Nulki-Tachick Lakes Macrophyte Harvesting Program Feasibility Study

Prepared For
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EXECUTIVE SUMMARY

Nulki and Tachick lakes lie just south of Vanderhoof, BC, in the traditional territory of the Saik'uz First Nation, and have become more eutrophic since the 1950's. These lakes are now among the most hypereutrophic lakes in BC, and experience frequent algal blooms, including blue-green algae (cyanobacteria), high summer water temperatures and low oxygen concentrations which has recently resulted in fish kills. This study was done on behalf of the Nulki Tachick Lakes Stewardship Society, and with agreement and support of the Saik'uz First Nation, to investigate the feasibility of an aquatic macrophyte harvest program on Nulki and Tachick lakes. A harvester program has been suggested to improve water quality and health of the lake ecosystems through control of macrophyte growth and removal of nutrients from the system, namely phosphorus (P). This report includes background information on the status of the lakes, a literature review of P in lakes and methods to remediate excessive P, a field-based investigation of the aquatic macrophytes present in the lakes including distribution and density, and results of laboratory analyses of nutrients and metals present in the macrophyte tissue. Based on these data, the potential for removing P from the lake ecosystems using an aquatic macrophyte harvesting program was investigated as one of the management options for a larger restoration effort. Guidance on the permitting process and a proposal for a long-term monitoring program for the lakes is provided.

Macrophyte surveys were performed on Nulki and Tachick Lakes in late August 2023, and identified nine aquatic macrophyte communities on Nulki Lake and seven communities on Tachick Lake. Aquatic macrophytes were present over 18% of the surface area of Nulki Lake and over 25% of the area of Tachick Lake, including emergent, floating, submergent, and mixed floating/submergent macrophyte community types. Aquatic macrophytes were generally present around the perimeter of the lakes and shallow bays in water depths of 2.5 m or less, with some macrophytes present in water depths up to 3.7 m. Submergent macrophyte beds deemed harvestable covered 264 ha of Nulki Lake and 485 ha of Tachick Lake. Macrophyte communities of Canadian waterweed / common hornwort (CH) and common hornwort / Canadian waterweed / Richardson's waterweed (HC), present in the shallow areas and bays, especially on the western end of the lakes, were highest in density and contained the highest concentration of P in their tissue.

An analysis of macrophyte feasibility indicated that an area of 2.1-3.1 ha could be harvested daily with a single mechanical harvester, equating to 180-261 ha of harvested area per year. Due to the variability in macrophyte distribution and density, the biomass and P that could potentially be removed from the lakes also varies widely. Assuming a single Aquamarine H5-200 harvester is used at harvesting speeds of 2-3 km/h, biomass harvest estimates range from 3,414 kg/day to 137,530 kg/day, which results in 1.6 kg P/day to 711.9 kg P/day removed, depending on the macrophyte community being harvested. These harvest rates assume the harvester operates 7 h/day at a constant speed regardless of macrophyte density or distance from a lakeshore access point. A similar aquatic macrophyte harvesting program on nearby Tabor Lake in 1995 removed an estimated 11,593 kg of aquatic macrophytes per day containing 6.72 kg P.

Achieving the maximum harvest rates on Nulki and Tachick lakes would require additional equipment and logistical coordination. For instance, equipment requirements would include the use of a net system to

contain harvested material for the harvester to work continuously, one or more dedicated vessels to transport nets full of harvested material to a shoreline access point, and a crane or excavator large enough to lift the nets over a dump truck to empty the nets. The identification of a nearby disposal site would also be required to limit transport costs.

Using data from Nulki Lake, it was estimated that 332,000 ± 16,191 kg P (mean ± SE) exists in the top 2 cm of lake sediment, representing a large potential for internal P loading during anoxic sediment conditions.

No hazards were identified in Nulki or Tachick lakes during macrophyte field surveys that could affect a harvesting program. Of the fish species present in Nulki and Tachick lakes, redside shiners (*Richardsonius balteatus*), peamouth (*Mylocheilus caurinus*), and largescale suckers (*Catostomus macrocheilus)* are likely to use vegetated habitat and shallow depths where macrophyte harvest would be likely.

Opportunities for shoreline improvement for Nulki and Tachick lakes were identified including residential structures with minimal setback and lawns extending to the shoreline, and roads, agricultural fields, and domestic livestock operations with minimal riparian buffers.

This study suggests an aquatic macrophyte harvest program may be an important part of a larger restoration effort for Nulki and Tachick lakes and a possible option to address immediate ecological risks (i.e. fish kill, severity and frequency of algal blooms and presence of cyanobacteria). To maximize the effectiveness of an aquatic macrophyte harvest program, EDI recommends that a focused approach is taken in conjunction with a larger watershed-scale restoration effort. A focused macrophyte harvest program would include harvesting submergent macrophyte beds in a limited area on the western end of Nulki and Tachick lakes, where macrophyte communities with the highest density and containing the highest concentration of P extend 1-2 km from shore. This effort should be combined with other larger-scale watershed restoration techniques to improve overall water quality in the upper watershed and decrease nutrient inputs into the lakes. Such restoration could include re-establishing wetlands, establishment and maintenance of riparian buffers, reduction of point and non-point sources of nutrients, increasing community and industrial awareness, and continued water quality monitoring. In addition, to mitigate the potential dissolution of P from lake sediments, chemical application, such as alum, to bind and precipitate P could be considered. Hypolimnetic oxygenation, sediment dredging, and hypolimnetic water withdrawals are not recommended as P removal options for Nulki and Tachick lakes.

Permitting guidance for establishing a macrophyte harvest program include the submission of a Change Order application under the *Water Sustainability Act* as well as submitting a Request for Review to DFO for alterations to fish habitat under the *Fisheries Act*.

ACKNOWLEDGEMENTS

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AUTHORSHIP

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
BC	British Columbia
BC MoE	British Columbia Ministry of Environment
BC MoECCS	British Columbia Ministry of Environment and Climate Change Strategy
DFO	Department of Fisheries and Oceans
DWT	Dry weight
EDI	EDI Environmental Dynamics Inc.
HA	Hectare
HADD	Harmful alteration, disruption or destruction
NTLSS	Nulki-Tachick Lakes Stewardship Society
ORP	Organic reactive phosphorus
P	Phosphorus
RFR	Request for Review
SRP	Soluble reactive phosphorus
TP	Total phosphorus
UNBC	University of Northern British Columbia
WWT	Wet weight

1 INTRODUCTION

1.1 NULKI-TACHICK LAKES AND THEIR WATERSHED

The Nulki-Tachick watershed (440 km^2) is near the geographic centre of British Columbia (BC), about 12 km southwest of the town of Vanderhoof (Figure 1). Nulki Lake (10 U 424805E 5973716 N) and Tachick Lake (10 U 421515E 5979206 N) are by far the largest lakes in the watershed (Table 1). Most of the Nulki-Tachick watershed is located to the south and southwest of Nulki Lake. Nulki Lake's largest tributaries are Corkscrew Creek (the largest), Bear Creek, Upper Stony Creek, Second Creek and Sinkut Creek (not to be confused with the Sinkut River; Figure 1). Nulki Lake is drained from the north by Middle Stony Creek which flows northward for about 6 km to where it discharges to the east end of Tachick Lake (Figure 1). The Saik'uz First Nation (Dakehl [Carrier] Nation) community of Stony Creek is located along Middle Stony Creek about halfway between Nulki Lake and Tachick Lake (Figure 1). The only other major tributary to Tachick Lake is Tachick Creek, which discharges to the west end of the lake. Tachick Lake is drained by Lower Stony Creek from the northeast. Lower Stony Creek flows northward for about 11 km to where it discharges to the Nechako River..

Nulki and Tachick lakes have historically supported important sustenance and sport fisheries for rainbow trout (*Oncorhynchus mykiss*; McIntosh 1997) and recreational and tourism opportunities (e.g., Saik'uz Park on Nulki Lake and Tachick Lake Resort), but there is concern that deteriorating water quality in the lakes and their tributaries is putting the ecology, and other values, of the lakes at risk. In recent years, several initiatives, mostly in partnership with Saik'uz First Nation, have been undertaken, or proposed, to improve conditions in Nulki and Tachick lakes and their major tributaries (see Zaldokas 1999; EDI 2006). The desired outcome of these initiatives is to restore habitat integrity, including water quality, and to support local values and practices that rely on clean water and sustainable ecosystems, such as fishing, tourism, recreation and social well-being (e.g., the Indigenous Healing Facility that is proposed for Tachick Lake).

1.2 DECLINING WATER QUALITY TREND

In the early 1980s, several cows died after drinking from Nulki Lake during the late summer when the lake is most productive (Jacoby and Kann 2007). It is believed that the cows died from the effects of hepatotoxins and/or neurotoxins that are produced by the lake's dominant cyanobacteria (a.k.a. "blue-green algae") taxa (Jacoby and Kann 2007). Microcystin-LR (MC-LR) is a potent hepatotoxin and is believed to be the most toxic microcystin. In 1995, measurements of microcystin-LR in cyanobacteria from Nulki and Tachick lakes indicated concentrations of 129 µg MC-LR/g and 220 µg MC-LR/g, respectively (Jacoby and Kann 2007). These concentrations are considered to be very high. Northern Health Authority has issued public health advisories for Nulki Lake in the past, with the following advice (e.g., NHA 2016):

- "*Avoid all contact with blue-green algae blooms. If contact occurs, wash with tap water as soon as possible.*
- *Do not swim or wade (or allow your pets to swim or wade) in any areas where blue-green algae are visible.*

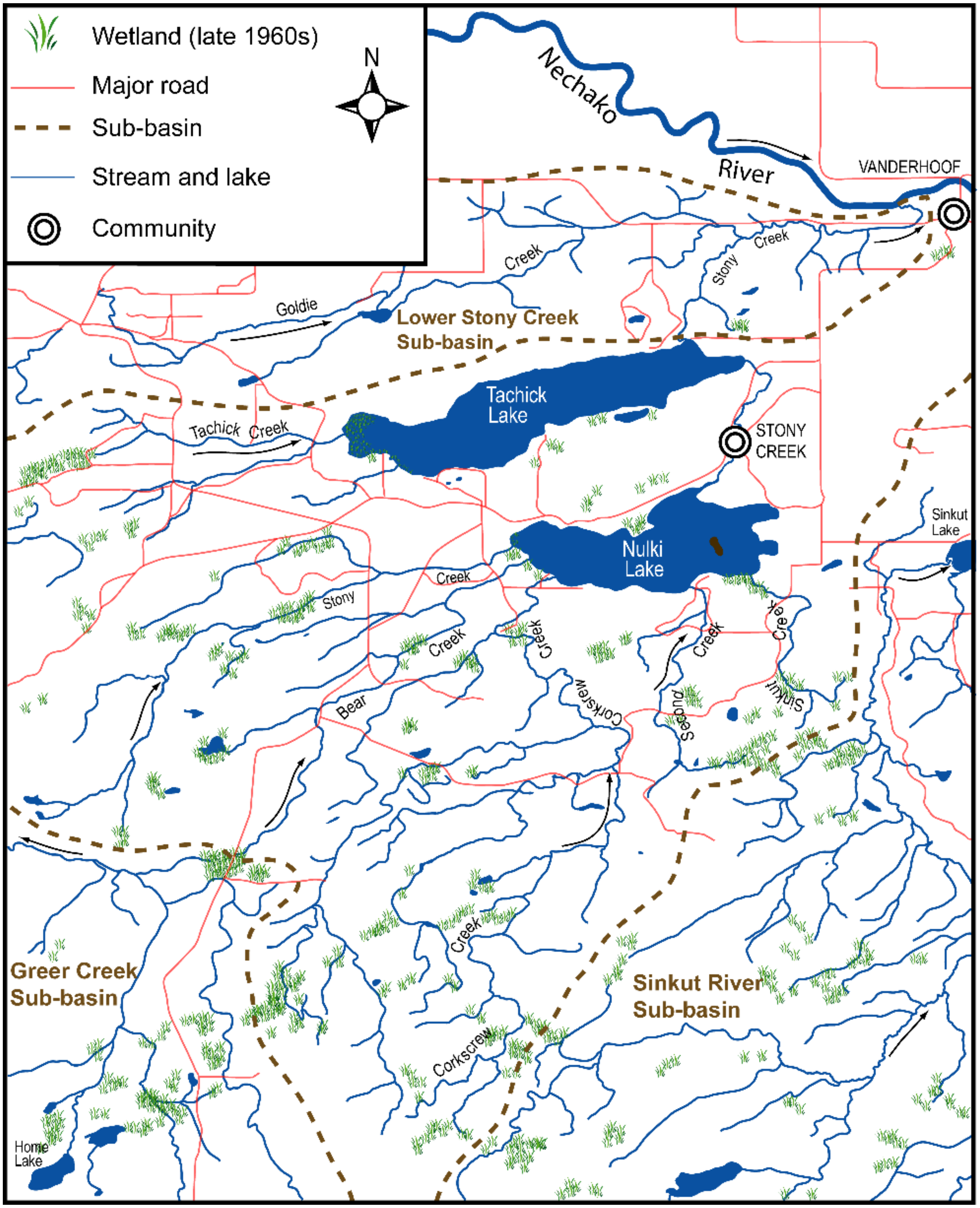


Figure 1. **The Nulki-Tachick watershed, central British Columbia, showing Nulki and Tachick lakes and their major tributaries, and the approximate distribution of wetlands as shown on 1:50,000 NTS maps from the late 1960s. For scale, Nulki and Tachick lakes are 8.0 and 9.9 km long, respectively (Table 1). From EDI (2022).**

Table 1. Morphometry of Nulki Lake and Tachick Lake, central British Columbia. Information from French and Petticrew (2007) except surface area from this study.

Morphometric Parameter	Nulki Lake	Tachick Lake
Shoreline perimeter (km)	25	30
Total length (km)	8.0	9.9
Maximum width (km)	2.6	2.7
Wetted surface area (ha)	1,621	2,128
Volume (m^3)	72.1×10^6	96.4×10^6
Average depth (m)	4.5	4.5
Maximum depth (m)	7.6	7.6

- *You can safely consume fish fillets from this lake, but should limit your consumption of whole fish and trimmings as fish may store toxins in organs such as the brain, liver and intestines. Pets should avoid eating whole fish and trimmings.*
- *As always, visitors and residents are reminded to never drink or cook with untreated water taken directly from any lake at any time. Boiling lake water will not remove the toxins produced by blue-green algae. An alternate source of drinking water should also be provided for pets and livestock, while this advisory is active.*"

Due to concerns relating to deteriorating water quality in Nulki and Tachick lakes, the BC Ministry of Environment (BC MoE), now the BC Ministry of Environment and Climate Change Strategy (BC MoECCS), Saik'uz First Nation, and the University of Northern British Columbia (UNBC) undertook limnological assessments of the lakes and their tributaries during early 1980s through the 1990s (e.g., French and Petticrew 1997). Similar studies have continued, with intermittent pauses, to the present with support from BC MoECCS and the BC Lake Stewardship Society's Volunteer Lake Monitoring Program. The limnological studies focused on seasonal nutrient dynamics (i.e., internal versus external phosphorus [P] loading), nutrient transport and delivery, and on the causes of cyanobacteria and algal blooms in the lakes.

In 1999, BC MoE, in partnership with Saik'uz First Nation and Queen's University, undertook a paleolimnological (lake coring) assessment of Nulki Lake to assess long-term water quality trends. The results of the paleolimnological assessment showed that Nulki Lake is naturally very productive (mid-eutrophic). An abrupt shift toward declining water quality started during the early 1950s when the area was opened up by a network of road throughfares which, in turn, promoted agricultural development, forestry activities and shoreline development (Figure 2). From the early 1950s to 1999 (surficial core interval), Nulki Lake's trophic status shifted from being mid-eutrophic to strongly hypereutrophic. The initial observance of water quality deterioration in the 1950s coincided with a concurrent increase in sediment (originating from landscape erosion) and organics (originating from cyanobacteria and algal biomass) accumulation on the lakebed (Figure 2). While Nulki Lake is the only lake in the watershed that has been cored, observations suggest that a similar trend in water quality deterioration has occurred in Tachick Lake and in Middle Stony Creek and Lower Stony Creek which receive water from Nulki Lake and Tachick Lake, respectively.

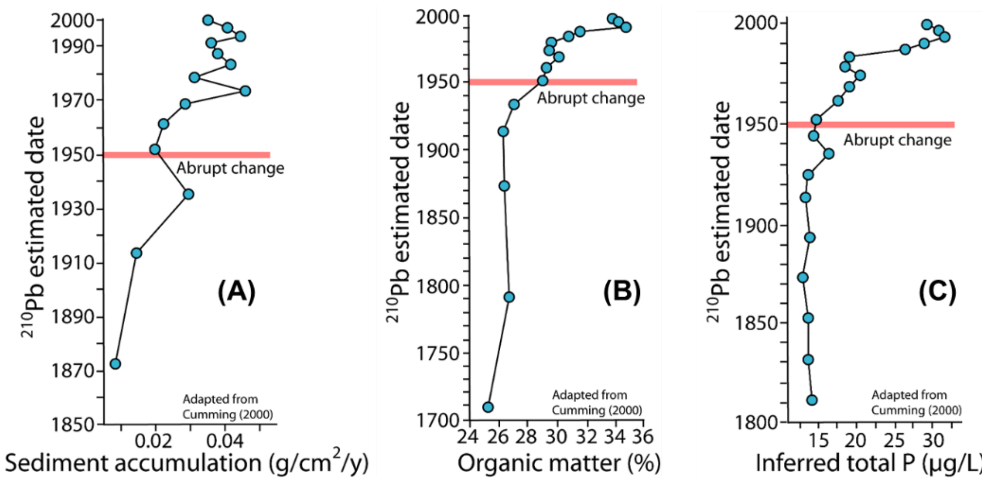


Figure 2. **Nulki Lake's paleolimnological record based on a bottom sediment core collected in 1999. The data show that (A) sediment accumulation rates on the lakebed, (B) organic matter content of the lakebed, and (C) water column total phosphorus concentration started to increase during the early 1950s when the area was opened up for development. Data are from Cumming (Cumming 2000).**

Data collected during the period 2000 to the present, through the Volunteer Lake Monitoring Program, suggest that water quality has continued to decline as evidenced by intense cyanobacteria blooms that reduce water transparency to near zero and the expansion and increased density of rooted aquatic plant (macrophyte) beds. Nulki and Tachick lakes are now amongst the most eutrophic lakes in BC (EDI 2022; Figure 3 and Figure 4).

