Technical Status Memorandum
For
Lakes Limerick and Leprechaun 2015
Aquatic Plant Management

DECEMBER 16, 2015

PREPARED FOR:

Lake Committee

Lake Limerick Country Club

PREPARED BY:

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Acknowledgements

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1.0 INTRODUCTION

The continued goals for aquatic plant management in Lakes Limerick and Leprechaun during 2015 were to preserve the ecological balance and to maintain good water quality within both lakes, while also improving conditions for recreational and aesthetic beneficial uses.

Aquatic plants are a critical component of lake ecosystems. Submerged aquatic vegetation provides physical habitat for fish and other aquatic life, and also influences lake chemistry. As aquatic plants grow, they take up nutrients (such as nitrogen and phosphorus) from lake sediments and from the water column and photosynthesize, producing oxygen. These processes can mitigate the deleterious impacts of high nutrient concentrations (e.g. the occurrence of toxic algae blooms) by lowering overall nutrient concentrations, and can also benefit fish populations by increasing concentrations of dissolved oxygen. However, if runoff and/or inflows consistently contribute nutrients to littoral areas, concentrations of nutrients can become elevated, stimulating excessive growth of both aquatic plants and algae. This impedes recreational and aesthetic beneficial uses and impairs aquatic habitat. Comprehensive lake management and monitoring is necessary in order to maintain a balanced aquatic ecosystem.

With the information provided by annual plant surveys, proactive lake management practices have been implemented at this site since 2005, and have had good success. Aquatic plant communities in both lakes were previously dominated by Brazilian elodea (*Egeria densa*), but with repeated four-year cycles of herbicide treatments, native species such as the pondweed *Potamogeton amplifolius* have reestablished and become dominant. Following the 2014 surveys and treatments, it was recommended that the Lake Limerick Country Club (LLCC) dredge a portion Lake Leprechaun and a portion of Lake Limerick in order to reduce aquatic plant habitat and increase recreational access within specific regions.

In 2015, as in previous years, aquatic plant surveys were conducted at both Lake Limerick and Lake Leprechaun in June and again in September in order to assess the spatial distribution, composition, and relative density of aquatic plant communities. Aquatic plants are prevalent around the rim of each lake, suggesting that inflows of shallow groundwater and perhaps septic systems may be contributing nutrients (particularly nitrogen) to the lake system.

In 2013, a water quality monitoring program was initiated in order to gather data to inform future lake management decisions. This monitoring program was continued in 2014 and again in 2015, but was conducted only three times in 2015: in April, June, and September. As in 2013 and 2014, water samples were collected from five sites in Lake Limerick and at one site in Lake Leprechaun. The indicators of water quality for which samples from each site were analyzed were soluble reactive phosphorus (SRP) and total phosphorus (TP). Samples from three of the five sites in Lake Limerick and the sample from Lake Leprechaun were also analyzed for concentrations of chlorophyll *a* and phaeophytin *a*.

The 2015 monitoring program also included continuous monitoring of water levels in Lake Limerick and Lake Leprechaun, and below the Lake Limerick dam.

2.0 LAKE LIMERICK

2.1 AQUATIC PLANTS

In summer 2014, 7.1 acres of aquatic plants were treated with herbicides in order to limit the growth of the native plant *Potamogeton amplifolius*, which had flourished in response to high nutrient concentrations and the successful reduction of the invasive species *Egeria densa* through herbicide treatments. The June 2015 survey of aquatic plants in Lake Limerick indicated that plants were present, but in low densities, and no *Egeria densa* was observed. As a result, no treatment was planned for summer 2015.

2015 management efforts instead focused on limiting the growth of yellow iris in shoreline areas. In summer 2015, visible patches of yellow iris on the shoreline of Lake Limerick were sprayed with the herbicide Glyphosate. This herbicide was used because of its minimal deleterious effect on other terrestrial and shoreline plants as well as on water quality. Its first-treatment effectiveness in carry-over control will likely range from 50-75% (i.e. not all of the plants will be killed). 2016 treatment and control efforts will need to target not only the plants that survive, but also the new plants that will emerge due to the seed bank in the sediment. It will take two to three years of monitoring and spot control to exhaust this seed bank. During this period LLCC should continue spraying observed patches and should encourage area residents to hand pull individual small clumps.

In September 2015, a second survey (conducted in coordination with the bathymetric survey described in section 2.2) confirmed that the density of aquatic plant communities within the lake remained low and that no *Egeria densa* was present (Figure 1). The spatial distribution of plant communities was similar to that observed in previous years. The bathymetric survey (section 2.2) did reveal the presence of additional, low density communities of aquatic plants in deeper zones (Figure 1). A mix of species appeared to be present within these communities, but filamentous algae was dominant. Filamentous algae was also present in lake-shore areas, and its coverage and density was much more than observed in previous years. This is directly related to climatic conditions in 2015 and the relatively low density of native plants in Lake Limerick due to carry-over control from previous years' treatments.

Pre- and post- treatment maps of aquatic plant distributions within Lake Limerick in 2014, and in earlier years (2008 – 2009, 2011 – 2013) are shown in Figures 2 – 9.

2.2 BATHYMETRIC SURVEY

On September 11th, 2015, Tetra Tech staff mapped the bathymetry of Lake Limerick using a Lowrance HDS-7 fishfinder/chartplotter with a StructureScan HD sonar imaging system and an LSS-2 HD Transom Transducer.

The survey was conducted during the dry summer period when the lake level is raised for recreational uses (through the installation of control boards in the outlet structure). This allowed the survey to map the full extent of the lake bottom. On the date of the bathymetric survey (September 11th, 2015), the water level logger at the Inn Dock registered a water pressure of 2.47 feet of water (ft. H_2O). Accordingly, the surveyed water depths are accurate at the water level associated with this pressure. The water pressure data have not been correlated to actual lake levels, but the data can be correlated once a survey point is taken for the elevation of the data logger. The depths surveyed in September can be considered representative of water depths in the lake during the dry summer period in which lake level is raised, but are not representative of water depths during the rainy season, which change as the level of the lake fluctuates in response to precipitation events. Although water levels fluctuate, the bathymetry of the lake floor is fixed. The bathymetry mapped in September represents the true bathymetry of Lake Limerick regardless of water level, as it is the areal variation in surveyed water depths, not the magnitude of those depths that reveals the bathymetry (relief) of the lake floor.

The following section describes the bathymetry of the lake as well as areal variations in water depth at the time of the survey (when lake level was raised).

The slope of the lake bottom is generally gradual in near-shore areas, and within approximately 150 feet of shore the water is generally 0 to 6 feet deep (Figure 10). However, at a few places along the north, southeast, and southwest shores the gradient is steeper, and near-shore water depths quickly reach 9 – 12 feet. Beyond nearshore areas, the slope of the lake bottom is less consistent. In the northeast section of the lake, the lake bottom slopes only slightly to the southwest, and maximum water depths are approximately 12 feet. The northwest corner, by the outlet of Cranberry Creek, is very shallow, as is the small extension of the lake along the north shore (King Cove). The deepest portions of the lake lie within two regions: the large central bay, and the small southern bay where the dam is located. The bathymetric shape of the central bay mimics that of the lake as a whole (Figure 10). Within this bay, the water is 9 – 12 feet deep ~ 200 – 400 feet from shore, and 9 – 12 feet deep in the central area in the areas, and 12-15 feet deep in the areas more than 400 feet from the shore. However, there are pockets where the lake bottom drops and water depths reach 15 – 18 feet. The bathymetry of the southern bay is asymmetrical, as the bay is deeper to the west than it is to the east. Within the central portion of this bay, the water is approximately 9 – 15 feet deep, but reaches 15 – 18 feet deep where the lake bottom dips in two places (Figure 10).

The bathymetric data collected on September 11th, 2015 will be used in future assessments of dredging and sediment removal activities in Lake Limerick. Dredging is planned for the northeast section of King Cove and the bay by the inlet of Cranberry Creek. Once these areas have been dredged, the bathymetry of both regions will be re-surveyed. The original and post-dredging bathymetries will be compared in order to estimate the quantity of sediment removed by dredging and to calculate the efficiency of dredging activities. In addition, these data can be used in the future to document any changes over time that may require future sediment removal activities, as sediment deposition continues to fill these area from external sources.

2.3 PRECIPITATION AND LAKE LEVEL

During 2015, water level monitoring continued at the Lake Limerick inn dock (Figure 11) and below the Lake Limerick dam (Figure 12). The loggers at these sites provide accurate lake level data at 60 minute intervals by recording water pressure (in feet of water). No data was available from 6/3/2015 – 7/3/2015. Precipitation data was obtained from the KWASHELT3 weather station, located at the tip of the small extension of Lake Limerick along its north shore (King Cove).

From December, 2014 through November, 2015, recorded water level in Lake Limerick fluctuated by a foot (Figure 13). From December, 2014 through mid-April, 2014, during the rainy season, water level fluctuated in response to precipitation events, with larger events triggering larger changes in lake level. The lake response slightly lagged the onset of the precipitation due to the time required for soil moisture deficits to be met and for the resultant runoff to travel through the watershed. The lag was in part due to the dry conditions in 2015, and would likely be shorter under a normal precipitation regime. During each storm, lake level rose rapidly as runoff reached the lake and discharge from inflowing streams increased, and then receded at a slower rate as the storm event waned (Figure 13). In late April, the Lake Limerick Country Club inserted additional outlet control boards into the Lake Limerick dam outlet structure in order to raise the lake level for summertime recreational uses. These boards remained in place during the full summer season (May through mid-October, 2015). For the majority of the summer there was little to no precipitation and lake level was stable, increasing only slightly at the end of August following a rare summer storm (Figure 13). The additional outlet control boards were removed at the end of the recreational season in mid-October in order to lower lake levels in advance of the winter rainy season (Figure 13).

At the dam outlet, water level fluctuated by 1.5 feet during the rainy season, mimicking the level changes observed in the lake, but remained low during the summer period when the additional outlet control boards were installed (Figure 14).

Water level records from December 2013 through November 2014 for Lake Limerick and the Lake Limerick dam outlet are shown in Figures 15 and 16, respectively. The figures also include the precipitation record for the same time period.

2.4 WATER TEMPERATURE

During 2015, in conjunction with water level monitoring, water temperature was monitored continuously (at 60-minute intervals) at the Lake Limerick inn dock (Figure 11) and below the Lake Limerick dam (Figure 12). Monitoring occurred from December, 2014 through early November, 2015, although no data was recorded from 6/3/2015 – 7/3/2015. The air temperature record for the full period was downloaded from the KWASHELT3 weather station, located at the northeast end of King Cove.

From December, 2014 through early November, 2015, average air temperature ranged from -2.8 to 24.1 °C (Figure 17). Air temperatures were lowest in December, 2014 and January and February, 2015, and highest in July and August, 2015. During this same period, surface water temperatures recorded at the Lake Limerick inn dock ranged from 3.9 to 27.6 °C (Figure 17), and water temperatures recorded at the dam outlet ranged from 4.4 to 27.5 °C (Figure 18). Water temperatures at both sites varied seasonally, and were lowest in December, 2014 and January, 2015, and highest in July and August, 2015. Throughout the year, there was little to no difference between water temperatures at the inn dock, located between the lake inlet (Cranberry Creek) and the lake outlet, and water temperatures at the lake outlet, at the dam outlet site (Figures 17, 18, and 19). Accordingly, it appears that there is no significant thermal gain in the reservoir between the inlet and the outlet given the prevailing wind is from the SW, which limited the potential thermal gain from the open water as measured at the Lake Limerick inn dock nearest the major inlet inflow versus the open water near the outlet temperature measurements.

In general, the temperature of surface water in Lake Limerick (and water at the dam outlet) appeared to respond to fluctuations in average air temperature, as the temporal trend in water temperatures mimicked, but slightly lagged, that of average air temperatures (Figures 17 and 18). The lake response to fluctuating ambient air temperatures was evident in April, 2015, and appeared to be greatest either when daily high and low temperatures were both elevated or depressed in comparison to those of the preceding day or when the difference between the daily high and low air temperatures was large (Figure 19).

Water temperatures in Lake Limerick and at the dam outlet varied diurnally (i.e., followed a daily cycle) as well as seasonally (Figure 19). From December, 2014 through early November 2015, the magnitude of the diurnal variation in surface water temperatures in Lake Limerick ranged from 0.2 to 4.3 °C. The diurnal range in water temperatures at the dam outlet was slightly larger: 0.1 to 6.6 °C. Within a given period, the magnitude of the diurnal variation appeared to be greatest when there was a large difference between the high and low air temperatures on the preceding day (e.g., April, 2015 in Figure 19). The magnitude also varied seasonally. The diurnal variation was small and inconsistent during the winter months, but became larger and well defined by the end of March, 2015 and through the summer. By early October, 2015, the diurnal variability had diminished and the pattern had begun to deteriorate. Diurnal variability in surface water temperatures is likely greater in spring and summer months than in the winter because longer days, fewer cloudy days, and seasonal differences in the angle and position of the sun mean that net solar radiation is greater in these months. The increase in solar energy overpowers wind mixing, and the lake slowly stratifies, forming a surface layer that readily warms during the day and cools at night in response to changes in direct solar radiation and corresponding fluctuations in ambient air temperatures. This causes the observed diurnal variation in water temperatures. With the onset of fall, this process reverses itself: net solar energy decreases, the surface layer of the lake cools and the lake is mixed by wind, leading to the observed deterioration of the diurnal temperature variation in surface waters.

2.5 WATER QUALITY

Water samples were collected in April, June, and September 2015 at five sites within Lake Limerick: Dam (1m and 2m samples), Banbury, King cove, Tipperary, and Cranberry (Figure 20). Samples from all five sites were analyzed for total phosphorus (TP) concentrations [method detection limit (mdl): 2.0 μg/L], and concentrations of soluble reactive phosphorus (SRP) [mdl: 1.0 μg/L]. Samples from three of the five sites (Dam 1m, Banbury, and Tipperary) were analyzed for concentrations of chlorophyll *a* [mdl: 1.0 μg/L**]**, and phaeophytin *a* [mdl: 1.0 μg/L].

The phytoplankton analysis was not conducted in 2015 because Maribeth Gibbons, the taxonomist, was ill and unable to complete the analysis. However, Harry Gibbons conducted a microscopic scan of the phytoplankton in water samples collected in April, June, and September, 2015, and verified that the dominant species were the same as in previous years and that the relative density of species was also consistent. Based on the cost of the analysis, and the limited information that it provides as a result of the good water quality conditions, low nutrient levels, and historical lack of cyanobacteria, we recommend that phytoplankton samples not be taken in 2016 unless a surface algal scum that is suspected of being blue-greens occurs.

Vertical profiles of water temperature and concentrations of dissolved oxygen were not taken during each of the 2015 sampling events, as recommended, because the water quality of the lake was not stressed. This allowed for a greater portion of the budget to be reserved for conducting the bathymetric survey of Lake Limerick.

During the 2015 monitoring period, concentrations of total phosphorus (TP) were higher at the 2 m depth at the dam site than at any of the other sampling locations in Lake Limerick (Figure 21). Among the remaining five sampling locations, TP was highest at the Cranberry site in April (13.2 μg/L) and June (9.0 μg/L) and at the Tipperary site (9.0 μg/L) in September. Concentrations of total phosphorus were similar between June and September at all sampling locations except for the 2 m depth at the dam site (Figure 21).

Concentrations of soluble reactive phosphorus (SRP) were above detection limits at only the Cranberry site (3.7 µg/L) in April, at no sites in June, and at only the Cranberry (1.0 µg/L) and Dam sites – at 1 m (2.0 µg/L) and 2 m (3.0 µg/L) – in September (Figure 22). These concentrations are indicative of good water quality.

Concentrations of chlorophyll *a* and phaeophytin *a* (degraded and non-photosynthetic chlorophyll) were measured only in samples from the Banbury site, the Tipperary site, and the 1 m depth at the Dam site (Dam 1m). Concentrations of chlorophyll *a* at the Banbury and Dam 1 m site increased throughout the monitoring period, while concentrations of chlorophyll *a* were highest in June at the Tipperary site (Figure 23). Concentrations of chlorophyll were, on average, highest at the Dam 1 m site, but all observed concentrations fell between 2.7 and 4.8 µg/L. These concentrations are below eutrophic levels (over-enriched and too productive) and reflect oligotrophic (low nutrients and productive with good water quality) to oligo-mesotrophic (low to moderately enriched waters) conditions. Concentrations of phaeophytin *a* dropped at all three sites during the 2015 monitoring period (Figure 24). The greatest drop in concentrations from April, to June, to September, was observed at the Banbury site (3.8 to 2.0 to 0.2 µg/L).

The ratio of concentrations of chlorophyll *a* to total phosphorus concentrations (Chl:TP) is an indicator of the relative productivity of a system and the degree to which algae are utilizing the available phosphorus. The worldwide average Chl:TP ratio is 0.3:1. Chl:TP was lowest in June at all three sites in Lake Limerick, and peaked in September at the Dam 1 m and Banbury sites and in June at the Tipperary site (Figure 25). The increase in Chl:TP over the summer period is likely due to the dry climatic conditions, which reduced the rate of flushing through the system and increased the residence time of algal and chlorophyll in the lake. The increased residence time of the algae in the lake likely boosted algal productivity, and as a result of the dry conditions the productivity remained in the system (as chlorophyll) instead of being flushed out. The increase in concentrations of chlorophyll *a* (Figure 23) led to the observed increase in Chl:TP (Figure 25). The observed increase in chlorophyll *a* relative to phaeophytin *a* is consistent with increased algal productivity and the trend in Chl:TP (Figure 26). Future water quality monitoring should track Chl:TP to see if this trend continues with drier summers due to climate change. If it does, phosphorus levels within Lake Limerick may need to be prevented from any increase in order to maintain good water quality.

During the 2015 monitoring period, lake-wide averages (not volume-weighted, but as the average of all data points) of total phosphorus (TP) concentrations and concentrations of chlorophyll *a* were below established year-round and summer management goals. Lake-wide average TP in Lake Limerick was 16.9 µg/L in April, 11.0 µg/L in June, and 16.3 µg/L in September (Figure 27), below the established management goal for lake average TP of 25 µg/L or less (≤ 25 µg/L). The summer lake average TP for Lake Limerick was 13.7 µg/L, below the established management goal for summer lake average TP of 15 µg/L or less (≤ 15 µg/L). Despite the increased algal productivity, lake-wide averages of chlorophyll *a* were below the peak lake average management goal of 8 µg/L or less (≤ 8 µg/L) in April, June, and September, 2015 (Figure 28). The summer lake average concentration of chlorophyll *a* (3.8 µg/L) was also below the management goal of 4 µg/L or less (≤ 4 µg/L). These low concentrations of TP and chlorophyll *a* indicate that water quality in Lake Limerick is good and that there is competition between aquatic macrophytes (rooted aquatic plants) and periphyton (algae attached to the lake bottom and rooted plants) for nutrients.

The 2015 water quality monitoring results can be compared to data from previous years. However, the timing of and frequency of water quality monitoring has varied year to year, making direct comparisons difficult. In 2013, water quality was monitored in August, September, and October. In 2014, water quality was monitored monthly from March through November. In 2015, water quality was monitored in April, June, and September. Annual site averages discussed below are not volume-weighted, but were computed as the average of all data points. Summer site averages were computed as the average of the measurements taken at a given site during summer months (August and September in 2013; June, July, August, and September in 2014; June and September in 2015).

At all of the Lake Limerick sites (including the 2 m depth at the dam site), the average total phosphorus (TP) concentration measured in 2015 was lower than the average of concentrations measured in either 2013 or 2014. The summer average TP concentration was also lower in 2015 than in either 2013 or 2014 at all sampling locations except for the 2 m depth at the dam site (Figure 29). Average concentrations over the full monitoring period and summer average concentrations of soluble reactive phosphorus (SRP) were less in 2015 than in 2014 at all sites (Figure 30). These data indicate that external loading of phosphorus is still more important than internal phosphorus loading for the lake sediments during the growing season. This is consistent with the observation of a balance system and good water quality within the reservoir.

At the Banbury, Dam 1 m, and Tipperary sites, the annual and summertime average concentrations of chlorophyll *a* were higher in 2015 than in either 2013 or 2014 (Figure 31). 2015 average concentrations of phaeophytin *a* were lower in 2015 than in 2014, but higher than in 2013. Summer average concentrations of phaeophytin *a* were lower in 2015 than in either 2013 or 2014 (Figure 32). The summer average Chl:TP was higher in 2015 than in 2013 or 2014, likely because of the dry climatic conditions, as discussed above (Figure 33). The lower percentage in 2015 than in 2013 or 2014 phaeophytin *a* relative to chlorophyll *a* was consistent with this trend (Figure 34).

3.0 LAKE LEPRECHAUN

3.1 AQUATIC PLANTS

In 2014, just over an acre of aquatic plant beds were treated in Lake Leprechaun, as populations of *Potamogeton amplifolius* had rebounded following the 2012 herbicide treatment (Figure 35). The treatment successfully reduced the presence of *Potamogeton amplifolius* (Figure 36). The June 2015 survey indicated that a small patch of mixed species was present by the launch area, and this small area was treated. A second survey of aquatic plants in Lake Leprechaun in September 2015 confirmed that the treatment had been effective.

As at Lake Limerick, the herbicide Glyphosate was applied to patches of yellow iris in shoreline areas in order to control the growth and spread of this invasive species. Glyphosate was used because of its minimal deleterious effect on other terrestrial and shoreline plants as well as on water quality. Its first-treatment effectiveness in carry-over control will likely range from 50-75% (i.e. not all of the plants will be killed). This means that in 2016 treatment and control efforts will be needed to target not only the plants that survive, but also the new plants that will emerge due to the seed bank in the sediment. It will take two to three years of monitoring and spot control to exhaust this seed bank. During this period LLCC should continue spraying observed patches and should encourage area residents to hand pull individual small clumps.

Maps of aquatic plant distributions and treatment areas within Lake Limerick in 2013, and in earlier years (2007, 2009, and 2012) are shown in Figures 37 – 40.

3.2 PRECIPITATION AND LAKE LEVEL

During 2015, lake level monitoring continued near the outlet of Lake Leprechaun (Figure 41). The logger at this site provides accurate lake level data at 60 minute intervals by recording water pressure (in feet of water). Precipitation data was obtained from the KWASHELT3 weather station, located at the tip of the small extension of Lake Limerick along its north shore (King Cove).

From December, 2014 through November, 2015, recorded water level in Lake Leprechaun fluctuated by just over one foot (Figure 42). The water level record in Lake Leprechaun was similar to that in Lake Limerick. As in Lake Limerick, water level in Lake Leprechaun fluctuated in response to rain events from December, 2014 through mid-April, 2015, with a rapid, lagged, increase followed by a slower recession over a number of days (Figure 42). Outlet control boards were installed in late April, 2015 to raise the water level in Lake Leprechaun for the summer recreational season. These boards remained in place until mid-October, and water level was stable during this time, changing only in response to a storm in late August (Figure 42).

The water level record for Lake Leprechaun from January through November 2014 is shown in Figure 43. The figure also includes the precipitation record for the same time period. Figure 44 compares the 2014 water level record for Lake Leprechaun to that from 2013.

