2012 Blue Lake Water Quality Report

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Introduction

Blue Lake is a spring fed lake located just south of the Columbia River in Fairview, Oregon that was created by ancestral flooding of the Columbia River. The lake itself is 61 acres (27 hectares) and has a watershed basin of 128 acres (51.8 hectares) which is made up of open water (49.7%), developed land (29.7%), and wetlands (20.6%) (Lycan, 1985). The majority of the watershed area (101 acres) is managed by Metro as Blue Lake Regional Park. The remainder is comprised of privately owned residences located along the south shore of the lake, which is made of a sandstone formation dividing Blue Lake from Fairview Lake.

Blue Lake's total water input is comprised of precipitation, surface runoff from the watershed, and groundwater seepage through the area of groundwater recharge at the bottom of the lake. The average annual precipitation at Blue Lake is 43.5 inches (NOAA, 2011). There is a weir located at the east end of Blue Lake in Salmon Creek, where water can spill over and flow north and east, where it is diverted through Multnomah County drainage district channels to the Columbia River. The weir can be adjusted to create outflow, though this is uncommon. Most years, water is retained in Blue Lake contributing to the recycling of nutrients.

Blue Lake lies 14 ft above sea level, with a maximum depth of 24 feet. However, about half of the lake is less than 10 feet deep. Located at the deepest point in the lake (Site 2) is an area of groundwater recharge (Figure 1). Depending on the level of the Columbia River, groundwater flow rates into Blue Lake are affected. The nutrient concentrations in the groundwater are higher than the lake. Historic data indicate that the lake stratifies from April to September, with a thermocline between 4 and 6 meters deep (Beak, 1979). Hypoxic conditions in the hypolimnion persist during the summer, accompanied by nutrient concentrations exceeding those in shallower water. Fall turnover allows anoxic and nutrient-rich bottom water to enrich the lake and stimulate algae growth in fall and winter.

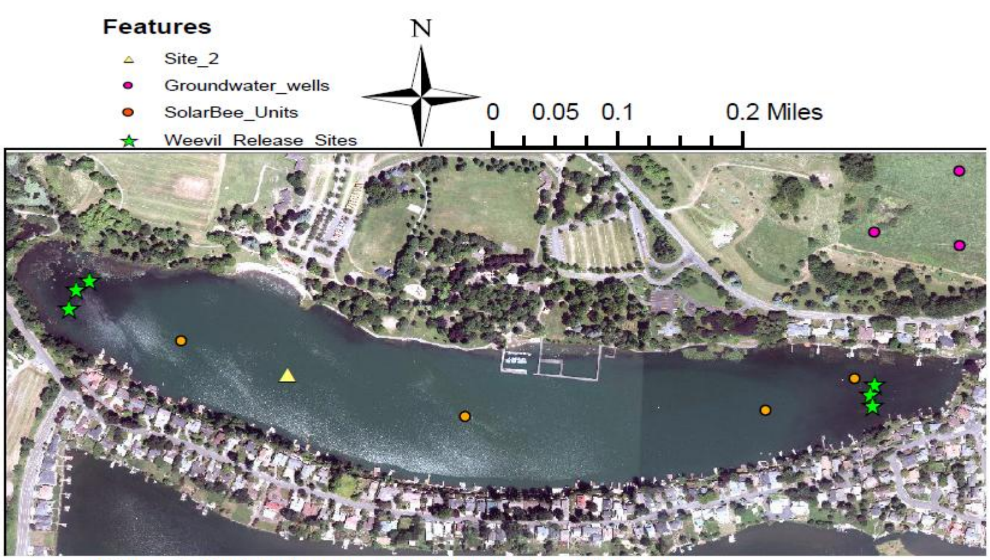


Figure 1: Aerial photograph of Blue Lake with features

Beneath the lake floor are several geologic layers that have been set down throughout history. The oldest layer is the Sandy River Mudstone which includes the Sand and Gravel Aquifer (SGA). The upper SGA contains abundant groundwater (Figure 2). Overlying the SGA is the Troutdale Sandstone Aquifer (TSA) which serves as a regional aquifer. Directly beneath the bottom of Blue Lake lies a deposit of sand and gravel deposited from erosion of the Troutdale sandstone by the ancestral Columbia and Sandy Rivers (Figure 2). These Blue Lake Gravels include the Blue Lake Aquifer (BLA) which provides water for the Interlachen PUD (Beak, 1979). Wells that tap into the SGA provide water for the Portland Water Bureau to supplement the Bull Run Watershed during summer months, when reservoir levels get low.

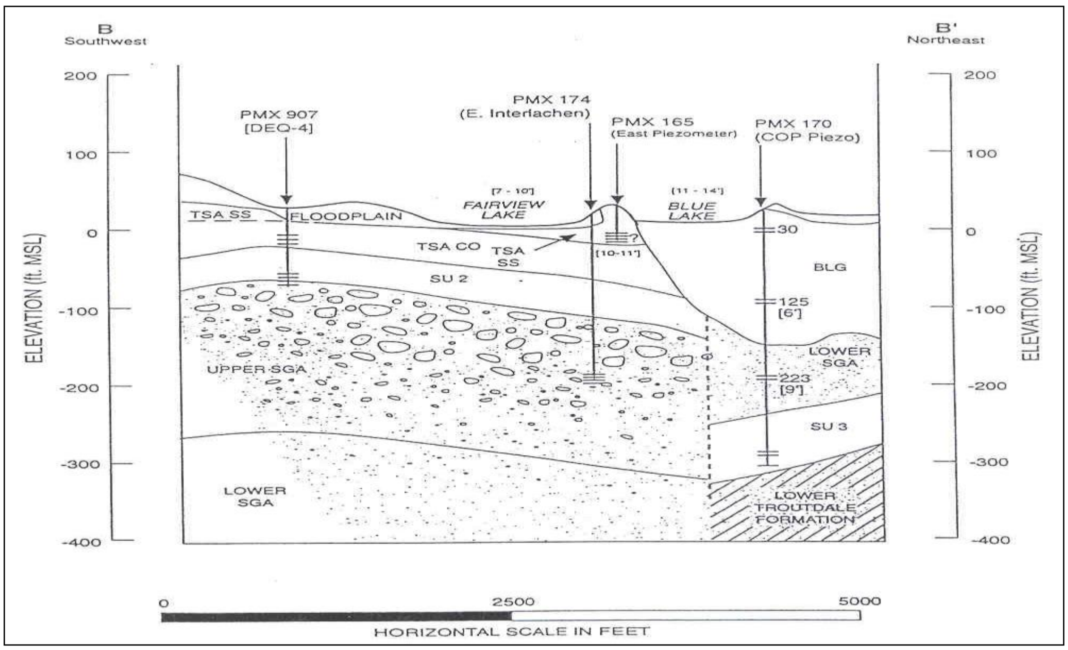


Figure 1: A drawing of the underlying sediment layers and aquifers beneath Blue Lake. (Woodward-Clyde Consultants, 1994)

Current Uses

The south and east shores of Blue Lake are occupied by residents along Interlachen road and Blue Lake road. These residents have access to the lake by personal docks. The remainder of the watershed (101 acres) is managed by Metro as Blue Lake Regional Park. The north shore contains a fishing pier and boat dock, which houses canoes and paddleboats that are available as rentals for the public. There is a designated swim beach located on the west end of the north shore of Blue Lake.

Blue Lake Regional Park serves as a recreational area for the public, bringing in several hundred thousand visitors each year. Blue Lake hosts several summer events that attract a substantial number of visitors to the lake including several triathlons. The Blue Lake Triathlon on June 9th and 10th, 2012 brought in over a thousand competitors as well as various event staff and volunteers. The Fourth of July is one of the busiest weekends at Blue Lake, attracting many visitors. Blue Lake attendance from January through September 2012 was 349,546 visitors, which is up from 315,420 from the same period last year (D. Kromer, personal communication, October 4th, 2012). A Disc Golf Course was added to the east side of the park to attract new visitors to Blue Lake. Although it is uncertain what portion of the visitors came to Blue Lake Regional Park primarily for the disc golf course, a counter has been added to the course to determine how many visitors are using the course.

Many visitors come to Blue Lake Regional Park to go fishing on the lake. The Oregon Department of Fish and Wildlife stocks the lake, typically on an annual basis unless there is overstock available. In April, ODFW added 200 of the 2010 brood-year rainbow trout from the Desert Springs Hatchery. Another 4,743 of the 2010 brood-year rainbow trout from the Leaburg Hatchery were stocked to Blue Lake. In May, stock (2011 brood-year rainbow trout) was available from Desert Springs Hatchery and another 6,416 trout were added to Blue Lake (D. Faucera, personal communication, October 26th, 2012).

Water Quality Concerns

Blue Lake has historically been problematic for nuisance aquatic plants and algae blooms, hindering recreational activities on the lake as far back as 1937 (Beak, 1979). Prior to 1979, Blue Lake would often become thick with native aquatic macrophytes during the summer months. Heavy recreation on Blue Lake through this time allowed for the introduction of several non-native species of aquatic plants from visiting boats. Since the first positive identification of Eurasian water watermilfoil (*Myriophyllum spicatum)* in 1979, Blue Lake has become dominated by the non-native macrophyte species. Several factors that contribute to the success of *M. spicatum* in Blue Lake include the lack of natural grazers of watermilfoil, the fact that new plants can be established from root fragments of the parent watermilfoil, and its relatively long growing season. The Clean Lake Study, performed by Beak Consulting Inc. from 1979-1982 provided the first comprehensive water quality data and environmental assessment of Blue Lake.

The Oregon Department of Environmental Quality placed Blue Lake on the Clean Water Act Section 303(d) list of impaired water bodies for 4 criteria. Most critical of the violations is excessive pH readings. The pH criterion for the Lower Columbia Basin (OAR 340-41-202) states that freshwater pH values shall not fall outside the range of 6.5-8.5 pH units, at which aquatic life thrives. The DEQ 303(d) standard maximum benchmark for pH is 8.5. Blue Lake has regularly exceeded this standard maximum, typically beginning in August. One driving factor in elevation of pH is algal photosynthesis which consumes CO_2, nitrogen, and phosphorus in the water column. Blue Lake is also in violation for supporting nuisance aquatic weeds. Aquatic weed criteria state that weed growth having deleterious effects on stream bottoms, fish or aquatic life, or which are injurious to health, recreation, or industry shall not be allowed (OAR 340-041-0007(11)). Additionally, Blue Lake is supportive of algae-blooms which may be potentially toxic. Since being placed on the list, Metro and the Oregon DEQ have coordinated monitoring of water quality, aquatic plant populations, and algae blooms to better manage efforts aimed at improving lake health and providing recreational opportunities at Blue Lake for the region's inhabitants.

Water Quality Monitoring and Management

During the summers of 2002 and 2003, intense chemical parameter monitoring of the lake was performed. Monitoring included profiling of temperature, dissolved oxygen, pH, and specific conductivity throughout the water column, as well as monitoring of chlorophyll-a, nutrients, and phytoplankton at both the surface and thermocline. Metro has provided a water quality intern to conduct monitoring of Blue Lake's water quality, aquatic plant populations, and presence of harmful algae blooms (HABs) since 2007; DEQ has provided sampling equipment and laboratory services for nutrient tests. Each year, Metro's monitoring efforts have provided more insight into the driving forces behind HABs as well as the natural processes that link elevated pH levels, plant growth, and the presence of algae blooms in Blue Lake.

For the monitoring season of 2012, the Oregon DEQ significantly scaled back sampling at Blue Lake. Monthly sampling for nutrients, dissolved silica, and chlorophyll-*a* was no longer required. Testing from last year closed out a 10-year dataset that DEQ and Metro had been compiling on nutrients, dissolved silica, and chlorophyll-*a* levels. Light is the most limiting factor for algal growth, followed by nitrogen and phosphorus limitations. Algal productivity is often correlated to levels of nitrogen (N) and phosphorus (P) but other nutrients are required including carbon, silica, and other micronutrients. Algal biomass is usually measured by the amount of chlorophyll-*a* in the water column. Many Oregon lakes are plagued by harmful algae blooms that can pose serious human health risks. Because Blue Lake has a tendency to form algae blooms and a complete dataset had been collected, The US Environmental Protection Agency has issued a grant to DEQ for a contract with Tetra Tech, Inc to examine how nutrients and other water quality parameters may be resulting in harmful algae blooms (K. Williams, personal communication, November 5th, 2012). The "Oregon's Nutrient Framework Technical Support" grant should shed some light on the forces that drive algal blooms.