Figure 3. **Intense cyanobacteria blooms in Nulki Lake during summers 2020 and 2021 (photographs by Ray Klingspohn).**

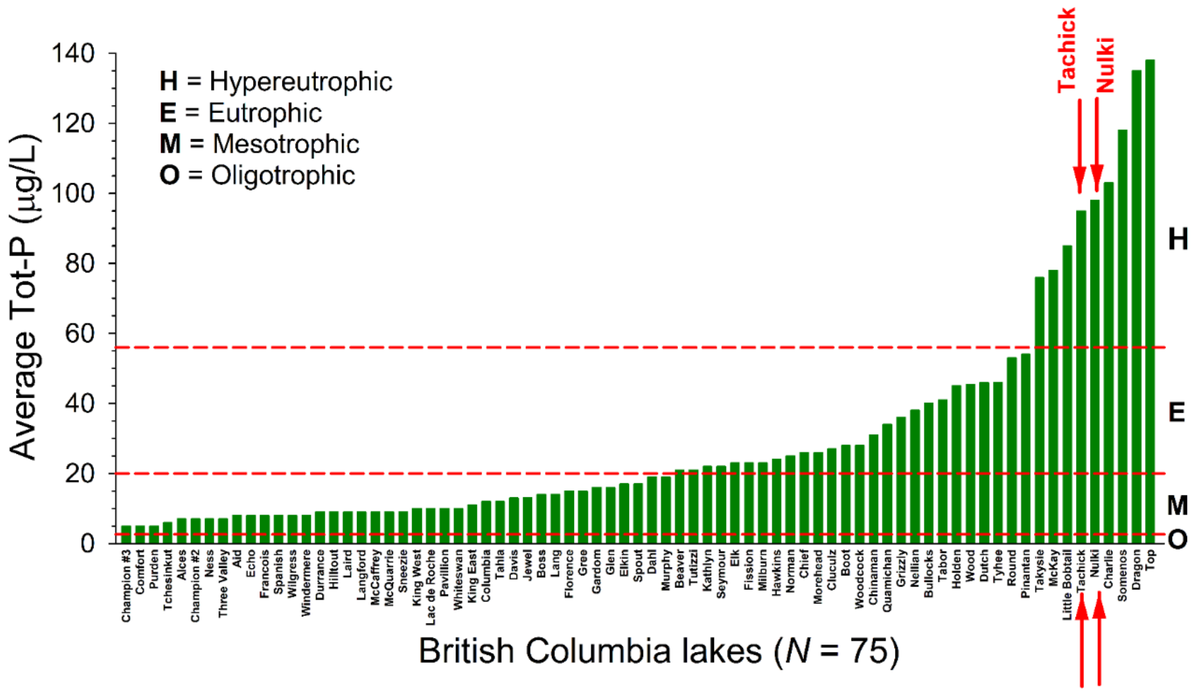


Figure 4. **Average total phosphorus (TP) concentration in 75 lakes across British Columbia, including Nulki and Tachick lakes (indicated by red arrows). Data are from Reavie et al. (1995a,b), Reavie et al. (2000), Jensen (2010) and British Columbia's Environmental Monitoring System.**

The frequency and duration of algal blooms has continued to increase in recent years. During 2023, suspected blue-green algal blooms were documented on June 21, July 10, July 17, July 28, and August 29. In addition, a large number of dead suckers washed ashore on the north side of Nulki Lake the second week of June, and on July 31 a local resident documented thousands of dead snails washing ashore (Figure 5). Residents on the lake also report that rainbow trout captured mid-summer were stressed due to high temperatures and low oxygen levels, causing almost immediate mortality when angled from a boat (R. Klingspohn personal communication).

Figure 5. **Example of dead sucker, suspected blue-green algal blooms, and dead snails on Nulki Lake recorded during 2023. Left to right: Clair Neilsen, June 13, 2023; Crystal Ward, June 21, 2023; unknown, July 28, 2023; Ray Klingspohn, July 17, 2023; and Dave Smith, July 31, 2023).**

1.3 CAUSES OF WATER QUALITY DETERIORATION IN THE NULKI-TACHICK WATERSHED, INCLUDING NULKI AND TACHICK LAKES

Much of the Nulki-Tachick watershed has been cleared for agriculture and forestry, including salvage logging in response to mountain pine beetle (*Dendroctonus ponderosae*) infestations (Figure 6). Significant areas of riparian habitat along the major tributaries to Nulki and Tachick lakes have also been affected by landscape development. The Nulki-Tachick watershed once had extensive wetlands that lined the stream networks and the numerous small lakes in the watershed (Figure 1). Anecdotal evidence suggests that wetlands in the Nulki-Tachick watershed have receded significantly since the 1950s, with recession having occurred in parallel with landscape development and climatic change.

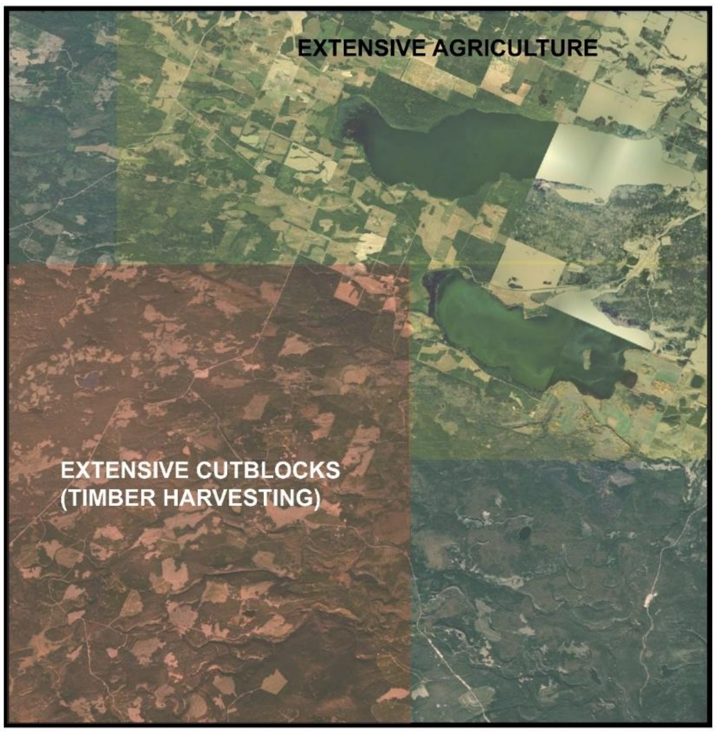


Figure 6. Current land use patterns in the Nulki-Tachick watershed, central British Columbia. Note that the intense cyanobacteria and algal blooms in Nulki and Tachick lakes are visible in the satellite imagery. Adapted from Google Earth Pro imagery (June 2021).

With the loss of forest cover and wetlands, both of which attenuate runoff and efficiently retain nutrients within the landscape, and the trend toward the drying of surficial soil horizons during summer, runoff in the Nulki-Tachick watershed has become flashier with an increase in peak flows during spring snowmelt and during precipitation events. While freshet flows and flows during precipitation events have increased in parallel with development and climatic change, water deficits during normal basal flow periods (late summer and winter) have become more extreme. Water deficits during basal flow periods are caused by increased overland flow and, in turn, reduced groundwater recharge. This trend toward increasing flow flashiness and water deficits during normal basal flow periods has occurred in watersheds across interior BC (Warkentin et al. 2022). It is believed that the hydrologic impacts of land use and climatic change and reduced nutrient retention by forests and wetlands in the Nulki-Tachick watershed have increased the delivery of sediment and production-limiting nutrients (e.g., P and nitrogen [N]) to Nulki and Tachick lakes and to Middle Stony and Lower Stony creeks. Moreover, the water deficits that are now occurring in Nulki-Tachick tributaries during normal basal flow periods are likely reducing the flushing rates of the lakes during bloom seasons with this, perhaps, being an additional cause of the increase in cyanobacteria bloom intensity.

1.4 FISH COMMUNITY IN NULKI AND TACHICK LAKES

Fish present in Nulki and Tachick lakes were determined from querying the iMapBC database and from McIntosh (1997) and are presented in Table 2. In addition to these species, prickly sculpin (*Cottus asper*) and mountain whitefish (*Prosopium williamsoni*) have been recorded in the Nulki-Tachick watershed, including tributary streams, but are not reported within the lakes.

Table 2. Fish species present in Nulki and Tachick lakes.

Common Name	Scientific Name
Rainbow trout	*Oncorhynchus mykiss*
Northern pikeminnow	*Ptychocheilus oregonensis*
Peamouth	*Mylocheilus caurinus*
Redside shiner	*Richardsonius balteatus*
Longnose sucker	*Catostomus catostomus*
Largescale sucker	*Catostomus macrocheilus*
Burbot	*Lota lota*

1.5 STUDY OBJECTIVES

EDI's objectives of the study included the following:

1) assess the current distribution, relative densities and species composition of macrophyte beds in Nulki and Tachick lakes and to determine the elemental composition (e.g., P, N and metals concentrations) of the dominant species;
2) determine the feasibility of the proposed macrophyte harvesting program (i.e., benefits to water quality and risks);
3) propose a monitoring program that can be used to evaluate the Nulki-Tachick macrophyte harvesting program; and,
4) give the Nulki-Tachick Lakes Stewardship Society (NTLSS) guidance in the permitting process, including the completion and submission of permitting applications, if it is determined that a macrophyte harvesting program will benefit Nulki and Tachick lakes.

2 LITERATURE REVIEW

2.1 LAKE EUTROPHICATION

Human activities have resulted in a trend for increasing productivity (eutrophication) resulting in algal blooms in freshwater lakes. These human activities include agriculture, ranching, forestry, human caused erosion, wastewater inputs and pollution. Cultural eutrophication is a world-wide water quality issue (Smith and Schindler 2009). Through experimentation, including whole lake experiments, researchers have discovered that eutrophication is almost entirely due to excessive nutrients. The nutrient that is limiting for macrophyte and algal growth in freshwater lakes is P. By reducing the P levels in lakes, algal growth and increases in productivity can be controlled (Schindler et al. 2016). Although macrophytes and algae produce oxygen during photosynthesis, excessive macrophyte and algal growth leads to depletion of oxygen due to the accumulation and subsequent microbial decomposition of organic material. This leads to low dissolved oxygen concentration (hypoxia) or a complete lack of oxygen (anoxia) in the deeper colder hypolimnion when lakes stratify in the warmer months and is a common symptom of eutrophication. When lakes mix, or turn over, the oxygen depleted water is mixed throughout the water column and can lead to death of aquatic organisms, such as fish.

2.2 PHOSPHORUS IN LAKES

Phosphorus does not commonly exist in elemental form in nature, but instead is contained in phosphate molecules (PO_4^{-3}). Phosphates exist in three forms: orthophosphates, metaphosphates, and organically bound phosphate. Only orthophosphates are available for uptake by plants, and once absorbed are transformed into organic phosphates. Metaphosphates occur in boiler water treatment and in detergents and are converted to orthophosphates in water. Organic phosphates exist in plant and animal tissues. The organic phosphates in dead plant or animal tissue can be transformed back into orthophosphates by bacteria during decomposition, making them available again to plants and phytoplankton.

Phosphorus exists in lake environments in various forms. Phosphorus exists in the water column in the form of particulate P (PP), and in dissolved form as dissolved organic P (DOP), and soluble reactive P (SRP) also known as orthophosphate. Collectively, the forms of P in the water column, including PP, DOP, and SRP, are referred to as total P (TP). Phosphorus exists in lake sediments in several forms, including inorganic P (IP) and organic P (OP). Lake sediments function as a sink for P and can absorb and release P from the water column even after nutrient loading has ceased from other sources (Wang and Liang 2015). Phosphorus in sediments can be adsorbed by fine particles such as clays, carbonates, iron (Fe) and aluminum (Al) oxides and humic acids (Reis et al. 2021). For instance, the $FePO_4$ molecule can exist in lake sediments and be transformed back to Fe + PO_4 by a redox reaction under anoxic conditions, releasing organophosphates back into the water column (Petticrew and Arocena 2001). Phosphorus can also exist in the living plant and animal tissue within the lake environment as organically bound P. The plant tissue component is the dominant portion as the biomass in lakes is predominantly plant tissue. As plants die and decompose, the P is released back into the water in the form of both dissolved and particulate forms.

There are three origins for P in lake water. External loading occurs through surficial water flowing into lakes. This includes tributary streams, overland flows and riparian inputs along the lake shore. Atmospheric deposition is the second source of P in lake water. Phosphorus is present in precipitation and can also be deposited with ash from forest fires. A third source of P in lake water is internal loading caused by release of P from lake sediments or decomposing plant tissue.

Tributary streams often dominate nutrient inputs through external loading by carrying excess nutrients from the upland portion of the watersheds. These nutrients may originate from agricultural fertilizers, point and non-point pollution sources, erosion of soils and minerals, etc. Agriculture and forest harvest activities can exacerbate these processes by reducing natural wetlands and water storage on the landscape, where phosphates would be bound by contact with soil particles and utilized by vegetation. The inputs from tributary streams are counterbalanced by streams and rivers flowing from lakes carrying nutrients downstream. The net difference between the inflow and outflow of nutrients is the amount stored in the lake environment. The flushing rate of a lake will affect the residence time of water in the lake and influence the amount of time the nutrients are available to be deposited in lake sediments or taken up by phytoplankton and aquatic macrophytes.

Simmons (1997) developed a whole lake P budget for Tabor Lake (380 ha) and quantified the sinks, sources and flow of P through the lake ecosystem. The lake contained P in three main compartments; the top 3 cm of sediment contained 162,000 ± 10,100 kg of P (mean ± SE); aquatic plants contained 3,087 ± 1,194 kg of P, and the water column contained 362 to 2,364 kg P. He estimated in 1995 that stream inflows accounted for 136 kg P/year and outflow was 188 kg/year, atmospheric deposition resulted in an increase of 60 ± 9 kg of P over the year. An aquatic macrophyte harvest program designed to reduce P in the lake removed 578 ± 117 kg of P, while senescing plants added 1,958 ± 867 kg P, and 1,197 to 2,290 kg P was released from lake sediments. Simmons results suggest that the largest sink of P in Tabor Lake by far is the sediments, while aquatic macrophytes and sediment release similar amounts of P over the course of the year. It seems likely then that P is flowing between the two main sinks, aquatic plants absorbing nutrients through the growing season and releasing them back into the water and sediments during senescence and decomposition. The lake sediment can function as a source of P in the water column when the lake stratifies and the bottom layer becomes anoxic, but the sediment is an effective sink that can store P in both organic and inorganic forms. Petticrew and Arocena (2001) concluded that orthophosphates in Tabor Lake were predominantly bound to iron-containing minerals in the sediment and released under optimal anoxic (redox) conditions. However, the release of P from sediments is complex and can occur through a wide variety of mechanisms (Orihel et al. 2005)

2.3 ALGAL BLOOMS

Increased productivity and algal blooms often take the form of cyanobacteria. Cyanobacteria are commonly referred to as blue-green algae, and can contain toxins to humans and animals, including neurotoxins and hepatotoxins. Toxic cyanobacteria blooms have been associated with high P levels, high water temperatures and water column stability (Jacoby and Kann 2007). Toxic cyanobacteria blooms have caused animal poisonings, lake closures, and public health concerns. Cyanobacteria produce cyanotoxins, including microcystins, which are hepatotoxins, and to a lesser extent anatoxins, which are neurotoxins (Jacoby and Kann 2007).

2.4 METHODS TO CONTROL AND REDUCE PHOSPHORUS IN LAKES

2.4.1 REDUCING INPUTS

Primary methods to control P in lake environments include reducing external loading by managing upstream sources (e.g., reducing wastewater input, agricultural runoff), reduction of P sinks (e.g., removing sediment through dredging, harvesting aquatic plants) chemical application to bind P in sediments (e.g., alum), oxygenation to eliminate anoxic conditions, and water level manipulation. Following is a brief description of the advantages and disadvantages of each control method.

2.4.2 DREDGING

Dredging is the removal of lake substrate using either mechanical or hydraulic dredges. Moore et al. (1988) found dredging to be an ineffective tool to remove P due to the uneven removal of sediment allowing nutrient rich sediment to slump into trenches formed by the dredges, thereby exposing more nutrients. They recommend that dredging needs to uniformly remove the top layer of sediment to be effective at reducing P inputs. Researchers have found dredging can have a long-term detrimental effect on water quality (Moore et al. 1983). The sediment removed also requires proper disposal.

2.4.3 CHEMICAL APPLICATION TO BIND PHOSPHORUS

Salts of aluminum, iron or calcium have been used to bind P to remove it from the water column through flocculation (Cooke et al. 1993). Depending on the binding substance and redox potential this may permanently bind P and prevent it from resuspending from the sediment layer. Alum, or aluminum sulfate, is one potential substance used to bind P and has been used in whole lake systems to reduce internal P loading and control algal blooms (Cooke et al. 1982, Kennedy et al. 1987). This treatment is most effective in shallow, softwater, polymictic lakes. Grund et al. (2022) found alum surface treatment reduced TP 66%, SRP 93%, and total nitrogen (TN) 31% in the epilimnion. One disadvantage of aluminum treatment is that aluminum can be toxic to fish at pH outside the 6 to 8 range (Cooke et al. 1993). Lime has also been used to bind P in large, eutrophic lakes and is commonly used in wastewater treatment and wastewater holding ponds (Prepas et al. 1997). Some laboratory research had also been performed on the use of Zeolite clays to inactivate P in lake sediments (Li et al. 2019).

2.4.4 OXYGENATION

Oxygenating hypolimnetic waters has also been used as a method to reduce P (Prepas et al. 1997). However, whole lake oxygenation is an expensive undertaking for lakes larger than a few hectares. Gachter and Wehrli (1998) found that hypolimnetic oxygenation did not result in reduced P cycling in two lakes after a 10-year study period and concluded that anoxic conditions and P release by sediments might not be cause and effect.

2.4.5 AQUATIC MACROPHYTE HARVESTING

Harvesting aquatic macrophytes has been used to achieve a variety of goals, including removing nutrients, improving water quality and improving fish habitat (Alam et al. 1996). Phosphorus is released from plants during senescence into the water column. Aggressive harvesting of plants before senescence is thought to prevent internal loading of P from dying vegetation (James et al. 2002). Plant harvesting has a temporary effect on plant biomass. Harvesting plants may increase their growth rate, and biomass can return to pre-harvest levels in three to six weeks (Crowell et al. 1994, Cooke et al. 1990, Rawls 1975). In nearby Tabor Lake, plants harvested in early summer needed to be harvested again in late summer/early autumn (Simmons 1997). Harvesting of floating vegetation in a Florida lake caused significant decrease in plant biomass, with small effects on water quality including decreases in TP, TN, and chlorophyll a concentration. The largest effect on water quality was an increase in turbidity during harvest (Alam et al. 1996).

2.4.6 MIXED APPROACHES

James et al (2002) found that internal loading accounted for 80% of the summer P budget for a small eutrophic lake in Wisconsin, mostly from flux of P from the sediment, whereas macrophyte decomposition accounted for 20% of the P budget. They suggested a combined approach of chemical application to bind P along with macrophyte harvesting and limiting motor boat activity should be used to control internal P loading. Grund et al. (2022) found a combination of hypolimnetic oxygenation and alum treatment was effective at reducing P and cyanobacteria dominance in the phytoplankton community of Oswego Lake, Oregon.

3 METHODS

3.1 MACROPHYTE COMMUNITY IDENTIFICATION

3.1.1 FIELD SURVEYS

Macrophyte species and community surveys were intended to provide an inventory of existing macrophyte species and communities within Nulki and Tachick lakes. Aquatic macrophytes were sampled from each lake to identify species present, quantify densities to estimate the mass of macrophytes that would be removed with a harvesting program and quantify the amount of P within the macrophyte tissues. A series of transects were established at 200 m intervals around the perimeter of the lakes and extending to the deepest part of the lakes. The transects were separated into four quadrants: N, S, E and W of each lake. From each set of potential transects, two transects per quadrant were chosen. Bathymetry data was acquired from the i-Boating website (https://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html#12.5/37.8115/-122.3890) and the 1, 2 and 3 m contour lines were digitized by the EDI GIS team. Transects were spaced to sample macrophyte communities from various areas of the lakes based on lake bathymetry. Thus, eight pre-defined transects were identified on both Nulki and Tachick lakes. Macrophytes were sampled along all eight transects on Nulki Lake plus an additional transect in the W quadrant that was added to capture an area with a high macrophyte density. On Tachick Lake, seven of the eight transects were sampled and one of the N transects was moved for safety reasons due to high winds and waves during field sampling.

To identify the macrophyte community structure (species composition and dominance hierarchy) of the macrophyte beds within the lakes, a sampling program was created and adapted from *USGS Long Term Resource Monitoring Program Procedures: Aquatic Vegetation Monitoring* (Yin et al. 2000). Along each transect, a plot was placed in different pre-defined water depth classes (i.e., 0 to 1 m, 1 to 2 m, 2 to 4 m, and 4 to 7 m) equating to approximately four (4) plots per transect. Transects occasionally contained less then four plots in areas where the lake bottom had a steep gradient and the macrophyte bed was narrow.

A long handled (i.e., approximately 3 m long with a rope extension), double-headed rake was used to collect macrophyte samples (Photo 1). Each plot along the transect contained four subsampling areas which were approximately 1.5 m long and 0.36 wide (i.e., width of the rake). Macrophyte community samples were collected from an anchored boat, one over each corner of the boat. The subsampling areas were numbered from one to four clockwise starting from the front right corner of the boat (Figure 7). Macrophytes for sampling and identification were collected by dragging a rake along the lake substrate 1.5 m toward the boat, then twisting the rake 180 degrees as it was lifted off the lake bottom (to minimize loss of macrophyte from rake teeth) and pulled into the boat. At each subsampling area, the following data were collected:

- UTM coordinates, date, photographs, and water depth;
- macrophyte relative abundance (i.e., as a percent of macrophytes covering the rake) and life form (i.e., unvegetated, submergent, floating, emergent, algae, and non-rooted floating);

- substrate type;
- species relative abundance on the rake; and,
- species observed within a 2-m ring around the boat, which were not observed in the subsampling area.

