Technical Status and Monitoring Results Memorandum
For
Lake Limerick 2019

DECEMBER 2019

PREPARED FOR:

Lake Committee

Lake Limerick Country Club

PREPARED BY:

LAKE ADVOCATES

Scientifically Based Lake Restoration, Management & Protection

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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, Dave Kohler, and Larry Duvall for their assistance with this project. Joe Castelluccio (LLCC staff) continued to provide project assistance, delivering quality service, and working within stringent deadlines outline in the environmental permit.

1.0 INTRODUCTION

The continued goals for aquatic plant management in Lakes Limerick and Leprechaun during 2017 through 2019 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. In addition, post-dredging project monitoring of the benthic macroinvertebrate community in Cranberry Cove was completed in order to identify changes in community structure and function.

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-lake treatment of non-native and excessively dense aquatic plant growth was targeted for 2018 and 2019 as identified by the 2017 survey (Figure 2.2-1 and Figure 2.2-2). However, other monitoring requirements outlined in the Environmental Permit issued by Mason County for the lake dredging project were completed. Benthic macroinvertebrates were collected in September 2017 in order to monitor progress of potential effects of shifting sediment in the dredged area. This material was expected to be shifted from shallow areas during the high flow input in each of the coves to the deeper areas away from the shoreline.

A major component of 2016 lake management efforts were 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. As a result, benthic macroinvertebrate community characterization was completed before dredging and one-year following the project. Results of the post-dredging monitoring results are discussed in this report.

2.0 LAKE LIMERICK

2.1 DREDGING

During summer 2016, two shallow coves in Lake Limerick – King's Cove and Cranberry Cove– were dredged to remove sediment that had accumulated on the lake bottom (Figure 7-1). 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 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 7-2). 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 7-3). The MudCat loosened fine sediments with a cutter head and then suctioned the loose material into a pump intake (Figure 7-5), 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 7-4). The pump intake on the MudCat connected to a floating pipeline (Figure 7-4), 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 7-5, 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 7-6). 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 7-7). 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 7-8), 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 7-9).

When the dredging was conducted, the MudCat cut a channel in the sediment, removing the accumulated material (Figure 7-10). 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 7-11). As the material was removed from the newly cut channel, it exposed hard sediments (Figure 7-12), 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 7-13 and 7-14). Dredging increased the depth of the water throughout the northeastern portion of the cove, especially near the mouth of the inlet (Figure 7-15).

The gradient of the thalweg was also improved in Cranberry Cove (Figures 7-16 and 7-17). Water depth increased by approximately 2 feet along the length of the thalweg (Figure 7-16). In addition, dredging increased the depth of the water throughout the center of the cove, in particular near the Cranberry Creek inlet (Figure 6-17). 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 aesthetically pleasing.

The pre-dredging benthic macroinvertebrate samples were collected from three locations in Cranberry Cove (August 29, 2016). Three replicate benthic samples were collected from each location using a petite ponar dredge; one location nearest the mouth of Cranberry Creek, a second site located further into the deeper part of Cranberry Cove, and a third site near the deepest part of the cove. Benthic sampling results reflect pre-dredging conditions along the original thalweg from the creek mouth to the lake. Results from pre-dredging samples are compared against samples collected during years 1 (Year 2017), 3 (Year 2019), and 5 (Year 2021) following completion of dredging. This report compares pre-dredging samples to those benthic macroinvertebrate samples collected one-year following the dredging project.

Pre-Dredging Benthic Macroinvertebrate Samples

Density of benthic macroinvertebrate taxa at each of the locations was relatively similar among sites (Table 6-1). Three benthic taxa were dominant at each sampling location; the isopod *Caecidotia*, Oligochaeta (aquatic earthworms), and chironomid larvae (Table 6-2; midges). Taxa from these groups of benthic macroinvertebrates are tolerant of environmental conditions present in lake (lentic) environments like high oxygen demand in organically-enriched sediments (results in low dissolved oxygen), warm water temperature, and a large organic food base (unconsolidated sediment and abundant algae and plant material). Also, indicators for these types of conditions in the lake are the caddisflies (Trichoptera) collected in all three of the samples. *Agraylea* sp. *Oxyethira* sp. inhabit lakes throughout North America (Wiggins 1977) and were found in low density from Cranberry Cove samples. These taxa inhabit areas with aquatic plants and feed on filamentous algae by piercing and then emptying the contents. The fingernail clams (Sphaeriidae) were collected in all but one replicate sample from Cranberry Cove. This mollusk group is known to inhabit lakes throughout North America and is tolerant of a variety of lake water quality and habitat conditions that more sensitive taxa find stressful (Pennak 1978).

Post-Dredging Benthic Macroinvertebrate Samples

Benthic samples were collected from three locations the year following dredging in Cranberry Cove (October 7, 2017) and two years following the initial post-dredging sample collection (September 28, 2019). Three replicate benthic samples were collected from each location using a petite ponar dredge; one location nearest the mouth of Cranberry Creek, a second site located further into the deeper part of Cranberry Cove, and a third site near the deepest part of the cove. Benthic sampling results reflect pre-dredging conditions along the original thalweg from the creek mouth to the lake. Results from pre-dredging samples are being compared with the post-dredging activity during years 1, 3, and 5 following completion of dredging. Year 1 comparisons are based on results from 2017 sampling in Cranberry Cove and reported in Table 6-3 (general taxonomic groups) and Table 6-4 (Chironomidae taxa). Post-dredging (year 3) 2019 sample collection from Cranberry Cove is reported in Table 6-5 (general taxonomic groups) and in Table 6-6 (Chironomidae taxa).

Dominant taxa from the 2017 samples collected at locations in Cranberry Creek included the same as those from 2016 (e.g., *Caecidotia* and Oligochaeta) with Sphaeriidae (pea clams) and *Hyallela* sp. (sideswimmers) appearing as co-dominant. The pea clams require hard-bottomed surface to colonize and survive. The sideswimmers typically reside in open water and in locations where vertical habitat, like macrophytes, are established. The year following the dredging project has resulted in exposure of existing habitat and is one of the goals for improving ecosystem function for the benefit of fish use; including natural production of fish food and improvement of habitat for rearing, and spawning.

Benthic samples were collected again in 2019 (Year 3) following completion of dredging. Location for replicate samples remained the same as those collected before dredging in 2016 and immediately following dredging in 2017. Three replicate samples were collected in each of three locations in Cranberry Cove. Benthic community development continued to change from the previous sample collection in 2017 (Year 1). The upper site in Cranberry Cove had much lower aquatic invertebrate densities when compared with previous years. The lower site in Cranberry Cove had thicker, low-growing aquatic macrophytes that hosted a variety of Chironomidae taxa and aquatic worms. This was the primary substrate used by these large groups of aquatic invertebrates. In contrast, the upper site in Cranberry Cove had noticeably more gravel-sized substrate than in previous years with embedded sticks and twigs that serve as substrate for algae and aquatic invertebrates. The number of caddisfly taxa increased from 2017, but resembled the densities and varieties found at all sites from pre-dredging sampling. Portions of the aquatic invertebrate community returned to pre-dredging conditions based on individual taxa and densities. The pea clams were present in almost all replicate samples from the lower- to the upper Cranberry Cove locations indicating availability of hard-bottomed substrates; including those where the low-growing aquatic macrophytes were dominant in the lower collection site.

2.2 LEPRECHAUN AND LIMERICK AQUATIC PLANT SURVEY RESULTS

The results of the June 16, 2017 and conformation aquatic plant survey in September 28, 2017 for Lakes Leprechaun and Limerick are present below in Figures 2.2-1 and 2.2-2, respectfully. Also, shown on these figures are the 2018 proposed treatment area. In the December 2018 update report proposed future treatment areas for 2019 (Figure 2.2-3 and Figure 2.2-4), 2020, 2021, and 2022 will be presented.

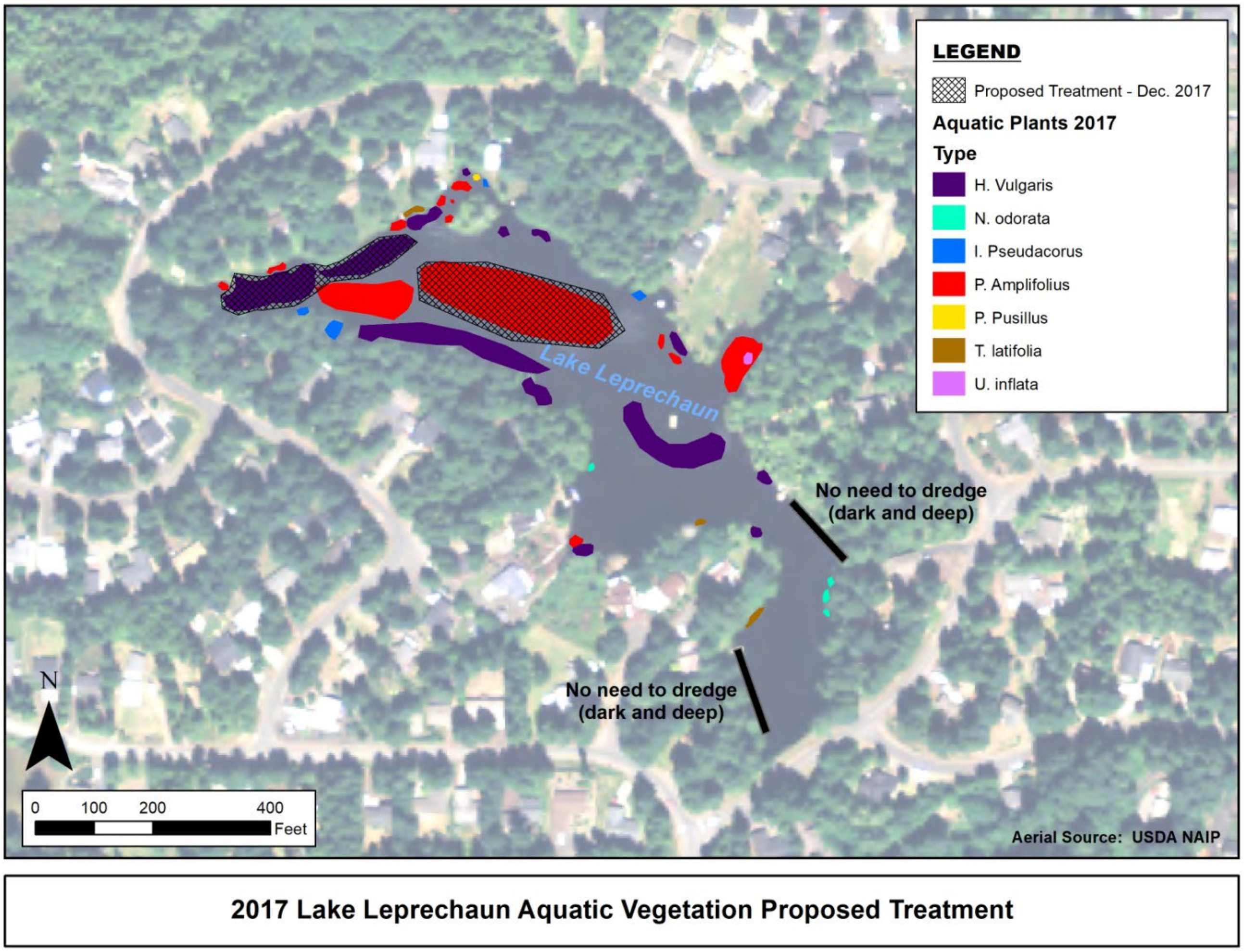


Figure 2.2-1. Aquatic plant 2017 map for Lake Leprechaun showing treatment areas for 2018.

