Technical Status Memorandum
For
Lakes Limerick and Leprechaun 2016
Aquatic Plant Management

DECEMBER 28, 2016

PREPARED FOR:

Lake Committee

Lake Limerick Country Club


PREPARED BY:

TETRA TECH

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Acknowledgements

Thank you to all the Lake Limerick and Leprechaun volunteers who care about the health of their lakes and want to preserve their ecological and recreational uses. Special thanks to Debbie Moore, Tim Reber, Brian Smith, and Larry Duvall for their assistance with this project. Joe Castelluccio (LLCC staff) prepared the dredging construction areas prior to startup of sediment removal that helped the dredging construction company maintain a tight schedule. Joe Bernert (Marine Industrial Construction) and Matt Fobert (Marine Industrial Construction) provided project and site-management, respectively, delivering quality service, and working within stringent environmental permit requirements.

1.0 INTRODUCTION

The continued goals for aquatic plant management in Lakes Limerick and Leprechaun during 2016 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 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. Aquatic plants also benefit fish populations by providing both physical habitat structure for different age classes of fish, but also, for the invertebrates (aquatic insects) that fish feed upon. 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.

Based on the information provided by annual plant surveys, proactive lake management practices have been implemented at this site since 2005, and have had good success relative to attaining lake management goals and overall ecological stability of the lakes. Aquatic plant communities in both lakes were previously dominated by Brazilian elodea (*Egeria densa*), but with repeated limited 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 of Lake Leprechaun and a portion of Lake Limerick in order to increase fish access to Cranberry Creek and King Creek while also allowing boating access. In addition, the sediment removal project removed nutrients and reduced aquatic plant densities within these specific target areas regions.

In 2016, 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. This does not imply that the septic drain fields are not functioning correctly, just that there is a potential impact of drain fields and landscaping on the overall lake nutrient balance. To date this potential impact is only observed in the enhancement of the aquatic plant community and not in the overall water quality of either lake.

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 once during 2016, in April. As in 2013 - 2015, water samples were collected from five sites in Lake Limerick and at one site in Lake Leprechaun. Water samples from each site were analyzed for total phosphorus (TP).

A major component of 2016 lake management efforts was the dredging of King's Cove and Cranberry Cove in Lake Limerick. Fine sediments had accumulated in both regions, limiting fish habitat and impeding recreational use of these areas.

The 2016 monitoring program also included updating and re-installing continuous data loggers to monitor water levels in Lake Limerick and Lake Leprechaun and below the Lake Limerick dam.

2.0 LAKE LIMERICK

2.1 AQUATIC PLANTS

In June 2015 aquatic plants were present in Lake Limerick, but in low densities, and no *Egeria densa* was observed. As a result, no treatment was planned for summer 2015. 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.

The June 2016 aquatic plant survey indicated that the distribution and speciation of aquatic plant species had changed little along the southwestern shoreline (from the inn to the dam), the eastern shoreline (from the dam to just outside of the bird sanctuary), and the northwestern shoreline (between Cranberry Cove and King's Cove). The southwestern shoreline had patches of *Potamogeton amplifolius* (largeleaf pondweed) and patches of mixed species at low density, as well as scattered patches of *Elodea canadensis* (Canadian pondweed), *Brasenia schreberi* (watershield), and *Nuphar polysepala* (yellow pond lily) (Figure 1). Spread out along the eastern shoreline were patches of *Potamogeton amplifolius* (largeleaf pondweed) and mixed species at low density. The northwestern shoreline had patches of *Potamogeton amplifolius* (largeleaf pondweed) and mixed species at low density, as well as *Vallisneria americana* (tape grass), *Nuphar polysepala* (yellow pond lily) and *Brasenia schreberi* (watershield) (Figure 1). In September 2016, the distribution of aquatic plants along these shorelines was the same as in June (Figure 2).

In June 2016, the aquatic plant community in Cranberry Cove was dominated by *Elodea canadensis* (Canadian pondweed) (Figure 1), much as it had been in 2015 (Figure 3). However, *Vallisneria americana* (tape grass) was also present, and in the southern portion of the cove there was dense growth of green filamentous algae (Figure 1). When the survey was conducted again in September 2016, dredging had significantly cut back plant growth in this cove – all of the algae was gone and the areal extent of *Elodea canadensis* was greatly reduced (Figure 2).

The composition of the aquatic plant community in King's Cove changed in part between 2015 and 2016. In June 2016, the coverage of mixed species and green filamentous algae within the center of the cove (Figure 1) was reduced compared to in 2015 (Figure 3), and there was much more extensive growth of *Utricularia inflata* (inflated bladderwort) near the inlet (Figure 1). Near Log Toy Park, there continued to be a large patch of *Potamogeton amplifolius* (largeleaf pondweed) and there was a new patch of *Brasenia schreberi* (watershield) (Figure 1). As in Cranberry Cove, dredging activities altered the distribution of plants near the inlet in King's Cove – the patch of *Utricularia inflata* (inflated bladderwort) was much smaller in September 2016 (Figure 2).

The greatest observed change in the density of plant growth in Lake Limerick occurred along the northern shoreline and in the bird sanctuary. Along the northern shoreline (from Log Toy Park to just west of the bird sanctuary) there were patches of mixed species at low density, as in previous years, but at the eastern end of the northern shoreline, just west of the bird sanctuary, dense growth of *Potamogeton amplifolius* (largeleaf pondweed) was observed in both June and September 2016 (Figure 1 and Figure 2). In the bird sanctuary, the density of plant growth had increased since 2015, and the composition had also changed. In June 2016, patches of *Brasenia schreberi* (watershield) and *Nuphar polysepala* (yellow pond lily) were more extensive than in 2015, and *Utricularia inflata* (inflated bladderwort) and *Potamogeton filiformis* (slender-leaved pondweed) were no longer present (Figure 1). In addition, there was one small patch of *Egeria densa* (Brazilian waterweed) (Figure 1). By September, the *Egeria densa* had experienced an early decline and was no longer present, but there was significant new growth of green filamentous algae, further increasing the density of aquatic plant growth in the bird sanctuary (Figure 2).

Yellow iris (*Iris pseudacorus*) was observed along the southwestern, eastern, and northwestern shorelines in June 2016 (Figure 1). In September 2016, the yellow iris on the southwestern and northwestern shorelines remained, but the yellow iris on the eastern shoreline had been successfully controlled (Figure 2.) by the 2015 efforts. Efforts to limit the growth of yellow iris in shoreline areas continued in 2016. As in summer 2015, visible patches of yellow iris on the shoreline of Lake Limerick were sprayed with the herbicide Glyphosate in summer 2016. 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). 2017 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.

Pre- and post- treatment maps of aquatic plant distributions within Lake Limerick in 2015, and in earlier years (2008 – 2009, 2011 – 2014) are shown in Figures 3 – 11.

2.2 DREDGING

During summer 2016, two shallow coves in Lake Limerick – King's Cove and Cranberry Cove – were dredged in order to remove sediment that had accumulated on the lake bottom (Figure 12). Over time, the accumulation of fines (silts and decomposed organic material) at the mouths of the creeks that drain into these coves had covered up potential habitable substrate for aquatic life. In addition, the sediment had filled in the lake bottom, reducing the overall depth of water in these coves by 1 to 5 feet – limiting the ability of boats to access these coves and shrinking the area in which it was possible to swim. The primary objectives of the dredging operation were to a) improve in-lake fisheries habitat and fish access to streams, and b) provide better access to the coves for recreation. Specific goals were to a) remove a total of 5,000 cubic yards of soft sediment from Kings Cove and Cranberry Cove, b) expose hard sediment to improve habitable areas for benthic communities and fish spawning, and c) improve the thalweg gradient in both coves, allowing remaining soft sediments to be moved during future high flow events and preventing the coves from being clogged for an extended time.

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. This survey confirmed that the northwest corner, by the outlet of Cranberry Creek, was very shallow, as was the small extension of the lake along the north shore (King Cove) (Figure 13). In 2016, both the dredging contractor (Marine Industrial Construction) and Tetra Tech independently conducted additional, higher resolution bathymetric surveys of Cranberry Cove and King's Cove before and after dredging. The pre-dredge surveys were used to plan dredging activities and to establish dredging transects and document volume and area of sediment removal.

The dredging was conducted using a barge-mounted hydraulic MudCat dredge (Figure 14). The MudCat loosened fine sediments with a cutter head and then suctioned the loose material into a pump intake (Figure 16), effectively removing the material from the lake bottom while also limiting turbidity impacts (MIC 2016). Dredging began at the upstream end of each job site boundary and proceeded downstream. Turbidity impacts were further limited by the installation of a turbidity curtain along the boundary of the dredging area (Figure 15). The pump intake on the MudCat connected to a floating pipeline (Figure 15), which transported the dredged material to the de-watering site at Log Toy Park. As the dredge material arrived at the de-watering site, a flocculent was injected into it in order to accelerate the de-watering process (Figure 16, MIC 2016). The flocculent used for the Lake Limerick project was Aquamark®, a readily biodegradable organic polymer. After the flocculent was injected, the dredge material was pumped into geosynthetic de-watering bags (Figure 17). When it was initially collected, the dredge material was approximately 80% water and 20% sediment (MIC 2016). The de-watering bags allowed water to seep from the dredge materials over a period of days so that the sediment gradually dried out and became compressed (Figure 18). After passing through a ground filter cloth and silt fences positioned to block direct re-entry of water into the lake, the clean water runoff from the geo-bags seeped into the ground and was allowed to run into the lake (MIC 2016). Once the de-watering process was complete (after 2-3 days), the de-watering bags were split open to reveal the compacted de-watered material (composed primarily of silt) (Figure 19), which was loaded into trucks and transported to a gravel mine for use as fill. The de-watered sediment was significantly lighter and more compact than the original wet material (Figure 20).

When the dredging was conducted, the MudCat cut a channel in the sediment, removing the accumulated material (Figure 21). As the dredging occurred, some additional material sloughed from the banks of the newly cut channel and was suctioned up, adding to the total volume of material being dredged (Figure 21). As the material was removed from the newly cut channel, it exposed hard sediments (Figure 22), improving benthic habitat. Water quality monitoring during dredging ensured that containment structures were functioning properly. Turbidity monitoring during dredging indicated that the design of the dredging equipment and set-up successfully minimized turbidity impacts. Turbidity was monitored during dredging operations above dredging in the tributary, below the dredge (roughly 150 feet and inside the turbidity curtain) for an early warning site, and 300 feet downstream of the work site (outside of the turbidity curtain) (MIC 2016). Turbidity remained low throughout the project and no violations occurred (MIC 2016).

Detailed topographic/bathymetric transect profiles were completed within one week upon completion of dredging in each of the coves. In King's cove, the dredging improved the gradient of the thalweg, increasing the water depth by 2 to 2.5 feet along most of the thalweg (Figures 23 and 24). Dredging increased the depth of the water throughout the northeastern portion of the cove, especially near the mouth of the inlet (Figure 25).

The gradient of the thalweg was also improved in Cranberry Cove (Figures 26 and 27). Water depth increased by approximately 2 feet along the length of the thalweg (Figure 27). In addition, dredging increased the depth of the water throughout the center of the cove, in particular near the Cranberry Creek inlet (Figure 28). The post-dredging substrate in this cove was composed of moderate-to-large round cobbles (MIC 2016).

The volume of sediment removed was estimated both during and after dredging, using multiple techniques. While dredging was actively underway, the depth and lateral progress of the dredge were monitored in-situ using GPS data and logs of cutter head depth and were used to estimate removal volumes. On shore, the rate at which sediment was pumped into the de-watering bags was recorded, as was the volume of compacted sediment removed from the de-watering bags. Finally, the original and post-dredging bathymetries were compared in order to estimate the quantity of sediment removed by dredging. In-situ estimates of dredging in King's Cove totaled 2,650 cubic yards of material, and in-situ estimates for Cranberry totaled 3,764 cubic yards of material (MIC 2016). The total in-situ estimate was 6,454 cubic yards of material (MIC 2016). The on-shore volumetric estimate of dredge material was reached using pumping logs, and totaled 6,600 cubic yards of material (MIC 2016). Volumetric totals were also computed by comparing pre- and post- dredging maps of lake-bottom bathymetry. By this method the total dredging volumes were estimated to be 2,899 cubic yards for King's Cove and 3,291 cubic yards for Cranberry Cove (MIC 2016). The overall total computed using bathymetric data and accounting for sloughing was 6,809 cubic yards of dredged material (MIC 2016). Once de-watering was complete, the volume of compacted dredged sediment was estimated to be approximately 1,000 cubic yards, indicating that the de-watering system achieved a compaction ratio of 6:1 (original volume:compacted volume), reducing the volume of the dredged material by approximately 85% (MIC 2016). The 1,000 cubic yards of compacted material was trucked off site to a gravel quarry to be used as fill (MIC 2016).

Overall, the dredging operations in King's Cove and Cranberry Creek successfully met the goals of the project. Over 6,000 cubic yards of material was removed from the two coves. The fishery habitat has been increased in both coves, as dredging exposed substrate that is better for spawning and improved access to inflow streams for winter steelhead, coho, and resident cutthroat. The substrate is now also more habitable for benthic macroinvertebrates, which will help to restore the natural ecological function of benthic communities. Recreational opportunities in both coves have also been improved, as the increased water depth provides better access for boats, makes swimming more enjoyable, affords a better fishing environment, and is more aesthetically pleasing.

Moving forward, it is recommended that periodic bathymetric surveys be conducted in order to evaluate the effect of sloughing sediments on the transect gradient and channel shape over time, and to evaluate potential long-term maintenance needs. It is expected that the deeper portions of the thalweg transects in both coves will become slightly shallower due to sloughing from the upstream shallow areas.

2.3 PRECIPITATION AND LAKE LEVEL

During 2016, continuous water level data loggers were cleaned and reinstalled at the Lake Limerick inn dock (Figure 29) and below the Lake Limerick dam (Figure 30). The loggers at these sites provide accurate lake level data at 60 minute intervals by recording water pressure (in feet of water). The loggers will be maintained and operated throughout 2016 and 2017, so that the water level record can be analyzed in 2017.

2.4 WATER QUALITY

Water samples were collected in April 2016 at five sites within Lake Limerick: Dam (1m and 2m samples), Banbury, King cove, Tipperary, and Cranberry (Figure 31). Samples from all five sites were analyzed for total phosphorus (TP) concentrations [method detection limit (mdl): 2.0 µg/L].

The phytoplankton analysis was not conducted in 2016 because, 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 had recommended that phytoplankton samples not be taken in 2016 unless a surface algal scum that was suspected of being blue-greens occurred. We make this same recommendation for 2017.

In April 2016, concentrations of total phosphorus (TP) were higher at the 2 m depth at the dam site (21.9 µg/L) than at any of the other sampling locations in Lake Limerick (Figure 32). The next highest concentrations of TP were measured at the King Cove site (16.8 µg/L) and at Cranberry (13.4 µg/L). The lowest concentrations of total phosphorus were observed at Tipperary and Banbury and at the surface at the Dam site (8.1 µg/L, 7.0 µg/L, and 7.4 µg/L respectively).

Overall, water quality in Lake Limerick remains good, but there are several water quality indicators that will need to be monitored closely in 2017. In 2016, increased growth of filamentous algae was observed in Cranberry Cove (pre-dredging) and in the bird sanctuary. These areas should be monitored early in spring 2017 in order to evaluate potential treatment needs. In addition, TP was higher in both Cranberry Cove (13.4 µg/L) and King's Cove (16.8 µg/L) than in the main portions of the lake (at the Banbury, Tipperary, and dam surface sites – 8.1 µg/L, 7.0 µg/L, and 7.4 µg/L respectively). There also continued to be a build-up of TP in deep waters near the dam (22 µg/L), as in 2015. In July 2017, when water quality samples are collected, TP concentrations at the Cranberry, King's Cove, and deeper dam site should be evaluated in light of lake conditions at that time.

3.0 LAKE LEPRECHAUN

3.1 AQUATIC PLANTS

In June 2015, a survey of Lake Leprechaun revealed a small, mixed patch of aquatic plants 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, 2015 plant management efforts also focused on controlling the growth and spread of invasive species along the shoreline, namely yellow iris. Treatment efforts continued in 2016 and will also be needed in 2017 in order 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, and small clumps.

A more detailed survey of aquatic plants in Lake Leprechaun was conducted in June 2016 (Figure 34). The survey indicated that *Hippuris vulgaris* (mare's tail) continues to succeed in and dominate the aquatic plant community in Lake Leprechaun. In addition, *Potamogeton amplifolius* (largeleaf pondweed) and *Nymphaea odorata* (white waterlily) were observed in a few locations around the edge of the lake. Near the launch area, there were clusters of mare's tail as well as largeleaf pondweed, and a small patch of *Potamogeton pusillus* (small pondweed). At three points along the shore there were clumps of *Typha latifolia* (cattails). Near the inlet, there was a fairly large patch of largeleaf pondweed that also contained *Utricularia inflata* (inflated bladderwort). Yellow iris (*Iris pseudacorus*) was observed at two points along the southwestern shoreline of the lake. The densest area of plant growth in June was in the western end of the lake, where there was a large region of mare's tail. By September, this patch had grown considerably, extending out into the central portion of the lake and around the swimming raft (Figure 35).

The June 2016 plant survey in Lake Leprechaun also identified two near-shore areas close to the lake outlet that would not need to be dredged should any dredging occur in Lake Leprechaun. Plant growth is naturally impeded in these areas as they receive little light and are deep in comparison to other shoreline areas (Figure 34).