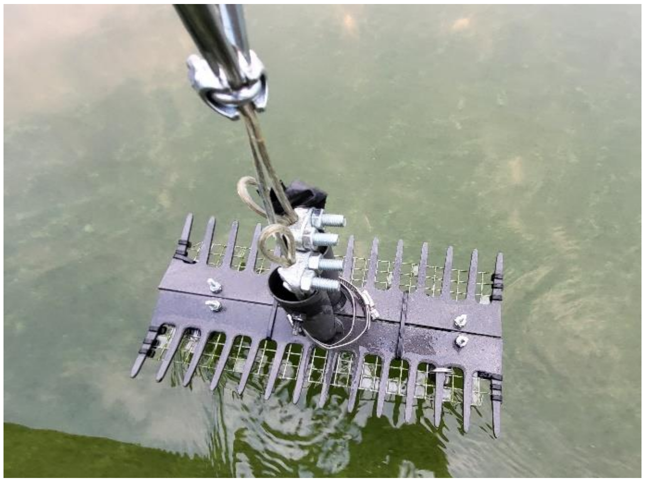


Photo 1. Macrophyte collection rake.

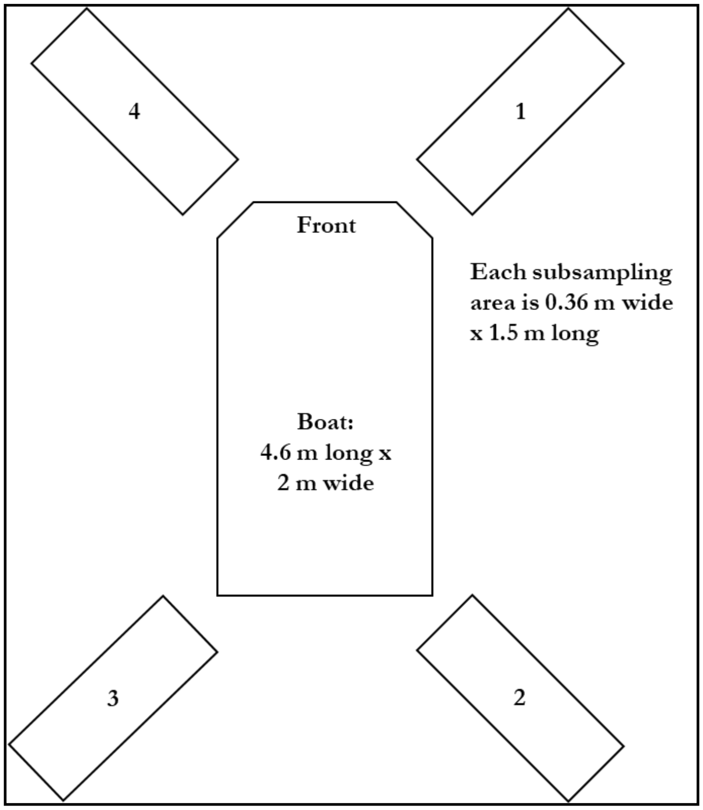


Figure 7. Subsampling design adapted from *USGS Long Term Resource Monitoring Program Procedures: Aquatic Vegetation Monitoring* (Yin et al. 2000).

3.1.2 MACROPHYTE COMMUNITY MAPPING

Field data and ESRI 2016 aerial imagery were used to identify dominant macrophyte communities within the lakes. Macrophyte communities were delineated and defined as areas having similar characteristics (water depth and sediment) and supporting similar macrophyte species assemblages. Mapping was completed using ArcGIS Pro 3.0 with the digitized lake bathymetry contours.

3.2 LABORATORY SAMPLING AND ANALYSES

Two types of laboratory samples were taken: composite samples (i.e., all species collected on the rake) and individual species samples (i.e., the four most dominate macrophyte species on each lake). Samples for laboratory analyses were taken from plots (i.e., subsampling locations) in conjunction with the macrophyte species and community surveys. Plots were randomly selected within each pre-defined depth class (i.e., 0 to 1 m, 1 to 2 m, 2 to 4 m, and 4 to 7 m) along transects in each lake (i.e., 18 composite samples with two duplicates and four species samples per lake). The macrophytes pulled from subsample area one (1) were generally used for composite samples. In areas where macrophyte biomass was limited, multiple rake samples from the remaining subsampling areas (i.e., 2 to 4) were collected to obtain the macrophyte wet weight (i.e., at least 100 to 200 grams) required for lab analysis. If more then four rake samples were required, the right side of the boat was sampled and then the left side. The number of rakes required to obtain the required macrophyte sample weight was recorded to be use in the biomass calculation.

Macrophyte samples were removed from the rake, placed in plastic Ziploc bags and stored on ice in a cooler and frozen at end of each field day. For each sample, the following laboratory analyses were performed: total wet weight of each sample, TN, metals, and mercury (dry and wet units) including P, and moisture content.

3.3 DETERMINING MACROPHYTE HARVEST FEASIBILITY

3.3.1 HARVESTABLE AREA AND EFFORT

To determine the feasibility of a macrophyte harvesting program in Nulki and Tachick lakes, the area of each lake with the identified macrophyte communities was quantified. It was assumed that macrophyte harvesting would focus on submergent macrophytes and avoid emergent and floating leaf communities. Therefore, the total area of each lake with submergent macrophytes was estimated by summing the areas of macrophyte beds composed of submergent macrophyte communities. This defined the harvestable area of each lake.

The specifications of the Aquamarine H5-200 Aquatic Plant Harvester were used to estimate the area that could be harvested per day (Appendix A). This is a commonly used harvester around the world for both freshwater and marine applications, is manufactured in Canada, and was a model being considered for purchase by the NTLSS for harvesting Nulki and Tachick lakes. The harvester has a cutting width of 1.5 m and a maximum cutting depth of 1.7 m. It was assumed the harvester would be operated for seven hours per day at the harvesting speed ranging from 2 to 3 km/h (Craig Bollinger, Aquamarine Inc., personal communication).

3.3.2 BIOMASS AND PHOSPHORUS REMOVAL FROM HARVESTING

To estimate macrophyte biomass, the weight of the sample (i.e., obtained from the laboratory) was divided by the area sampled to estimate kilograms (kg) per metre squared (m^2) of biomass for each plot. The total macrophyte biomass that would be removed daily for each macrophyte community type was estimated using the mean area density of macrophytes (kg wwt/m^2) from the macrophyte surveys for submergent macrophyte communities multiplied by the area harvested per day.

The mean P concentration (mg P/kg wet weight) from the laboratory analyses for submergent macrophyte communities was multiplied by the estimated macrophyte biomass removed per day to estimate the quantity of P removed per day for each community type using the equation:

$$\text{P removed (kg)} = \text{Area harvested } (m^2) \times \text{mean density (kg wwt}/m^2) \times \text{P concentration (mg/kg wwt)} / 10^6$$

3.3.3 PHOSPHORUS IN NULKI LAKE SEDIMENT

The quantity of P stored in Nulki Lake sediment was estimated using data provided by C. Nielsen on analysis of the top 2 cm of lake sediment collected on May 2, 2021 and analyzed by Northern Analytical Laboratory Services at UNBC (Appendix B; C. Nielsen, unpublished data). The mean P concentration from the three samples collected (1,862 mg/kg) was used, and a dry bulk sediment density of 0.55 g/ml or 0.55 kg/L was assumed (Engstrom et al. 2009). By applying the sediment volume in the top 2 cm per square metre of sediment (or 20 L/m^2), and the lake area of 1,621 ha, the total P in sediment was calculated using the following equation:

$$\text{Total P (kg)} = \text{P concentration (mg/kg)} \times \text{Sediment density (kg/L)} \times \text{Sediment volume } (L/m^2) \times \text{Area } (m^2) / 10^6$$

3.4 SHORELINE IMPACTS AND LAKE HAZARDS

Concurrent with the macrophyte sampling and macrophyte community mapping, shoreline impacts and lake hazards were identified and data were collected digitally within a mobile map application (i.e., Avenza Maps). Field assessments were conducted from August 28 to September 1, 2023. Documentation included:

- visual shoreline impacts (e.g., erosion, degraded riparian habitat, pollution sources, and livestock access points) that could be affecting water quality in the lakes (identification of shoreline restoration opportunities); and,
- hazards and/or consequences that could be associated with using a mechanical harvester on the lakes (e.g., risks to within-lake and shoreline infrastructure, species that use macrophyte beds as habitat, and risks related to lake morphometry).

3.5 STUDY ASSUMPTIONS AND LIMITATIONS

Differences in macrophyte biomass may arise from year to year and season to season due to water depth, temperature, oxygen, and sunlight availability. As such the estimation of both biomass and total P followed the following assumptions:

- the rake sampler removed all macrophyte biomass from the subsampling areas;
- macrophyte biomass was consistent in the mapped communities and areas of the lakes (N, S, E, W); and.,
- total P concentration was consistent in the mapped communities and areas of the lakes (N, S, E, W).

To estimate the effort required to harvest macrophytes, the following assumptions were made:

- the harvester would be operated for seven hours each day;
- the speed at which the harvester operated would be 2 to 3 km/h (Craig Bollinger, Aquamarine Inc. personal communication);
- harvested macrophytes would be placed in floating nets for later retrieval;
- there would be no overlap of previously harvested areas when cutting macrophytes; and,
- there would be no shutdowns for maintenance or fuelling.

4 RESULTS AND DISCUSSION

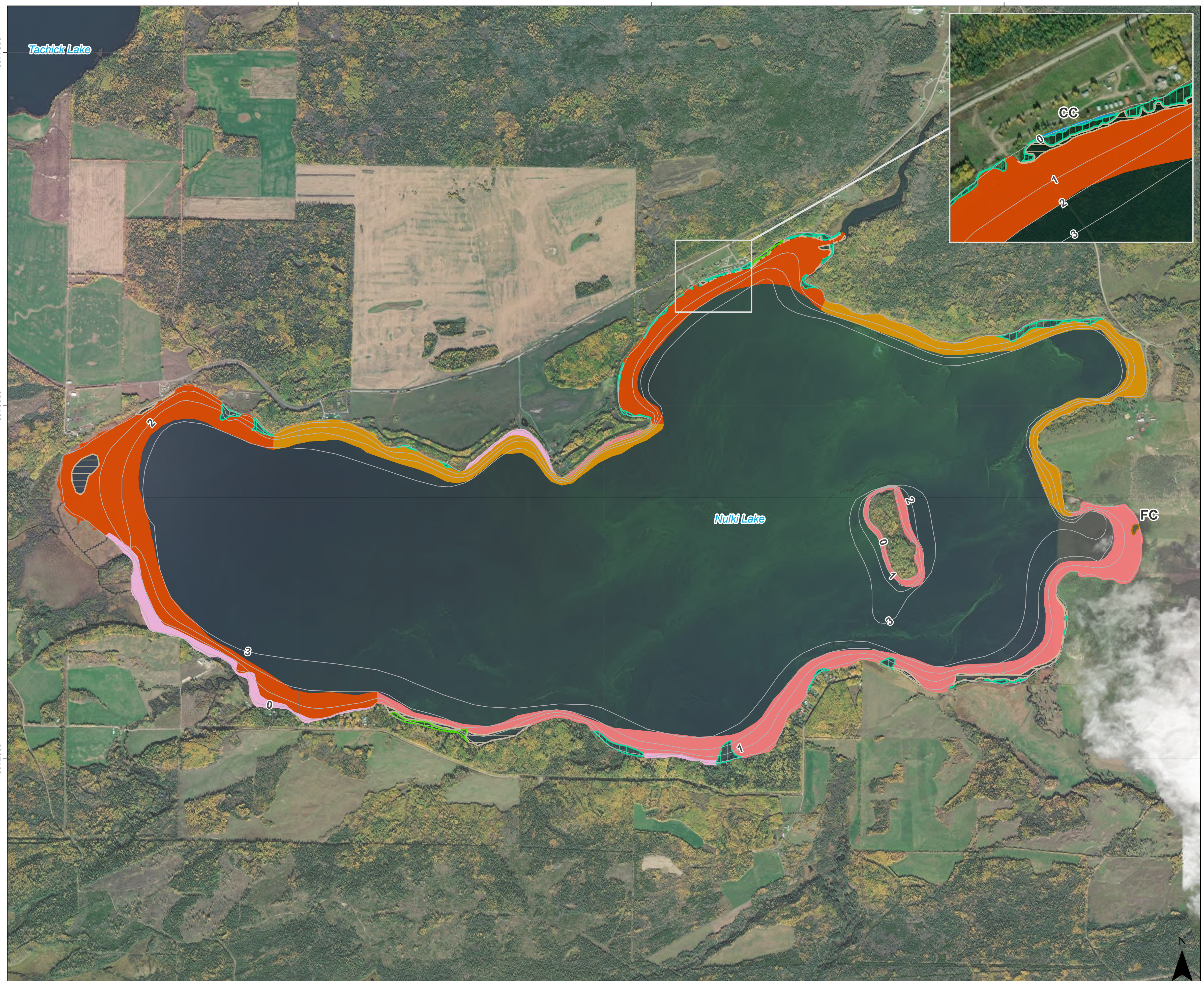
4.1 MACROPHYTE COMMUNITIES MAPPING

Nine macrophyte communities were identified on Nulki Lake. Approximately 82% of the lake is unvegetated in water depths greater than 2.5 m, with the most abundant macrophyte communities being common hornwort (*Ceratophyllum demersum*) / Canadian waterweed (*Elodea canadensis*) / Richardson's pondweed (*Potamogeton richardsonii)* (HC), eel-grass pondweed (*Potamogeton zosteriformis)* / Canadian waterweed (EC), and Richardson's pondweed / Siberian water-milfoil (*Myriophyllum sibiricum*) (RM). Macrophyte communities exhibiting higher biomass were mainly observed on the western end and within smaller bays within the lake. A summary of macrophyte communities mapped within Nulki Lake is presented in Table 3 and Map 1.

Seven macrophyte communities were identified on Tachick Lake. Approximately 75% of the lake is unvegetated in water depths greater than 2.5 m, with the most abundant macrophyte communities being common hornwort / Canadian waterweed / Richardson's pondweed (HC) and Canadian waterweed / common hornwort (CH). The bay on the western edge of the lake holds the largest submerged macrophyte bed. Minimal macrophytes occur on the northern shoreline and portions of the southern shoreline due to the steep gradient in depth, and the wind effect not allowing macrophytes to root. A summary of mapped macrophyte communities within Tachick Lake is presented in Table 4 and Map 2.

Table 3. Macrophyte communities identified within Nulki Lake.

Map Code	Common Name	Scientific Name	Average Depth (m)	Average Rake Cover (%)	Substrate Texture	Area (ha)	Lake Area (%)
Emergent Macrophyte Communities							
CC	common cattail	*Typha latifolia*	0.5 (range 0.1–0.8)	90 (range 25–100)	unknown	0.08	0.01
SH	swamp horsetail	*Equisetum fluviatile*	0.7 (range 0.1–0.8)	58 (range 25–90)	gravel/rock	2.37	0.15
HB	hard-stemmed bulrush	*Schoenoplectus acutus*	0.6 (range 0.2–0.9)	65 (range 29–100)	silt/clay, gravel/rock	14.87	0.92
Submergent Macrophyte Communities							
CH	Canadian waterweed / common hornwort	*Elodea canadensis* / *Ceratophyllum demersum*	0.8 (range 0.5–1.1)	78 (range 41–100)	silt/clay, silt with sand	16.79	1.00
EC	eel-grass pondweed / Canadian waterweed	*Potamogeton zosteriformis* / *Elodea canadensis*	1.1 (range 0.5–2.0)	6 (range 2–13)	variable	77.59	4.79
HC	common hornwort / Canadian waterweed / Richardson's pondweed	*Ceratophyllum demersum* / *Elodea canadensis* / *Potamogeton richardsonii*	1.7 (range 0.8–2.3)	51 (range 2–100)	silt/clay, gravel/rock	109.98	6.79
RM	Richardson's pondweed / Siberian water-milfoil	*Potamogeton richardsonii* /*Myriophyllum sibiricum*	1.5 (range 0.8–2.2)	15 (range 1–31)	variable	59.77	3.69
Mixed Floating and Submergent Macrophyte Community							
FC	floating-leaved pondweed / Canadian waterweed / common hornwort	*Potamogeton natans* / *Elodea canadensis* / *Ceratophyllum demersum*	1.6 (range 0.8–1.8)	98 (range 80–100)	silt/clay	0.32	0.02
Floating Macrophyte Community							
VP	variegated yellow pond-lily	*Nuphar variegata*	1.3 (range 0.9–1.5)	75 (range 35–100)	variable	15.03	0.93
Non-Vegetated							
NV	non-vegetated	–	2.5 +	0 (range 0–0.4)	variable	1,324.03	81.69



Mapped Macrophyte Communities on Nulki Lake

Nulki-Tachick Lakes Stewardship Society

Legend

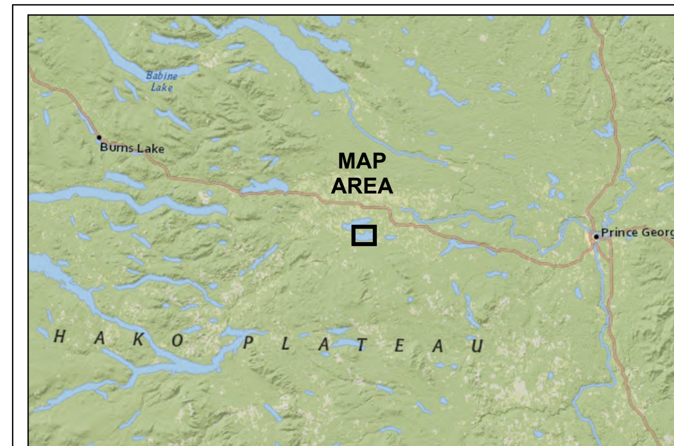
- Bathymetry Lines

Floating Leaf
- Variegated yellow pond lily (VP)

Emergent
- Common cattail (CC)
- Hardstem bullrush (HB)
- Swamp horsetail (SH)

Mixed Floating Leaf & Submergent
- Floating-leaved pondweed / Canadian waterweed / Common hornwort (FC)

Submergent
- Canadian waterweed / Common hornwort (CH)
- Common hornwort / Canadian waterweed / Richardson's pondweed (HC)
- Eelgrass pondweed / Canadian waterweed (EC)
- Richardson's pondweed / Siberian watermilfoil (RM)



0 0.5 1 1.5 2
Kilometres

Map Scale = 1:27,000 (printed on 11 x 17)
Map Projection: NAD 1983 UTM Zone 10N

Data Sources
- Inset Basemap. National Geographic World Map: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.
- Main Basemap. World Imagery: Maxar
- Vegetation community and bathymetry data. EDI, 2023.

Disclaimer
EDI Environmental Dynamics Inc. has made every effort to verify this map is free of errors. Data has been derived from a variety of digital sources and, as such, EDI does not warrant the accuracy, completeness, or reliability of this map or its data.