Water quality monitoring of Blue Lake included weekly profiling at the deepest point of the lake (Site 2) with the Hydrolab unit (Figure 1). Profiling included temperature, pH, dissolved oxygen, and specific conductance readings. Samples were collected with a Van Dorn Sampler at a half meter and at the thermocline for pH and dissolved oxygen testing. Winkler titration was used to obtain dissolved oxygen levels at the surface and thermocline. Field pH readings were also taken with the DEQ issued pH meter. Although no samples were sent to the DEQ laboratory, these field readings were shared with Karen Williams of the DEQ.

Algae

Typically, algae are autotrophic (derive cell carbon from inorganic carbon dioxide), photosynthetic (derive energy for cell synthesis from light), and contain chlorophyll. They are also chemotrophic in terms of nighttime respiration, e.g., metabolism of molecular oxygen (O_2) (Kromkamp, 1989). Algae utilize photosynthesis to convert simple inorganic nutrients into more complex organic molecules. Photosynthetic processes result in surplus oxygen and non-equilibrium conditions by producing reduced forms of organic matter. Nutrients are present in several forms in aquatic systems, including dissolved inorganic, dissolved organic, particulate organic, and biotic forms. Only dissolved forms are directly available for algal growth: for nitrogen and phosphorus these include ammonia, nitrate, nitrite, and orthophosphate (as well as dissolved CO_2, and dissolved silica, etc.).

Though not true algae, certain strains of cyanobacteria (blue green-algae) can produce an active intracellular toxin, especially when phytoplankton are senescent (the growth phase following maturity and prior to death, characterized by accumulated metabolic products, increased respiration, and loss of dry weight) and decaying (Kromkamp, 1989). Through photosynthesis, algae produce oxygen in excess of respiratory requirements during daylight hours. Conversely, during low light or nighttime periods algae respire (consume) dissolved oxygen, sometimes depleting water column concentrations. Thus, high algae concentrations may lead to low dissolved oxygen concentrations.

Cyanobacteria blooms have been noted on Blue Lake dating back to 1900, based on a sediment study by Beak Consulting Inc. in 1979. Blue-green algae have the tendency to form massive blooms which can produce neurotoxins, hepatotoxins, and dermatoxins which can be harmful to aquatic life, humans, and pets. Early attempts to control blooms included treatment with copper sulfate from the 1940s through the 1970s (Beak, 1979). Algaecides were used in 2000 in an effort to control blue-green algae blooms and muskgrass (*Chara),* which is a native plant-like alga. However, due to Blue Lake's natural tendency to recycle nutrients in summer months, early efforts were mostly unsuccessful in controlling problematic aquatic macrophytes and algae.

Oregon Public Health Division (OPHD) is working to gain an understanding of cyanobacterial harmful blooms (cyanoHABs) in Oregon and their impact on human health. The US Centers for Disease Control and Prevention (CDC) has funded this work through a five year federal grant (10/2008 – 9/2013). The Oregon Harmful Algae Bloom Surveillance (HABS) Program provides sampling guidelines for managers of recreational waters for the testing of cyanobacterial harmful blooms.

Recent changes to OPHD's guidance for HAB management require lake managers to obtain toxin data rather than cell counts of potentially toxin-forming cyanobacteria (the previous method). A monitoring program based on toxins rather than cell counts will likely result in fewer and shorter duration on public health advisories, but may have higher sampling costs. Toxin-based monitoring programs provide the most accurate information in terms of public health because toxins pose actual risk whereas the presence of cyanobacterial cells represents potential risk. It is important to test for toxins that are potentially produced by the dominant species of cyanobacteria in a specific water body. For this reason, it is first necessary to identify the dominant species to determine the associated toxins. New to the HABS program in 2012, toxin analyses are now required to lift a public health advisory for cyanoHABs.

Although no chlorophyll-a sampling was conducted, weekly algal monitoring was performed by recording Secchi depth, a measurement of water clarity. If Secchi depth was lower than 2 meters, water samples were collected at site 2, both at the surface and thermocline, as well as a surface sample from the swim beach. Samples were preserved in bottles containing Lugol's solution, which preserves the samples. These samples were saved for Nicole Alfafara with Portland State University to perform cell counts and identification of the phytoplankton community. Algal sampling was conducted according to the Harmful Algal Bloom Surveillance guidelines in the event of an algae bloom.
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Documents/HABSamplingGuidance8.01.2012.pdf

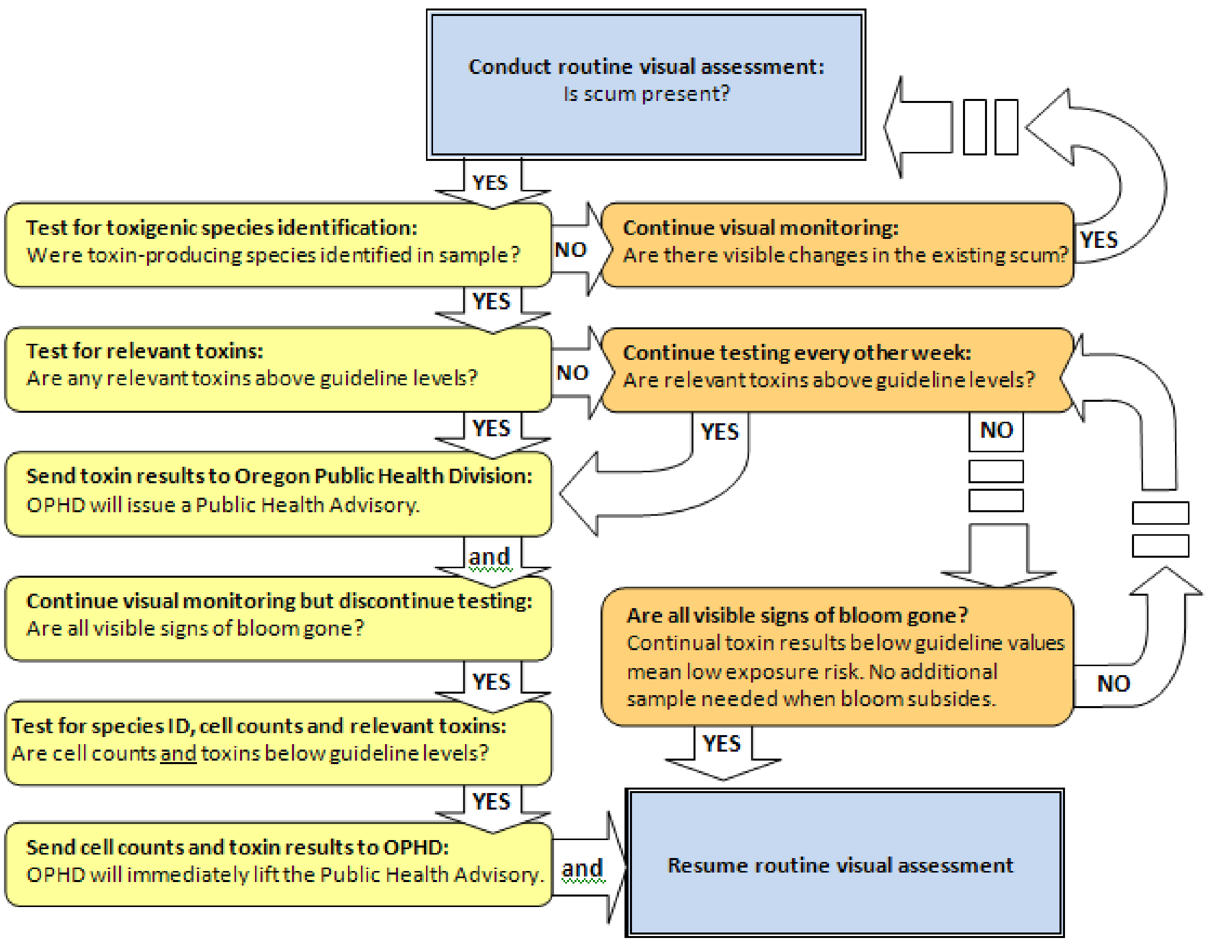


Figure 3: 2012 HABS program sampling guidelines

When a visible bloom was present, a worst case sample was collected for toxic algae identification. Worst case samples were sent to Aquatic Analysts for cell counts and species identification. If toxic species were identified at levels exceeding the DHS standard (100,000 cells/ml) lake closure was required for at least 2 weeks from initial sampling. DHS requirements also state that toxin testing must be performed to identify and quantify the amount of toxins being produced by the algae. Samples revealing toxic algae cell counts above DHS standard were sent to Lake Superior State University Environmental Analysis Laboratory for high-performance liquid chromatographic (HPLC) testing. HPLC testing includes toxin testing for cylindrospermopsin, anatoxin, and microcystin variants. An advisory cannot be lifted until toxin concentrations are below guideline levels and an algae bloom is no longer visible. When a bloom has dissipated, subsequent sampling for cell count and species identification must reveal cell counts below the DHS standard for toxin producing species.

Vegetation

In 2004 an extensive vegetation study funded with a DEQ 319 grant was performed on Blue Lake by PSU's Center for Lakes and Reservoirs, resulting in the Vegetation Management Plan that suggested a short term strategy to control macrophyte (aquatic plant) populations by implementing physical, mechanical, and biological controls to reduce the biovolume of aquatic weeds and algae (Pfauth & Sytsma, 2004). Physical controls include hand pulling or raking of aquatic plants, the placement of bottom barriers, diver harvesting, and water level manipulation (Pfauth & Sytsma, 2004).

Water level draw-down during the winter to expose macrophytes to freezing temperatures has been ruled out as an effective treatment. An attempt to draw down water levels in 1981 caused extensive damage to private property along Blue Lake and was determined to be unsuccessful in controlling macrophytes (Pfauth & Sytsma, 2004). This method is also ineffective in removing the phosphorus from decayed macrophytes from the watershed system. Elevating water levels in Blue Lake by pumping groundwater from Portland Water Bureau (PWB) wells into the lake has been helpful in reducing entanglement of boats in aquatic weeds. However, due to high costs of pumping PWB water, this technique has been used sparingly. Also, adding nutrient rich groundwater to Blue Lake has the potential to introduce more nutrients to Blue Lake which may lead to macrophyte growth and/or harmful algae blooms. There has been no water pumped into Blue Lake since 2010.

Mechanical controls that have been suggested for Blue Lake include sediment agitation, rotovation, and mechanical harvesting. Both rotovation and mechanical harvesting would not be successful in controlling Eurasian waterwatermilfoil populations in Blue Lake because they create plant fragments that may establish new plants. In 2007, a cost-sharing arrangement with Metro and the Blue Lake homeowners funded the introduction of SolarBees to Blue Lake to circulate the water. The manufacturer asserts that SolarBees cause oxidation of the littoral zone sediments, inhibiting aquatic weed growth (SolarBee,Inc., 2007). SolarBee representatives also state that SolarBees disturb the buoyancy of cyanobacteria, preventing them from forming large blooms.

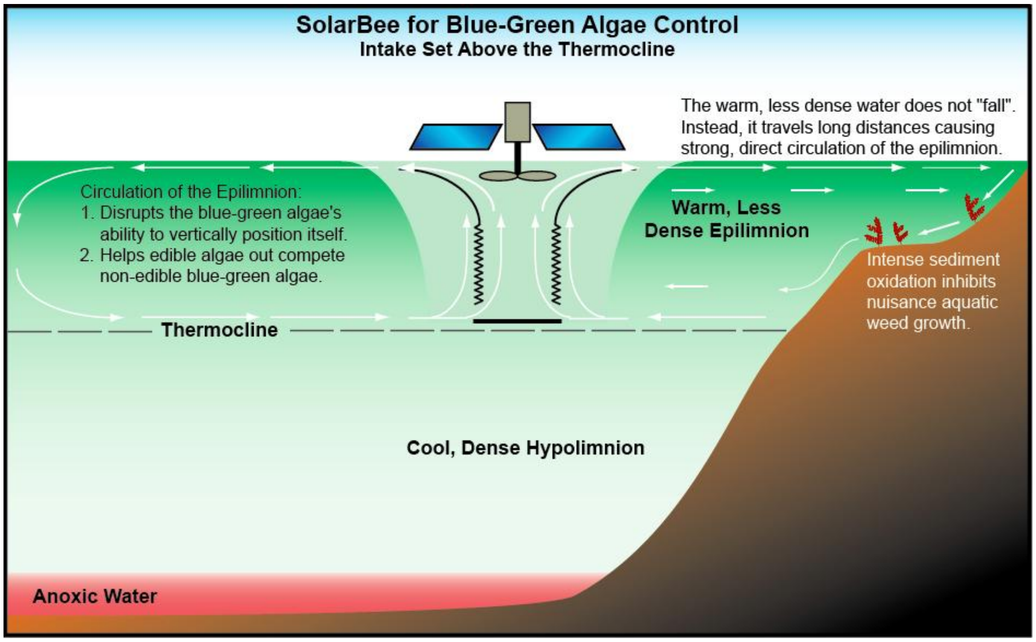


Figure 4: SolarBee publication for controlling cyanobacteria and aquatic weeds.