3.3 WATER TEMPERATURE

During 2015, in conjunction with water level monitoring, water temperature was monitored continuously (at 60-minute intervals) near the outlet of Lake Leprechaun (Figure 41). Monitoring occurred from December, 2014 through November, 2015, although no data was recorded from 6/3/2015 – 7/3/2015. The air temperature record for the full period was downloaded from the KWASHELT3 weather station, located at the northeast end of King Cove.

During the monitoring period, average air temperature ranged from -2.8 to 24.1 °C (Figure 45). Air temperatures were lowest in December, 2014, and January and February, 2015, and highest in July and August, 2015 (Figure 45). Surface water temperatures in Lake Leprechaun during this same period ranged from 3.2 to 26.5 °C, a slightly lower range than observed in Lake Limerick or at the Lake Limerick dam outlet (Figure 45). Water temperatures in Lake Leprechaun varied seasonally, and were lowest in December, 2014 and January, 2015, and highest in July and August, 2015.

As at the Lake Limerick monitoring sites, the temperature of surface water in Lake Leprechaun appeared to respond to fluctuations in average air temperature, displaying a similar temporal pattern (Figure 45). The degree of response appeared to be influenced by the same set of factors mentioned in section 2.4. In addition, surface water temperatures in Lake Leprechaun varied diurnally. From December, 2014 to early November, 2015, the magnitude of the diurnal variation in surface water temperatures in Lake Leprechaun ranged from 0.2 to 5.4 °C. The magnitude changed seasonally, as was observed in Lake Limerick and at the Lake Limerick dam outlet (Figure 46). A more in-depth analysis of these trends is available in section 2.4.

3.4 WATER QUALITY

A water quality monitoring program was implemented at Lake Leprechaun during the summer of 2013 and continued in 2014 and 2015. The water sampling site in Lake Leprechaun is located near the outlet structure (Figure 47). Samples from the site were analyzed for total phosphorus (TP) concentrations [method detection limit (mdl): 2.0 µg/L], and concentrations of soluble reactive phosphorus (SRP) [mdl: 1.0 µg/L], chlorophyll *a* [mdl: 1.0 µg/L], and phaeophytin *a* [mdl: 1.0 µg/L].

The phytoplankton analysis and vertical profiles of water temperature and concentrations of dissolved oxygen were not completed in 2015 for the reasons described in section 2.4.

During the 2015 monitoring period, concentrations of total phosphorus (TP) in Lake Leprechaun increased from April (8.6 µg/L), to June (12.0 µg/L), to September (14.0 µg/L; Figure 21). The concentration of soluble reactive phosphorus were above detection limits only in September, when it was 2.0 µg/L (Figure 22). The concentration of chlorophyll *a* was 2.8 µg/L in April and fell to 2.1 µg/L in June and September (Figure 23). Concentrations of phaeophytin *a* were similar in all three months, but slightly higher in June (1.6 µg/L) than in April (1.4 µg/L) or September (1.2 µg/L; Figure 24). These concentrations reflect oligotrophic conditions.

Unlike in Lake Limerick, the Chl:TP ratio (which is indicative of the productivity of the system and the degree to which algae are utilizing the available phosphorus) decreased over the course of the monitoring period, from 0.33 in April to 0.18 in June to 0.15 in September (Figure 25). The relatively high percentage of phaeophytin *a* relative to chlorophyll *a* from April to June to September (Figure 26) appears to be consistent with the low available phosphorus (SRP) concentration and light limitation that is greater at Leprechaun than Limerick due to shade from trees and greater water color at Leprechaun.

During the 2015 monitoring period, concentrations of total phosphorus (TP) never exceeded the established management goal for peak lake TP of 25 µg/L or less (≤25 µg/L; Figure 27). As well, although concentrations of TP were higher in the two summer months (June and September), than in April, they never exceeded the established summertime goal for lake TP of 15 µg/L or less (≤15 µg/L; Figure 27). Neither the peak lake chlorophyll goal (< 8 µg/L) nor the summer lake chlorophyll goal (< 4 µg/L) was exceeded during any of the three sampling months in 2015 (Figure 28). These low concentrations of TP and chlorophyll *a* indicate that water quality in Lake Leprechaun is good and that there is competition between aquatic macrophytes (rooted aquatic plants) and periphyton (algae attached to the lake bottom and rooted plants) for nutrients as well as significant light limitation particularly around the lake shoreline due to shade from terrestrial trees.

The 2015 water quality monitoring results can be compared to data from previous years. However, the timing of and frequency of water quality monitoring has varied year to year, making direct comparisons difficult. In 2013, Lake Leprechaun water quality was monitored in August and September, but not in October as it was in Lake Limerick. In 2014, water quality was monitored monthly from March through November. In 2015, as stated above, water quality was monitored in April, June, and September. Annual Lake Leprechaun averages discussed below are not volume-weighted, but were computed as the average of all data points. Summer averages for Lake Leprechaun were computed as the average of the measurements taken during summer months (August and September in 2013; June, July, August, and September in 2014; June and September in 2015).

In Lake Leprechaun, the average total phosphorus (TP) concentration measured in 2015 (11.5 µg/L) was similar to the average TP in 2014 (10.9 µg/L) and in 2013 (11.8 µg/L – average of data from August and September only). The summer average TP in 2015 (13 µg/L) was only slightly above summer average TP in both 2013 (11.8 µg/L) and 2014 (12.5 µg/L; Figure 29). Average concentrations of soluble reactive phosphorus (SRP) over the full monitoring period and summer average concentrations of SRP were less in Lake Leprechaun in 2015 than in 2014, and similar to concentrations in 2013 (Figure 30).

In Lake Leprechaun, the annual average concentration of chlorophyll *a* was higher in 2015 (2.3 µg/L) than in either 2013 (1.3 µg/L) or 2014 (1.5 µg/L). The same was true of the summer average concentration of chlorophyll *a* (Figure 31). The 2015 average concentration of phaeophytin *a* was lower in 2015 (1.4 µg/L) than in either 2013 (1.5 µg/L) or 2014 (1.8 µg/L), as was the 2015 summer average concentration (Figure 32).

4.0 PERMIT STATUS

AquaTechnex is the administrator for the herbicide permit and that permit is good through 2016. In 2016, LLCC should initiate a new permit application process.

5.0 RECOMMENDATIONS FOR 2016

2016 Recommendations:

- In 2016, the bathymetry of Lake Leprechaun should be surveyed in preparation for dredging activities.

- The bathymetry of both Lake Leprechaun and Lake Limerick should be re-surveyed after dredging is complete, so that sediment removal and the efficiency of dredging activities can be estimated.

- Aquatic plant mapping should be continued at both Lakes Limerick and Leprechaun in late May to June 2016 to establish 2016 treatment zones and develop management plans for both lakes.

    - Given that aquatic macrophytes have been successfully controlled in both lakes, management efforts in 2016 should focus on very specific areas where treatment is needed in order to maintain competition with filamentous green algae that is becoming a recreational nuisance (excluding the areas targeted for dredging in Lake Limerick in 2016).

    - Management efforts should continue to strive to establish and support balanced macrophyte communities, so that invasive species are kept out of the lakes. To date, management activities have succeeded in this capacity (e.g., *Egeria densa* has not been seen in recent surveys).

        - It is important, however, to avoid over-controlling the growth of aquatic macrophytes, because filamentous green algae are more likely to succeed and become established if aquatic macrophytes are stressed or sparse. This could lead to cyanobacteria establishment which would contribute to overall water quality decline.

    - To this end, next year's plant management program be comprised of the following:

        - Assessment of carry-over growth of yellow iris, and continued treatment of the invasive species in shoreline areas, to curtail its growth (see section 2.1). The timing of the iris treatment and the chemicals to be used for treatment will be reviewed and will depend on the assessment of carryover in the spring survey, the permit requirements for potential herbicides, and the fishery window for the permit.

        - Targeted control of non-native species, if any are identified in spring surveys.

        - Treatment of specific patches of native species that are excessively impeding recreational activities.

- Plant mapping should also be conducted in both lakes September 2016 in order to assess the effectiveness of the summer control activities and in order to plan for the efforts that will be needed in 2017.

- During 2016, water quality monitoring should be only in July and September. Water quality monitoring will be more limited in scope in 2016 than in previous years because the lakes are in good shape. Water quality data from July and September will be sufficient to monitor general water quality in both lakes for signs of change. In addition, based on the cost of the analysis, and the limited information that it provides as a result of the good water quality conditions, low nutrient levels, and historical lack of cyanobacteria within both lakes, we recommend that phytoplankton samples not be taken in 2016 unless a surface algal scum that is suspected of being blue-greens occurs.

- A survey point should be taken for the elevation of the data loggers in Lake Limerick and Lake Leprechaun, so that the water pressure data from 2013, 2014, and 2015 (and that from future years) can be correlated to actual lake levels.

6.0 FIGURES

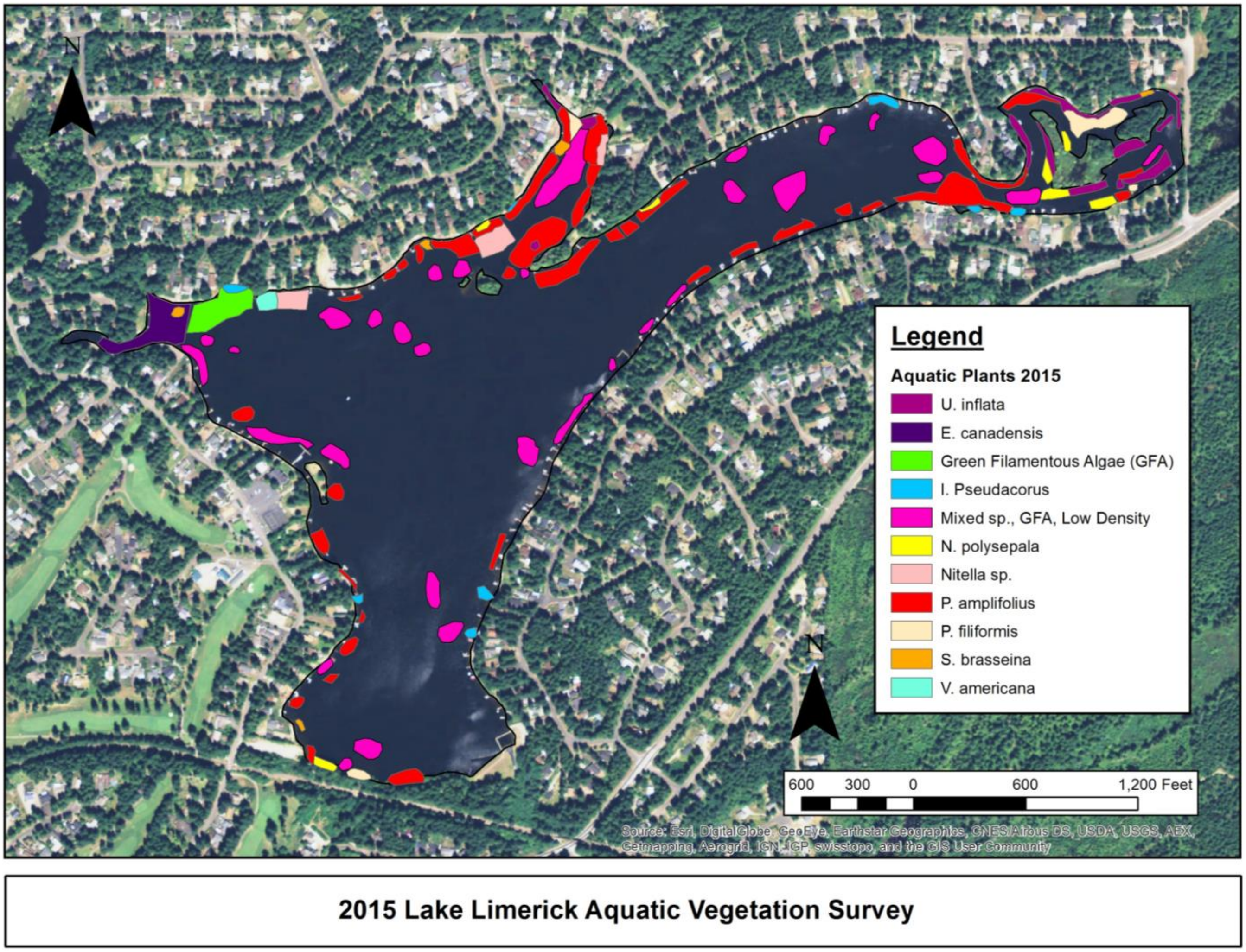

Figure 1 – Map of aquatic plant distribution in Lake Limerick in September, 2015.

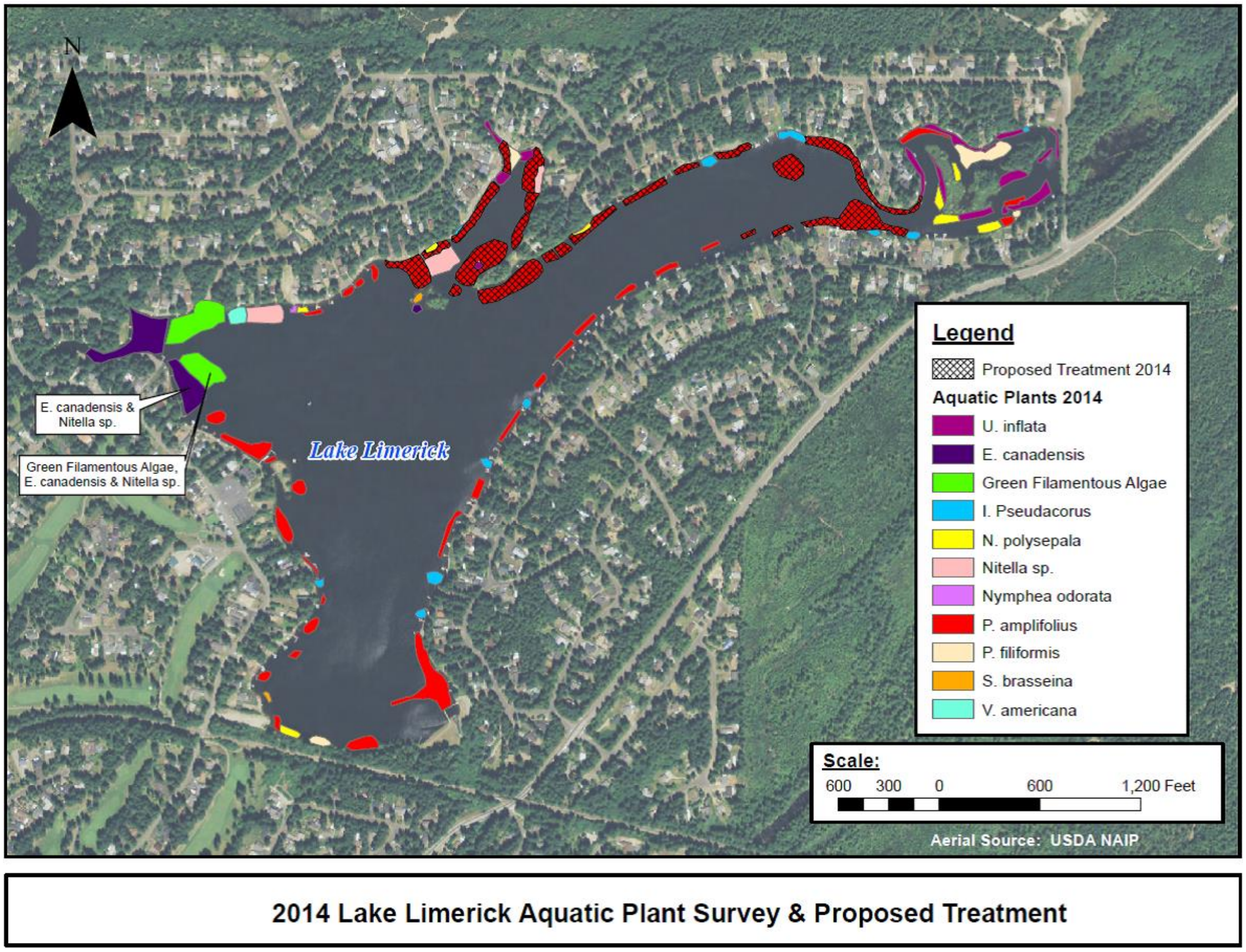

Figure 2 – Map of aquatic plant distribution in Lake Limerick in June 2014. Cross-hatching indicates the areas where treatment was proposed for summer 2014.

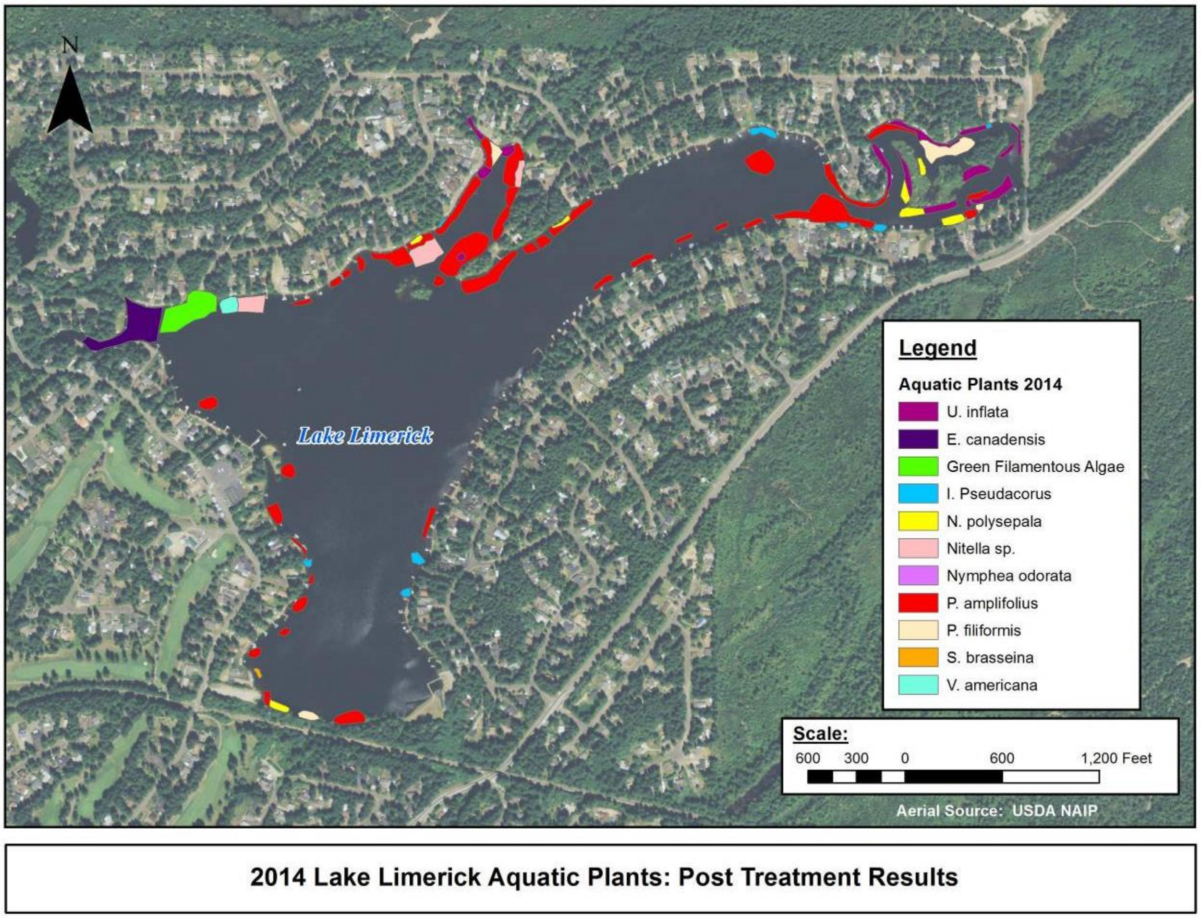

Figure 3 – Map of aquatic plants distribution in Lake Limerick in fall 2014 after the proposed treatment had been completed.

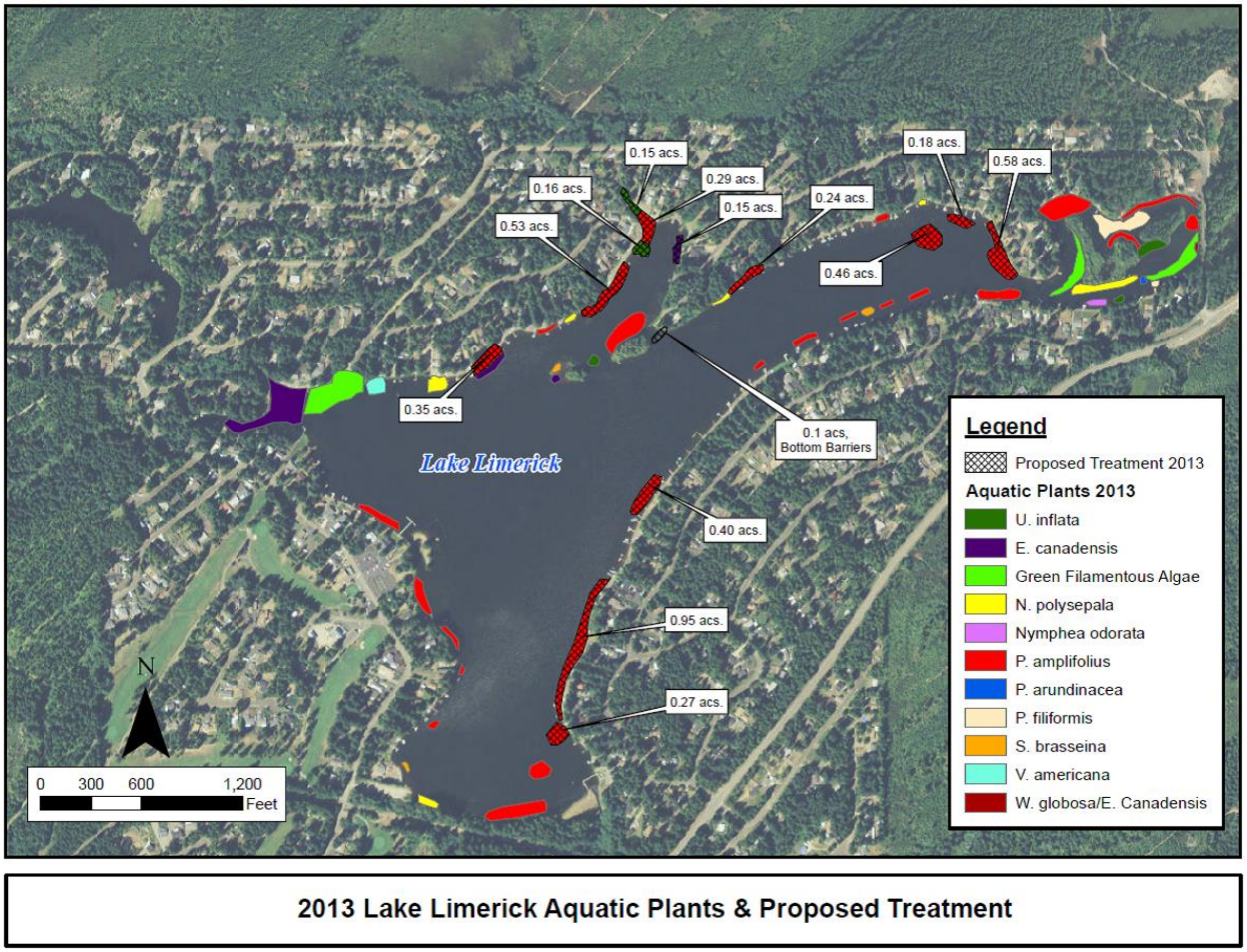

Figure 4 – Map of aquatic plant distribution in Lake Limerick in June 2013. Cross-hatching indicates the areas where treatment was proposed for summer 2013.