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 36 – 41.

3.2 PRECIPITATION AND LAKE LEVEL

During 2016, the continuous lake level data logger located near the outlet of Lake Leprechaun (Figure 42) was cleaned and replaced. The logger at this site provides accurate lake level data at 60 minute intervals by recording water pressure (in feet of water). The logger will be maintained and operated throughout 2016 and 2017, so that the water level record can be analyzed in 2017.

3.3 WATER QUALITY

A water quality monitoring program was implemented at Lake Leprechaun during the summer of 2013 and continued in summer 2014, summer 2015, and in April 2016. The water sampling site in Lake Leprechaun is located near the outlet structure (Figure 43). The April sample from the site was analyzed for total phosphorus (TP) concentrations [method detection limit (mdl): 2.0 µg/L]. The TP concentration was relatively low, at 8.1µg/L, indicating that overall the water quality in Lake Leprechaun is good.

4.0 PERMIT STATUS

AquaTechnex is the administrator for the herbicide permit and that permit is good through 2016. In 2017, LLCC should initiate a new permit application process. For economic and liability efficiency Tetra Tech recommends that AquaTechnex continue to be the permit holder and administrator for the becoming permit cycle.

5.0 RECOMMENDATIONS FOR 2017

2017 Recommendations:

- Staff from LLCC, representative of the Dam Committee, and Tetra Tech staff should meet in spring 2017 to coordinate lake level monitoring and sampling efforts for the 2017 season. Water quality sampling in 2017 should continue but on a limited basis to help provide the long-term data base for future reference.

- Aquatic plant mapping should be continued at both Lake Limerick and Lake Leprechaun in late May to June 2017 to establish 2017 treatment zones and develop management plans for both lakes.

    - Given that aquatic macrophytes have been successfully controlled in both lakes, management efforts in 2017 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 (e.g., the bird sanctuary).

    - 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 succeeded in the lake in recent years).

        - 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 should be comprised of the following:

        - Exploration of management alternatives for the bird sanctuary, given observed dense growth of aquatic plants and filamentous algae in this area. This would include macrophyte control and nutrient inactivation (small alum treatment) to limit algal growth by reducing sediment phosphorus recycling. In addition, a future small scale dredging action may be needed to remove nutrient enriched shallow sediments.

        - 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 2017 in order to assess the effectiveness of the summer control activities and in order to plan for the efforts that will be needed in 2018.

- During 2017, water quality monitoring should be conducted only in July and September. Water quality monitoring will continue to be more limited in scope in 2017 than in 2013-2015 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 2017 unless a surface algal scum that is suspected of being blue-greens occurs. To help track phytoplankton densities, chlorophyll a should be sampled for along with the phosphorus samples.

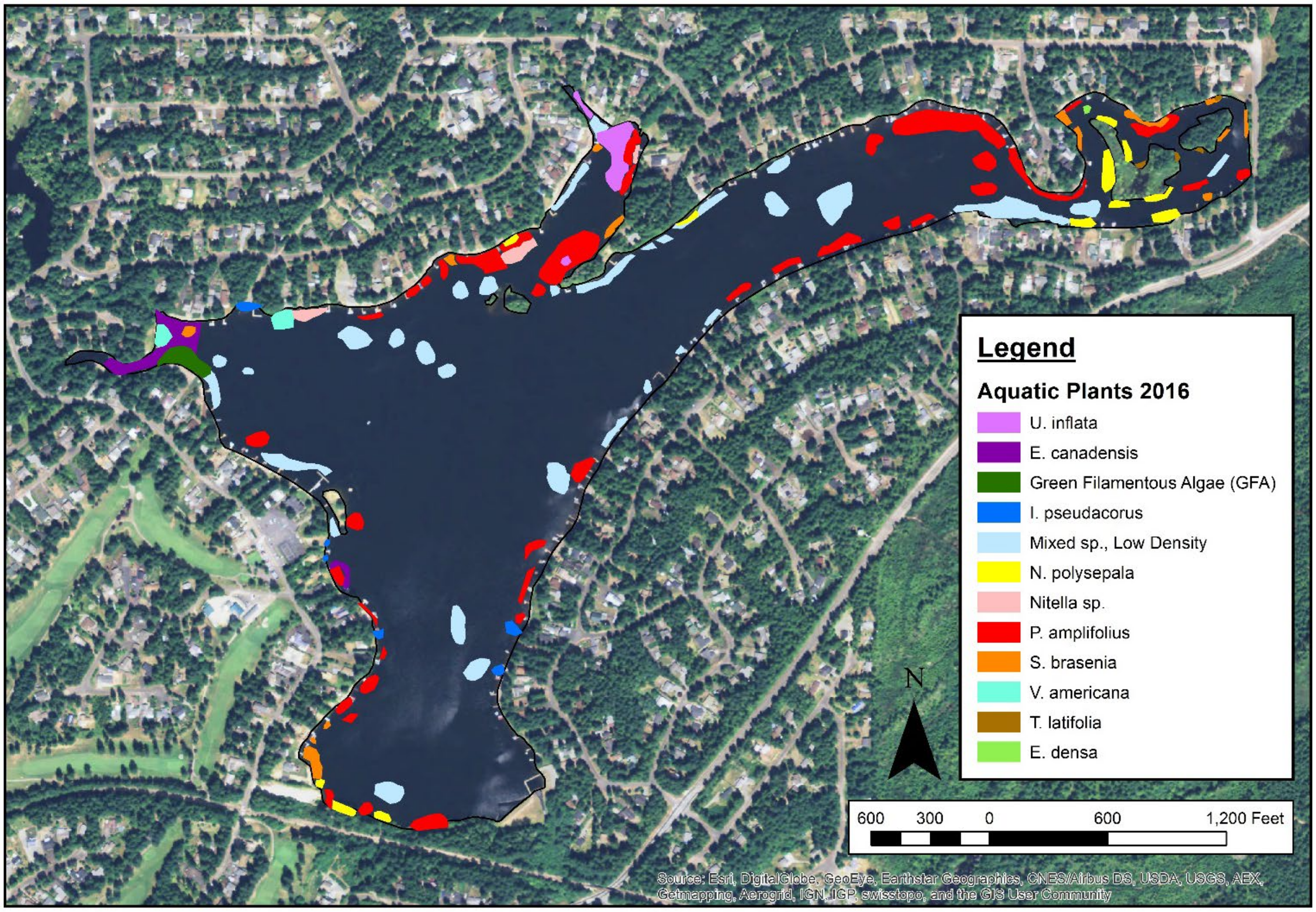
- During 2017, LLCC should explore future dredging projects in Lake Limerick and Lake Leprechaun and evaluate long-term maintenance needs associated with the completed dredging projects in Lake Limerick.

    - More information on sediment in Lake Leprechaun will be necessary in order to effectively explore dredging portions of that lake.
    - Monitoring on an annual basis of topographic/bathymetric transect profiles will be conducted in each of the coves to track future sediment filling of the dredged areas. This monitoring will be completed for at least the first five years from the start of the dredging.

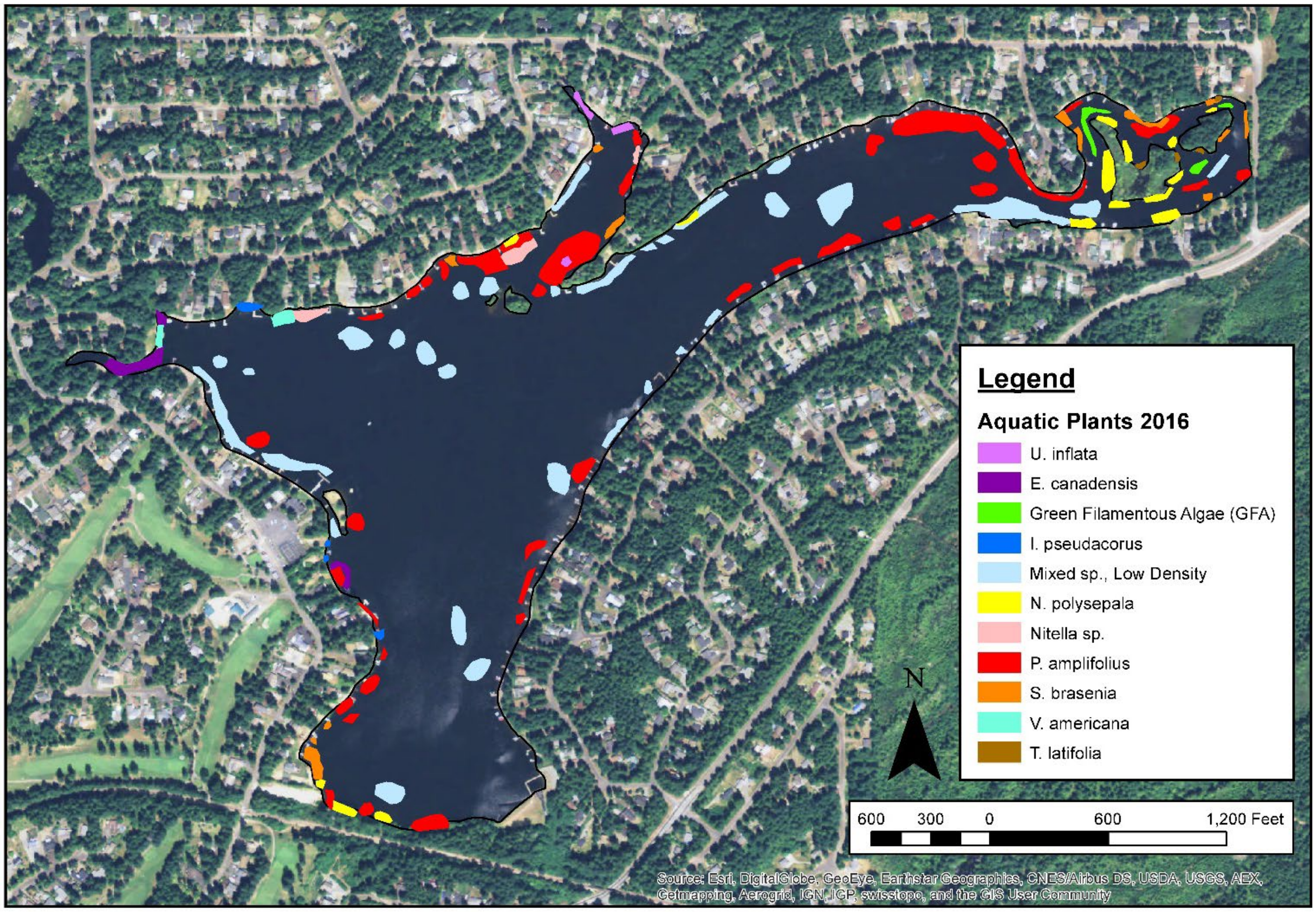
6.0 REFERENCES

Marine Industrial Construction, LLC (MIC). 2016. 2016 Lake Limerick Dredging: Final Report.

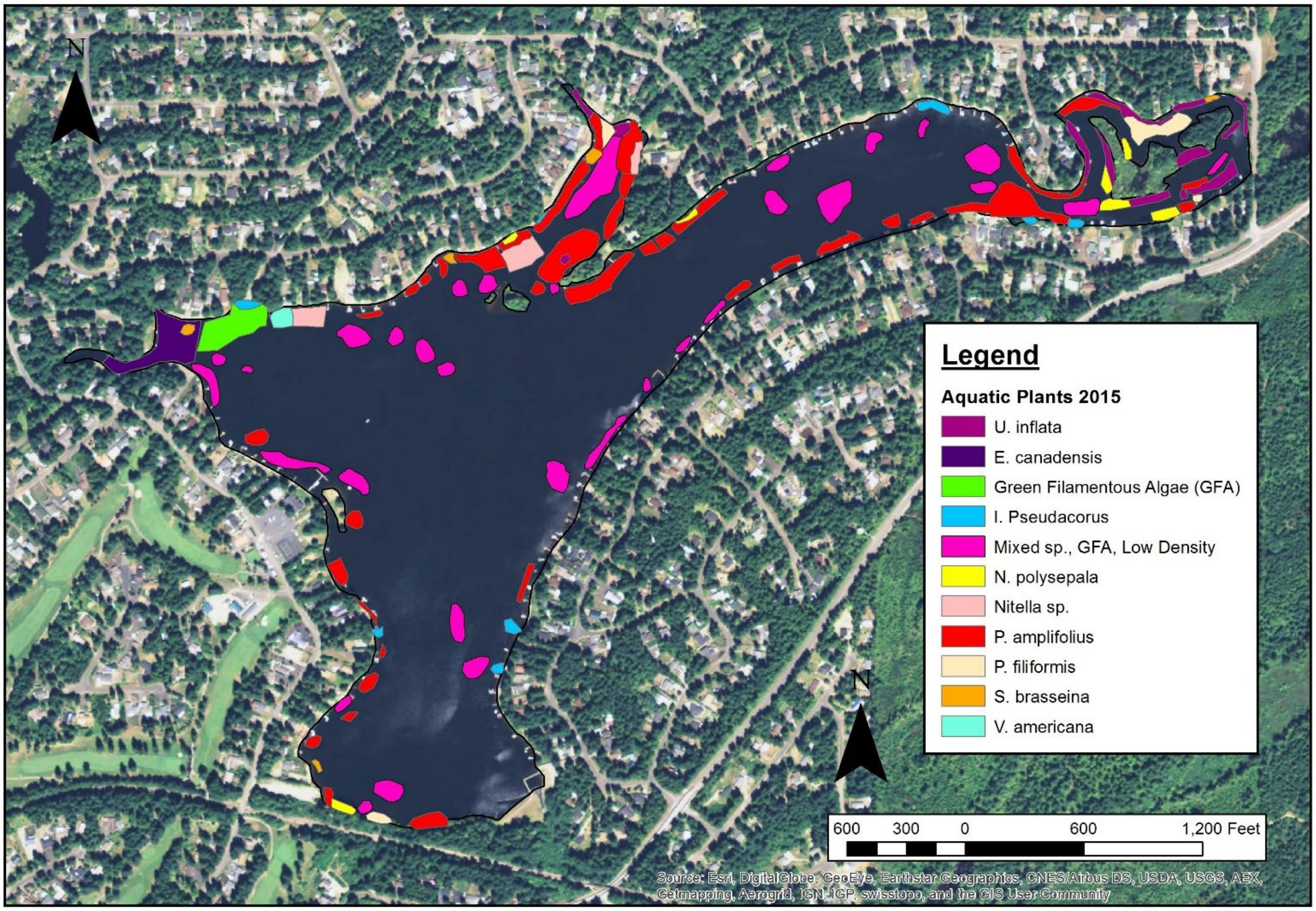
7.0 FIGURES



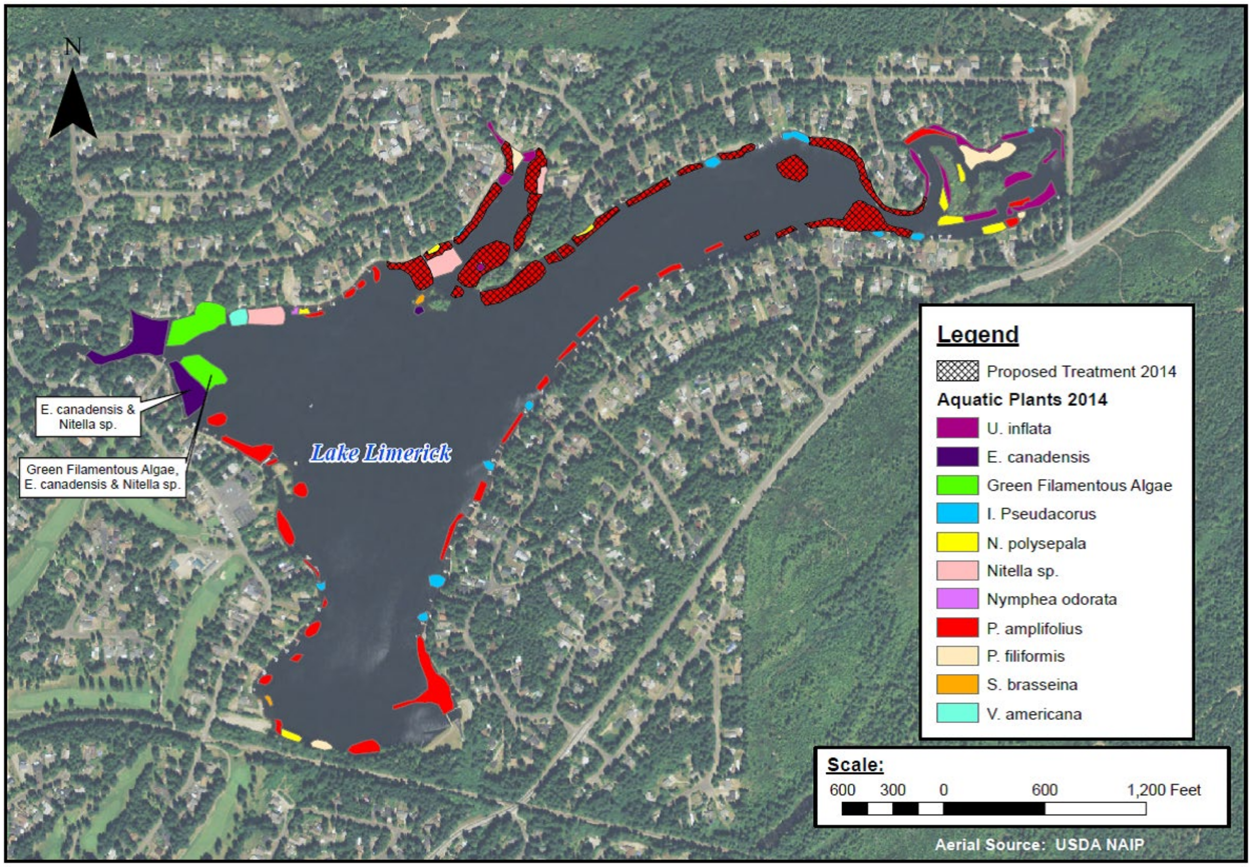
June 2016 Lake Limerick Aquatic Vegetation Survey