Metro established three criteria for success with SolarBees that included decreasing pH measurements below 8.5, the absence of harmful algae blooms, and the improvement of water clarity. After algae blooms in 2009 and 2010 and increasing complaints about macrophyte density in the eastern portion of the lake, Solar Bee representatives recommended changing the SolarBee configuration, moving the eastern Solar Bee further into the shallower eastern portion of the lake. While homeowners have noted increased lake clarity and wildlife, particularly osprey, around the lake, the lake continues to experience high pH readings and algae blooms. The first year that Solarbee units were used, there were no pH exceedances in July or September. However, subsequent summer seasons yielded increasing occurrences of pH levels exceeding 8.5. This would suggest that the number of pH violations is not directly related to the presence or absence of SolarBee units. 2011 was the first summer in which there were no exceedances of the pH standard. There is a well-understood relationship between water temperature and pH; warmer water stimulates plants, increasing photosynthesis which increases pH. Water temperatures in 2011 only reached 24°C once; at Blue Lake, high pH measurements tend to occur at temperatures greater than 24^{o}C. Although the presence of a fourth SolarBee unit in 2011 provided additional circulation, the absence of pH violations in 2011 was more likely due to the cooler water temperatures related to cooler weather and higher water levels.

Weevils (*Euhrychiopsis lecontei)* are an example of one biological control of nuisance aquatic plants in Blue Lake. Weevils are a natural grazer of Eurasian waterwatermilfoil. Initial stocks of weevils were introduced to Blue Lake in 2010 by Enviroscience Inc, at the request of the Blue Lake Improvement Association (BLIA), funded by a DEQ 319 grant. An additional stock was added in 2011. Enviroscience Inc has provided weevils as well as subsequent monitoring of weevil population and evidence of weevil damage to watermilfoil. Results from the 2011 survey conducted by Enviroscience Inc showed that the weevils had established a population and were showing positive effects. The 2012 watermilfoil program survey of Blue Lake showed that weevil populations had moved beyond the release areas and into the former control area. Damage to Eurasian watermilfoil from weevil larvae was evident throughout the areas surrounding the release sites. The weevil population had successfully overwintered and new larvae were noted (S. Lomske, personal communication, October 4th, 2012).

2012 Conditions

Climatic changes heavily influence the conditions in Blue Lake from year to year. These conditions are affected by available sunlight hours, cloud cover, air temperatures, and precipitation, and river levels. In 2012, fairly heavy cloud cover continued through June. In July, days became clearer providing more sunlight hours per day for growing plant and algae populations to photosynthesize. Air temperatures remained around average for July, but both August and September experienced higher than average maximum air temperatures for the month. Days with elevated air temperatures and very little cloud cover can contribute to significant warming of the epilimnion. Warmer water temperatures provide ideal growing conditions for macrophytes and phytoplankton populations.

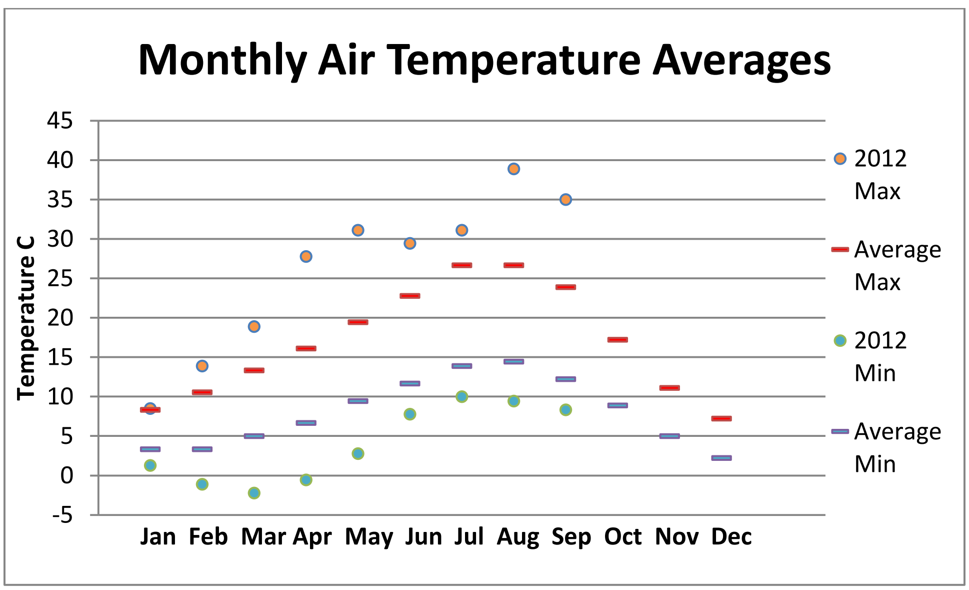


Figure 5: 2012 air temperature averages compared to Portland area averages.

Precipitation can have several effects on lake water quality. Precipitation provides cloud cover and additional water, allowing the surface water to cool slightly. Precipitation also provides nutrient loading from run-off, which can include phosphates from lawn fertilizers. Such loading can provide nutrients to growing algal and macrophyte populations, further affecting water quality. Eutrophication occurs when excess nutrient loading causes aquatic plants and phytoplankton to choke up waterways. June experienced precipitation that was above average for the time of year. Precipitation abruptly ceased in July, with only scant precipitation from July through September. Blue Lake likely experienced external nutrient loading through June, when precipitation stopped, followed by a significant increase in sunlight availability and evaporation for the next 2 months.

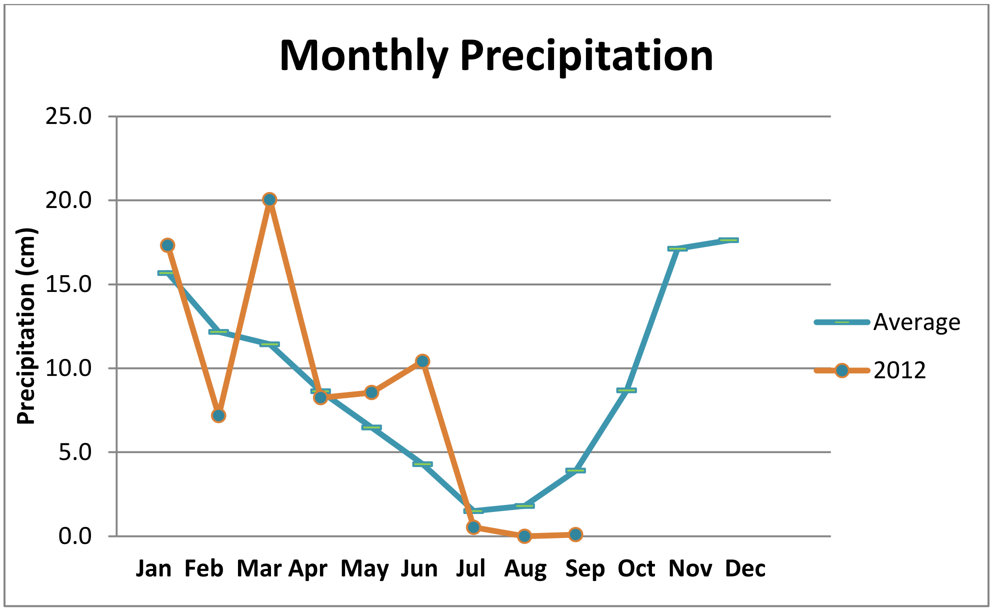


Figure 6: Portland area precipitation for 2012 compared to monthly averages

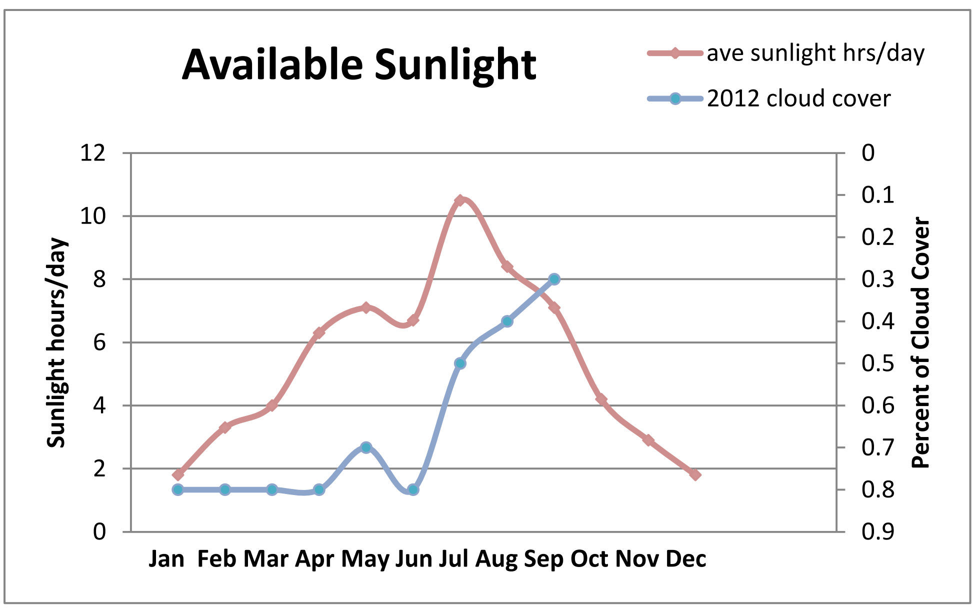


Figure 7: 2012 monthly average sunlight availability vs. cloud cover.

Generally speaking, freshwater lakes typically have background levels of total phosphorus less than 0.03mg/L. Natural levels of phosphate usually range from 0.005-0.05mg/L (Kromkamp et al., 1989). Increasing the available phosphorus allows plants to assimilate more nitrogen before the phosphorus is depleted. Thus, if enough phosphorus is available, elevated concentrations of nitrates may lead to algal blooms. In a typical freshwater lake, phosphate levels of 0.08-0.10 ppm may trigger periodic algae blooms. Eutrophication may be prevented by maintaining total phosphorus levels below 0.5 ppm (Kromkamp et al., 1989). However, this may not necessarily be true of Blue Lake. The goal of the Oregon's Nutrient Framework Technical Support grant is to determine the role that nutrients play in algal blooms in Blue Lake. Phosphorus can originate from natural sources as well as point sources. Phosphorus is naturally released by lake sediments during seasonal turnover. Decaying plant and phytoplankton matter in the sediments are re-suspended during lake turnover. Point sources of phosphorus are sewer treatment plants or septic tanks. Additional phosphorus from industrial products like toothpaste, detergents, pharmaceuticals, and food-treating compounds can leach into the waterways.

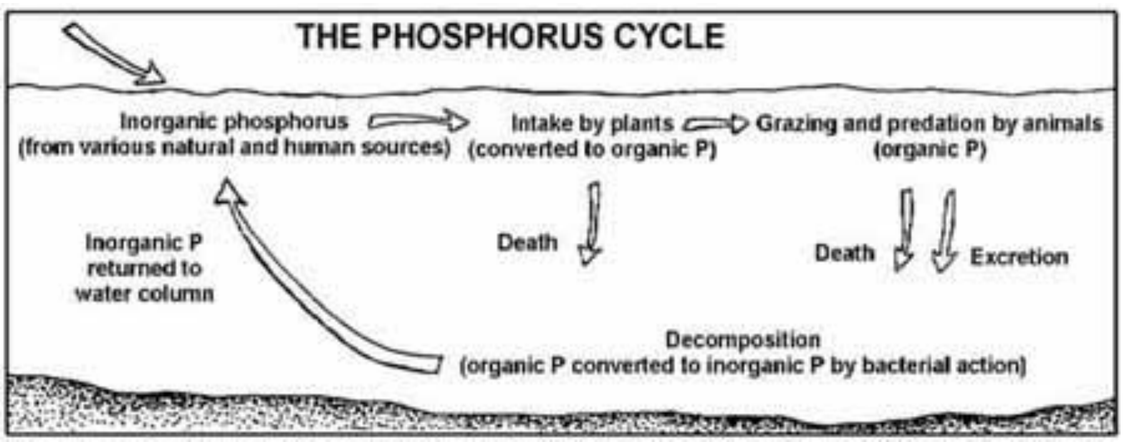


Figure 8: Diagram of the phosphorus cycle in a lake

Water Quality

Staff gauge

A slow decrease in lake level can be noted in early July as precipitation decreased. After July, precipitation ceased completely and cloud cover dissipated. As cloud cover decreased, lake levels began to drop more significantly due to evaporation of surface water. Evaporation began to slow toward the end of September when air temperature cooled and cloud cover increased again. When compared with data from previous years, lake depth progressed similarly to previous seasons. However, lake depth for the monitoring season of 2012 started out much lower in elevation than lake depth for 2011. This was due to unusually high river levels that were noted in 2011.

