	Cyclotella	1	0	1	0		0	5	2		0		0	3	1		0	1	0	3	1		0
	Cymbella	9	3	7	2	4	1		0	7	2	4	1	8	3	2	1		0		0	12	4
	Dinobryon	7	2	2	1		0		0		0	1	0		0		0		0		0	3	1
	Fragilaria	**21**	7	**23**	8	20	7	14	5	8	3	6	2	16	5	9	3	4	1	10	3	11	4
	Gomphonema		0		0		0	2	1		0	2	1	1	0	1	0		0	8	3	2	1
	Navicula	14	5	8	3	7	2	10	3	4	1	7	2	4	1	9	3	4	1	11	4	4	1
	Synedra	**24**	8	16	5	9	3	16	5	6	2	7	2	3	1	17	6	**31**	10	**16**	5	15	5
	Synura	3	1	6	2		0		0	2	1		0		0		0	2	1		0		0
	11 TOTAL		**31**		**29**		**15**		**18**		**15**		**15**		**21**		**16**		**19**		**26**		**25**
Dinophyta	*Peridinium*	2	1		0	3	1		0		0		0	6	2		0		0	5	2	3	1
	1 TOTAL		**1**		**0**		**1**		**0**		**0**		**0**		**2**		**0**		**0**		**2**		**1**
Euglenophyta	*Euglena*		0		0		0		0	1	0		0	2	1		0		0		0	1	0
	Phacus	3	1	2	1		0		0	1	0		0	8	3	4	1	4	1		0		0
	Trachelomonas		0	4	1		0		0	4	1		0	5	2	3	1		0		0	2	1
	3 TOTAL		**1**		**2**		**0**		**0**		**2**		**0**		**5**		**2**		**1**		**0**		**1**
Cryptophyta	*Cryptomonas*	7	2	10	3	3	1	8	3	8	3	5	2	7	2	6	2	4	1	14	5	13	4
	1 TOTAL		**2**		**3**		**1**		**3**		**3**		**2**		**2**		**2**		**1**		**5**		**4**
		300		300		300		300		300		300		300		300		300		300		300	
	35	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100