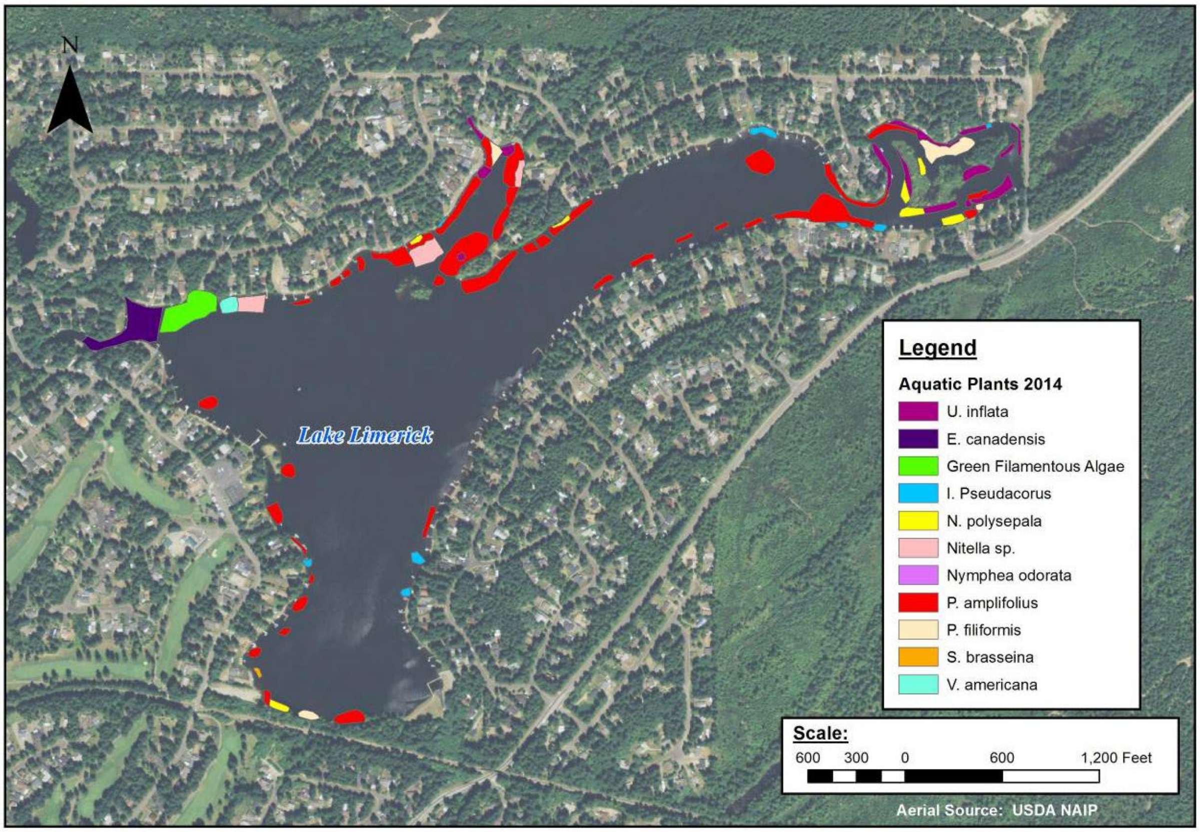
September 2016 Lake Limerick Aquatic Vegetation Survey



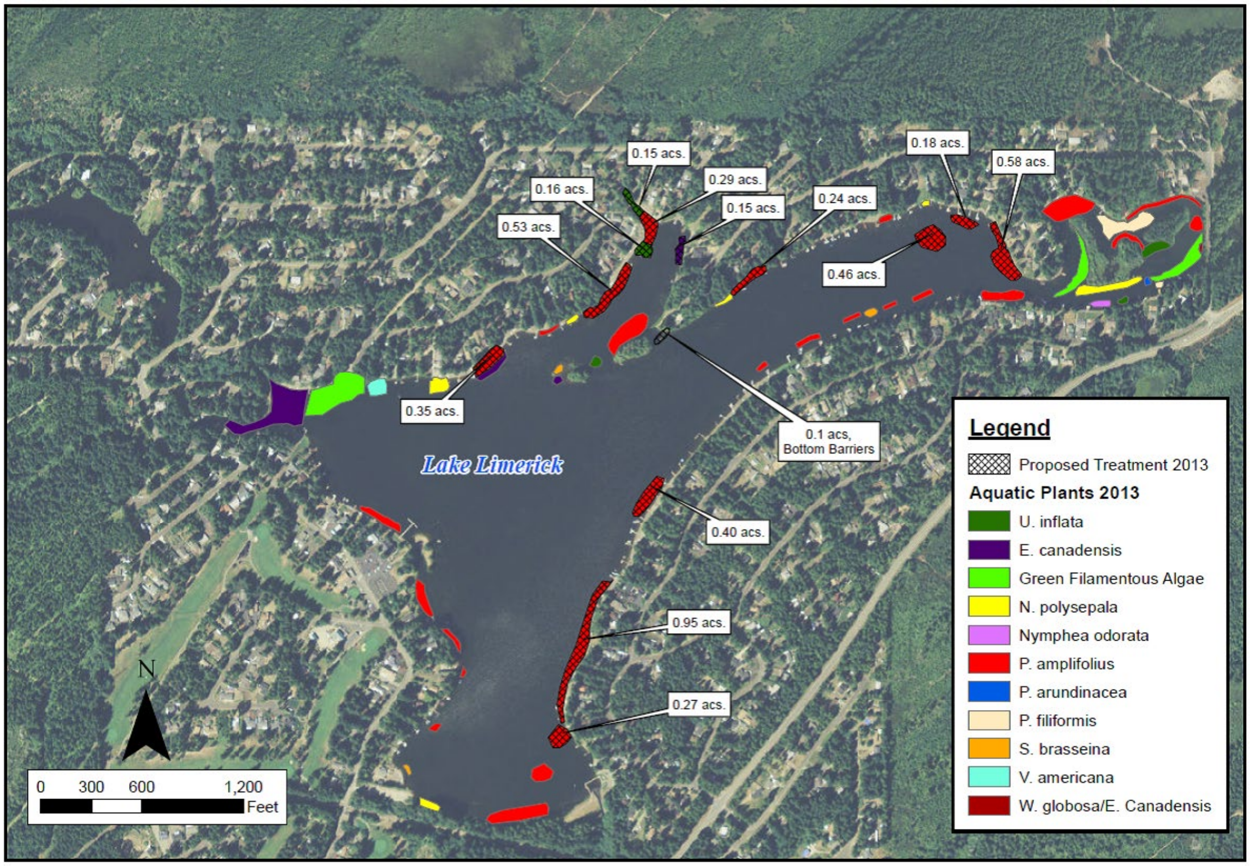
2015 Lake Limerick Aquatic Vegetation Survey



2014 Lake Limerick Aquatic Plant Survey & Proposed Treatment



2014 Lake Limerick Aquatic Plants: Post Treatment Results



2013 Lake Limerick Aquatic Plants & Proposed Treatment

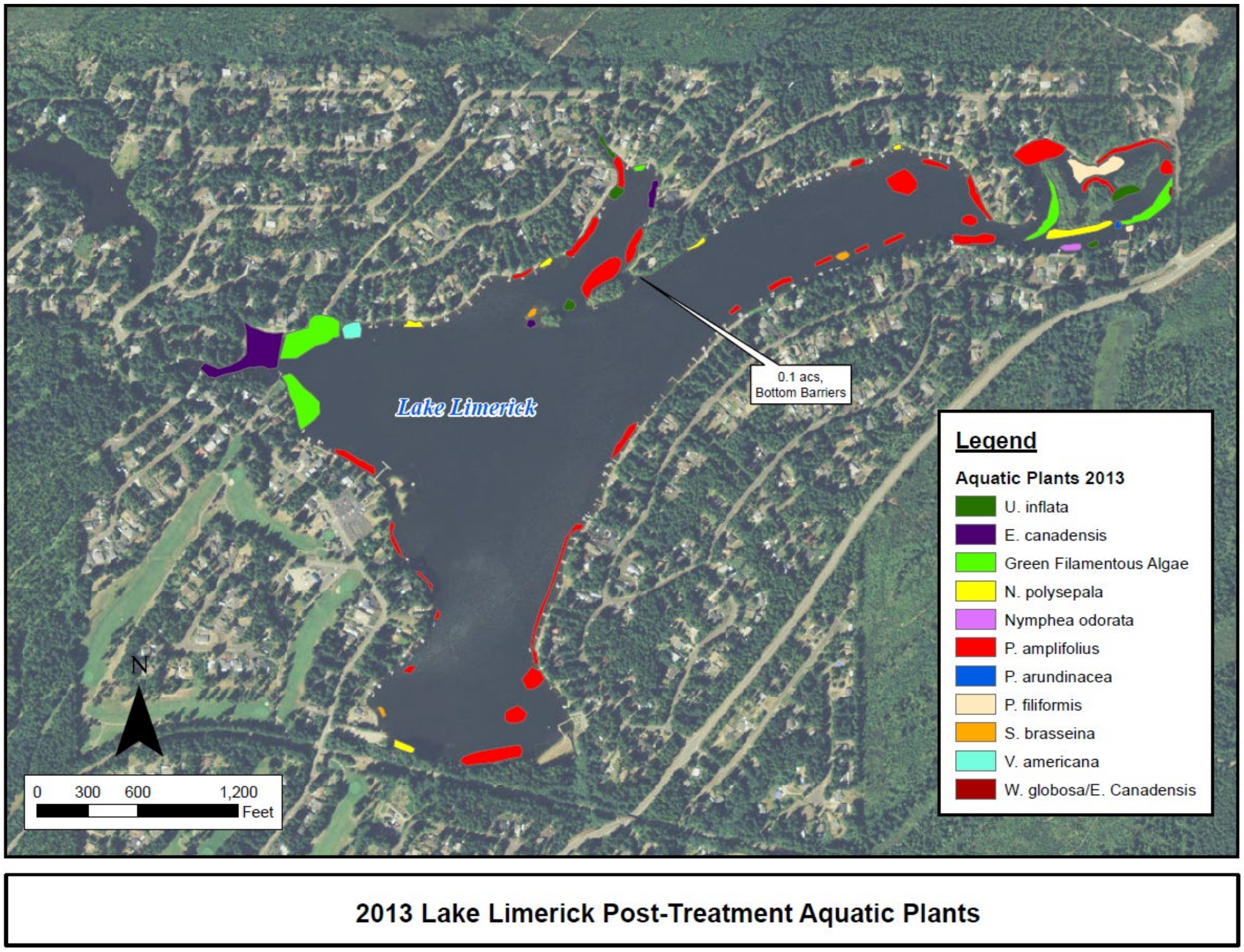


Figure 7 – Map of aquatic plants distribution in Lake Limerick in fall 2013 after the proposed treatment had been completed.

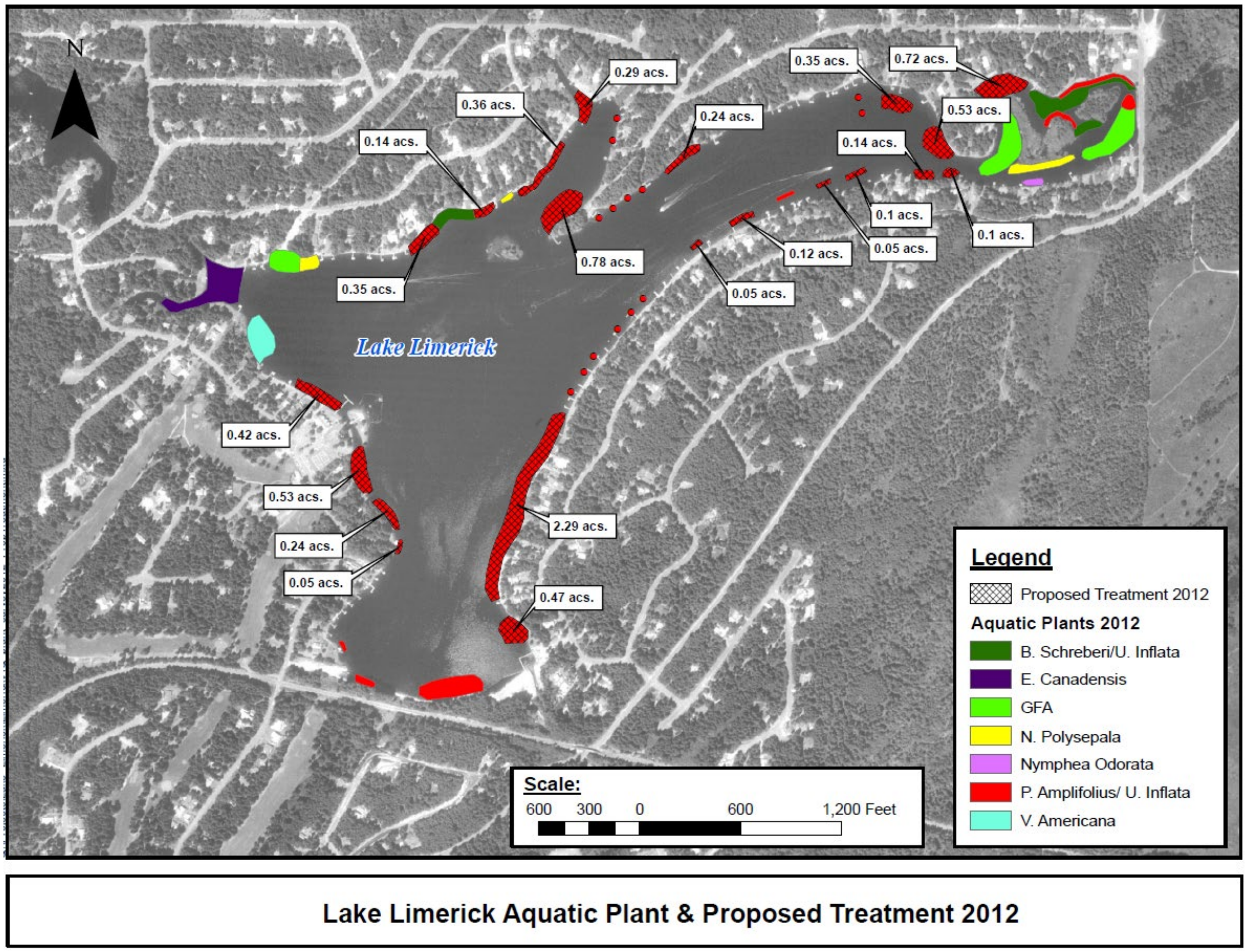


Figure 8 – Map of aquatic plant distribution in Lake Limerick in early summer 2012. Cross-hatching indicates the areas where treatment was proposed for summer 2012.

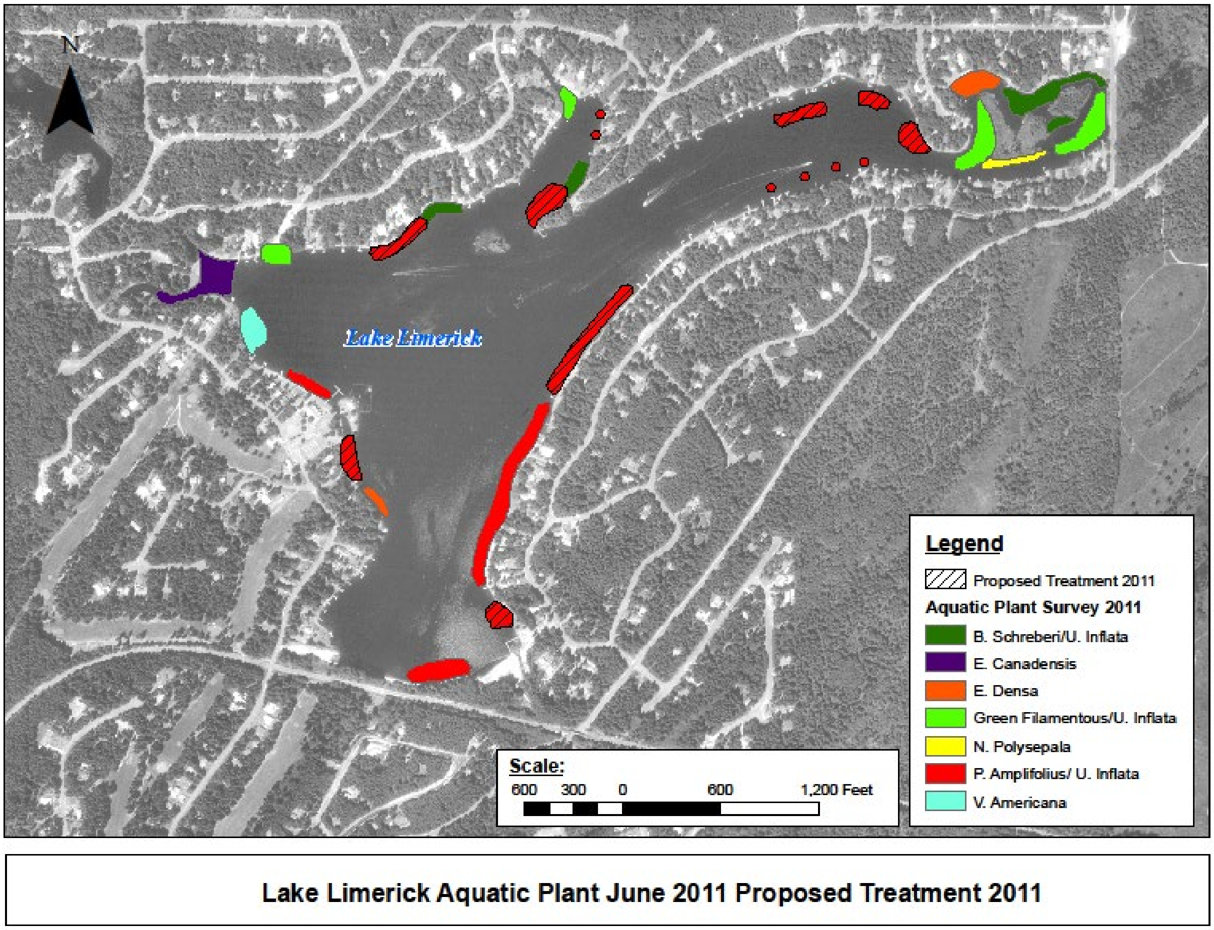


Figure 9 – Map of aquatic plant distribution in Lake Limerick in June 2011. Cross-hatching indicates the areas where treatment was proposed for summer 2011.

