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Technical Monitoring Report and Management Actions: Lake Limerick and Lake Leprechaun

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Thank you to all the Lake Limerick and Leprechaun volunteers who care about the health of their lakes and want to preserve the ecological and recreational uses. Special thanks to the Lake Limerick Country Club (LLCC) management and staff and Lake Dam Committee members who assisted in conducting this project. LLCC participants delivered quality support within stringent deadlines as defined in the environmental permit.

EXECUTIVE SUMMARY

This report encompasses several years of pre- and post-monitoring work following the 2016 dredging project in Cranberry Cove and King's Cove in Lake Limerick. These two coves were filling in with fine sediment contributed by tributaries to Lake Limerick and the reason why a decision to remove these sediments and return the lake to an ecologically less productive condition. This means the sediment fill over time had promoted loss of native plant communities, benthic communities and increased a supply of in-lake nutrients for invasive plant and algae growth.

Goals for the lake management program, including the dredging of fine sediment from Cranberry Cove and King's Cove were to:

- Manage the aquatic plant community that encouraged growth of native species and the eradication/management of invasive species.
- Remove excess nutrient in the sediment and ultimately, the water column that promotes invasive species plant growth as well as that of nuisance aquatic algae.
- Preserve an ecological balance between those features of the lake that promoted appearance of a healthy benthic community and habitat for fish species.
- Improve conditions for recreational and aesthetic beneficial uses.

The aquatic plant community has evolved in both lakes since the beginning of this treatment period (2017-2021). The non-native invasive *Egeria densa* (Brazilian elodea) is still present throughout the lake but dramatically less dense than historical levels and now is at depth from 8 to 20 feet, except in the northeast littoral area including the Bird Sanctuary. The aquatic plant, *Potamogeton amplifolius* (broad-leaf pondweed) is a native to lakes in our region. It's established area has been increased in the lakes and maintains a healthy presence for use by aquatic life (fish and aquatic insects).

The fragrant waterlily (*Nuphar odorata*) has appeared in a greater number of areas over time and should be assessed annually. This non-native species will be assessed to determine how aggressive control should be on an annual basis. Successful treatment of filamentous green algae occurred in both lakes. Keeping this invasive species subdued is important for promoting healthy fish habitat and to reduce the amount of nutrients released to the water column. Mechanisms for nutrient release led to blue-green algae blooms that periodically produce neural toxins dangerous to pets and humans. Moving forward with plant treatment strategies will include contact herbicide and hydrogen peroxide application. This proved to be effective in removing target non-native plants and filamentous algae.

Over 6,000 cubic yards of dredged material was taken from King's Cove and Cranberry Cove. Once dewatering and compaction of this material was complete the total volume of dredged material was approximately 1,000 cubic yards. Fine sediment carries adsorbed nutrient that eventually is released when deposited on the lake bottom and is bioavailable for algae and aquatic plant growth. Removal of this material represents extraction of a substantial amount of organic nutrient from the two coves enabling greater success of the plant management program.

The fishery habitat was increased in both coves with exposed bottom substrate used for spawning and improved access to inflow streams for winter steelhead, coho, and resident cutthroat. The exposed substrate promotes improved conditions for benthic macroinvertebrates colonization and restoring the natural ecological function of the habitat.

Initial changes in the coves increased recreational opportunities through increased water depth that provided better access for boats, makes swimming more enjoyable, and is aesthetically pleasing. On-going input of sediment and nutrients from Cranberry Creek is a concern resulting in filamentous algae and aquatic rooted plant growth that has reduced some of the immediate benefits of the dredging project.

Dredging was effective in removing nutrient load from the two coves. Initial results revealed hard substrate in the dredged area that are known to be beneficial for spawning by warmwater fishes and colonization by aquatic invertebrates. Areas in King's Cove that had sloughing of the remaining fine sediment filled in the deeper portions of this area during post-dredging. Cranberry Cove had approximately 400 cubic yards more material removed than in King's Cove, but still accumulated fine sediment from Cranberry Creek over the five-year period. Dredging proved to be beneficial and slowed the lake aging process by 1) removing nutrients from the sediment resulting in effective aquatic herbicide treatments, and 2) improving habitat use by aquatic life. Future dredging projects could dramatically slow the lake aging process and promote healthier natural plant and animal communities.

Over the next five years, the following recommendations will be the focus for management of Lake Limerick and Lake Leprechaun:

- Aquatic plant management will be guided by the spring and fall surveys to determine herbicide treatment the following year.
- Management effort will be to enhance and prevent over production of native rooted aquatic plants while minimizing appearance of non-native invasive plants and green filamentous algae.
- Water quality monitoring will resume at the deepest location in both lakes (18" below the surface and 18" above the lakebed) at two depths. Recommended parameters collected at these locations are temperature, dissolved oxygen, pH, total phosphorus (TP), total nitrogen (TN), and soluble-reactive phosphorus (SRP).
- Evaluation of dredging effectiveness should be determined by performing a bathymetric survey in Cranberry Cove and King's Cove. The rate of infilling should be calculated based on time elapsed since last dredging and location of greatest in-filling.
- Sediment core analysis collected in October 2021 will be used to determine organic content in Lake Leprechaun. This data will be used to determine the feasibility of dredging areas of the lake to abate the expansion of mare's tail.
- Source of sediment and input volume into lake Limerick needs to be identified from Cranberry Creek. A feasibility study that determines potential strategies for removing sediment from Cranberry Creek before entering Lake Limerick should be completed. A determination for effectiveness of dredging every 5 to 10 years should be evaluated.
- Non-native aquatic plant growth has expanded in the bird sanctuary and several strategies should be evaluated to reduce this invasion including aggressive herbicide application, nutrient inactivation, mechanical harvesting, diver suction dredging, or a combination of one or more of the approaches.

5-YEAR LAKE MANAGEMENT PRIORITIES

Control of invasive aquatic plants while encouraging native aquatic plant communities to grow is a top priority on the short-term. The management strategy of invasive plants includes herbicide application and additional effort like hand-pulling invasive plants whenever possible. On-going contribution of nutrients to the lake from homeowner properties originates from on-site septic systems and from shoreline lawns along the edge of the lake. Septic tank maintenance on a regular basis is the most expedient way to ensure excess nutrients are not travelling to the lake through drain fields. Education about landscaping and on-site septic maintenance area simple and cost-effective way to reduce nutrient contribution to both Lake Limerick and Lake Leprechaun.

Sources of soft sediment to Lake Limerick can be determined through simple, investigative reconnaissance in Cranberry Lake, Cranberry Creek, and the inlet to Lake Leprechaun. Time since dredging in 2016, Cranberry Cove and King's Cove have become shallower. A bathymetric survey in each of these locations will inform on rate of in-filling at these locations and confirm likely sources. A combination of soft-sediment source tracing from Cranberry Creek and the upstream side of the outlet dam, and a stream walk to identify eroding banks is necessary. A similar effort is needed in Lake leprechaun near the inlet to determine depth and extent of soft-sediment distribution in this lake.

>10 YEAR LAKE MANAGEMENT PRIORITIES

Priorities for lake maintenance and restoration in the long-term includes dredging, need for construction of a sedimentation pond, and/or formation of a utility local improvement district. Each of these solutions for maintaining long-term improvements of lake condition are the most costly but rely on learning more about soft-sediment transport into both lakes included as a short-term priority. Dredging has the more immediate and noticeable impact to the lakes following completion. Removal of nutrient-laden sediments and decaying plant matter appears to have lasting effects for five or more years. Short-term priorities including bathymetric survey will lend more insight into length of positive contribution from dredging.

Control of invasive plants and soft-sediment deposition around the bird sanctuary is an emerging issue and is beginning to impact shorelines and deeper areas with appearance of green, filamentous algae. One or more solutions is suggested for inactivation and/or removal of soft sediment with high nutrient content. Cost and effectiveness for each of the strategies requires evaluation and depends on depth of soft sediment, nutrient content, and extent of invasive plant growth.

Lake Leprechaun has some in-filling by soft sediment, but less is known about distribution and nutrient content. Growth of invasive aquatic plants has been successful over the past years and provides some time to investigate soft sediment dynamics in the lake. Identification of nutrient source to this lake will explain growth of invasive aquatic plants like mare's tail (*Hyppurus vulgaris*) interspersed by *Egeria densa* (Brazilian elodea). Further investigation through bathymetric survey would establish a baseline for measuring soft sediment in-filling of this lake over time.

Establishment of a utility local improvement district (wastewater treatment system) is another option that has the highest cost with unknown positive effects to lake conditions. Although this long-term alternative could be beneficial it's not known what portion of nutrients, beyond sources like shoreline lawns and soft-sediment contribution from inlet sources, is contributed by on-site septic systems. Cost for establishing infrastructure like this may be borne by issuance of local improvement bonds.

GLOSSARY OF TERMS

Amphipoda is an order of malacostracan crustaceans with no carapace and generally with laterally compressed bodies. Freshwater Amphipods average in size 0.5 inches are mostly detritivores or scavengers.

Bathymetric Data (**Bathymetry**) is the study of underwater depth. Often depicted in adjoining depth intervals on a map.

Benthic Habitat (**Benthos**) is substrate on which animals and plants live at the bottom of waterways.

Benthic Macroinvertebrate aquatic animals with an exoskeleton and less than 0.595mm in size that live on the bottom of waterways.

Chironomidae is a family of semi-aquatic invertebrates informally known as chironomids, non-biting midges, or lake flies. This is a large group of insects that live in a variety of habitats worldwide.

Cyanobacteria is a division of microorganisms (also known as Blue-Green algae) that are related to the bacteria but are capable of photosynthesis.

Flocculents are substances that promote the agglomeration of fine particles present in a solution, creating a floc, which then floats to the surface (flotation) or settles to the bottom (sedimentation).

HABs is an acronym for Harmful Algal Blooms and results from proliferation of blue-green algae that produce neural toxins.

in-Situ is the Latin meaning in the natural or original place.

Midges belongs to the Order Diptera (Family Chironomidae) and is a group of semi-aquatic invertebrates that are included in this group with blackflies and mosquitoes.

Mollusca is a phylum of invertebrates referring to freshwater snails (Gastropoda) and bivalves (Pelecypoda) found in lakes and rivers/streams.

Oligochaeta is a class of annelid worms which includes the earthworms. They have simple setae projecting from each segment and a small head lacking sensory appendages.

Phytoplankton are the autotrophic (self-feeding) components of the plankton community and a key part of freshwater ecosystems.

Senescence is the condition or process of deterioration with age.

Sphaeriidae is a family of small to minute freshwater bivalve molluscs in the order Sphaeriida. In the US, they are commonly known as **pea clams** or **fingernail clams**.

Taxa is a taxonomic group of any rank, such as a species, family, or class.

Thalweg is a line connecting the lowest points of successive cross-sections along the course of a valley or river.

Turbidity is the quality of being cloudy, opaque, or thick water with suspended matter.

1.0 INTRODUCTION

The continued goals for aquatic plant and water quality management in Lakes Limerick and Leprechaun during 2017 through 2021 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 through 2021 to identify changes in community structure and function post- 2016 dredging.

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 organic carbon and oxygen. These processes can mitigate the deleterious impacts of high nutrient concentrations (e.g. the occurrence of toxic algae blooms) by lowering overall water column 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. In addition, introduction of non-native invasive plants can accelerate over fertilization of the lake with direct and indirect negative impacts to the aquatic ecosystem, such as increasing dissolved oxygen demand in the sediment and lake water, which leads to both water quality decline and aquatic habitat impairment. This impedes recreational and aesthetic beneficial uses and impairs aquatic habitat. Comprehensive lake management and monitoring is necessary to maintain a balanced aquatic ecosystem.

Based on the information provided by annual plant surveys (see Section 2.2), 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. On-going primary concerns for condition in the Coves and in the lake have been the introduction of sediment, an increase of nutrient load associated with sediment, and promotion by this material of invasive aquatic plant growth. Following the 2014 surveys and treatments describing these conditions, it was recommended that the Lake Limerick Country Club (LLCC) dredge a portion of Lake Leprechaun and a portion of Lake Limerick to reduce the nutrient load, limit ability for invasive aquatic plant growth and, secondarily, expose hard sediment that would be beneficial to fisheries in Cranberry Creek and King Creek while also allowing boating access. Inlet streams to lakes serve as suitable spawning habitat when substrate size is one-half to three inches in diameter and is not inundated by fine sediments (Behnke 1992).

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 Limerick dredging project were completed. Benthic macroinvertebrates were collected in October 2017, September 2019 and October 2021 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 and directed to deeper areas away from the shoreline.

A major component of 2016 lake management efforts were dredging of King's Cove and Cranberry Cove in Lake Limerick. As inlet streams to the lake, fine sediments accumulated in both regions diminish quality of potential rearing and spawning fish habitat as well as limit recreational use of these areas. As a result, benthic macroinvertebrate community characterization was completed before dredging, one-year following the project, two years following that collection and another collection completed five years after dredging in 2016. 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 A2-1). 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 an estimated 1 to 5 feet– limiting the ability of boats to access these coves and shrinking the area in which it was possible to swim. Initial depth estimates for fine sediment deposits were made with a stadia rod from depth of hard-bottom sediment to the surface of fine sediment that had accumulated. 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 potential fish spawning/rearing, c) to remove deposited nutrients, phosphorus and nitrogen that are accelerating eutrophication (aging and over production) of the lake, and d) 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. Additional photos detailing dredging operations are found in Appendix 2.

On September 11th, 2015, Tetra Tech staff mapped the bathymetry of Lake Limerick using a Lowrance HDS-7 fish-finder/chartplotter with StructureScan HD sonar imaging system and an LSS-2 HD Transom Transducer (Figure A2-2). 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's Cove) (Figure A2-2). 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. A final plan was reviewed and approved by Mason County in consultation with the Squaxin Island Tribe, Washington Department of Fish and Wildlife, and Washington Department of Ecology.

The dredging was conducted using a barge-mounted hydraulic MudCat® dredge (Figure A2-3). The MudCat® loosened fine sediments with a cutter head and then suctioned the loose material into a pump intake, 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 A2-4). The pump intake on the MudCat® connected to a floating pipeline (Figure A2-4), 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 to accelerate the de-watering process (Figure A2-5, 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 A2-6). 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 and became compressed (Figure A2-7). 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 (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 A2-8), 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 A2-9).

When the dredging was conducted, the MudCat® cut a channel in the sediment, removing the accumulated material (Figure A2-10). As the dredging occurred, additional material sloughed from the edges of the newly cut channel and was suctioned up, adding to the total volume of dredged material (Figure A2-10). Hard bottom sediments were exposed in the newly cut channel (Figure A2-11) removing nutrient load and 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 exceedances occurred (MIC 2016). Detailed bathymetric transect profiles were completed within one week upon completion of dredging in each of the coves.

Dredging followed along the transect in King's Cove as specified in the permit and proceeded to near the mouth of the inlet (Figure A2-12). 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 (Figure A2-13). A comparison of bathymetry in King's Cove, pre-dredging versus post-dredging, shows changes resulting from sediment removal. Transect profiles following dredging resulted in an increase in depth of the water throughout the northeastern portion of the cove, especially near the mouth of the inlet (Figure A2-14).

Dredging was conducted in Cranberry Cove along defined transects shown in Figure A2-15. The gradient of the thalweg was also improved in Cranberry Cove (Figures A2-16) from a uniformly shallower profile to a steeper gradient. Water depth increased by approximately 2 feet along the length of the. In addition, dredging increased the depth of the water throughout the center of the cove thalweg with expansion of area in the 2ft - 3ft contour interval (Figure A2-17). The post-dredging substrate exposed 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 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 6,414 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 was increased in both coves, as exposed substrate following dredging is known to support spawning and rearing for resident salmonids. The substrate exposed for benthic macroinvertebrate colonization and native aquatic plant establishment is intended to restore natural ecological function of this lake habitat. Recreational opportunities in both coves have also been improved, as the increased water depth provide better access for boats, makes swimming more enjoyable, affords a better fishing environment, and is aesthetically pleasing. However, the on-going input of sediment and nutrients, especially from Cranberry Creek, has resulted in filamentous algae and aquatic rooted plant growth as observed in twice-yearly visual surveys and reduced some of the immediate benefits of the dredging project.