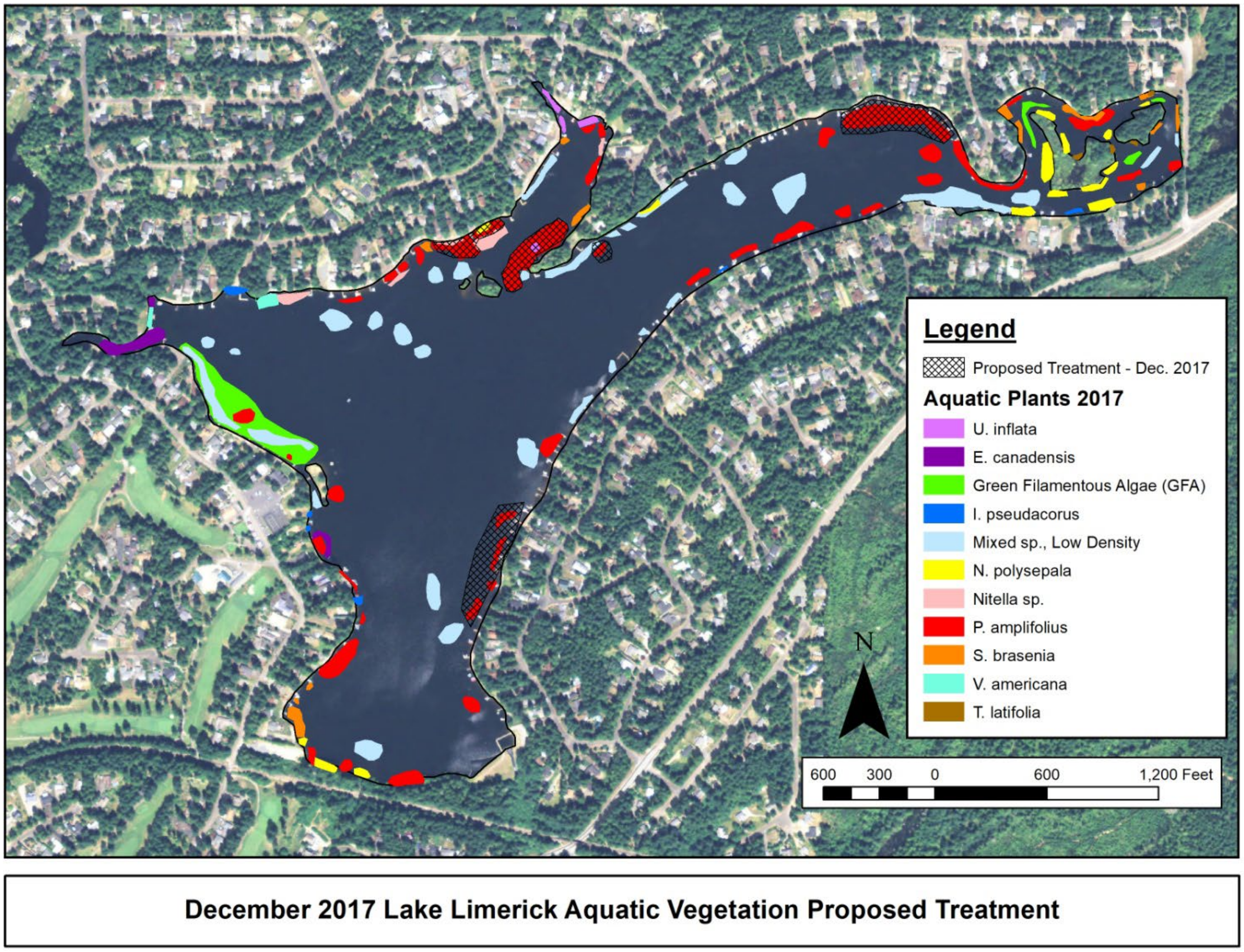


Figure 2.2-2. Aquatic plant 2017 map for Lake Limerick showing treatment areas for 2018.

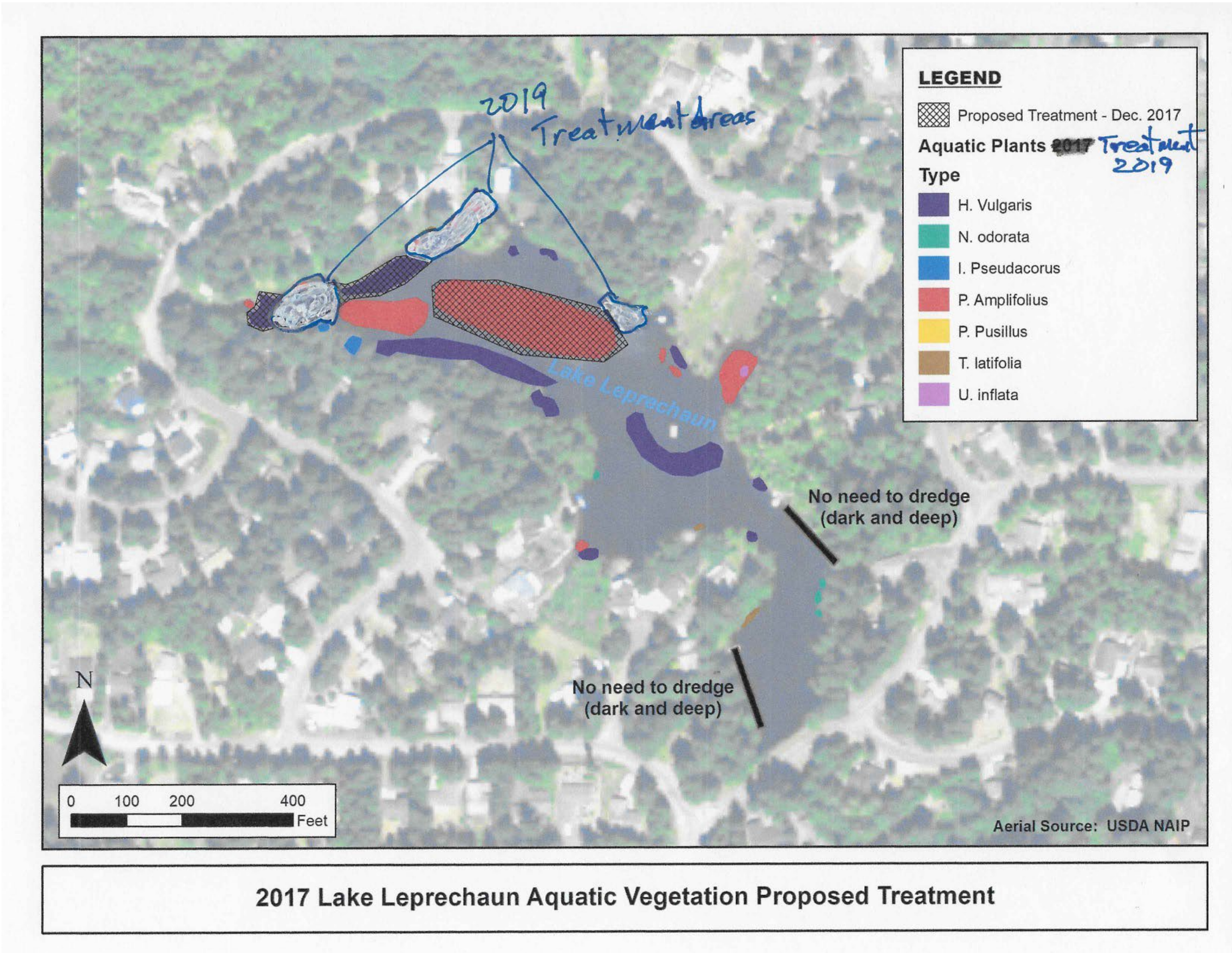
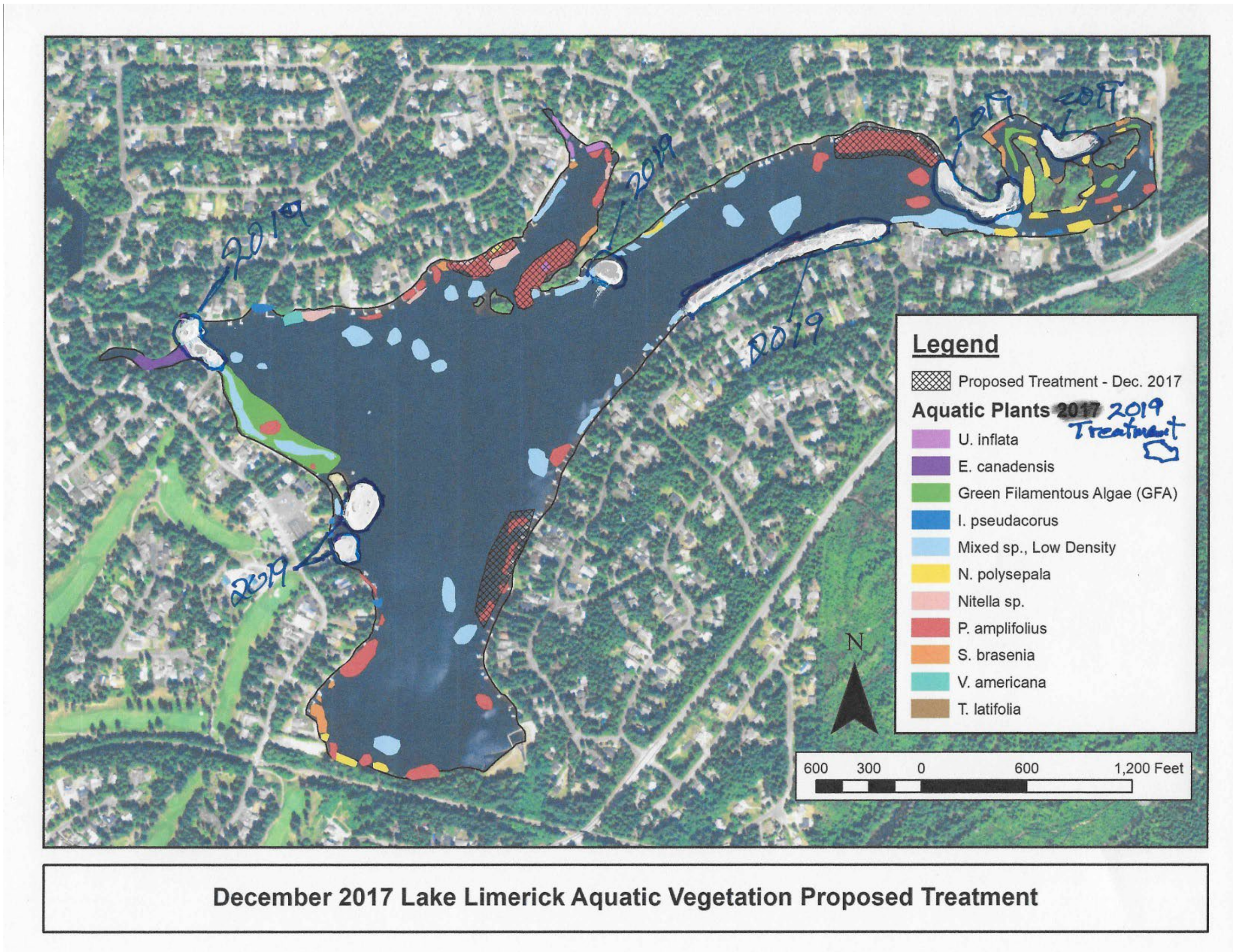