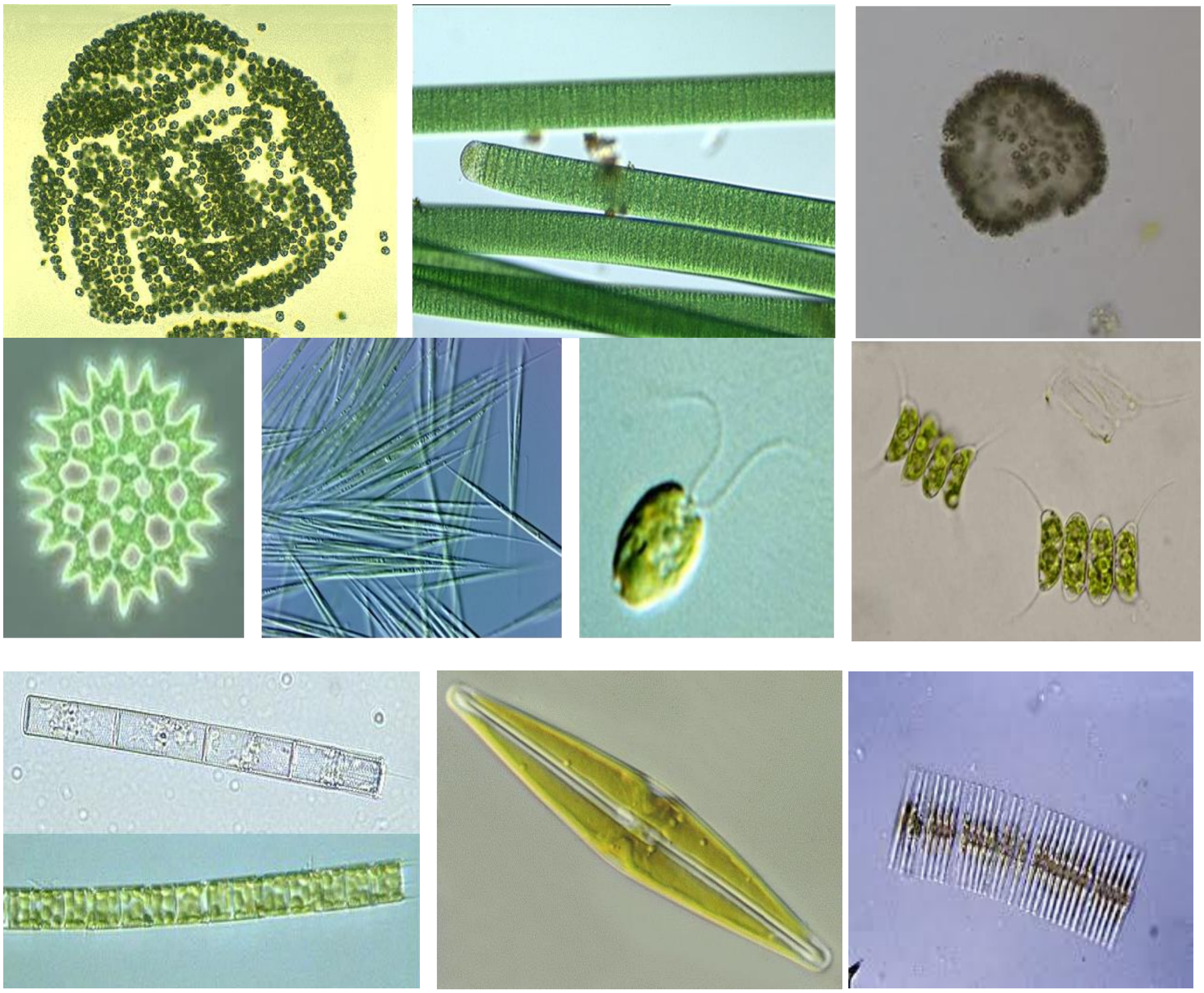


Figure 41. Selected, most common taxa from Bear Lake, Forest County. Top row, left to right – Cyanobacteria: *Microcystis*, *Oscillatoria*, *Woronichinia*. Middle row, left to right – Chlorophyta: *Pediastrum*, *Ankistrodesmus*, *Chlamydomonas*, *Scenedesmus*. Bottom row, left to right – Ochrophyta (diatoms): *Aulacoseira*, *Navicula*, *Fragilaria*.

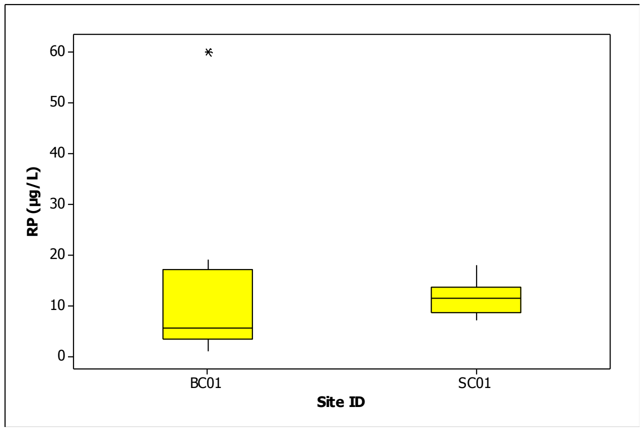


Figure 42. A box plot displaying the range in concentrations of reactive phosphorus at BC01 and SC01 from 6/15/2010 to 10/20/2010.

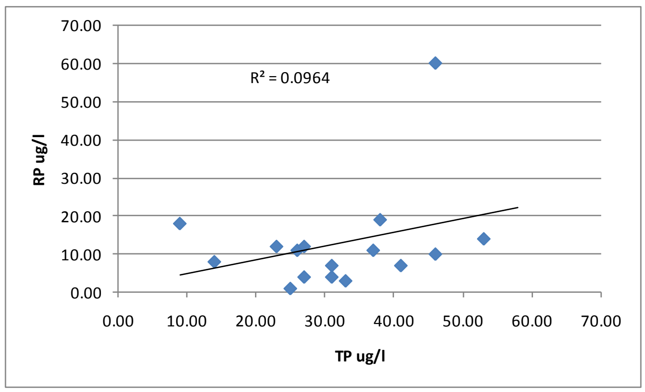


Figure 43. A scatter plot displaying the relationship between total phosphorus and reactive phosphorus at BC01 and SC01.

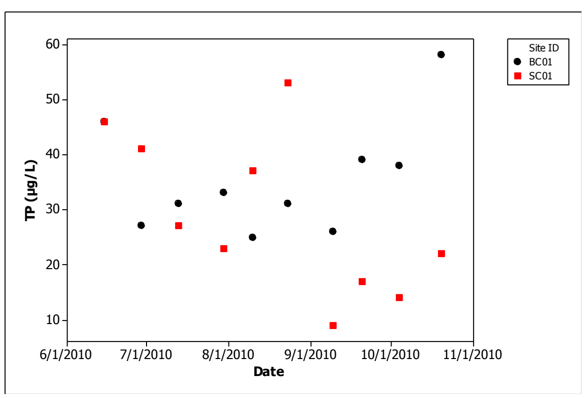


Figure 44. Scatter plot of total phosphorus concentrations at BC01 and SC01 over time.

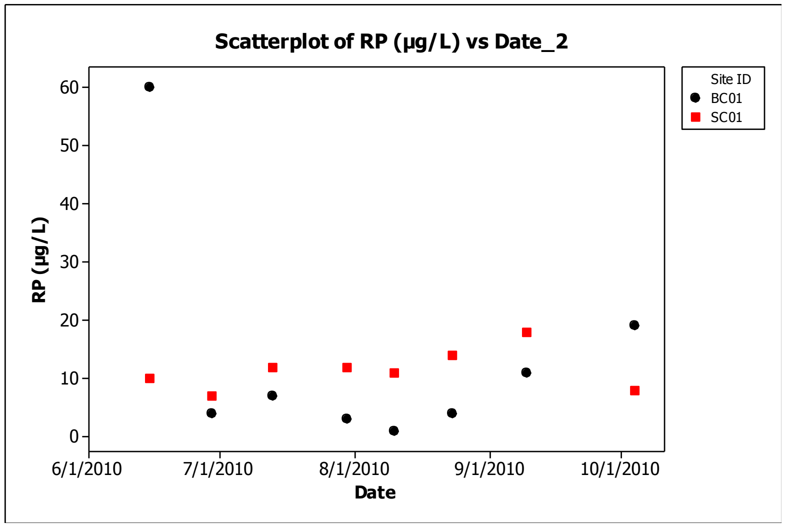


Figure 45. Scatter plot of reactive phosphorus concentrations at BC01 and SC01 over time.