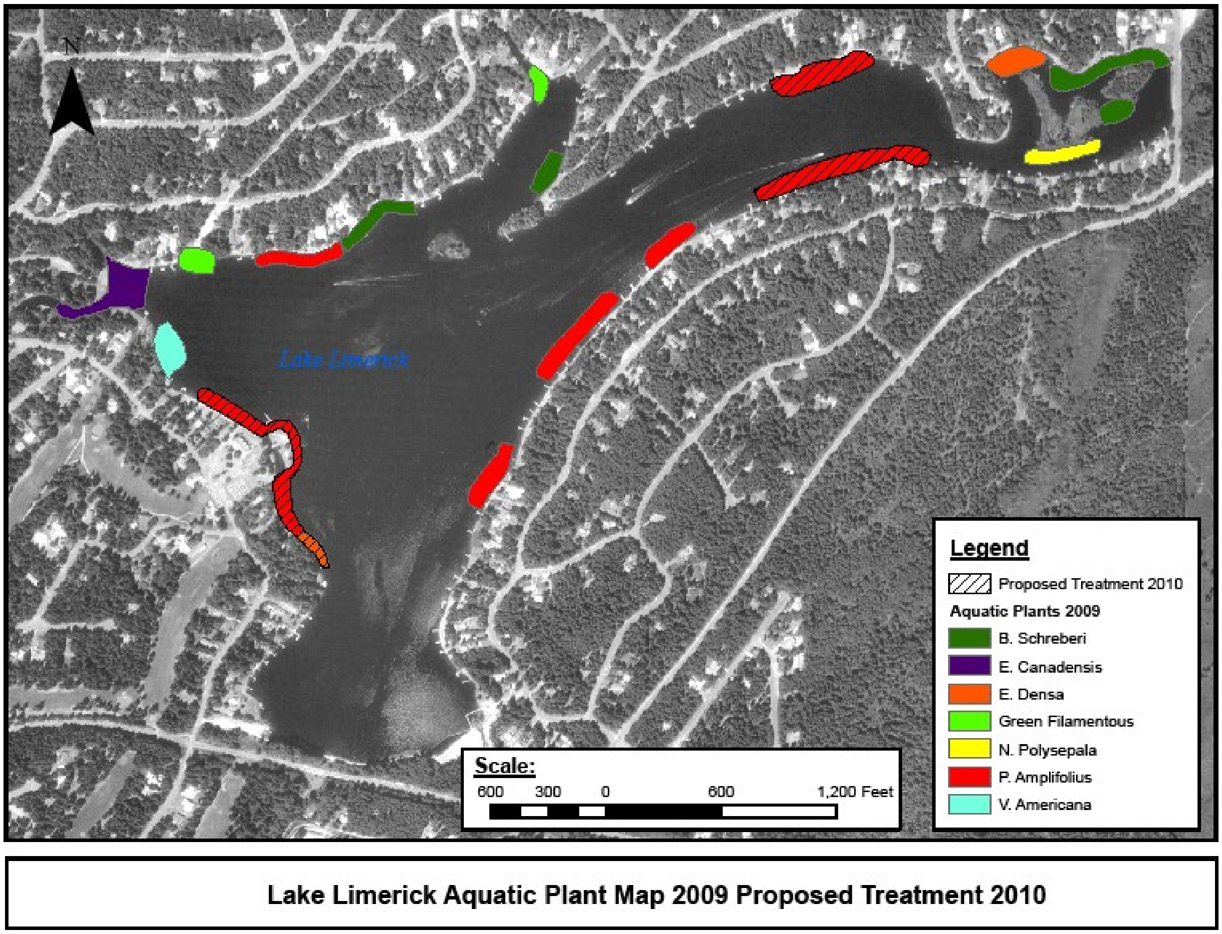
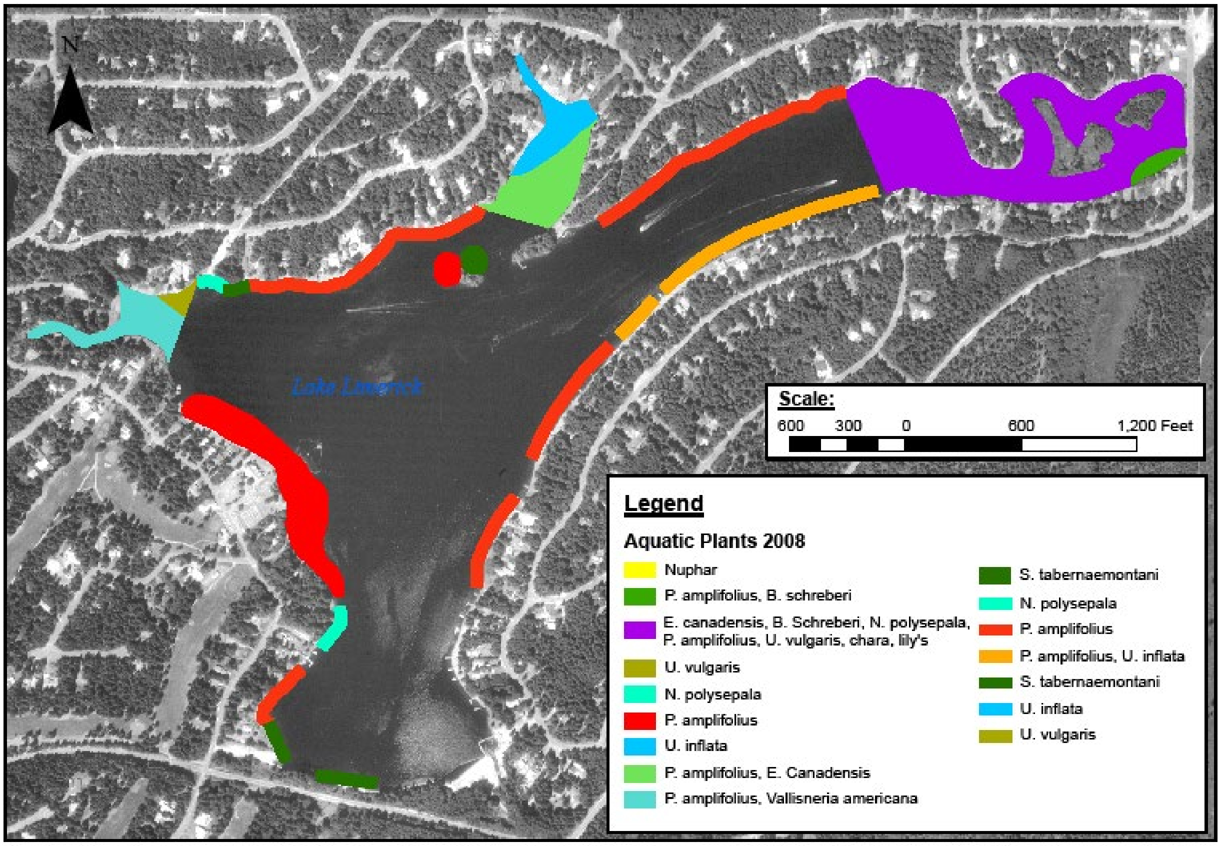


Figure 10 – Map of aquatic plant distribution in Lake Limerick in summer 2009. Cross-hatching indicates the areas where treatment was proposed for summer 2010.



Lake Limerick Aquatic Plant Map (August 08)

Figure 11 – Map of aquatic plant distribution in Lake Limerick in August 2008.

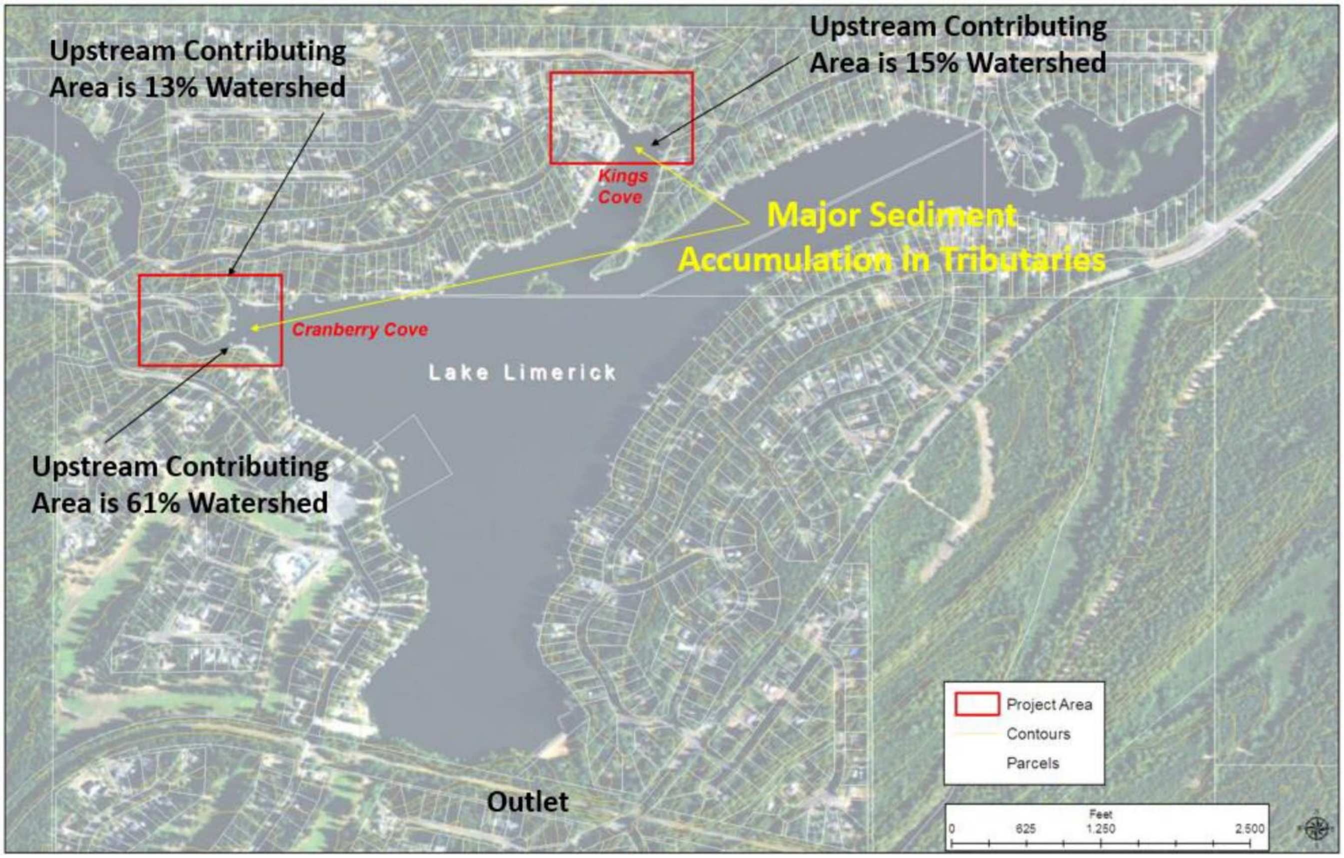
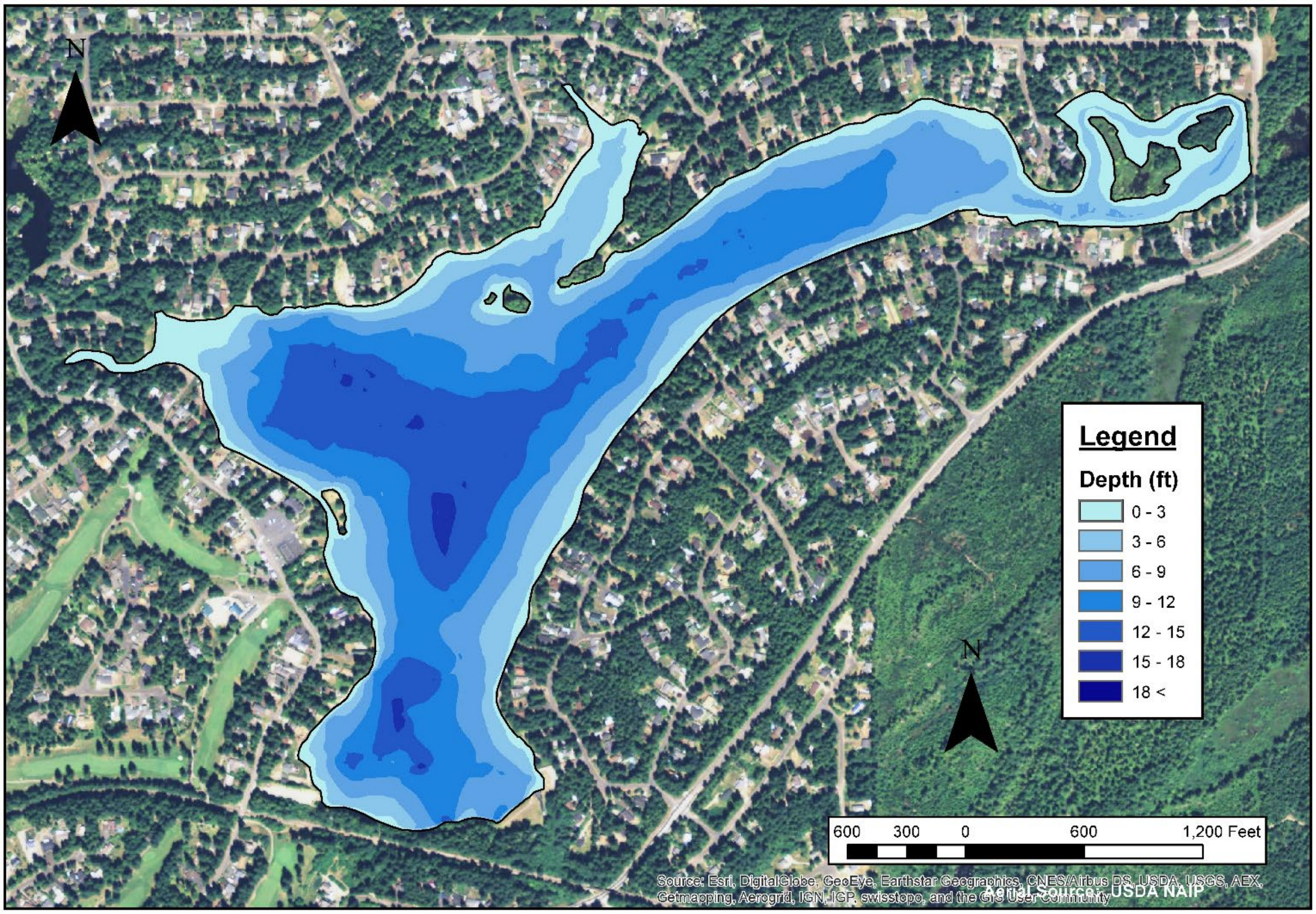