Figure 2.2-1. Aquatic plant 2017 map for Lake Leprechaun showing treatment areas for 2018.



December 2017 Lake Limerick Aquatic Vegetation Proposed Treatment

Figure 2.2-2. Aquatic plant 2017 map for Lake Limerick showing treatment areas for 2018.

2.3 WATER QUALITY MONITORING RESULTS

Lake water quality samples were taken on September 28, 2017. The general results indicate that the lake remains in a mesotrophic state, meaning that the lake is moderately productive but not overly enriched with nutrients. The target range to phosphorus for Lake Limerick is less than 25 µg/L. The indicator threshold for eutrophic over productive lake is 25 to 35 µgP/L. At that range the lake will start to show cyanobacteria dominance of the phytoplankton with chlorophyll *a* (photosynthetic pigment) at 7.5 µg/L or greater concentration. At that density there is a possibility for a potential HAB event (harmful algal bloom) that can also potentially produce toxins. Currently, the lake's phytoplankton is dominated by diatoms and green algae that are not blooms former nor do they produce algal toxins. However, we have are observed, over the last two decades, a significant increase in occurrence and density of green filamentous algae that originates on the sediment surface and within the macrophytes littoral plants (rooted shallow water plants). This is a direct result of increasing nutrient availability. The combination of this increasing production will also trend over time to potential HABs. Hence, now is the time to engage in direct and indirect steps to limit both phosphorus and nitrogen within the lake by controlling nutrient loading. General recommendations for this are presented in the recommendation Section 4. See Table 2.3-1 below for detailed results.

Table 2.3-1. Water quality results from September 2017 sampling.

Location	Total-Phosphorus, µg/L	Soluble Reactive-Phosphorus, µg/L	Chlorophyll a, µg/L	Relative rating H-high, M-moderate, L-low
Dam S1	21	1	5.3	M-H, L, M-H
Dam S2	22	1		M-H, L
Banbury	20	1	2.7	M-H, L, L-M
Tipperary	19	1	2.9	M-H, L, L-M

2.4 BENTHIC MACROINVERTEBRATES: COMPARISON OF RESULTS

Comparison of the taxa (species) list between 2016 and 2017 benthic macroinvertebrate monitoring samples documented taxa loss and taxa gain (Table 6-8). These Tables report presence and absence of species at each of the monitoring locations in Cranberry Creek (upper, middle, and lower) and report species presence during the 2016 and 2017 sampling events. An example shows that the snail, *Physa* sp., was absent during the 2016 sampling event at upper- and middle locations but appeared at the lower sampling location during both years.

Table 6-7 (general taxa) and Table 6-10 (Chironomidae) highlight change in the species list at each of the sampling locations in Cranberry Creek with shaded cells. These cells were further examined to determine if a species loss or gain occurred between the 2016 and 2017 sampling events. These changes in taxa composition were tallied and reported in Table 6-8 (general taxa) and Table 6-11 (Chironomidae). This information identifies when species richness increases and those responsible for the increase. An increase in species richness reflects improvement in substrate conditions by establishment of post-dredging habitat complexity and in the chemical environment (e.g., dissolved oxygen concentrations). A similar comparison of taxa change for each sampling location in Cranberry Cove was made between pre-dredging (2016) and year 3 (2019). Changes in general aquatic invertebrate taxa between the years 2016 and 2019 are reported in Table 6-9. Changes in the Chironomidae taxa between the years 2016 and 2019 are reported in Table 6-12.

In all sampling locations, species richness increased from the 2016 event to the 2017 event for both general taxa (Table 6-8) and the Chironomidae (Table 6-11). The overall number of general taxa increased at the upper-location by one and increased by four taxa at the lower sampling location (Table 6-8). The lower sampling location had greater depth of soft-, organic dredge material than did the upper site. Snails (*Physa* sp.) and caddisflies (*Triaenodes* sp.) appeared at sampled locations with hard-bottomed substrates. These taxa appeared at the upper and middle sites following dredging indicating presence of hard-bottom substrate that remained free of overlying organic deposits in contrast to pre-dredge conditions (Table 6-

5). Crayfish (Mystacidae) were captured at all sites during post-dredge sampling. Crayfish consume detritus (dead plant and animal material) from the bottom of lakes and streams preferring the larger particle sized organic material (CPOM: coarse particulate organic matter). The pre-dredge organic matter was much finer and represented a poor food-base for crayfish, as well, smothered hard-bottomed sediments for other taxa that eventually appeared following dredging and opportunity for benthic macroinvertebrate colonization.

Taxa that appeared in 2019 that were not collected in previous years were: Ephydridae (shore flies), *Hemerodromia* (dance flies), and *Polycentropus* (a caddisfly species that was not collected either before or following dredging). Shore flies and dance flies are members of a large, and diverse group of aquatic invertebrates known as Diptera (black flies, mosquitoes and midges). These aquatic invertebrates inhabit wetlands and other still water environments including shallow lake habitat. Both groups are fairly tolerant to stressful environmental conditions in the lake environment but are more sensitive species than most others in the Order Diptera. The other aquatic invertebrate not previously collected in 2016 or 2017 was *Polycentropus* (a lake-dwelling caddisfly). Appearance of this aquatic invertebrate species in 2019 collections indicates a maturing benthic community that is beginning to diversify in successive years and contains taxa sensitive to stressful environmental conditions. *Ferrissia* (a freshwater limpet) has been collected during all three sampling events (pre- and post-dredging). This limpet species inhabits northern lakes that have cool, well-oxygenated water and is an indicator of good water quality conditions.

Moving forward, it is recommended that periodic bathymetric surveys starting in 2019 be conducted in order to evaluate the effect of sediment translocation 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 sediment transport from the upstream shallow areas.

3.0 PERMIT STATUS

AquaTechnex is the administrator for the herbicide permit and that permit is good through 2022. For economic and liability efficiency Lake Advocates recommends that AquaTechnex continue to be the permit holder and administrator for the coming permit cycle.

4.0 CURRENT AND ON-GOING RECOMMENDATIONS

2019-2020 Recommendations:

- Staff from LLCC, representative of the Dam Committee, and Lake Advocates staff should continue to meet each spring to coordinate lake level monitoring and sampling efforts for the following season. Water quality sampling should continue twice a year late spring and late summer, to help provide the long-term data base for future reference.

- Aquatic plant mapping should be continued annually at both Lake Limerick and Lake Leprechaun in May to June and in late August to September to establish treatment zones, assess effectiveness of past treatment efforts and develop management plans for both lakes on a sustainable adaptive basis.

- Given that aquatic macrophytes have been successfully controlled in the past in both lakes, management efforts in moving forward should focus on very specific areas where treatment is needed in order to maintain and enhance aquatic habitat and recreational activities while tracking and exploring filamentous green algae reduction through nutrient limitation and other means (e.g., the bird sanctuary).

- Management efforts should continue to strive to establish and support balanced native 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 a dominant plant in the lakes in recent years).

    - It is important, however, to avoid over-controlling the growth of aquatic macrophytes, because filamentous green algae are more likely to emerge as dominant species and will result in increased nutrient recycling and reduction in aquatic and fisheries habitat as well as recreation. This could lead to cyanobacteria establishment, which would contribute to overall water quality decline and potentially result in HABs.

- 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. 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 and adversely impacting aquatic habitat and water quality due to excess density.

Plant mapping should continue to be conducted in both lakes during September in order to assess the effectiveness of the summer control activities and in order to plan for the efforts that will be needed in coming years.

- During 2019, water quality monitoring was conducted only in May-June and August-September. Water quality monitoring will continue to be more limited in scope in the ensuing years than in

2013-2015 because the lakes are in relatively good shape. Water quality data from late spring and late fall 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, phytoplankton samples were taken in 2019 as long as a surface algal scum was not suspected of being blue-green algae. To help track phytoplankton densities, chlorophyll *a* was sampled along with the phosphorus samples.

- Continued benthic macroinvertebrate monitoring should be conducted in 2021 during the index period for the Puget Lowland Ecoregion (July 1 through October 15) (Ecology 2014). A comparison of succeeding samples from Cranberry Cove will be made with the pre-/post-dredging results in this report. Data analysis will include indicator aquatic invertebrate taxa that identify stressors from physical habitat or water quality degradation. Biometrics normally used for analysis of biological condition will not be used because a Benthic Index of Biotic Integrity does not exist for lake and reservoirs in the Puget Lowland Ecoregion. Instead, simple expressions like number of species, function of notable species, and changes in the benthic community identified by appearance and disappearance of species are the primary indicators for interpreting results. The focus for analysis will continue to identify benthic macroinvertebrate response to removal of fine sediments from hard sediments, recolonization of hard sediments, and availability of food base following dredging reflected in the benthic community results. The benthic macroinvertebrate community following dredging is examined for suitability as food for resident fish in Lake Limerick.

- 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 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.
    - Also, assessment of dredging alternatives should be considered. Specifically, nutrient and sediment loading prevention via sedimentation pond(s) on Cranberry Creek before it enters the lake.