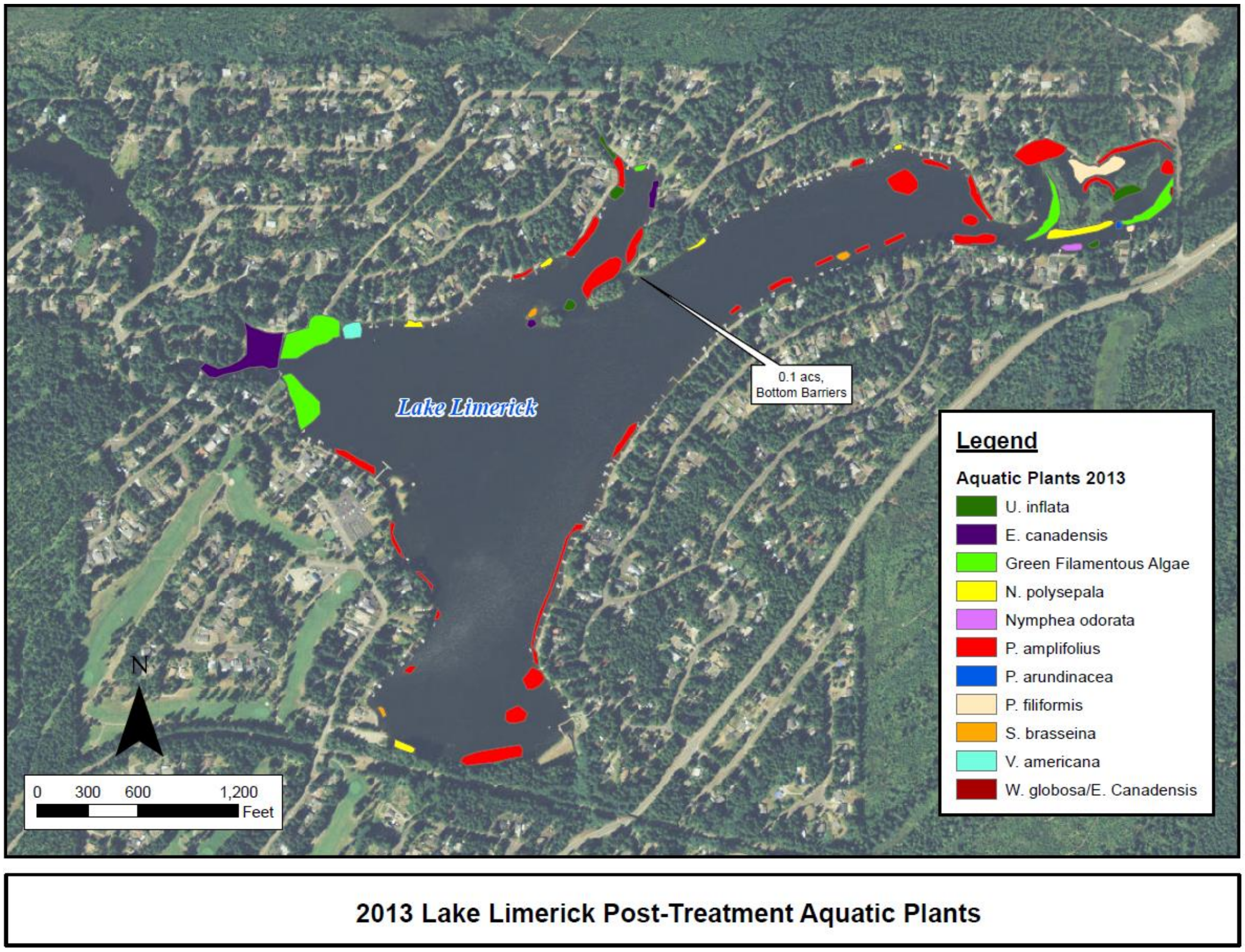

Figure 5 – Map of aquatic plants distribution in Lake Limerick in fall 2013 after the proposed treatment had been completed.

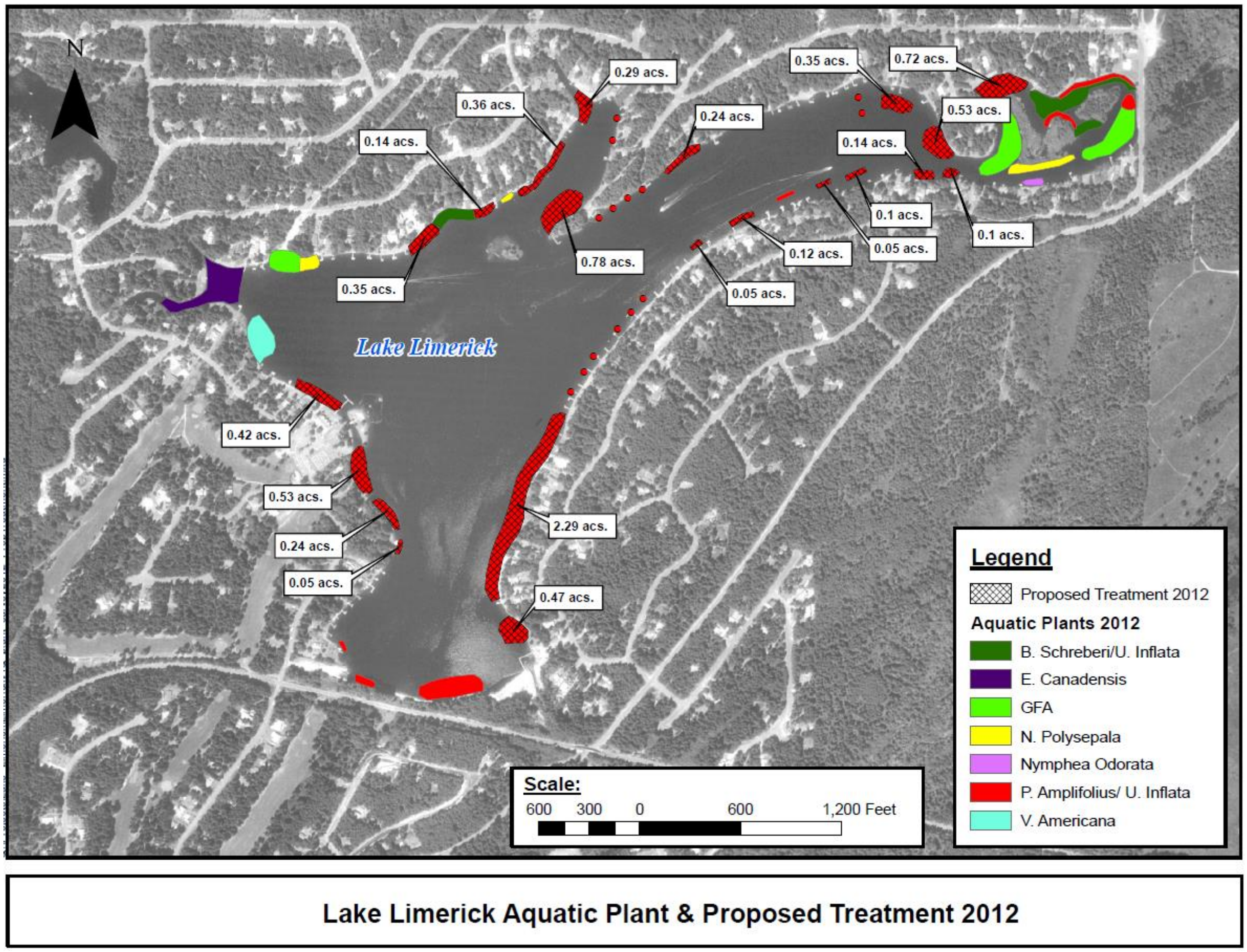

Figure 6 – Map of aquatic plant distribution in Lake Limerick in early summer 2012. Cross-hatching indicates the areas where treatment was proposed for summer 2012.

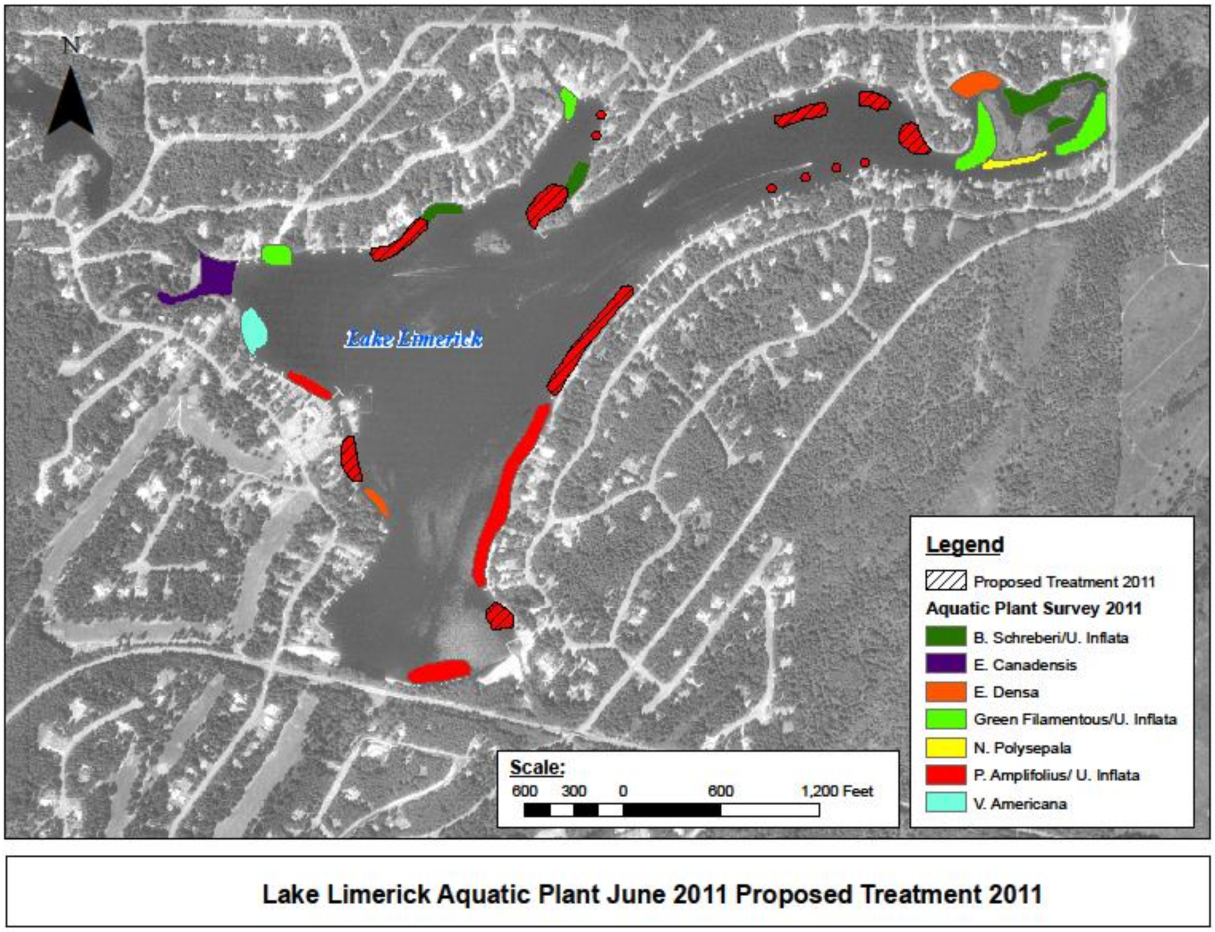

Figure 7 – Map of aquatic plant distribution in Lake Limerick in June 2011. Cross-hatching indicates the areas where treatment was proposed for summer 2011.

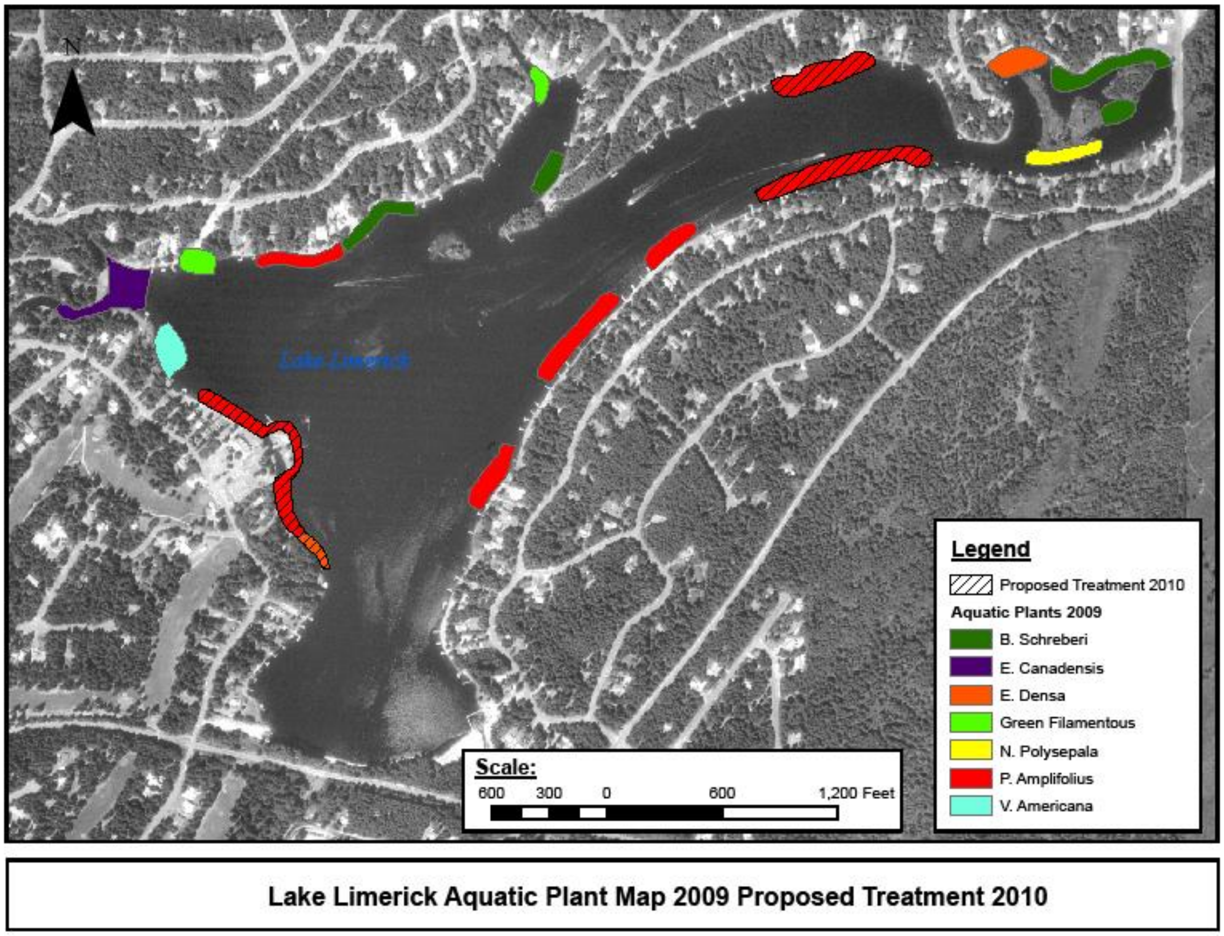

Figure 8 – Map of aquatic plant distribution in Lake Limerick in summer 2009. Cross-hatching indicates the areas where treatment was proposed for summer 2010.

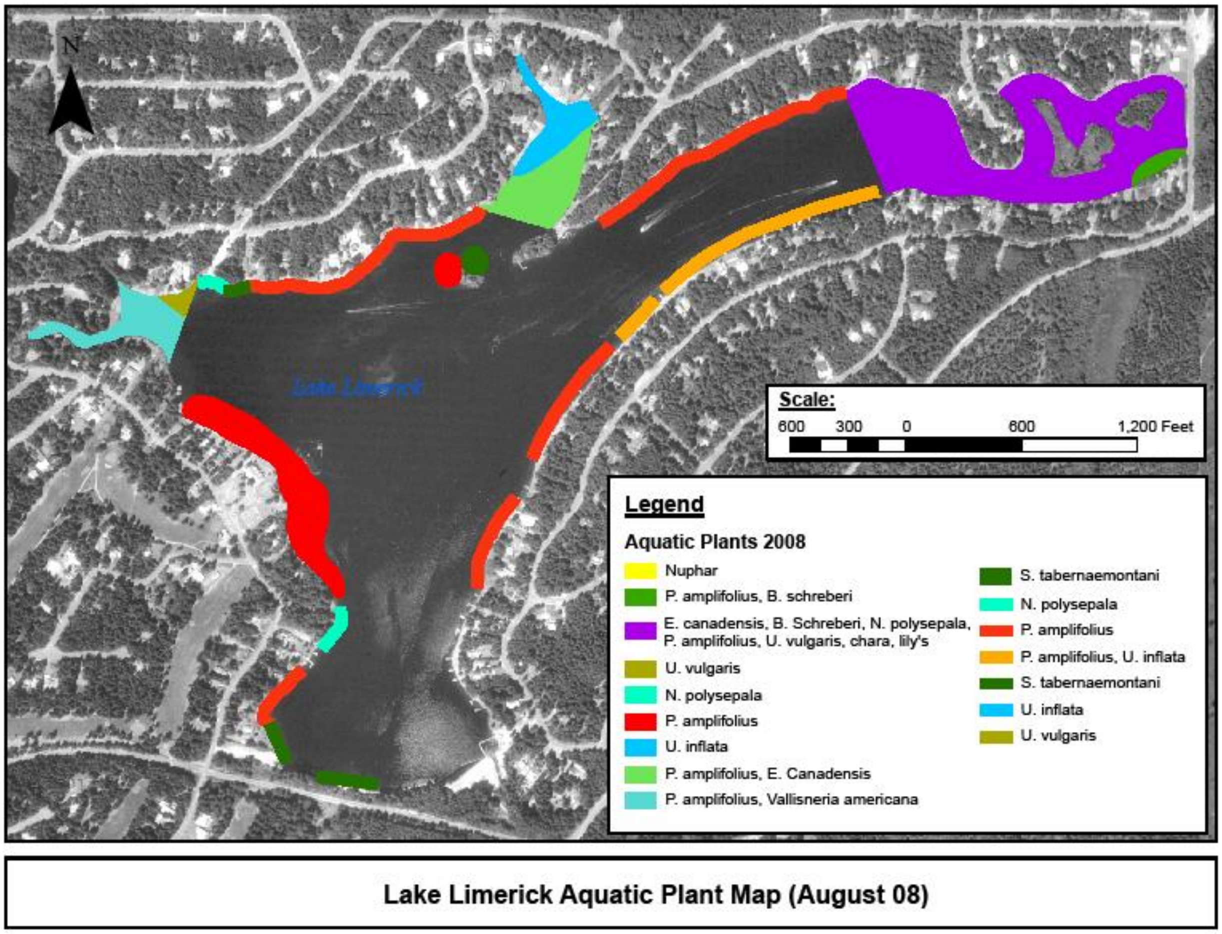

Figure 9 – Map of aquatic plant distribution in Lake Limerick in August 2008.

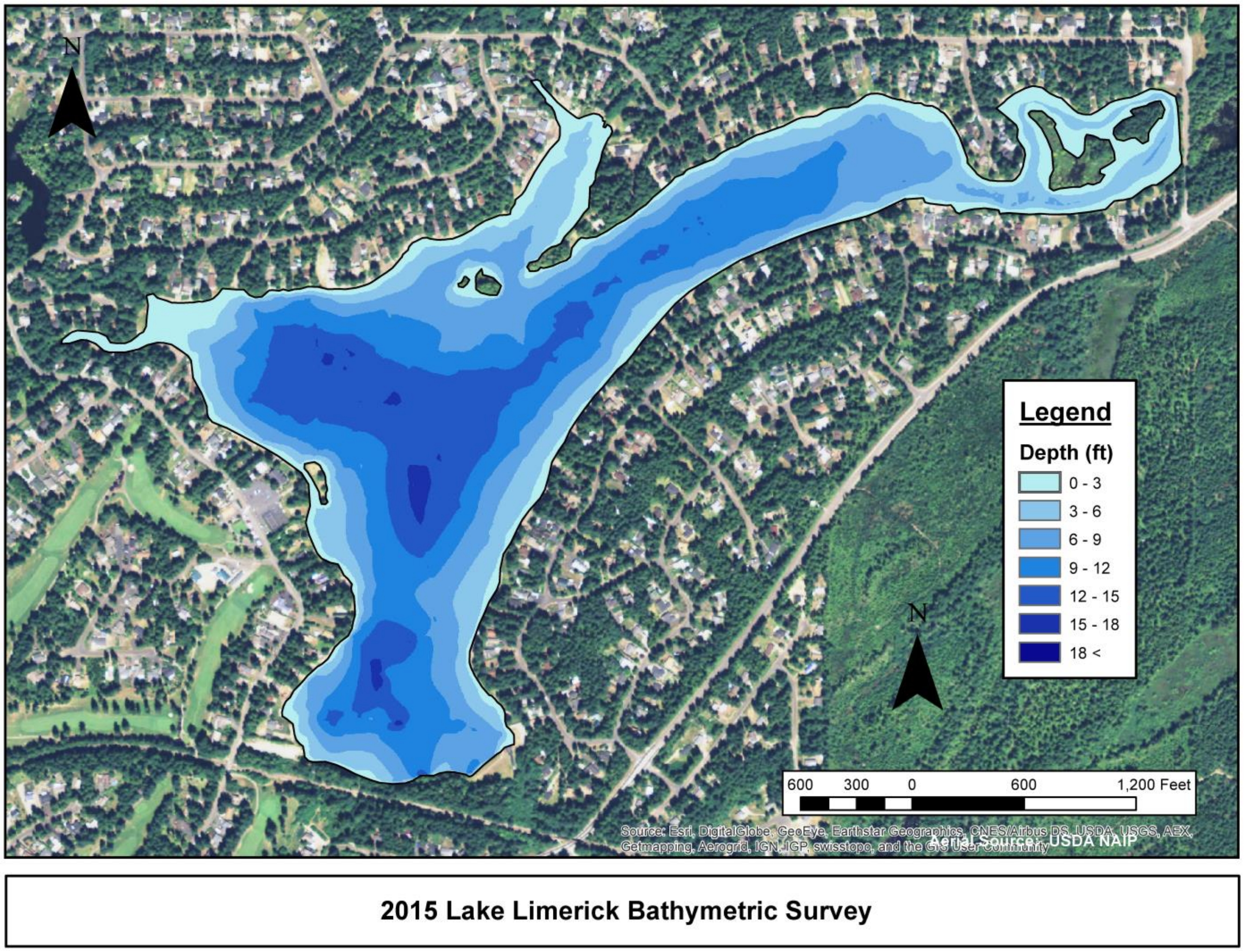

Figure 10 – Bathymetry of Lake Limerick. Bathymetric data collected in September 11th, 2015 survey.

Figure 11 – Level logger located at the Lake Limerick Country Club dock.