Figure 12 – Locations for dredging in Lake Limerick



2015 Lake Limerick Bathymetric Survey

MudCat Dredge

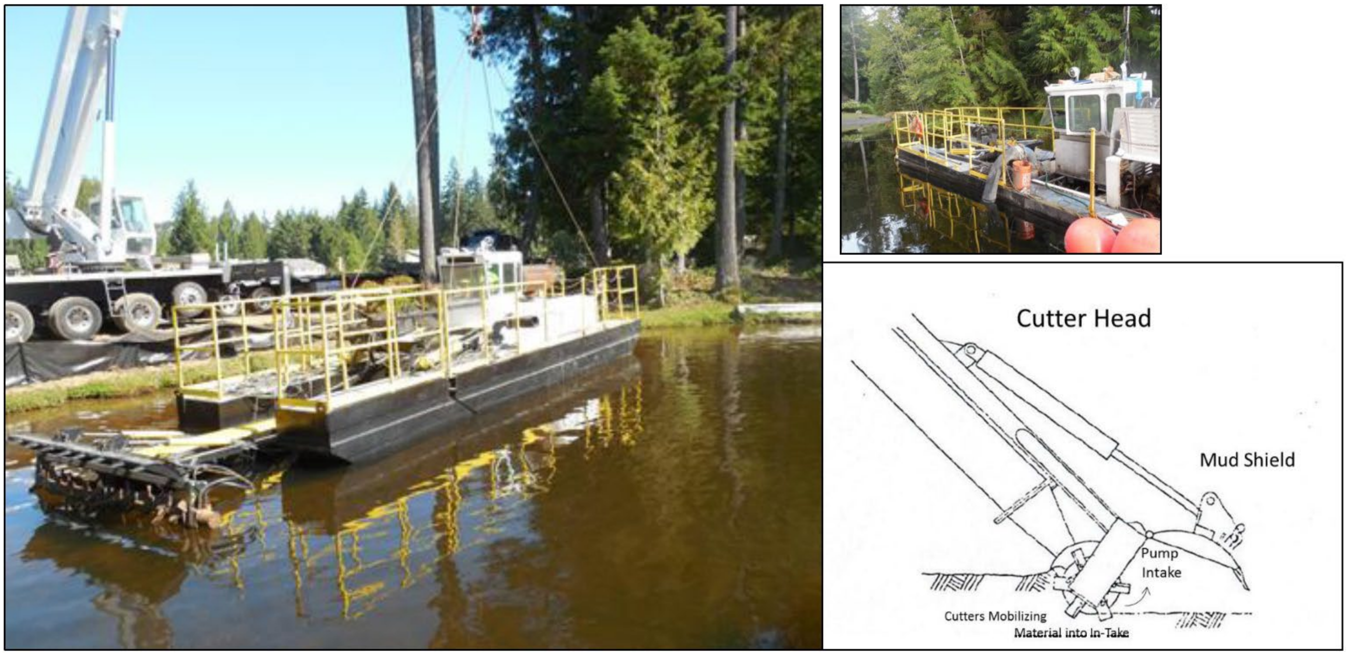


Figure 15 – Dredging pipeline

Figure 16 – Injection of flocculent into dredge material

Figure 17 – De-watering bags

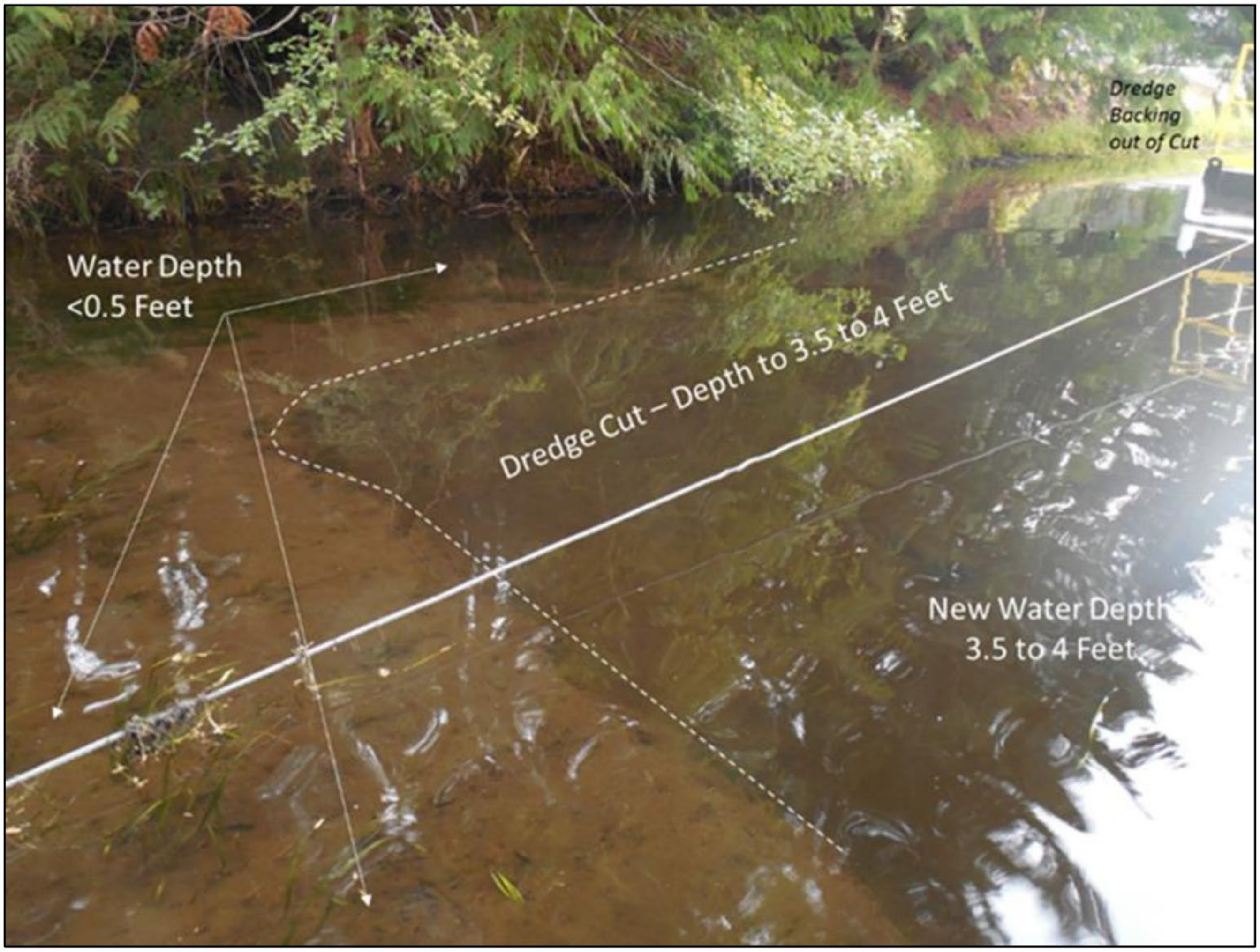
Dredge Material:
20% Sediment
80% Water

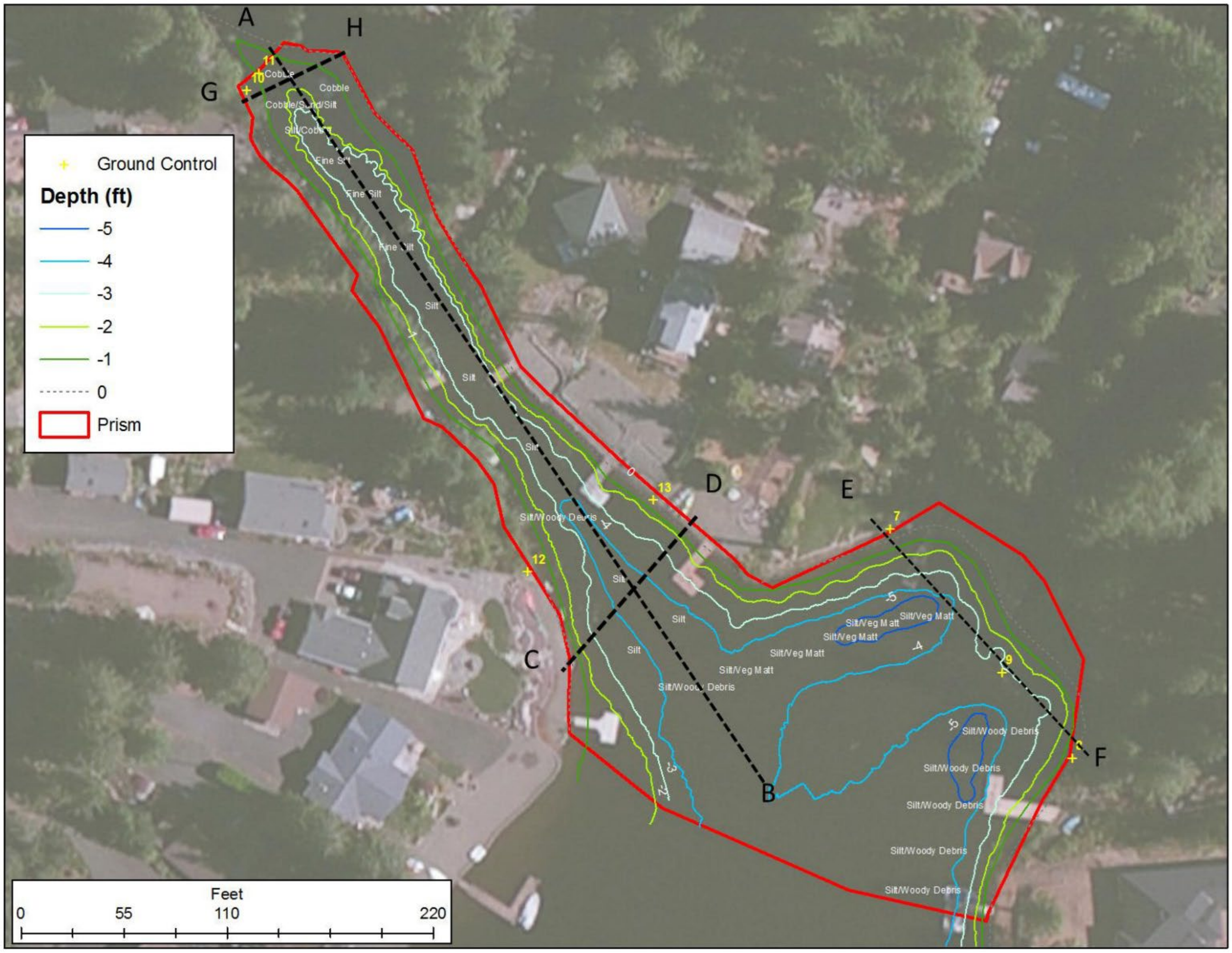
Figure 19 – De-watered material

Fresh Sediment

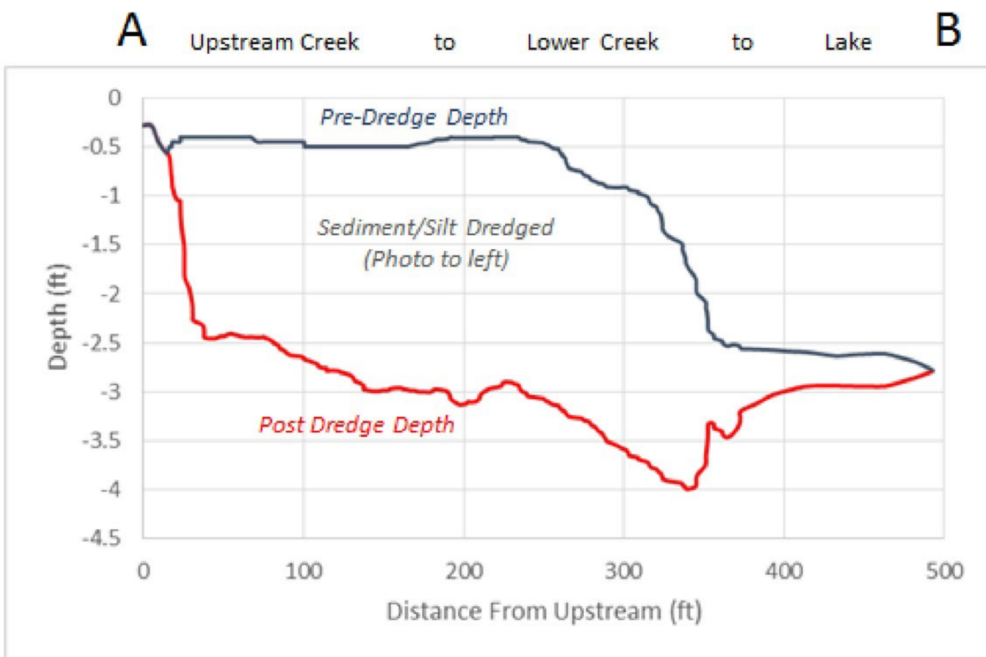
De-Watered Sediment

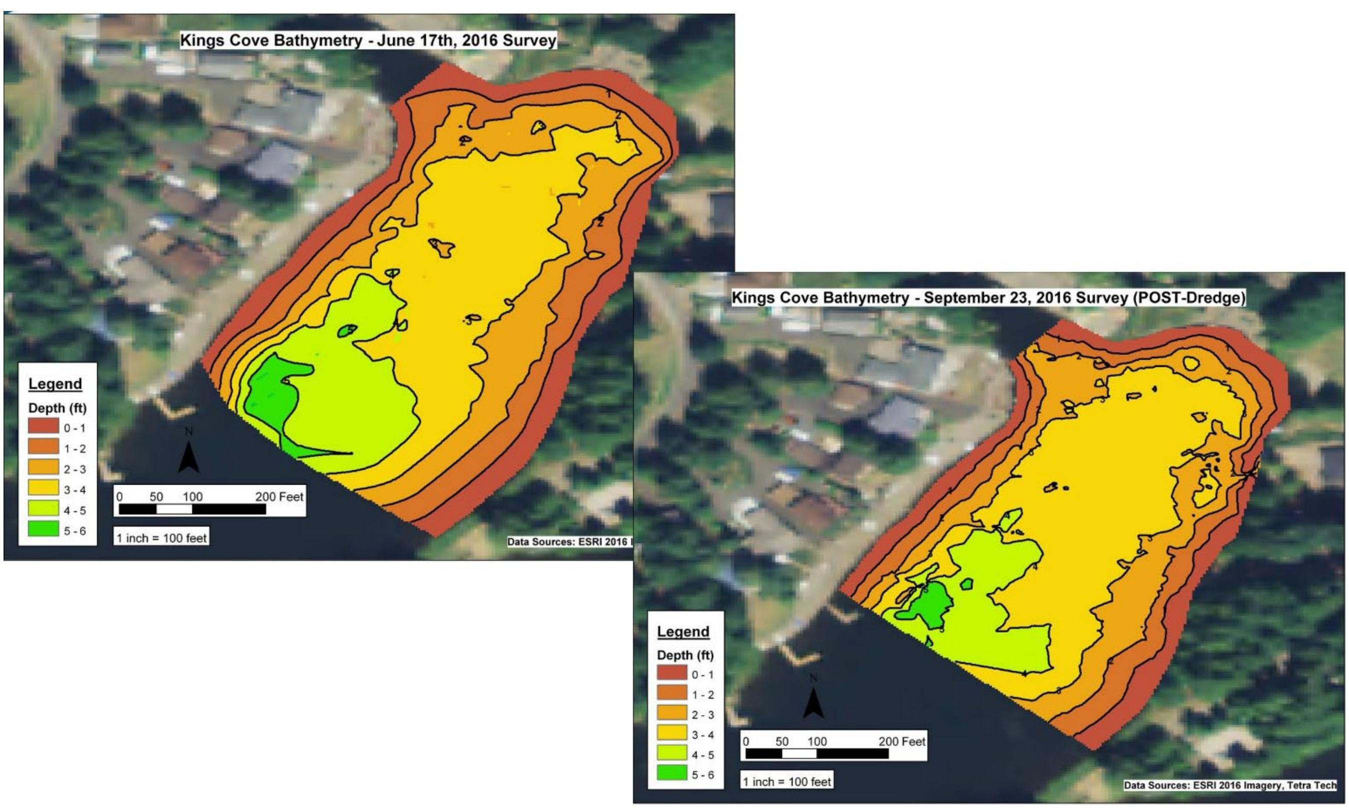
Dried Sediment

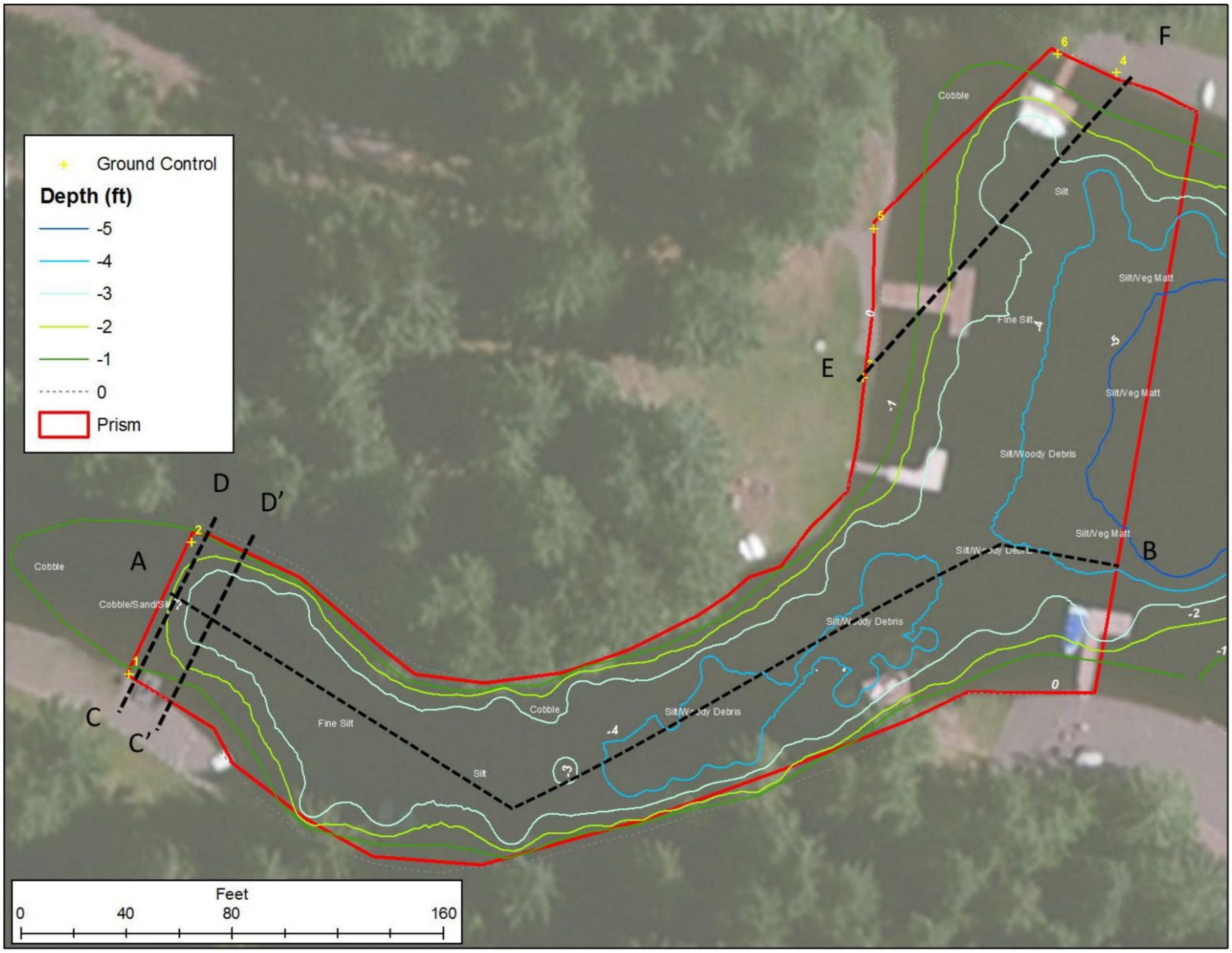

Dredge
Backing
out of Cut
Water Depth
<0.5 Feet
Dredge Cut – Depth to 3.5 to 4 Feet
New Water Depth
3.5 to 4 Feet