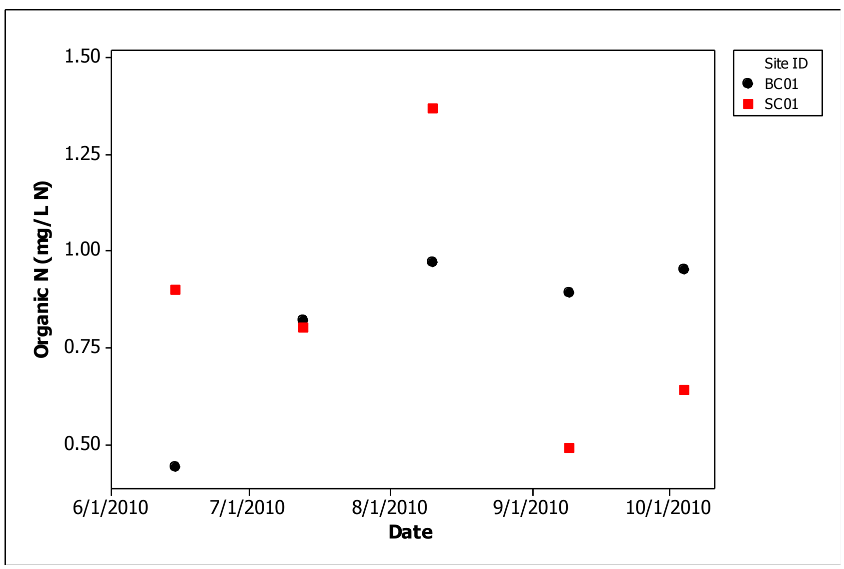


Figure 46. Scatter plot of organic nitrogen concentrations at BC01 and SC01 over time.

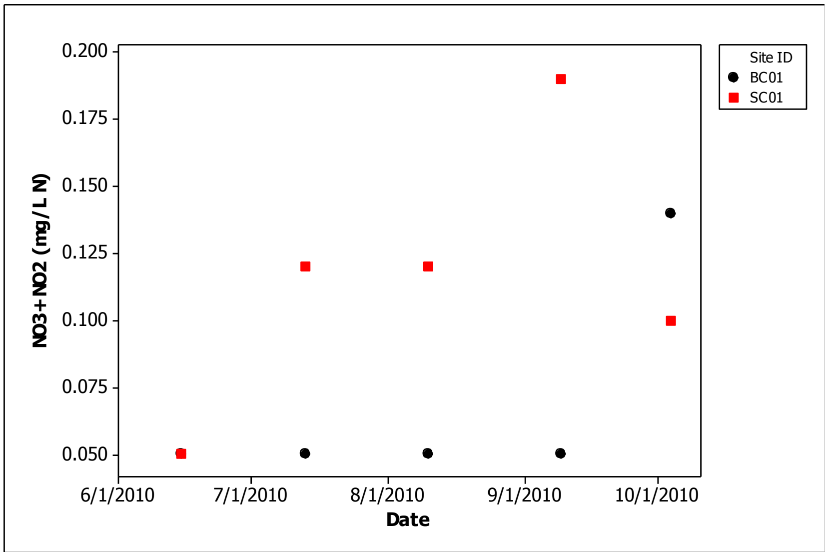


Figure 47. Scatter plot of nitrate concentrations at BC01 and SC01 over time.

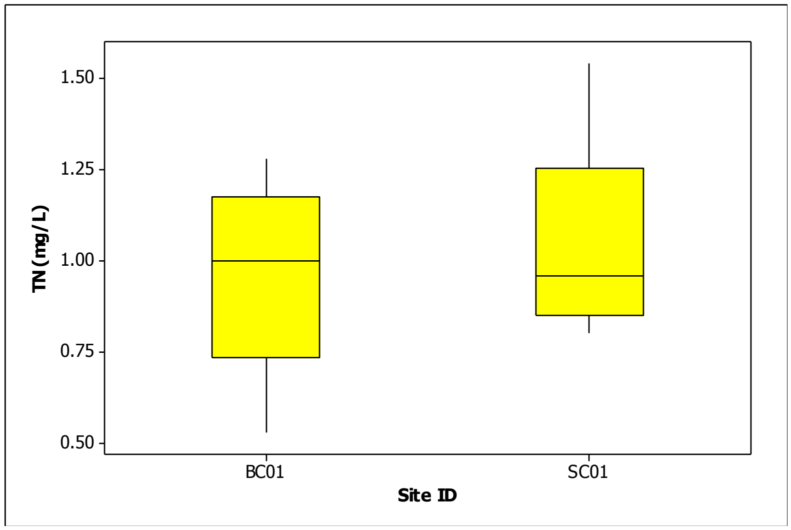


Figure 48. Box plot displaying the range of total nitrogen concentrations at BC01 and SC01 from 6/15/2010 to 10/20/2010.