- LLCC should actively promote septic tank management and education to reduce nutrient loading the lakes as well as landscaping education to enhance shoreline protection (including waterfowl management) and nutrient buffering.

- Controlling sediment and nutrient inflow from Cranberry Creek
    - Alternatives include:
        - Extensive watershed management,
        - Dredging every 2 to 5 years,

        - Interception of sediment and potential nutrients via a sedimentation pond targeting Cranberry Creek high flow events.

- Sediment removal from portions of Lake Leprechaun
    - Alternatives include:
        - Hydraulic dredging,
        - Lake draw-down for mechanical sediment removal.

- Bird Sanctuary sediment removal and/or nutrient inactivation
    - Alternatives include:
        - Hydraulic dredging without nutrient inactivation,
        - Hydraulic dredging followed by nutrient inactivation,
        - Nutrient inactivation,
        - Rotovation followed by nutrient inactivation,
        - Harvesting, followed by mechanical dredging and nutrient inactivation.

Additional detail for sediment control and dredging recommendations included here is reported in the Technical Memorandum (November 23, 2018) from Lake Advocates. The focus of technical discussion in this Memorandum was prioritizing of potential management activities for lake beneficial use sustainability.

5.0 REFERENCES

Ecology (Washington Department of Ecology). 2014. Quality Assurance Project Plan for Status and Trends Monitoring of Small Streams in the Puget Lowlands Ecoregion. Publication Number 14-10-054. Washington Department of Ecology, Olympia, WA. 62p.

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

Pennak, R.W. 1978. Fresh-Water Invertebrates of the United States, 2nd Ed. John Wiley and Sons, Inc. New York, NY. 803p.

Wiggins, G.B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera). University of Toronto Press, Toronto. 401p.

6.0 BENTHIC DATA TABLES

Table 6-1. Benthic sampling results from three locations in Cranberry Cove before dredging (08/29/2016).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	47^{o} 17' 12" N			47^{o} 17' 00" N			47^{o} 17' 12" N		
Longitude	123^{0} 03' 18" W			123^{0} 03' 15" W			123^{0} 03' 13" W		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Acari		1					1		
Amphipoda			33	1	4	2	1	7	3
Hyalella	1	4					1		
Caecidotia	49	77	19	8	104	56	89	37	16
Cladocera		1	1				1		
Copepoda		2	4	1	4		1		
Hirudinea		1		1	1			1	
Hydra			1						
Ferrissia		5	1	7	2	1		1	1
Gyraulus		10	3	1	1	1	2		
Physa								2	
Sphaeriidae	1	3		48	9	18	4	16	4
Pisidium							2		
Nematoda	1	2	10	3	6	6	3	15	11
Oligochaeta	14	81	49	9	32	10	111	59	25
Ostracoda		2	1		1	1	17	6	2
Turbellaria		3		3	4			1	
Coenagrion					1				
Agraylea larva		6	2	3	1		5	9	
Agraylea pupa							4	5	
Oxyethira larva							1	1	
Oxyethira pupa				1					
Leptoceridae Pupa					1				
Neotopsyche			2		1				
Sialis sp.			1		6		1	1	
Ceratopogoninae		2	3		5		5	3	5
Chironomidae larva	8	89	161	65	87	15	128	46	32
Chironomidae pupa		2			1		1		
Total Density	**74**	**291**	**291**	**151**	**271**	**110**	**378**	**210**	**99**
Additional Notes: Mollusc shell had decalicified, Amphipod genus possibly *Hyallela* sp., Oligochaeta bodies damaged. Whole samples sorted.									

Table 6-2. Chironomidae identified from pre-dredging replicate samples from Cranberry Cove (08/29/2016).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	47^{o} 17' 12" N			47^{o} 17' 00" N			47^{o} 17' 12" N		
Longitude	123^{0} 03' 18" W			123^{0} 03' 15" W			123^{0} 03' 13" W		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Chironomus			6	2			48	21	19
Cladopelma		1	6	1	3		4	1	
Clinotanypus				1	10	3	2	1	1
Cricotopus			7		8			1	
Dicrotendipes		53	46	3	9	1	7	4	2
Microtendipes pedellus grp.		1	1			1	2	1	
Nanocladius			2		4				
Pagastiella							1		
Parachironomus		1	1		2				
Paratanytarsus		3	4		1				
Phaenopsectra					1		1		
Polypedilum	4	16	47	5	12	2	8	4	1
Procladius	5	6	29		32	5	39	7	3
Psectrocladius			3						
Pseudochironomus		1							
Tanytarsus		1							1
Thienemannimyia complex			1	1				2	
Total Density	**9**	**83**	**153**	**13**	**82**	**12**	**112**	**42**	**27**

Table 6-3. Benthic sampling results from three locations in Cranberry Cove after dredging (10/07/2017).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	47°17'12" N			47°17'00" N			47°17'12" N		
Longitude	123°03'18" W			123°03'15" W			123°03'13" W		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Acari	2	1	5	1	2	3			
Crangonyx					2				
Hyalella	9	14	16	9	3	15	26	35	58
Caecidotea	15	17	24	42	28	4	46	111	109
Cladocera		1		1	1		5	17	15
Cladocera				1			1		
Copepoda	2	8	9	1			7	6	1
Hirudinea		1	1	1		1			1
Hydra	10	6	4	36	6	85	3		
Ferrissia					1	16	2	3	2
Gyraulus	1			8	1	9	9	15	4
Menetus			2				1	3	
Physa	3			1		1		1	
Sphaeriidae	9	9	19	26	13	5	10	81	76
Nematoda								1	
Oligochaeta	337	203	144	170	39	140	295	162	121
Ostracoda		2	4	1					
Turbellaria	14	21	92	8		5	31	19	20
Coenagrionidae	1								
Coenagrion/Enallagma								1	
Agraylea Larva	26	15	34	9	1	5			
Oxyethira larva	14	90	133	2			1	3	
Oxyethira pupa	17	110	45						
Mystacidea	2	1		3	2	3	22	41	41
Triaenodes			4	1					
Ceratopogoninae	5	7	2	4	3	4	21	10	3
Empididae									1
Chironomidae larva	50	31	27	200	34	237	85	96	81
Chironomidae pupa	1				1				
Total Density	**515**	**537**	**565**	**525**	**137**	**533**	**565**	**605**	**533**

Table 6-4. Chironomidae identified from post-dredging replicate samples from Cranberry Cove (10/07/2017).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	**47º17'12" N**			**47º17'00" N**			**47º17'12" N**		
Longitude	**123º03'18" W**			**123º03'15" W**			**123º03'13" W**		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Chironomus				2	1		1	2	1
Cladopelma	5			6	2		3	2	
Cladotanytarsus	1						1		
Clinotanypus			1						
Cricotopus		1							
Cricotopusbicinctus grp		1	1						
Cryptochironomus			1		1				
Dicrotendipes	70	86	66	172	21	217	41	21	12
Guttipelopia									2
Labrundinia						1			
Microtendipespedellus grp.						1	2	1	2
Nanocladius				1					
Pagastiella		2							
Parachironomus									
Paratanytarsus		1		2		1			
Phaenopsectra									
Polypedilum	1	1		1	1	4		2	
Procladius	3	2	11	3	10	3	4	3	9
Psectrocladius				1					
Pseudochironomus									
Tanytarsus	1	1		2		3		1	
Thienemannimyia complex						1			
Total Density	**81**	**95**	**80**	**190**	**36**	**231**	**52**	**32**	**26**

Table 6-5. Benthic sampling results from three locations in Cranberry Cove after dredging (09/28/2019).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	47º17'12" N			47º17'00" N			47º17'12" N		
Longitude	123º03'18" W			123º03'15" W			123º03'13" W		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Acari		4	1			2	1	1	
Amphipoda	2	7	1	5	25	9	23	40	14
Caecidotea	4	8	11	4	9	17	5	1	3
Hirudinea		1				4	1		1
Hydra		1	1	1		1	8	15	18
Ferrissia				3	2	7			
Gyraulus					1	1	17	4	5
Physa						1	1	2	4
Sphaeriidae			1	4	6	2	8	11	2
Nematoda	2	2	8	1		1	1		
Oligochaeta	2	10		1	4	38	40	43	116
Ostracoda	1	5		3	6	8	7	28	1
Turbellaria		3			2		5	6	10
Coenagrionidae						1			
Sialis			4						
Agraylea Larva	2	1	9		3	14		7	6
Orthotrichia		6	3			4	5	1	
Oxyethira larva		1					2		
Oxyethira pupa			1		1	1			1
Oecetis									1
Triaenodes							3	5	2
Polycentropus					1	1			1
Ceratopogoninae		1			2	2	2	2	1
Chironomidae larva	24	80	62	13	88	398	208	335	362
Chironomidae pupa		2	2		1	3	2	4	1
Hemerodromia								9	
Ephydridae pupa					1				
Total Density	**35**	**132**	**104**	**35**	**151**	**515**	**339**	**505**	**549**

Table 6-6. Chironomidae identified from post-dredging replicate samples from Cranberry Cove (09/28/2019).

	Cranberry Creek (Upper Location)			Cranberry Creek (Middle Location)			Cranberry Creek (Lower Location)		
Latitude	**47º17'12" N**			**47º17'00" N**			**47º17'12" N**		
Longitude	**123º03'18" W**			**123º03'15" W**			**123º03'13" W**		
Sample Replicate	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Ablabesmyia							1	5	4
Chironomus	3		1	2	1	10	6	1	4
Cladopelma	2	1	4	1	2	3			
Cladotanytarsus									
Clinotanypus			2		1				
Corynoneura		7	2				1		
Cricotopus									
Cricotopusbicinctus grp									
Cryptochironomus									
Dicrotendipes	3	36	38	3	50	288	112	291	263
Guttipelopia									
Labrundinia	6		1	1				1	
Microtendipes pedellus grp.					4	11	28		10
Nanocladius		1	1		1	3	1	4	
Nilotanypus					8				
Pagastiella									
Parachironomus									
Paratanytarsus		8	5		2	2			2
Phaenopsectra									3
Polypedilum	2	9	1	2	3		6		
Procladius	5	8	3	4	5	6	9	2	8
Psectrocladius					1		2	6	2
Pseudochironomus									
Tanytarsus	2	1				5	19	11	31
Thienemanniella					1	1		1	
Thienemannimyia complex						15	2	2	
Total Density	**23**	**71**	**58**	**13**	**79**	**344**	**187**	**319**	**327**

Table 6-7. Benthic taxa comparison between 2016, 2017 and 2019 sampling results.