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 were compared against samples collected during Year 1 (2017), Year 3 (2019), and Year 5 (2021) following completion of dredging. This report compared pre-dredging samples to those benthic macroinvertebrate samples collected one-year following the dredging project, three years following and then five years following completion of the dredging project.

Pre-Dredging Benthic Macroinvertebrate Samples

Density of benthic macroinvertebrate taxa at each of the locations was relatively similar among sites (Table A1-1). Three benthic taxa were dominant at each sampling location; the isopod *Caecidotia*, Oligochaeta (aquatic earthworms), and chironomid larvae (Table A1-2; 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. and *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), two years following the initial post-dredging sample collection (September 28, 2019) and the final post-dredging sample collection five-years later (October 8, 2021). 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 A1-3 (general taxonomic groups) and Table A1-4 (Chironomidae taxa). Post-dredging (Year 3) 2019 sample collection from Cranberry Cove is reported in Table A1-5 (general taxonomic groups) and in Table A1-6 (Chironomidae taxa). Final benthic sampling was conducted in Cranberry Cove during the end of the index sampling period Year 5 (2021).

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 native aquatic plants, 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 and lake use. These improvements inevitably have a positive impact on fish populations with an increased food base and habitat for predator avoidance and potential use for spawning and rearing, respectively.

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.

Benthic samples were collected again in 2021 (Year 5) following completion of dredging. Location for replicate samples remained the same as those collected before dredging in 2016 and immediately following dredging in 2017 and again three years following dredging in 2019. 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 2019 (Year 3). Total number of chironomid taxa continued to decline at the Cranberry Cove locations with losses in the Chironomidae taxa and increases in specialized taxa from the Order Trichoptera (caddisflies). Densities of chironomid (midge) taxa were greatest at the outermost collection site in Cranberry Cove in 2019 and dominated by *Dicrotendipes* sp. (Table A1-6). This midge larvae lives in muck bottoms as well as on plants. This location had both invasive plant and filamentous algae growth at that time of sampling in 2019. The invasive aquatic plants and filamentous algae had disappeared following the 2021 treatment and *Cladopelma* sp. was dominant at all collection sites in Cranberry Cove (Table A1-8). This midge larva lives in a variety of substrate types with larger densities than *Dicrotendipes* sp. in 2021 benthic samples. Aquatic plant management herbicide treatment in the lake resulted in little to no plants growing during benthic macroinvertebrate collection in 2021. This meant that taxa appearing for the first time at Cranberry Cove sites were taking advantage of a different food base and habitat conditions. The shallower, lake inlet of Cranberry Cove had greater midge larva densities in the upper portion of the dredge area in 2021 even though total number of taxa was smaller.

Fish Habitat and Dredging

Fish use a variety of habitat in lakes that include native aquatic plants (for cover), underwater ledges (transition between shallow and deep), and require specific substrate sizes for spawning. Food sources include a variety of benthic macoinvertebrates (aquatic insects) in addition to terrestrial insects and emergers from the benthic community. Life stages for a fish species require specific physical habitat conditions, water quality, and food base for survival.

A secondary benefit of dredging was the improvement of habitat in Cranberry Cove and King's Cove for spawning and rearing. The strategy for fish habitat improvement was to remove excess fine sediment suspended above the hardpan in the lake. By removing the fine, suspended sediment excess nutrients would be removed and limit growth of non-native aquatic plants. Removal of non-native aquatic plants encourages replacement by native plants that serve as vertical structure and cover for fish and benthic macroinvertebrates.

Native to most Puget Sound streams and lakes are the salmon species. Substantial effort has been made to maintain and restore salmon throughout the region. Based on what is known about salmon distribution and use of lakes and streams in this drainage, the following list was assembled from Salmonscape (Table 2.1- 1), a Washington Department of Fish and Wildlife database documenting distribution of species.

Table 2.1- 1 Salmon species distribution in Cranberry Creek and Lake Limerick.

Salmon Species	Location	Supporting Function
Coho	Lower Cranberry Creek	Documented Spawning
	Lake Limerick	Documented Presence
	Upper Cranberry Creek	Documented Spawning
Summer Chum	Lower Cranberry Creek	Documented Spawning
	Lake Limerick	Documented Presence
	Upper Cranberry Creek	Documented Presence
Fall Chum	Lower Cranberry Creek	Documented Spawning
	Lake Limerick	Documented Presence
	Upper Cranberry Creek	Documented Presence
Winter Steelhead	Lower Cranberry Creek	Documented Presence
	Lake Limerick	Presumed Presence
	Upper Cranberry Creek	Presumed Presence

Lake Limerick is periodically stocked by the Washington Department of Fish and Wildlife. Stocking is intended as a put-and-take fishery affording a recreational opportunity for residents and the public.

Habitat for fish depends on maintaining or restoring native aquatic plant structure, enhancing the food base, and maintaining good water quality. Maintenance of native plant conditions through control and eradication of invasive species like *Egeria densa* and filamentous green algae were largely successful. Decline of *E. densa* in shallow areas of Cranberry Cove and disappearance of filamentous green algae by the fall 2021survey was evidence for control of invasive species. The contrast between fall 2017 and fall 2021 showed a much smaller filamentous green algae footprint (Figure 2.2-2 and Figure 2.2-7). Number of benthic macroinvertebrate species increased post-dredging to 2021. Among the most notable were the long-lived species like the alderflies and purse-case caddisflies both of which are an expansion of the variety of feeding groups in this area from post-dredging communities (Section 2.4). These changes represent a benthic community that is becoming more diverse based on positive changes in habitat and in native food source, which also implies that the food base for fish has also improved.

The disappearance of green filamentous algae and rooted aquatic plants following the 2021 treatment in Cranberry Cove was an indication that progress was made in improving fish habitat goals. Dredging was effective initially in removing a primary source of nutrients that promote plant and algae growth and for uncovering preferred substrate habitat used to complete portions of the salmonid life cycle. Time elapsed since dredging showed moderate plant growth until the last treatment in 2021. Sampling for benthic macroinvertebrates in 2021 at the same locations since 2016 was on lake bottom with absence of aquatic plants and algae. There was a thin layer of fine sediment that had been re-deposited in Cranberry Cove discovered during this sampling event and was strongly divergent from those conditions sampled during pre-dredging.

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) was presented. Aquatic plant survey maps from 2020 (Figure 2.2-5 and Figure 2.2-6) and 2021 (Figure 2.2-7 and Figure 2.2-8) include proposed treatment areas.

Aquatic plant surveys were conducted twice annually, once in the spring and again in late summer and used to determine a plan for herbicide application and then effectiveness of the applications once growing season was over. These surveys were the basis for constructing aquatic plant maps and the strategy for herbicide application.

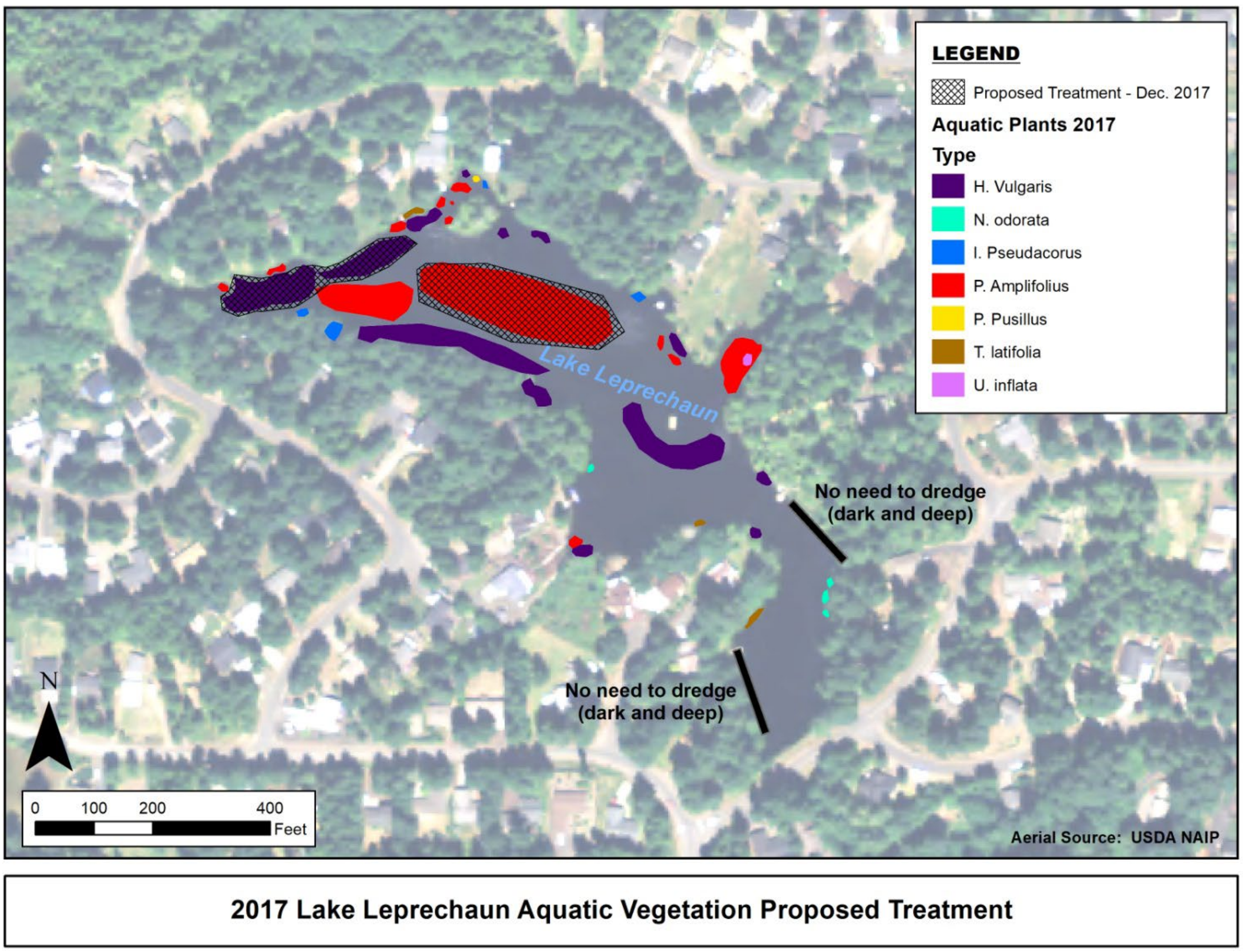

Figure 2.2-1. Aquatic plant 2017 map for Lake Leprechaun showing treatment areas for 2018.

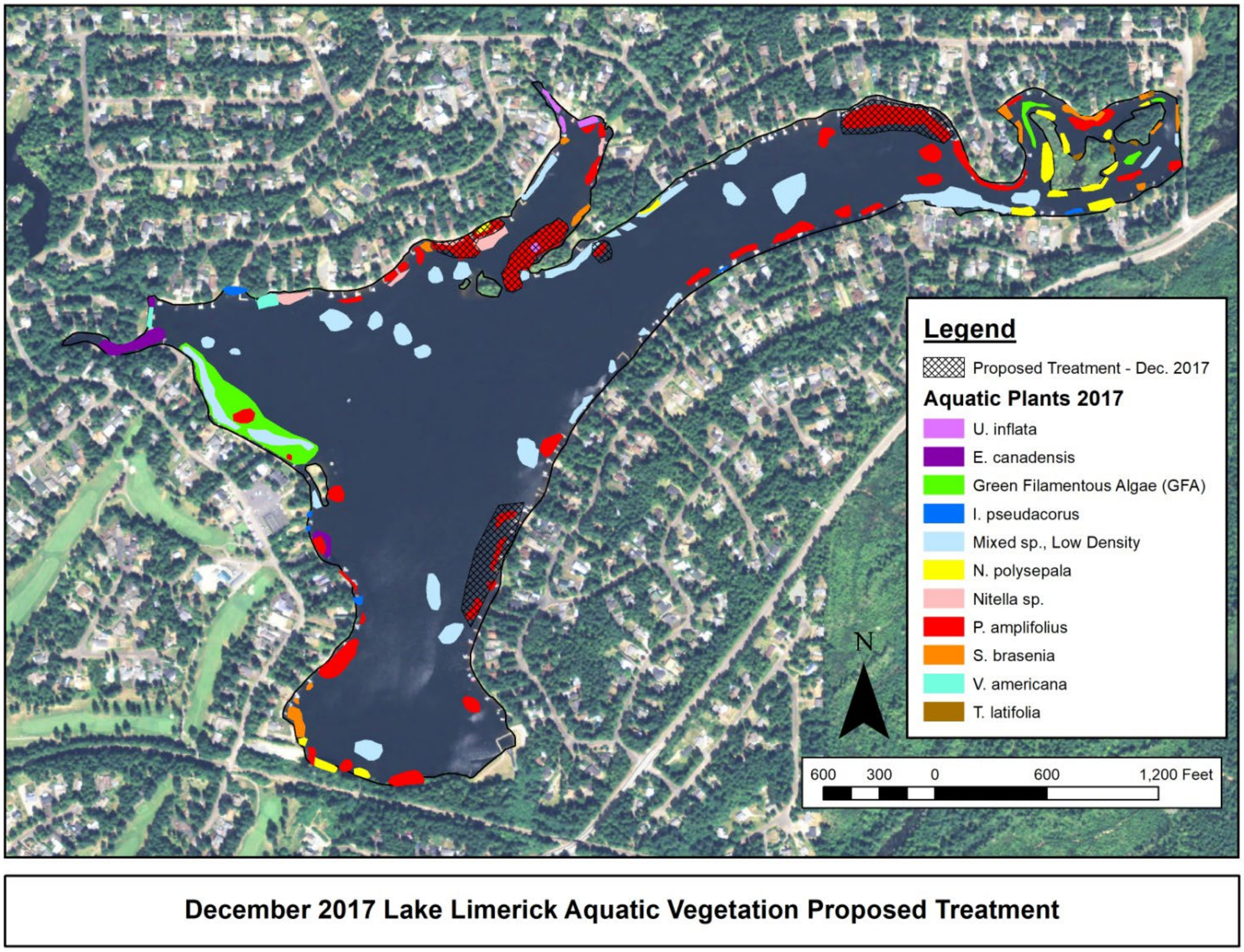

Figure 2.2-2. Aquatic plant 2017 map for Lake Limerick showing treatment areas for 2018.