Drawn: AR	Checked: JG	Map 1	Date: 1/9/2024

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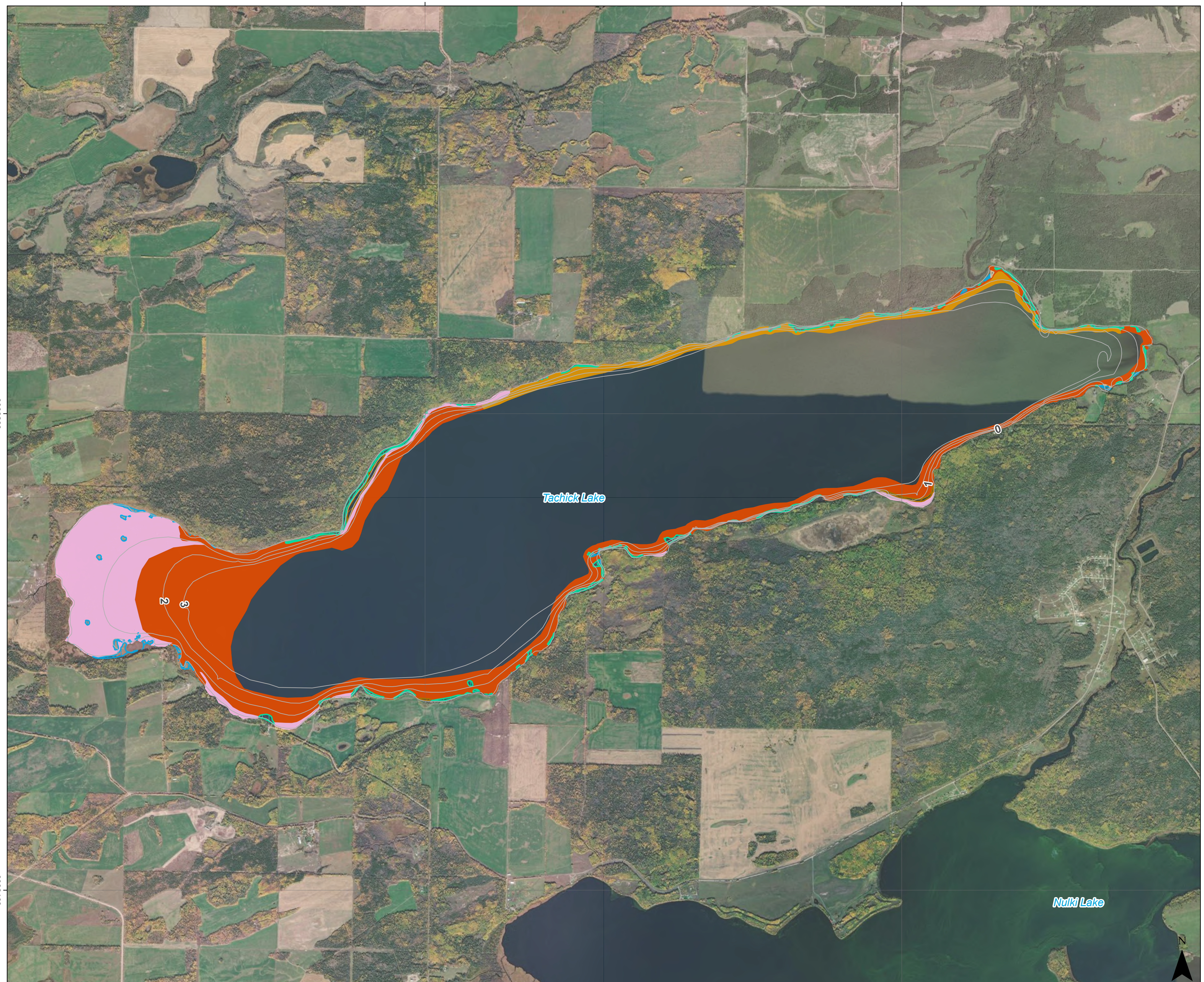
Table 4. Macrophyte communities identified within Tachick Lake.

Map Code	Common Name	Scientific Name	Average Depth (m)	Average Rake Cover (%)	Substrate Texture	Area (ha)	Lake Area (%)
Emergent Macrophyte Communities							
CC	common cattail	*Typha latifolia*	0.5 (range 0.1–0.8)	90 (range 25–100)	unknown	11.58	0.54
HB	hard-stemmed bulrush	*Schoenoplectus acutus*	0.6 (range 0.2–0.9)	65 (range 29–100)	silt/clay, gravel/rock	34.98	1.64
Submergent Macrophyte Communities							
CH	Canadian waterweed / common hornwort	*Elodea canadensis* / *Ceratophyllum demersum*	1.2 (range 0.4–1.9)	96 (range 88–100)	silt/clay	148.21	6.97
HC	common hornwort / Canadian waterweed / Richardson's pondweed	*Ceratophyllum demersum* / *Elodea canadensis* / *Potamogeton richardsonii*	2.2 (range 0.7–4.4)	63 (range 2–100)	silt/clay, gravel/rock	298.39	14.02
RM	Richardson's pondweed / Siberian water-milfoil	*Potamogeton richardsonii* / *Myriophyllum sibiricum*	2.0 (range 1.7–2.2)	50 (range 1–96)	silt/clay, gravel/rock	38.66	1.82
Mixed Floating and Submergent Macrophyte Community							
FC	floating-leaved pondweed / Canadian waterweed / common hornwort	*Potamogeton natans* / *Elodea canadensis* / *Ceratophyllum demersum*	1.6 (range 0.8–1.8)	98 (range 80–100)	silt/clay	6.51	0.31
Floating Macrophyte Community							
VP	variegated yellow pond-lily	*Nuphar variegata*	1.3 (range 0.9–1.5)	75 (range 35–100)	variable	0.55	0.03
Non-Vegetated							
NV	non-vegetated	–	2.5+	0 (range 0–0.4)	variable	1,588.83	74.67



Mapped Macrophyte Communities on Tachick Lake

Nulki-Tachick Lakes Stewardship Society

Legend

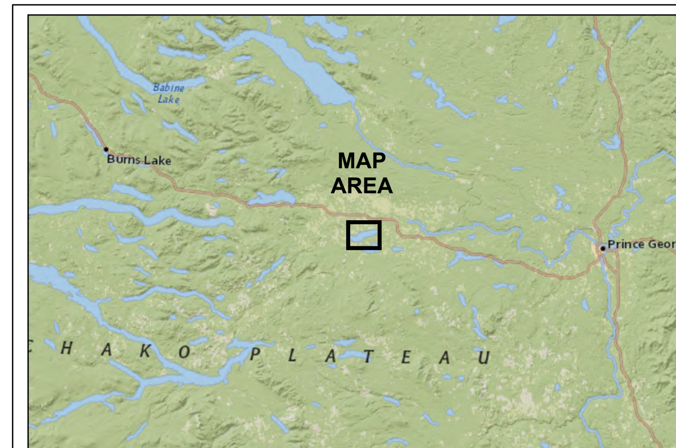
- Bathymetry Lines

Floating Leaf
- Variegated yellow pond lily (VP)

Emergent
- Common cattail (CC)
- Hardstem bullrush (HB)

Mixed Floating Leaf & Submergent
- Floating-leaved pondweed / Canadian waterweed / Common hornwort (FC)

Submergent
- Canadian waterweed / Common hornwort (CH)
- Common hornwort / Canadian waterweed / Richardson's pondweed (HC)
- Richardson's pondweed / Siberian watermilfoil (RM)



0 0.5 1 1.5 2
Kilometres

Map Scale = 1:40,000 (printed on 11 x 17)
Map Projection: NAD 1983 UTM Zone 10N

Data Sources
- Inset Basemap. National Geographic World Map: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.
- Main Basemap. World Imagery: Maxar
- Vegetation community and bathymetry data. EDI, 2023.

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4.2 MACROPHYTE COMMUNITY DESCRIPTIONS

4.2.1 COMMON CATTAIL (CC)

The common cattail (*Typha latifolia*) (CC) is an emergent macrophyte community which occurs along the shoreline extending approximately 1 to 15 m from the shoreline in water depths under 1 m (Map 1 and Map 2). It is characterized by a homogeneous dense cover of common cattail with trace occurrences of bulrush species (*Schoenoplectus* spp. and *Scirpus* spp.) in transitional areas. This plant community generally has very dense macrophyte cover ranging from 25% to 100% with an average of 90% (Photo 2 and Photo 3).

Nulki Lake has 0.01% cover of the common cattail macrophyte community, located on the northern shoreline. Tachick Lake has a cover of 0.54% for common cattail, and it occurs sporadically along all edges of the lake.

Photo 2. Example of common cattail vegetation community on the south side of Tachick Lake (August 30, 2023).

Photo 3. Example of common cattail vegetation community on the north side of Tachick Lake near the Stony Creek outlet (August 31, 2023).

4.2.2 CANADIAN WATERWEED / COMMON HORNWORT (CH)

The Canadian waterweed / common hornwort (CH) plant community occurs within sheltered bays generally in shallower depths and was present in on both lakes (Map 1 and Map 2). It is characterized by a dense cover of Canadian waterweed, with a minor component of common hornwort, and occasionally trace amounts of Richardson's pondweed and/or arum-leaved arrowhead (*Sagittaria cuneata*), variegated yellow pond-lily (*Nuphar variegata*) and eel-grass pondweed. This macrophyte community appears to be highly productive, with Canadian waterweed forming thick matts with minor components of other species (Photo 4 and Photo 5).

In Nulki Lake, this macrophyte community was generally infrequent, occurring in bays along the western side of the lake. Substrate textures are generally silty with a high organic content or silt with sand at depths of 0.5 m to 1.1 m with macrophyte cover on the rake ranging from 41 to 100%.

In Tachick Lake, this macrophyte community accounts for over a quarter (i.e., approximately 7% of entire lake) of the vegetated portions of the lake. It occurs in depths of 0.4 m to 1.9 m with rake macrophyte cover ranging between 88 to 100%. This community occurs within bays along the western half of the lake; with the largest area of CH located on the shallow shoreline on the western edge extending over 1 km from the lake shoreline.

Photo 4. Sampling rake full of Canadian waterweed / common hornwort vegetation community on the southwest side of Nulki Lake (August 29, 2023).

Photo 5. Example of Canadian waterweed / common hornwort vegetation community on the west end of Tachick Lake (August 30, 2023).

4.2.3 EEL-GRASS PONDWEED / CANADIAN WATERWEED (EC)

The Eel-grass pondweed / Canadian waterweed (EC) submergent macrophyte community is characterized by a lower cover of macrophytes, but consistently dominated by eel-grass pondweed with Canadian waterweed, Richardson's pondweed and occasionally common hornwort occurring sporadically throughout (Map 1 and Map 2). Substrate textures are generally silty sands or sandy silts (Photo 6 and Photo 7).

Photo 6. Example of eel-grass pondweed / Canadian waterweed vegetation community off the south shore of Nool Island on Nulki Lake (August 29, 2023).

Photo 7. Example of eel-grass pondweed sampled from the southeast side of Tachick Lake (August 30, 2023).

In Nulki Lake, this macrophyte community accounts for approximately a quarter of the vegetated portions of the lake (i.e., approximately 5% of entire lake area). It occurs in depths of 0.5 m to 2.0 m with rake cover ranging from 2 to 13%. This macrophyte community was not observed during surveys on Tachick Lake, although eel-grass was present in Tachick Lake as a minor component of other plant communities.

4.2.4 HARD-STEMMED BULRUSH (HB)

The Hard-stemmed bulrush (*Schoenoplectus acutus*) (HB) emergent macrophyte community is a minor, but consistent component of each lake. It is characterized by hard-stemmed bulrush dominant macrophyte cover, with traces of other bulrush species (*Schoenoplectus* spp. and *Scirpus* spp.) throughout (Map 1 and Map 2). In areas that had a lower cover of rush species or were transitional with other macrophyte communities, variegated yellow pond-lily, Richardson's pondweed, swamp horsetail and Canadian waterweed were observed in limited cover. This macrophyte community generally occurs directly adjacent to shoreline (or boarding the common cattail macrophyte community) and was observed at depths of 0.2 m to 0.9 m and rake covers of 29 to 100% (Photo 8 and Photo 9). This community made up approximately 1.0% of the vegetated areas on Nulki Lake and 1.6% of the vegetated areas on Tachick Lake.

Photo 8. Example of hard-stemmed bullrush vegetation community on the north side of Tachick Lake (August 31, 2023).

Photo 9. Example of hard-stemmed bullrush vegetation community on the east end of Tachick Lake (August 31, 2023).

4.2.5 COMMON HORNWORT / CANADIAN WATERWEED / RICHARDSON'S PONDWEED (HC)

The Common hornwort / Canadian waterweed / Richardson's pondweed (HC) submergent macrophyte community was the most abundant macrophyte community in both lakes and was observed throughout the lakes (Map 1 and Map 2). Common hornwort is dominant with minor components of Canadian waterweed, variable cover of Richardson's pondweed and trace amounts of eel -grass pondweed (Photo 10 and Photo 11).

In Nulki Lake, substrate textures were mainly silty with a high organic content. This community was observed within depths of 0.5 m to 2.5 m with rake cover ranging from 2 to 100%. On Nulki Lake, the HC community accounts for over one third the vegetated area (i.e., approximately 14% of entire lake area).

In Tachick Lake, substrate textures were generally silty with a high organic content. This community has been observed within depths of 0.7 m to 4.4 m with rake cover ranging from 2 to 100%. Within the vegetated area on Tachick Lake, the HC community accounts for approximately half the area.

Photo 10. Example of the common hornwort / Canadian waterweed / Richardson's pondweed vegetation community on the west end of Nulki Lake (August 28, 2023).

Photo 11. Sample of the common hornwort / Canadian waterweed / Richardson's pondweed vegetation community from the southeast side of Tachick Lake (August 30, 2023).

4.2.6 RICHARDSON'S PONDWEED / SIBERIAN WATER-MILFOIL (RM)

The Richardson's pondweed / Siberian water-milfoil (RM) submergent macrophyte community occurred on both lakes and was generally observed in deeper depths with lower cover of macrophytes (Map 1 and Map 2). It was characterized by Richardson's pondweed, with limited cover of Siberian water-milfoil (*Myriophyllum sibiricum*), and occasionally trace amounts of variegated yellow pond-lily, eel-grass pondweed, and Canadian waterweed (Photo 12 and Photo 13).

In Nulki Lake, substrate textures vary from silt/clay, gravel/rock, and sand with silt. This community was observed within depths of 1.5 m to 2.2 m with rake cover ranging from 1 to 31% Within the vegetated area on Nulki Lake, the RM community accounts for 20%.

In Tachick Lake, substrate textures are generally silt/clay and gravel/rock. This community was observed within depths of 1.7 m to 2.2 m with rake cover ranging from 1 to 96%. Within the vegetated area on Nulki Lake, the RM community accounts for 7%

Photo 12. **Example of Richardson's pondweed / Siberian water-milfoil vegetation community on the east end of Nulki Lake (August 29, 2023).**

Photo 13. **Sample of Richardson's pondweed / Siberian water-milfoil vegetation community from the north side of Nulki Lake (August 29, 2023).**

4.2.7 SWAMP HORSETAIL (SH)

The swamp horsetail (*Equisetum fluviatile*) (SH) community is characterized by an evident cover of both emergent and submergent macrophytes. Swamp horsetail dominates the cover with trace amounts of variegated yellow pond-lily and hard-stemmed bullrush. waterweed, Richardson's pondweed and occasionally common hornwort occurring sporadically throughout. Substrate textures are generally silty sands, sandy silts or less common rock/gravel.

In Nulki Lake, this macrophyte community accounts for a small portion of the lake cover. It occurred depths of 0.1 m to 0.8 m with rake cover ranging from 25 to 90% (Map 1, Photo 14 and Photo 15).

Photo 14. **Example of swamp horsetail vegetation community on the north side of Nulki Lake by the Stony Creek outlet (August 29, 2023).**

Photo 15. **Example of swamp horsetail vegetation community on the south side of Nulki Lake (August 28, 2023).**

4.2.8 VARIEGATED YELLOW POND-LILY (VP)

The floating leaf macrophyte community variegated yellow pond-lily (VP) occurred in small clusters throughout both lakes, generally in more sheltered areas (Map 1 and Map 2). It was characterized by a high cover of variegated yellow pond-lily and components of Canadian waterweed, Richard's pondweed, and eel-grass pondweed (Photo 16 and Photo 17). Substrate texture varied from silt/clay, silt with sand and gravel/rock. It occurred in depths of 0.9 m to 1.5 m with rake cover ranging from 35 to 100%. The variegated yellow pond-lily was often scattered throughout other macrophyte communities within the same depth range.

Photo 16. Example of the variegated yellow pondweed vegetation community on the north side of Nulki Lake by the Stony Creek outlet (August 29, 2023).

Photo 17. Example of the variegated yellow pondweed vegetation community on the southeast side of Nulki Lake (August 28, 2023).

4.2.9 FLOATING-LEAVED PONDWEED / CANADIAN WATERWEED / COMMON HORNWORT (FC)

This mixed floating and submergent macrophyte community consisted of floating-leaved pondweed (*Potamogeton natans*) / Canadian waterweed / common hornwort (FC) and generally occurred in small clusters throughout both lakes (Map 1 and Map 2). It is characterized by the dominating floating-leaved pondweed with significant amounts of common hornwort, Canadian waterweed, and eel-grass pondweed, and occasional trace amounts of Richardson's pondweed, ivy-leaved duckweed (*Lemna trisulca*), and variegated yellow pond-lily (Photo 18 and Photo 19). Substrate texture was generally silty and high in organics, occurring in depths of 0.8 m to 1.8 m. A key characteristic of this macrophyte community is the high rake cover ranging from 80 to 100%.

Photo 18. **Sample of the floating-leaved pondweed / Canadian waterweed / common hornwort vegetation community from the east end of Nulki Lake (August 29, 2023).**

Photo 19. **Example of the floating-leaved pondweed / Canadian waterweed / common hornwort vegetation community on the north side of Tachick Lake (August 30, 2023).**

4.2.10 NON-VEGETATED (NV)

Non-vegetated (NV) areas occur on over 81% of Nulki Lake and over 74% of Tachick Lake. Non-vegetated areas were observed at depths of 2 m to 6.7 m with an average depth of 3.25 m (Map 1 and Map 2, Photo 20 and Photo 21). Substrate was variable with textures of silt/clay, gravel/rock, sand/silt observed. Dipteran larvae of the family *Chironomidae*, commonly referred to as midges or bloodworms, were often collected from non-vegetated substrate.

Photo 20. **Example non-vegetated habitat on Nulki Lake (August 28, 2023).**

Photo 21. **Example of non-vegetated habitat taken from the north side of Tachick Lake (August 31, 2023).**

4.3 MACROPHYTE LABORATORY ANALYSES

Macrophyte samples were collected from 22 transect locations on both lakes: Nulki Lake between August 28 to 29, 2023 and Tachick Lake between August 30 to 31, 2023. From each lake, 16 composite macrophyte samples (i.e., all macrophytes on rake), two duplicate samples and four single species samples were submitted to an accredited laboratory (ALS in Burnaby) for analyses. Full laboratory analyses results for each sample are presented in Appendix C (Nulki Lake) and Appendix D (Tachick Lake).

The four most common submergent macrophyte species in both lakes included common hornwort, Canadian waterweed, eel-grass pondweed, and Richardson's pondweed.

To understand the average P tissue concentration among the most common submergent species and macrophyte communities within Nulki and Tachick lakes, total P concentrations were averaged among the lakes and are presented in Table 5. Common hornwort and Canadian waterweed had the highest P concentration expressed as mg/kg dry weight. The two macrophyte communities that were dominated by these species, Canadian waterweed / common hornwort (CH) and common hornwort / Canadian waterweed / Richardson's pondweed (HC) had the highest P concentration expressed both as mg/kg dry weight and mg/kg wet weight (Table 5)

Table 5. Average total phosphorus (TP; dry and wet weight), and moisture content in four dominate macrophyte species and four submergent plant communities in macrophyte samples from Nulki and Tachick lakes combined.