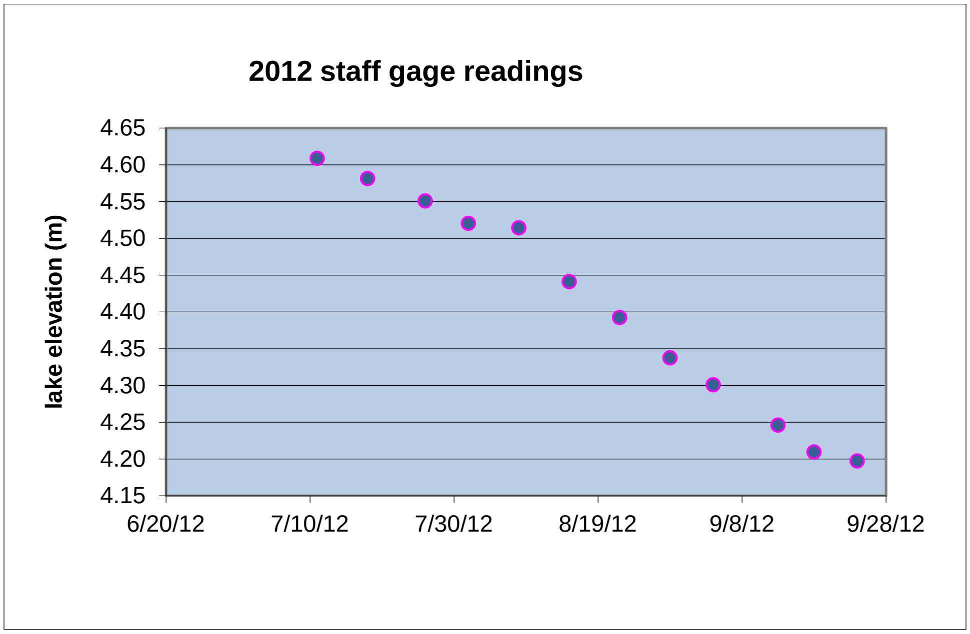


Figure 9: Water elevation (in meters) of Blue Lake through the summer of 2012.

Secchi Depth

Throughout June and July water clarity was at its maximum at 13 feet, more than half the depth of Blue Lake. For the time of year, water clarity was above average. By August, when cloud cover had completely vanished there was plenty of sunlight available for plant and phytoplankton populations. By the second week of August, Secchi depth was half of what it was in July. As air temperatures continued to rise throughout August, surface water temperatures also rose. Water clarity continued to decrease for the last two weeks of August, reaching its lowest point (1m) in the first week of September. Secchi depth was about average for September and August, despite the above average clarity earlier in the season.

By looking at monthly averages for Secchi depth, we can compare water clarity from year to year. It is typical for Blue Lake water clarity to increase in June and July compared to a decrease in clarity through August and September. Water clarity in 2011 was significantly increased throughout the entire summer season, due to the unusually high water levels. 2012 experienced more typical water levels, as well as water clarity. Although water clarity started out well in July, as cloud cover cleared and sunlight availability increased, Blue Lake experienced a dramatic shift in water clarity. The overall green color of the lake was an indication of an increased phytoplankton populations, although no specific testing was performed to confirm.

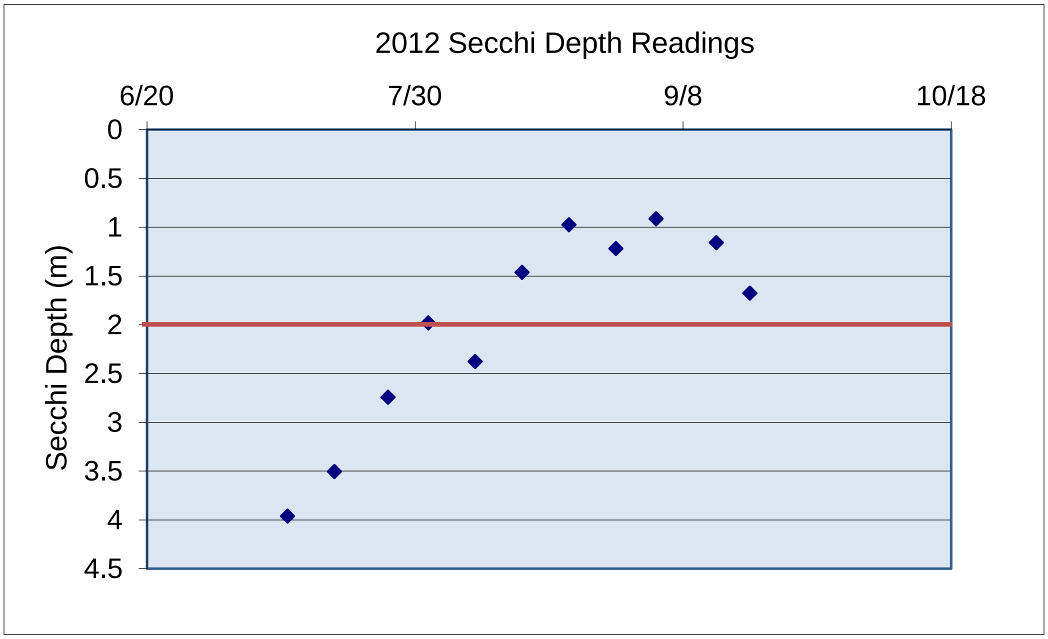


Figure 10: Water clarity readings (Red line indicates risk of algal bloom)

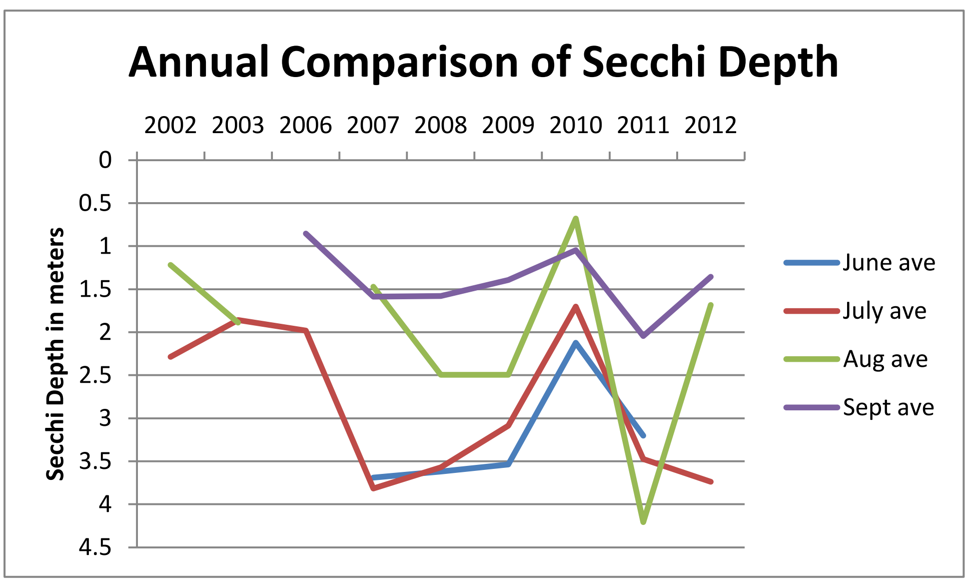


Figure 11: Comparison of monthly averaged water clarity each year.

Temperature

Blue Lake had stratified before the monitoring season had begun. A thermocline was identified at 5 meters deep in July. The epilimnion ranged from about 23-24 C while the hypolimnion was cooler, ranging from 19-21 C. Early August was relatively cool, and surface water temperatures were maintained at 23.76 C. By the second week in August, the air temperatures increased. Surface water temperatures also increased to 25.36 C. Water temperatures at the surface exceeded 25 C until the last week of August when it cooled to 23. By September, water temperatures had cooled to 21-22.4 C. No thermocline could be identified by the second week in September. Based on temperature profiles that were analyzed, fall turnover occurred after September 4th, 2012.

pH

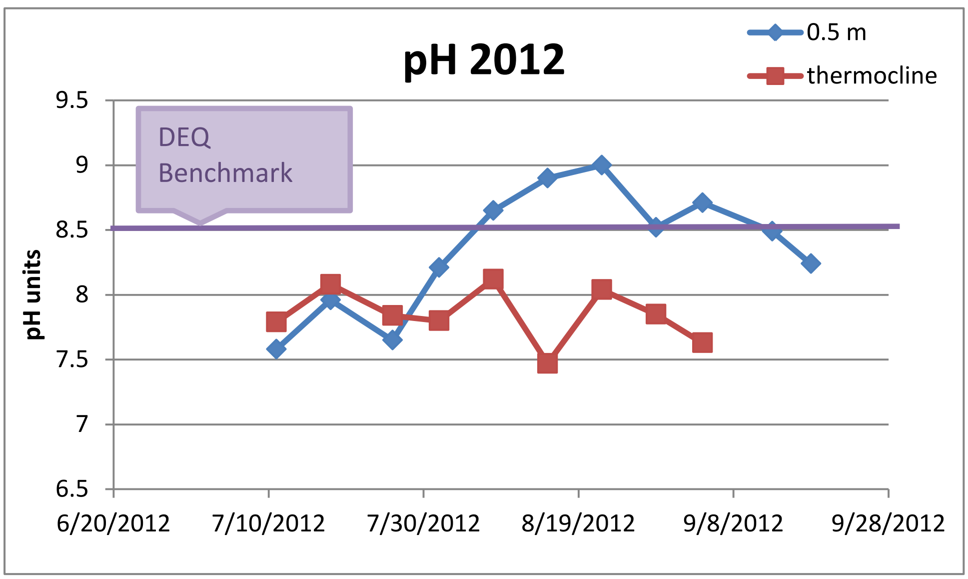


Figure 12: pH readings from the Hydrolab unit at the surface and thermocline.

A pH range of 6.5-8.5 is best maintained for aquatic life in Blue Lake. Although Blue Lake did experience several violations of the DEQ benchmark, the number of incidences has decreased. In the past, Blue Lake has experienced violations of the DEQ benchmark, typically in August or September. In 2011, there were no exceedences of the benchmark, most likely related to the elevated lake levels. This season, Blue Lake experienced 2 violations in late August and one in early September, both from surface samples. These violations seem to coincide with the warmest days of the season with the least cloud cover, allowing the epilimnion to warm quickly. A warm epilimnion with available nutrients provides ideal conditions for algae growth. When algae or macrophyte populations are increased, photosynthesis can cause a significant diurnal swing in pH readings, leading to violations.

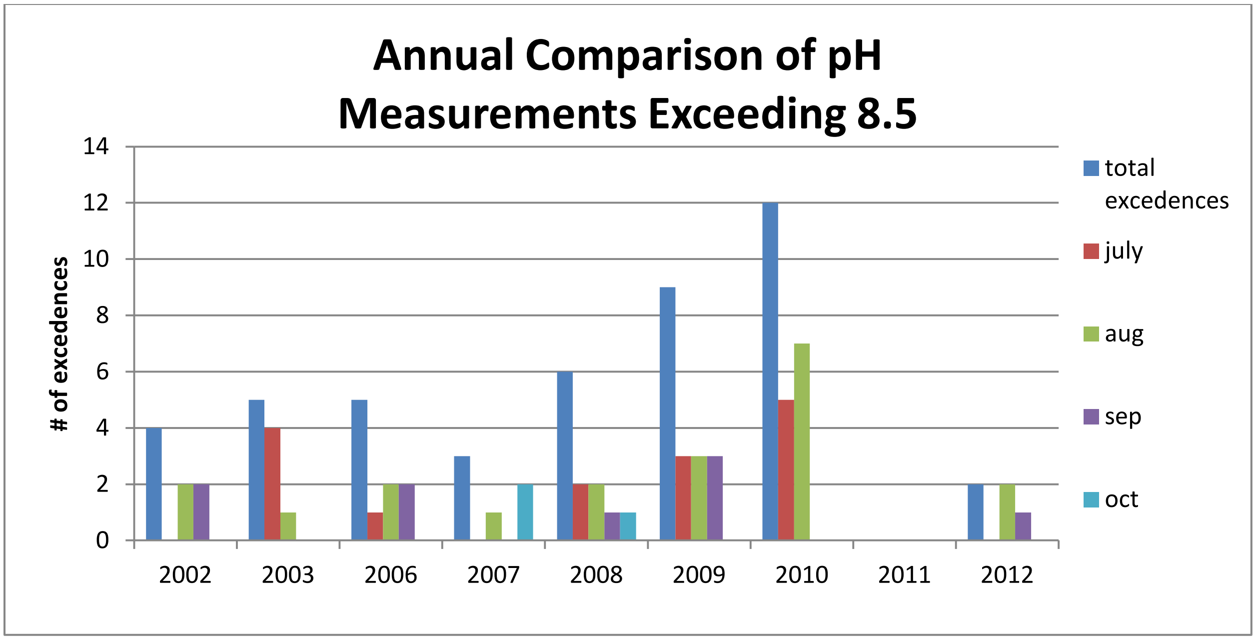


Figure 13: Frequency of excessive pH readings each year, measured weekly from June or July and the end of September.