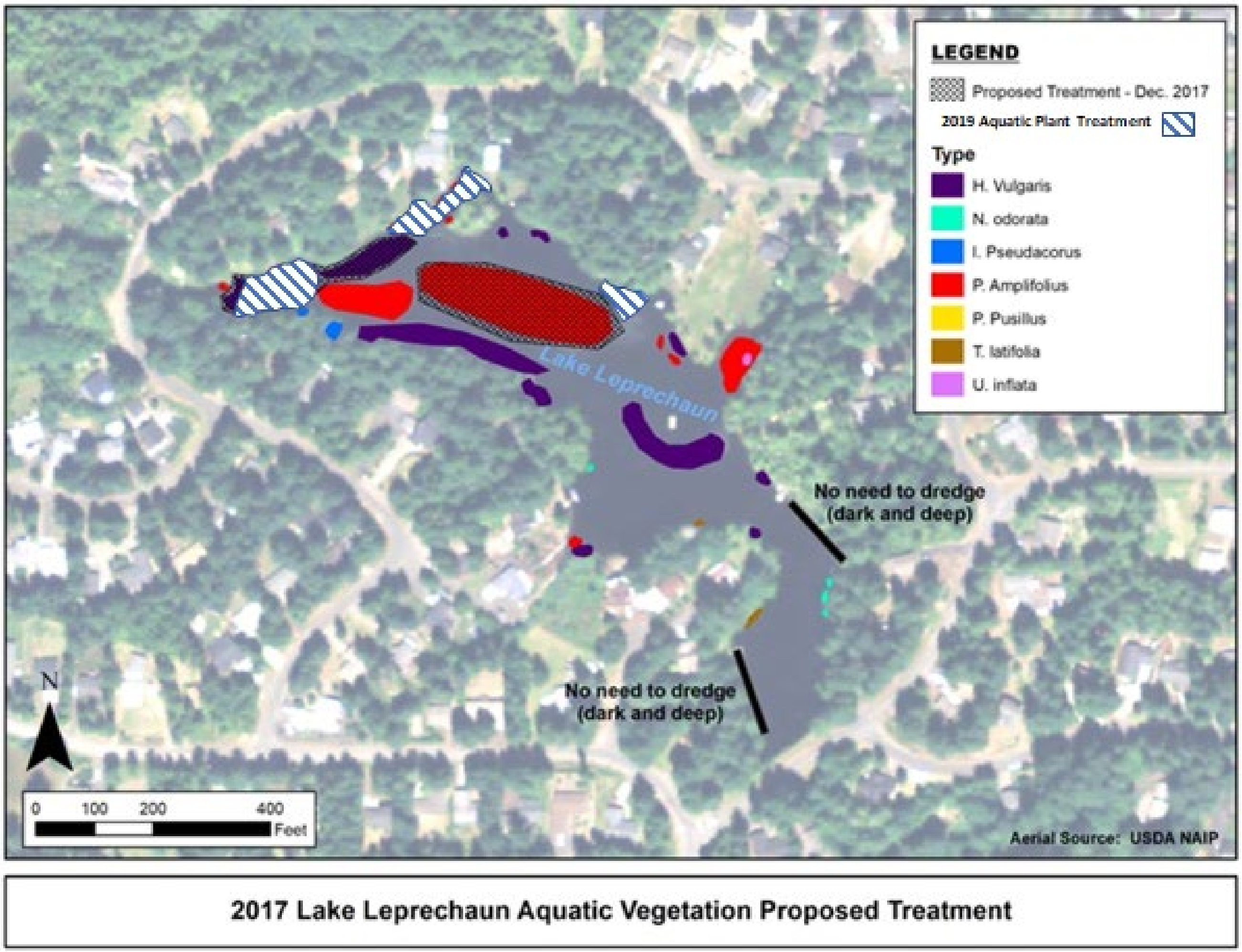

Figure 2.2-3. Aquatic plant 2017 map for Lake Leprechaun showing treatment areas for 2019.

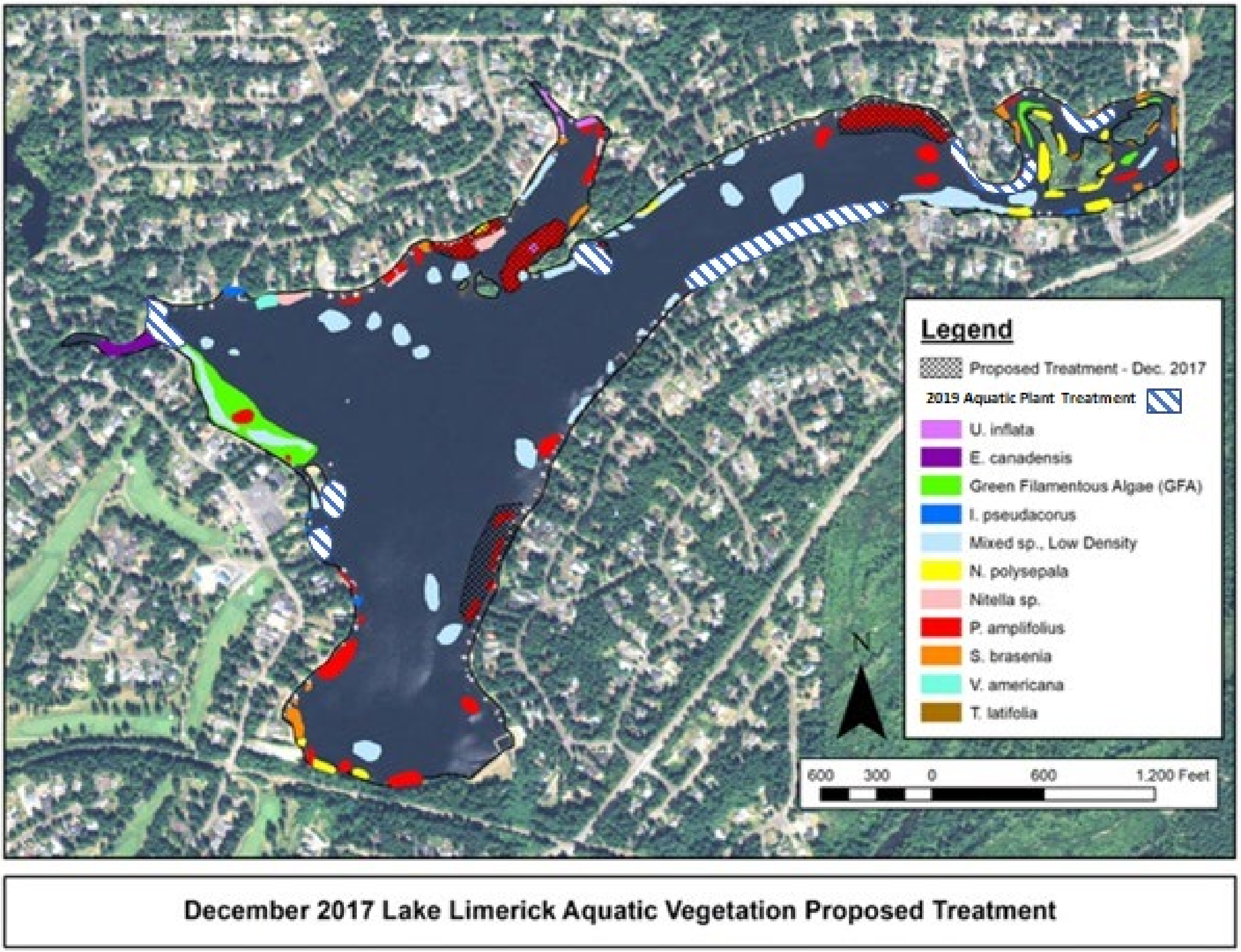

Figure 2.2-4 Aquatic plant 2017 map for Lake Limerick showing treatment areas for 2019.

Recent aquatic plant surveys were completed on June 26, 2020 and October 2, 2020 on Lake Limerick and on Lake Leprechaun(Figure 2.2-5 and 2.2-6, respectively). Invasive aquatic plants were identified two times during the year, at the beginning of the growing season and before senescence began. Treatment areas are identified in Figure 2.2-3 and Figure 2.2-4 including suggested treatment strategies identified for each of the areas where invasive plant patches were identified.

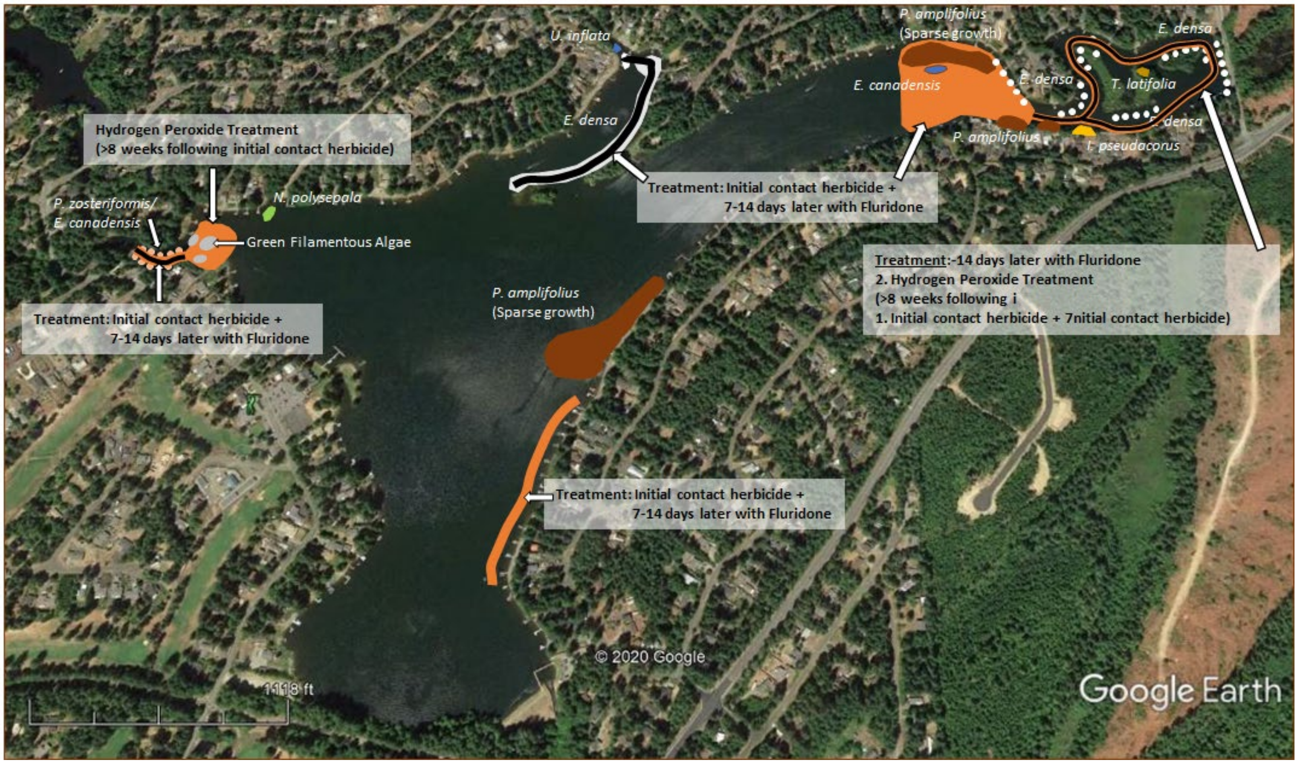

Figure 2.2-5. Invasive aquatic plants identified from surveys on June 26, 2020, and October 2, 2020 in Lake Limerick, including suggested treatment strategies.

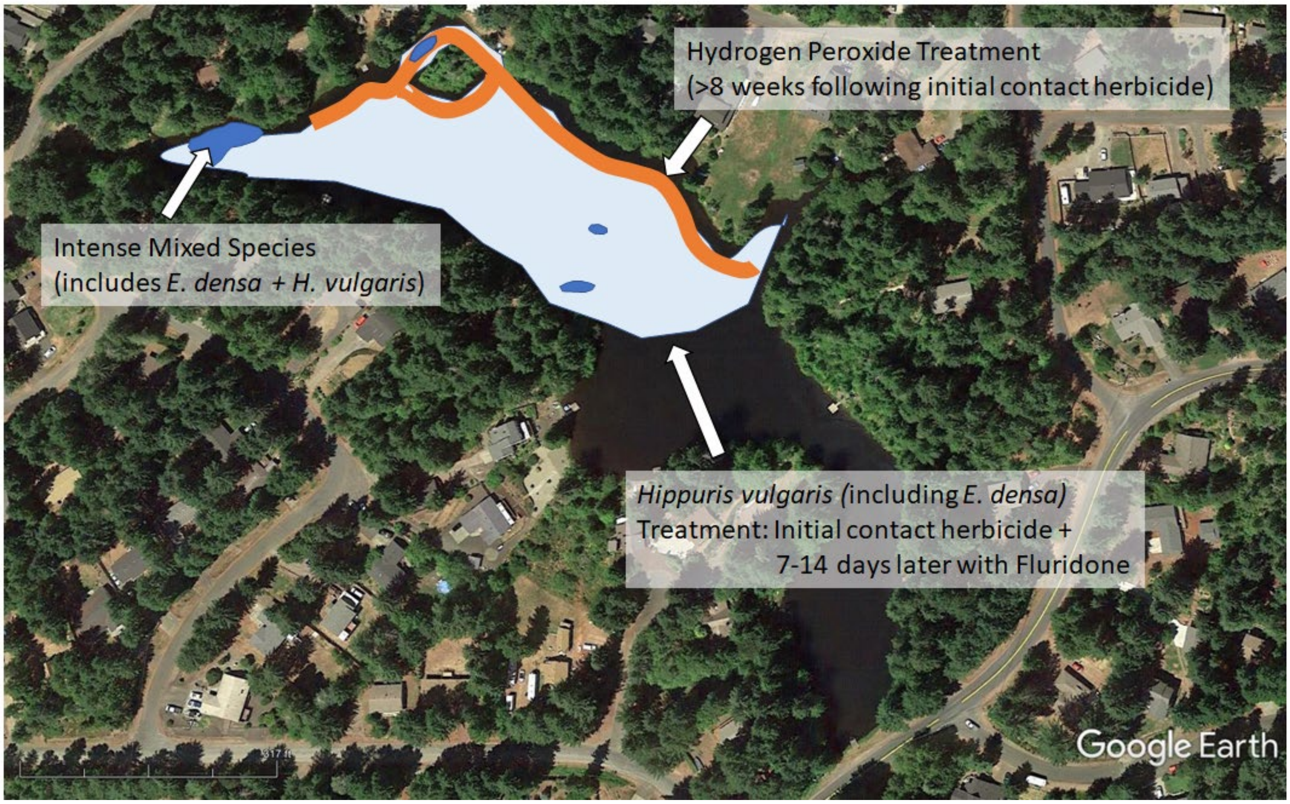

Figure 2.2- 6. Invasive aquatic plants identified from surveys on June 26, 2020, and October 2, 2020 in Lake Leprechaun, including suggested treatment strategies.

Recent aquatic plant surveys were completed on June 4, 2021 and October 8, 2021 on Lake Limerick and on Lake Leprechaun (Figure 2.2-7 and 2.2-8, respectively). Invasive aquatic plants were identified two times during the year, at the beginning of the growing season and before senescence began. The non-native invasive *Egeria densa* is still present throughout the lake but dramatically less dense than historical levels and now is at depth from 8 to 20 feet, except in the northeast littoral area including the Bird Sanctuary. Treatment areas are identified in Figure 2.2-7 and Figure 2.2-8 including suggested treatment strategies identified for each of the areas where invasive plant patches were identified.

Treatment with Diquat® (a contact herbicide) will be followed in same area by Sonar One® (a fluridone pellet systemic herbicide) within 10 days of the initial treatment. Another treatment that will be applied in spring and late July is PAK 27 algaecide (sodium carbonate peroxyhydrate; hydrogen peroxide) represented by the goldenrod swath in Figure 2.2-7 and Figure 2.2-8.