Common Name	Scientific Name/ Macrophyte Community Code	Sample size	Average TP (mg/kg dwt)	Average TP (mg/kg wwt)	Average Moisture Content (%)
Dominant Macrophyte Species					
Common hornwort	*Ceratophyllum demersum*	2	4,665	591	87.3
Canadian waterweed	*Elodea canadensis*	2	4,500	533	88.2
Eel-grass pondweed	*Potamogeton zosteriformis*	2	3,300	434	85.5
Richardson's pondweed	*Potamogeton richardsonii*	2	3,125	450	86.7
Submergent Macrophyte Communities					
Canadian waterweed / common hornwort	CH	10	4,183	523	87.6
Eel-grass pondweed / Canadian waterweed	EC	4	3,830	439	88.0
Common hornwort / Canadian waterweed / Richardson's pondweed	HC	9	5,041	526	89.2
Richardson's pondweed / Siberian water-milfoil	RM	5	4,148	468	87.3

5 MACROPHYTE HARVEST FEASIBILITY

5.1 HARVESTABLE AREA AND EFFORT

Submergent macrophyte beds were considered harvestable and covered approximately 264 ha in Nulki Lake, or about 20% of the lake surface area (Table 3). Harvestable submergent macrophyte beds in Tachick Lake covered approximately 485 ha, or 30% of the lake surface area (Table 4). Based on the previously stated assumptions that the mechanical harvester would be operated at a speed of 2 to 3 km/h for seven hours per day, it was estimated that a single Aquamarine H5-200 harvester could cover 2.1 to 3.1 ha per day. This equates to harvesting 0.8 to 1.2% of the total submergent macrophyte beds in Nulki Lake daily, or 0.4 to 0.6% of the total submergent macrophyte beds in Tachick Lake daily. Assuming the harvesting program runs from Monday through Friday from June 1 to September 30 (approximately 86 days), a single harvester could cover 180 to 267 ha annually.

5.2 BIOMASS AND PHOSPHORUS REMOVAL FROM HARVESTING

Densities of submergent macrophyte beds varied greatly throughout Nulki and Tachick lakes based upon the location of the beds, macrophyte community type, lake bathymetry and substrate type. The presence of various macrophyte communities appears to correlate with water depth and substrate type, although these variables could not be statistically correlated due to the limited sample size (Map 1 and Map 2 and Table 3 and Table 4). For each macrophyte community type, the mean area biomass density (kg wwt/m^2) and estimated daily biomass harvested and P removed at two different harvesting rates is presented in Table 6. The biomass area density estimates and predicted quantity of biomass and P removed daily vary greatly among macrophyte community types. The highest densities and opportunities for P removal occur within the Canadian waterweed/common hornwort (CH) and common hornwort/Canadian waterweed/Richardson's waterweed (HC) community types (Table 6), ranging from 14,659 to 137,530 kg of biomass harvested per day and 7.7 to 71.9 kg P removed per day.

Assuming the harvester would be operated seven hours per day for 86 days per year, it was estimated that 1,260 to 1,891 tons of biomass could be removed from the HC community type annually based on harvester speeds of 2 to 3 km/h. This relates to an estimated range of 662 to 998 kg P removed annually. For the CH community type, it was estimated that 7,885 to 11,828 tons of biomass could be harvested annually, equating to 4,128 to 6,183 kg P removed annually at harvester speeds of 2 to 3 km/h. It is likely that biomass and P removal may be substantially lower when harvesting high density submergent macrophyte beds, and the harvest estimates provided may not be achievable due to logistical constraints of offloading and transporting harvested material from the harvest location to one of a few access points on Nulki and Tachick lakes. In addition, the speed at which the harvester can operate is greatly dependent on the density of the macrophytes as the harvester can reach capacity very quickly in very dense macrophyte beds. A mechanical harvester may fill to capacity after moving as little as one harvester length in extreme conditions, thus requiring constant offloading. With the net system Aquamarine Inc. offers, a full net can be detached and an empty net attached to the harvester in 5 minutes. In this case, the harvester can continue harvesting as long as the operator has a supply of empty nets (C. Bollinger, Aquamarine Inc., personal communication).

Table 6. Estimates of mean biomass density (kg wwt/m²), biomass harvested at harvester speeds of 2 and 3 km/h, and associated phosphorus (P) removed at harvester speeds of 2 or 3 km/h for the submergent macrophyte communities based on samples from Nulki and Tachick lakes. See text for assumptions.

Macrophyte Community Name	Macrophyte Community Code	Mean Biomass Density (kg wwt/m² ± 1 SD)	Biomass Harvested per Day at 2 km/h (kg)	Biomass Harvested per Day at 3 km/h (kg)	P Removed per Day at 2 km/h (kg)	P Removed per Day at 3 km/h (kg)
Canadian waterweed /common hornwort	CH	4.36 ± 4.85	91,686	137,530	48.0	71.9
Eel-grass pondweed / Canadian waterweed	EC	0.23 ± 0.13	4,866	7,300	2.1	3.2
Common hornwort / Canadian waterweed / Richardson's pondweed	HC	0.70 ± 0.82	14,659	21,988	7.7	11.6
Richardson's pondweed / Siberian water-milfoil	RM	0.16 ± 0.15	3,415	5,122	1.6	2.4

Tabor Lake, a 380 ha lake approximately 125 km east of Nulki and Tachick lakes, has been managed in part through a macrophyte harvesting program using a single mechanical harvester for the past 20 years. Simmons (1997) documented the macrophyte harvest in 1995 from Tabor Lake which provides a real-world example and realistic expectations from a similar macrophyte harvest program. Between June and September 1995, the Tabor Lake Cleanup Society removed 882 macrophyte harvester loads from Tabor Lake, with each load removing an estimated 1,130 kg of wet material, for a total of 997,000 kg of wet biomass harvested. This equates to about 10.25 macrophyte loads totalling 11,593 kg per day. Based on these biomass quantities, Simmons (1997) estimated that 578 kg P was removed from Tabor Lake through macrophyte harvesting in 1995. The Tabor Lake Cleanup Society has similar goals to the NTLSS of 1) Weed control; 2) Cleaning up weeds; 3) Improving water quality; 4) Improving fish habitat; 5) Education about pollution and control; and 6) Monitoring of the lake including phosphate levels, trophic status and coliform levels (Tabor Lake Cleanup Society website https://taborlakecleanup.com/).

Given the differences between Tabor Lake and Nulki and Tachick lakes, additional logistical and cost challenges may limit the capacity of a large-scale macrophyte harvesting program. Nulki and Tachick lakes are approximately 4.25 and 5.6 times the surface area of Tabor Lake, which increases the logistical complexity by increasing travel time of the harvester within each lake and the transport time to move harvested material to a shoreline access point. The size of the lakes and associated wind fetch may hamper the ability to harvest or transport material in high wind and wavy conditions due to safety concerns. The mechanical harvesting program should utilize a net system to contain the harvested material as well as a dedicated vessel to collect and transport the material once harvested to reach the estimated biomass harvest levels. In addition, this approach would require a crane or excavator large enough to hoist the full nets over a dump truck to empty the nets (C. Bollinger, Aquamarine Inc., personal communication). The quantity of macrophytes harvested from Tabor Lake in 1995 required the equivalent of 153 6.5-ton dump truck loads to transport. A local disposal option for harvested material would be necessary to reduce transport costs. These considerations would increase the labour and operational expense of the harvesting program, including fuel and maintenance costs.

5.3 PHOSPHORUS IN NULKI LAKE SEDIMENT

Based on the data provided on the quantity of P in Nulki Lake sediments (Appendix B), it was estimated that 332,000 ± 16,191 kg (mean ± SE) of P is stored in the top 2 cm of Nulki Lake sediment, and 498,000 ± 24,287 kg of P is present in the top 3 cm of sediment. Simmons (1997) reported that 162,000 ± 10,100 kg of P was stored in the top 3 cm of sediment in Tabor Lake, with an estimated 1,197 to 2,290 kg being released from the sediment to the water column in 1995. The total quantity of P estimated in the top 3 cm of lake sediments equates to 307 kg P/ha for Nulki Lake compared to 425 kg P/ha for Tabor Lake. Although the concentration of P is lower in Nulki Lake sediments, this still represents a large sink of P that could be a source of nutrient into the water column. If P were released from the sediment to the water column at a similar rate in Nulki Lake compared to Tabor Lake, it would represent 3,685-7,022 kg P mobilized into the water column annually. This could easily surpass the quantity of P removed from the Nulki Lake ecosystem through a macrophyte harvesting program. It is well documented that P release into the water column can occur through redox reactions under anoxic conditions (Petticrew and Arocena 2001). However, French and Petticrew (2007) documented increases in TP in the Nulki Lake water column in late summer and early fall under isothermal conditions. They concluded this increase in TP was from internal loading and hypothesized that P was released from bottom sediments through an alternative mechanism, such as decomposition of P-containing organics, when temperatures were above 15°C and pH was greater than 9. These conditions occur during the summer and early fall months in Nulki Lake (French and Petticrew 2007). As mentioned earlier, the mechanisms of P mobilization from lake sediments are complex and can occur through a variety of mechanisms (Orihel et al. 2005).

5.4 SHORELINE IMPACTS AND LAKE HAZARDS

Shoreline impacts were documented by the field crew and included small areas of shoreline erosion on Tachick Lake, as well as foreshore development on both lakes including residential structures with minimal setbacks and lawns extending to the shoreline, as well as roads, agricultural fields and domestic livestock operations with minimal buffer strips (Map 3 and Map 4).

During the macrophyte field surveys, no lake hazards were identified. Due to low water visibility created by phytoplankton and algae, it was difficult to see below the surface of the water. Unobserved hazards may exist that the field crew could not identify visually during macrophyte surveys. Therefore, it is recommended that hazards be mapped as they are encountered if a macrophyte harvesting program is pursued.

Of the fish species present in Nulki and Tachick lakes, redside shiners, peamouth, and largescale suckers are most likely to be associated with aquatic vegetation (Scott and Crossman 1998, Roberge and Slaney 2001). Redside shiners are known to congregate around rooted aquatic vegetation and spawn along shorelines, including around aquatic macrophytes. Peamouth prefer the shallow weedy zones of lakes and rivers.

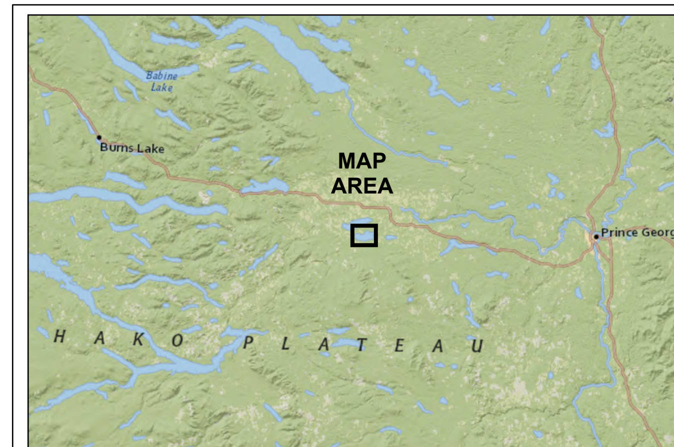
Largescale suckers tend to occur in shallow areas with aquatic macrophytes (Roberge and Slaney 2001). Other fish species in Nulki and Tachick lakes tend to use deeper, colder water habitats in the summer when the macrophyte harvesting would occur. Rainbow trout and burbot, are more likely to occur near the mouths of tributary or outlet streams, especially during spawning.

Shoreline Erosion and Foreshore Development
Nulki Lake

Nulki-Tachick Lakes Stewardship Society

Legend

Photo Location



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Kilometres

Map Scale = 1:30,000 (printed on 11 x 17)
Map Projection: NAD 1983 UTM Zone 10N

Data Sources
• Inset Basemap. National Geographic World Map: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.
• Main Basemap. World Imagery: Maxar

Disclaimer
EDI Environmental Dynamics Inc. has made every effort to verify this map is free of errors. Data has been derived from a variety of digital sources and, as such, EDI does not warrant the accuracy, completeness, or reliability of this map or its data.

Drawn: AR	Checked: JG	Map 3	Date: 1/5/2024

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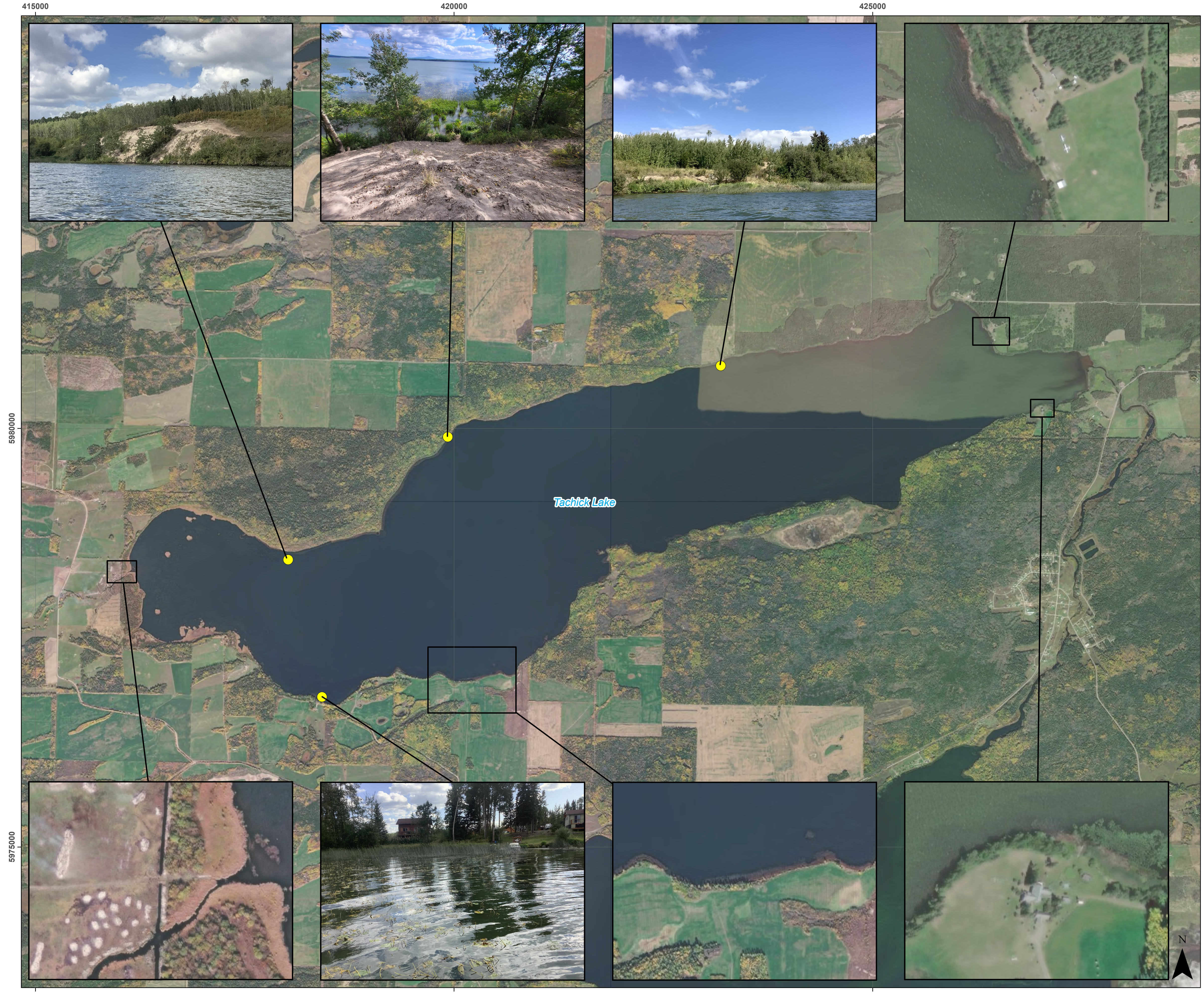
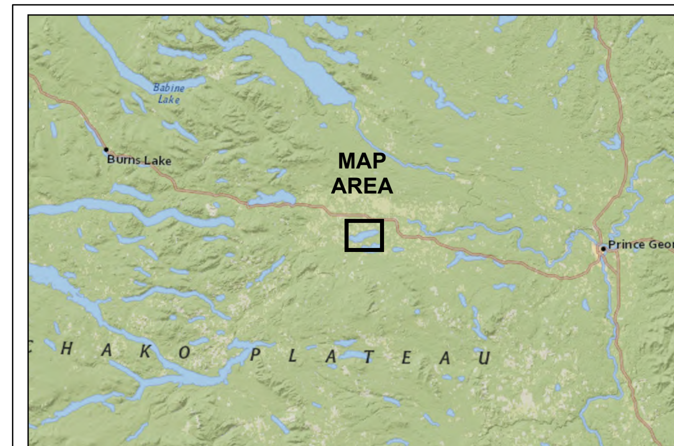


Shoreline Erosion and Foreshore Development
Tachick Lake

Nulki-Tachick Lakes Stewardship Society

Legend

Photo Location



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Kilometres

Map Scale = 1:45,000 (printed on 11 x 17)
Map Projection: NAD 1983 UTM Zone 10N

Data Sources
• Inset Basemap. National Geographic World Map: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.
• Main Basemap. World Imagery: Maxar

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6 MANAGEMENT RECOMMENDATIONS

Nulki and Tachick lakes have undergone a transformation in trophic status from mesotrophic to hypereutrophic over the course of decades. This transformation was brought upon by multiple factors, including the development of the watershed upstream of the lakes for agriculture, ranching and forestry. Lakeshore development, atmospheric deposition of nutrients and wildfire ash, point and non-point sources of pollution, changes in hydrologic regime, and loss of wetlands within the watershed have contributed to the eutrophication of these lakes. The result has been increased P in the lake sediments and water column (Cumming 2000), increased frequency and severity of algal blooms, including frequent cyanobacteria blooms, increases in the density and extent of aquatic macrophyte beds, and increased summer water temperature and subsequent decreased dissolved oxygen concentrations (French and Petticrew 1997, R. Klingspohn personal communication). These environmental changes are manifesting not only in increased primary productivity within the lake ecosystems which has decreased the recreational value of the lake, but also in kills of suckers and invertebrates (gastropods) over the past year. The Saik'uz First Nation and local residents are becoming increasingly concerned with these environmental changes which threaten their water and food supplies and quality of their local environment.

Reversing these changes will not be an easily attainable goal. EDI has attempted to present in this report an analysis of the potential impacts of an aquatic macrophyte harvest program aimed at reducing aquatic macrophyte biomass and thus having positive effects on water quality through time by removing some of the excess P stored in the lake ecosystems and reducing the organic material leading to anoxic conditions. External P loading in the lakes was not addressed in this report, but it must be addressed in future management actions to reverse the process of eutrophication. Specifically, actions such as identifying and removing any point or non-point sources of P upstream of the lakes, restoring wetlands in the watershed, restoring adequate riparian buffers both in the tributary streams and the shores of Nulki and Tachick lakes, and public education on the value of riparian buffers and the potential impacts of fertilized lawns and inadequate septic systems are key to the long-term success of reversing eutrophication of the lakes.

It will likely require a multi-pronged approach to reverse the trends of eutrophication in Nulki and Tachick lakes. A properly designed aquatic macrophyte harvesting program can be an important component of this restoration program and address immediate ecological risks in the lakes (i.e., fish kills, severity and frequency of algal blooms and presence of cyano-bacteria). Because of the size of Nulki and Tachick lakes and the logistical challenges of implementing an aquatic macrophyte harvesting program that is feasible and financially realistic, EDI suggests a focused approach should be taken to maximize the benefits. Because the estimated annual maximum harvest area of 180 to 267 ha is only a portion of the combined 749 ha of submergent macrophyte beds estimated to be harvestable from both lakes combined, a targeted approach is recommended based on the densities and [P] measured from the various macrophyte communities to maximize both biomass and TP removal. In the case of Nulki and Tachick lakes, macrophyte beds consisting of Canadian waterweed / common hornwort (CH) and common hornwort / Canadian waterweed / Richardson's pondweed (HC) macrophyte communities should be targeted. EDI also advises that to minimize negative impacts of fish habitat, harvest should be focused on small geographic regions of the lakes where macrophyte density is highest. Both Nulki and Tachick lakes have extensive CH and HC community macrophyte beds on the western end of the lakes where the shallow water depths and thus macrophyte beds extend 1 to 2 km from shore (Map 1 and Map 2). The western end of both lakes also likely receive nutrient inputs from tributary streams, including Stony, Bear and Corkscrew creeks flowing into Nulki Lake and Tachick Creek flowing into Tachick Lake. By focusing macrophyte harvest efforts in the western extent of Nulki and Tachick lakes, the benefits of the program can be maximized while reducing the logistical constraints. In addition, there may be an operational and safety benefit to working in shallow bays on the western side of the lakes to avoid prevalent westerly winds and associated waves. Finally, EDI sees a likely benefit as a higher probability of successfully negotiating the permitting process by focusing the aquatic macrophyte harvesting program on smaller areas within each lake.