Figure 12 – Level logger located below the Lake Limerick dam

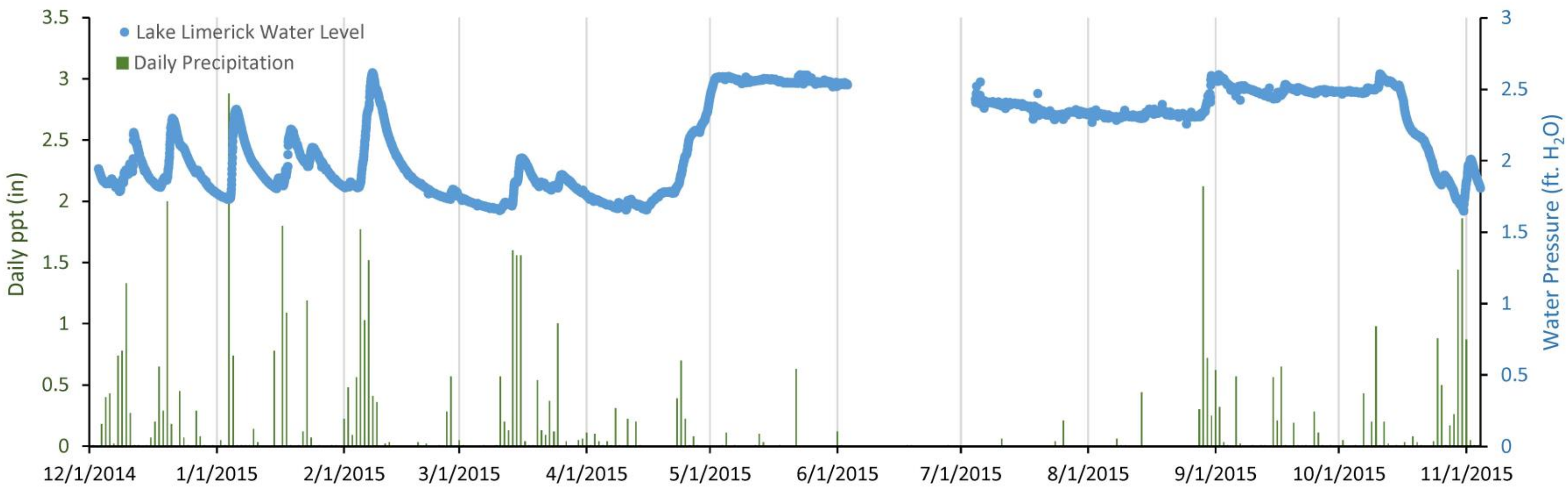

Figure 13 – Lake Limerick water level and daily precipitation from December, 2014 through early November, 2015. Precipitation data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level logger for Lake Limerick located at the inn dock.

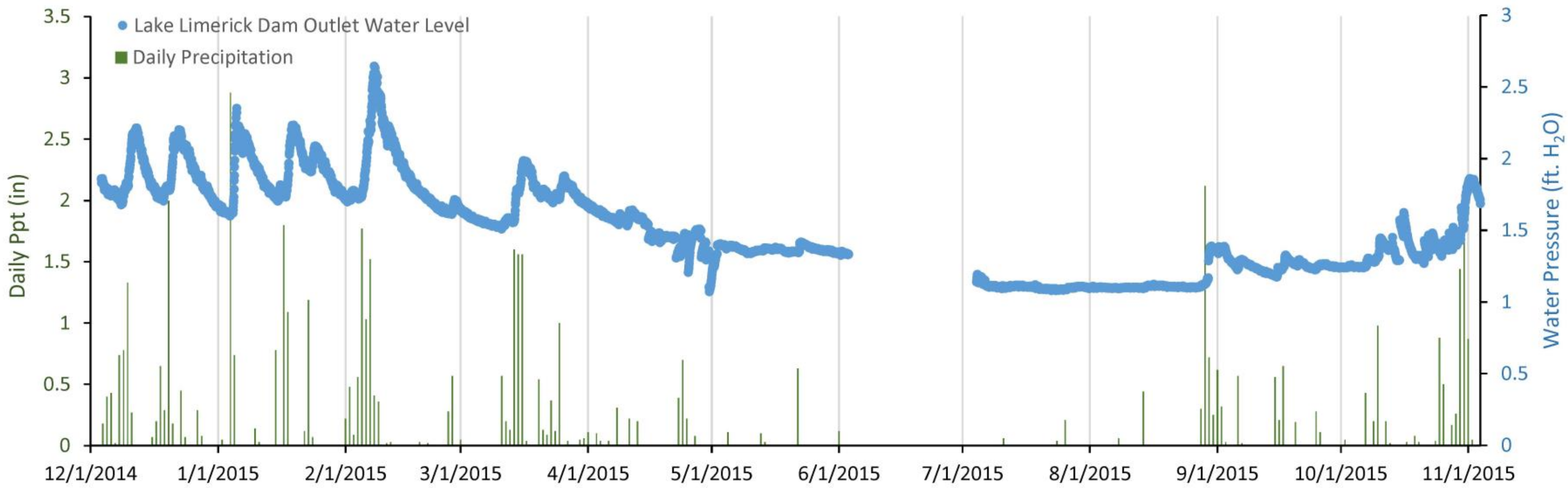

Figure 14 – Water level at the Lake Limerick dam outlet and daily precipitation from December, 2014 through early November, 2015. Precipitation data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level logger for Lake Limerick Dam Outlet located just below the Lake Limerick Dam.

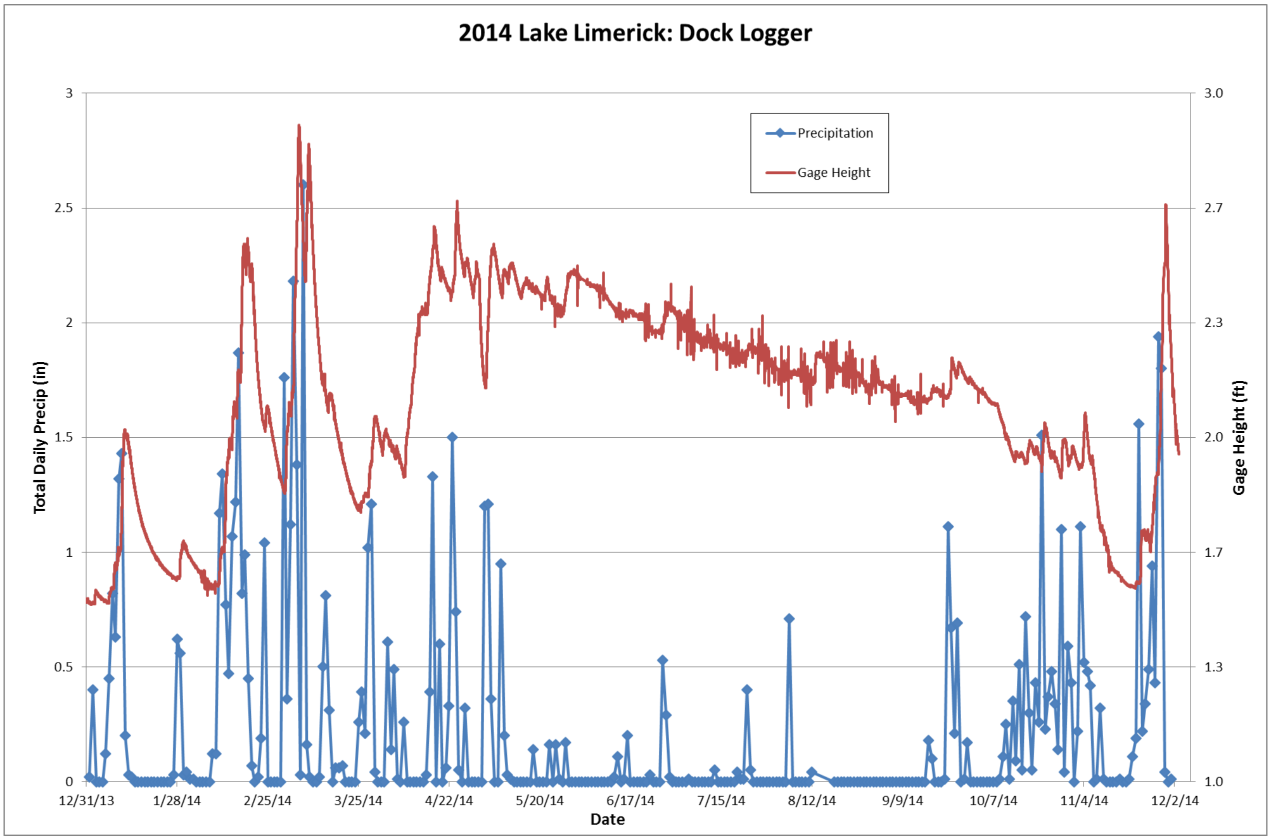

Figure 15 – Continuous record of lake level in Lake Limerick from December 2013 through November 2014 and daily precipitation within this same time period.

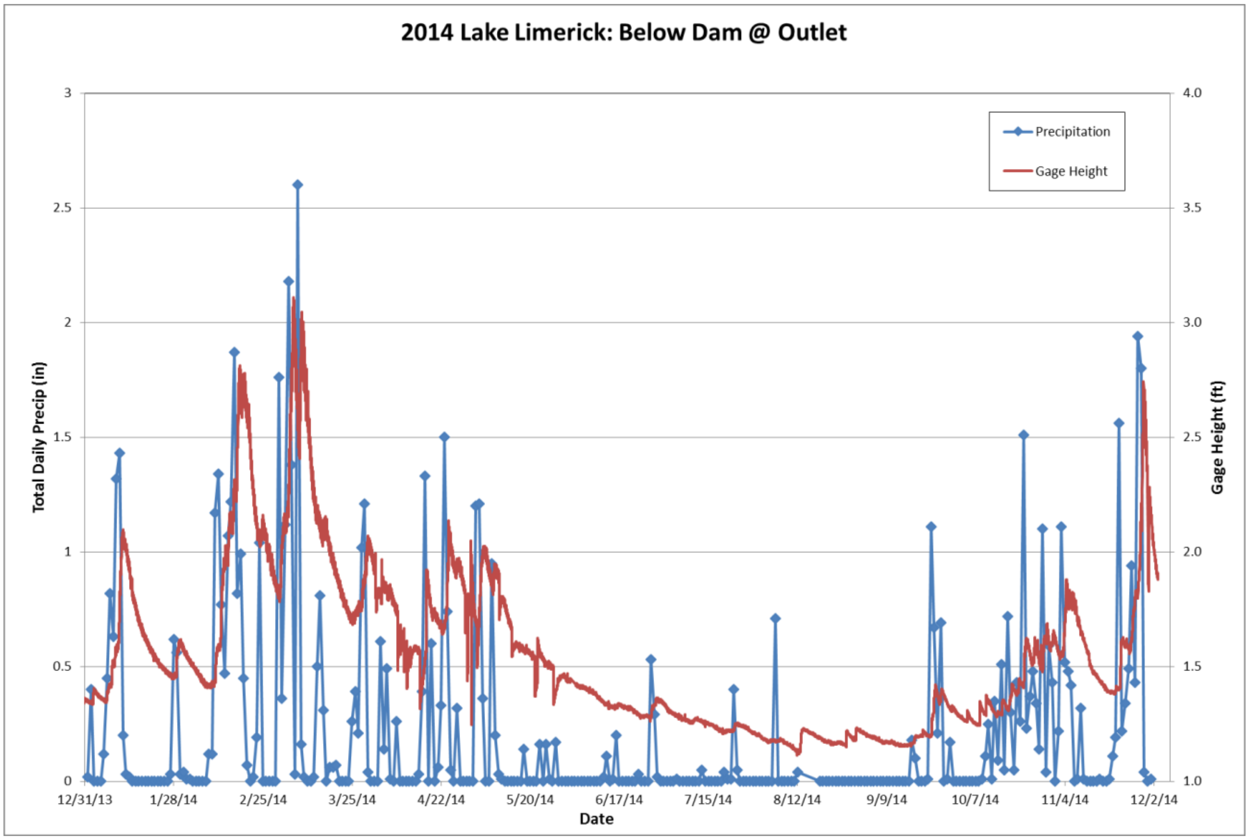

Figure 16 – Continuous record of water level below the Lake Limerick dam from December 2013 through November 2014 and daily precipitation within this same time period.

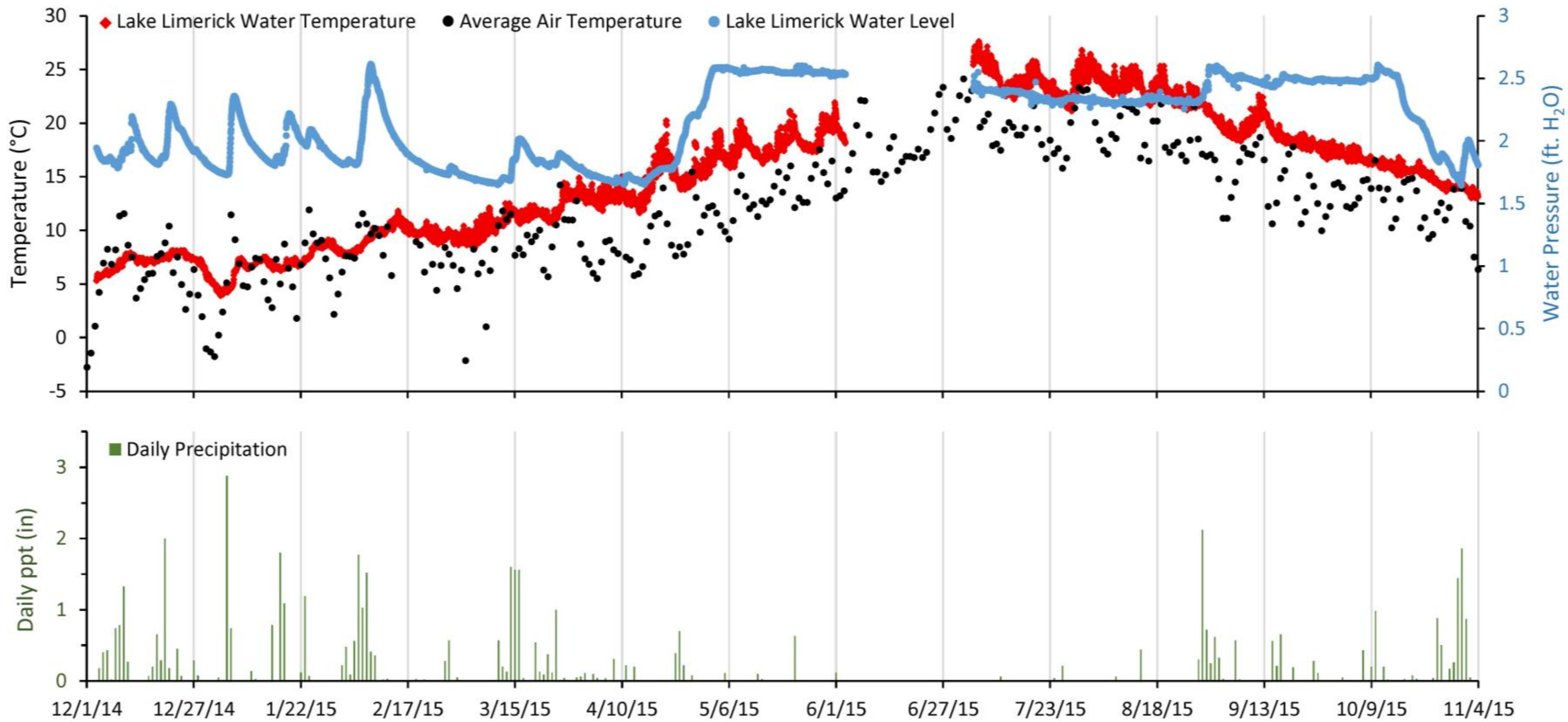

Figure 17 - Lake Limerick water temperature, Lake Limerick water level, average air temperature, and daily precipitation from December, 2014 through early November, 2015. Precipitation and air temperature data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level and temperature logger for Lake Limerick located at the inn dock.

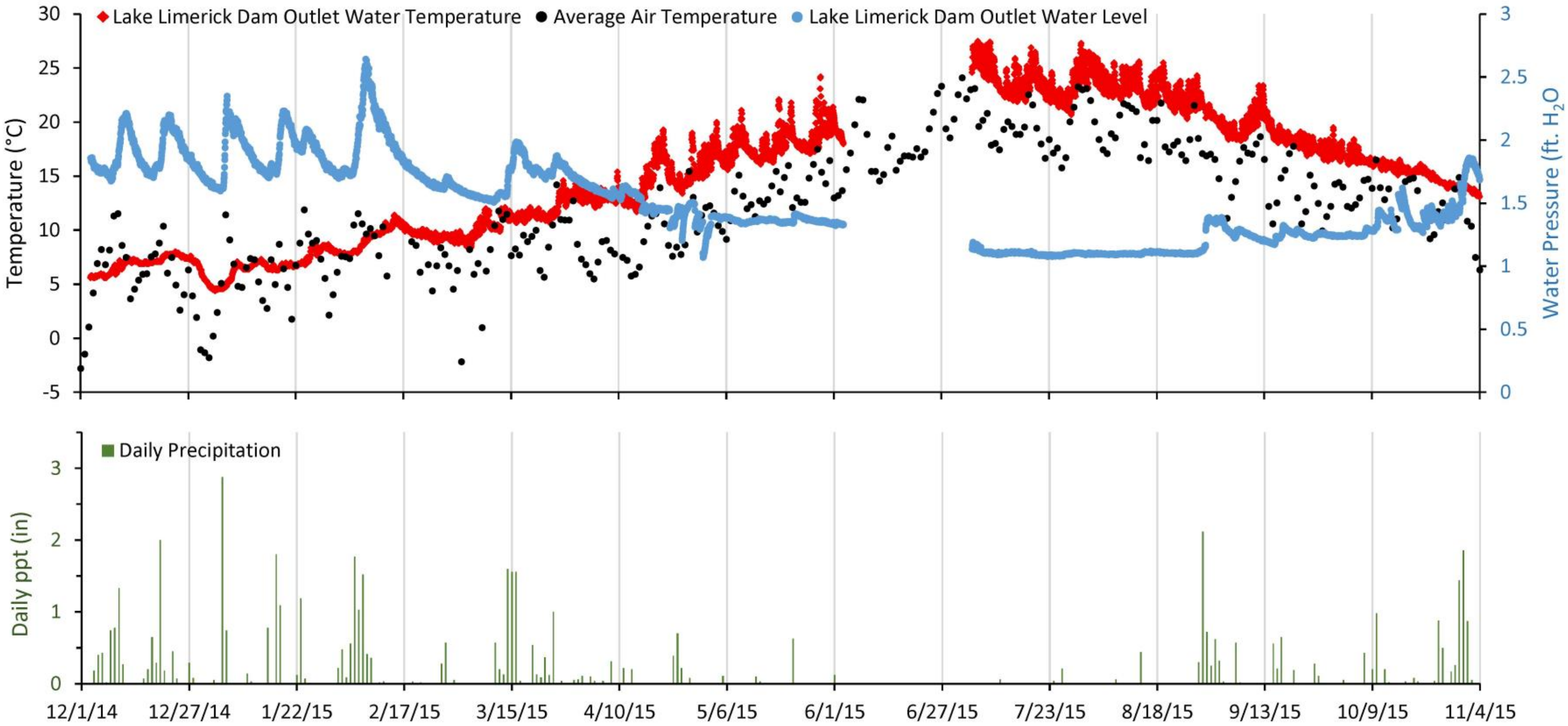

Figure 18 – Water temperature and water level at the Lake Limerick dam outlet, average air temperature, and daily precipitation from December, 2014 through early November, 2015. Precipitation and air temperature data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level and temperature logger for Lake Limerick Dam Outlet located just below the Lake Limerick Dam.

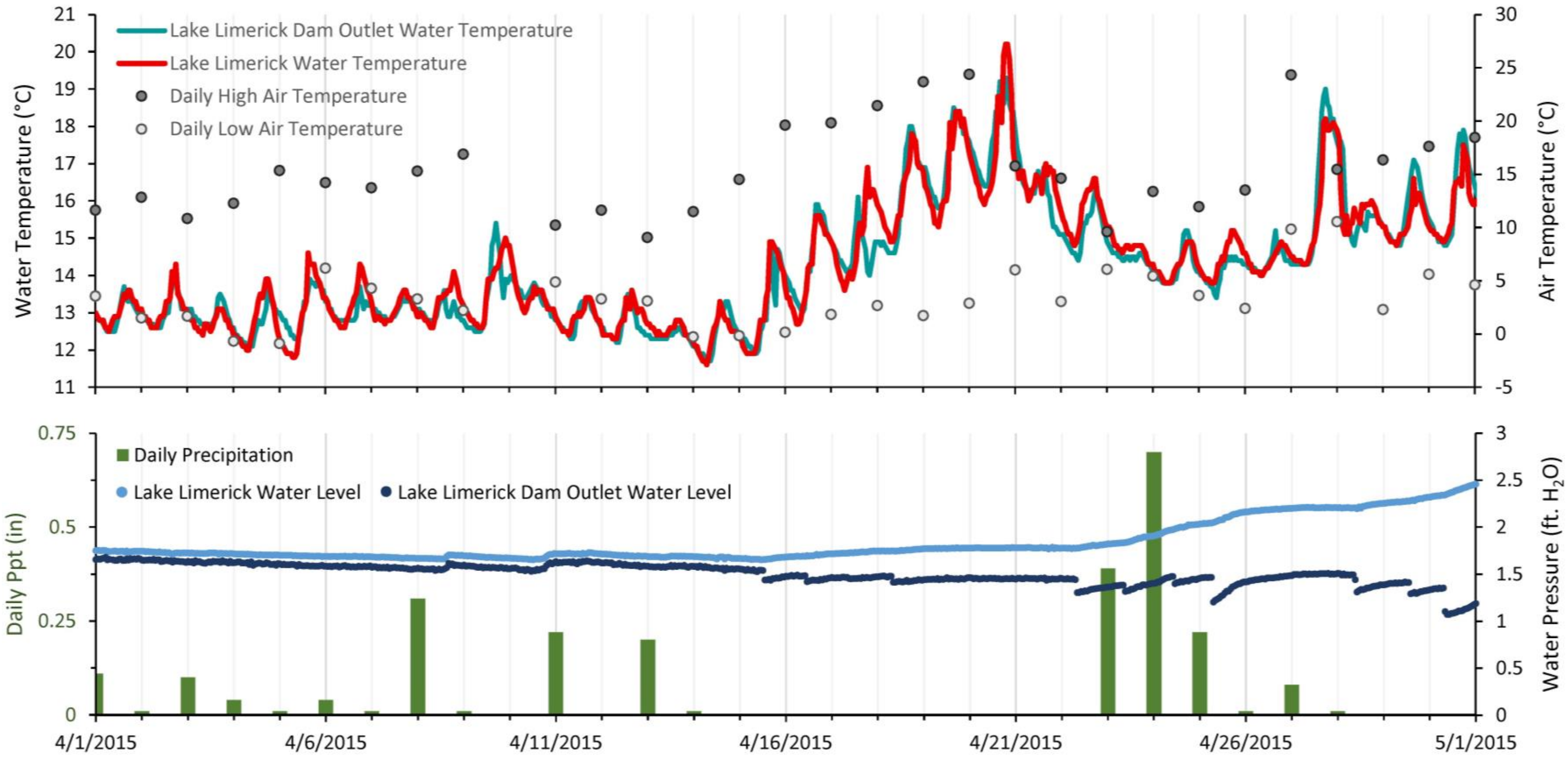

Figure 19 – Water temperature in Lake Limerick and at the Lake Limerick dam outlet during April 2015, and daily high and low air temperatures for the same period. Water level in Lake Limerick and at the Lake Limerick dam outlet in April 2015, and daily precipitation during the same period. Precipitation and air temperature data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level and temperature logger for Lake Limerick located at the inn dock. Water level and temperature logger for Lake Limerick Dam Outlet located just below the Lake Limerick Dam.