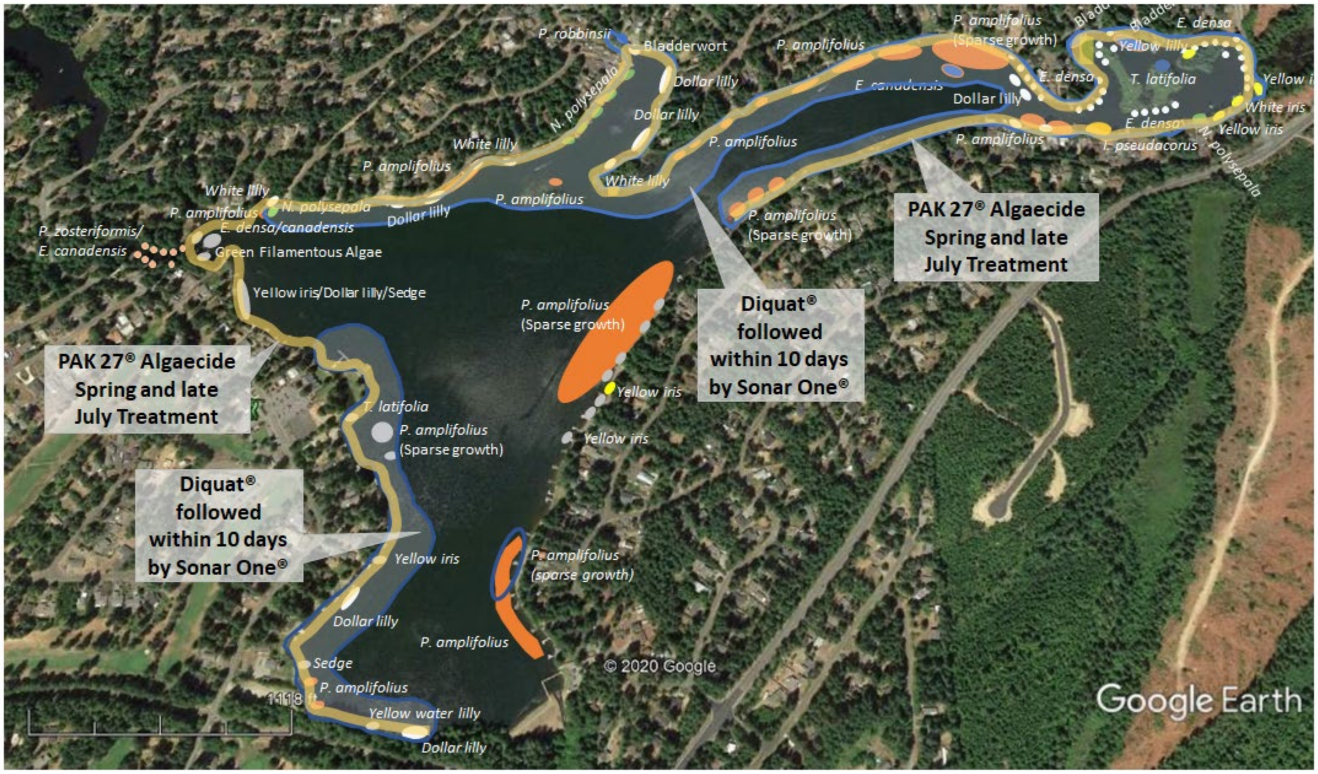

Figure 2.2- 7. Invasive aquatic plants identified from surveys on June 4, 2021, and October 8, 2021 in Lake Limerick, including suggested treatment strategies.

Most notable from the fall plant survey is that *Egeria densa* has been greatly reduced in coverage and density and is now only randomly observed in the south end of Lake Leprechaun.

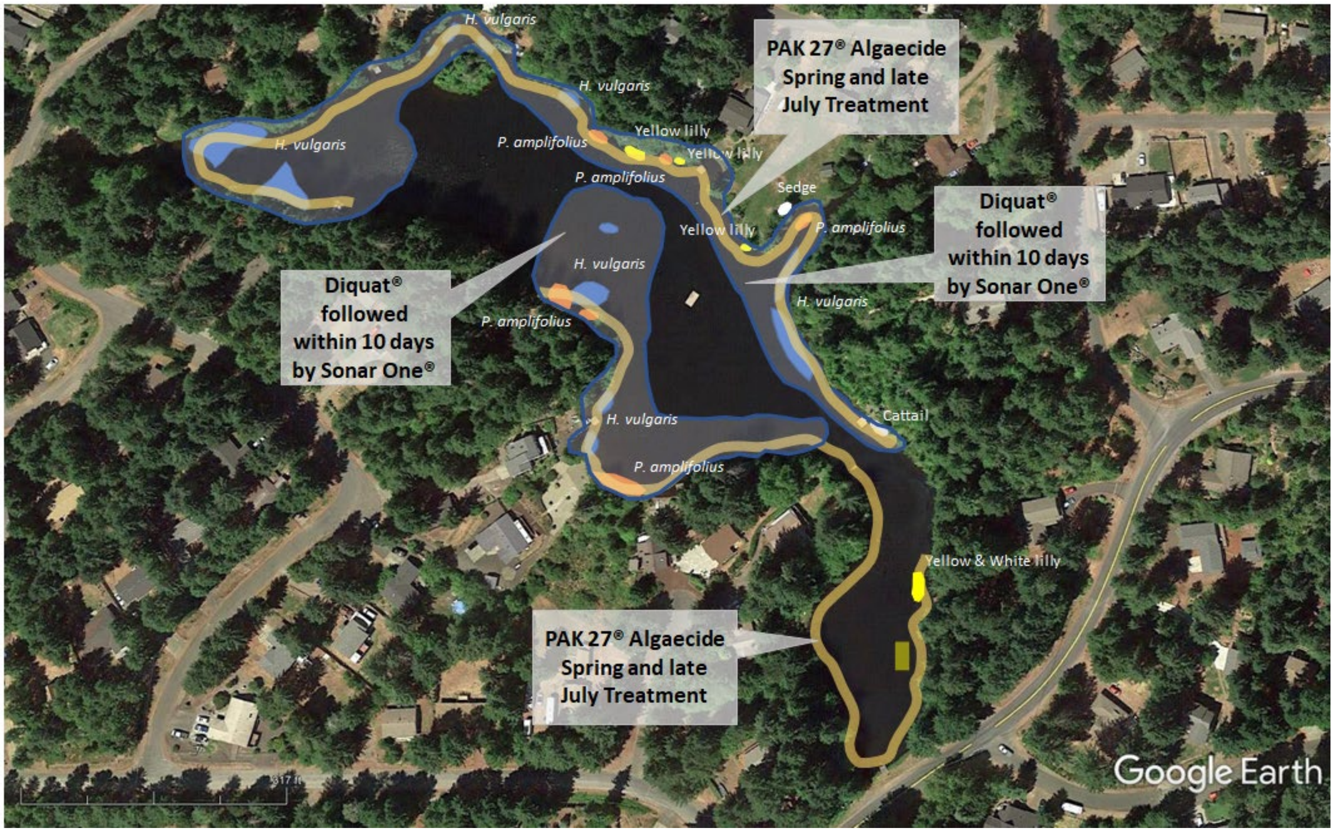

Figure 2.2- 8. Invasive aquatic plants identified from surveys on June 8, 2021, and October 15, 2021 in Lake Leprechaun, including suggested treatment strategies.

Broad-leaved pondweed (*Potamogeton amplifolius*) was dispersed around margins of Lake Limerick in 2017 (Figure 2.2-2). Over the next several years aquatic plant treatment strategies reduced the footprint of this species to a few marginal patches and sparse density (Figure 2.2-7). The distribution of this species is an important a deepwater species providing habitat for lake fisheries but can grow in extensive patches that impede boat traffic and swimming areas.

Green filamentous algae were present along the shoreline of Lake Limerick outside of Cranberry Cove and was persistent from 2017 through 2020. Aquatic plant survey in 2021 noted only a small patch remained outside of Cranberry Cove (Figure 2.2-7). Use of contact herbicide followed by hydrogen peroxide treatment appeared to be effective in managing large, green filamentous algae patches.

Egeria densa (Brazilian elodea) has been persistent along margins of the Lake Limerick in the bird sanctuary. *Typha latifolia* (cattail or bulrush) has established some distinct patches along the island margins in the bird sanctuary over the past five years (Figure 2.2-2, Figure 2.2-5, and Figure 2.2-7).

Lake Leprechaun had several patches of well-established mare's tail (*Hippurus vulgaris*) when surveyed in 2020 (Figure 2.2-6). *H. vulgaris* was limited to marginal patches in 2017 and at the boat launch area of Lake Leprechaun (Figure 2.2-3). Aquatic plant herbicide treatment in 2021 reduced the footprint of mare's tail to a few shoreline patches and a reduced presence in the boat launch area (Figure 2.2-8). The control of mare's tail will be the focus for future treatments as the footprint can be extensive as observed in 2017.

Proposed treatment areas in Figure 2.2-7 were more extensive (52 acres) than the 30 acres allowed in the APAM permit. Priority areas of the lake were selected where aquatic plant growth required more immediate control (Figure 2.2-9). Justification for treatment of areas highlighted in Figure 2.2-9 were based on observations from 2021 plant surveys and the advancement of *Egeria densa* and *Potamogeton amplifolius* (Figure 2.2-7)

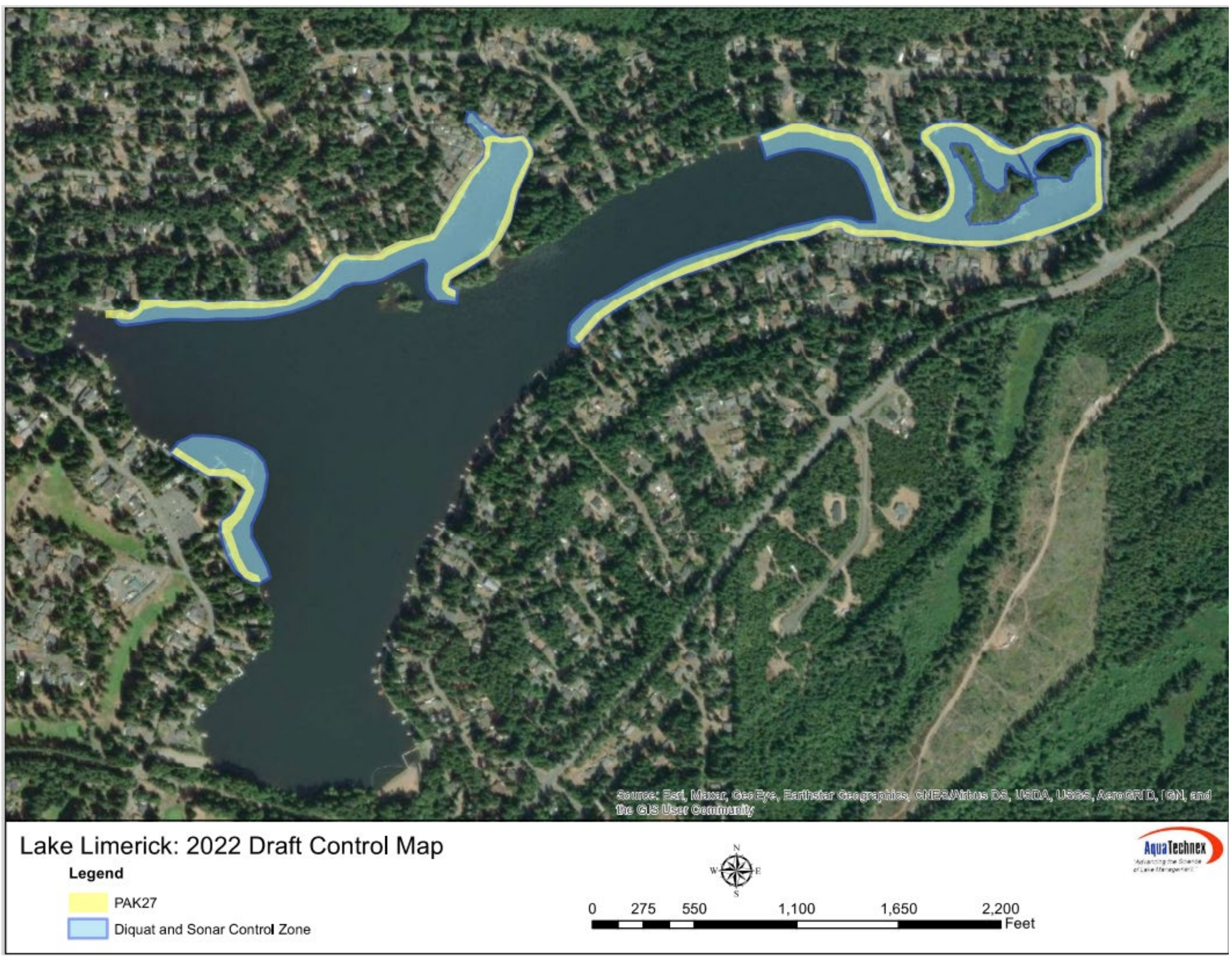

Figure 2.2-9. Revised 2022 aquatic plant treatment areas in Lake Limerick. (Courtesy of AquaTechnex)

Vulnerable areas for plant growth in Lake Leprechaun are highlighted by the treatment areas in Figure 2.2-10. Both *Egeria densa* in the south end of Lake Leprechaun and mare's tail in the north and central portion of the lake were of greatest concern in 2020. Continued treatment of these areas in 2022 will encourage sustained progress in controlling distribution of these aquatic plants.

Figure 2.2-10. Revised 2022 aquatic plant treatment areas in Lake Leprechaun. (Courtesy of AquaTechnex)

Aquatic plant management is an on-going effort as several factors influencing appearance, growth and density of patches is different between years. Direct treatment of some species is necessary when a fast-growing and invasive plant can spread rapidly. Spot treatments of herbicide are effective in maintaining low density and distribution of plants once under control. The strategy of aquatic plant management is informed by the twice per year surveys performed before and following the growing season.

2.3 WATER QUALITY MONITORING RESULTS

Lake water quality samples were taken on September 28, 2017. The general results indicated that the lake remains in a mesotrophic state at that time, meaning 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 a eutrophic (over-productive) lake is 25 µg P/L to 35 µg P/L. At that range the lake will start to show cyanobacteria dominance by 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 nor do they produce algal toxins. However, we have 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 with 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

Total phosphorus in Puget Sound lakes averages 22µg/L during summer months and 27µg/L during winter months (USGS 1983). In the same study of seventeen Puget Sound lakes chlorophyll a range indicating various stages of lake productivity were as follows: <3µg/L=low productivity lakes, 3-9µg/L=medium productivity lakes, and >9µg/L=high productivity lakes. There is some variation of these ranges determined by whether a lake stratifies and timing for turnover. This study occurred almost 40 years ago during a time when human stress on lakes was a lot less than current conditions. Most of the water quality observations here indicate results trending toward moderate productivity (Table 2.3-1). Other visual indicators, like appearance of algae blooms and filamentous green algae are factors that force a productivity assessment higher.

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 A1-8). 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 A1-7 (general taxa) and Table A1-10 (Chironomidae) highlight with shaded cells change in the species list at each of the sampling locations in Cranberry Creek. 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 A1-8 (general taxa) and Table A1-11 (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 among the years 2016, 2017, 2019 and 2021 are reported in Table A1-9. Changes in the Chironomidae taxa between the years 2016, 2017, 2019 and 2021are reported in Table A1-12.

In all sampling locations, species richness increased from the 2016 event to the 2017 event for both general taxa (Table A1-8) and the Chironomidae (Table A1-11). The overall number of general taxa increased at the upper location by one and increased by four taxa at the lower sampling location (Table A1-8). 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 A1-5). 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 four 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.

Common taxa that appeared in 2021 at all sampling locations in Cranberry Cover were: Amphipoda, *Caecidotea* sp., Sphaeriidae, Oligochaeta, and *Bezzia* sp. (a biting midge that inhabits lake environments). Highest densities of individual taxa were Sphaeriidae (also known as pea clams or fingernail clams) and Oligochaeta at all benthic sampling locations. Notable taxa collected from Cranberry Cove were *Sialis* sp. (also known as alderflies) and collected from the upper- and middle locations while the caddisflies Hydroptilidae and *Oxyethira* sp. were collected from the lower location. The remaining caddisfly Leptoceridae was found in low abundance at each of the three locations in Cranberry Cove (Table A1-7). This species preys on freshwater sponges found in lakes and on snails (Morse and Lenat 2005). Highest non-midge density of benthic macroinvertebrates was collected from the middle Cranberry Cove sampling location (Table A1-7).