Ground Control
Depth (ft)
-5
-4
-3
-2
-1
0
Prism
Feet
0
55
110
220
A
B
C
D
E
F
G
H
Cobble
Cobble/Sand/Silt
Silt/Cobble
Fine Silt
Silt
Silt/Woody Debris
Silt/Veg Matt

Thalweg Transect: King's Cove






Ground Control
Depth (ft)
-5
-4
-3
-2
-1
0
Prism
Feet
0
40
80
160
A
B
C
C'
D
D'
E
F
Cobble
Cobble/Sand/Silt
Fine Silt
Silt
Silt/Woody Debris
Silt/Veg Matt
Cobble

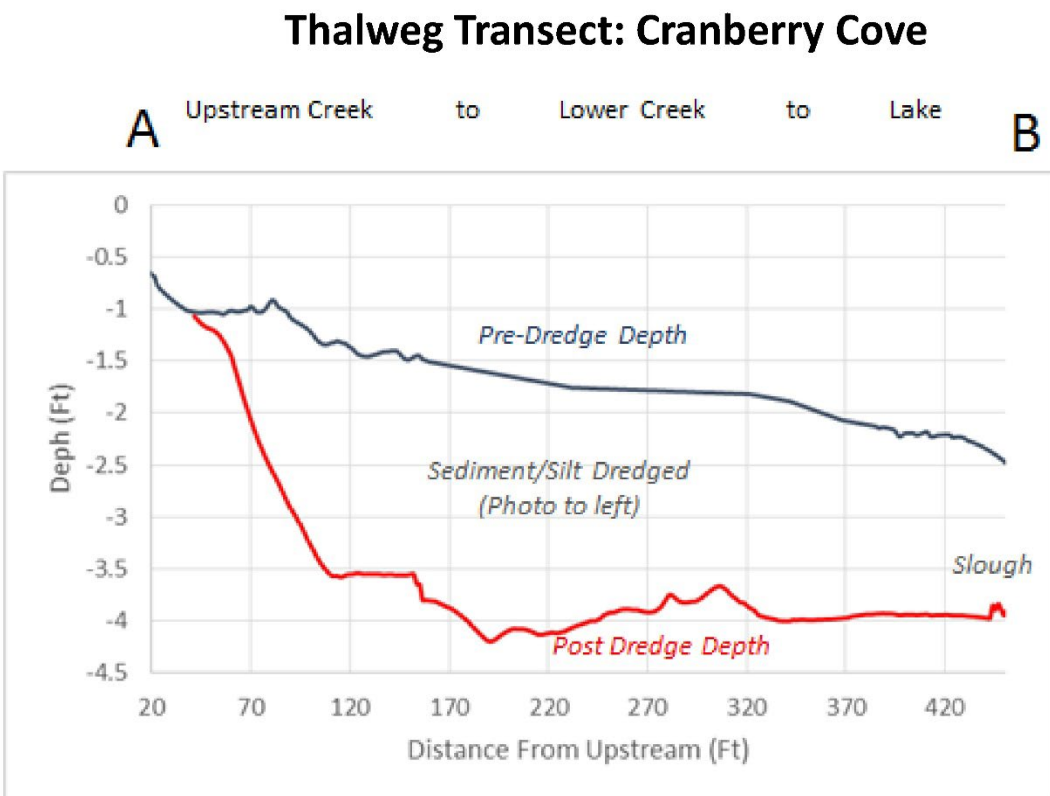


Figure 27 – Thalweg gradient for inflows into Cranberry Cove, before and after dredging

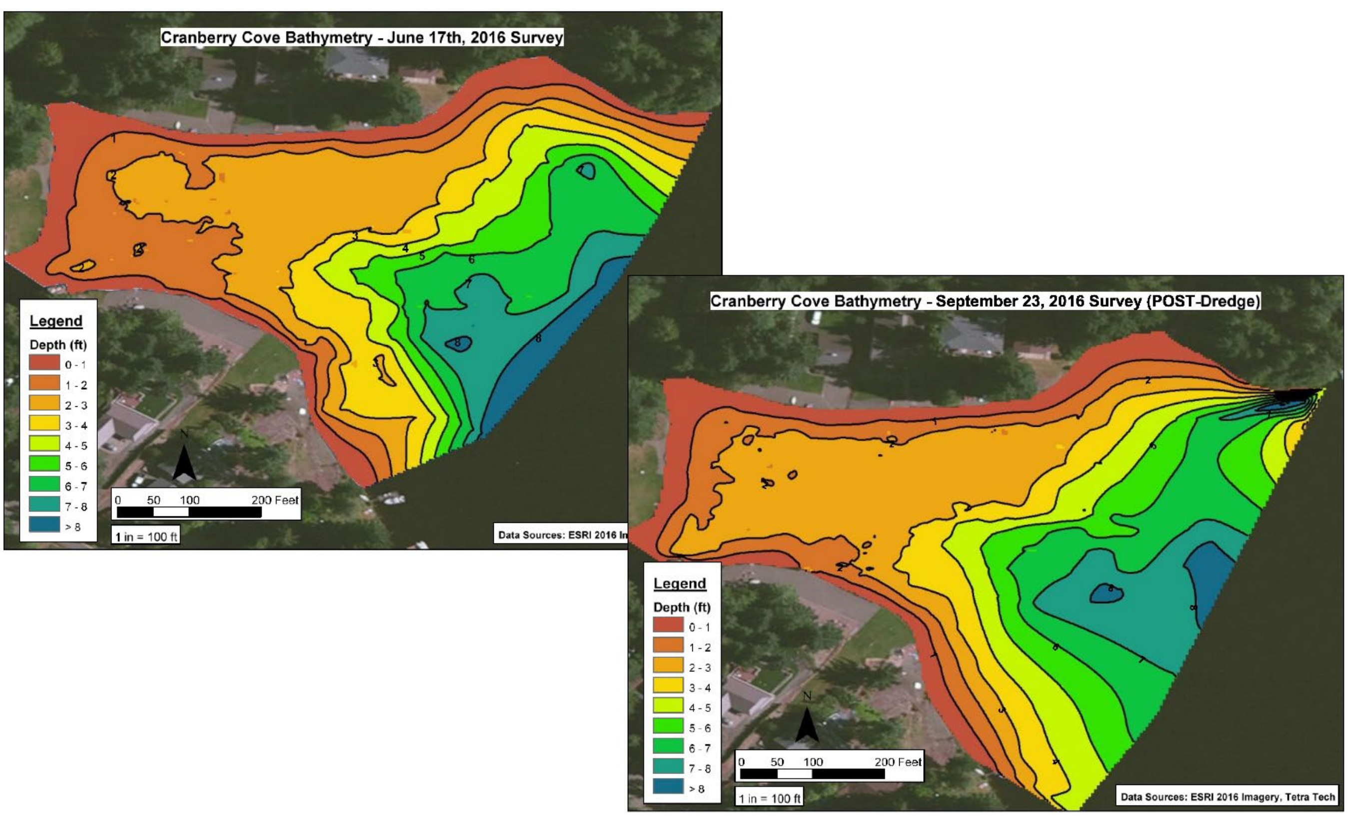


Figure 29 – Level logger located at the Lake Limerick Country Club dock.

Figure 30 – Level logger located below the Lake Limerick dam

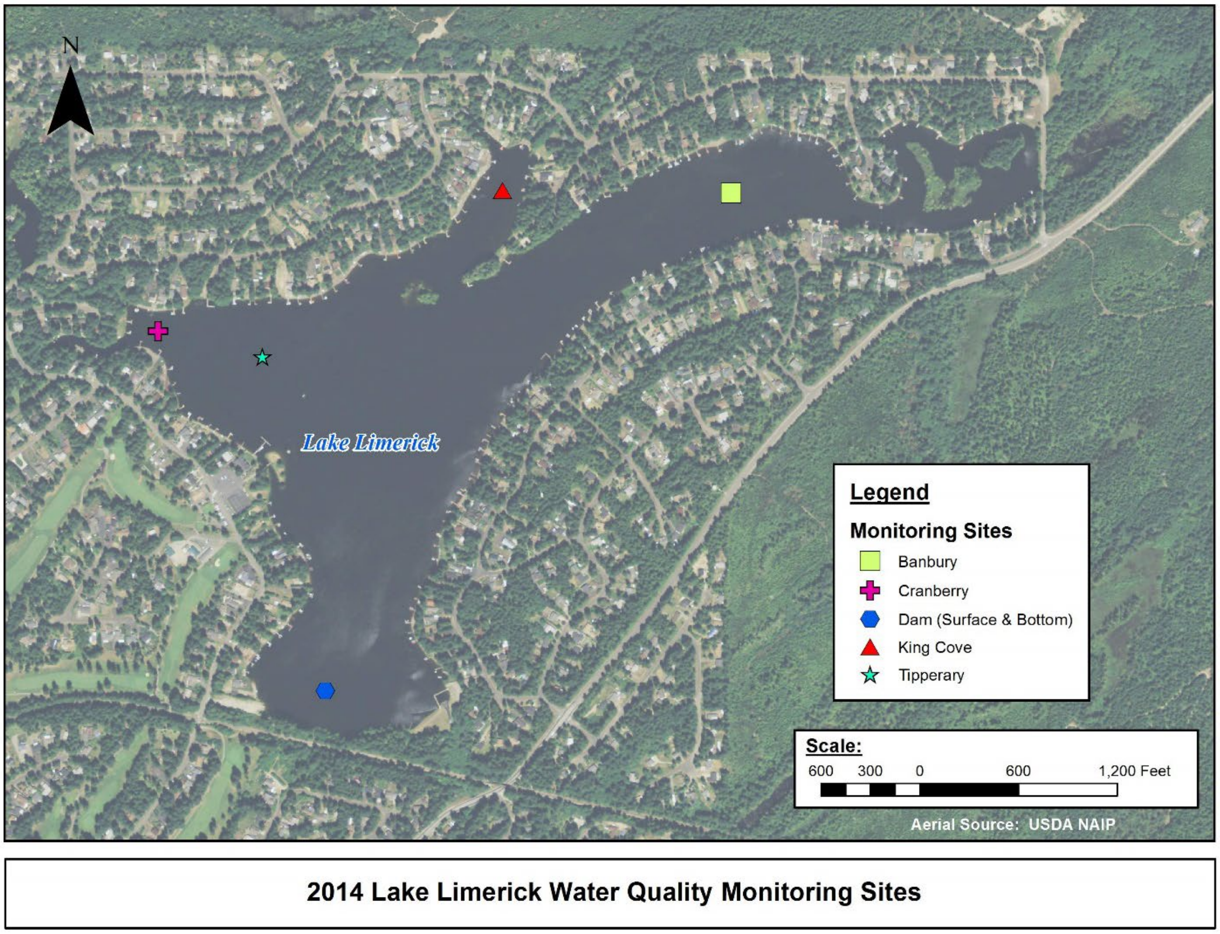


Figure 31 – Locations of water quality monitoring sites within Lake Limerick.

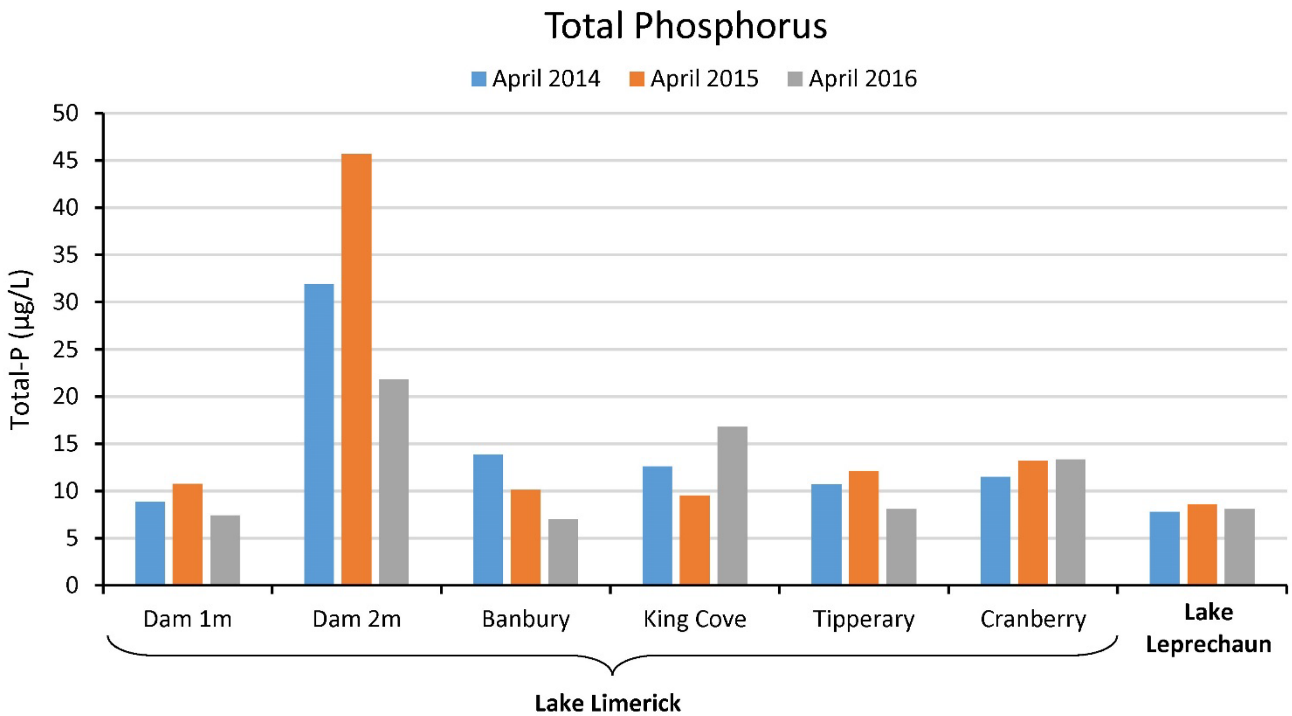


Figure 32 – Total phosphorus concentrations at the water quality monitoring sites within Lake Limerick and Lake Leprechaun on April 9th, 2014; April 2nd, 2015; and April 21st, 2016. The method detection limit for total phosphorus analysis is 2.0 µg/L.

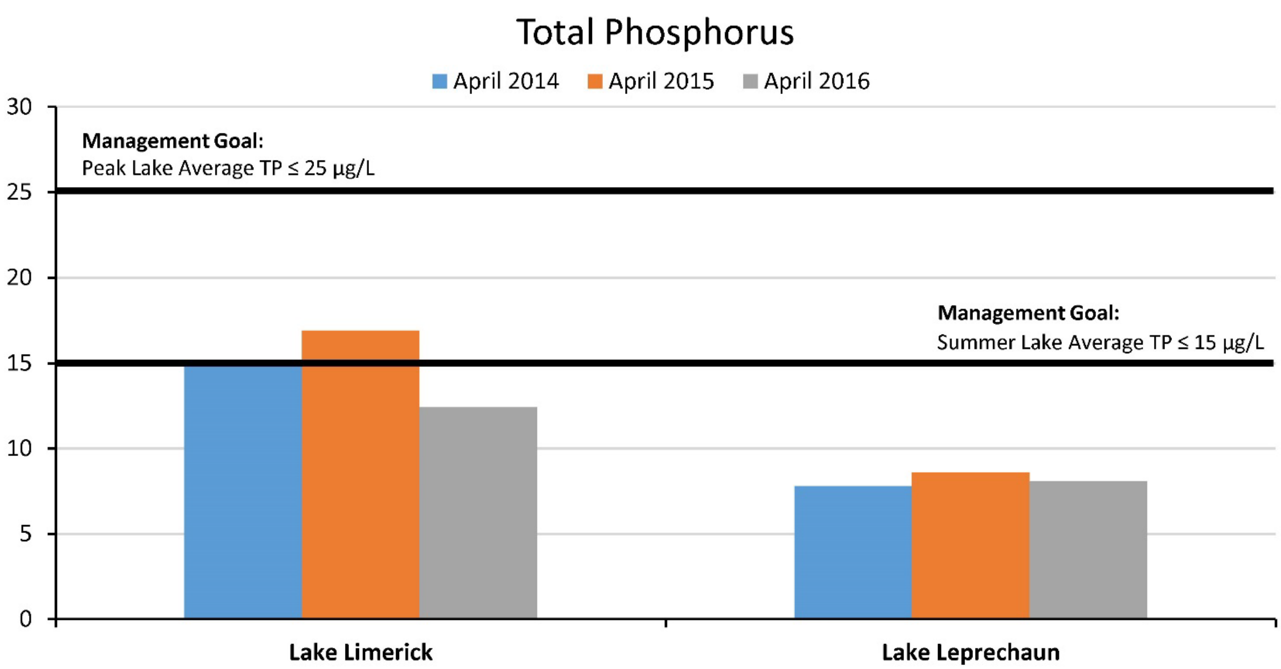


Figure 33 – Lake-wide average total phosphorus concentrations in Lake Limerick and Lake Leprechaun on April 9th, 2014; April 2nd, 2015; and April 21st, 2016. Lake-wide means are not volume-weighted. The lake average concentrations for Lake Limerick are the average of data from all five stations (including 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.