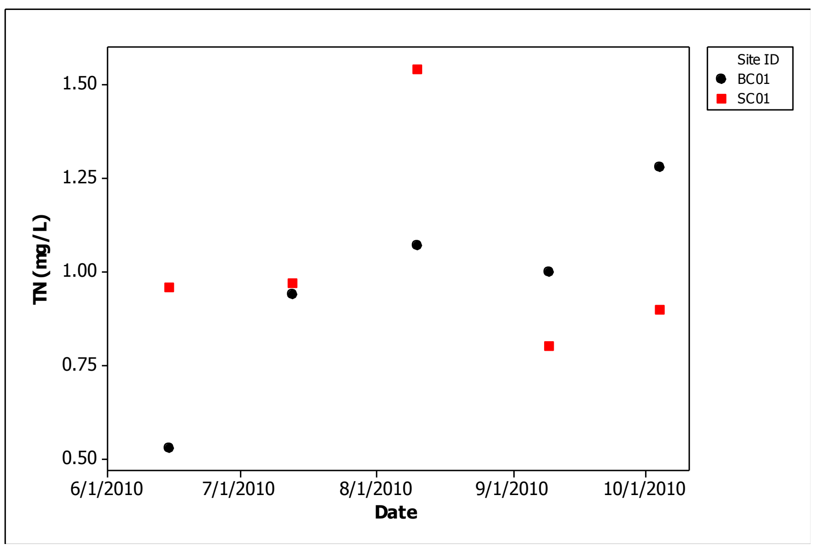


Figure 49. Scatter plot of total nitrogen concentrations at BC01 and SC01 over time.

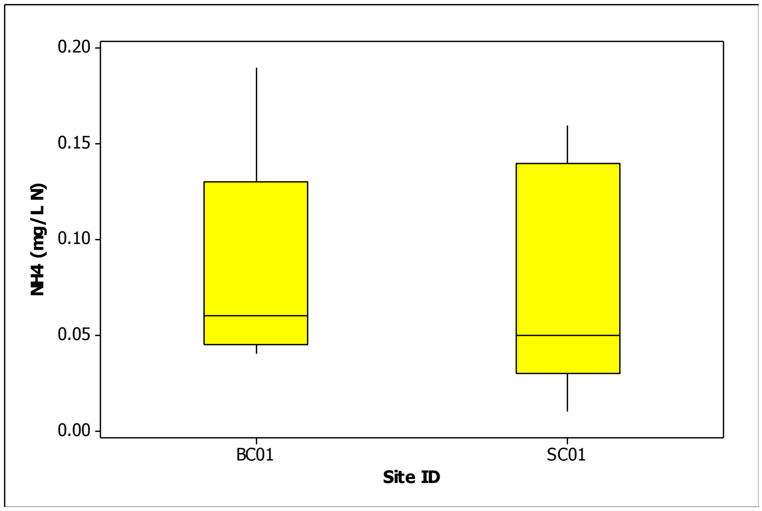


Figure 50. Box plot displaying the range in concentrations of ammonium at BC01 and SC01 from 6/15/2010 to 10/20/2010.

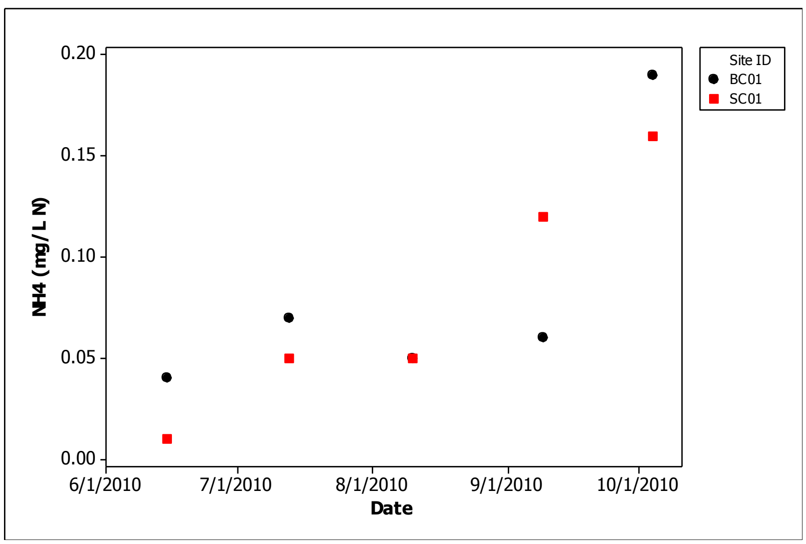


Figure 51. Scatter plot of ammonium concentrations at BC01 and SC01 over time.