Unique taxa appearing in 2021 (five years following dredging) were Hydroptilidae (purse-case caddisflies) and *Sialis* sp. (alderflies). The hydroptilid caddisflies are piercers and feed on either algal cells or on fluid of prey (micro- benthic macroinvertebrates) (Pritchard and Leischner 1973). Their presence indicates development of the biological community to include higher trophic levels than from previous years following dredging. *Sialis* sp. is a top predator that has a long-lived life cycle (two-years) in the aquatic environment. Among preferred benthic prey preferred by *Sialis* sp. are the Chironomidae and Oligochaeta. Both taxonomic groups represent the largest number of benthic macroinvertebrates collected in both the upper- and middle-sampling locations of Cranberry Cove. The benthic macroinvertebrate community is becoming more complex by increasing in number of species and in representation of trophic (feeding) groups. Fully functioning freshwater benthic communities include representative taxa from all trophic levels like primary consumers (plant and algae food base), detritivores (consume dead plants and animals), and predators (consume live benthic invertebrates).

Changes in the lake bottom occur in Cranberry Cove as sediment source of delivery continues from Cranberry Creek. Moving forward, periodic bathymetric surveys starting in 2022 should be conducted to evaluate the effect of sediment translocation on the transect gradients established prior to and following dredging. Channel shape in Cranberry Cove should be mapped over time leading to recommendation of potential long-term maintenance needs. It is expected that deeper portions of the thalweg transect in both coves will become slightly shallower due to sediment transport from the upstream shallow areas.

Future benthic macroinvertebrate monitoring should occur every five-years following the 2021 monitoring event. This frequency for benthic monitoring will benefit consideration of future dredging needs. Coordination of the benthic macroinvertebrate surveys with the bathymetric surveys is recommended beginning 2026.

3.0 PERMIT STATUS

AquaTechnex is the administrator for the herbicide permit and that permit is valid through 2022. For economic and liability efficiency Lake Advocates recommends that AquaTechnex should continue to be the permit holder and administrator for the coming permit cycle (historically every 5 years).

The permit for dredging fine sediment material from Cranberry Cove and King's Cove was issued by Mason County Public Works with input from the Washington Department of Fish and Wildlife, Washington Department of Ecology and The Squaxin Island Tribe. Final requirements for monitoring have been completed that effectively closes this permit. Proposed future dredging would require a new permit be issued with an updated set of monitoring requirements.

4.0 CURRENT AND ON-GOING RECOMMENDATIONS

4.1 GENERAL RECOMMENDATIONS:

Aquatic Plant Management

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

* Aquatic plant mapping will continue annually at both Lake Limerick and Lake Leprechaun in May to June (may be suspended in lieu of a one-time fall survey) 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 managed in the past in both lakes, management efforts moving forward focus on continued general aquatic plant management with a focus on non-native invasive species as well as native excessive density plant beds. This also included very specific areas where treatment is needed 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 are continuing 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, but it is still resident and will return in the absence of basic control efforts and will expand its coverage and density). Another invasive non-native plant that has recently expanded its coverage is *Nuphar odorata* (fragrant waterlily also known as white, blue or pink waterlily) should be annually assessed as to how aggressive control should be planned.

- 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 increasing cyanobacteria presence, which would contribute to overall water quality decline and potentially result in HABs. Hence, a rotating control program that targets 15 to 30% of the lakes area each year will continue as in the past two decades.

- Control of filamentous green algae was successfully achieved following 2021 application of herbicide and then hydrogen peroxide. The fall plant survey (October 2021) noted the absence of the filamentous green algae in both Lake Limerick and Lake Leprechaun, especially where growth was dense (area outside of Cranberry Cove).

- To this end, next year's plant management program (2022) will include the following:

  - Exploration of management alternatives for the bird sanctuary, given observed dense growth of aquatic plants and filamentous algae in this area. This includes macrophyte control and filamentous green-algae control with hydrogen peroxide. Future efforts may also include nutrient inactivation (small alum treatment) to limit algal growth by reducing sediment phosphorus recycling. In addition, a future small-scale dredging action will 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 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, will be identified by fall surveys (and spring survey if needed).

  - 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 will continue to be conducted in both lakes during September/October to assess the effectiveness of the summer control activities and to plan for the efforts that will be needed in coming years.

Water Quality Monitoring

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 collected in 2019 in the absence of surface algal scum (possible presence of blue-green algae). To help track phytoplankton densities, chlorophyll *a* was sampled along with phosphorus samples.

Dredging and Future Projects

The final dredging permit required benthic macroinvertebrate monitoring collection through 2021 (July 1 through October 15) (Ecology 2014). A comparison of succeeding samples from Cranberry Cove was completed with the pre-/post-dredging results in this report. Data analysis focuses on indicator aquatic invertebrate taxa that identified stressors from physical habitat or water quality degradation. Biometrics normally used for analysis of biological condition were not used because a Benthic Index of Biotic Integrity did not exist for lake and reservoirs in the Puget Lowland Ecoregion (the region both lakes are located). 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 identified benthic macroinvertebrate response to removal of fine sediments from hard sediments, recolonization of hard sediments, and availability of food base following dredging. The benthic macroinvertebrate community following dredging was examined for suitability as food for resident fish in Lake Limerick. Benthic macroinvertebrate sampling should be conducted every five-years following the 2021 sampling event. This information is useful for detecting change based on sediment deposition and movement in the coves.

The LLCC will explore future dredging projects in Lake Limerick and Lake Leprechaun and evaluate short-term planning and long-term maintenance needs associated with the completed dredging projects in Lake Limerick. The first step is to develop a feasibility study that will examine source of sediment, volume of sediment delivered to each of the lakes over time, volume of sediment that could be removed in each lake once sediment control is achieved, and sediment removal maintenance including cost to perform maintenance on potential structures.

- More information on sediment in Lake Leprechaun is necessary to effectively explore dredging portions of that lake such as analysis of the sediment core collected in October 2021.
- Bathymetric survey of previously dredged areas should be completed to determine rate of in-filling from sediment sources like Cranberry Creek.
- An estimate of dredge material that could be removed from Cranberry Cove and King's Cove will be based on a recent bathymetric survey and will help a future decision whether to proceed with a similar project.

A long-term Dredging Strategy is needed to inform LLCC management and staff on location and frequency projects may be required. Cost determination and feasibility to implement projects over time will help define environmental outcomes for comparison against long-term goals.

- Dredging portions of Lake Leprechaun is needed due to sedimentation, *i.e.*, the inlet bay.

- It's estimated that approximately one quarter of lake Leprechaun shoreline area should be dredged along with aquatic plants.
- A strategy should be explored for lowering lake level prior to implementing a dredging project.
- An effort should be made to locate the existing valve at Lake Leprechaun outlet spillway (need to determine distance below the surface).
- Prior to dredging in Lake Leprechaun, water should be pumped below the level of the valve.

Bird Sanctuary sediment removal and/or nutrient inactivation in Lake Limerick is important to consider as the islands in the lake are beginning to expand and plant material becoming increasingly dense on the margins. A few suggested combinations of treatment should be considered.

- Alternatives include and will be evaluated against lake maintenance and restoration goals:
  - 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.

The short-term aquatic plant management strategy should continue to include spring and late summer surveys that help develop a plant management strategy for each year. Effectiveness of past herbicide applications inform the following year's treatment strategy.

- The goal for management of invasive aquatic plants is to stress plants earlier in the season with a contact herbicide, either Diquat or Endothall and follow with hydrogen peroxide. The second application occurs 14 days following contact application and use a systemic herbicide (Fluridone: soluble form early or quick release pellet in the late spring or early summer followed by a pellet form, time-release later in the summer.).
- Application permits are already in place for 2022 aquatic plant treatment.
- Aquatechnex is the applicator holding the current permit; May/June 2022 timeline for permit application for treatment.

Additional efforts to educate lake residents on maintaining a healthy lake is an on-going recommendation. Sources of nutrient as well as sediment input to the lake are on-going concerns that erode the ecological quality of the lakes as well as recreational and aesthetic experiences.

- LLCC should actively promote septic tank management and education to reduce nutrient loading to the lakes as well as landscaping education to enhance shoreline protection (including waterfowl management) and nutrient buffering. Specifically, all septic tanks should be pumped every other year and septic drainfields and drainage areas below drainfields should be inspected at least every three years.
- A comprehensive study that focuses on nutrient sources to Lake Limerick and Lake Leprechaun should be implemented. The on-going weed management effort is directly

affected by nutrient availability in the lake and outside sources can be reduced or abated when identified.

The volume of fine sediment dredged from Cranberry Cove was larger than the same dredge area from King's Cove. Source of fine sediment could only be delivered to the lake from Cranberry Creek. Unknowns about this sediment delivery are the rate of deposition in the lake, extent of deposition in Cranberry Cove, and timing for fine sediment delivery. Evidence for nutrient input to the lake in Cranberry Cove is identified through growth of the filamentous green algae. Further investigation that provides answers to these questions will prompt a feasibility study to determine sediment removal approach and the best alternative for slowing aging of the lake through delivery of fine sediments and associated nutrients. The following are suggested strategies to address this problem:

- Control sediment and nutrient inflow from Cranberry Creek
  - Alternatives include:
    - Extensive watershed management.
    - Dredging every 5 to 10 years.
    - Sediment removal/control from above the outlet dam in Cranberry Lake (Alternative 1).
    - Interception of sediment and potential nutrients via a sedimentation pond targeting Cranberry Creek high flow events (Alternative 2).

Alternate methods for aquatic plant management under consideration by Lake Advocates include hand-harvest with bottom barriers and diver dredging that will enhance current and past plant and sediment management effort. Lake management is an on-going effort and is exemplified in Lake Limerick and Lake Leprechaun through successful invasive aquatic weed reduction and control of harmful algal blooms (HABs). Managing these ecological elements of the lakes has also improved conditions of recreation, aesthetic value, and for the fishery. Exploration of additional nutrient and sediment control will help the lakes maintain an ecological balance that promotes the goals of this program.

4.2 PRIORITIZED RECOMMENDATIONS

Several lake quality management actions have been the focus of efforts for the past number of years. Those activities include aquatic plant management, water quality monitoring, and future dredging projects. Management of the lakes for improvement of native plant presence and invasive plant eradication has been on-going and will be a short- and long-term priority. Other natural processes like sedimentation in lakes and the sources become greater issues over time and are managed with periodic actions like dredging. The following are prioritized management actions organized in the short-term (5-Year Lake Management Priorities) and over the long-term (>10-Year Lake Management Priorities).

4.2.1 Short-Term Management Activities

Short-term lake management priorities are organized in the following Table identifying management action, reason for the priority order, and evaluation of the benefit and cost in achieving lake management goals. The benefit and cost analysis considers the effectiveness of a treatment (e.g., immediate or passive, size of the area a treatment option encompasses, and how long effects of a treatment last). The cost estimate is based on previous years application of these options and known cost from other project experience.

Top Priority (5-Year Lake Management Priorities)

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
1*	Annual aquatic plant survey during the late summer season.	Results from this survey are an indication of effectiveness of the herbicide application earlier in the year.	High - **$8,400**/year
2*	Annual aquatic herbicide treatments in both Lake Limerick and Lake Leprechaun.	Continued control of invasive aquatic plants that promote establishment and distribution of native aquatic plants.	High - 15% to 30% of each lake - **$15,000** to **$30,000**/year
3*	Water Quality Monitoring	Water sampling in months near end of spring and end of summer explain appearance (and source) of algae growth. Concentrations determine risk for detecting blue-green algal blooms (Harmful Algal Blooms).	High **- $1,500**/year
4	Geese Mitigation	Presence of geese contributes substantial quantities of waste including phosphorus that reaches the lakes. Increasing density of geese exacerbates nutrient input directly to the lakes encouraging invasive aquatic plant growth and proliferation of filamentous green algae. Note 0.7 pounds of phosphorus contributed per goose per year that will lead to 6,700 pounds of algae production. Control of geese can	High – Shoreline landscape to discourage geese, plus geese harassment by trained dogs, and drones. Note drone boats and planes can be operated by citizens. – Education promotion and training – **limited cost** (Cost=Purchase of drone)

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
		use passive methods at relatively low cost.	
5	Annual on-site septic system maintenance.	Filamentous green algae are beginning to appear in greater density and areas along select areas of the lake shorelines. Establishment of filamentous green algae usually indicates excess nutrient seepage from drain fields toward the lake. Septic tank pumping and inspection should occur on at least a 3-year recurring interval. Although a functioning drain field can result in nutrient absorption by soils prior to entering the lakes, soil enhancement of nutrient absorbents and vegetation buffers are needed.	High – Education annually to promote action – 3 to 4 years
6	Shoreline lawn removal	Fertilized lawns extending to the edge of the lake contribute nitrogen at levels that promote algae growth. Filamentous green algae are appearing now at lake margins and blue-green algae may result in "blooms" and potentially, release neurotoxins.	High – Education and training to promote understanding and action by citizens (**Limited Cost)**
7a	Investigate source(s) of soft-sediment to Lake Limerick. (Cranberry Creek)	Shifting of sediments following 2016 dredging in King's Cove and Cranberry Cove have contributed to a decline in depth.	High - **$7,000** to **$14,000**
7b	Stream walk of Cranberry Creek to identify sources of soft-sediment from bank or channel erosion.	Cranberry Cove soft-sediment may originate from one or more locations at Cranberry Lake and Cranberry Creek. Measuring depth of soft-sediment in front of the outlet dam in Cranberry Lake and searching for erosional areas	High – **Cost covered in 7a**

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
		along Cranberry Creek will confirm potential sources (Priority 7a). Removal of soft-sediment from above the outlet dam when first constructed will be used to estimate accumulation since 1989.	
7C	A bathymetric survey is required in areas where soft-sediment in-filling has occurred since the last dredging project.	The change in bathymetric shape will indicate how rapidly soft-sediment deposition is occurring in Cranberry Cove and King's Cove. Source(s) of soft-sediment delivery to the lake will be identifiable based on results from this survey (Priority 7a).	High - **$10,000**/event

Notes:
∗ Prioritized actions that must be conducted annually.

4.2.2 Long-Term Management Activities

Long-term lake management priorities are organized in the following Table identifying management action, reason for the priority order, and evaluation of the benefit and cost in achieving management goals. The benefit and cost analysis considers the effectiveness of a treatment (e.g., immediate or passive, size of the area a treatment option encompasses, and how long effects of a treatment last). The cost estimate is based on previous years application of these options and known costs from other project experience.

Top Priority (>10 Year Lake Management Priorities)

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
1*	Bird sanctuary dredging and plant removal.	The two islands once separated are growing together. Increased invasive plant growth encouraging additional sedimentation along the shoreline of these islands is shrinking channel width between islands. Additionally, homeowner shorelines on one side of this area are experiencing an increase in filamentous algae growth.	High - **$1,000,000 to $1,500,000** – 10 years
2*	Dredging in Lake Limerick (Cranberry Cove, King's Cove, Bird Sanctuary).	This an expensive, but immediately effective approach to extending the life of Lake Limerick. A bathymetric survey (Priority 7C in Short-Term Priorities) is necessary before any estimates for volume of soft-sediment removal is finalized. Dredging prolongs manageable lake conditions including reduced invasive aquatic plant control and green filamentous algae. Dredging could be implemented on a 5- to 10-year interval depending on rate of accumulating nutrients and sediments.	High - **$2,000,000** to **$5,000,000 –** 15 to 20 years
3	Construct sedimentation pond near base of Cranberry Creek.	Construction of a new sedimentation pond may be necessary if the source of soft-sediment to Cranberry Creek is not	Moderate - **$1,500,000** to **$2,000,000** – Long-term Operation with annual Maintenance cost

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
		identifiable or Priority 7B (in Short-Term Priorities) does not inform the source is from Cranberry Lake or there is an absence of signs of bank erosion on Cranberry Creek.	
4	Dredging In Lake Leprechaun.	Signs for soft-sediment in Lake Leprechaun were not immediately evident during the October 2021 survey for core samples. Coarse sediment has accumulated at the inlet and may contain some nutrients as indicated by past prolific growth of the aquatic plant mare's tail (*Hippurus vulgaris*). Confirmation of areas with soft-sediment and depth will need to be completed before estimating volume of soft-sediment for removal.	**Moderate** to **High** – Cost to design and implement dredging of Leprechaun would be **$1,000,000** to **$2,000,000** – 10-15 years
5	Establishing a local sewer district.	This is the costliest of all long-term alternatives in nutrient control to the lake. A utility local improvement district can be formed within the LLCC community as it is not part of a city or town. [RCW 36.94.220: Local improvement districts and utility local improvement districts—Establishment—Special assessments. (wa.gov)] Cost for establishing infrastructure may be borne by issuance of local improvement bonds. The larger grants for establishment of wastewater treatment facilities are typically available for counties, cities or jurisdictional health departments.	Moderate - **$12,000,000** to **$25,000,000**, Note cost of sewer-line is **$1,000,000**/milein addition to constructing a treatment plant with phosphorus control is **$5, 000,000** to **$10,000,000**. Plus, **$250,000** to **$500,000** operational and maintenance cost – Long-term utility that maintains effectiveness over time.