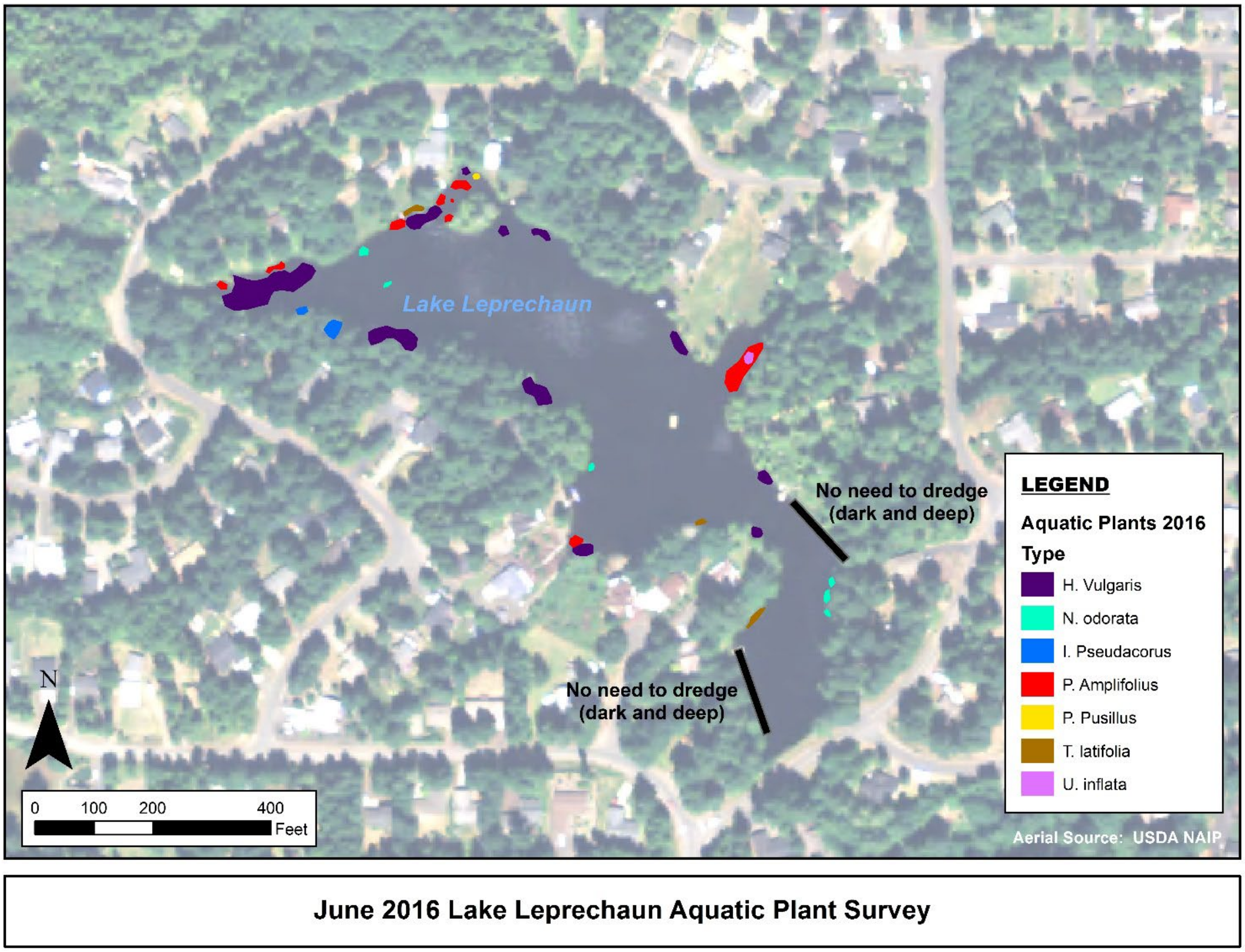


Figure 34 – Map of aquatic plant distribution in Lake Leprechaun in June 2016.

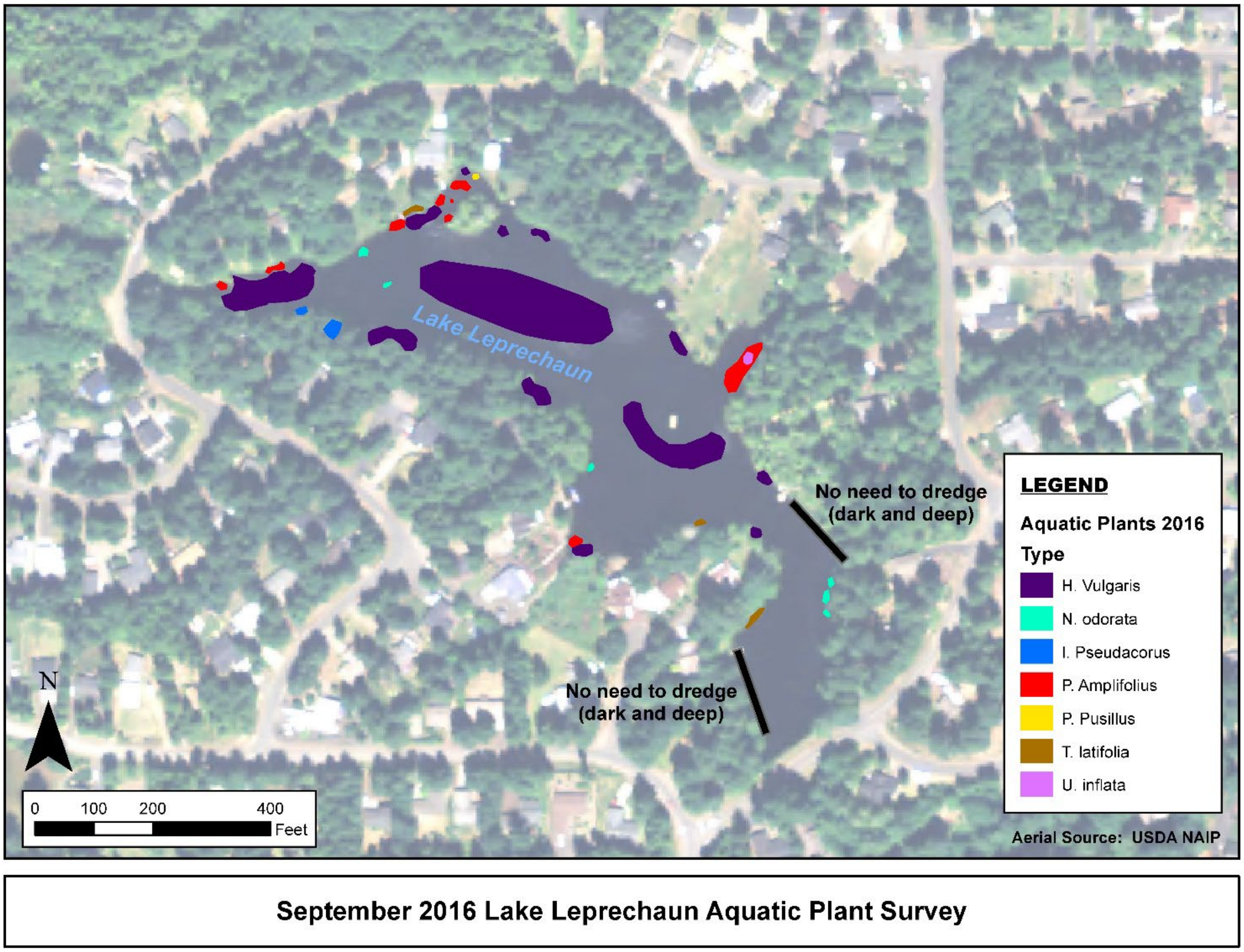


Figure 35 – Map of aquatic plant distribution in Lake Leprechaun in September 2016

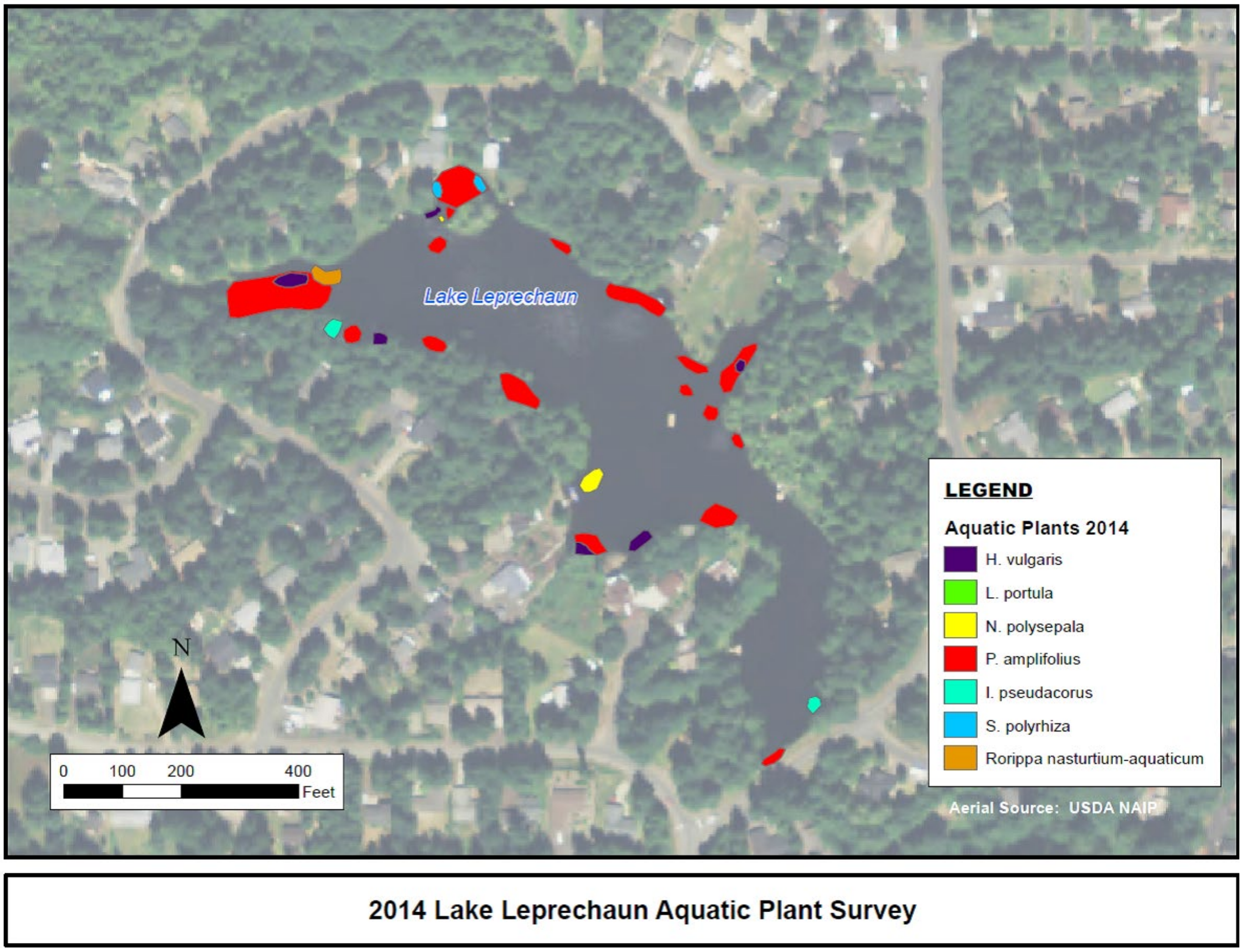


Figure 36 – Map of aquatic plant distribution in Lake Leprechaun before the summer 2014 treatment was conducted.

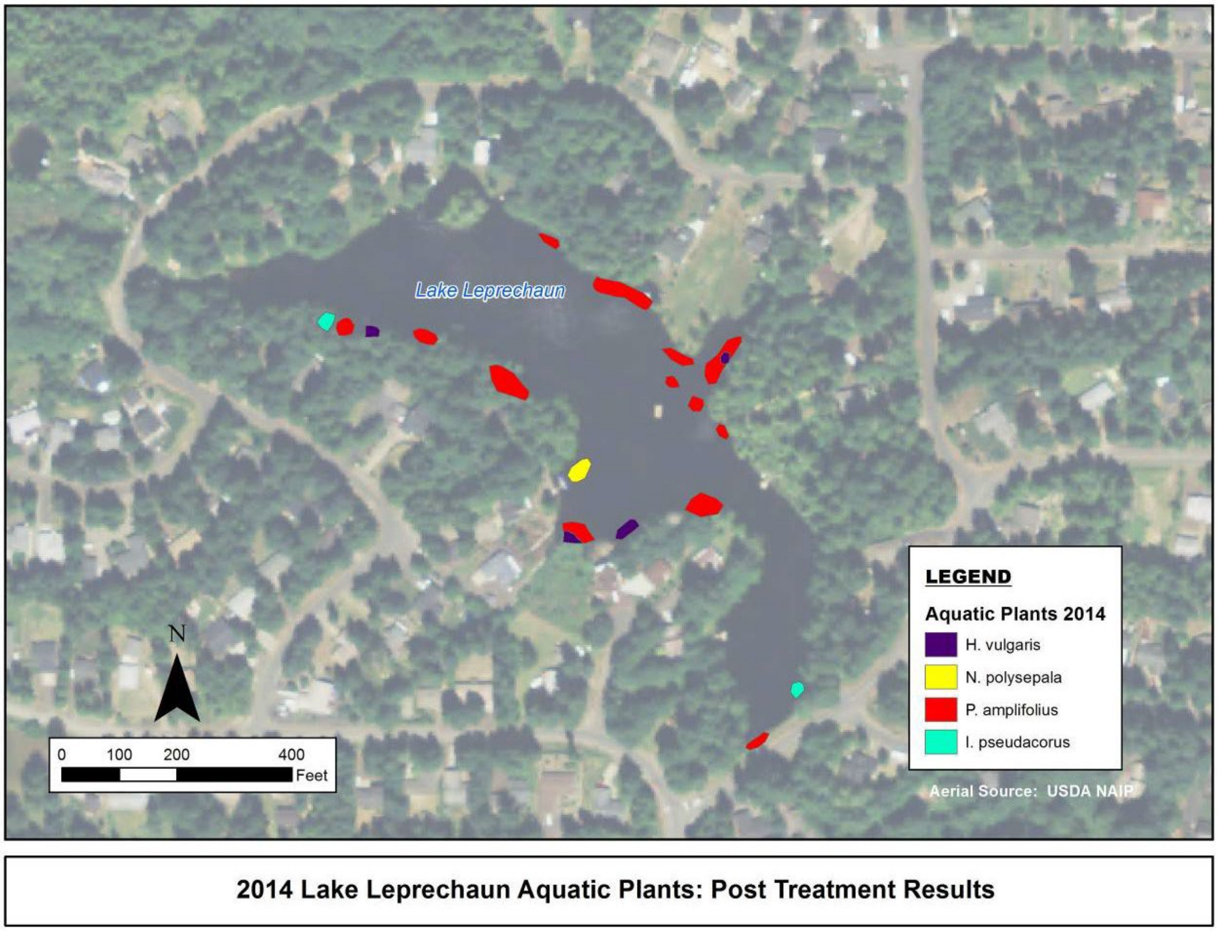


Figure 37 – Map of aquatic plant distribution in Lake Leprechaun after the summer 2014 treatment was conducted.