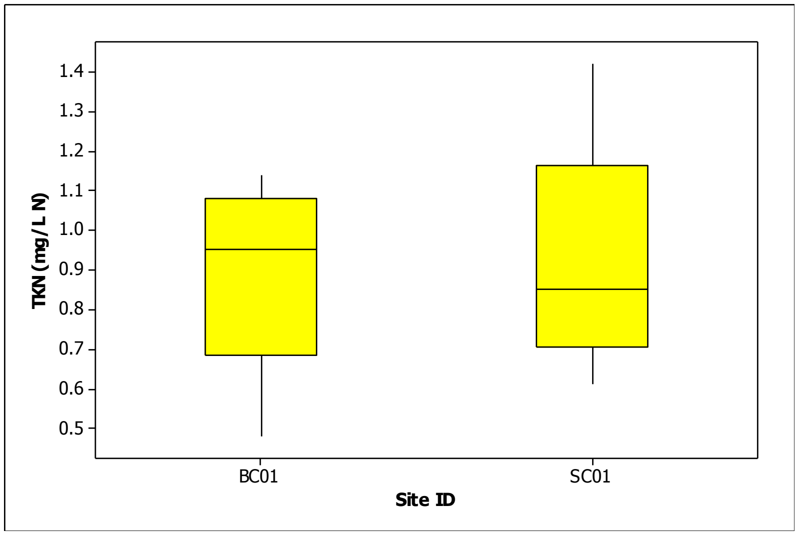


Figure 52. Box plot displaying the range in concentrations of total Kjeldahl nitrogen at BC01 and SC01 from 6/15/2010 to 10/20/2010.

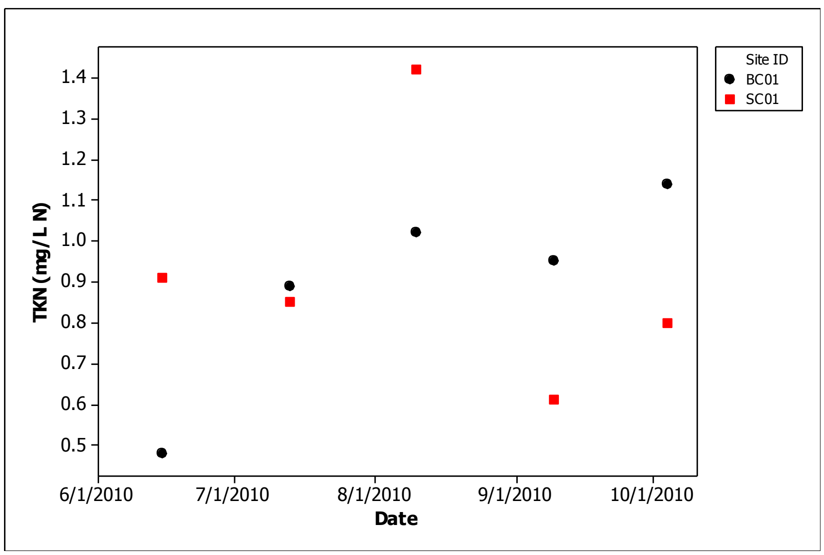


Figure 53. Scatter plot of the concentrations of total Kjeldahl nitrogen at BC01 and SC01 over time.

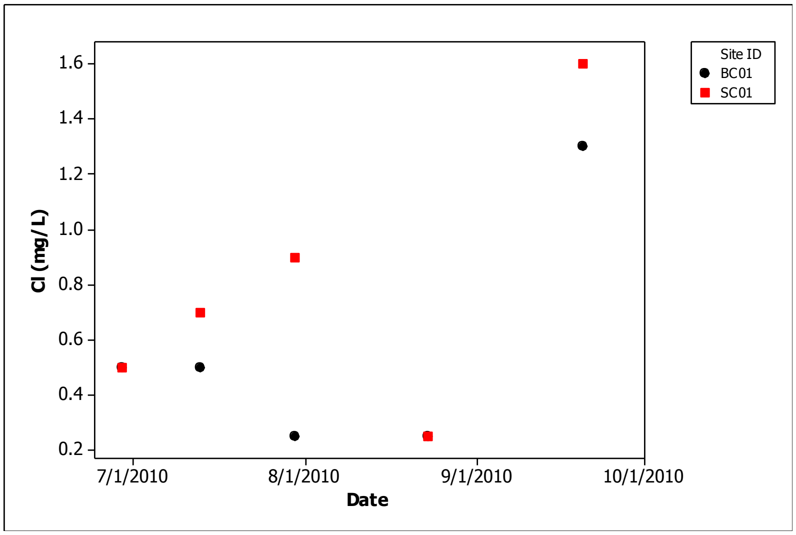


Figure 54. Scatter plot of chloride concentrations at BC01 and SC01 over time.

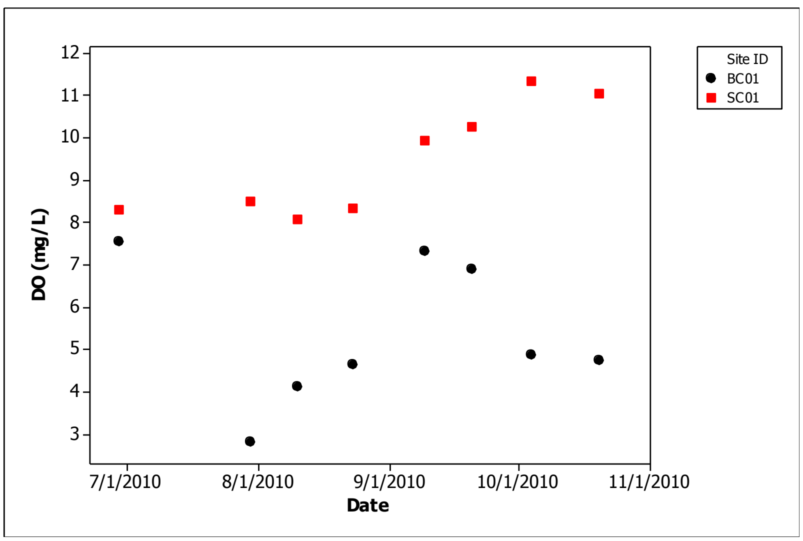


Figure 55. Scatter plot of dissolved oxygen concentrations at BC01 and SC01 over time.