Taxon	Collection Year								
	2016	2017	2019	2016	2017	2019	2016	2017	2019
	Cranberry Cr (Upper)			Cranberry Cr (Middle)			Cranberry Cr (Lower)		
Acari	X	X	X	X	X	X	X		X
Amphipoda			X			X			X
Crangonyx					X				
Hyalella	X	X			X		X	X	
Caecidotea	X	X	X	X	X	X	X	X	X
Cladocera	X	X		X	X		X	X	
Copepoda	X	X		X	X		X	X	
Hirudinea	X	X	X	X	X	X	X	X	X
Hydra	X	X	X		X	X		X	X
Ferrissia	X			X	X	X	X	X	
Gyraulus	X	X		X	X	X	X	X	X
Menetus		X					X	X	
Physa		X			X	X	X	X	X
Sphaeriidae	X	X	X	X	X	X	X	X	X
Nematoda	X		X	X		X	X	X	X
Oligochaeta	X	X	X	X	X	X	X	X	X
Ostracoda	X	X	X	X	X	X	X		X
Turbellaria	X	X	X	X	X	X	X	X	X
Coenagrionidae		X				X			
Coenagrion/Enallagma				X				X	
Agraylea Larva	X	X	X	X	X	X	X		X
Oxyethira larva		X	X		X		X	X	X
Oxyethira pupa		X	X	X		X			X
Polycentropus						X			X
Mystacidae		X			X			X	
Triaenodes		X			X				X
Ceratopogoninae	X	X	X	X	X	X	X	X	X
Empididae								X	
Hemerodromia									X
Ephydridae pupa						X			
Chironomidae larva	X	X	X	X	X	X	X	X	X
Chironomidae pupa	X	X	X	X		X			X

Table 6-8. Relative change in number of taxa from Cranberry Creek sample locations (2016/2017).

Direction of Change	Collection Year		
	2016 → 2017	2016 → 2017	2016 → 2017
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	3	6	5
Decreasing # of Taxa	2	3	1
Net Taxa Gain	+1	+3	+4

Table 6-9. Relative change in number of taxa from Cranberry Creek sample locations (2016/2019).

Direction of Change	Collection Year		
	2016 → 2019	2016 → 2019	2016 → 2019
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	1	5	3
Decreasing # of Taxa	5	3	5
Net Taxa Gain	-4	+2	-2

Table 6-10. Comparison of Chironomidae taxa in Cranberry Creek between 2016, 2017 and 2019 sampling results.

Taxon	Collection Year								
	2016	2017	2019	2016	2017	2019	2016	2017	2019
	Cranberry Cr (Upper)			Cranberry Cr (Middle)			Cranberry Cr (Lower)		
Ablabesmyia									X
Chironomus	X		X	X	X	X	X	X	X
Cladopelma	X	X	X	X	X	X	X	X	
Cladotanytarsus		X						X	
Clinotanypus		X	X	X		X	X		
Corynoneura			X						X
Cricotopus	X	X		X			X		
Cricotopusbicinctus grp		X							
Cryptochironomus		X			X				
Dicrotendipes	X	X	X	X	X	X	X	X	X
Guttipelopia			X			X		X	
Labrundinia			X		X	X			X
Microtendipes pedellus grp.	X			X	X	X	X	X	X
Nanocladius	X		X	X	X	X			X
Pagastiella		X					X		
Parachironomus	X			X					
Paratanytarsus	X	X	X	X	X	X			X
Phaenopsectra				X			X		X
Polypedilum	X	X	X	X	X	X	X	X	X
Procladius	X	X	X	X	X	X	X	X	X
Psectrocladius	X				X	X			X
Pseudochironomus	X								
Tanytarsus	X	X	X		X	X	X	X	X
Thienemanniella						X			X
Thienemannimyia complex	X			X	X	X	X		X

Table 6-11. Relative change in number of Chironomidae taxa from Cranberry Creek sample locations (2016/2017).

Direction of Change	Collection Year		
	2016 → 2017	2016 → 2017	2016 → 2017
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	5	4	5
Decreasing # of Taxa	5	3	1
Net Taxa Gain	0	+1	+4

Table 6-12. Relative change in number of Chironomidae taxa from Cranberry Creek sample locations (2016/2019).

Direction of Change	Collection Year		
	2016 → 2019	2016 → 2019	2016 → 2019
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	3	4	5
Decreasing # of Taxa	6	3	4
Net Taxa Gain	-3	+1	+1

7.0 DREDGING FIGURES

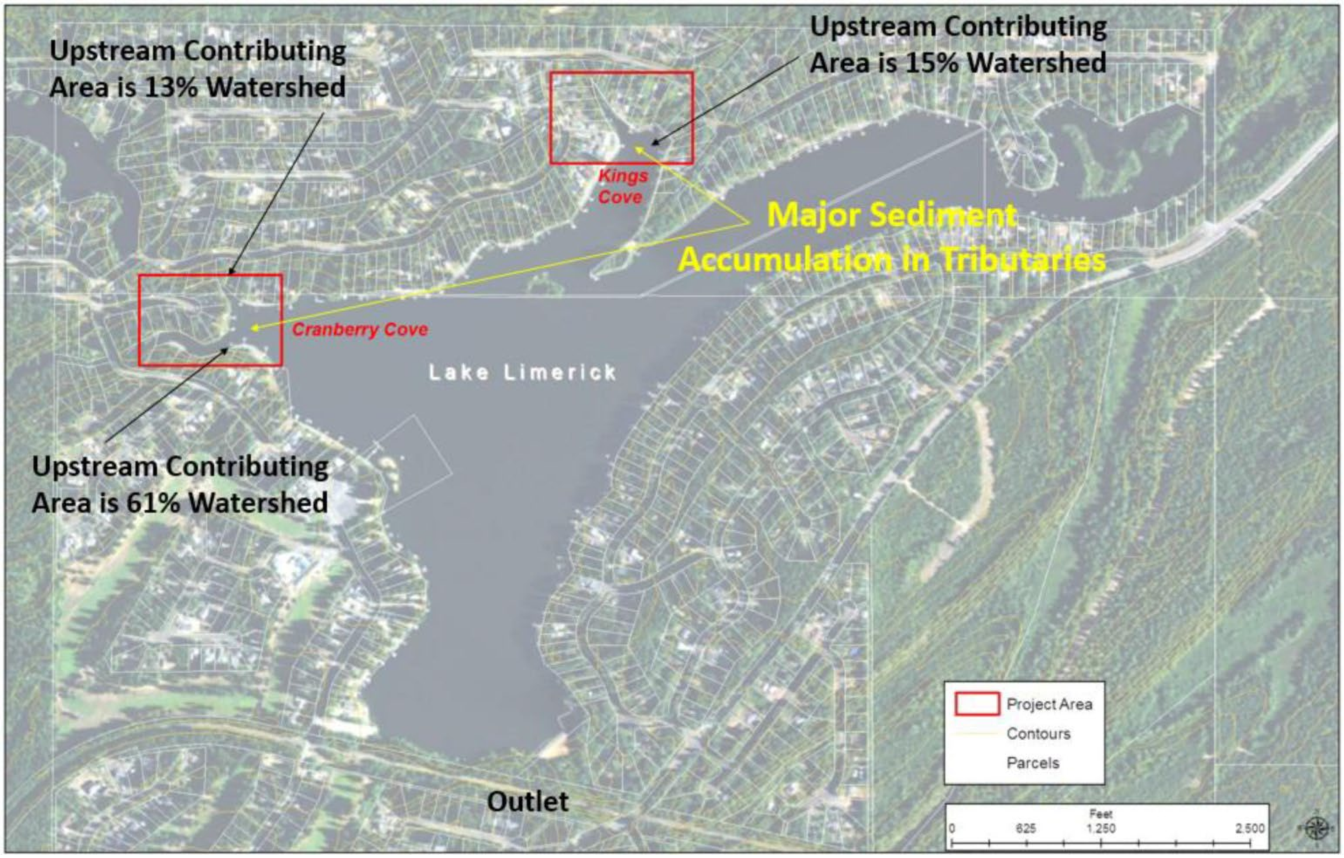


Figure 7-1 – Locations for dredging in Lake Limerick

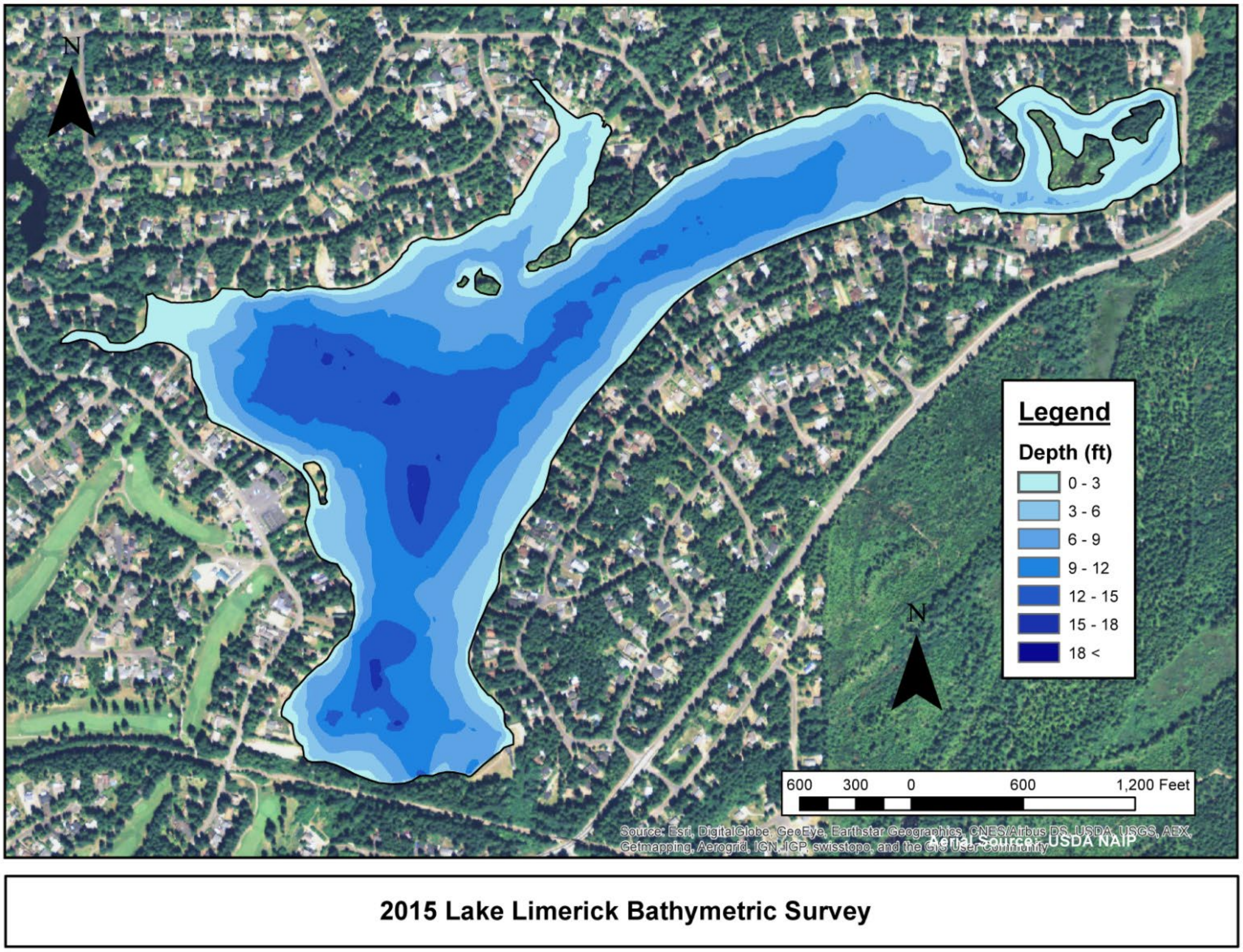


Figure 7-2 – Bathymetry of Lake Limerick. Bathymetric data collected in September 11th, 2015 survey.