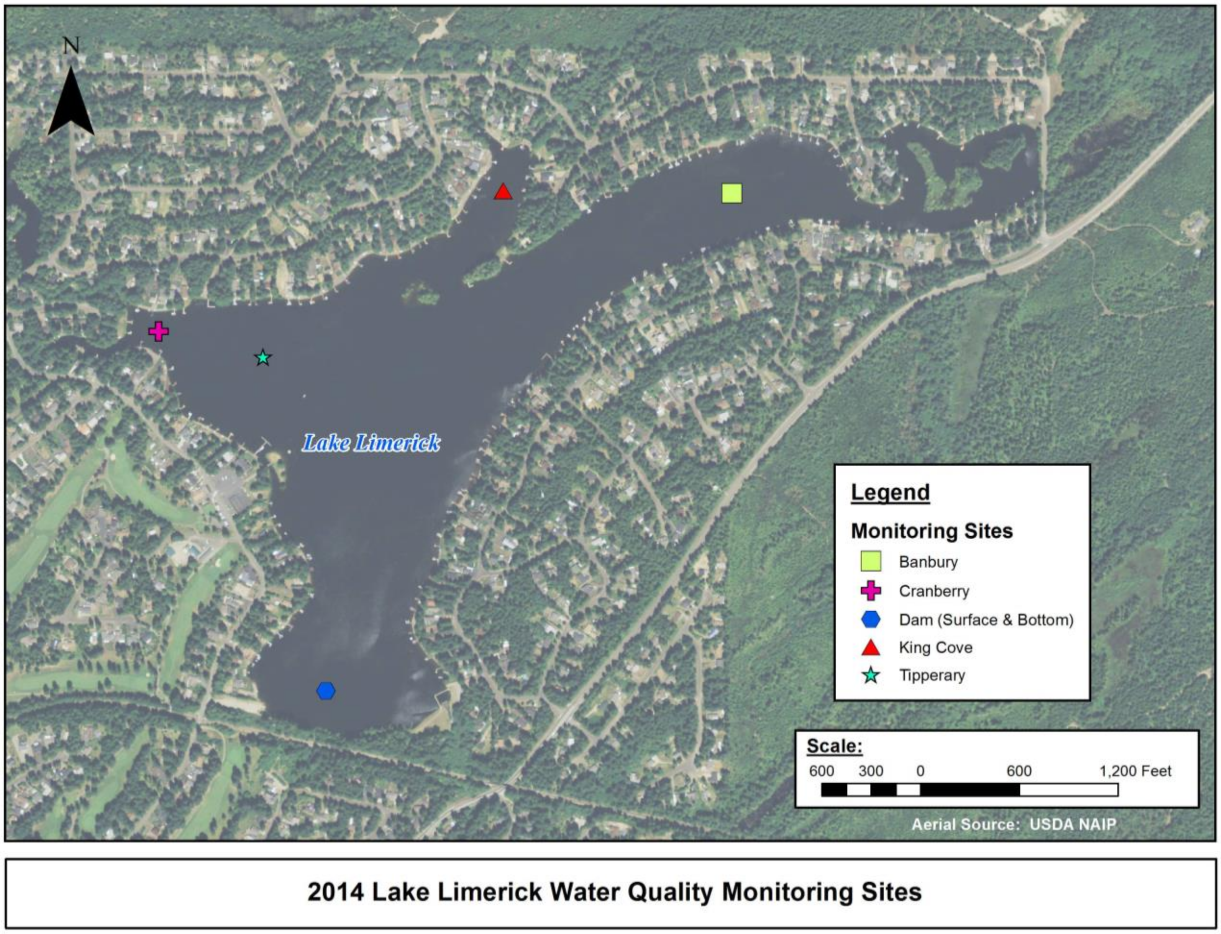

Figure 20 – Locations of water quality monitoring sites within Lake Limerick.

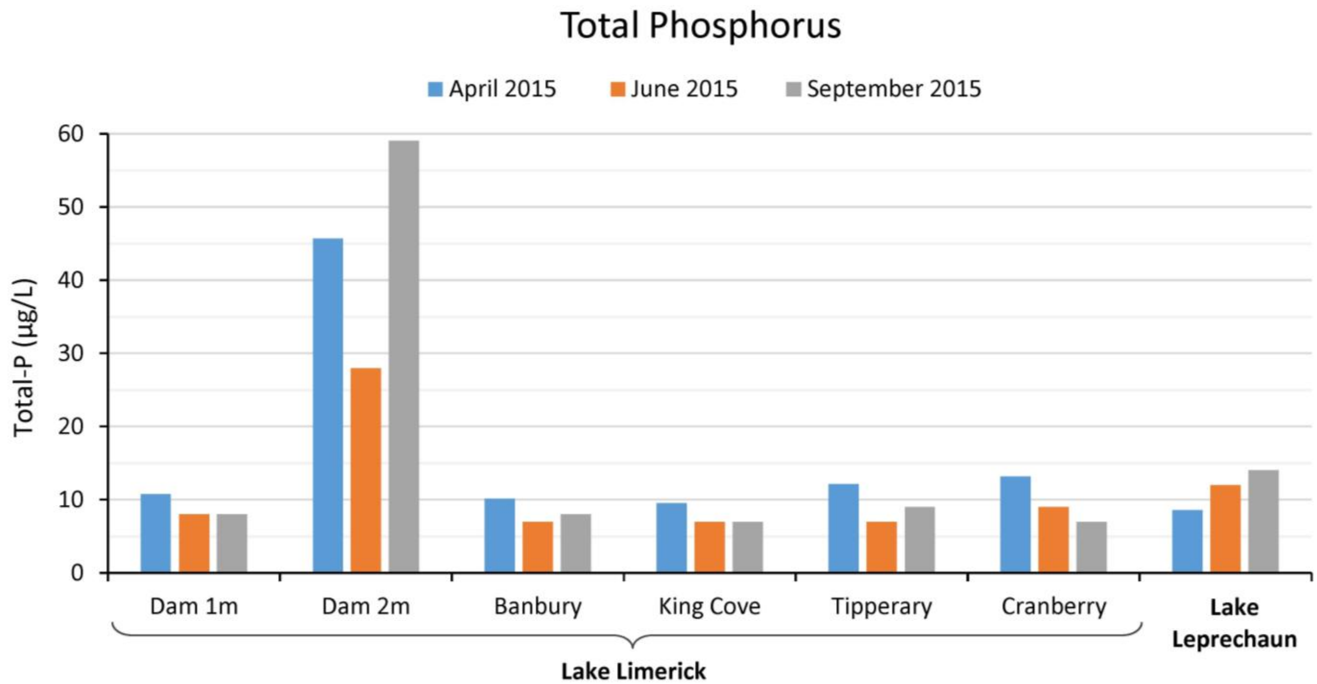

Figure 21 – Total phosphorus concentrations at the water quality monitoring sites within Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. The method detection limit for total phosphorus analysis is 2.0 µg/L.

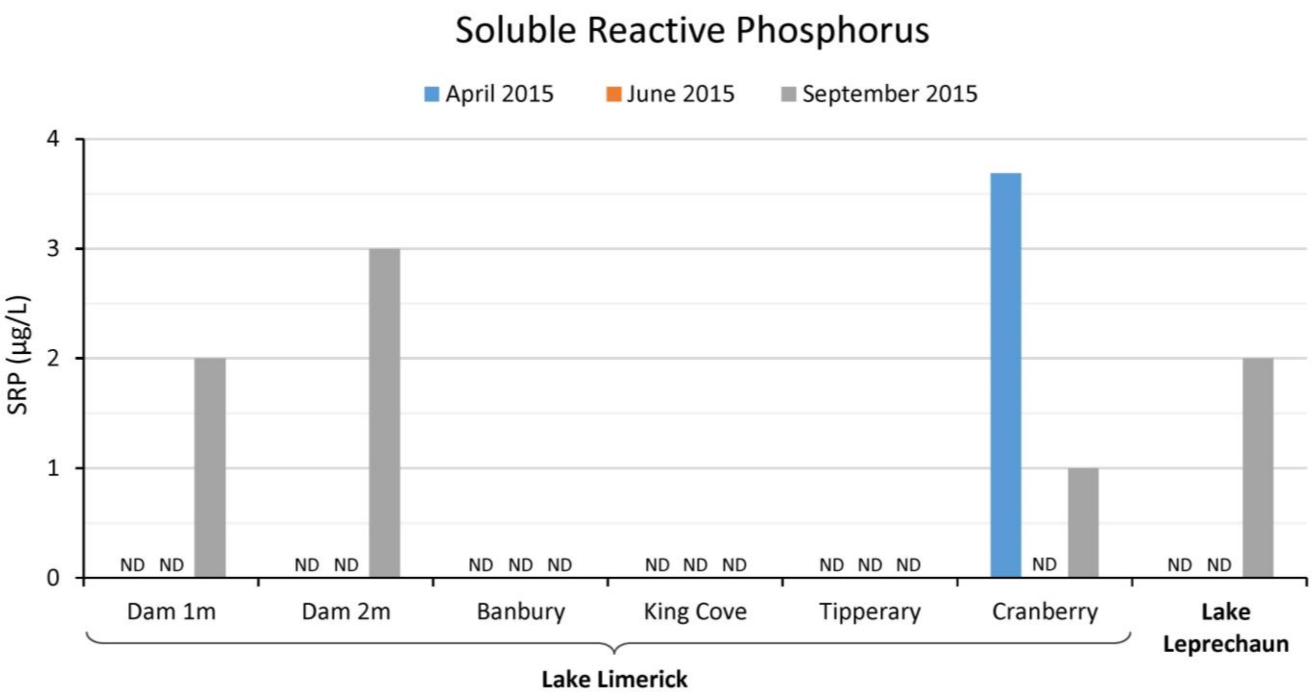

Figure 22 – Concentrations of soluble reactive phosphorus (SRP) at the water quality monitoring sites within Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. ND stands for "not detected" and indicates that concentrations of SRP in the water sample were below the method detection limit of 1.0 µg/L.

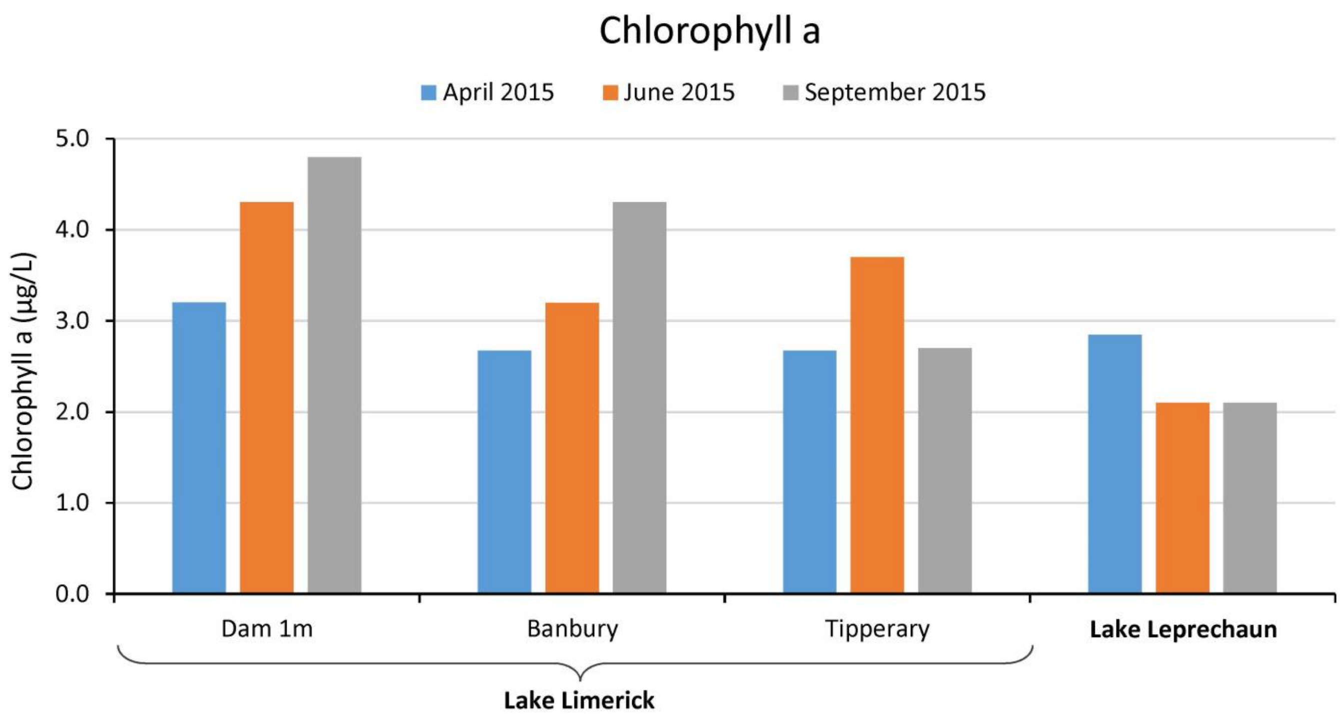

Figure 23 – Concentrations of chlorophyll *a* at the water quality monitoring sites within Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. The method detection limit for chlorophyll *a* analysis is 0.1 µg/L.

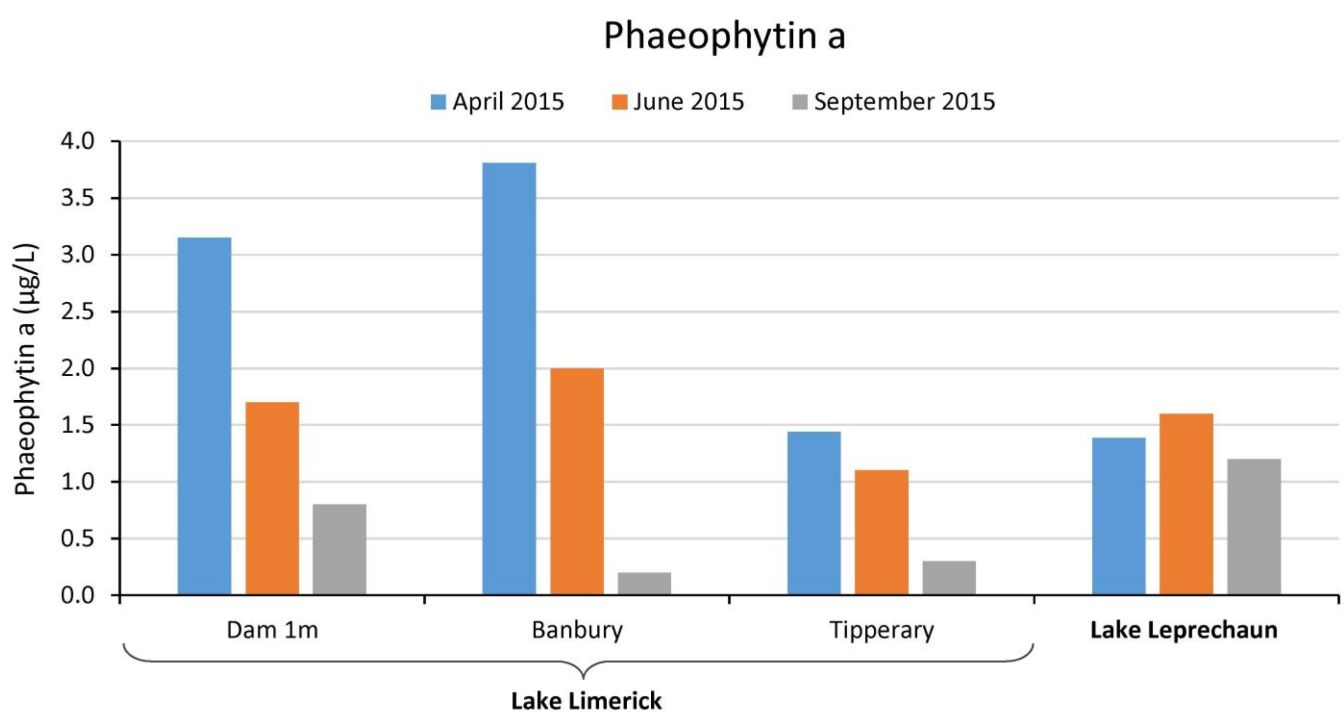

Figure 24 – Concentrations of phaeophytin *a* at the water quality monitoring sites within Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. The method detection limit for phaeophytin *a* analysis is 0.1 µg/L.

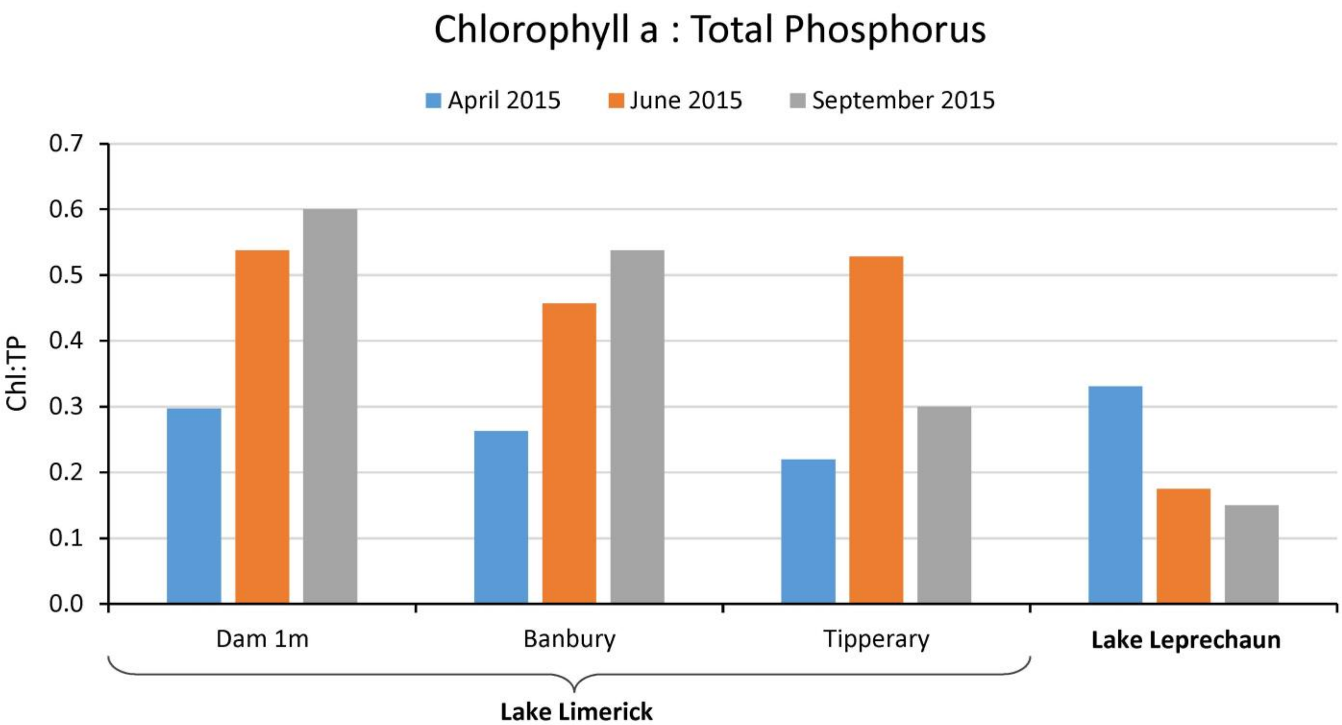

Figure 25 – Ratio of chlorophyll *a* to Total-P at three Lake Limerick water quality monitoring sites and the Lake Leprechaun water quality monitoring site on April 2nd, June 3rd, and September 2nd, 2015.

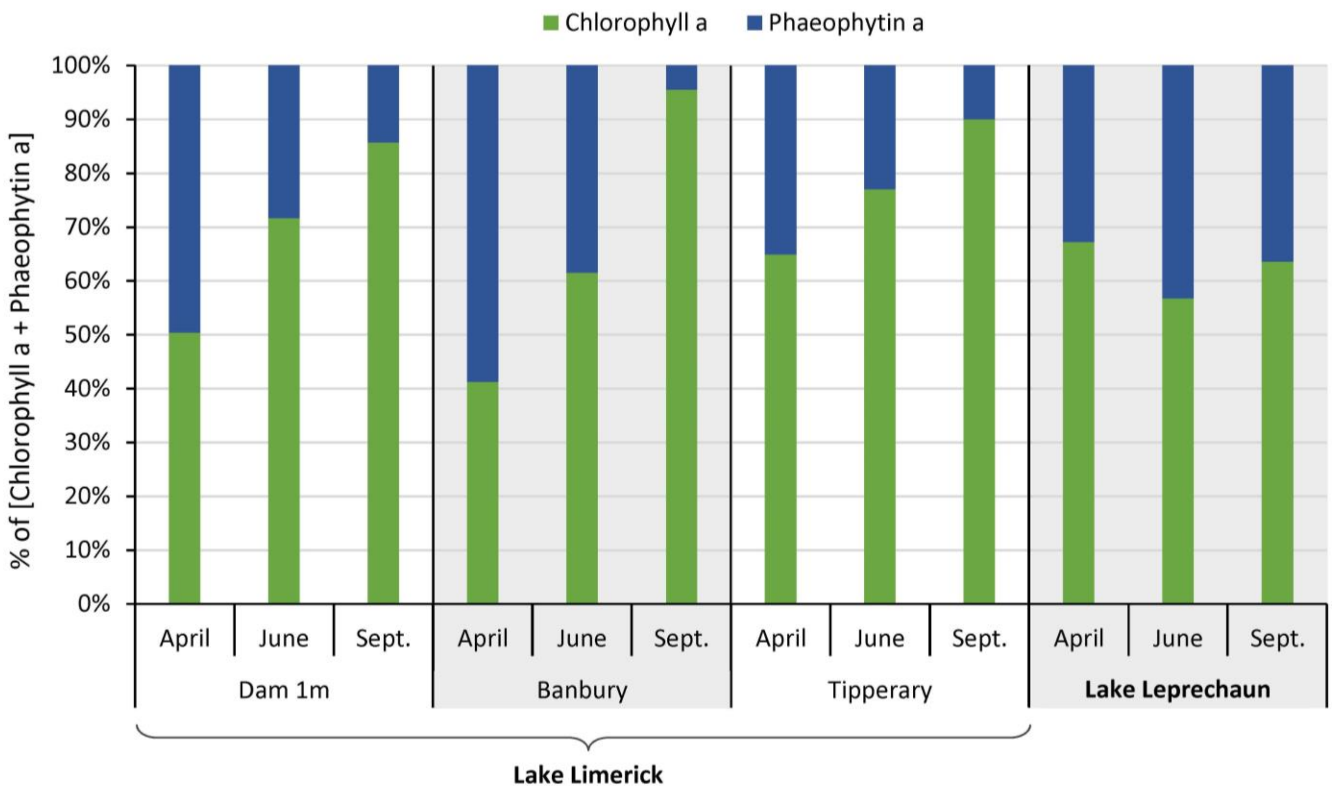

Figure 26 - Concentrations of chlorophyll *a* and phaeophytin *a* as a percent of the sum of the concentrations of the two parameters at three Lake Limerick water quality monitoring sites and the Lake Leprechaun water quality monitoring site on April 2nd, June 3rd, and September 2nd, 2015.