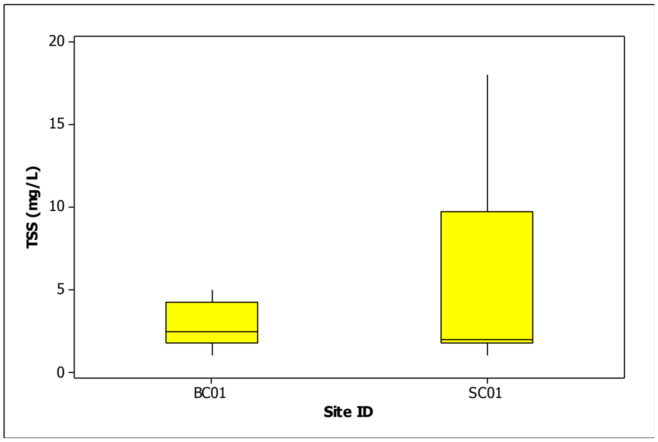


Figure 56. Box plot displaying the range in total suspended solids concentrations at BC01 and SC01 from 6/15/2010 to 10/20/2010.

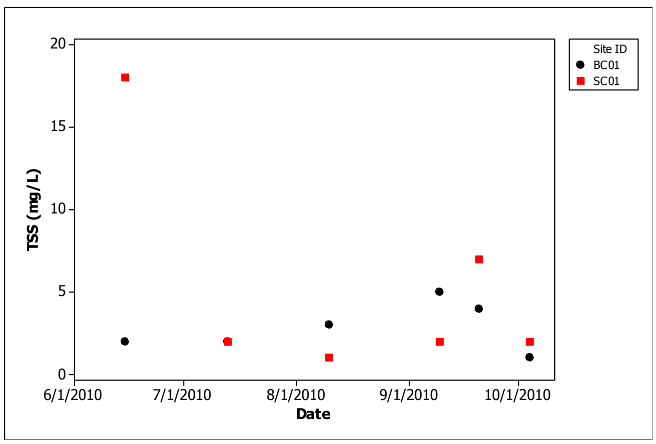


Figure 57. Scatter plot of the concentrations of total suspended solids at BC01 and SC01 over time.

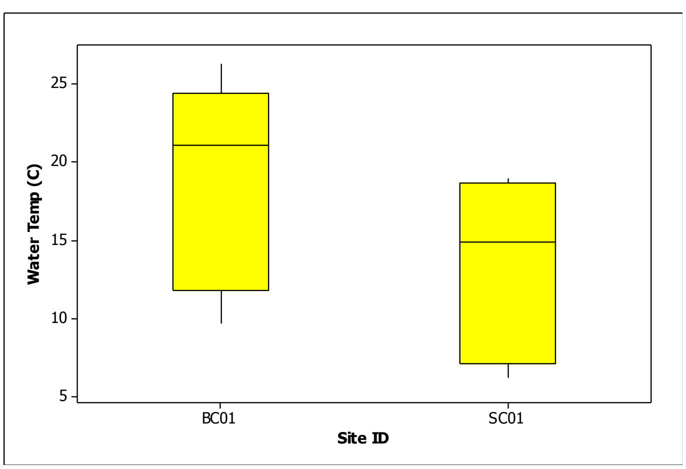


Figure 58. Box plot displaying the range of water temperatures at BC01 and SC01 from 6/15/2010 to 10/20/2010.

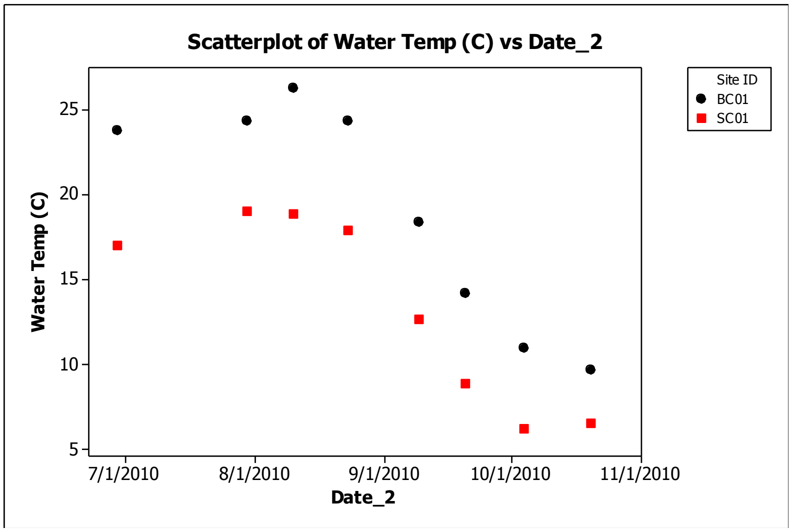


Figure 59. Scatter plot of water temperatures at BC01 and SC01 over time.