EDI advises the macrophyte harvesting program should focus on dense submergent macrophyte beds and avoid emergent and floating macrophyte communities, which provide more habitat for other animals. For instance, emergent macrophytes such as cattail and bullrush provide habitat and food for a wide variety of wildlife include red-winged and yellow headed blackbirds, marsh wrens, mallards, Canada geese, frogs, salamanders and mammals such as muskrats, racoons and deer. Floating leaf macrophytes can provide nesting habitat for red necked grebes and insects and provide shade which may reduce water temperature and increase oxygen concentration.

Dense beds of submergent aquatic macrophytes provide cover, habitat and food for invertebrates. Species of fish in Nulki and Tachick lakes that are likely to use aquatic macrophyte beds include redside shiners, peamouth and largescale suckers. Therefore, EDI suggests avoiding harvesting in water shallower than 0.5 m and areas around the mouths of tributary streams to reduce the impact on fish.

EDI recommends that consideration should be given to a multi-pronged approach to managing nutrients in the Nulki and Tachick lake watersheds. Besides establishing an aquatic macrophyte sampling program, other approaches that should be considered on a larger scale throughout the watershed are wetland restoration, establishment and maintenance of riparian buffers, education and outreach efforts to landowners and residents, and further research on sources and quantities of nutrients entering the lake ecosystems. Further, an approach such as chemical binding and precipitation of P using alum application, or a similar approach could be investigated to address the large quantities of P stored in the lake sediments. While whole lake treatment of alum may be prohibitively expensive, smaller scale experimental application may be beneficial to provide some remediation of P levels. Aluminum can be toxic to fish outside the pH range of 6 to 8, and there are guidelines for aluminum concentration in freshwater in Canada, so careful research and planning would be required to pursue this approach and gain approvals and permitting. In Nulki Lake, pH is within the 6-8 range early and late in the growing season (French and Petticrew 2007).

Three approaches that are not recommended are hypolimnetic oxygenation, sediment dredging and water withdrawal. Given the size of Nulki and Tachick lakes and the fact that they do not stratify in summer, hypolimnetic oxygenation would be prohibitively expensive and provide negligible benefits. Sediment dredging has been shown to be ineffective and will almost certainly have detrimental effects on water quality. Water withdrawals and water level manipulations are also not practical on Nulki and Tachick lakes, as they are shallow lakes with no water control structures. Hypolimnetic water withdrawals would be practically limited due to the shallow nature of these lakes.

7 PERMITTING SUPPORT

Two distinct processes must be completed to be granted the appropriate permits to begin harvesting macrophytes from Nulki and/or Tachick lakes. First, a Change Approval for Changes in and About a Stream must be granted under the *Water Sustainability Act*. This application can be made online through FrontCounter BC and submitted electronically. The application process is fairly straightforward; however, there are two considerations that should be accounted for:

1) if the proponent (NTLSS) wishes to begin the macrophyte harvest before July 15, the changes would occur outside the timing window for rainbow trout in the Omineca Region; and,
2) since the project might require access to crown lands (for instance, to store equipment on the shoreline), the proponent (NTLSS) may be required to obtain Crown Tenure to complete the works.

Because it is well documented that rainbow trout enter tributary streams to spawn, a variance can be requested as part of the permit application to allow early macrophyte harvest within the rainbow trout timing window. Crown tenure can be requested through the application for a temporary use permit if required to deal with the second consideration, although an additional application fee would apply. Once the application is submitted and is deemed complete, it will be reviewed by a habitat officer and/or other technical experts and will be sent to First Nations for review. Based on the decision of the regulators, the applicant may be required to submit advice from a Qualified Professional, such as a Registered Professional Biologist, to present mitigation measures for reducing harm to aquatic organisms such as fish.

The second process that needs to be completed is a Request for Review (RFR) from the Fisheries and Oceans Canada (DFO) related to the *Fisheries Act*. Because the proposed project involves harvesting aquatic macrophytes, and therefore making changes to fish habitat, harvest of aquatic macrophytes could be deemed as a HADD to fish habitat. While the project will likely also have positive impacts to fish habitat, including the reduction of anoxic conditions that cause fish kills, DFO may require a *Fisheries Act* Authorization. Based on the response to the RFR, DFO will stipulate whether an Authorization is required.

The RFR requires the proponent to fill out a pdf form located at https://www.dfo-mpo.gc.ca/pnw-ppe/reviews-revues/forms-formes/request-demand-eng.pdf. The form requires contact information, a description of the project, the location of the project, and a description of the aquatic environment. The information to fill out the form can be taken from this document.

8 MONITORING PLAN

To assess the effectiveness of an aquatic macrophyte harvesting program, EDI Environmental Dynamics Inc. (EDI) proposes the following data are collected concurrent with the harvesting effort.

- Monthly water quality monitoring from May through October, including:
    - temperature/oxygen/pH profiles in the deepest portion of each lake, with measurements at 0.5 m depth increments from the surface to the bottom;
    - Secchi depth measurement; and,
    - duplicate water quality samples from the surface and 1 m from the bottom. These water samples should be sent to a laboratory for analyses of Chlorophyl a, TP, TN, dissolved organic carbon, alkalinity, pH, colour, turbidity, conductivity, and orthophosphorus (Phosphate).

In addition, a log should be kept of the time the harvester is run, the total number of macrophyte loads offloaded, the weight of macrophytes removed (loaded and tare weight for each dump truck load). The water quality samples should be enough to show trends in water quality through time, while the macrophyte harvest records will document the quantity of nutrients removed from the lakes due to the harvest program.

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APPENDICES

APPENDIX A AQUAMARINE H5-200 TECHNICAL SPECIFICATIONS

1

AQUAMARINE

586 Third Line, Oakville, Ontario, CANADA, L6L 4A7
Tel: 905-825-1371 info@aquamarine.ca www.aquamarine.ca Fax: (905) 825-4116

H5-200 AQUATIC PLANT HARVESTER: Technical Specifications & Pricing

DIMENSIONS & WEIGHT

Operating:		
Length - Overall	33'- 1"	10,08 m
Width – Wheels at Side	11'- 7"	3,53 m
Width – Wheels at Stern	8'- 6"	2,59 m
Height – From Water	7'- 6"approx	2,13 m *
Shipping: Length	*34'-1"*	*10,38 m*
Width	*7'-6"*	*2,29 m*
Height (Intl)	*7'-9"*	*2.36 m*
(Fits into a 40 ft. container)		
Height Overall on dry land	8'- 9"	2,67 m
Weight Dry without options	6,800 lbs.	3091 kg

CARRYING CAPACITY

Maximum Volume	200 cu ft.	5,7 m3
Maximum Weight	3,000 lbs.	1360 kg
(@ 30% Freeboard)		

FLOTATION – (304 / 18-8 Stainless Steel Flat Bottom Hull 14 ga – 2 mm)

Height	(23"/17.5")	(58 cm/44 cm)
Length	19'- 0"	5,8 m
Width	7'- 6"	2,3 m
Two Bolt on Stainless Steel	Pontoons	
Compartments	(5) Air & watertight	
Draft (average):		
- Light	10.5"	27 cm
- Loaded	15.5"	39 cm
Hull Bottom Protection	2 UHMW	
(add 3 1/2"/9 cm to draft)	Skids	

POWER SYSTEM & CONTROL BRIDGE

Engine Type	Kubota D1305-4KEA - 2100 rpm	
Cooling	Liquid Cooled	
Power Output (total)	24.8 HP (18.24 kW) @ max rpm	
Hydraulic Pump	load sensing piston pump	
SS Hydraulic Oil Tank	22 US gal	85 liter
Diesel Fuel Tank	13 US gal	49 liter
System EPA approved		
Operator's Seat	Adjustable, White	
Control Panel	Engine monitoring system (Diesel)	
Hydraulic Control	PVG 32 valve bank	
Hydraulic Fittings	O Ring Face Seal & O Ring Boss (Leak Proof)	

HARVESTING HEAD

Cutting Width	5'-0"	1,5 m
Cutting Depth (max.)	5'-6"	1,7 m
Horiz. / Vert. Knives	3" (76 mm) w. reciprocating stroke	
Belt & Cutter Drives	Hydraulic motors, direct drive	
Impact Absorption	Swinging pivot suspension system	
Conveyor Belting	Standard duty galvanized steel mesh Variable Speed	

STORAGE & UNLOADING SYSTEM

Type	Dual conveyors with articulating off-loading section	
Conveyor Bed Width	3'-7"	1,1 m
Conveyor Overhang	6'-0"	1,8 m
Unloading Height (above deck)	4'-0"	1,2 m
Unloading Time (avg.)	60 seconds (load dependent)	
Conveyor Belting Type	Standard duty galvanized steel mesh	
Conveyor Belt Drive	Hydraulic motor, direct drive	
Conveyor Belt Frames	Stainless Steel	

PROPULSION

Type	Stainless Steel Twin Paddle Wheels	
Machine Controls	Tethered proportional electronic remote control	
Diameter x Width	4'-2" x 1'-9"	1,27 x 0.53 m
Paddle Wheel Drives	Hydraulic motors	
Paddle Wheel Speed	Variable	
Paddle Wheel Deployment	Side propulsion or swing-a-round Stern propulsion	

GENERAL

Fasteners	Stainless Steel & high strength alloy steel, as required
Safety Railing	On Control Bridge
Conveyor Belting Supports	UHMW PE wear strips on running Surfaces
Anti-Corrosion System	Unpainted Stainless steel hull throughout, high visibility safety orange industrial epoxy/polyester powder coating on carbon steel super structure
Electrical System	12 Volt DC (Battery not included) Fire Extinguisher Bracket 2 – 12V Power Outlets
Navigation Lights & Horn	Marine Standards

* **Without Sun-Rain Bimini Cover**
Due to Aquamarine's ongoing efforts to improve its products, specifications are subject to change without notice.

H5-200 USD 89,980.00

Page 1 of 4 **June 13, 2023**

APPENDIX B NULKI LAKE SEDIMENT SAMPLES

Nulki Lake Sediment Collection

Author and Sampler: Connor Nielsen

Sampling Date: May 2, 2021

Methods

The top 2 cm of sediment from the lake bottom was collected roughly 100 m from shore. Samples were collected via scuba diving, in roughly 3 m of water. Sediment was collected in Tupperware containers, then transferred over into plastic Ziploc bags. The sediment was stored in a fridge and taken to Northern Analytical Laboratory Services at UNBC within 24 hours.

Sampling Locations: Three sample locations were marked and chosen for the collection period. These sites will be visited again in the fall to have a proper representation of the increase in nutrients over the summer. Refer to Appendix Table B-1 for site characteristics and Appendix Map B-1 for a display of the sampling locations.

- Sample site 1 is in front of the outflow of Nulki Lake, where the lake flows into Stoney Creek.
- Sample site 2 is in front of an area where runoff from cattle is suspected to be present.
- Sample site 3 is in front of the inflow into Nulki Lake, Corkscrew Creek.

Appendix Table B-1. Coordinates of Nulki Lake sediment samples collected May 2, 2021.

Site	Coordinates	Depth (m)
1	N 53°55.4550' W 124°7.7094'	4
2	N 53°54.6153' W 124°11.7520'	3
3	N 53°54.1208' W 124°10.9743'	3

Appendix Map B-1. Nulki Lake sediment sampling locations.

Results

The parameters measured by Northern Analytical Laboratory Services at UNBC are presented in Appendix Table B-2.

Appendix Table B-2. Parameters from Nulki Lake sediment samples collected May 2, 2021.

Elemental	Units	Site 1 Outflow	Site 2 Cattle	Site 3 Inflow
Aluminum	%	1.43	1.39	1.65
Arsenic	mg/kg	<7	<7	<7
Boron	mg/kg	27	25	27
Barium	mg/kg	132	149	178
Calcium	%	0.913	0.871	0.823
Cadmium	mg/kg	0.5	0.5	0.7
Cobalt	mg/kg	12	12	13
Chromium	mg/kg	34.2	29.4	34.9
Copper	mg/kg	34	28	24
Iron	%	3.11	2.97	3.71
Potassium	mg/kg	1988	1805	1726
Magnesium	%	0.613	0.560	0.656
Manganese	mg/kg	562	711	817
Molybdenum	mg/kg	<2	<2	<2
Sodium	mg/kg	501	375	411
Nickel	mg/kg	38	31	29
Phosphorus	mg/kg	2043	1756	1788
Lead	mg/kg	4.7	4.1	4.5
Sulfur	mg/kg	3216	3208	1918
Antimony	mg/kg	<6	<6	8
Selenium	mg/kg	<15	<15	<15
Tin	mg/kg	<8	<8	<8
Uranium	mg/kg	42	42	53
Vanadium	mg/kg	63	54	64
Zinc	mg/kg	73	76	87

Additional Parameters	Units	Site 1 Outflow	Site 2 Cattle	Site 3 Inflow
$pH_{2:1}$[a]	-	6.26	6.08	5.69
Total C[a]	% by mass	16.4	14.7	8.8
Total N[a]	% by mass	2.1	1.9	1.0

APPENDIX C LAB RESULTS FROM THE NULKI LAKE MACROPHYTE SAMPLES

Appendix Table C-1. Lab results from the Nulki Lake macrophyte samples.

Client Sample ID			EAST 272-1	EAST 283-2	EAST 283-2 DUP	NORTH 306-1	NORTH 306-3	NORTH 332-1
Date Sampled			29-Aug-2023	29-Aug-2023	29-Aug-2023	29-Aug-2023	29-Aug-2023	29-Aug-2023
Time Sampled			11:00	13:00	13:00	14:00	14:00	15:00
	Lowest Detection Limit	**Units**						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	93.8	87.8	88.4	91.3	89.5	79.5
Anions and Nutrients (Matrix: Biota)								
Nitrogen, total	0.01	%	3.75	3.28	2.64	3.67	2.89	2.15
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	1600	291	359	732	3450	1170
Aluminum	0.40	mg/kg wwt	99.6	35.5	41.5	63.6	363	240
Antimony	0.010	mg/kg	0.038	0.022	0.024	0.028	0.052	0.030
Antimony	0.0020	mg/kg wwt	0.0024	0.0027	0.0028	0.0025	0.0055	0.0061
Arsenic	0.020	mg/kg	3.05	4.01	4.91	3.00	23.8	3.37
Arsenic	0.0040	mg/kg wwt	0.190	0.490	0.567	0.260	2.50	0.691
Barium	0.050	mg/kg	63.2	238	250	122	476	146
Barium	0.010	mg/kg wwt	3.93	29.1	28.9	10.6	50.1	29.8
Beryllium	0.010	mg/kg	0.070	0.036	0.044	0.033	0.232	0.055
Beryllium	0.0020	mg/kg wwt	0.0043	0.0044	0.0051	0.0029	0.0244	0.0114
Bismuth	0.010	mg/kg	0.016	<0.010	<0.010	<0.010	0.046	<0.010
Bismuth	0.0020	mg/kg wwt	<0.0020	<0.0020	<0.0020	<0.0020	0.0048	<0.0020
Boron	1.0	mg/kg	13.8	10.9	10.6	9.5	9.5	7.2
Boron	0.20	mg/kg wwt	0.86	1.34	1.23	0.83	1.00	1.48
Cadmium	0.0050	mg/kg	0.0593	0.0685	0.0642	0.0446	0.130	0.0352
Cadmium	0.0010	mg/kg wwt	0.0037	0.0084	0.0074	0.0039	0.0137	0.0072
Calcium	20	mg/kg	7930	14300	14000	7670	19800	7890

Client Sample ID			EAST 272-1	EAST 283-2	EAST 283-2 DUP	NORTH 306-1	NORTH 306-3	NORTH 332-1
Calcium	4.0	mg/kg wwt	493	1740	1610	666	2080	1620
Cesium	0.0050	mg/kg	0.170	0.0340	0.0550	0.0678	0.339	0.113
Cesium	0.0010	mg/kg wwt	0.0106	0.0042	0.0064	0.0059	0.0356	0.0232
Chromium	0.050	mg/kg	3.10	0.635	0.699	1.50	7.88	2.48
Chromium	0.010	mg/kg wwt	0.193	0.077	0.081	0.130	0.828	0.508
Cobalt	0.020	mg/kg	1.64	0.469	0.652	1.24	3.72	1.39
Cobalt	0.0040	mg/kg wwt	0.102	0.0573	0.0753	0.108	0.391	0.285
Copper	0.10	mg/kg	4.57	3.39	3.70	3.38	11.7	2.54
Copper	0.020	mg/kg wwt	0.284	0.414	0.428	0.294	1.23	0.521
Iron	3.0	mg/kg	6630	1580	2140	2930	31200	4620
Iron	0.60	mg/kg wwt	413	192	248	255	3280	946
Lead	0.020	mg/kg	1.00	0.453	0.539	0.679	2.44	0.762
Lead	0.0040	mg/kg wwt	0.0624	0.0553	0.0623	0.0589	0.257	0.156
Lithium	0.50	mg/kg	1.36	<0.50	<0.50	0.55	2.17	1.06
Lithium	0.10	mg/kg wwt	<0.10	<0.10	<0.10	<0.10	0.23	0.22
Magnesium	2.0	mg/kg	3270	7590	8440	4000	4010	3040
Magnesium	0.40	mg/kg wwt	204	927	975	347	422	623
Manganese	0.050	mg/kg	706	11400	12000	3860	20600	5040
Manganese	0.010	mg/kg wwt	44.0	1390	1390	335	2170	1030
Mercury	0.0050	mg/kg	0.0091	0.0067	0.0093	0.0070	0.0353	0.0076
Mercury	0.0010	mg/kg wwt	<0.0010	<0.0010	0.0011	<0.0010	0.0037	0.0016
Molybdenum	0.020	mg/kg	2.88	9.57	10.1	3.88	3.92	4.15
Molybdenum	0.0040	mg/kg wwt	0.179	1.17	1.17	0.337	0.412	0.851
Nickel	0.20	mg/kg	4.07	1.66	2.01	3.16	12.4	4.51
Nickel	0.040	mg/kg wwt	0.253	0.202	0.232	0.274	1.30	0.924
Phosphorus	10	mg/kg	4430	3910	4280	4790	7870	2950
Phosphorus	2.0	mg/kg wwt	276	478	494	416	827	605
Potassium	20	mg/kg	8250	17100	21700	24800	9620	11600
Potassium	4.0	mg/kg wwt	513	2090	2510	2150	1010	2370

Client Sample ID			EAST 272-1	EAST 283-2	EAST 283-2 DUP	NORTH 306-1	NORTH 306-3	NORTH 332-1
Rubidium	0.050	mg/kg	3.47	7.68	9.58	11.9	5.34	3.58
Rubidium	0.010	mg/kg wwt	0.216	0.937	1.11	1.03	0.561	0.734
Selenium	0.050	mg/kg	0.062	0.054	0.061	0.053	0.278	<0.050
Selenium	0.010	mg/kg wwt	<0.010	<0.010	<0.010	<0.010	0.029	<0.010
Sodium	20	mg/kg	2050	1650	1910	3080	1640	2550
Sodium	4.0	mg/kg wwt	128	201	220	267	173	522
Strontium	0.050	mg/kg	51.0	104	103	58.3	108	56.8
Strontium	0.010	mg/kg wwt	3.17	12.6	11.9	5.06	11.3	11.6
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0202	0.0331	0.0341	0.0118	0.0314	0.0179
Thallium	0.00040	mg/kg wwt	0.00126	0.00404	0.00394	0.00102	0.00330	0.00367
Tin	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	<0.10	0.12
Tin	0.020	mg/kg wwt	<0.020	<0.020	<0.020	<0.020	<0.020	0.025
Uranium	0.0020	mg/kg	1.08	0.443	0.485	1.16	2.44	0.697
Uranium	0.00040	mg/kg wwt	0.0669	0.0540	0.0560	0.101	0.257	0.143
Vanadium	0.10	mg/kg	10.5	2.87	3.36	5.06	22.6	7.30
Vanadium	0.020	mg/kg wwt	0.652	0.350	0.388	0.439	2.38	1.50
Zinc	0.50	mg/kg	16.1	15.1	14.9	12.0	31.2	10.6
Zinc	0.10	mg/kg wwt	1.00	1.84	1.72	1.04	3.28	2.16
Zirconium	0.20	mg/kg	2.29	0.49	0.58	0.95	4.62	1.41
Zirconium	0.040	mg/kg wwt	0.143	0.060	0.067	0.082	0.486	0.289

Appendix Table C-1. Lab results from the Nulki Lake macrophyte samples continued.