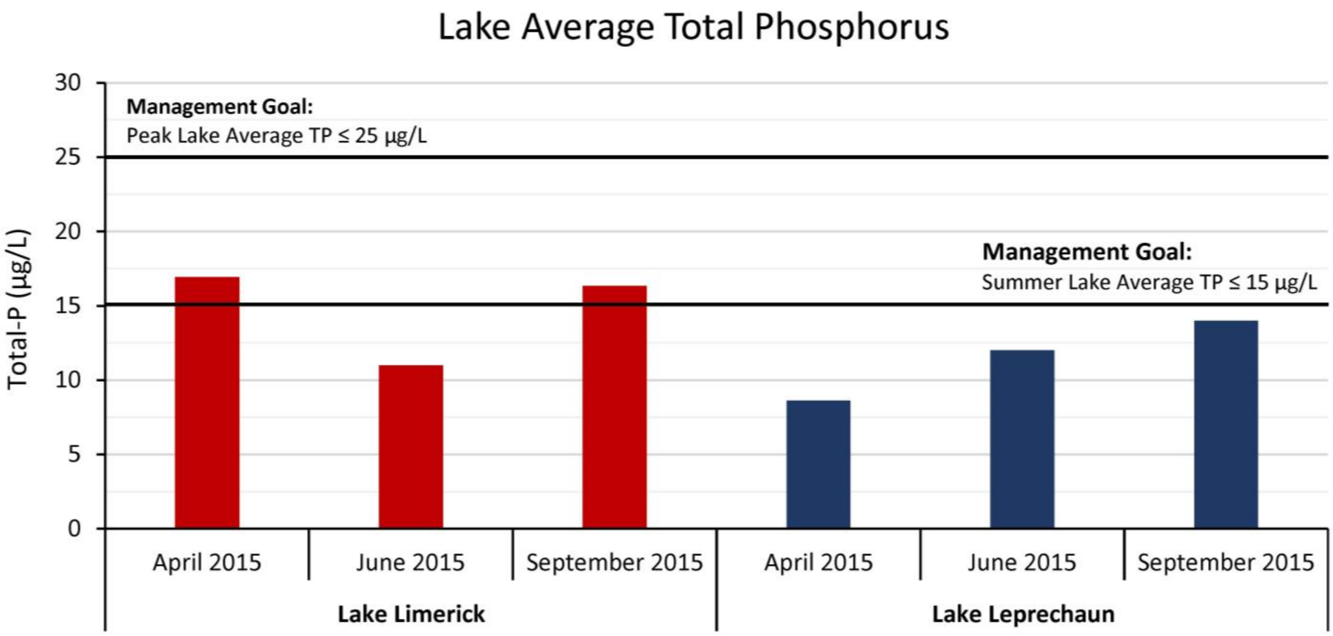

Figure 27 – Lake-wide average total phosphorus concentrations in Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. Lake-wide means are not volume-weighted. The lake average concentrations for Lake Limerick in each month are the average of data from all five stations (including both depths at the dam site, so six data points in all). The lake average concentrations given for Lake Leprechaun in each month are the data from the single water quality sampling site. The method detection limit for total phosphorus analysis is 2.0 µg/L.

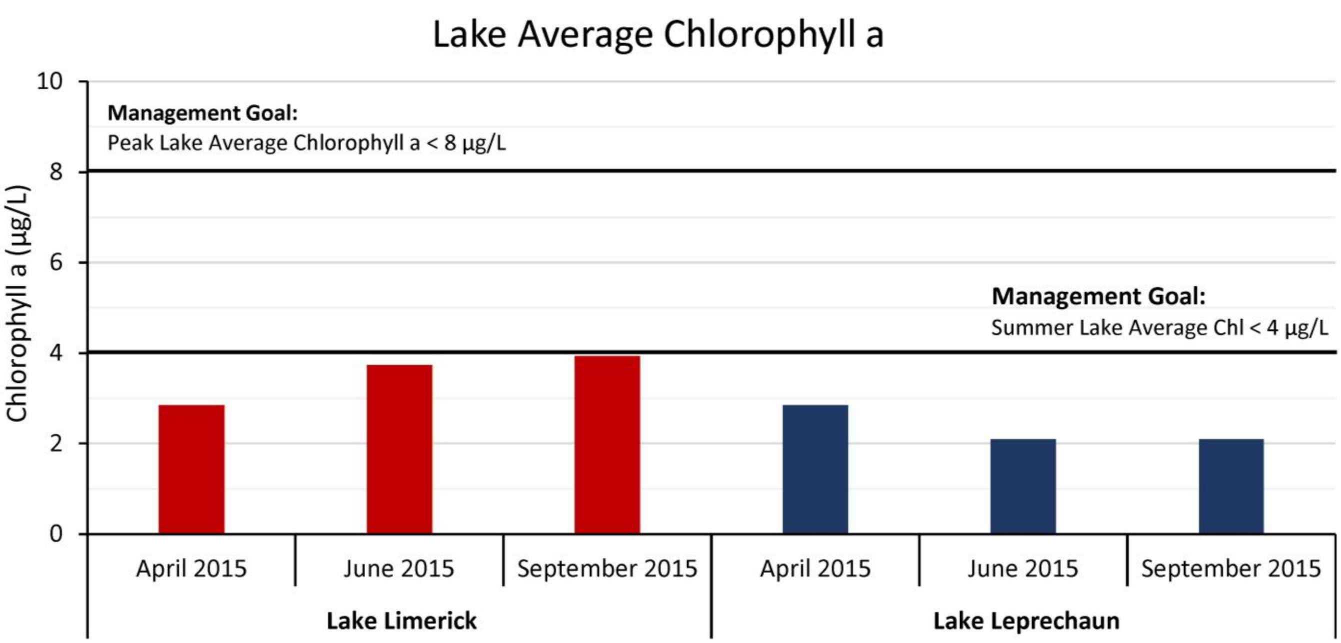

Figure 28 – Lake-wide average concentrations of chlorophyll *a* in Lake Limerick and Lake Leprechaun on April 2nd, June 3rd, and September 2nd, 2015. Lake-wide means are not volume-weighted. The lake average concentrations for Lake Limerick in each month are the average of data from all five stations (including both depths at the dam site, so six data points in all). The lake average concentrations given for Lake Leprechaun in each month are the data from the single water quality sampling site. The method detection limit for chlorophyll *a* analysis is 0.1 µg/L.

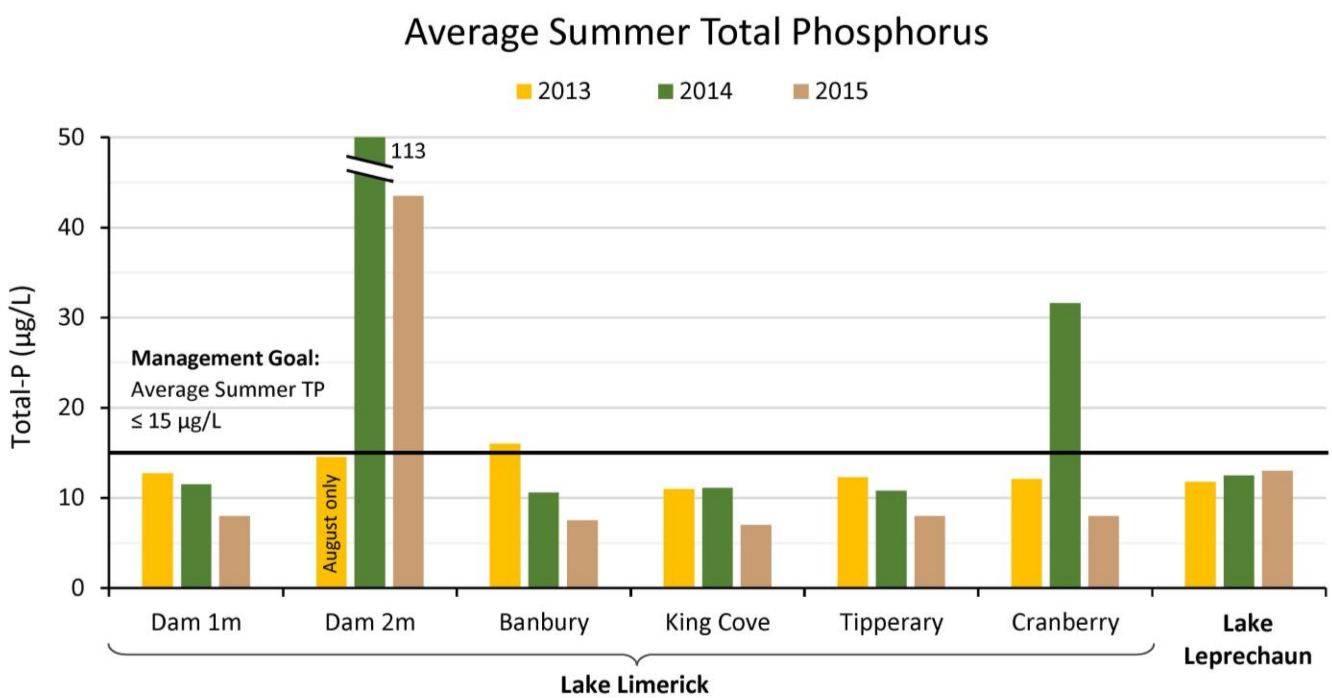

Figure 29 – Average summer total phosphorus (Total-P or TP) concentrations at the Lake Limerick and Lake Leprechaun sampling sites in 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015. The method detection limit for total phosphorus analysis is 2.0 µg/L.

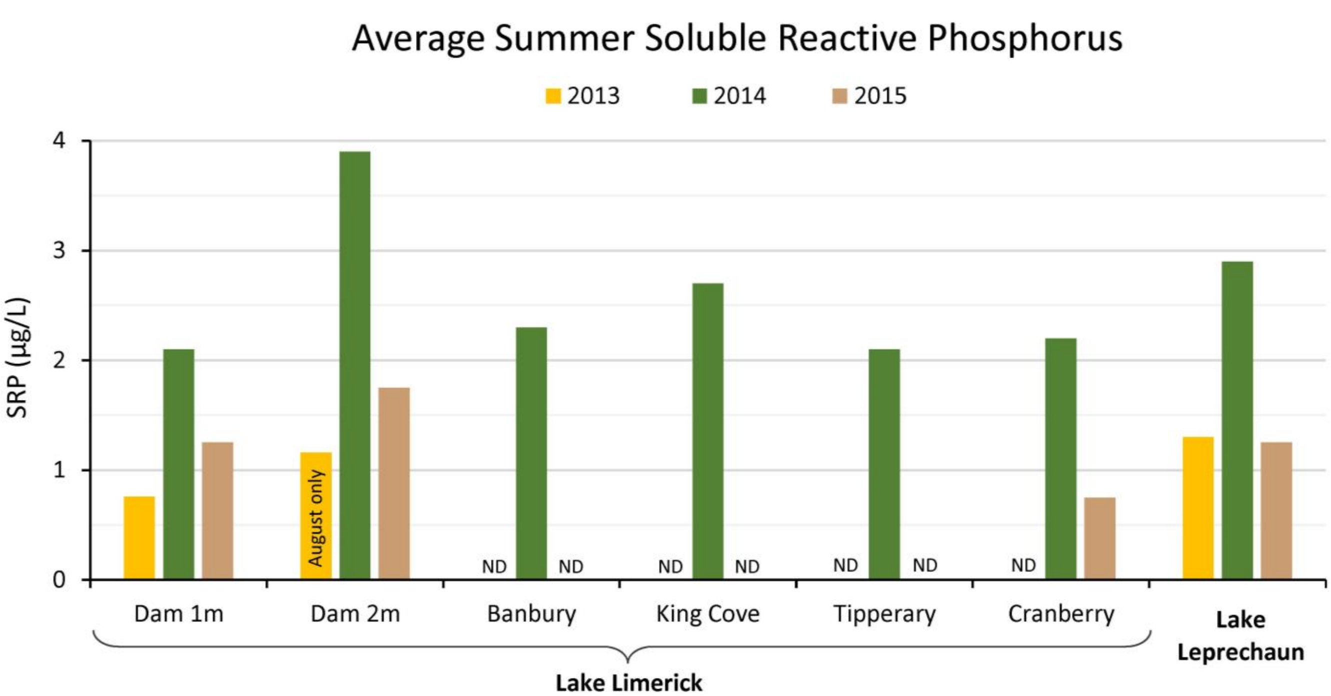

Figure 30 – Average summer concentrations of soluble reactive phosphorus at the Lake Limerick and Lake Leprechaun sampling sites in 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015. ND stands for “not detected” and indicates that concentrations of SRP in the water sample were below the method detection limit of 1.0 µg/L.

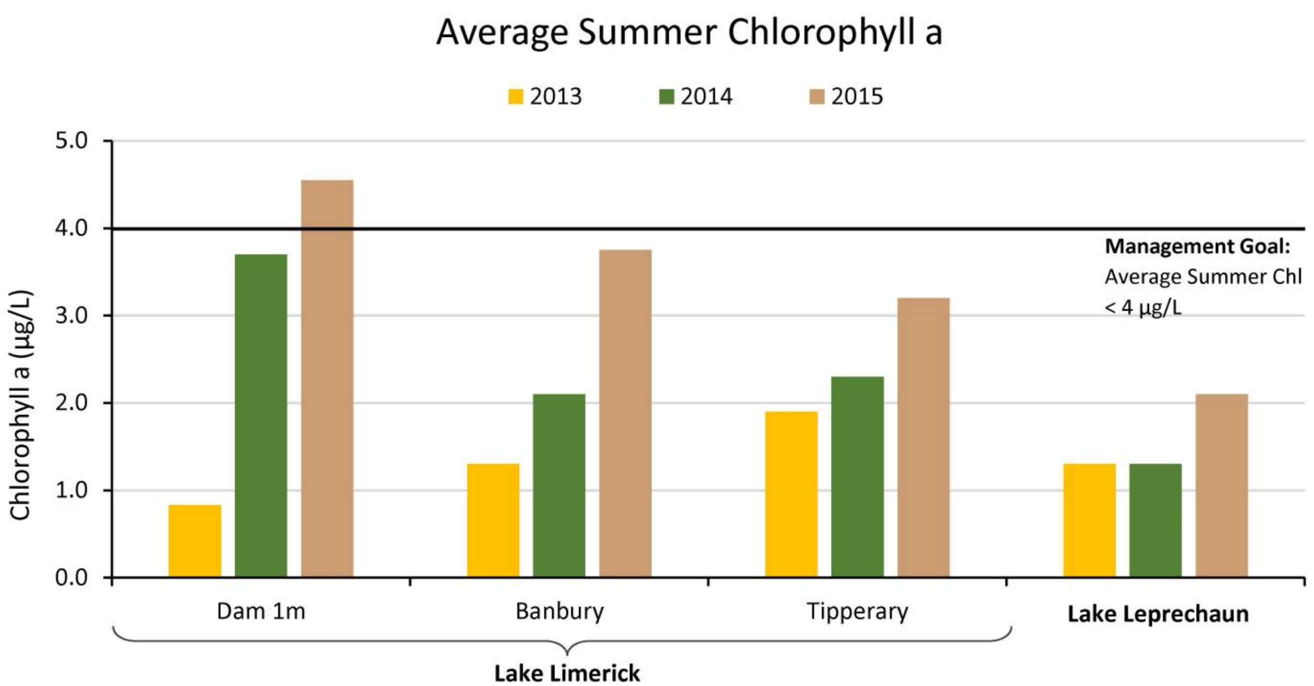

Figure 31 - Average summer concentrations of Chlorophyll a at the Lake Limerick and Lake Leprechaun sampling sites in 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015. The method detection limit for chlorophyll a analysis is 0.1 µg/L.

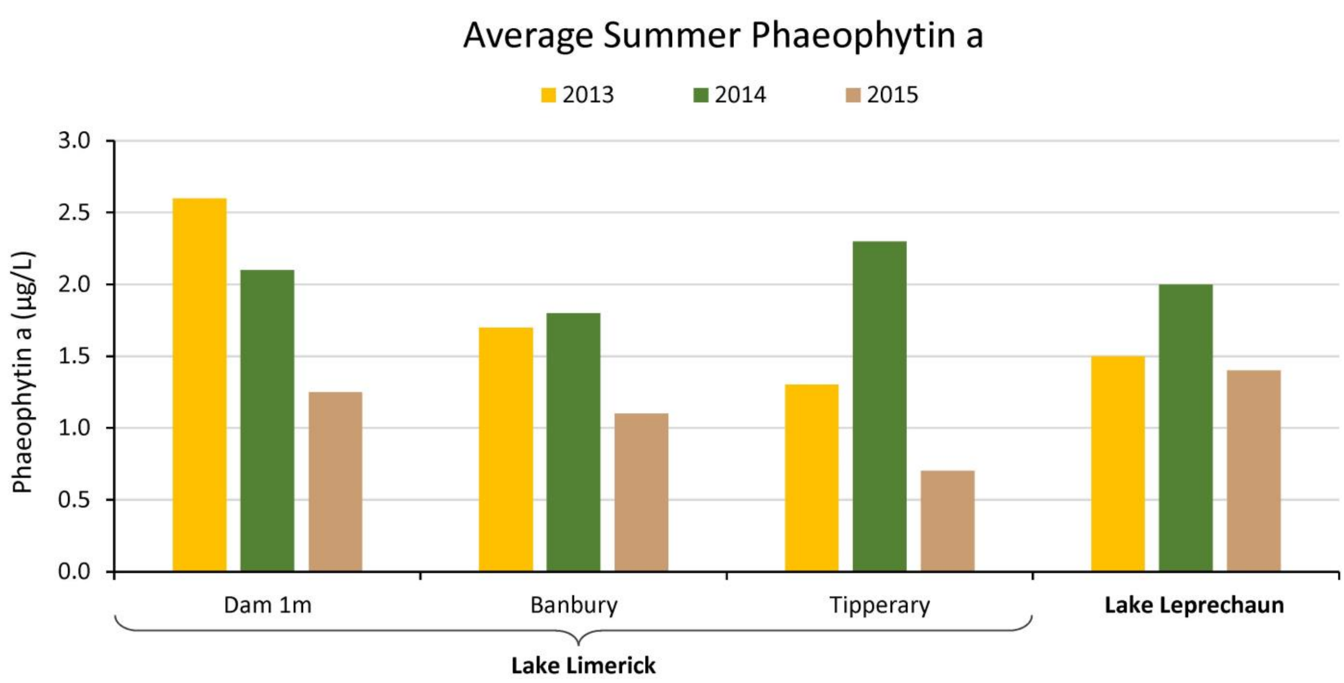

Figure 32 - Average summer concentrations of phaeophytin *a* at the Lake Limerick and Lake Leprechaun sampling sites in 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015. The method detection limit for phaeophytin *a* analysis is 0.1 µg/L.

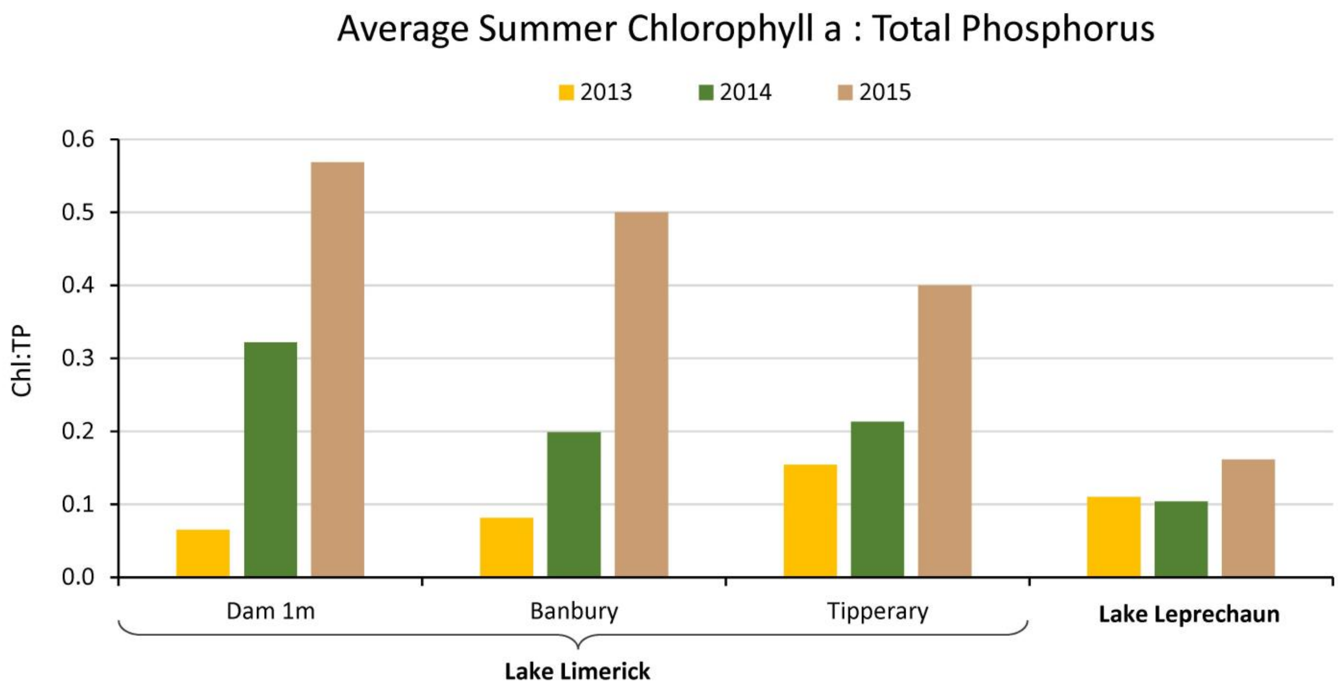

Figure 33 - Average summer ratio of chlorophyll *a* to Total-P at the Lake Limerick and Lake Leprechaun sampling sites in 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015.