Priority	Management Action	Reason for Priority	Benefit & Cost Analysis (Effectiveness – Extent - Longevity)
		The establishment of a sewered system for lots around the lake would be effective in removing nutrients that have long-term influence on plant and algae growth. However, sources of input exist from creek inlets, boats re-suspending existing nutrients deposited in bottom soft-sediments and decay of aquatic plants. This alternative is not a single solution for management of lake plant communities and continuing soft-sediment deposition.	

Notes:

* Focus of effort for these prioritized action items should be on a feasibility study that includes a phased approach and expected outcomes. Cost for implementing these action items will be high and generating funds will take time.

Management of Lake Limerick and Lake Leprechaun for eradication of non-native aquatic plants, reduction of fine sediment and nutrient is an on-going effort into the future. Some of the recommended priorities have been demonstrated to be effective in the short-term. These actions are necessary for inclusion in the annual budget to maintain advances in improved lake quality that are realized by long-term action priorities (e.g., periodic dredging). Short- and long-term action priorities will prolong the life of the lakes in a way beneficial for recreation, aquatic life, and aesthetics. The combination of these lake management actions have been demonstrated from past effort and support by the LLCC Lake and Dam Committee. Cost for the long-term lake management actions have estimated effectiveness times that are significantly longer than short-term priorities, but do not supersede necessity of short-term actions. The goal for selecting lake management actions is to determine which will achieve desired outcomes while fostering healthy aquatic resources and that can be implemented by the LLCC Lake and Dam Committee.

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APPENDIX 1: BENTHIC DATA TABLES

Table A1-1. 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° 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		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 A1-2. 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° 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**
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 A1-3. 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 A1-4. 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 A1-5. 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	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		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 A1-6. 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	**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**
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 A1-7. Benthic sampling results from three locations in Cranberry Cove after dredging (10/08/2021).

	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			1		1	1		5	4
*Amphipoda**	5	3	7	8	15	11	6	25	20
Caecidotea	24	19	20	28	78	12	7	32	17
Hirudinea							1		1
Ferrissia		1			1				
Gyraulus				1					
Menetus		3		1	1				
Planorbiidae						1			
Physella		2							
Sphaeriidae	66	61	33	57	54	35	22	70	30
Nematoda		1							
Oligochaeta	56	49	54	281	223	125	20	71	5
Ostracoda					6	1	2	14	13
Turbellaria		1			1				1
Epitheca				1					
Sialis		2				1			
Hydroptilidae								3	1
Oxyethira larva							2		
Oxyethira pupa								2	1
Leptoceridae	1				1		1		1
Bezzia	4	7	4	2	11	1	3	4	3
Chironomidae pupa								1	
Total Density	**151**	**149**	**119**	**379**	**392**	**188**	**64**	**227**	**97**

*Possibly *Crangonyx sp.*

Table A1-8. Chironomidae identified from post-dredging replicate samples from Cranberry Cove (10/08/2021).

	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**
Chironomus				5	7	11	4	20	15
Cladopelma	136	131	142	138	87	79	3	42	26
Cladotanytarus	1		1		2				
Clinotanypus	1							1	
Corynoneura		1							
Crytochironomus	1					1			1
Dicrotendipes	7	32	6		10	2	10	15	3
Labrundinia							1	10	3
Microtendipes pedellus grp.							1		
Polypedilum	3	1	5	15	9	4		12	21
Procladius	21	17	17	34	36	9	12	74	150
Psectrocladius		1		1					
Tanytarsus	4	7	3	6	4	1	1	8	6
Thienemannimyia complex		1							
Total Density	**174**	**191**	**174**	**199**	**155**	**107**	**32**	**182**	**225**

Table A1-9. Benthic taxa comparison between 2016, 2017, 2019 and 2021 sampling results.

Taxon	Collection Year											
	2016	2017	2019	2021	2016	2017	2019	2021	2016	2017	2019	2021
	Cranberry Cr (Upper)				Cranberry Cr (Middle)				Cranberry Cr (Lower)			
Acari	X	X	X	X	X	X	X	X	X		X	X
Amphipoda			X	X			X	X			X	X
Crangonyx				X		X		X				X
Hyalella	X	X				X			X	X		
Caecidotea	X	X	X	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	X
Hydra	X	X	X			X	X			X	X	
Ferrissia	X			X	X	X	X	X	X	X		
Gyraulus	X	X			X	X	X	X	X	X	X	
Menetus		X		X				X	X	X		
Physa		X				X	X		X	X	X	
Physella				X								
Planorbidae								X				
Sphaeriidae	X	X	X	X	X	X	X	X	X	X	X	X
Nematoda	X		X	X	X		X		X	X	X	
Oligochaeta	X	X	X	X	X	X	X	X	X	X	X	X
Ostracoda	X	X	X		X	X	X	X	X		X	X
Turbellaria	X	X	X	X	X	X	X	X	X	X	X	X
Epitheca								X				
Sialis				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	X
Oxyethira pupa		X	X		X		X				X	X
Hydroptilidae												X

Taxon	Collection Year											
	2016	2017	2019	2021	2016	2017	2019	2021	2016	2017	2019	2021
	Cranberry Cr (Upper)				Cranberry Cr (Middle)				Cranberry Cr (Lower)			
Polycentropus							X				X	
Leptoceridae				X				X				X
Mystacidae		X				X				X		
Triaenodes		X				X					X	
Ceratopogoninae	X	X	X		X	X	X		X	X	X	
Empididae										X		
Hemerodromia											X	
Bezzia												
Ephydridae pupa				X			X	X				X
Chironomidae larva	X	X	X	X	X	X	X	X	X	X	X	X
Chironomidae pupa	X	X	X		X		X				X	X

Table A1-10. 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 A1-11. 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 A1-12. Relative change in number of taxa from Cranberry Creek sample locations (2016/2021).

Direction of Change	Collection Year		
	2016 → 2021	2016 → 2021	2016 → 2021
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	+7	+7	+6
Decreasing # of Taxa	-10	-9	-9
Net Taxa Gain	-3	-2	-3

Table A1-13. Comparison of Chironomidae taxa in Cranberry Creek between 2016, 2017, 2019 and 2021 sampling results.

Taxon	Collection Year											
	2016	2017	2019	2021	2016	2017	2019	2021	2016	2017	2019	2021
	Cranberry Cr (Upper)				Cranberry Cr (Middle)				Cranberry Cr (Lower)			
Ablabesmyia											X	
Chironomus	X		X		X	X	X	X	X	X	X	X
Cladopelma	X	X	X	X	X	X	X	X	X	X		X
Cladotanytarsus		X		X				X		X		
Clinotanypus		X	X	X	X		X		X			X
Corynoneura			X	X							X	
Cricotopus	X	X			X				X			
Cricotopusbicinctus grp		X										
Cryptochironomus		X		X		X		X				X
Dicrotendipes	X	X	X	X	X	X	X	X	X	X	X	X
Guttipelopia			X				X			X		
Labrundinia			X			X	X				X	X
Microtendipes pedellus grp.	X				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	X	X	X
Procladius	X	X	X	X	X	X	X	X	X	X	X	X
Psectrocladius	X			X		X	X	X			X	
Pseudochironomus	X											
Tanytarsus	X	X	X	X		X	X	X	X	X	X	X
Thienemanniella							X				X	
Thienemannimyia complex	X			X	X	X	X		X		X	

Table A1-14. 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 A1-15. 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

Table A1-16. Relative change in number of Chironomidae taxa from Cranberry Creek sample locations (2016/2021).

Direction of Change	Collection Year		
	2016 → 2021	2016 → 2021	2016 → 2021
	Cranberry Cr (Upper)	Cranberry Cr (Middle)	Cranberry Cr (Lower)
Increasing # of Taxa	+3	+4	+2
Decreasing # of Taxa	-10	-8	-4
Net Taxa Gain	-7	-4	-2

APPENDIX 2: DREDGING FIGURES

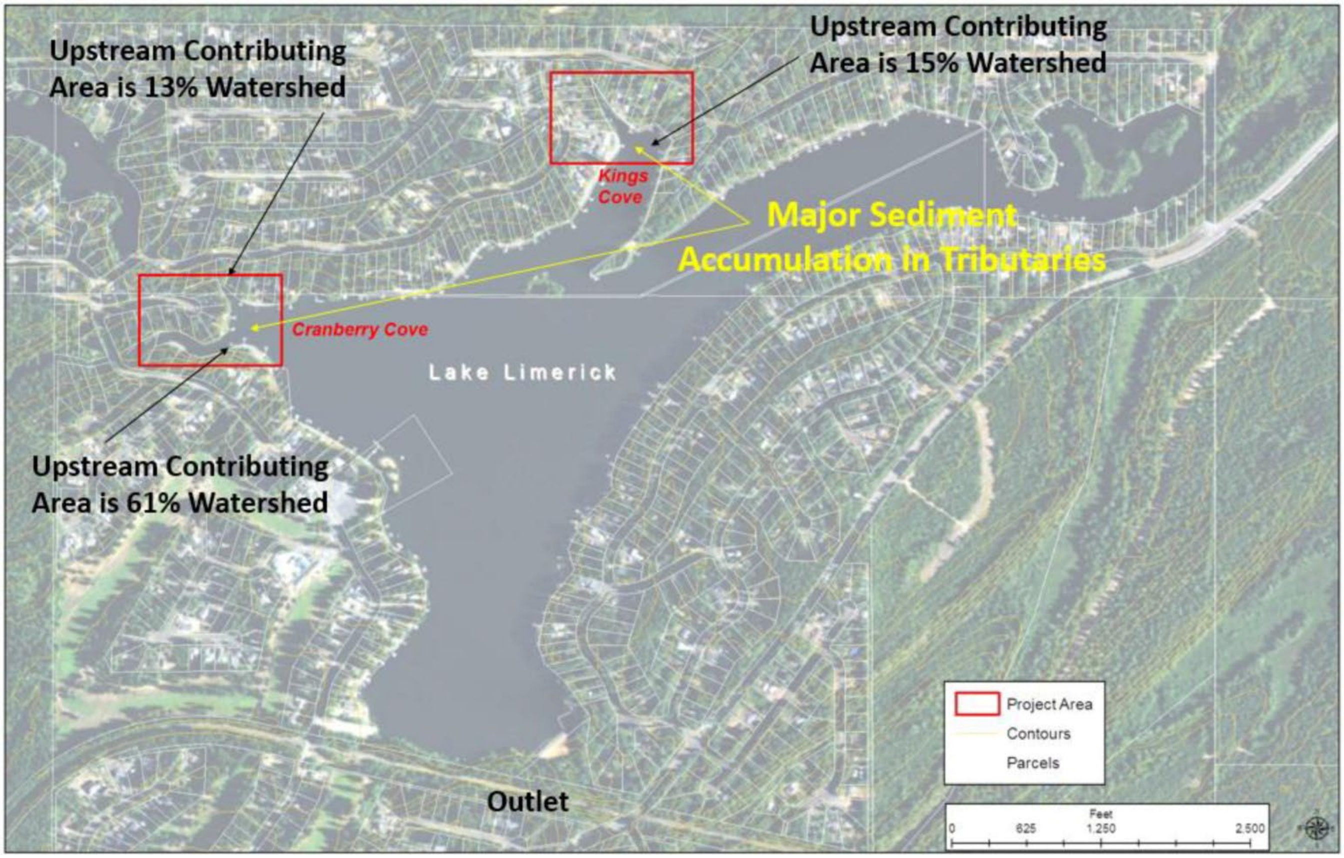
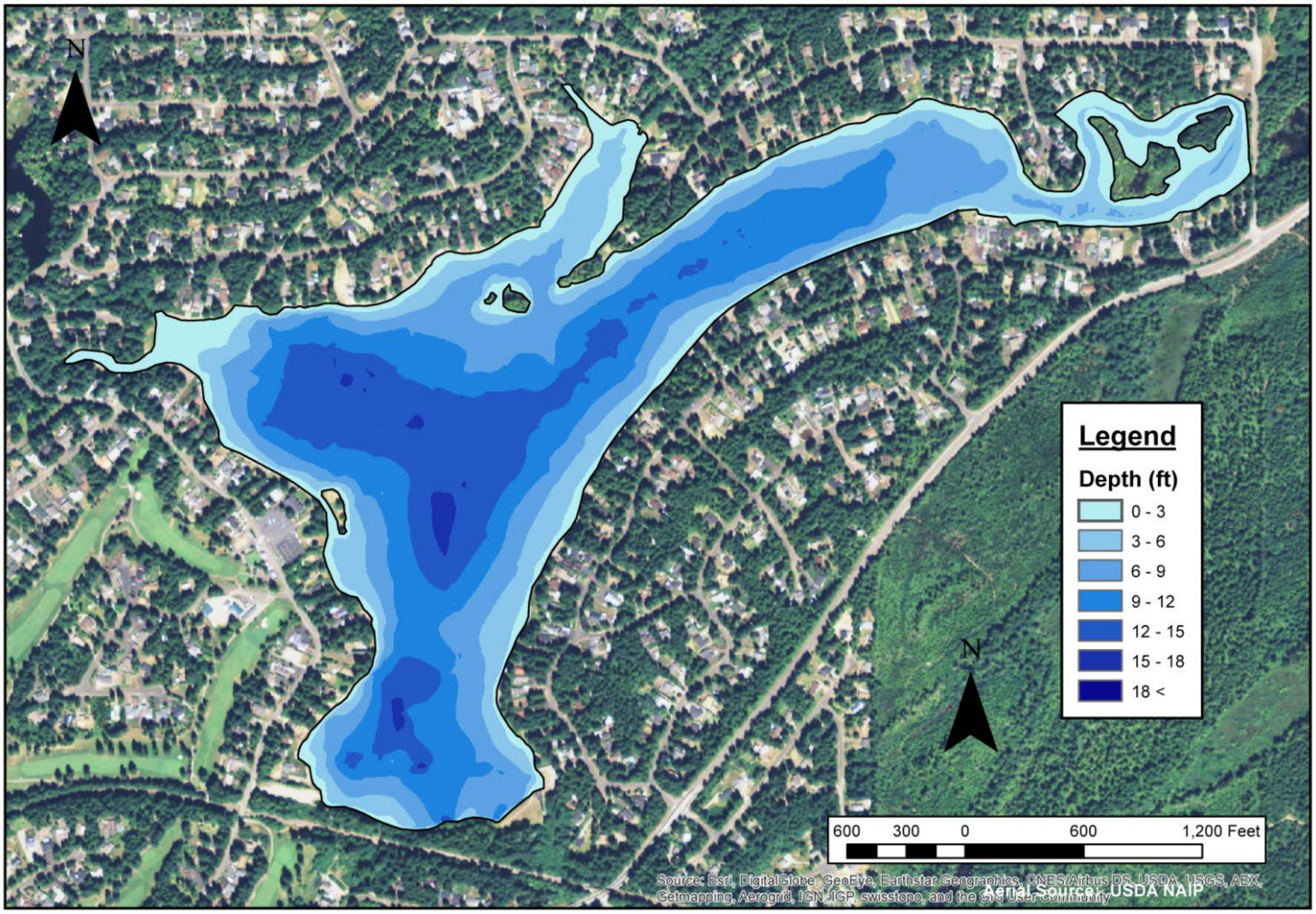


Figure A2-1. Locations for dredging in Lake Limerick



2015 Lake Limerick Bathymetric Survey

Figure A2-2. Bathymetry of Lake Limerick. Bathymetric data collected on September 11th, 2015 survey.