Dissolved Oxygen

Throughout July, surface samples maintained steady dissolved oxygen readings. In early July, samples at the thermocline also had fairly high dissolved oxygen readings. By August, a significant drop in dissolved oxygen level below the thermocline was noted. Near the lake bottom, anoxic conditions existed. These lower dissolved oxygen concentrations below the thermocline could be due to plant decay from early season plankton blooms. For the rest of the season, dissolved oxygen levels remained fairly low below the thermocline. At the surface an increase in dissolved oxygen can be noted in the third week of August followed by a decline until the first week of September. This bump in surface dissolved oxygen readings, which coincided with an algae bloom could be an indication of algal photosynthesis taking place above the thermocline. As the bloom dissipated by September 4th, 2012, dissolved oxygen readings also decreased before stabilizing again toward the end of September.

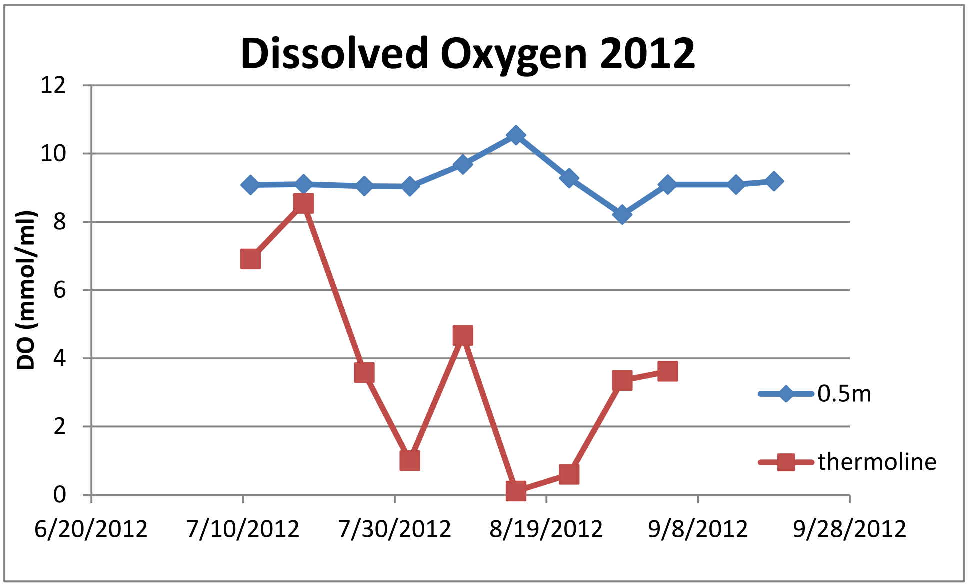


Figure 14: Hydrolab unit dissolved oxygen readings at the surface and thermocline.

Specific Conductance

Specific conductance is a measurement of solutes in the water column. Typically, when the lake is stratified, the specific conductance will be higher below the thermocline than at the surface. Specific conductance at the surface was lowest during the beginning of the sampling season. Between mid-July and mid-August there was a significant but steady increase in specific conductance in the surface samples. For the last two weeks of August and the first week of September, the specific conductance stabilized, while the lake was experiencing a cyanobacteria bloom. Then by the second week in September, the specific conductance had increased again and could not be distinguished with that deeper in the lake. It is estimated that this marked fall turnover.

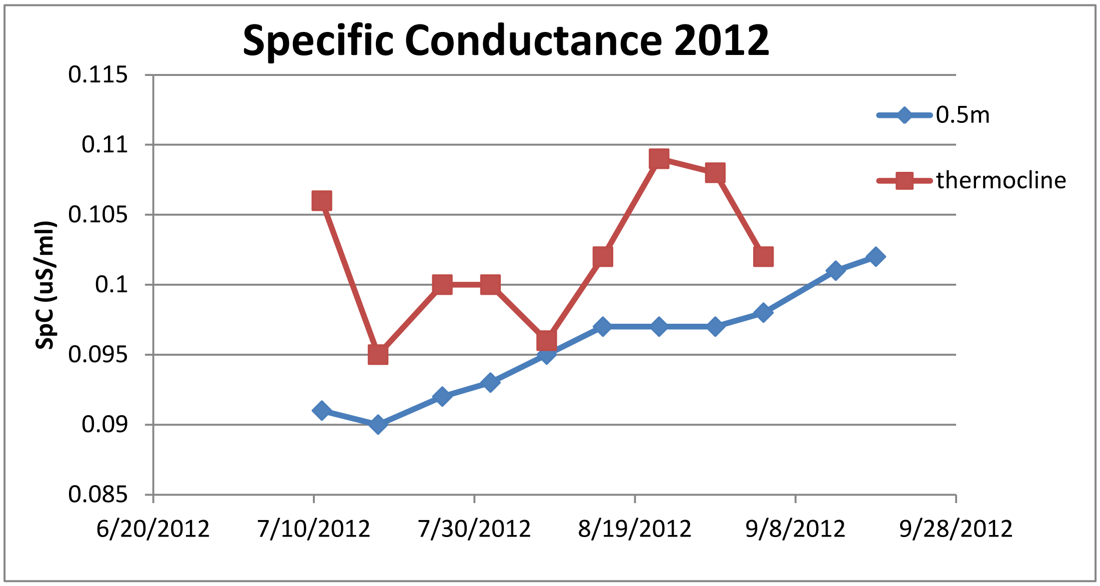


Figure 25: Hydrolab unit readings for specific conductance at the surface and thermocline.

Algae

Algal sampling consisted of collecting a surface sample, a thermocline sample, and a surface swim beach sample when the Secchi depth was less than 2 meters. These samples were collected in bottles containing Lugol's solution as a preservative. The samples were to be used for cell counts and identification, but not toxin testing. In the event of an algae bloom, a worst-case sample was collected for cell count and identification. If cell counts of toxin-producing species were above the DHS standard of 100,000 cells/ml, lake closure was issued and toxin testing was required prior to reopening. A worst-case sample on ice was to be sent to Lake Superior State University for HPLC testing. To lift an advisory, cell counts for potential toxin producing cyanobacteria must be below the DHS threshold of 100,000 cells/ml and toxin concentrations must be below guidelines.

Water clarity started out very well in July, but as surface water temperatures rose, Secchi depth decreased. By the third week of August, Secchi depth was less than 2 meters. Surface water temperatures rose above 25 C and the pH above the thermocline exceeded the DEQ standard of 8.5 pH units. All of these conditions indicated an algae bloom. By the fourth week of August, an algae bloom was visible (10 sq ft) in the southwest corner of the lake in very shallow water. On August 22nd a worst-case sample was collected and sent to Aquatic Analysts for cell count and identification. Results showed the dominant species was *Aphanizomenon flos-aquae*, with a cell count of 346,000 cells/ml. This is the same species that was identified during the bloom that occurred at the same time of year in 2010. Lake closure was issued on August 25th 2012. The lake remained closed for the next two weeks while the bloom remained visible. When the bloom had apparently dissipated, subsequent sampling was conducted for cell count and toxin testing. HPLC testing was performed at LSSU. Results showed cylindrospermopsin (<0.20ug/L) and anatoxin (<0.20ug/L) were below health risk levels, and results were negative for microcystin. The advisory for Blue Lake was lifted on September 10th, 2012.

Year	Month	Week	Peak cells/ml	Dominant
2003	Sept.	3	9,616,736	Microcystis
2009	Oct.	2	1,559,708	Anabaena
2010	Aug.	4	259,187	Aphanizomenon
2012	Aug.	3	346,595	Aphanizomenon

Figure 36: Table of identified cyanobacteria when blooms have occurred.

When cyanobacteria blooms occur in Blue Lake, it tends to happen toward the end of the summer, as water temperatures rise. Both cyanobacteria blooms from 2012 and 2010 were identified as *Aphanizomenon* (Figure 16). There was also a bloom of *Aphanizomenon* in 2011, but the cell count (5000) was below the toxic cell count threshold and no advisory was issued. These blooms both initiated in the third week of August and slowly dissipated into September (Figure 17). Previous cyanobacteria blooms that occurred in Blue Lake were dominated by *Anabaena* in 2009 and *Microcystis* in 2003. The *Microcystis* bloom occurred in late September, just after fall turnover when nutrient availability significantly increased. The *Anabaena* bloom began in the second week of October 2009 (Figure 17). It appears as though certain cyanobacteria prefer specific conditions that are present either prior or after fall turnover.

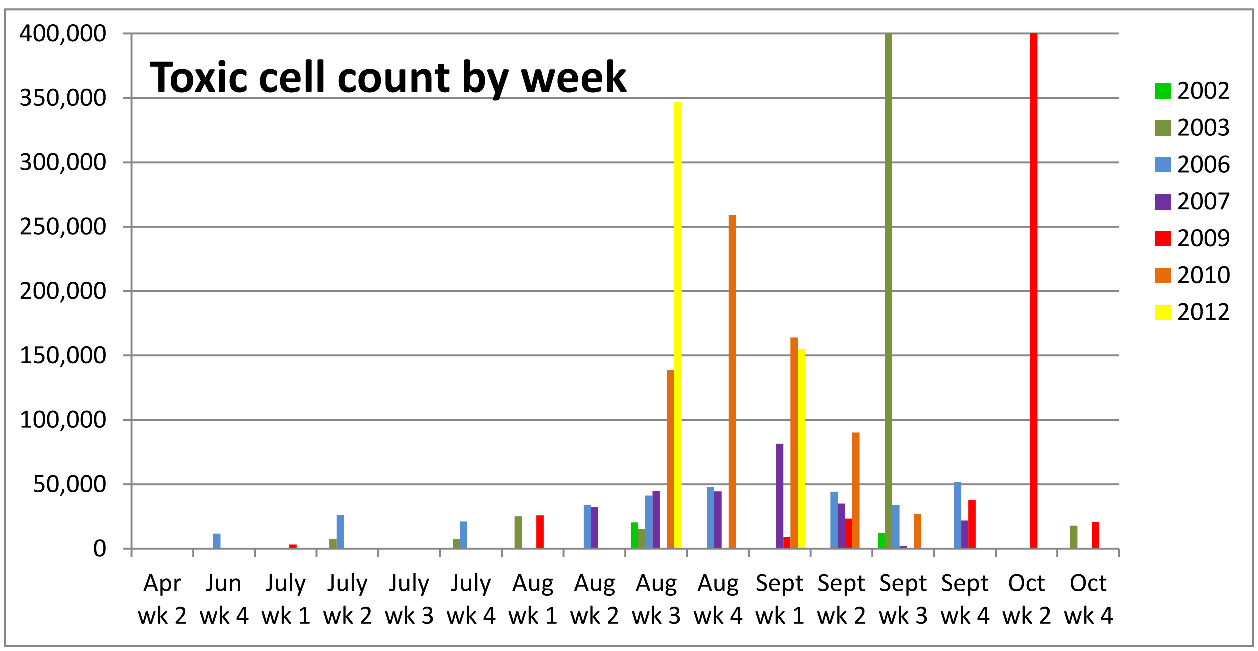


Figure 4: Toxic cell counts of dominant algae species each week during cyanobacteria blooms

Vegetation

Regular vegetation surveys have been conducted each summer since 2007 to provide valuable information that promotes the proper management of aquatic weeds in Blue Lake. Surveys include water depth measurements and aquatic plant sampling with a thatching rake at 101 randomly selected sampling points (the same array of points is sampled each year). A Trimble GPS unit was used to precisely navigate to each sampling point by boat. The rake had a telescoping pole with depth markings for easy depth reading and simultaneous sampling. Aquatic plant species were identified and given an abundance rating (0-5) for each sampling point. Depth measurements and species abundance were recorded using ArcPad on the Trimble unit. Typically vegetation surveys are conducted twice each summer, once in late July and again in early September. The early season sampling was cancelled this summer because the Trimble unit was sent out for repairs. When the Trimble was available again, a late season vegetation survey was conducted in mid September.