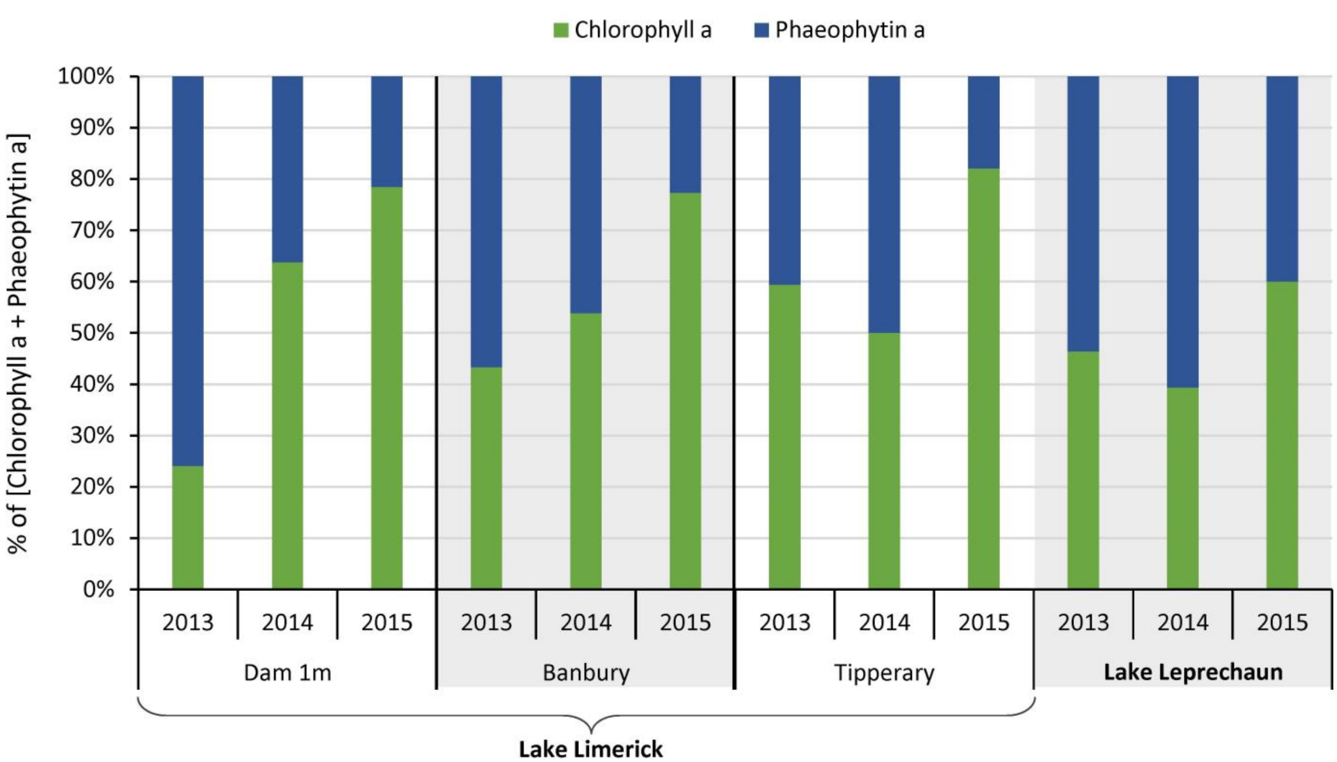

Figure 34 – Average summer concentrations of chlorophyll *a* and phaeophytin *a* as a percent of the sum of the concentrations of the two parameters during 2013, 2014, and 2015. Note: 2013 averages are for August and September 2013; 2014 averages are for June, July, August, and September 2014; and 2015 averages are for June and September 2015.

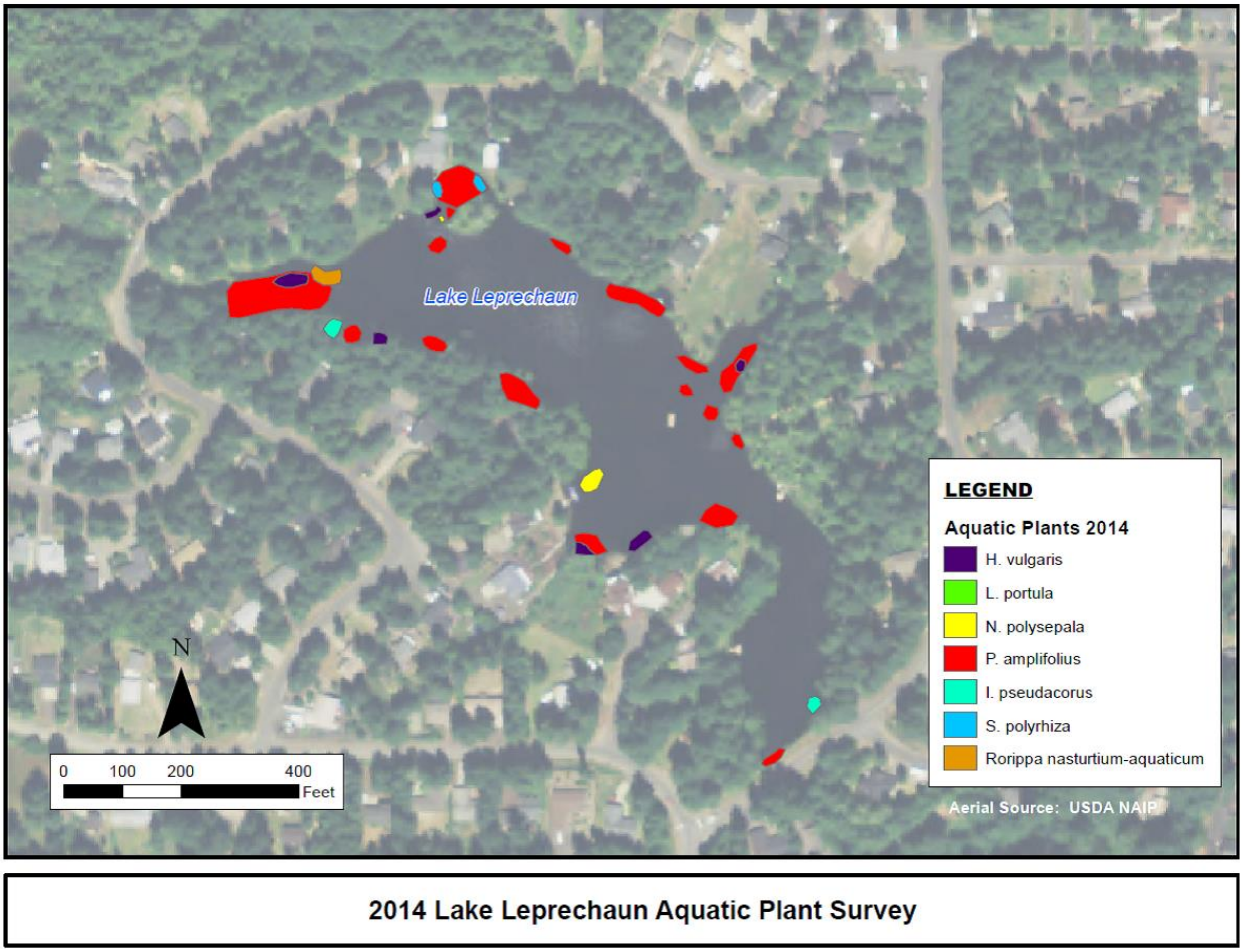

Figure 35 – Map of aquatic plant distribution in Lake Leprechaun before the summer 2014 treatment was conducted.

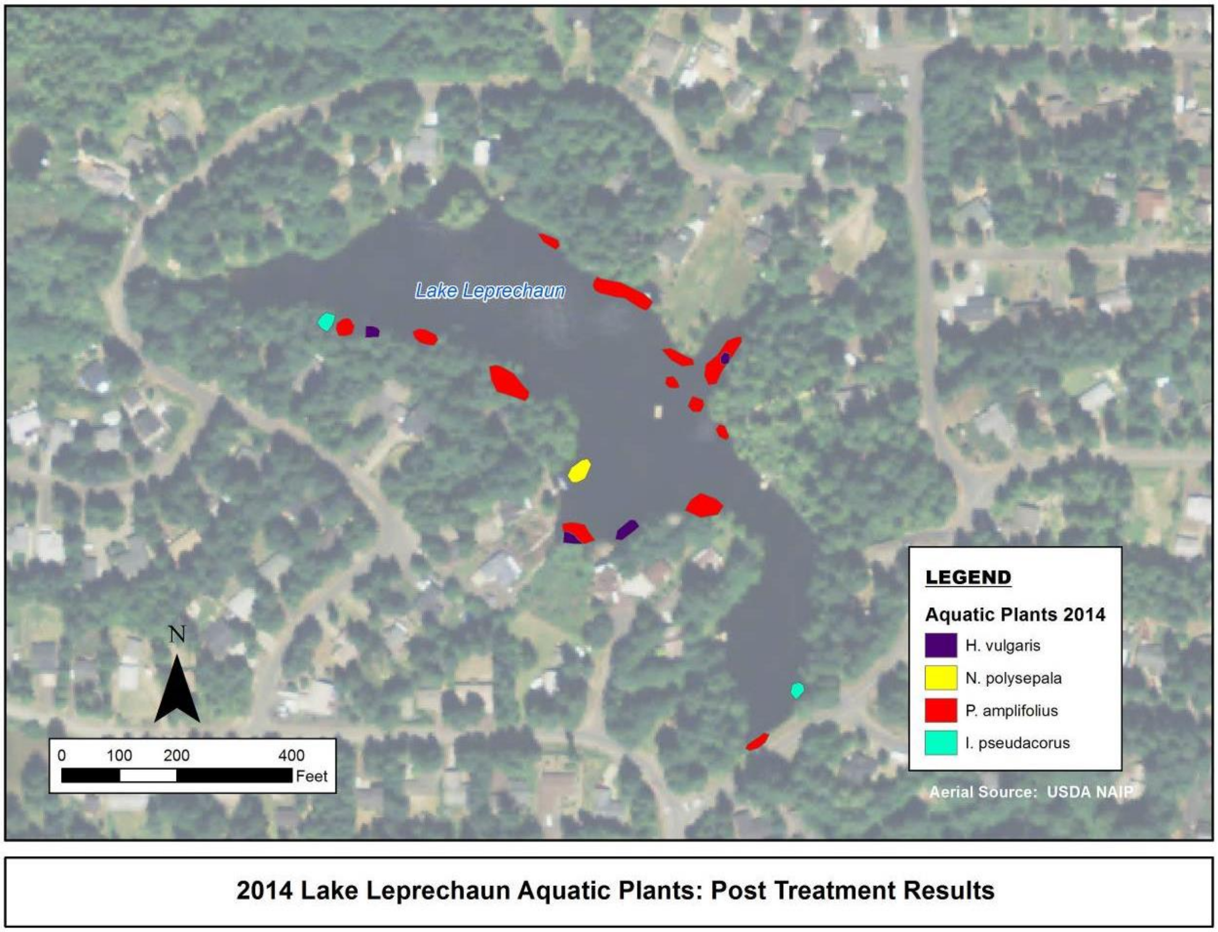

Figure 36 – Map of aquatic plant distribution in Lake Leprechaun after the summer 2014 treatment was conducted.

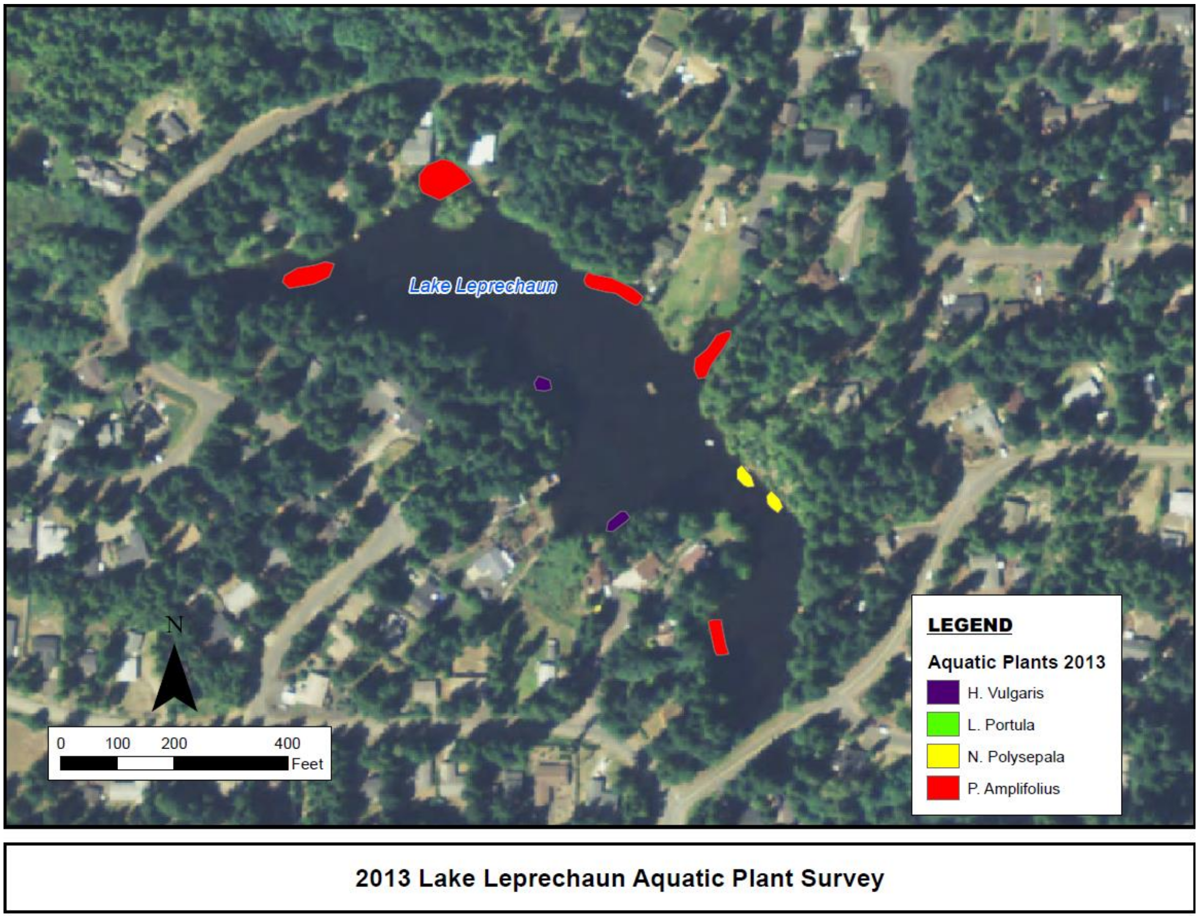

Figure 37 – Map of aquatic plant distribution in Lake Leprechaun in 2013

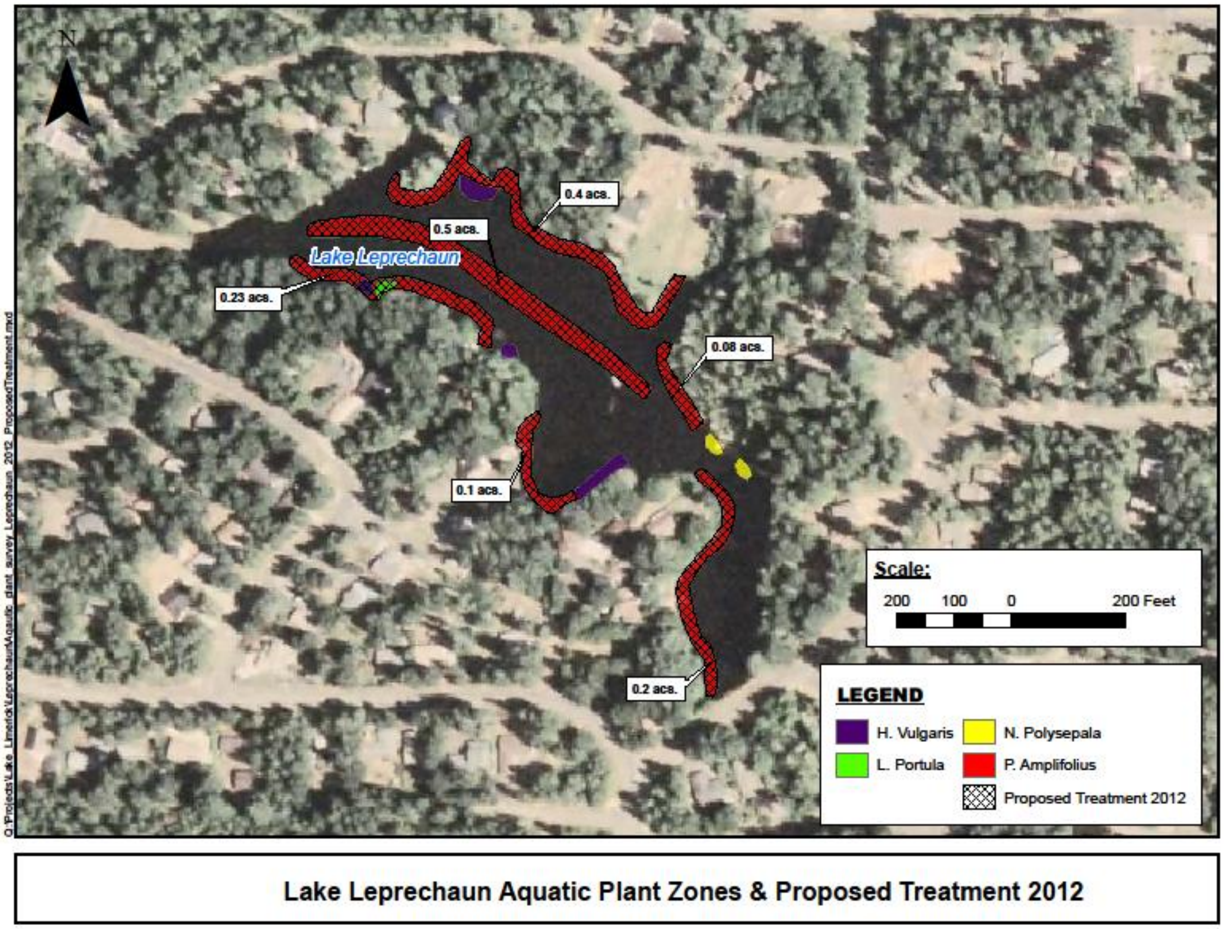

Figure 38 – Map of aquatic plant distribution in Lake Leprechaun in early summer 2012. Cross-hatching indicates the areas where treatment was proposed for summer 2012.

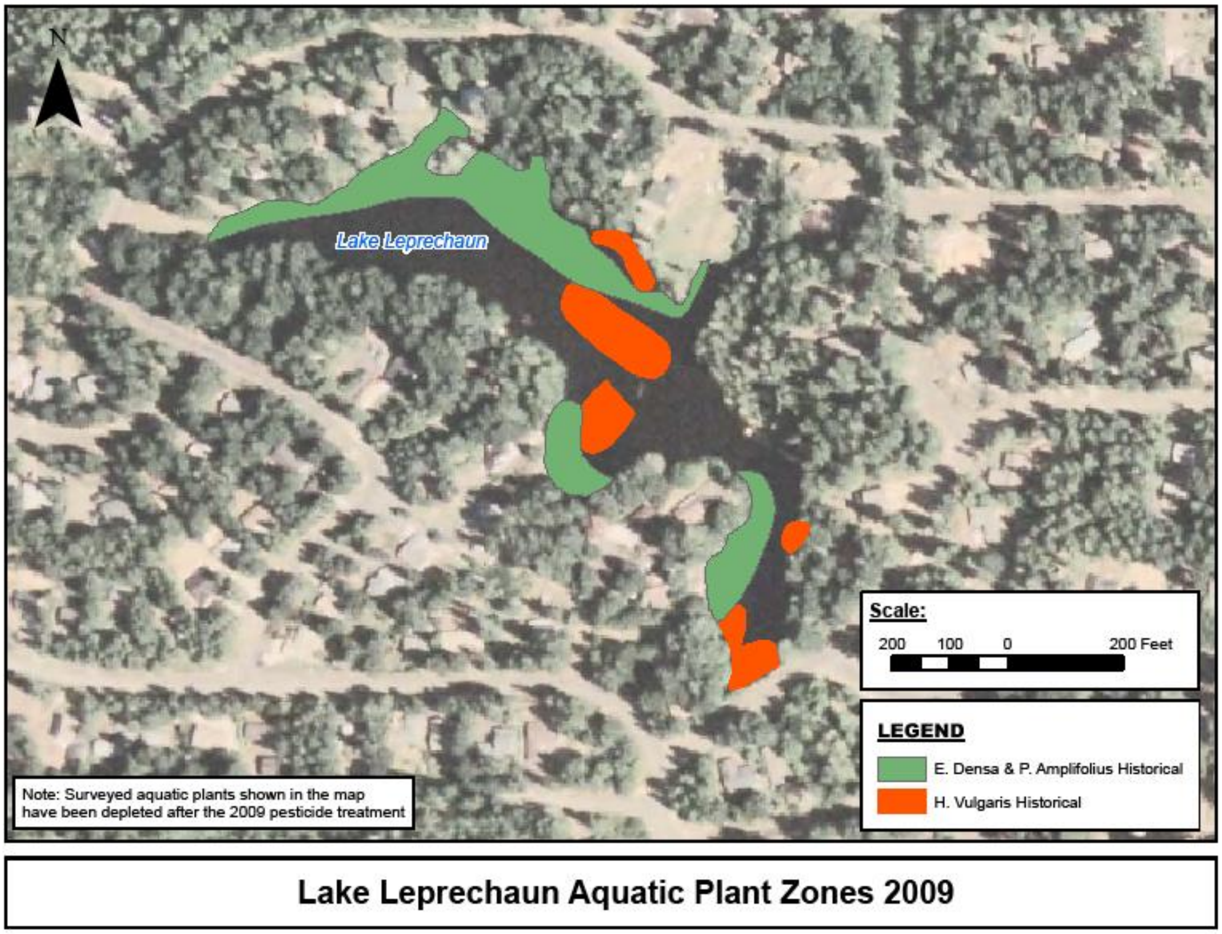

Figure 39 – Map of aquatic plant treatment locations in Lake Leprechaun in summer 2009.

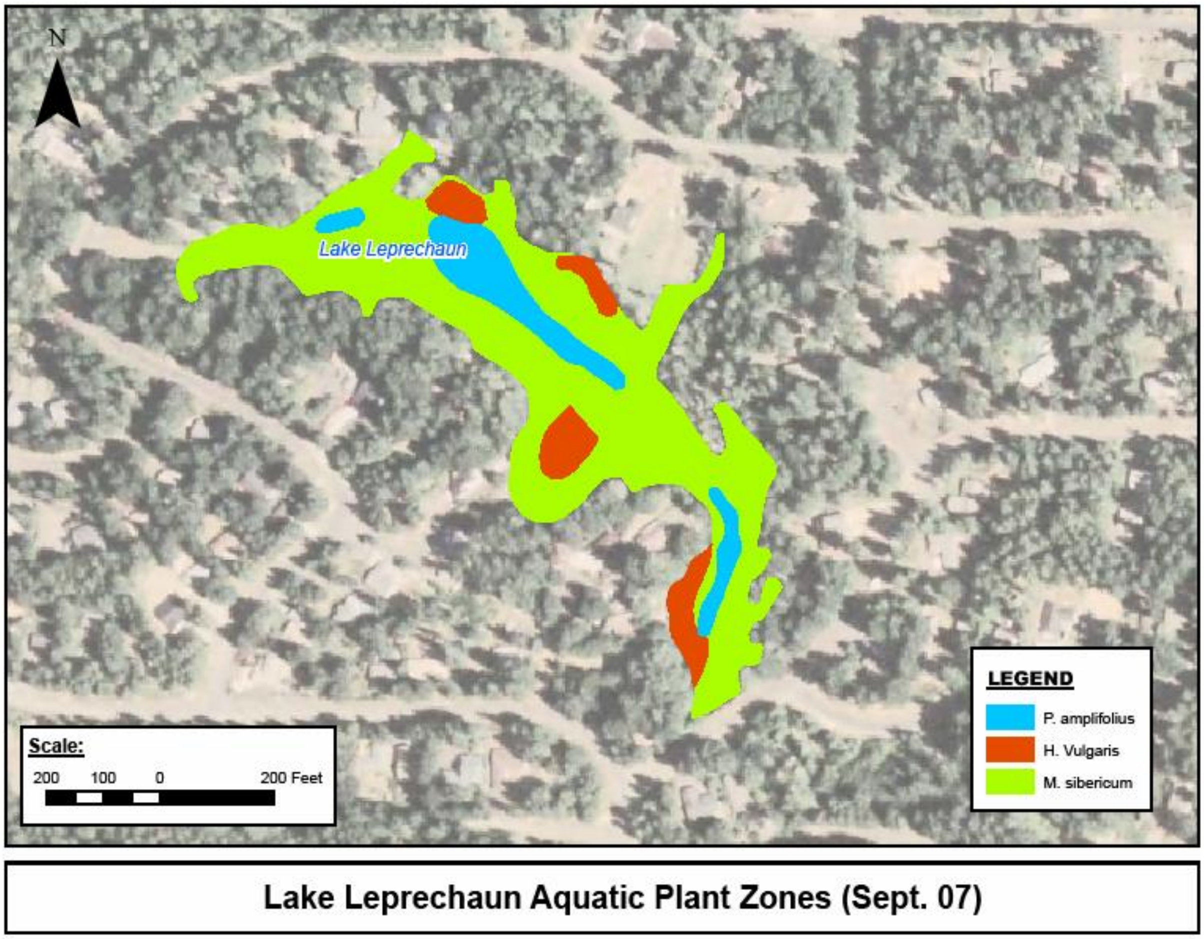

Figure 40 – Map of aquatic plant distribution in Lake Leprechaun in summer 2007.