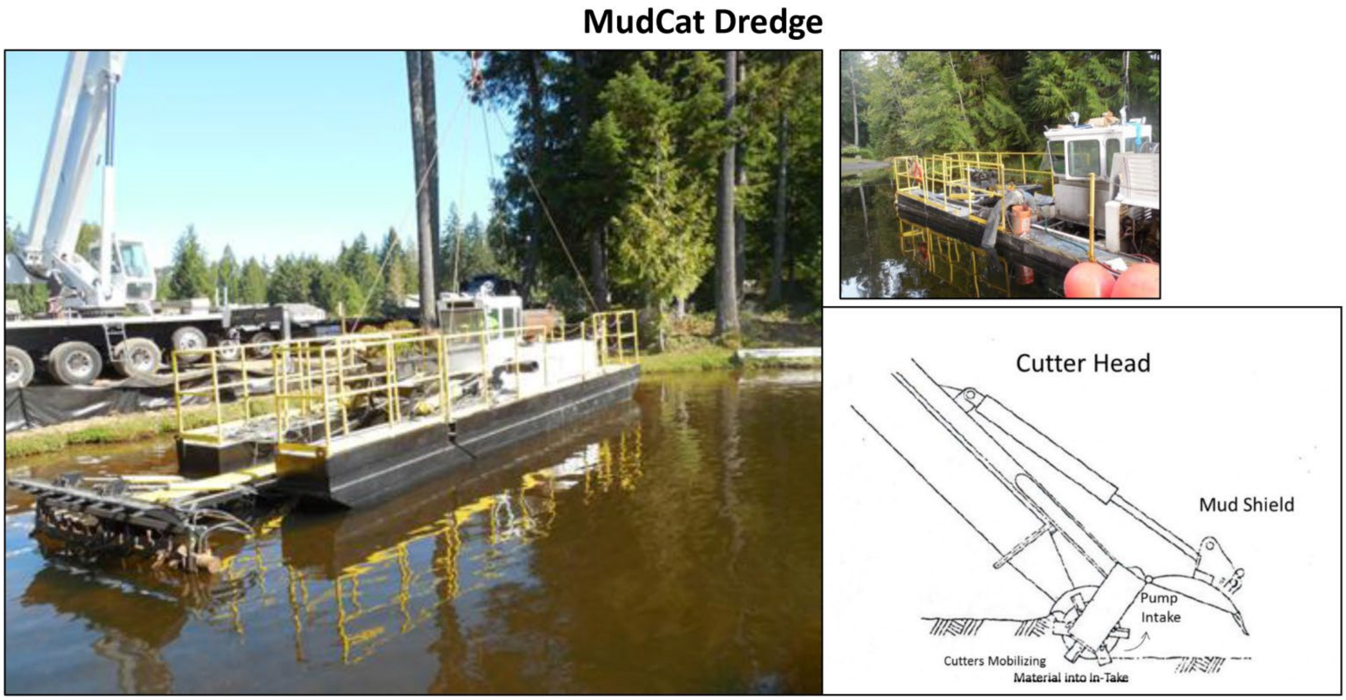


Figure 7-3 – Equipment used to conduct dredging in Lake Limerick

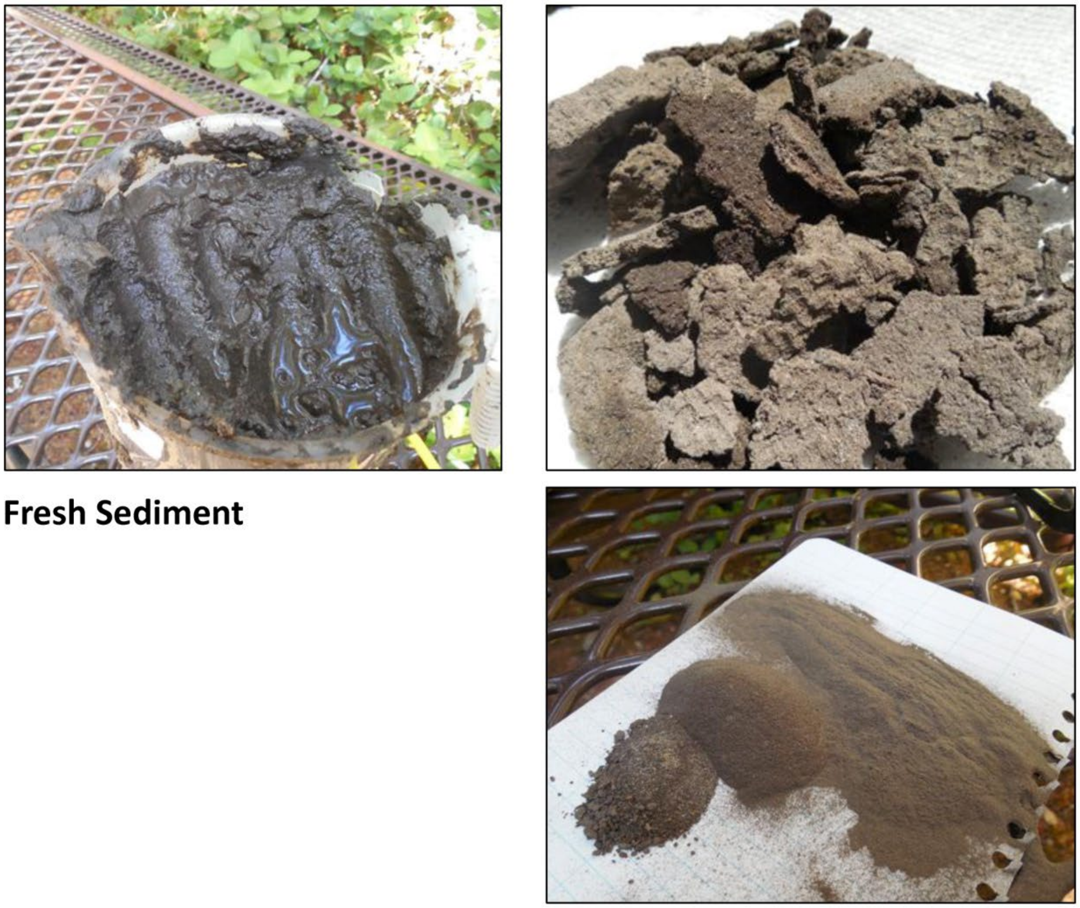
Figure 7-4 – Dredging pipeline

Figure 7-5– Injection of flocculent into dredge material

Figure 7-6– De-watering bags

Figure 7-7 - De-watering of dredge material

Figure 7-8 – De-watered material



De-Watered Sediment

Fresh Sediment

Dried Sediment