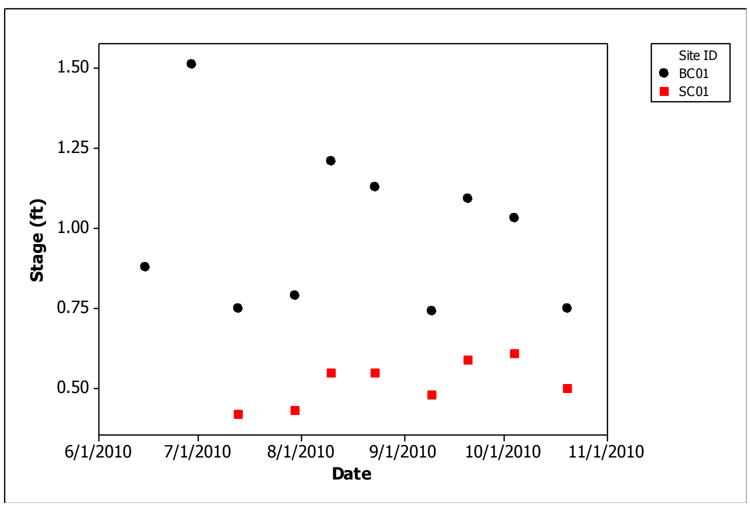


Figure 60. Scatter plot of stage height at BC01 and SC01 over time.

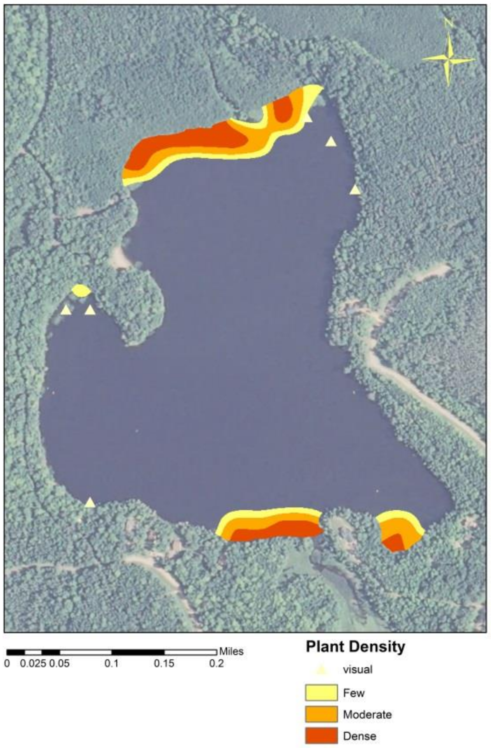
Aquatic Plant List for Bear Lake, Forest County

Type	Common Name	Scientific Name	2009	2010	2012
Submergent	common waterweed	Elodea canadensis	X		X
Submergent	coontail	Ceratophyllum demersum	X		X
Submergent	flat stem pondweed	Potamogeton zosteriformis	X		
Submergent	large leaf pondweed	Potamageton amplifolius	X		X
Submergent	northern water milfoil	Myriophyllum sibiricum		X	
Submergent	ribbon leaf pondweed	Potamogeton epihydrus		X	X
Submergent	slender naiad (bushy pondweed)	Najas flexilis			X
Submergent	small pondweed	Potamogeton pusillus		X	X
Submergent	water star grass	Zosterella dubia	X		X
Free floating	duckweed	Lemna sp.			X
Free floating	forked duckweed	Lemna trisulca		X	
Free floating	great duckweed	Spirodela polyrhiza		X	
Floating leaf	spatterdock	Nuphar variegata	X		X
Floating leaf	white water lily	Nymphaea odorata	X		X
Emergent	bristly (bottlebrush) sedge	Carex comosa		X	
Emergent	broad-leaved cattail	Typha latifolia	X		
Emergent	cattail				X
Emergent	common arrowhead	Sagittaria latifolia	X		X
Emergent	common bur-reed	Sparganium eurycarpum		X	
Emergent	creeping spike rush	Eleocharis palustris			X
Emergent	midwestern arrowhead	Sagittaria cuneata	X		
Emergent	narrow leaved cattail	Typha angustifolia		X	
Emergent	sedge	Carex spp	X		X
Emergent	soft stem bulrush	Schoenoplectus validus	X		X
Emergent	water horsetail	Equisetum fluviatile	X		
Shoreland	northern blue flag iris	Iris versicolor		X	X
Shoreland	reed canary grass	Phalaris arundinacea		X	X
Shoreland	skullcap	Scutellaria galericulata		X	