Client Sample ID			NORTH 332-2	NORTH 332-3	NULKI CERDEM	NULKI ELOCAN	NULKI POTRIC	NULKI POTZOS
Date Sampled			**29-Aug-2023**	**29-Aug-2023**	**29-Aug-2023**	**29-Aug-2023**	**29-Aug-2023**	**29-Aug-2023**
Time Sampled			**15:00**	**15:00**	**08:00**	**08:00**	**08:00**	**08:00**
	Lowest Detection Limit	**Units**						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	90.3	91.3	87.7	88.7	86.1	87.2
Anions and Nutrients (Matrix: Biota)								
Nitrogen, total	0.01	%	2.89	2.97	2.89	2.71	3.04	2.31
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	430	2110	1170	460	566	585
Aluminum	0.40	mg/kg wwt	41.6	183	144	51.9	78.9	74.6
Antimony	0.010	mg/kg	0.037	0.048	0.047	0.036	0.029	0.034
Antimony	0.0020	mg/kg wwt	0.0036	0.0042	0.0058	0.0041	0.0040	0.0043
Arsenic	0.020	mg/kg	8.00	11.2	5.00	3.60	4.80	5.13
Arsenic	0.0040	mg/kg wwt	0.774	0.973	0.615	0.406	0.669	0.654
Barium	0.050	mg/kg	404	428	174	275	290	232
Barium	0.010	mg/kg wwt	39.1	37.2	21.4	31.0	40.4	29.6
Beryllium	0.010	mg/kg	0.043	0.122	0.061	0.035	0.048	0.040
Beryllium	0.0020	mg/kg wwt	0.0041	0.0106	0.0075	0.0040	0.0068	0.0051
Bismuth	0.010	mg/kg	0.011	0.024	0.014	<0.010	<0.010	<0.010
Bismuth	0.0020	mg/kg wwt	<0.0020	0.0021	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	11.2	11.2	14.3	9.0	10.2	12.0

Client Sample ID			NORTH 332-2	NORTH 332-3	NULKI CERDEM	NULKI ELOCAN	NULKI POTRIC	NULKI POTZOS
Boron	0.20	mg/kg wwt	1.08	0.97	1.76	1.01	1.42	1.54
Cadmium	0.0050	mg/kg	0.0750	0.0781	0.0611	0.0370	0.0473	0.0318
Cadmium	0.0010	mg/kg wwt	0.0072	0.0068	0.0075	0.0042	0.0066	0.0040
Calcium	20	mg/kg	12900	14000	11000	14300	13200	13500
Calcium	4.0	mg/kg wwt	1240	1220	1360	1620	1830	1720
Cesium	0.0050	mg/kg	0.0489	0.217	0.120	0.0480	0.0616	0.0660
Cesium	0.0010	mg/kg wwt	0.0047	0.0189	0.0148	0.0054	0.0086	0.0084
Chromium	0.050	mg/kg	1.09	4.44	2.42	1.03	1.22	1.16
Chromium	0.010	mg/kg wwt	0.105	0.386	0.297	0.116	0.171	0.147
Cobalt	0.020	mg/kg	0.713	1.94	2.12	0.700	0.746	0.698
Cobalt	0.0040	mg/kg wwt	0.0690	0.169	0.260	0.0791	0.104	0.0891
Copper	0.10	mg/kg	3.95	7.24	4.38	2.80	3.30	2.33
Copper	0.020	mg/kg wwt	0.382	0.629	0.539	0.316	0.459	0.297
Iron	3.0	mg/kg	4930	12000	5250	2770	3280	3480
Iron	0.60	mg/kg wwt	477	1050	645	313	457	444
Lead	0.020	mg/kg	0.709	1.12	0.828	0.985	0.701	1.02
Lead	0.0040	mg/kg wwt	0.0686	0.0971	0.102	0.111	0.0976	0.130
Lithium	0.50	mg/kg	<0.50	1.39	0.92	<0.50	<0.50	<0.50
Lithium	0.10	mg/kg wwt	<0.10	0.12	0.11	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	4460	4370	8090	3670	5650	9370
Magnesium	0.40	mg/kg wwt	432	380	995	415	786	1200

Client Sample ID			NORTH 332-2	NORTH 332-3	NULKI CERDEM	NULKI ELOCAN	NULKI POTRIC	NULKI POTZOS
Manganese	0.050	mg/kg	20200	18200	11700	11200	12300	10400
Manganese	0.010	mg/kg wwt	1960	1580	1430	1260	1720	1330
Mercury	0.0050	mg/kg	0.0081	0.0217	0.0148	0.0078	0.0180	0.0090
Mercury	0.0010	mg/kg wwt	<0.0010	0.0019	0.0018	<0.0010	0.0025	0.0012
Molybdenum	0.020	mg/kg	5.27	3.45	7.27	6.80	6.48	7.03
Molybdenum	0.0040	mg/kg wwt	0.510	0.300	0.893	0.768	0.902	0.896
Nickel	0.20	mg/kg	2.43	6.31	5.12	2.31	2.32	2.14
Nickel	0.040	mg/kg wwt	0.235	0.548	0.629	0.261	0.323	0.273
Phosphorus	10	mg/kg	4080	6590	5290	4790	3920	4340
Phosphorus	2.0	mg/kg wwt	395	573	650	541	546	553
Potassium	20	mg/kg	21100	26000	25600	17100	19100	8470
Potassium	4.0	mg/kg wwt	2040	2260	3140	1930	2660	1080
Rubidium	0.050	mg/kg	10.3	12.8	11.4	2.90	8.98	5.65
Rubidium	0.010	mg/kg wwt	0.999	1.11	1.40	0.328	1.25	0.721
Selenium	0.050	mg/kg	0.067	0.168	0.102	0.060	0.067	0.057
Selenium	0.010	mg/kg wwt	<0.010	0.014	0.012	<0.010	<0.010	<0.010
Sodium	20	mg/kg	1520	1450	1360	5830	1240	1160
Sodium	4.0	mg/kg wwt	148	126	167	658	173	148
Strontium	0.050	mg/kg	101	100	102	112	95.9	111
Strontium	0.010	mg/kg wwt	9.82	8.70	12.6	12.6	13.4	14.1

Client Sample ID			NORTH 332-2	NORTH 332-3	NULKI CERDEM	NULKI ELOCAN	NULKI POTRIC	NULKI POTZOS
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0169	0.0285	0.0154	0.0095	0.0214	0.0129
Thallium	0.00040	mg/kg wwt	0.00164	0.00248	0.00189	0.00107	0.00298	0.00165
Tin	0.10	mg/kg	0.18	0.39	<0.10	<0.10	<0.10	<0.10
Tin	0.020	mg/kg wwt	<0.020	0.034	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	0.671	1.45	1.37	0.564	0.547	0.593
Uranium	0.00040	mg/kg wwt	0.0649	0.126	0.168	0.0637	0.0762	0.0756
Vanadium	0.10	mg/kg	5.58	14.3	8.39	3.77	4.80	4.51
Vanadium	0.020	mg/kg wwt	0.540	1.24	1.03	0.426	0.669	0.575
Zinc	0.50	mg/kg	11.7	21.7	14.7	11.1	13.1	10.8
Zinc	0.10	mg/kg wwt	1.13	1.88	1.81	1.26	1.82	1.38
Zirconium	0.20	mg/kg	0.62	3.20	1.00	0.68	0.78	1.12
Zirconium	0.040	mg/kg wwt	0.060	0.278	0.122	0.076	0.109	0.143

Appendix Table C-1. Lab results from the Nulki Lake macrophyte samples continued.

Client Sample ID			SOUTH 243-1	SOUTH 243-2	SOUTH 327-2	SOUTH 327-3	SOUTH 327-4	SOUTH 327-4 DUP
Date Sampled			29-Aug-2023	29-Aug-2023	28-Aug-2023	28-Aug-2023	28-Aug-2023	28-Aug-2023
Time Sampled			09:00	09:00	07:00	07:00	07:00	07:00
	Lowest Detection Limit	Units						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	90.7	88.4	87.2	91.3	89.7	88.5
Anions and Nutrients (Matrix: Biota)								
Nitrogen, total	0.01	%	2.85	2.79	2.60	2.37	2.43	3.12
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	659	1900	431	1290	602	1360
Aluminum	0.40	mg/kg wwt	61.3	219	55.1	112	61.8	157
Antimony	0.010	mg/kg	0.033	0.059	0.025	0.039	0.036	0.028
Antimony	0.0020	mg/kg wwt	0.0031	0.0068	0.0032	0.0034	0.0037	0.0033
Arsenic	0.020	mg/kg	4.63	7.10	4.95	3.49	2.83	3.04
Arsenic	0.0040	mg/kg wwt	0.431	0.819	0.632	0.304	0.291	0.351
Barium	0.050	mg/kg	534	484	374	290	252	323
Barium	0.010	mg/kg wwt	49.7	55.8	47.7	25.3	25.9	37.3
Beryllium	0.010	mg/kg	0.053	0.112	0.051	0.075	0.036	0.056
Beryllium	0.0020	mg/kg wwt	0.0050	0.0130	0.0065	0.0065	0.0037	0.0065
Bismuth	0.010	mg/kg	<0.010	0.020	<0.010	0.011	<0.010	<0.010
Bismuth	0.0020	mg/kg wwt	<0.0020	0.0024	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	12.7	11.7	11.6	6.4	7.8	8.8
Boron	0.20	mg/kg wwt	1.18	1.35	1.48	0.56	0.80	1.02
Cadmium	0.0050	mg/kg	0.0649	0.0775	0.0368	0.0398	0.0259	0.0267
Cadmium	0.0010	mg/kg wwt	0.0060	0.0089	0.0047	0.0035	0.0026	0.0031
Calcium	20	mg/kg	17100	14700	12500	8620	9430	11200

Client Sample ID			SOUTH 243-1	SOUTH 243-2	SOUTH 327-2	SOUTH 327-3	SOUTH 327-4	SOUTH 327-4 DUP
Calcium	4.0	mg/kg wwt	1590	1700	1600	752	968	1290
Cesium	0.0050	mg/kg	0.0808	0.257	0.0496	0.148	0.0603	0.0639
Cesium	0.0010	mg/kg wwt	0.0075	0.0297	0.0063	0.0130	0.0062	0.0074
Chromium	0.050	mg/kg	1.59	4.06	1.01	2.71	1.47	13.7
Chromium	0.010	mg/kg wwt	0.148	0.469	0.129	0.236	0.151	1.58
Cobalt	0.020	mg/kg	0.805	1.78	0.687	1.39	0.691	1.09
Cobalt	0.0040	mg/kg wwt	0.0749	0.206	0.0877	0.121	0.0709	0.126
Copper	0.10	mg/kg	4.69	4.86	2.12	3.09	1.78	3.29
Copper	0.020	mg/kg wwt	0.436	0.561	0.271	0.270	0.183	0.379
Iron	3.0	mg/kg	2530	7860	3390	3950	2340	4060
Iron	0.60	mg/kg wwt	236	908	434	344	240	468
Lead	0.020	mg/kg	0.551	1.20	0.579	0.985	0.624	0.802
Lead	0.0040	mg/kg wwt	0.0513	0.139	0.0740	0.0859	0.0640	0.0926
Lithium	0.50	mg/kg	0.64	1.51	0.50	1.13	0.64	0.71
Lithium	0.10	mg/kg wwt	<0.10	0.17	<0.10	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	5010	4280	5510	5340	2770	3340
Magnesium	0.40	mg/kg wwt	466	495	703	465	284	385
Manganese	0.050	mg/kg	20000	19000	16000	10000	7900	7730
Manganese	0.010	mg/kg wwt	1870	2200	2040	876	811	892
Mercury	0.0050	mg/kg	0.0104	0.0197	0.0072	0.0075	0.0069	0.0096
Mercury	0.0010	mg/kg wwt	<0.0010	0.0023	<0.0010	<0.0010	<0.0010	0.0011
Molybdenum	0.020	mg/kg	6.56	7.79	3.10	3.53	2.63	2.84
Molybdenum	0.0040	mg/kg wwt	0.610	0.899	0.396	0.307	0.270	0.328
Nickel	0.20	mg/kg	2.10	4.56	1.67	2.76	1.88	5.16
Nickel	0.040	mg/kg wwt	0.195	0.526	0.213	0.240	0.193	0.595
Phosphorus	10	mg/kg	4940	4740	4510	3430	2600	2840
Phosphorus	2.0	mg/kg wwt	459	547	576	299	267	328

Client Sample ID			**SOUTH 243-1**	**SOUTH 243-2**	**SOUTH 327-2**	**SOUTH 327-3**	**SOUTH 327-4**	**SOUTH 327-4 DUP**
Potassium	20	mg/kg	27400	11000	23200	8740	17000	21200
Potassium	4.0	mg/kg wwt	2550	1270	2960	762	1740	2450
Rubidium	0.050	mg/kg	7.43	4.48	11.1	4.23	8.60	11.0
Rubidium	0.010	mg/kg wwt	0.691	0.517	1.42	0.369	0.883	1.26
Selenium	0.050	mg/kg	0.072	0.095	<0.050	<0.050	<0.050	<0.050
Selenium	0.010	mg/kg wwt	<0.010	0.011	<0.010	<0.010	<0.010	<0.010
Sodium	20	mg/kg	4050	3500	1190	1520	6370	8260
Sodium	4.0	mg/kg wwt	377	404	152	132	654	953
Strontium	0.050	mg/kg	129	122	105	73.5	58.0	61.0
Strontium	0.010	mg/kg wwt	12.0	14.1	13.4	6.41	5.96	7.04
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0180	0.0270	0.0182	0.0178	0.0137	0.0163
Thallium	0.00040	mg/kg wwt	0.00168	0.00312	0.00233	0.00155	0.00140	0.00188
Tin	0.10	mg/kg	0.68	0.13	<0.10	<0.10	<0.10	<0.10
Tin	0.020	mg/kg wwt	0.064	<0.020	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	0.458	1.10	0.360	0.435	0.373	0.351
Uranium	0.00040	mg/kg wwt	0.0426	0.127	0.0460	0.0379	0.0383	0.0405
Vanadium	0.10	mg/kg	5.51	12.3	4.13	8.50	3.96	5.52
Vanadium	0.020	mg/kg wwt	0.513	1.42	0.528	0.741	0.407	0.636
Zinc	0.50	mg/kg	15.3	17.2	10.9	13.0	10.1	14.9
Zinc	0.10	mg/kg wwt	1.42	1.99	1.39	1.14	1.03	1.71
Zirconium	0.20	mg/kg	1.06	2.55	0.85	2.02	1.19	3.34
Zirconium	0.040	mg/kg wwt	0.099	0.294	0.109	0.176	0.122	0.386

Appendix Table C-1. Lab results from the Nulki Lake macrophyte samples continued.

Client Sample ID			WEST 194-2	WEST 211-2	WEST 222-1	WEST 222-2
Date Sampled			29-Aug-2023	28-Aug-2023	29-Aug-2023	29-Aug-2023
Time Sampled			10:00	09:00	11:30	11:30
	Lowest Detection Limit	Units				
Physical Tests (Matrix: Biota)						
Moisture	0.50	%	89.3	91.4	87.6	78.2
Anions and Nutrients (Matrix: Biota)						
Nitrogen, total	0.01	%	2.83	2.52	3.12	2.68
Metals (Matrix: Biota)						
Aluminum	2.0	mg/kg	27.0	1080	321	1150
Aluminum	0.40	mg/kg wwt	2.90	92.7	39.9	251
Antimony	0.010	mg/kg	<0.010	0.044	0.044	0.049
Antimony	0.0020	mg/kg wwt	<0.0020	0.0038	0.0054	0.0106
Arsenic	0.020	mg/kg	1.97	5.29	4.18	8.36
Arsenic	0.0040	mg/kg wwt	0.212	0.454	0.519	1.82
Barium	0.050	mg/kg	335	286	368	704
Barium	0.010	mg/kg wwt	36.0	24.6	45.8	154
Beryllium	0.010	mg/kg	<0.010	0.058	0.044	0.079
Beryllium	0.0020	mg/kg wwt	<0.0020	0.0050	0.0055	0.0173
Bismuth	0.010	mg/kg	<0.010	0.010	<0.010	0.018
Bismuth	0.0020	mg/kg wwt	<0.0020	<0.0020	<0.0020	0.0039
Boron	1.0	mg/kg	10.3	15.0	14.0	10.8
Boron	0.20	mg/kg wwt	1.11	1.29	1.74	2.35
Cadmium	0.0050	mg/kg	0.0160	0.0436	0.0426	0.0532
Cadmium	0.0010	mg/kg wwt	0.0017	0.0037	0.0053	0.0116
Calcium	20	mg/kg	12700	14200	16900	19700

Client Sample ID			WEST 194-2	WEST 211-2	WEST 222-1	WEST 222-2
Calcium	4.0	mg/kg wwt	1360	1220	2100	4310
Cesium	0.0050	mg/kg	0.0149	0.111	0.0408	0.113
Cesium	0.0010	mg/kg wwt	0.0016	0.0096	0.0051	0.0247
Chromium	0.050	mg/kg	0.119	2.09	0.876	2.39
Chromium	0.010	mg/kg wwt	0.013	0.180	0.109	0.522
Cobalt	0.020	mg/kg	0.116	1.31	0.692	1.69
Cobalt	0.0040	mg/kg wwt	0.0124	0.113	0.0860	0.368
Copper	0.10	mg/kg	1.26	3.46	2.78	4.40
Copper	0.020	mg/kg wwt	0.135	0.298	0.346	0.960
Iron	3.0	mg/kg	328	5190	2700	5360
Iron	0.60	mg/kg wwt	35.2	446	335	1170
Lead	0.020	mg/kg	0.380	0.805	0.362	1.16
Lead	0.0040	mg/kg wwt	0.0407	0.0692	0.0450	0.254
Lithium	0.50	mg/kg	<0.50	0.72	<0.50	1.22
Lithium	0.10	mg/kg wwt	<0.10	<0.10	<0.10	0.26
Magnesium	2.0	mg/kg	2510	8270	4130	5840
Magnesium	0.40	mg/kg wwt	269	711	513	1280
Manganese	0.050	mg/kg	5210	14700	14700	28300
Manganese	0.010	mg/kg wwt	559	1270	1820	6170
Mercury	0.0050	mg/kg	0.0053	0.0142	0.0087	0.0136
Mercury	0.0010	mg/kg wwt	<0.0010	0.0012	0.0011	0.0030
Molybdenum	0.020	mg/kg	2.12	9.72	7.95	8.76
Molybdenum	0.0040	mg/kg wwt	0.228	0.835	0.988	1.91
Nickel	0.20	mg/kg	0.54	3.56	2.16	4.16
Nickel	0.040	mg/kg wwt	0.058	0.306	0.269	0.907
Phosphorus	10	mg/kg	2890	4420	4220	5290
Phosphorus	2.0	mg/kg wwt	310	380	524	1160

Client Sample ID			WEST 194-2	WEST 211-2	WEST 222-1	WEST 222-2
Potassium	20	mg/kg	32600	20400	14900	24900
Potassium	4.0	mg/kg wwt	3500	1750	1850	5430
Rubidium	0.050	mg/kg	15.3	8.66	2.77	5.87
Rubidium	0.010	mg/kg wwt	1.64	0.744	0.344	1.28
Selenium	0.050	mg/kg	<0.050	0.095	0.076	0.096
Selenium	0.010	mg/kg wwt	<0.010	<0.010	<0.010	0.021
Sodium	20	mg/kg	12300	1320	6090	8340
Sodium	4.0	mg/kg wwt	1320	113	757	1820
Strontium	0.050	mg/kg	78.7	128	126	160
Strontium	0.010	mg/kg wwt	8.44	11.0	15.7	34.9
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0129	0.0154	0.0105	0.0220
Thallium	0.00040	mg/kg wwt	0.00139	0.00132	0.00130	0.00479
Tin	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10
Tin	0.020	mg/kg wwt	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	0.146	0.791	0.843	0.922
Uranium	0.00040	mg/kg wwt	0.0156	0.0680	0.105	0.201
Vanadium	0.10	mg/kg	0.91	6.18	3.90	9.08
Vanadium	0.020	mg/kg wwt	0.097	0.531	0.485	1.98
Zinc	0.50	mg/kg	13.7	11.4	11.5	20.1
Zinc	0.10	mg/kg wwt	1.48	0.98	1.43	4.38
Zirconium	0.20	mg/kg	<0.20	1.37	0.87	2.06
Zirconium	0.040	mg/kg wwt	<0.040	0.118	0.108	0.450

APPENDIX D LAB RESULTS FROM THE TACHICK LAKE MACROPHYTE SAMPLES

Appendix Table D-1. Lab results from the Tachick Lake macrophyte samples.