Figure 7-9 – Examples of sediment during stages of the de-watering process

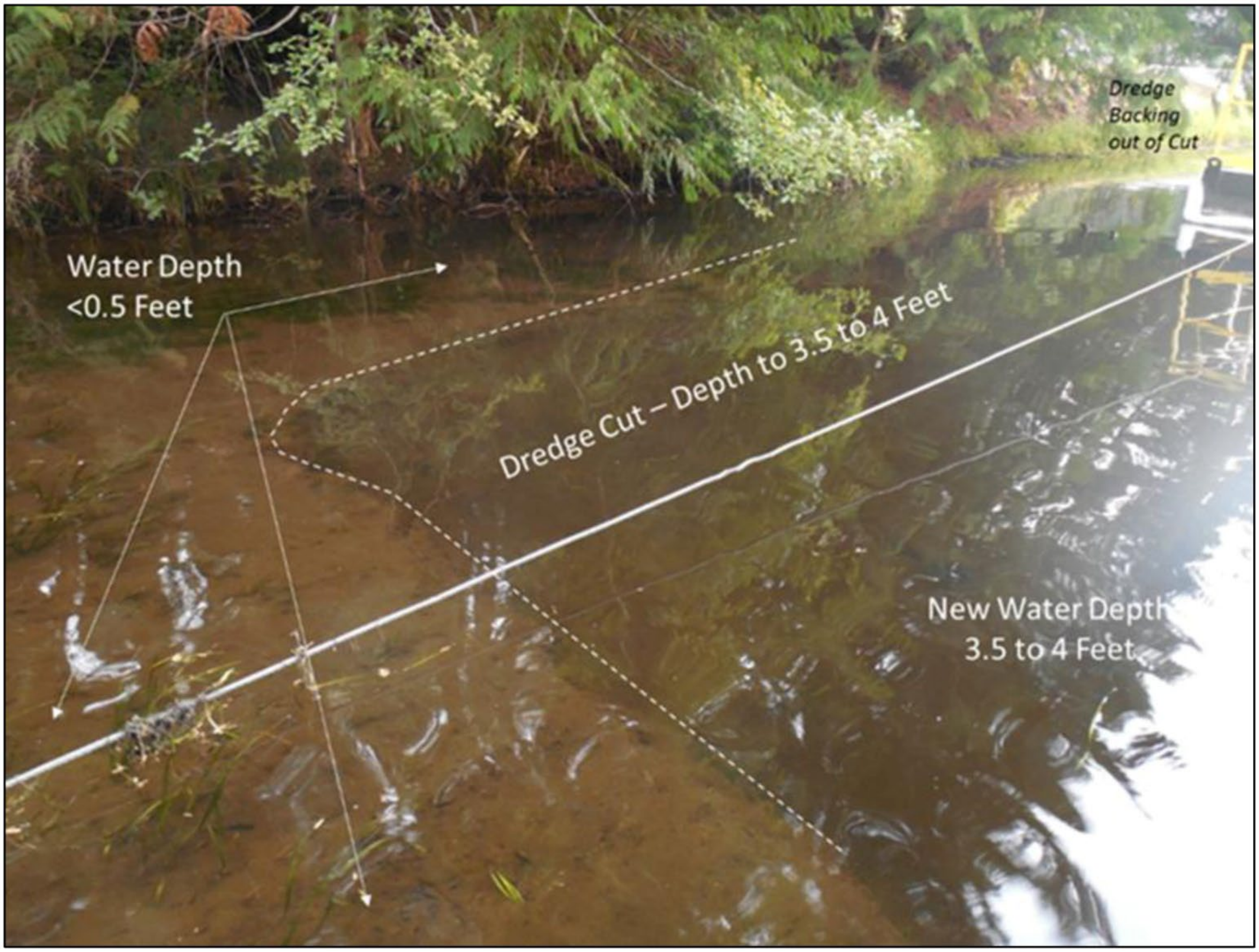


Figure 7-10 – Sloughing in dredged channel

Figure 7-11 – Exposure of hard sediments as a result of dredging

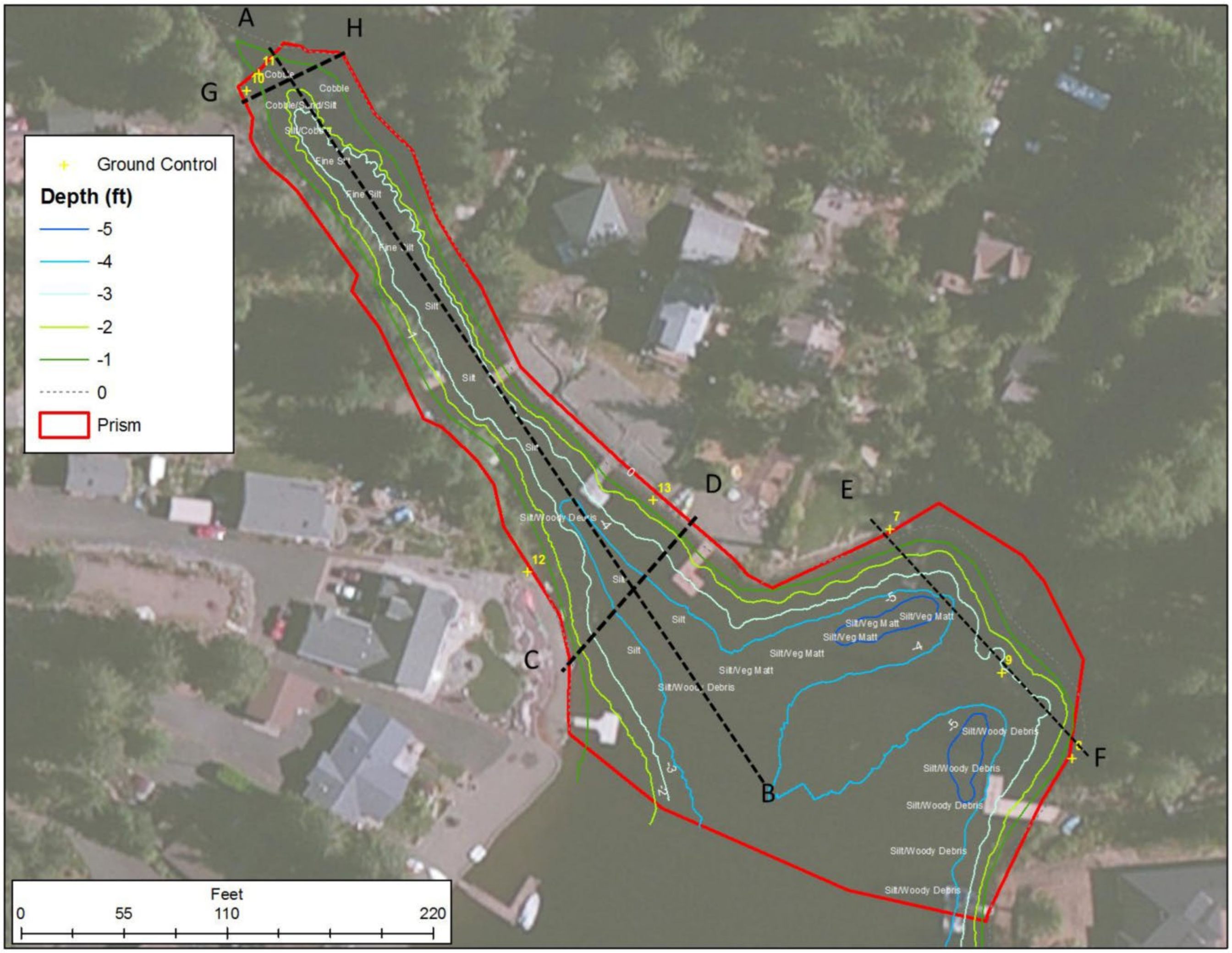


Figure 7-12 – Dredging transects in King's Cove

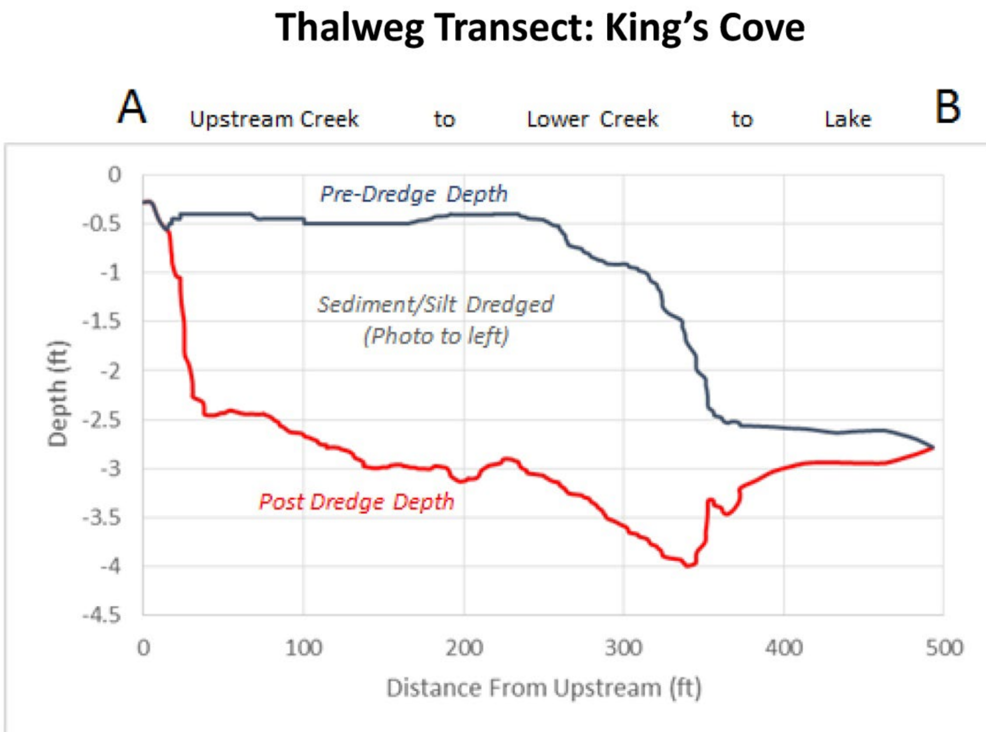


Figure 7-13 – Thalweg gradient for inflows into King's Cove, before and after dredging