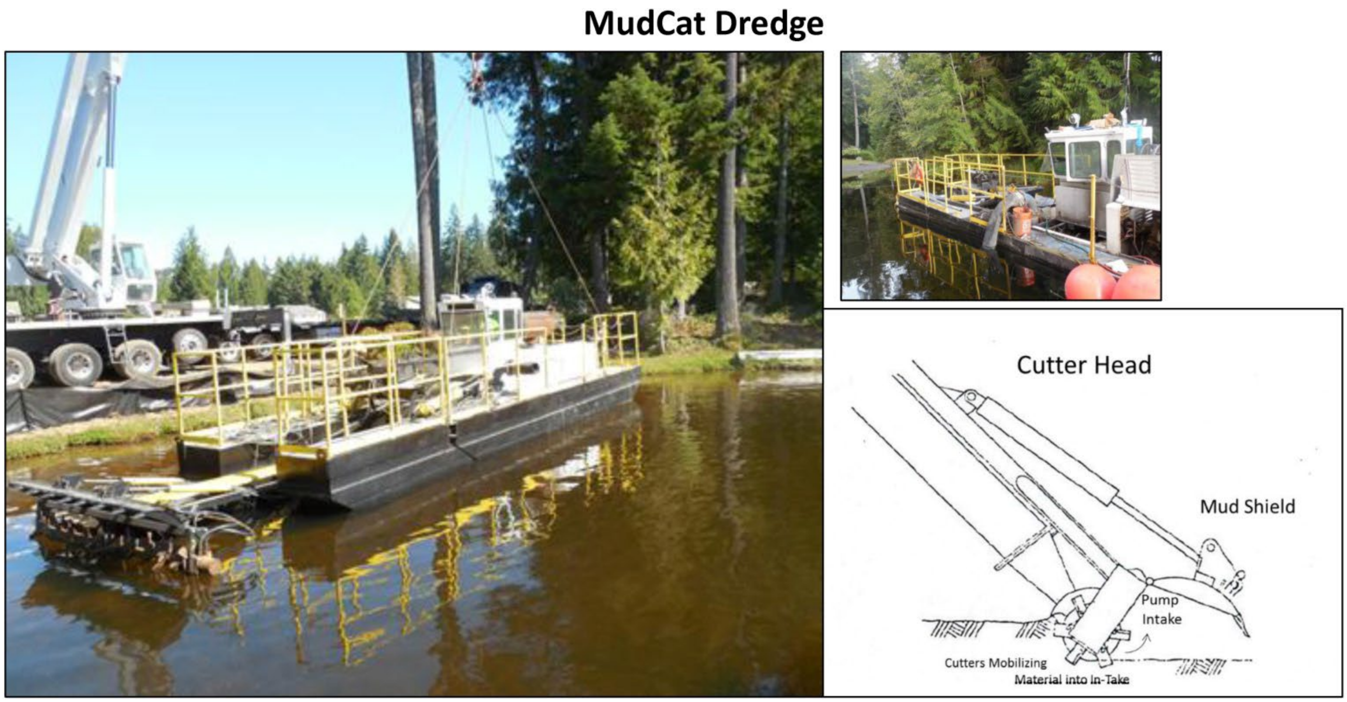


Figure A2-3. Equipment used to conduct dredging in Lake Limerick

Figure A2-4. Dredging pipeline

Figure A2-5. Injection of flocculent into dredge material

Figure A2-6. De-watering bags

Figure A2-7. De-watering of dredge material

Figure A2-8. De-watered material

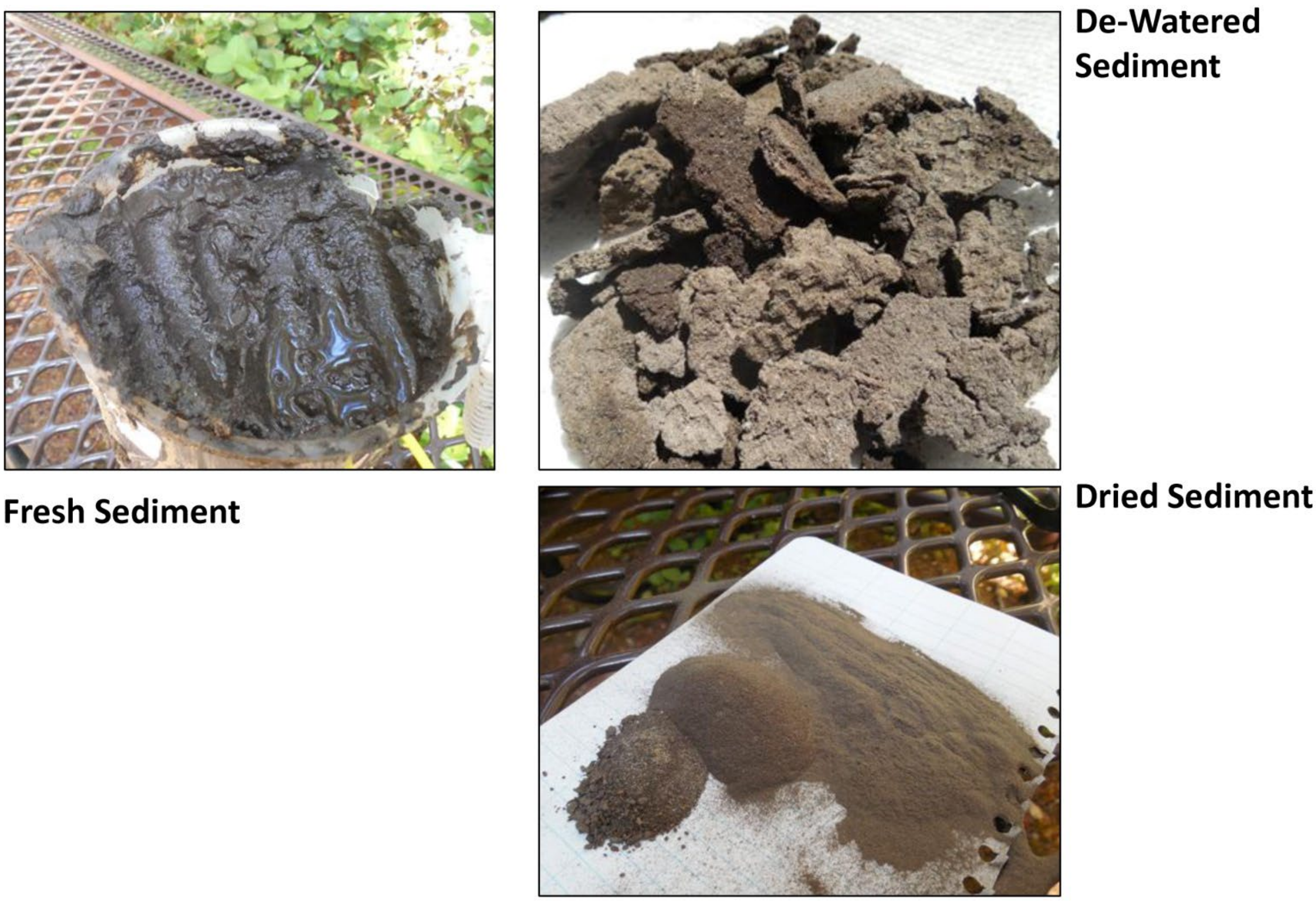


Figure A2-9. Examples of sediment during stages of the de-watering process

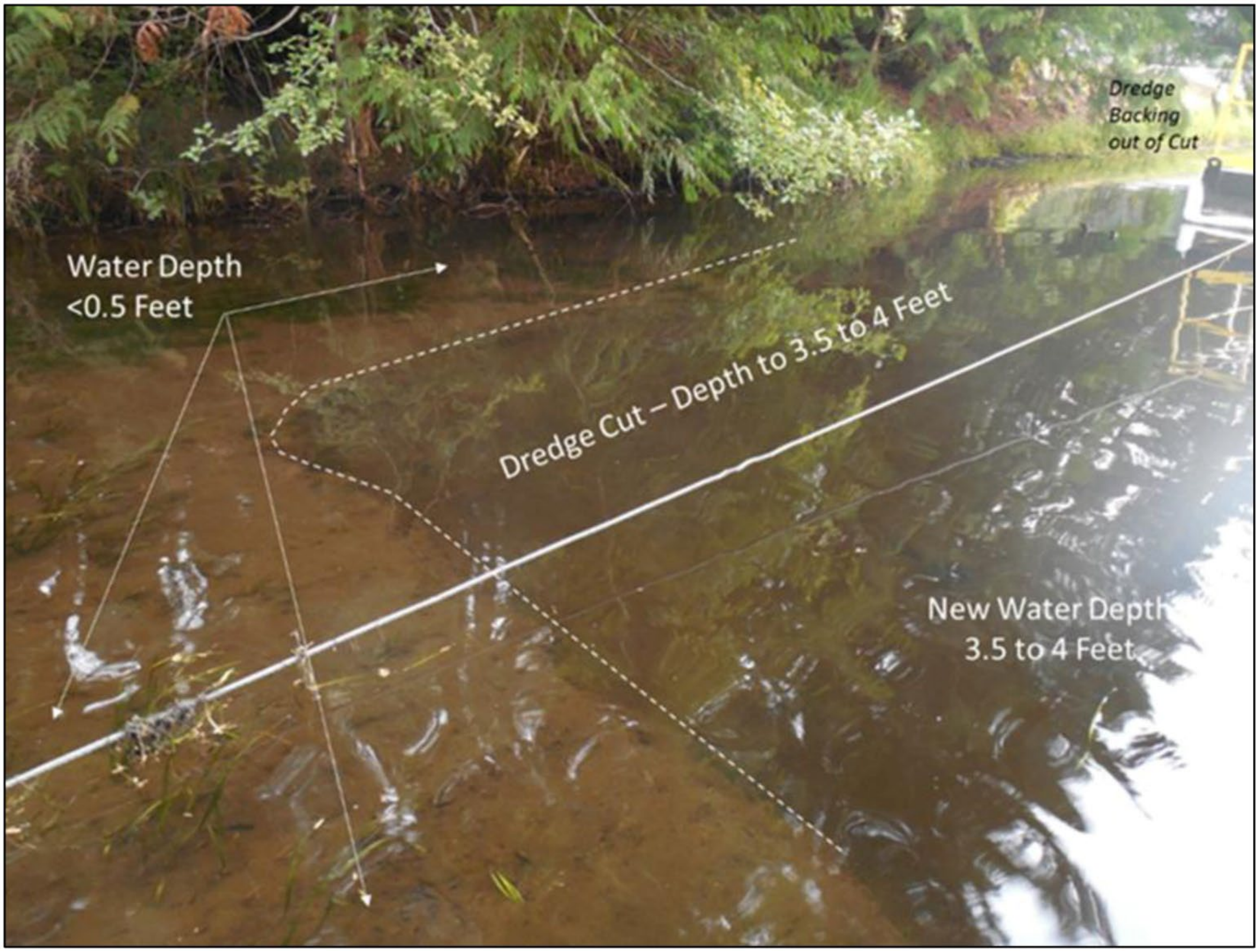


Figure A2-10. Sloughing in dredged channel

Figure A2-11. Exposure of hard sediments resulting from dredging

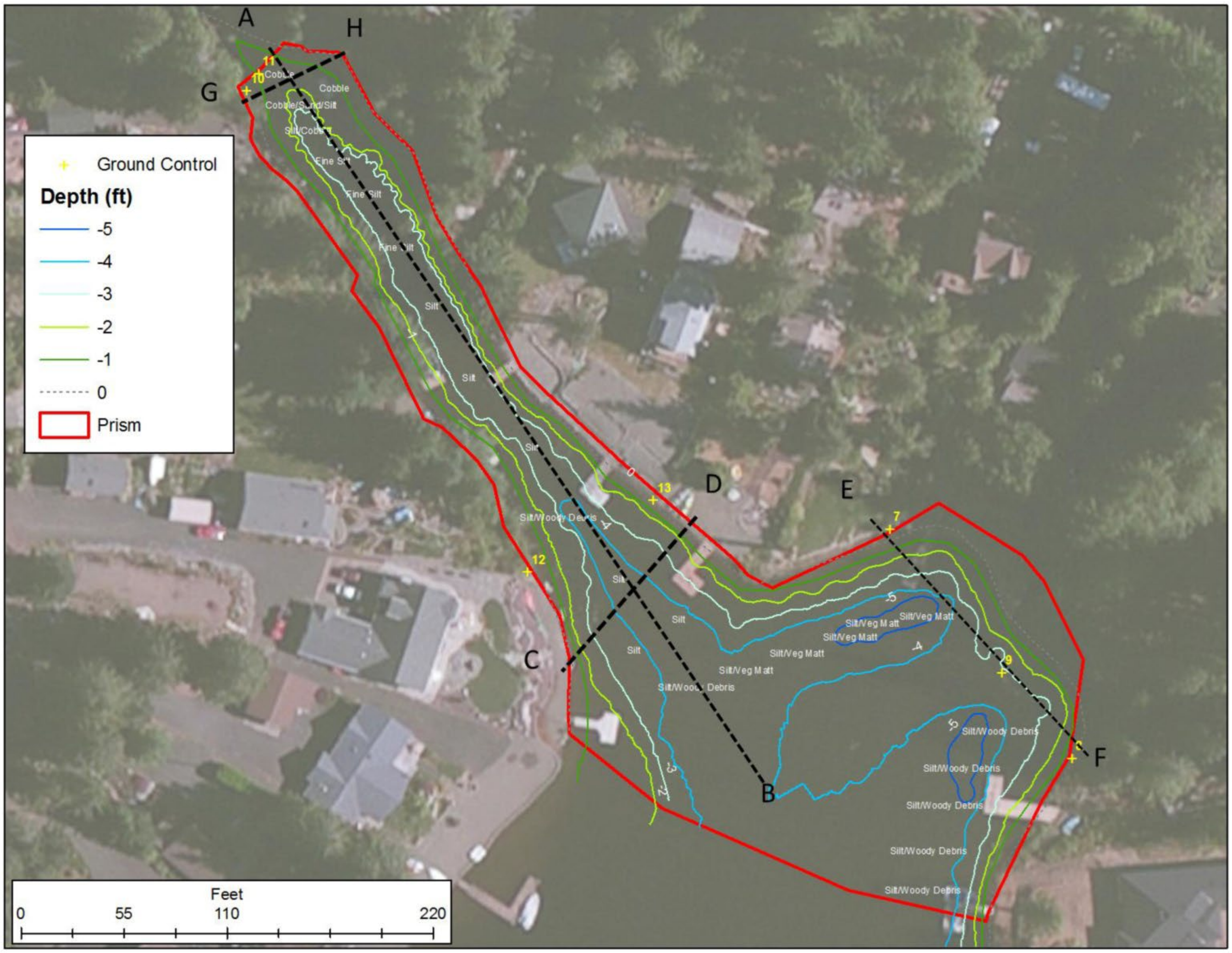


Figure A2-12. Dredging transects in King's Cove

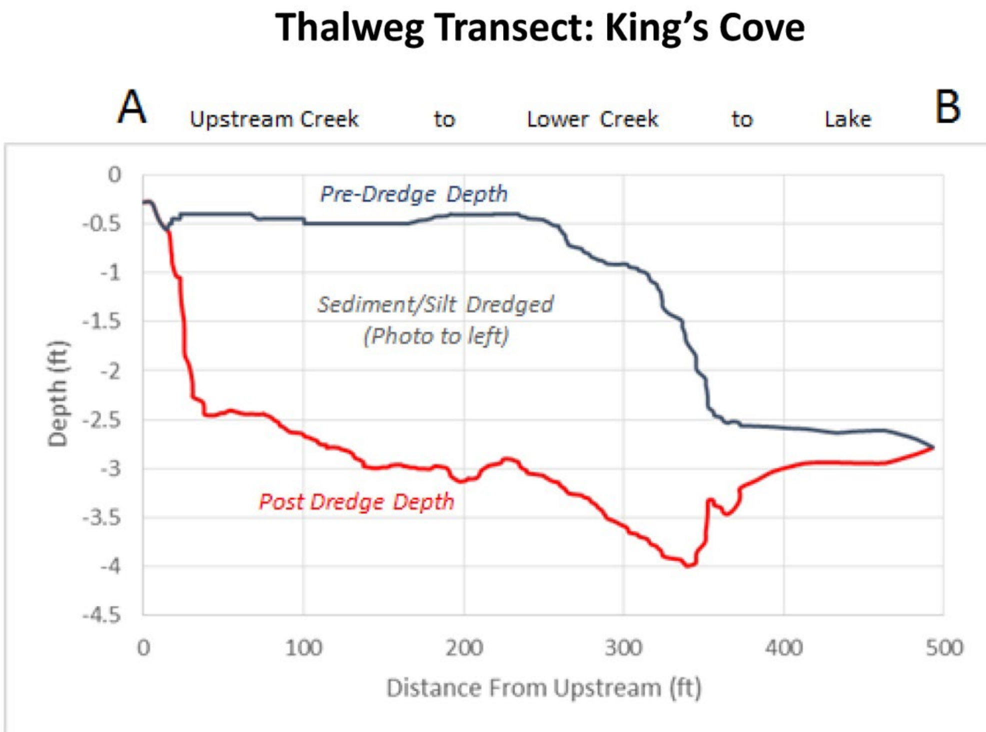


Figure A2-13. Thalweg gradient for inflows into King's Cove, before and after dredging