Figure 41 – Lake Leprechaun level logger

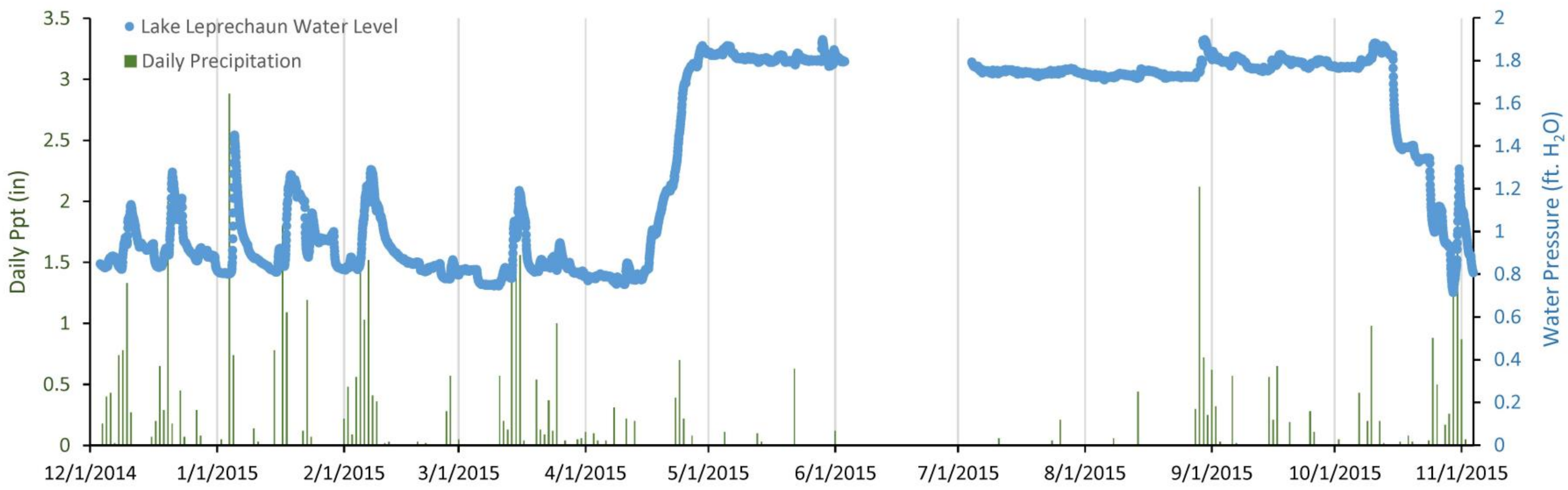

Figure 42 – Lake Leprechaun water level and daily precipitation from 12/1/2014 to 10/1/2015. Precipitation data from the KWASHELT3 weather station, located at the tip of the small extension of Lake Limerick along its north shore (King Cove). Water level logger for Lake Leprechaun located near the outlet structure.

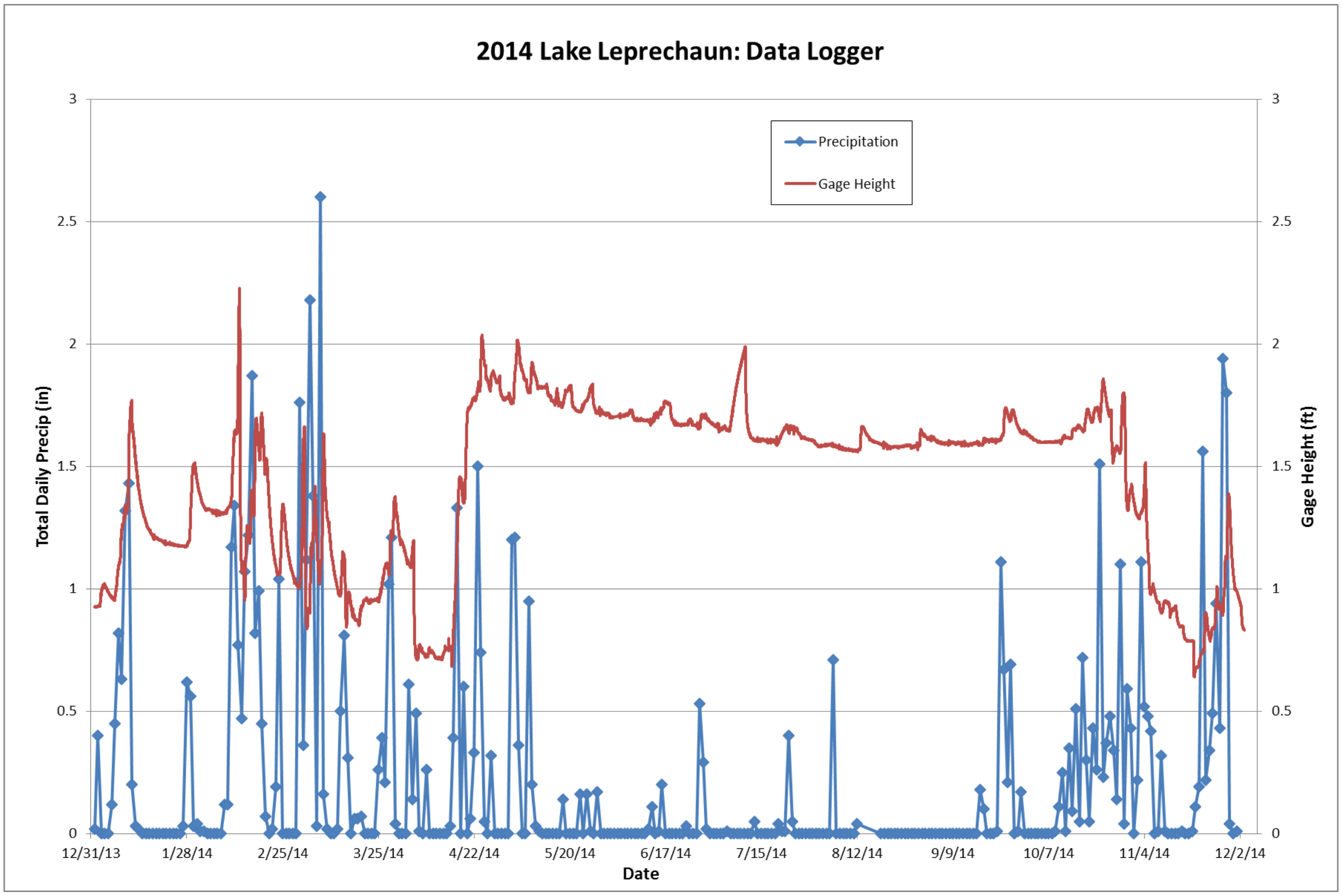

Figure 43 – Continuous record of lake level in Lake Leprechaun from January 2014 through November 2014 and daily precipitation within this same time period.

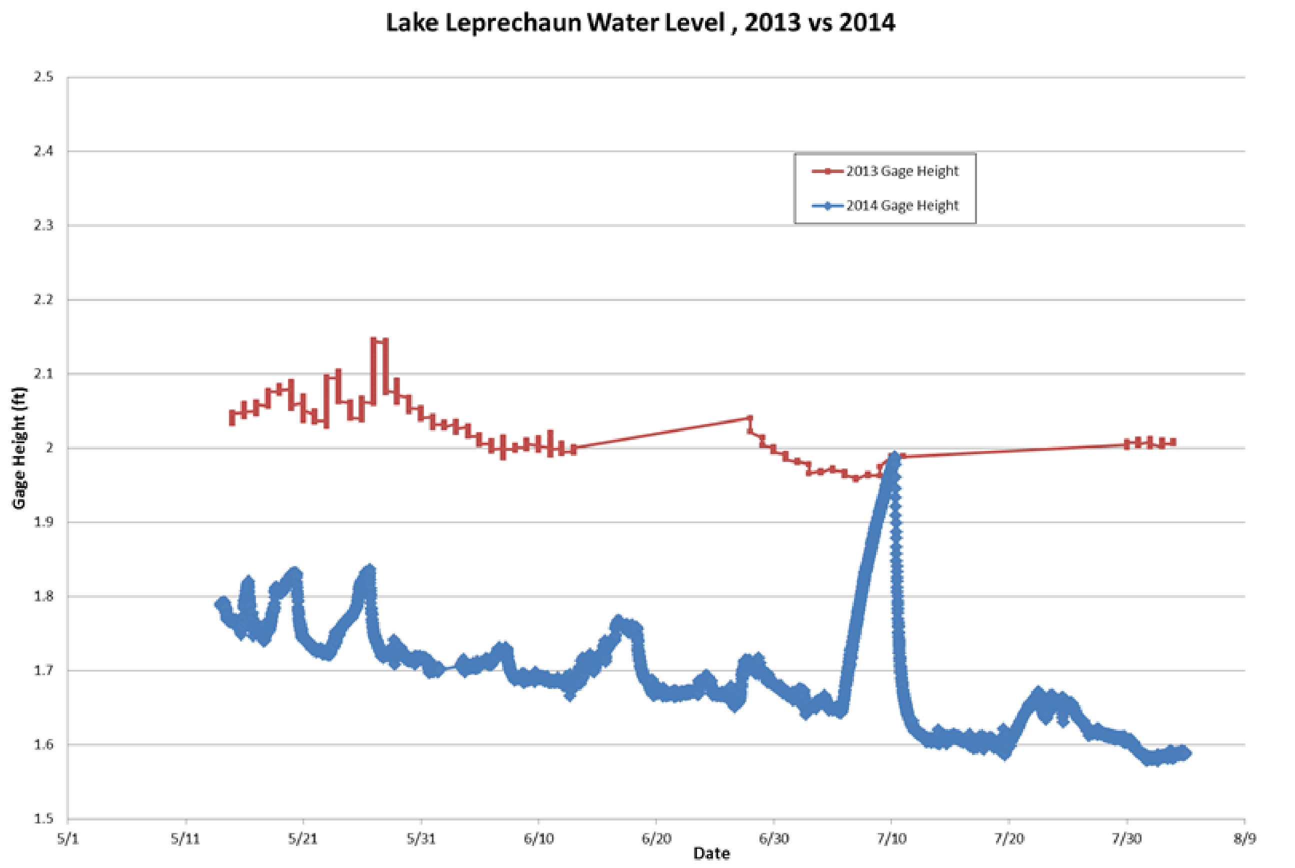

Figure 44 – Comparison of continuous records of lake level in Lake Leprechaun from 2013 and 2014.

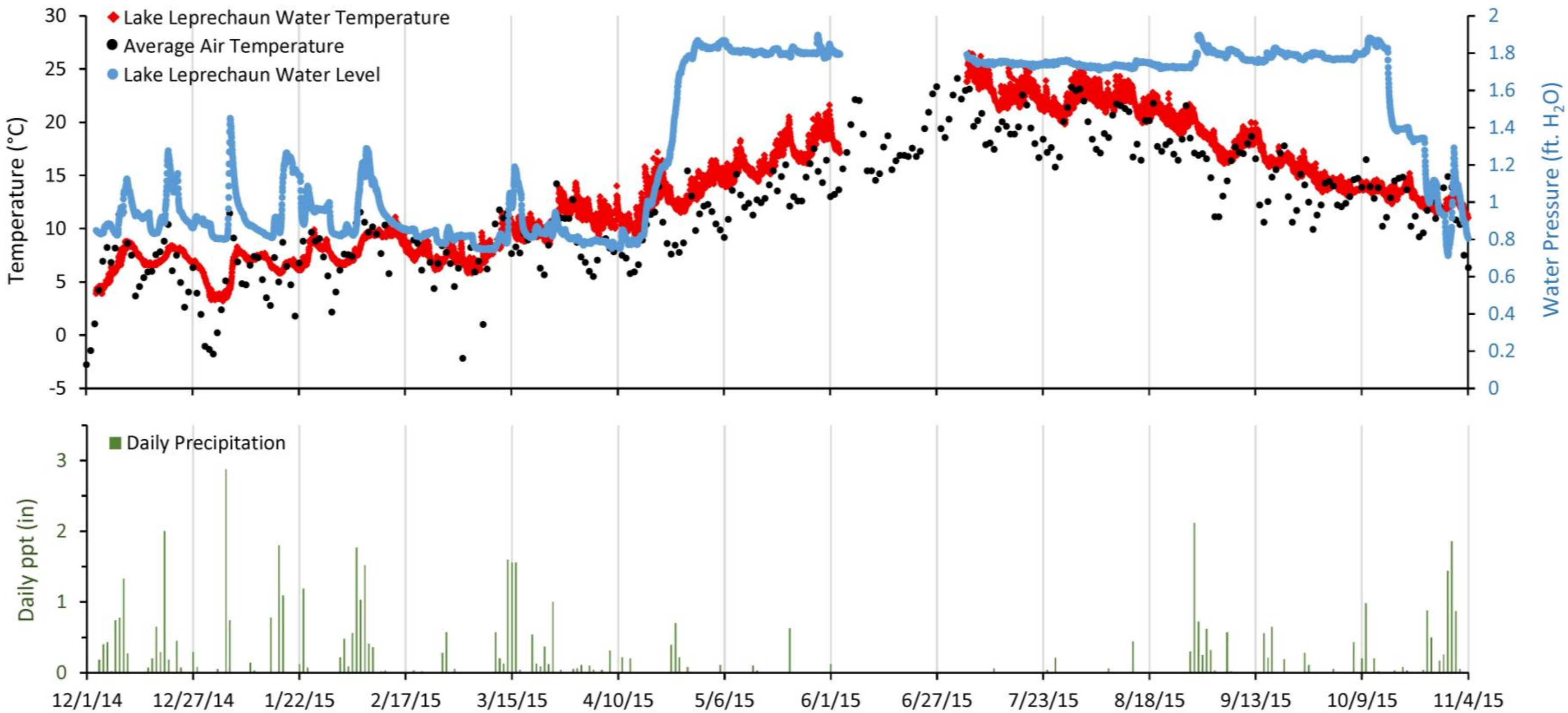

Figure 45 – Lake Leprechaun water temperature, Lake Leprechaun water level, average air temperature, and daily precipitation from 12/1/2014 to 10/1/2015. Precipitation and air temperature data from the KWASHELT3 weather station, located at the tip of the small extension of Lake Limerick along its north shore (King Cove). Water level and temperature logger for Lake Leprechaun located near the outlet structure.

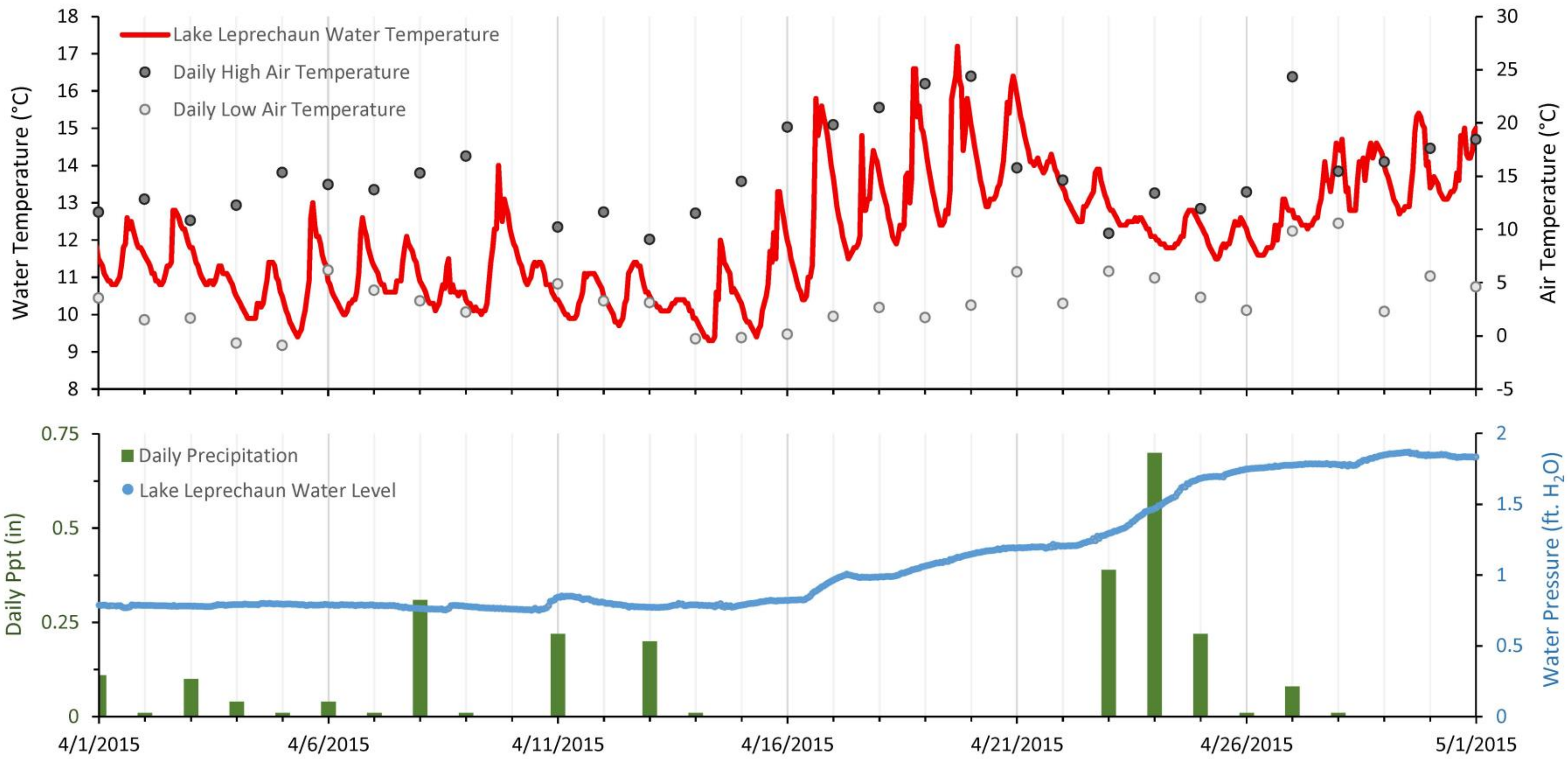

Figure 46 – Water temperature in Lake Leprechaun and daily high and low air temperatures during April 2015. Water level in Lake Leprechaun in April 2015, and daily precipitation during the same period. Precipitation and air temperature data from the KWASHELT3 weather station, located at the tip of the small extension of the lake along the north shore (King Cove). Water level and temperature logger for Lake Leprechaun located near the outlet structure.

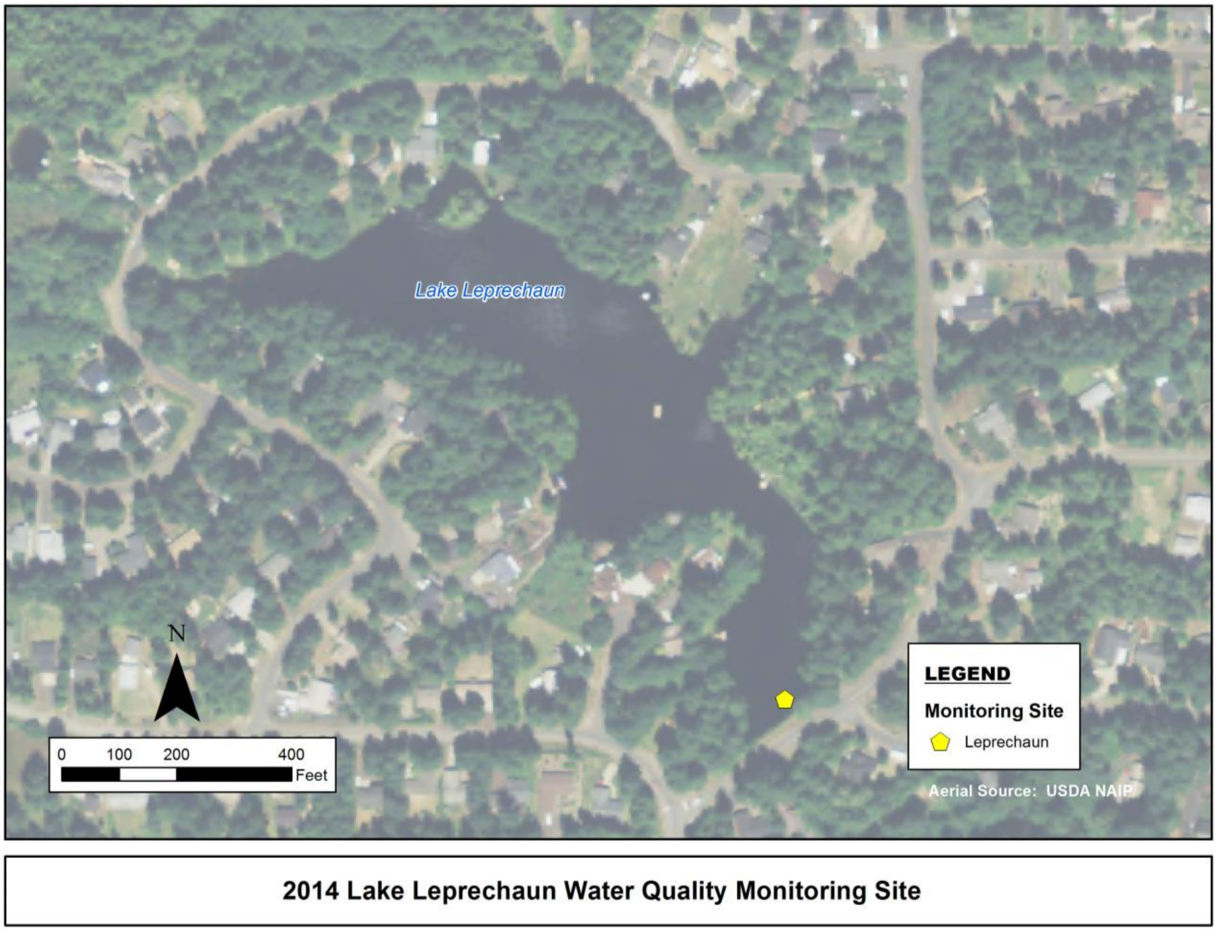

Figure 47 – Location of water quality monitoring site within Lake Leprechaun.