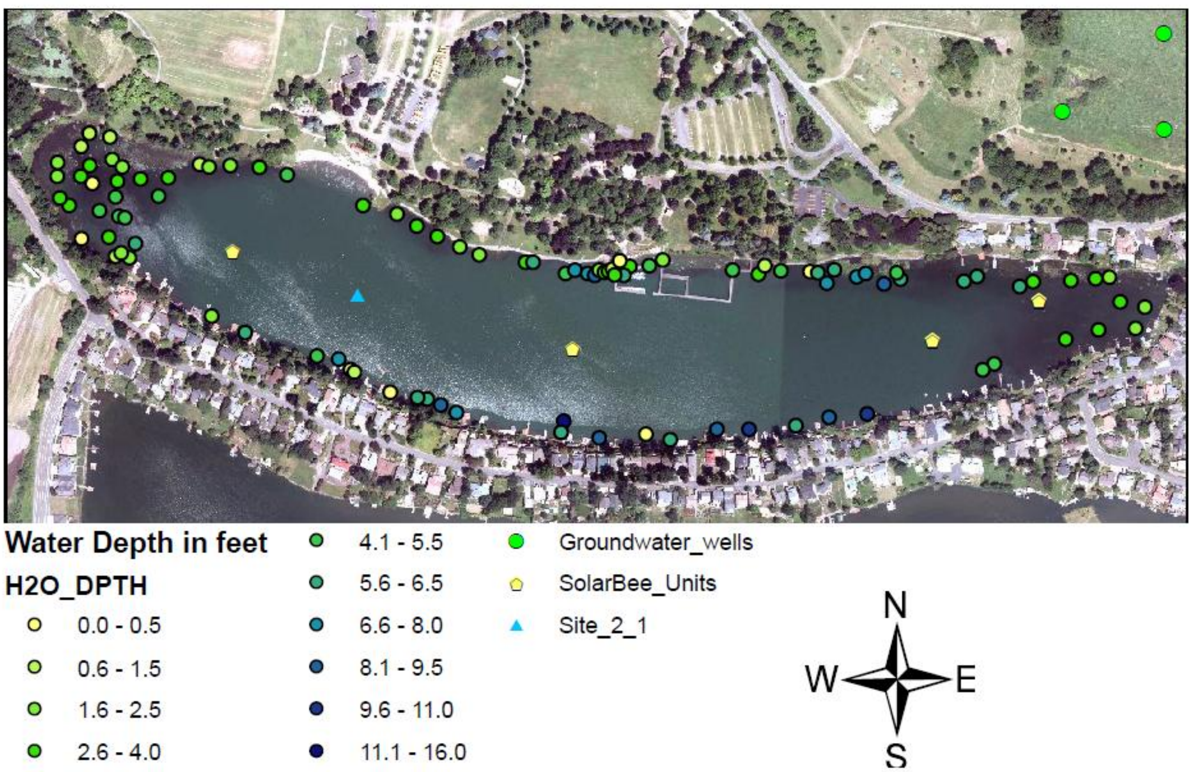


Figure 18: Water depth at each vegetation sampling point

Since there was no early season vegetation survey in 2012, the following studies focus primarily on late season surveys for annual comparisons. Some aquatic plant species, such as *Potamogeton crispus* are early season plants and are under-represented in the 2012 survey data. Of the other non-native aquatic plant species present in Blue Lake were *Nymphaea odorata* (fragrant waterlily) and *Myriophyllum spicatum* (Eurasian waterwatermilfoil). These plants were mostly found along the north shore of Blue Lake and the east and west ends where the water is shallow. The south shore of Blue Lake has an abrupt drop off along the sandstone formation, reaching 16 ft straight down in some places. Most of this area is deeper than the photic zone with a rocky substrate and does not support macrophytes.

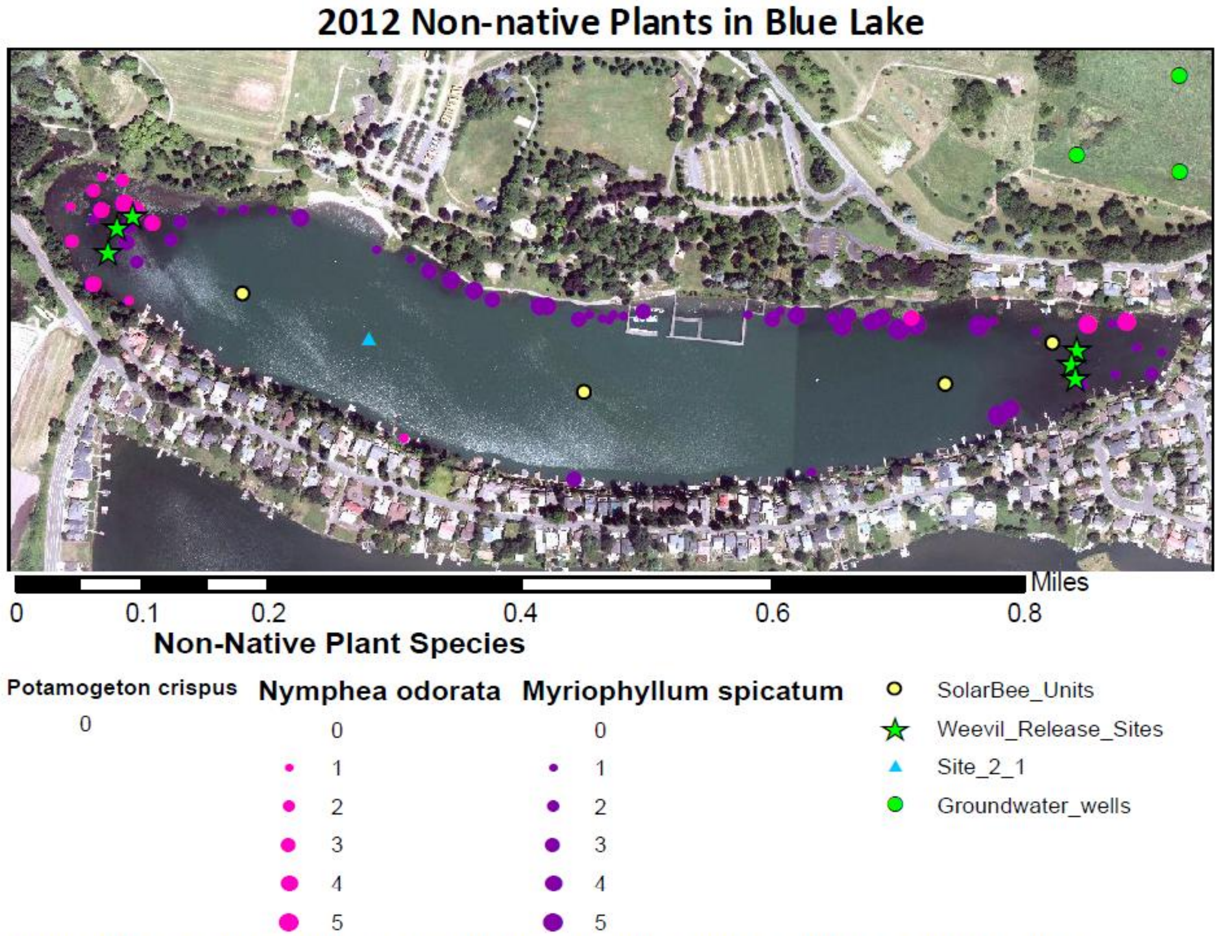


Figure 19: Non-native plant species in Blue Lake for September 2012 vegetation survey.

Large mats of a native plant like algae were identified in the same area where the cyanobacteria bloom occurred just 3 weeks prior. Figure 20 illustrates that Chara, a native plant like algae, was prominent in the southwest corner of the lake. Other native aquatic plant species were identified in Blue Lake, including *Elodea canadensis, Potamogeton foliosis,* and *Nitella*. The native plants tended to prefer the shallow waters at either end of the lake, which have siltier sediment. The south shore of Blue Lake has an abrupt drop off with a rocky substrate, that neither native nor non-native plants macrophytes appear to grow on.

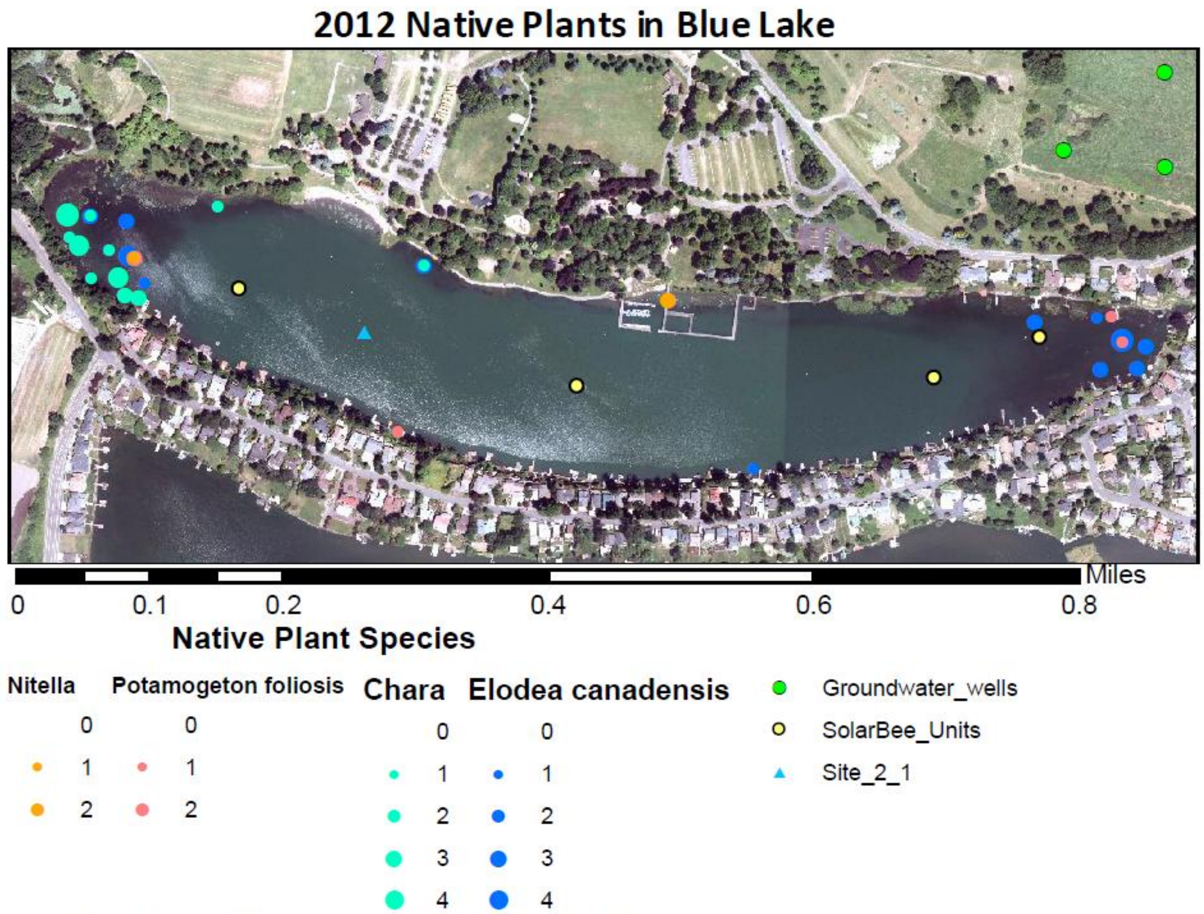


Figure 20: Native plant species in Blue Lake for the September vegetation survey.

To measure the effect the weevils were having on the *Myriophyllum spicatum* abundance, a test area surrounding the initial west weevil release site (pink circle) was examined as well as with a control group (blue polygon) containing equal number of sampling points at similar depths away from the weevil release sites (Figure 21). The same test and control areas were used for data prior to weevil introduction to Blue Lake and data from the 2012 survey. Prior to the introduction of weevils to Blue Lake, there was an abundance of Eurasian watermilfoil in the west end of the lake as well as along the north shore. By 2012, Eurasian watermilfoil near the west weevil release site was clearly less abundant. The east weevil release site also showed a decrease in watermilfoil abundance. However, this decrease was not as obvious as around the west weevil release site. Watermilfoil abundance in the control area had also decreased in 2012 (Figure 22). Perhaps the weevil population had dispersed beyond the initial release area to other areas of the lake. According to the survey performed by Enviroscience Inc in July 2012, weevils had been identified grazing beyond the areas of the release sites. This could also be an indication that the decrease in watermilfoil abundance was related to environmental conditions such as sunlight availability. However, watermilfoil abundance did increase in some parts of the lake. This may indicate that lakewide environmental factors may not have caused the decrease in watermilfoil abundance on the east and west ends of the lake.