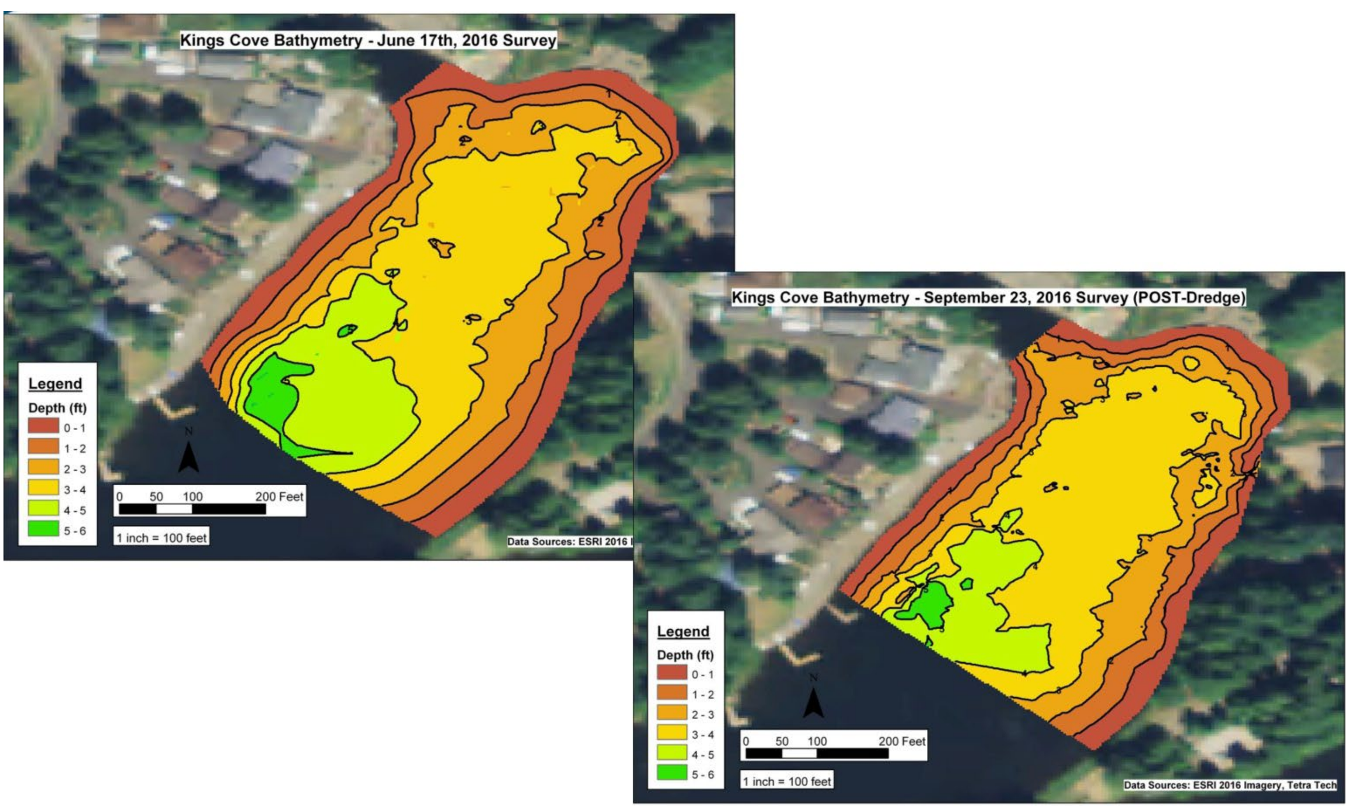


Figure 7-14 – King's Cove bathymetry before and after dredging

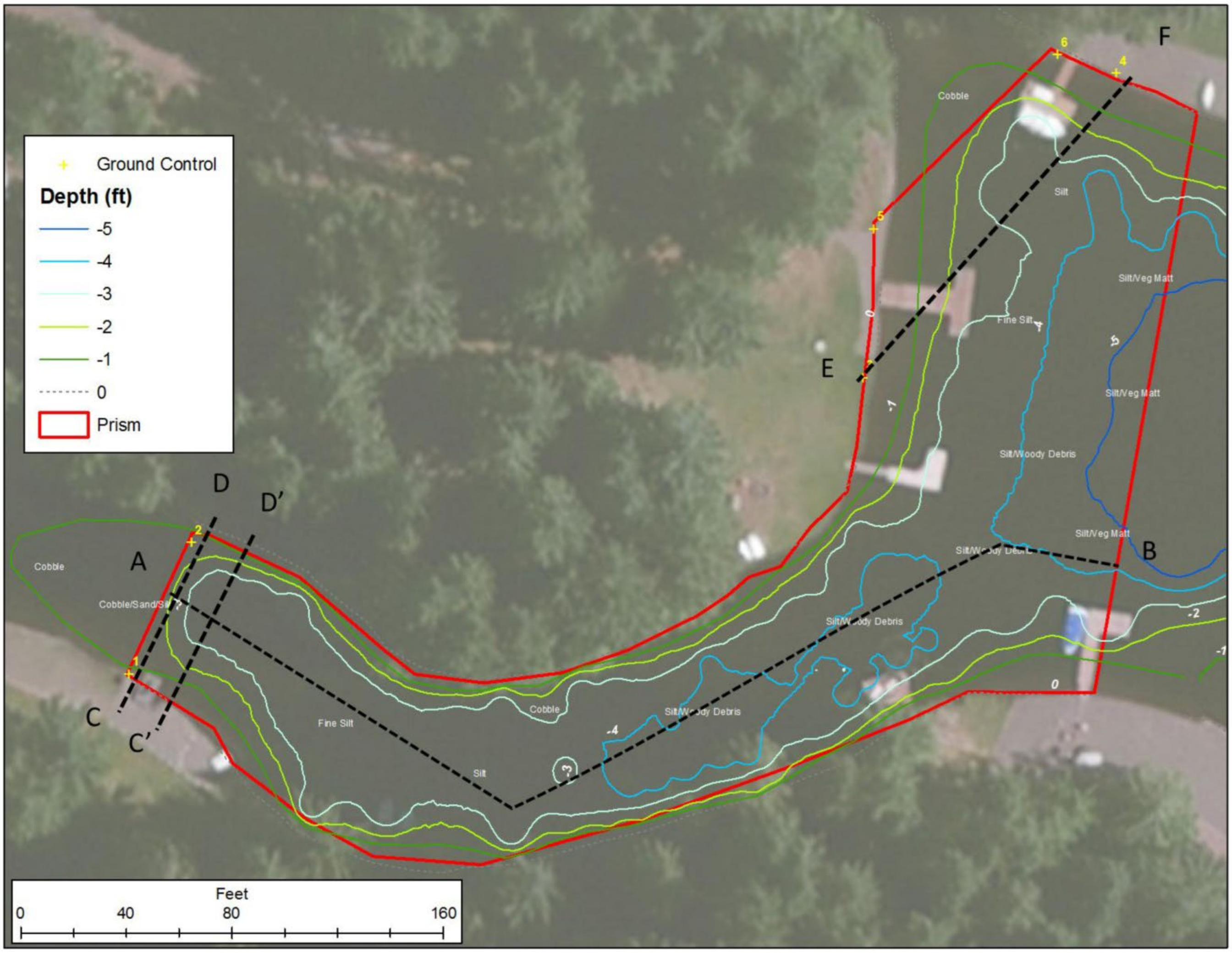


Figure 7-15 – Dredging transects in Cranberry Cove

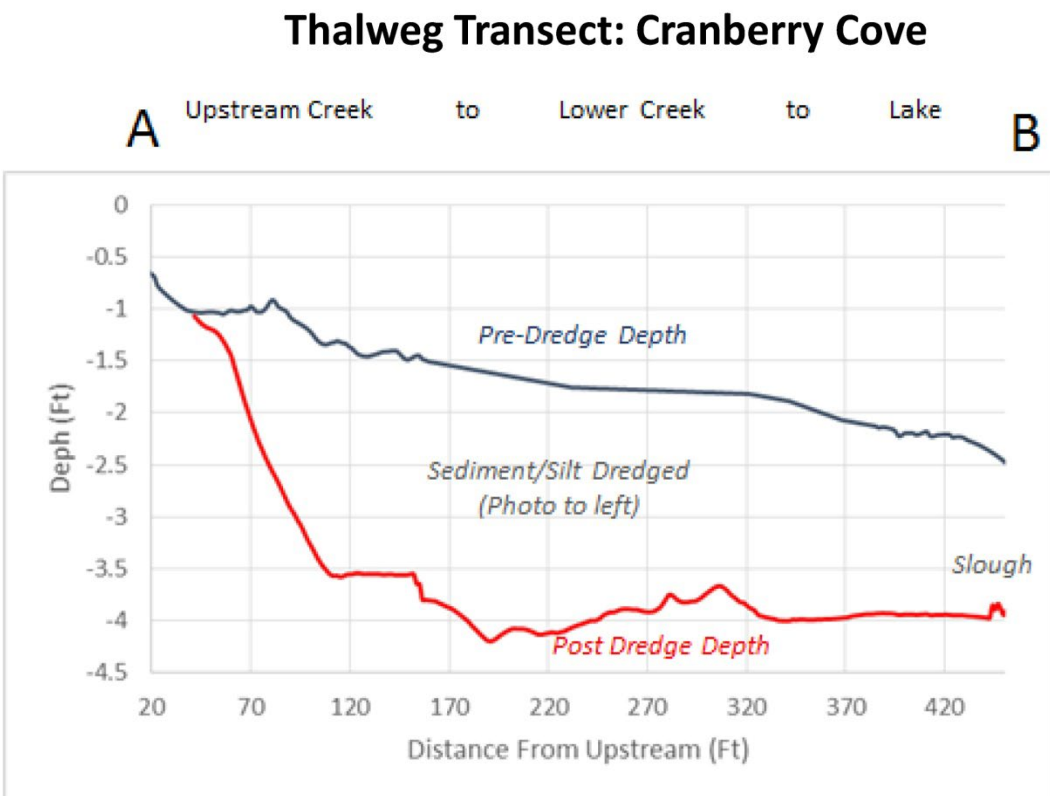


Figure 7-2 – Thalweg gradient for inflows into Cranberry Cove, before and after dredging

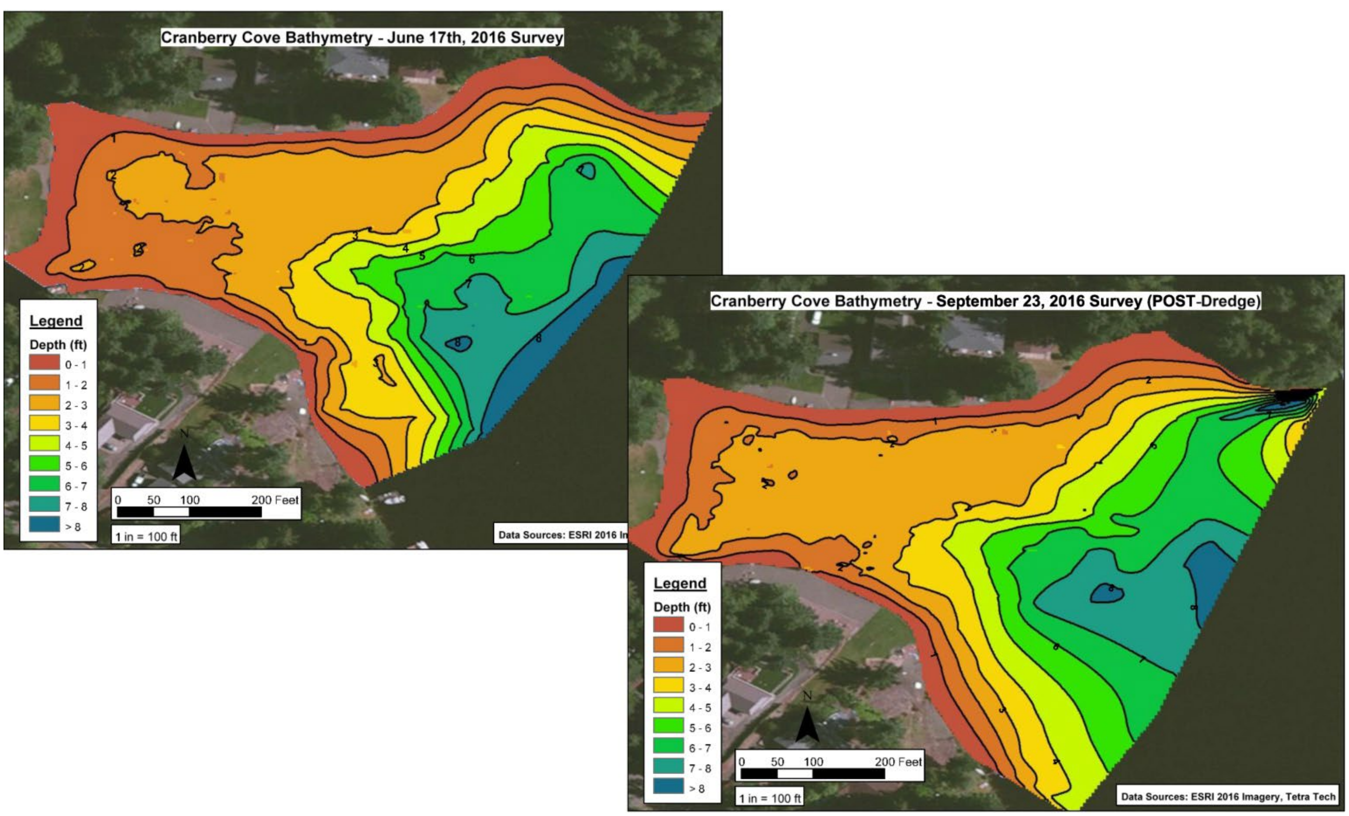


Figure 7-17 – Cranberry Cove bathymetry before and after dredging