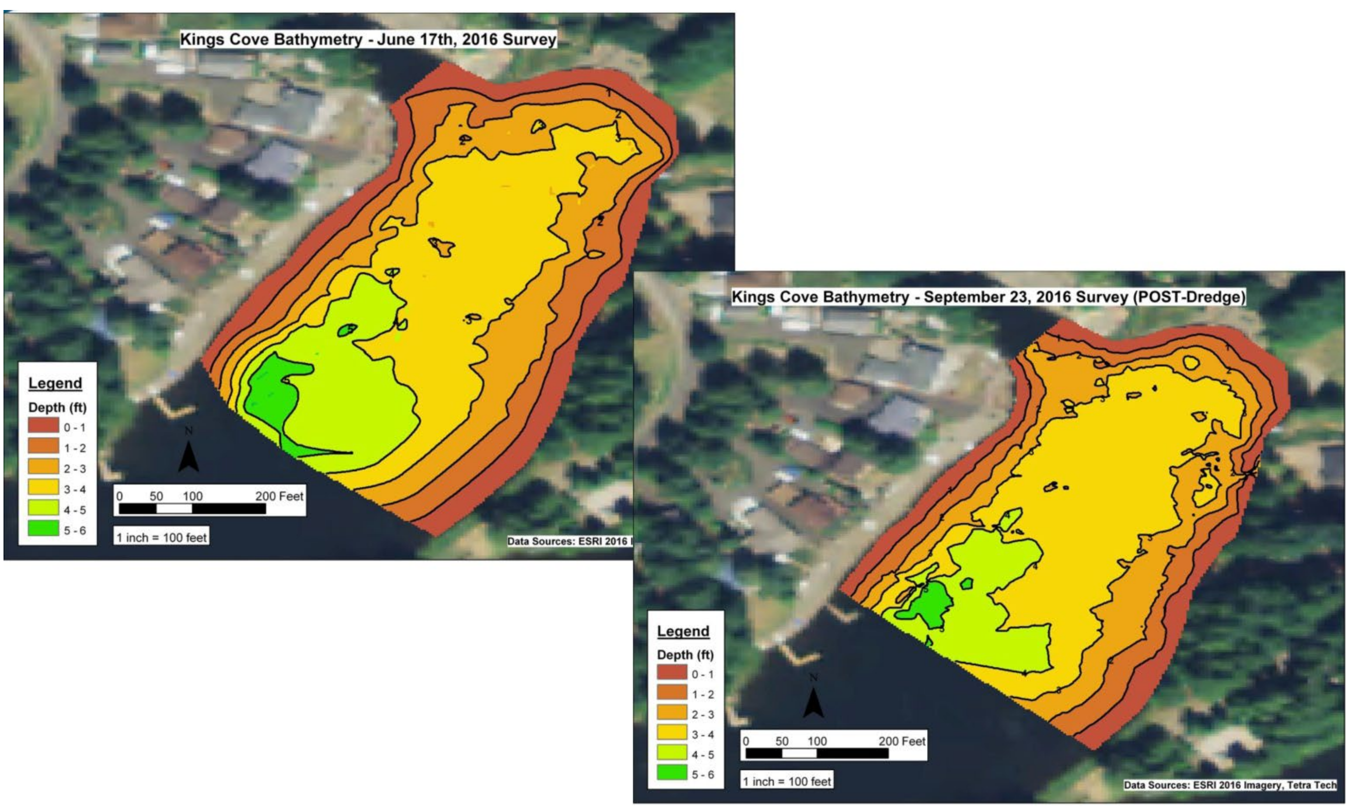


Figure A2-14. King's Cove bathymetry before and after dredging

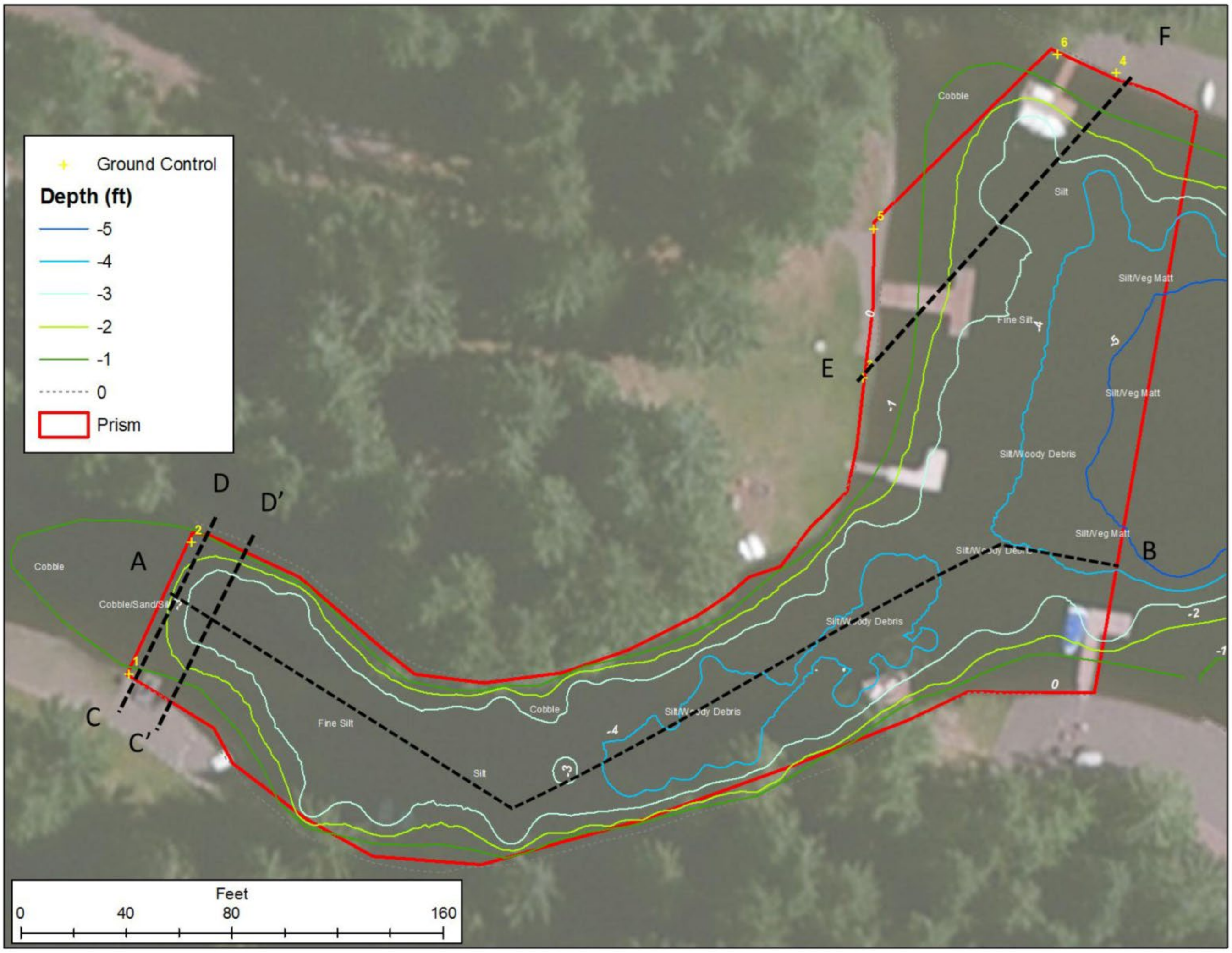


Figure A2-15. Dredging transects in Cranberry Cove

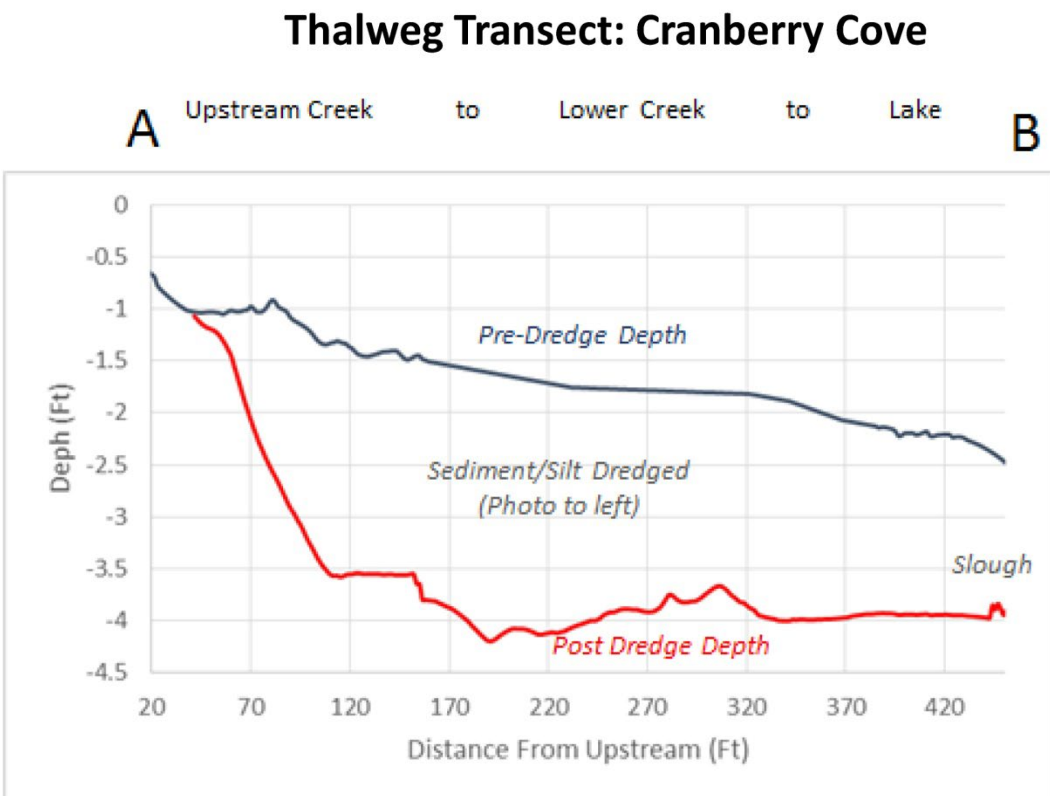


Figure A2-16. Thalweg gradient for inflows into Cranberry Cove, before and after dredging

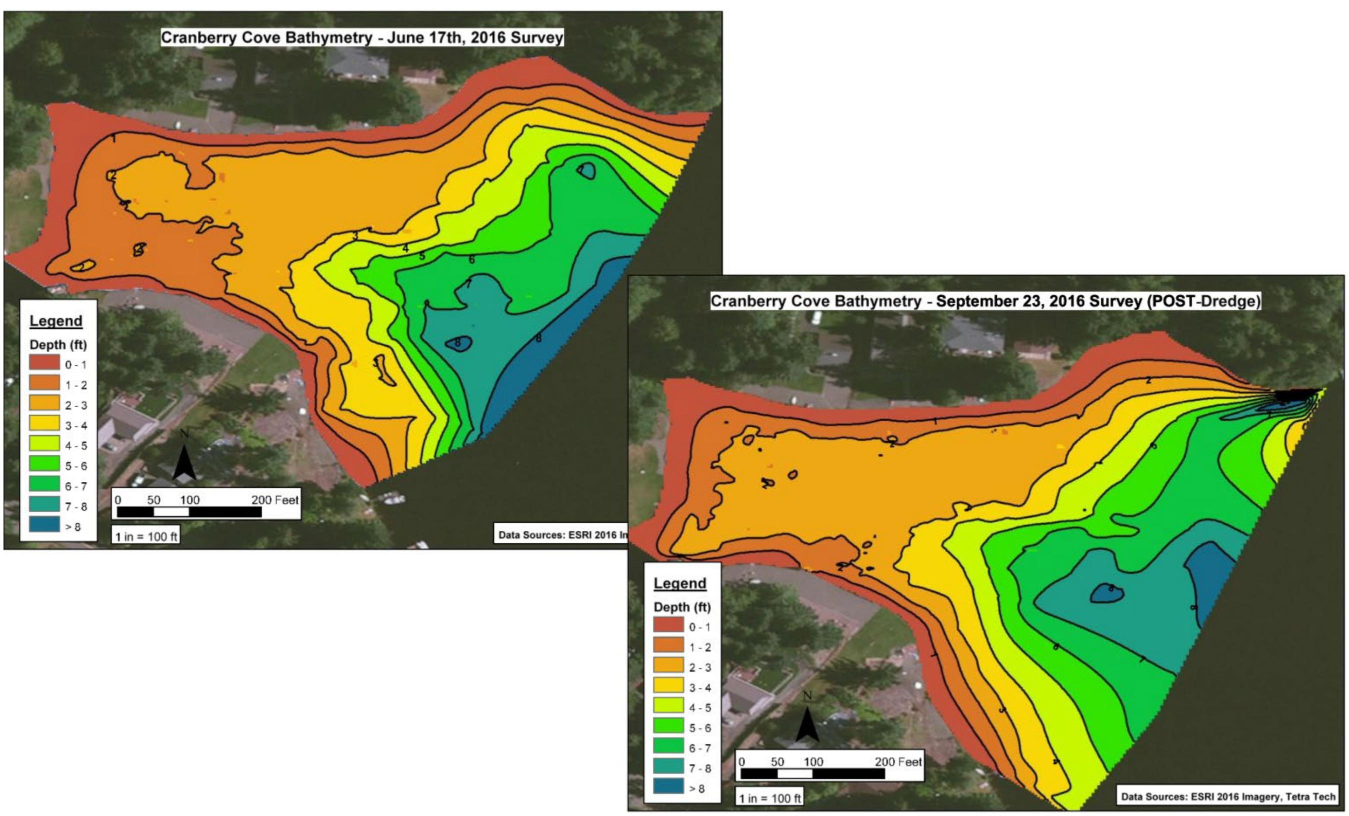


Figure A2-17. Cranberry Cove bathymetry before and after dredging

APPENDIX 3: DREDGE FINAL REPORT

< Placeholder; report attached as separate document (MIC 2016) >