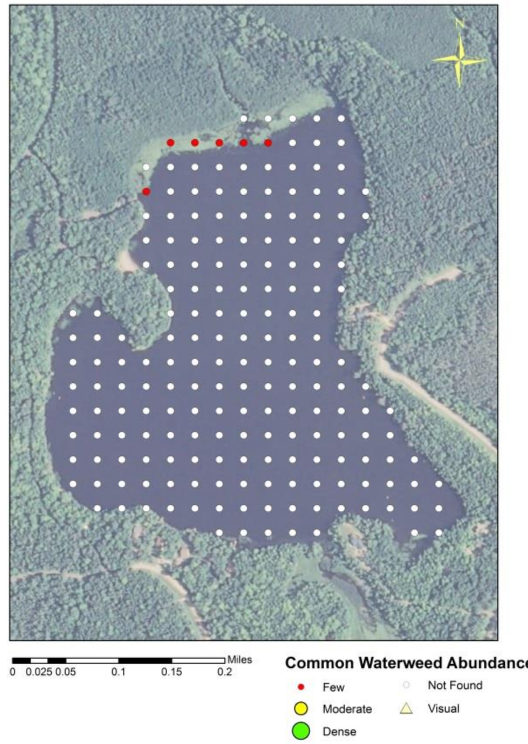
Figure 61. Cumulative list of plants at Bear Lake – from aquatic surveys July 2009 to present

Figure 62. Results of survey conducted by Bear Lake Association volunteer in 2012.

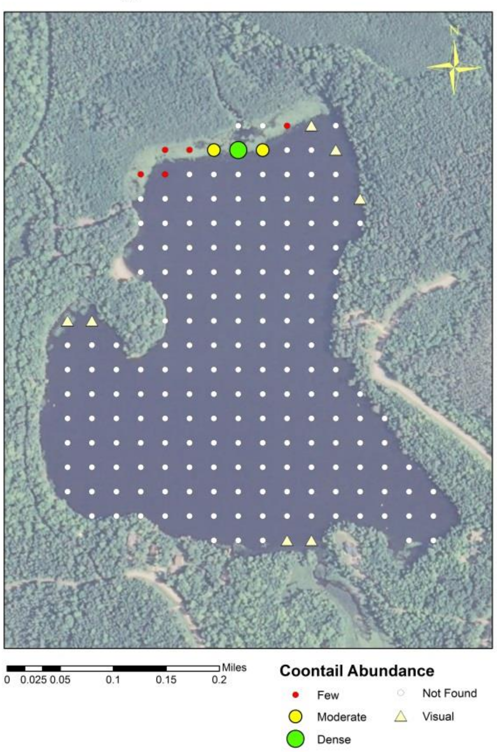
Bear Lake Aquatic Plants Survey
July, 2010 Plant Density



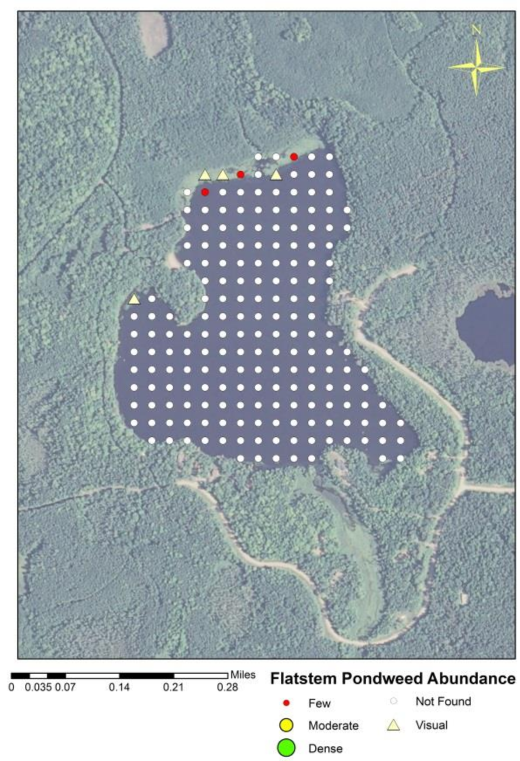
Bear Lake Aquatic Plants Survey
July, 2010 Common Waterweed Presence



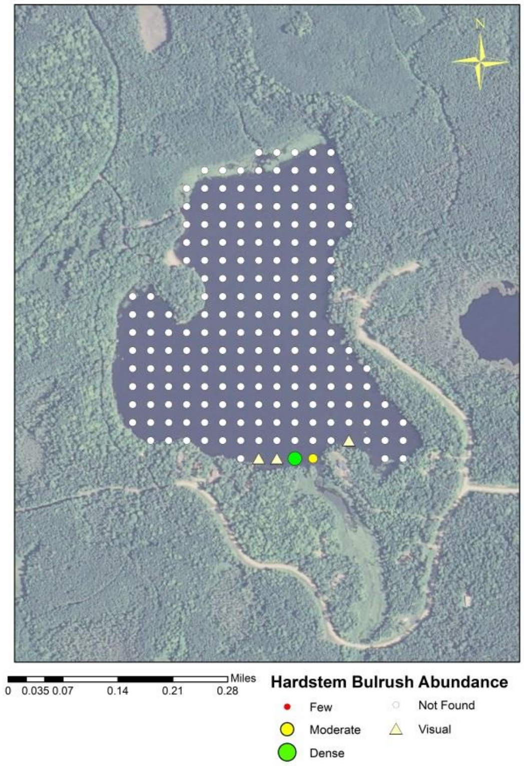
Bear Lake Aquatic Plants Survey
July, 2010 Coontail Presence



Bear Lake Aquatic Plants Survey
July, 2010 Flatstem Pondweed Presence



Bear Lake Aquatic Plants Survey
July, 2010 Hardstem Bulrush Presence



Bear Lake Aquatic Plants Survey
July, 2010 Lilies Presence