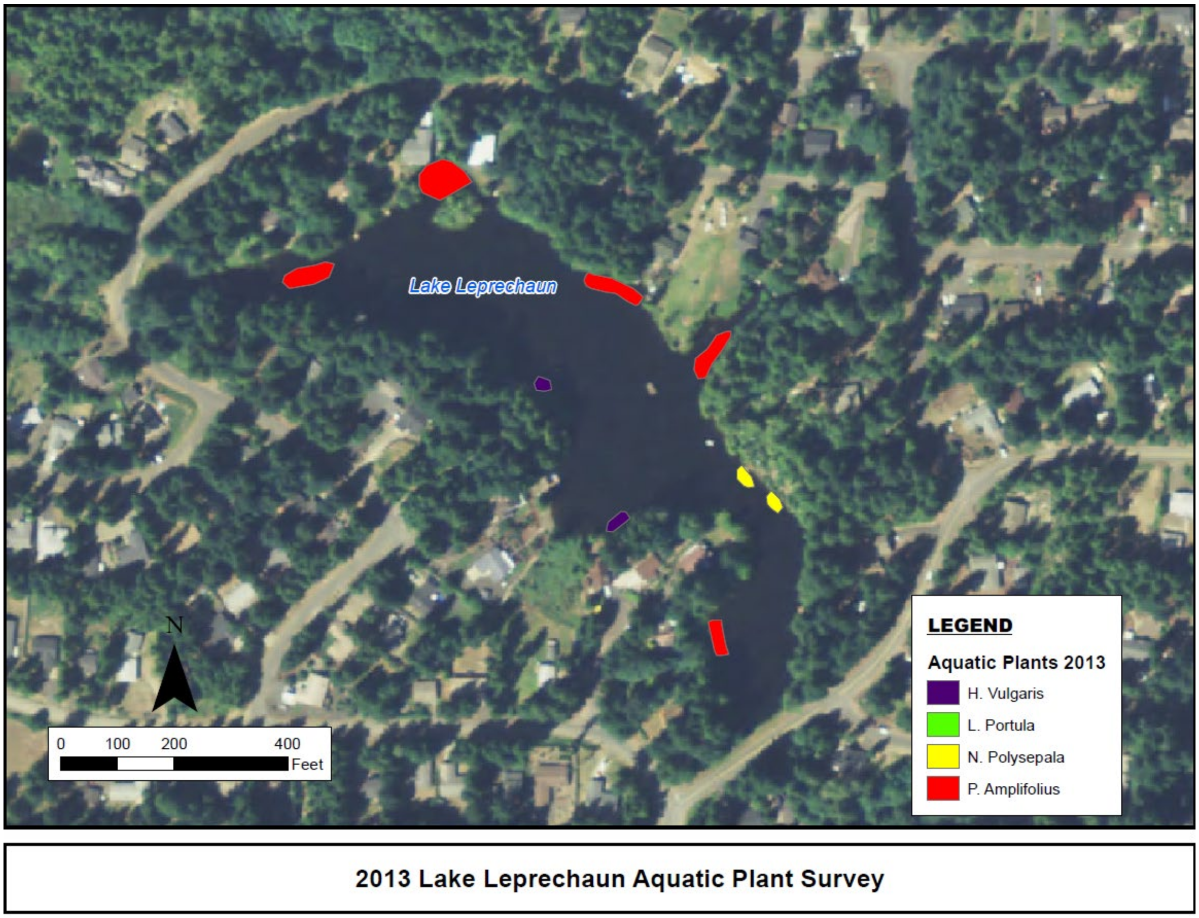


Figure 38 – Map of aquatic plant distribution in Lake Leprechaun in 2013

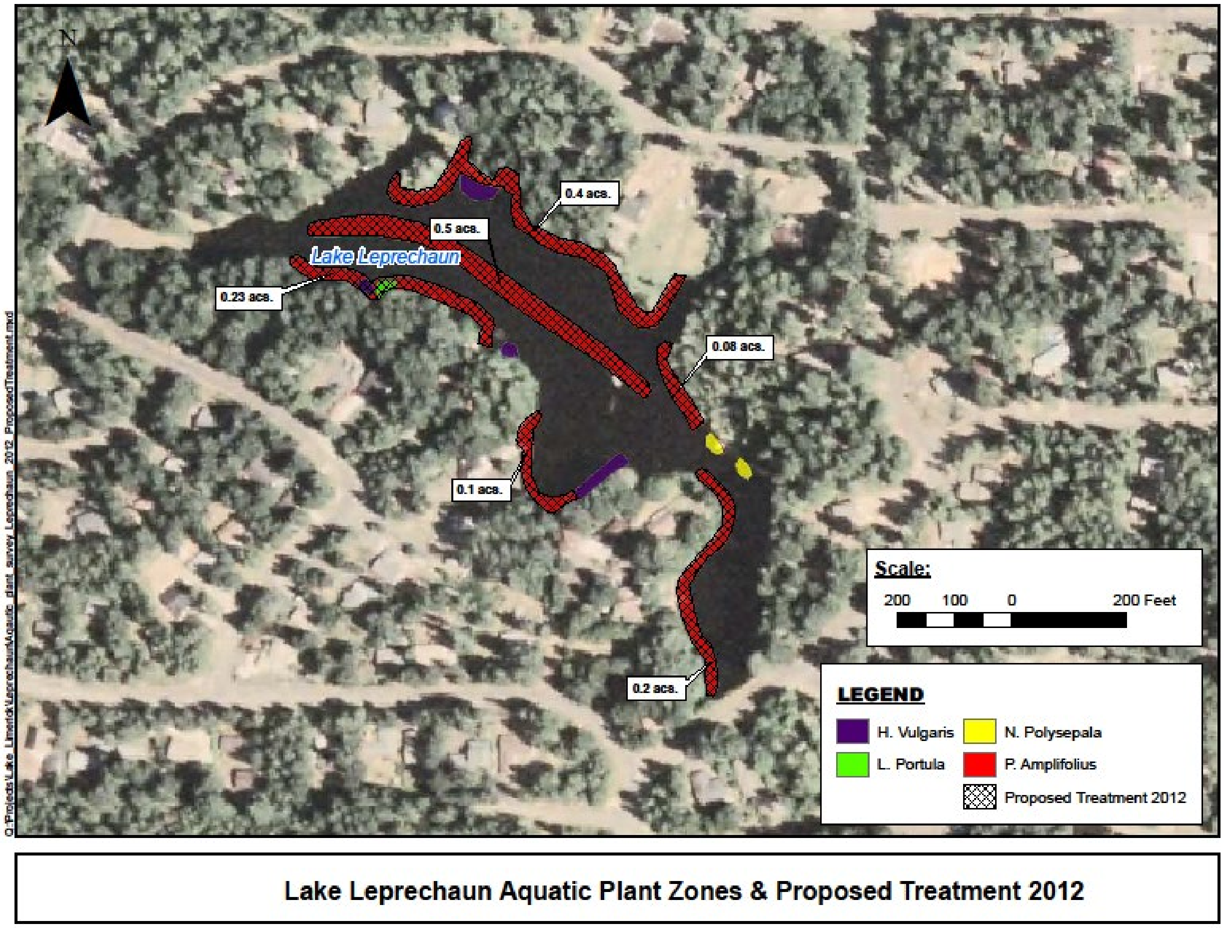


Figure 39 – Map of aquatic plant distribution in Lake Leprechaun in early summer 2012. Cross-hatching indicates the areas where treatment was proposed for summer 2012.

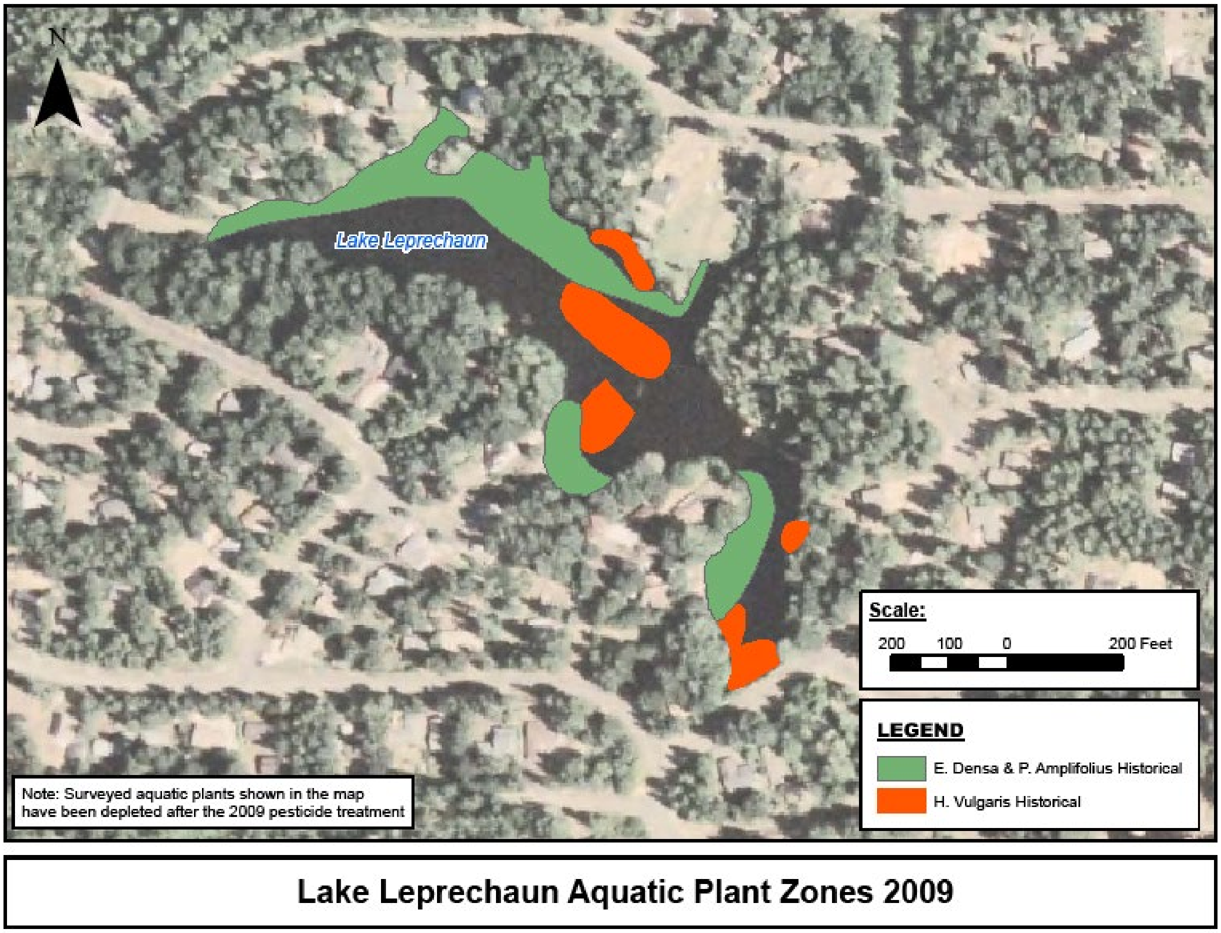


Figure 40 – Map of aquatic plant treatment locations in Lake Leprechaun in summer 2009.

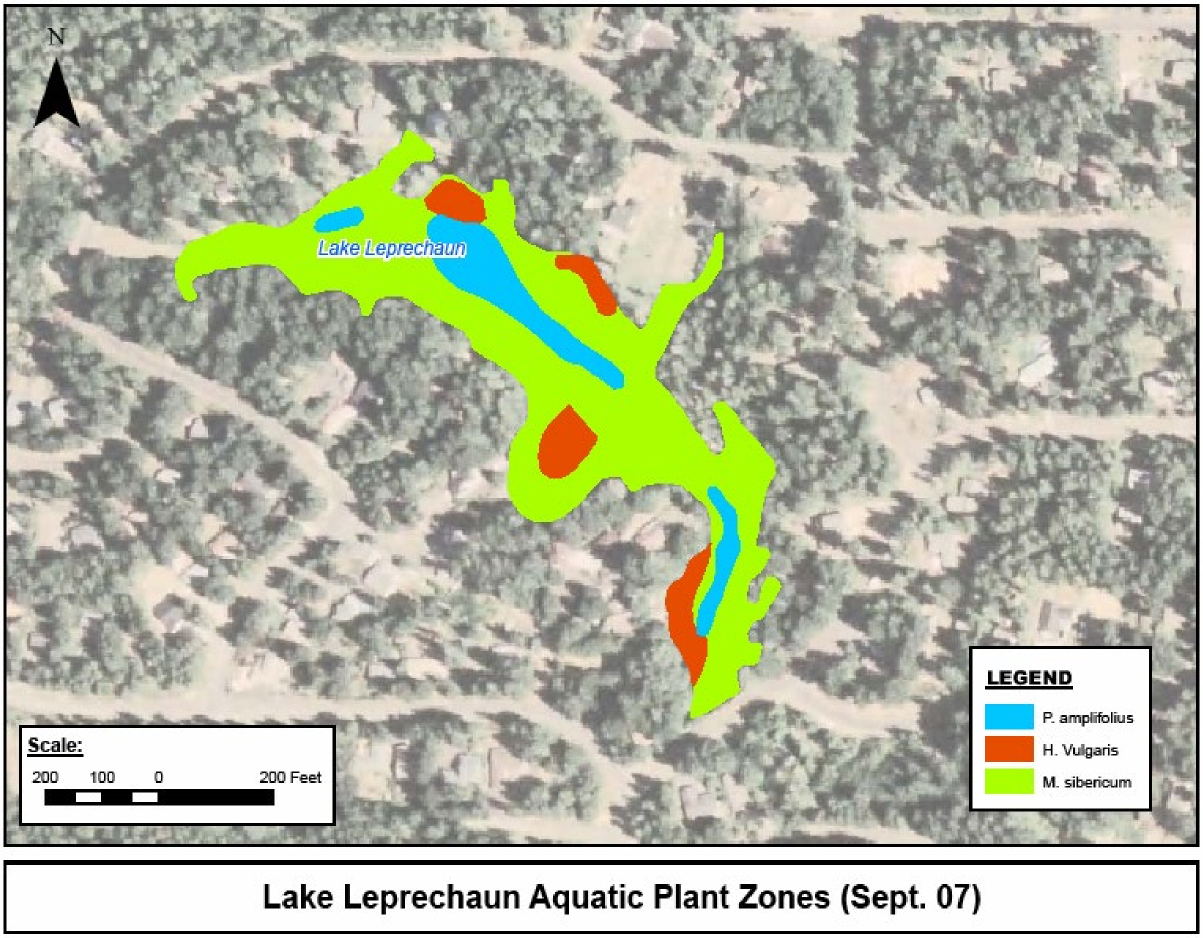


Figure 41 – Map of aquatic plant distribution in Lake Leprechaun in summer 2007.

Figure 42 – Lake Leprechaun level logger

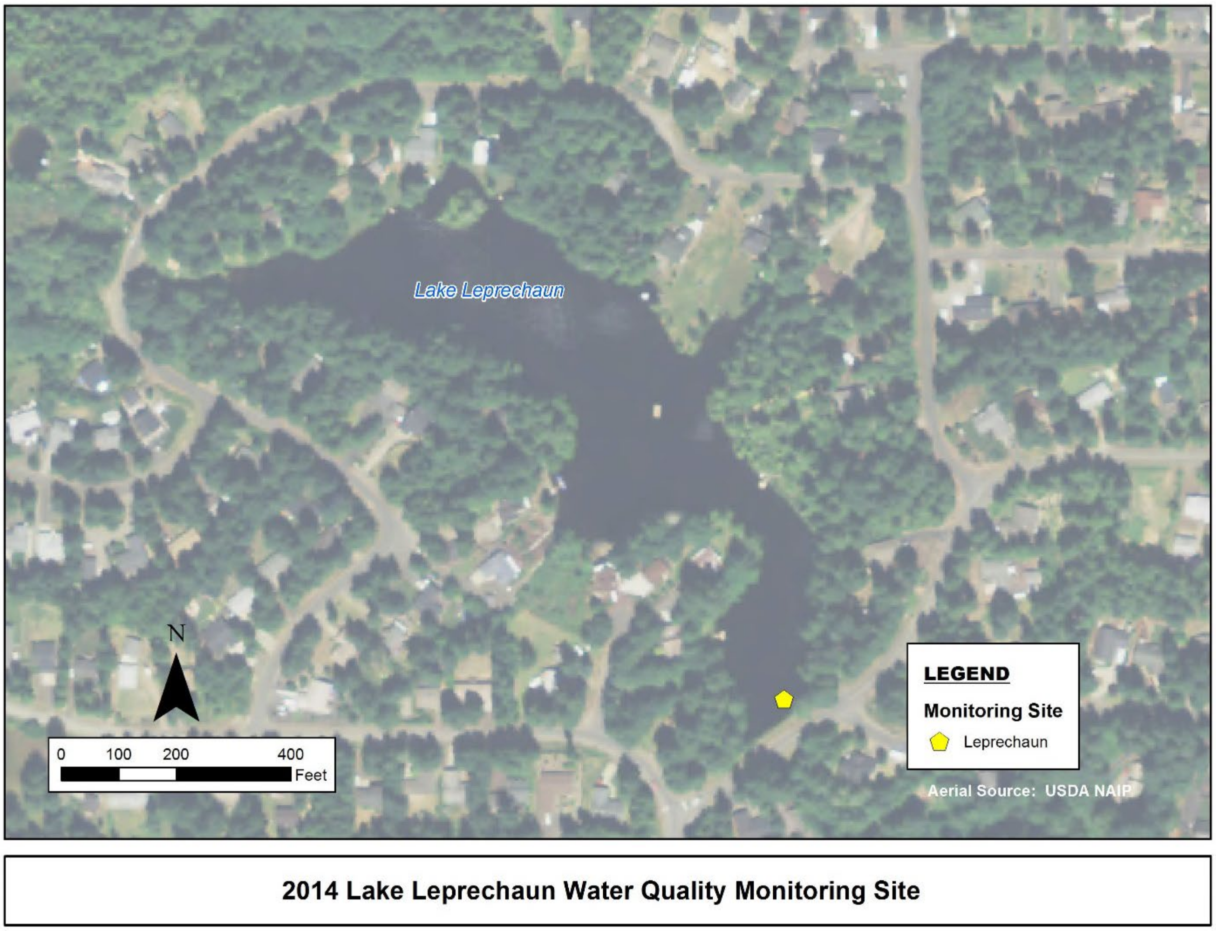


Figure 43 – Location of water quality monitoring site within Lake Leprechaun.