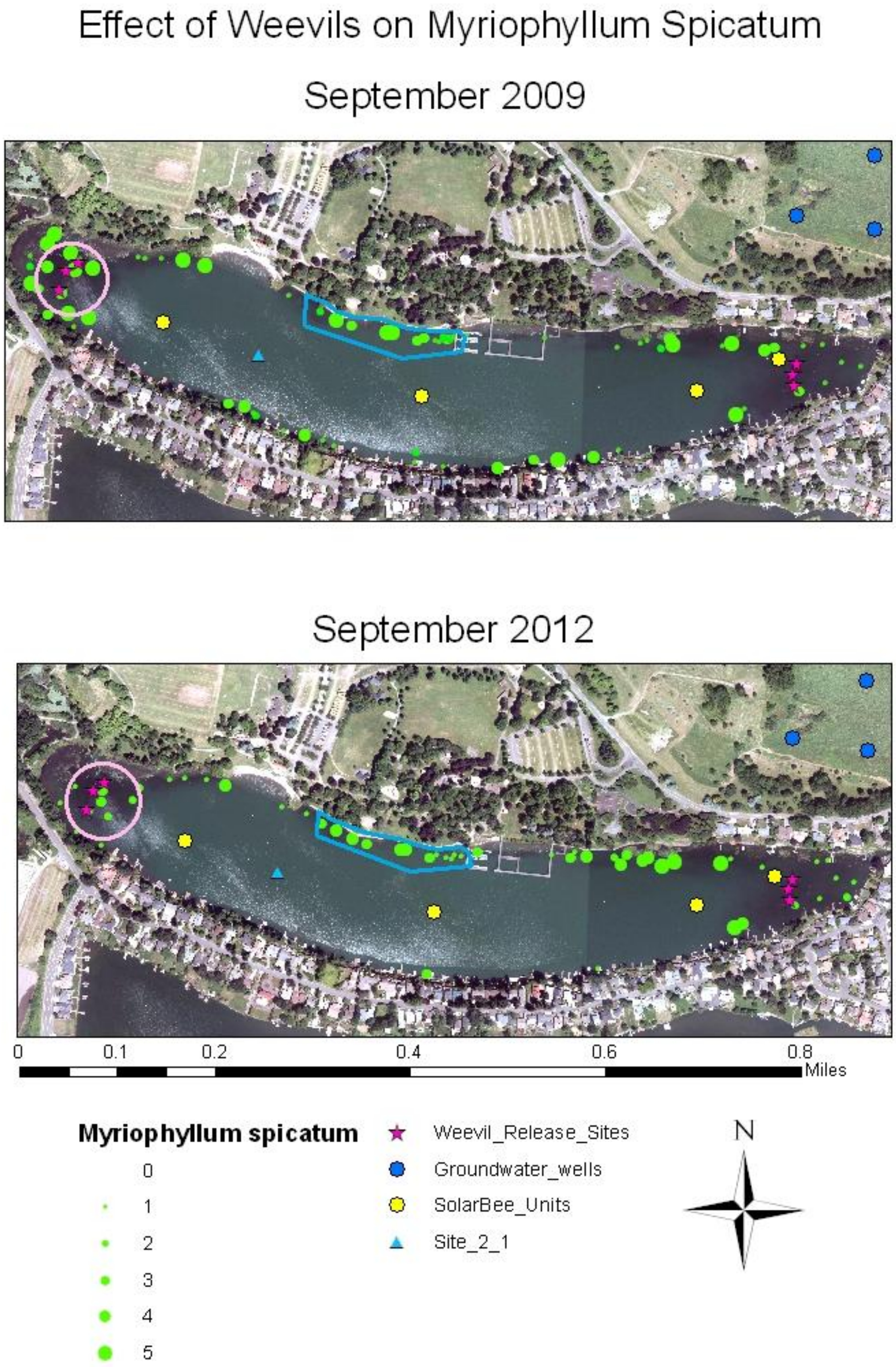


Figure 5: Comparison of test and control area prior to weevil release vs. 2 years after initial release.

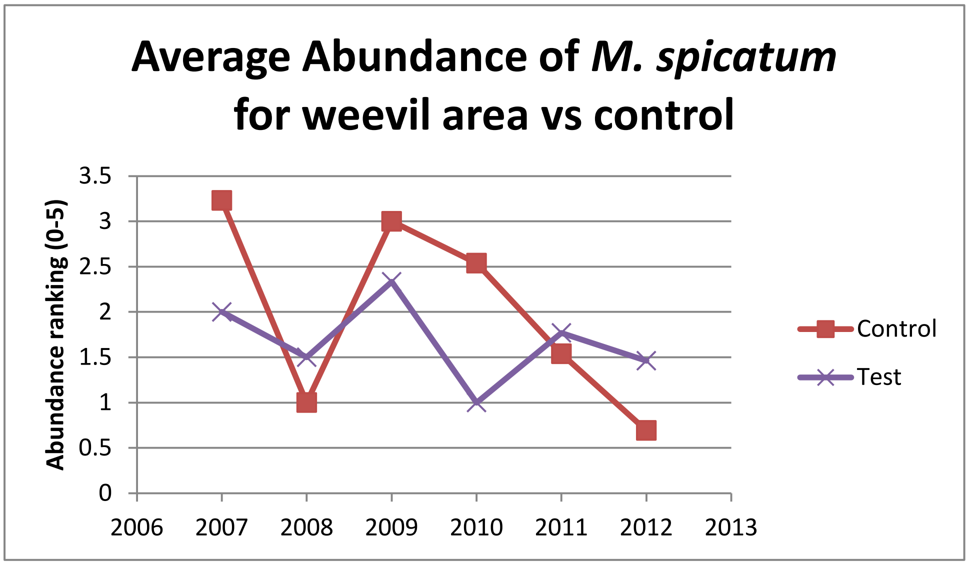


Figure 6: Average abundance comparison of *M. spicatum* in control area vs. test area. Weevils were released into Blue Lake in 2010 and 2011.

A large area on the east end of the lake was manually raked in 2010 and to a lesser extent in 2011. To evaluate the effect that raking has had on aquatic plant populations over several seasons, Figures 23 and 24 were created. The yellow polygon indicates the area that was raked, containing 10 sampling points. The blue circle on the west end of the lake represents the control group, also containing 10 sampling points at similar depths. A separate study was conducted for non-native plants (Figure 23). When comparing the native populations in the raked area from 2010 to 2012, native plants are found at all the same sites they were prior to raking. Furthermore, *Elodea canadensis* was more abundant at each site in 2012. Other plants native to Blue Lake like *Potamogeton foliosis* were identified in the raked area 2 years after raking that had not been detected previously. However, the control area also showed an increase in the number of different native species.

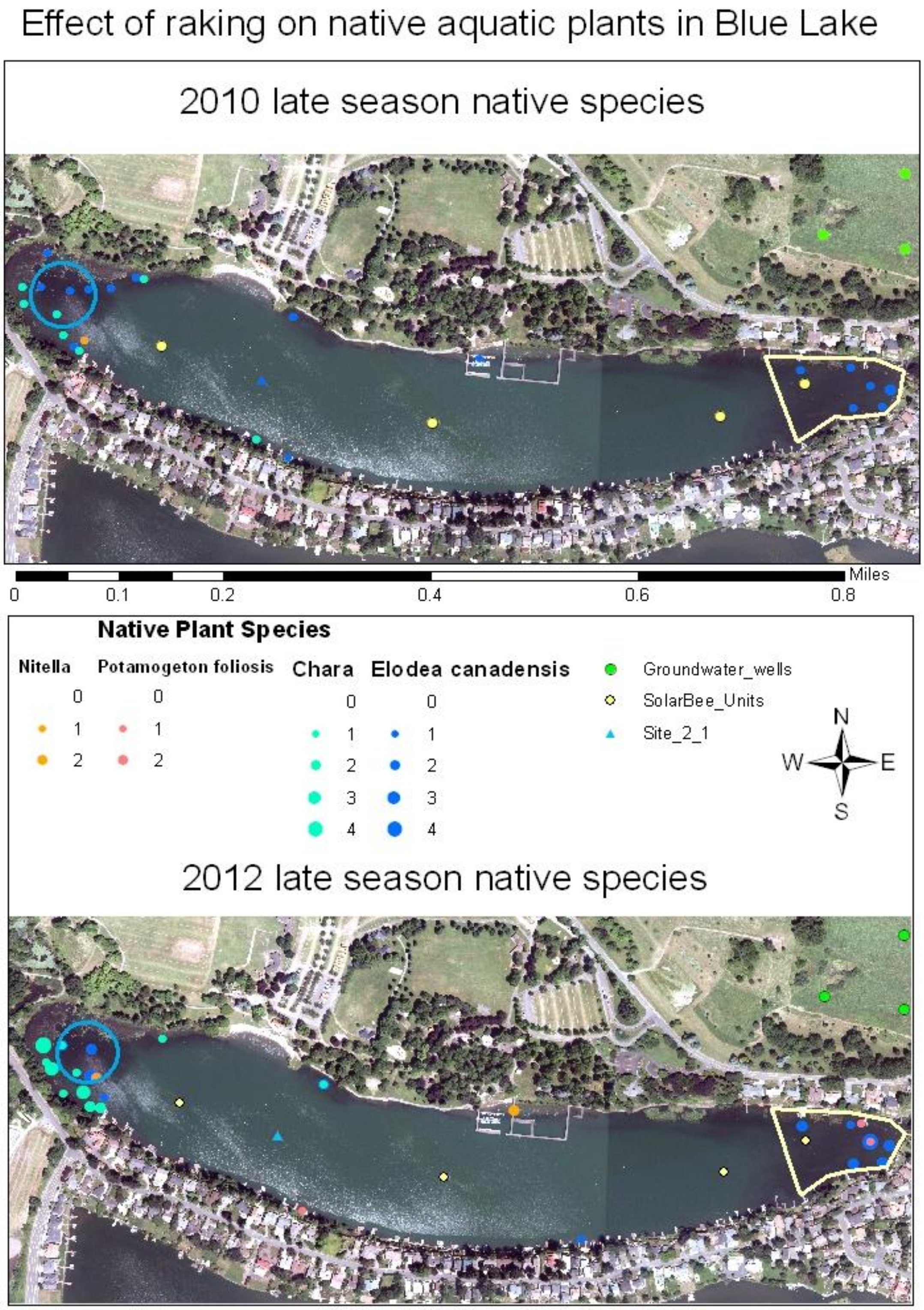


Figure 7: Evaluation of the effect that raking has on native plant species. Yellow polygon indicates the raked area. Blue circle indicates the control area.

When looking at the effect of raking on non-native aquatic plants, results were similar. In Figure 23, you can see that raking may have allowed other plants to move into the area, however, other factors may have been responsible (e.g., weather, movement of Solar Bees, releases of weevils). For the non-native species, *Myriophyllum spicatum* was certainly less abundant in the raked area than it was in the control area. However, *Myriophyllum spicatum* abundance could be secondarily affected by the presence of weevils and other factors in within the raked area. This reduction of *Myriophyllum spicatum* may have allowed other non-native species like *Nymphea odorata* to move into the raked area. *Potamogeton crispus* was under-represented in the 2012 survey because it has an early growing season, which had ended by the time the 2012 vegetation survey took place.

Raking may play an important role in preventing waterways from becoming choked up with fast growing weeds, at least temporarily. However, raking can be labor intensive and it does not prevent nutrients from decaying plants from recycling into the sediments. If raking is implemented, raked materials should be removed from the lake. This would prevent re-establishment of *M. spicatum* from parent root fragments and would remove nutrients from decaying plant matter from entering lake sediments. By decreasing the available nutrients in the sediment layer, future nuisance plant growth may be prevented or at least slowed.

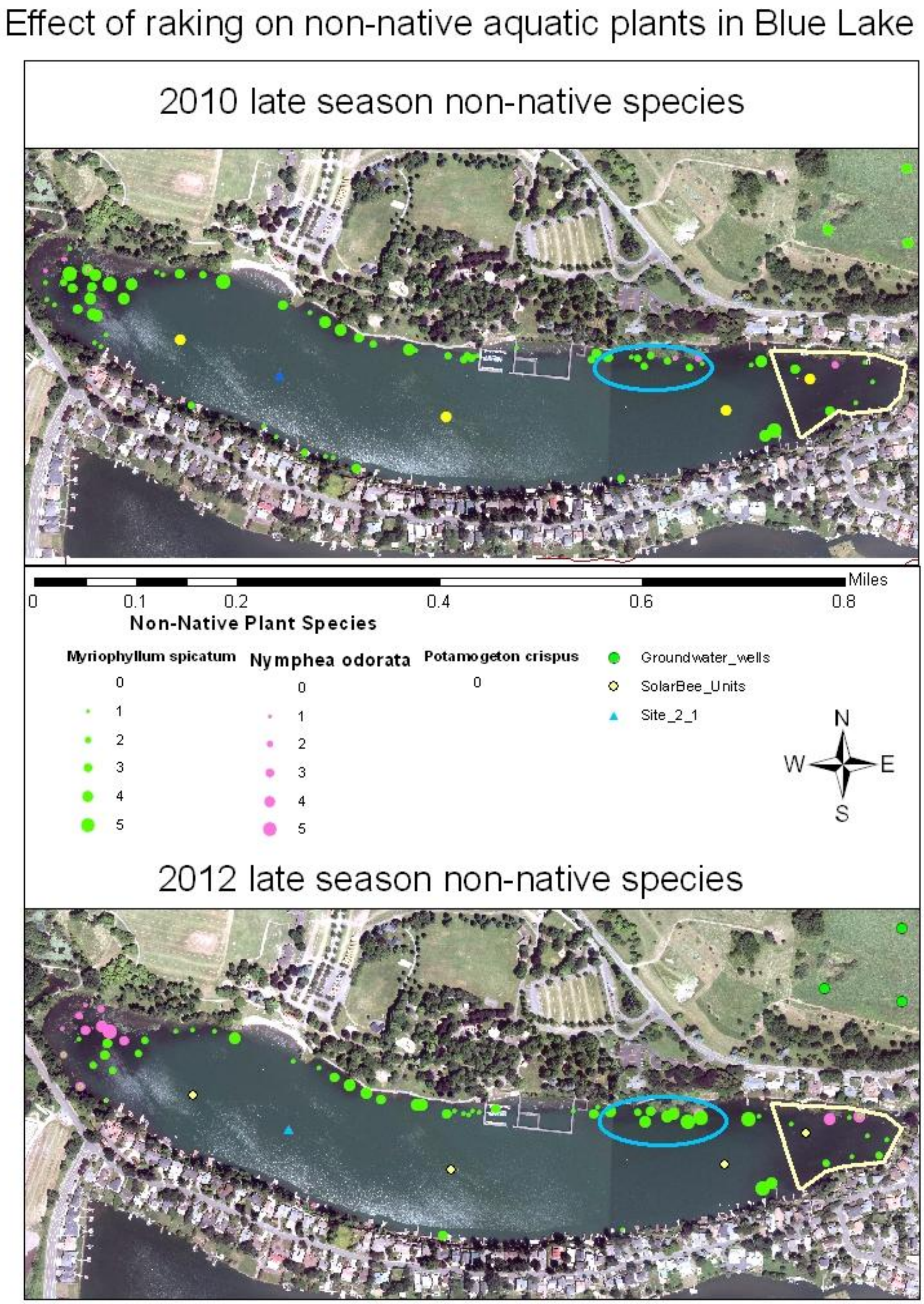


Figure 8: Evaluation of the effect raking has on non-native aquatic plants over 2 years. Yellow polygon indicates raked area, Blue ellipses indicates control area.

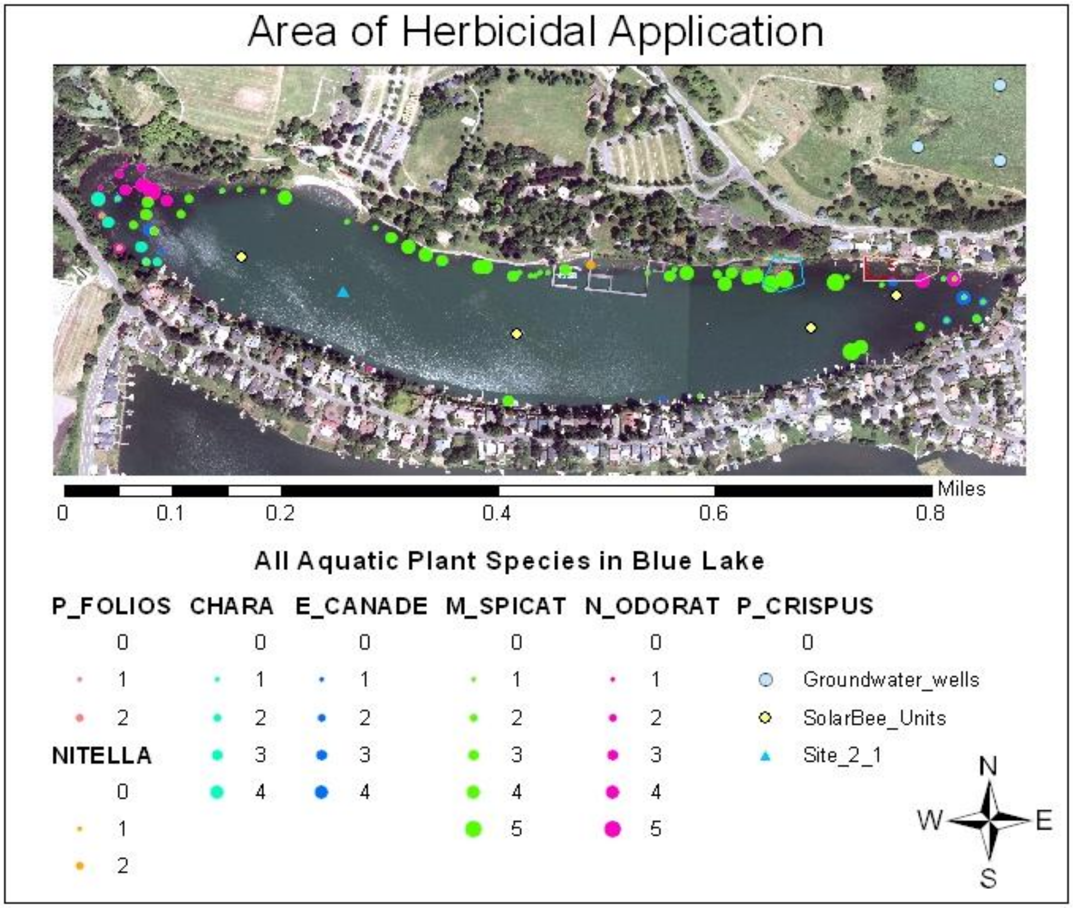
Conclusions

It is difficult to determine what, if anything, has been most effective in controlling nuisance aquatic plants in Blue Lake. Several management efforts by Metro, BLIA, and homeowners have confounded efforts to tease out cause and effect of changes in algae blooms, pH readings, and macrophyte abundance. Some sampling points have weevils grazing, have been raked, and have been treated with herbicides. Figure 25 displays areas that we know have been treated with herbicides (red polygon) as well as areas we suspect were affected by herbicide movement in the water column (pink polygon) because additional aquatic plants were decaying.

In spite of their confounding effects, simultaneous application of multiple strategies may be required to achieve the desired outcome in Blue Lake. Weevils may play an important role in controlling *Myriophyllum spicatum*. It has a long growing season and tends to grow rapidly, out competing native plants in Blue Lake. If weevils are able to clear areas of watermilfoil, other native plants may move into the area. However, additional efforts to control nuisance plants may be necessary. Finding mechanisms for removing, or at least reducing new input of phosphorus into Blue Lake may be helpful in controlling nuisance aquatic plants. Because the east end of the lake is shallow and within the photic zone (plant growth is not limited by light), preventing additional phosphorus inputs may be important. Nutrient inputs can be limited by selecting lawn fertilizers that contain less phosphorus or doing without fertilizer, as the park is doing. Blue Lake residents can also limit nutrient loading by removing yard debris from their property as it is cleared so it does not decay and leach nutrients into the lake. Similarly, treated aquatic plants that decay continue to recycle nutrients into the lake sediments. Removal of treated plants from the watershed would remove nutrients.

Blue Lake residents vary in their approaches to lawn and aquatic weed management. At times, nuisance aquatic plants can hinder recreation in Blue Lake and some homeowners may use herbicides to alleviate the situation. We encourage residents to consider "Herbicide Best Management Practices" compiled by Metro and DEQ. Selective treatment of nuisance aquatic plants is preferable to broader or indiscriminate treatment.

Figure 9: Area of herbicide application



SolarBee units appear to circulate water in the epilimnion but have not been effective in improving water clarity in the late summer/early fall, controlling ph violations in the late summer/early fall, or preventing cyanbacteria blooms. Even though 2011 seemed hopeful for the success of the SolarBee units, it appears that improvements in water quality during 2011 were due to weather conditions rather than the presence of a fourth SolarBee unit. Water quality data from 2012 indicate that, even with a fourth SolarBee unit in place, the circulation effect of the units did not prevent a cyanobacteria bloom or ph violations from occurring, and did not consistently improve water clarity. Metro's data indicate that when epilimnion temperatures exceed 24 C, circulating the epilimnion alone cannot prevent cyanobacteria blooms or pH violations. The warm water temperatures coupled with nutrient and light availability above the thermocline are still favorable conditions for the growth of cyanobacteria. Further, during growth, algae require carbon for cell growth. Although carbon may be present in the water column, during periods of peak growth algae may deplete readily available forms of carbon in weakly buffered systems. When dissolved forms are depleted carbon will enter the water column via the air-water interface as carbon dioxide. However, this process is often insufficient to keep up with algal demands. Under such conditions certain algae species are able to utilize (remove) CO_2 from bicarbonate ion: HCO_3^- $CO_2 + OH^-$. The result is an increase in hydroxyl (OH^-) concentration and an associated increase in pH. It is not uncommon to see diurnal variation in pH ranging from 0.5 to 1.5 pH units as a result of algal productivity. The increase in pH, if accompanied by elevated water temperature can cause a dramatic shift in unionized ammonia concentrations in aquatic systems. Although it may seem that Blue Lake is suffering from multiple, un-related water quality impairments, each parameter affects the other. Blue Lake water quality managers must adopt a holistic management plan to address the individual issues including ph violations, elevated ammonia concentrations, cyanobacteria blooms, and nuisance plants.

Cyanobacteria blooms will continue to be a problem for Blue Lake, and monitoring for algae blooms will continue to be necessary as a preventative measure to protect human health. We learned through years of monitoring that a cyanobacteria bloom may occur when certain conditions are met. As surface water warms in the summer sun, the epilimnion temperatures rise. Warm water with plenty of sunlight availability presents growing conditions for phytoplankton communities. Increase in phytoplankton biovolumes can be noted by a decrease in water clarity. We should be able to track phytoplankton growth in Blue Lake without collecting samples for chlorophyll-*a* testing. Through analysis of previous data, we know that an algae bloom is unlikely when the water clarity is less than 2 meters deep. As water clarity decreases to less than 2 meters, phytoplankton biovolumes are elevated enough to indicate conditions favorable for a cyanobacteria bloom. Cyanobacteria populations that are present can quickly grow if continued periods of sunlight occur. This tends to happen toward the end of summer in Oregon.

Moving forward, cyanobacteria monitoring should be conducted by the following protocol. Visual monitoring of the lake should take place throughout the summer. Typically, the conditions of Blue Lake are not favorable for a cyanobacteria bloom to occur until August. However, anomalies in weather patterns can certainly allow for such conditions to be present prior to late summer. Typically, we do not see elevations in pH readings until surface water temperatures have reached 24 C. When water temperatures rise above 24 C and an elevation in pH readings is noted, we know that cyanobacteria populations are significant enough that a bloom may occur.

Measuring Secchi depth is a quick and easy way to monitor water clarity in Blue Lake. Secchi depth readings will give a rough approximation of what is happening with the phytoplankton community throughout the summer. As water clarity decreases, phytoplankton populations increase. When water clarity is greater than 2 meters, phytoplankton biomass is not significantly elevated. No sampling is required at this stage. Once water clarity drops to less than 2 meters, phytoplankton communities in the epilimnion are significant enough that a bloom may occur. Even if no visible bloom is present, samples should be collected at the surface and thermocline as well as the swim beach. These samples should be stored in Lugol's solution for later evaluation of cyanobacteria populations. When a visible bloom occurs, samples should be collected according to the HABS sampling guidelines (Figure 3). It is necessary to collect a preserved sample for cell counts and identification as well as a fresh sample on ice for potential toxin testing if cell counts are above the DHS threshold for toxin producing species. It is best to ensure there are plenty of available sampling bottles and Lugol's solution at the beginning of the season. A cyanobacteria monitoring program at Blue Lake can be maintained with the same level of efficacy, even with limited sampling. A perceptive volunteer or intern could easily monitor Blue Lake for potential health risks with a simple understanding of lake dynamics.

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