Sample			EAST 1-1	EAST 1-2	NORTH 118-1	NORTH 141-1	NORTH 162-1	NORTH 162-2
Date Sampled			31-Aug-2023	31-Aug-2023	31-Aug-2023	31-Aug-2023	31-Aug-2023	31-Aug-2023
Time Sampled			08:30	08:30	15:00	12:00	10:00	10:00
	Lowest Detection Limit	**Units**						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	84.3	90.5	86.0	78.6	88.8	87.5
Anions and Nutrients (Matrix: Biota)								
Total Nitrogen	0.01	%	3.05	3.06	2.37	1.82	3.72	3.91
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	1450	910	49.4	164	189	549
Aluminum	0.40	mg/kg wwt	227	86.6	6.90	35.1	21.1	68.7
Antimony	0.010	mg/kg	0.038	0.055	0.014	0.017	0.023	0.045
Antimony	0.0020	mg/kg wwt	0.0060	0.0052	<0.0020	0.0037	0.0026	0.0056
Arsenic	0.020	mg/kg	3.33	2.63	1.12	2.28	1.29	2.12
Arsenic	0.0040	mg/kg wwt	0.522	0.250	0.156	0.487	0.144	0.265
Barium	0.050	mg/kg	203	88.8	185	249	60.1	133
Barium	0.010	mg/kg wwt	31.8	8.46	25.9	53.3	6.73	16.7
Beryllium	0.010	mg/kg	0.040	0.030	<0.010	0.020	<0.010	0.024
Beryllium	0.0020	mg/kg wwt	0.0064	0.0029	<0.0020	0.0043	<0.0020	0.0030
Bismuth	0.010	mg/kg	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Bismuth	0.0020	mg/kg wwt	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	10.5	13.9	10.0	11.9	14.5	12.7
Boron	0.20	mg/kg wwt	1.65	1.32	1.40	2.55	1.62	1.59
Cadmium	0.0050	mg/kg	0.0471	0.0334	0.0163	0.0340	0.0382	0.0464
Cadmium	0.0010	mg/kg wwt	0.0074	0.0032	0.0023	0.0073	0.0043	0.0058

Sample			EAST 1-1	EAST 1-2	NORTH 118-1	NORTH 141-1	NORTH 162-1	NORTH 162-2
Calcium	20	mg/kg	10700	7260	88600	121000	17400	12100
Calcium	4.0	mg/kg wwt	1670	692	12400	25800	1940	1520
Cesium	0.0050	mg/kg	0.109	0.0626	0.0056	0.0159	0.0163	0.0532
Cesium	0.0010	mg/kg wwt	0.0170	0.0060	<0.0010	0.0034	0.0018	0.0067
Chromium	0.050	mg/kg	2.25	1.55	0.414	0.340	0.380	1.15
Chromium	0.010	mg/kg wwt	0.352	0.148	0.058	0.073	0.042	0.144
Cobalt	0.020	mg/kg	1.60	0.966	0.103	0.235	0.375	0.662
Cobalt	0.0040	mg/kg wwt	0.251	0.0920	0.0144	0.0502	0.0419	0.0829
Copper	0.10	mg/kg	2.94	2.89	0.70	1.33	1.44	3.00
Copper	0.020	mg/kg wwt	0.460	0.275	0.099	0.284	0.162	0.376
Iron	3.0	mg/kg	4830	4400	767	1130	1440	2360
Iron	0.60	mg/kg wwt	756	419	107	242	161	295
Lead	0.020	mg/kg	2.56	1.37	0.248	0.266	20.7	0.687
Lead	0.0040	mg/kg wwt	0.401	0.130	0.0347	0.0569	2.31	0.0860
Lithium	0.50	mg/kg	1.18	0.76	<0.50	<0.50	<0.50	<0.50
Lithium	0.10	mg/kg wwt	0.18	<0.10	<0.10	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	4940	3560	4580	8630	6000	5040
Magnesium	0.40	mg/kg wwt	774	339	640	1840	671	631
Manganese	0.050	mg/kg	10400	2680	4040	7650	2660	6140
Manganese	0.010	mg/kg wwt	1630	255	564	1640	298	770
Mercury	0.0050	mg/kg	0.0079	0.0091	<0.0050	<0.0050	<0.0050	0.0066
Mercury	0.0010	mg/kg wwt	0.0012	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Molybdenum	0.020	mg/kg	4.83	4.50	5.64	6.03	7.44	6.15
Molybdenum	0.0040	mg/kg wwt	0.756	0.429	0.788	1.29	0.833	0.771
Nickel	0.20	mg/kg	2.61	2.12	0.49	0.70	0.65	1.70
Nickel	0.040	mg/kg wwt	0.408	0.202	0.068	0.150	0.072	0.213
Phosphorus	10	mg/kg	3450	4870	2230	1880	3540	5560
Phosphorus	2.0	mg/kg wwt	540	464	312	402	396	697
Potassium	20	mg/kg	18500	29200	12600	6720	22400	26900

Sample			EAST 1-1	EAST 1-2	NORTH 118-1	NORTH 141-1	NORTH 162-1	NORTH 162-2
Potassium	4.0	mg/kg wwt	2890	2780	1760	1440	2510	3370
Rubidium	0.050	mg/kg	4.98	6.25	1.44	1.97	6.75	9.44
Rubidium	0.010	mg/kg wwt	0.780	0.595	0.201	0.421	0.755	1.18
Selenium	0.050	mg/kg	0.061	0.059	<0.050	0.051	0.051	0.083
Selenium	0.010	mg/kg wwt	<0.010	<0.010	<0.010	0.011	<0.010	0.010
Sodium	20	mg/kg	2230	2960	4720	1500	2280	2900
Sodium	4.0	mg/kg wwt	349	282	660	320	255	363
Strontium	0.050	mg/kg	67.7	47.7	274	349	77.1	55.7
Strontium	0.010	mg/kg wwt	10.6	4.54	38.4	74.6	8.62	6.98
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0109	0.0080	0.0036	0.0080	0.0035	0.0064
Thallium	0.00040	mg/kg wwt	0.00171	0.00077	0.00051	0.00171	<0.00040	0.00080
Tin	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Tin	0.020	mg/kg wwt	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	0.684	1.18	0.295	0.326	0.528	0.716
Uranium	0.00040	mg/kg wwt	0.107	0.113	0.0412	0.0698	0.0591	0.0897
Vanadium	0.10	mg/kg	6.84	5.90	0.90	1.79	2.14	3.98
Vanadium	0.020	mg/kg wwt	1.07	0.562	0.126	0.382	0.239	0.499
Zinc	0.50	mg/kg	20.8	18.4	6.07	6.75	7.72	22.5
Zinc	0.10	mg/kg wwt	3.26	1.75	0.85	1.44	0.86	2.82
Zirconium	0.20	mg/kg	0.79	0.60	<0.20	0.33	0.37	0.52
Zirconium	0.040	mg/kg wwt	0.124	0.058	<0.040	0.071	0.041	0.065

Appendix Table D-1. Lab results from the Tachick Lake macrophyte samples continued.

Sample			SOUTH 21-2	SOUTH 21-2-DUP	SOUTH 21-3	SOUTH 41-1	SOUTH 41-2	SOUTH 41-2-DUP
Date Sampled			**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**
Time Sampled			**10:00**	**10:00**	**10:00**	**11:00**	**11:00**	**11:00**
	Lowest Detection Limit	**Units**						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	89.9	85.8	90.5	88.5	89.1	83.7
Anions and Nutrients (Matrix: Biota)								
Total Nitrogen	0.01	%	2.31	2.51	2.82	3.81	3.46	3.11
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	1810	2970	239	186	315	429
Aluminum	0.40	mg/kg wwt	183	424	22.7	21.4	34.4	70.0
Antimony	0.010	mg/kg	0.062	0.074	0.034	0.032	0.029	0.021
Antimony	0.0020	mg/kg wwt	0.0063	0.0105	0.0032	0.0037	0.0032	0.0035
Arsenic	0.020	mg/kg	4.12	5.27	3.36	2.31	1.85	1.53
Arsenic	0.0040	mg/kg wwt	0.416	0.750	0.319	0.266	0.202	0.250
Barium	0.050	mg/kg	415	433	660	192	197	193
Barium	0.010	mg/kg wwt	42.0	61.8	62.7	22.1	21.6	31.5
Beryllium	0.010	mg/kg	0.064	0.136	0.018	0.013	0.017	0.019
Beryllium	0.0020	mg/kg wwt	0.0064	0.0194	<0.0020	<0.0020	<0.0020	0.0031
Bismuth	0.010	mg/kg	0.020	0.035	<0.010	<0.010	<0.010	<0.010
Bismuth	0.0020	mg/kg wwt	0.0020	0.0050	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	16.9	45.6	18.2	21.2	18.4	16.7
Boron	0.20	mg/kg wwt	1.71	6.50	1.73	2.44	2.01	2.73
Cadmium	0.0050	mg/kg	0.0550	0.0858	0.108	0.0448	0.0335	0.0271
Cadmium	0.0010	mg/kg wwt	0.0056	0.0122	0.0102	0.0052	0.0037	0.0044
Calcium	20	mg/kg	49800	25800	38900	42600	79200	94200

Sample			SOUTH 21-2	SOUTH 21-2-DUP	SOUTH 21-3	SOUTH 41-1	SOUTH 41-2	SOUTH 41-2-DUP
Calcium	4.0	mg/kg wwt	5030	3670	3690	4900	8650	15400
Cesium	0.0050	mg/kg	0.160	0.251	0.0238	0.0166	0.0306	0.0467
Cesium	0.0010	mg/kg wwt	0.0161	0.0358	0.0022	0.0019	0.0033	0.0076
Chromium	0.050	mg/kg	2.67	4.66	0.382	0.270	0.463	0.543
Chromium	0.010	mg/kg wwt	0.270	0.664	0.036	0.031	0.050	0.089
Cobalt	0.020	mg/kg	1.38	2.48	0.355	0.333	0.312	0.315
Cobalt	0.0040	mg/kg wwt	0.139	0.353	0.0337	0.0383	0.0340	0.0514
Copper	0.10	mg/kg	3.47	6.18	1.95	2.01	1.83	1.48
Copper	0.020	mg/kg wwt	0.351	0.880	0.185	0.231	0.200	0.242
Iron	3.0	mg/kg	4610	8190	2370	1230	2120	1190
Iron	0.60	mg/kg wwt	466	1170	225	142	232	194
Lead	0.020	mg/kg	1.14	2.36	0.629	0.738	0.404	0.374
Lead	0.0040	mg/kg wwt	0.115	0.336	0.0597	0.0850	0.0441	0.0610
Lithium	0.50	mg/kg	1.48	2.02	<0.50	<0.50	<0.50	<0.50
Lithium	0.10	mg/kg wwt	0.15	0.29	<0.10	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	6010	5540	5890	4270	5890	6110
Magnesium	0.40	mg/kg wwt	607	790	559	491	644	997
Manganese	0.050	mg/kg	16200	16700	22300	5940	4690	3990
Manganese	0.010	mg/kg wwt	1640	2380	2120	684	512	651
Mercury	0.0050	mg/kg	0.0080	0.0138	0.0073	0.0051	<0.0050	0.0050
Mercury	0.0010	mg/kg wwt	<0.0010	0.0020	<0.0010	<0.0010	<0.0010	<0.0010
Molybdenum	0.020	mg/kg	5.60	7.18	6.63	5.88	4.29	3.53
Molybdenum	0.0040	mg/kg wwt	0.566	1.02	0.629	0.677	0.468	0.575
Nickel	0.20	mg/kg	2.72	4.78	0.93	0.83	0.78	0.79
Nickel	0.040	mg/kg wwt	0.275	0.681	0.088	0.095	0.086	0.130
Phosphorus	10	mg/kg	4280	3850	3360	5080	3100	2540
Phosphorus	2.0	mg/kg wwt	432	549	319	585	339	414

Sample			SOUTH 21-2	SOUTH 21-2-DUP	SOUTH 21-3	SOUTH 41-1	SOUTH 41-2	SOUTH 41-2-DUP
Potassium	20	mg/kg	23100	18100	15600	18700	15300	12600
Potassium	4.0	mg/kg wwt	2340	2570	1480	2150	1670	2050
Rubidium	0.050	mg/kg	5.90	6.94	5.62	3.64	5.44	4.14
Rubidium	0.010	mg/kg wwt	0.596	0.989	0.533	0.419	0.594	0.675
Selenium	0.050	mg/kg	0.078	0.128	0.101	0.070	0.054	<0.050
Selenium	0.010	mg/kg wwt	<0.010	0.018	<0.010	<0.010	<0.010	<0.010
Sodium	20	mg/kg	3670	2180	2010	4890	1800	2030
Sodium	4.0	mg/kg wwt	371	310	191	563	197	331
Strontium	0.050	mg/kg	188	98.5	167	148	250	278
Strontium	0.010	mg/kg wwt	19.0	14.0	15.8	17.0	27.3	45.4
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0156	0.0210	0.0092	0.0085	0.0087	0.0084
Thallium	0.00040	mg/kg wwt	0.00157	0.00299	0.00087	0.00098	0.00095	0.00138
Tin	0.10	mg/kg	0.24	0.27	<0.10	0.49	0.55	0.28
Tin	0.020	mg/kg wwt	0.024	0.039	<0.020	0.056	0.060	0.045
Uranium	0.0020	mg/kg	0.762	1.08	0.354	0.641	0.434	0.346
Uranium	0.00040	mg/kg wwt	0.0770	0.154	0.0336	0.0738	0.0474	0.0564
Vanadium	0.10	mg/kg	8.54	14.1	2.88	1.92	2.33	2.17
Vanadium	0.020	mg/kg wwt	0.863	2.01	0.273	0.221	0.254	0.354
Zinc	0.50	mg/kg	19.1	23.2	13.3	11.2	9.07	9.75
Zinc	0.10	mg/kg wwt	1.93	3.30	1.26	1.29	0.99	1.59
Zirconium	0.20	mg/kg	0.90	1.27	0.25	<0.20	0.31	0.33
Zirconium	0.040	mg/kg wwt	0.091	0.181	<0.040	<0.040	<0.040	0.054

Appendix Table D-1. Lab results from the Tachick Lake macrophyte samples continued.

Sample			TACHICK-CERDEM	TACHICK-ELOCAN	TACHICK-POTZOS	TACHICK-POTRIC	WEST 79-1	WEST 79-3
Date Sampled			**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**31-Aug-2023**	**31-Aug-2023**
Time Sampled			**13:00**	**13:00**	**13:00**	**13:00**	**17:00**	**17:00**
	Lowest Detection Limit	**Units**						
Physical Tests (Matrix: Biota)								
Moisture	0.50	%	86.8	87.6	86.1	84.9	86.5	85.8
Anions and Nutrients (Matrix: Biota)								
Total Nitrogen	0.01	%	3.56	2.42	2.41	2.25	2.52	3.37
Metals (Matrix: Biota)								
Aluminum	2.0	mg/kg	649	597	172	319	544	626
Aluminum	0.40	mg/kg wwt	85.3	74.3	24.0	48.2	73.4	88.8
Antimony	0.010	mg/kg	0.033	0.038	0.019	0.027	0.029	0.049
Antimony	0.0020	mg/kg wwt	0.0044	0.0048	0.0026	0.0041	0.0040	0.0069
Arsenic	0.020	mg/kg	1.91	2.22	1.56	2.42	1.17	4.38
Arsenic	0.0040	mg/kg wwt	0.251	0.276	0.217	0.366	0.158	0.620
Barium	0.050	mg/kg	133	205	150	224	127	685
Barium	0.010	mg/kg wwt	17.5	25.5	20.9	33.9	17.2	97.1
Beryllium	0.010	mg/kg	0.023	0.028	0.011	0.019	0.019	0.036
Beryllium	0.0020	mg/kg wwt	0.0030	0.0035	<0.0020	0.0029	0.0025	0.0051
Bismuth	0.010	mg/kg	<0.010	0.010	<0.010	<0.010	<0.010	0.013
Bismuth	0.0020	mg/kg wwt	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	14.1	16.1	14.1	14.3	38.2	13.7
Boron	0.20	mg/kg wwt	1.85	2.00	1.96	2.16	5.16	1.94
Cadmium	0.0050	mg/kg	0.0493	0.0432	0.0173	0.0304	0.0427	0.0528
Cadmium	0.0010	mg/kg wwt	0.0065	0.0054	0.0024	0.0046	0.0058	0.0075
Calcium	20	mg/kg	9350	38400	46800	90400	33400	23300

Sample			TACHICK-CERDEM	TACHICK-ELOCAN	TACHICK-POTZOS	TACHICK-POTRIC	WEST 79-1	WEST 79-3
Calcium	4.0	mg/kg wwt	1230	4780	6520	13700	4500	3310
Cesium	0.0050	mg/kg	0.0565	0.0575	0.0175	0.0307	0.0534	0.0660
Cesium	0.0010	mg/kg wwt	0.0074	0.0072	0.0024	0.0046	0.0072	0.0093
Chromium	0.050	mg/kg	1.09	0.967	0.301	0.577	0.675	1.05
Chromium	0.010	mg/kg wwt	0.143	0.120	0.042	0.087	0.091	0.149
Cobalt	0.020	mg/kg	0.778	0.616	0.184	0.342	0.586	0.608
Cobalt	0.0040	mg/kg wwt	0.102	0.0766	0.0257	0.0517	0.0791	0.0862
Copper	0.10	mg/kg	2.49	2.79	1.05	1.78	2.24	3.45
Copper	0.020	mg/kg wwt	0.327	0.347	0.146	0.269	0.302	0.489
Iron	3.0	mg/kg	2840	2950	1230	2230	1420	8460
Iron	0.60	mg/kg wwt	372	367	172	337	192	1200
Lead	0.020	mg/kg	0.685	0.614	2.67	0.672	0.468	0.598
Lead	0.0040	mg/kg wwt	0.0900	0.0763	0.372	0.102	0.0631	0.0848
Lithium	0.50	mg/kg	0.55	0.53	<0.50	<0.50	0.52	<0.50
Lithium	0.10	mg/kg wwt	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	6220	3490	4660	6770	6420	4860
Magnesium	0.40	mg/kg wwt	817	434	648	1020	867	689
Manganese	0.050	mg/kg	6690	6020	3970	6540	6570	21900
Manganese	0.010	mg/kg wwt	879	748	553	989	887	3110
Mercury	0.0050	mg/kg	0.0054	0.0068	<0.0050	<0.0050	<0.0050	0.0087
Mercury	0.0010	mg/kg wwt	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	0.0012
Molybdenum	0.020	mg/kg	4.46	6.35	2.95	4.88	10.6	3.60
Molybdenum	0.0040	mg/kg wwt	0.586	0.790	0.411	0.739	1.42	0.510
Nickel	0.20	mg/kg	1.53	1.62	0.59	1.00	0.87	2.23
Nickel	0.040	mg/kg wwt	0.202	0.201	0.083	0.151	0.118	0.316
Phosphorus	10	mg/kg	4040	4210	2260	2330	4000	5170
Phosphorus	2.0	mg/kg wwt	531	524	315	353	539	732

Sample			TACHICK-CERDEM	TACHICK-ELOCAN	TACHICK-POTZOS	TACHICK-POTRIC	WEST 79-1	WEST 79-3
Potassium	20	mg/kg	24100	16700	8400	15600	24700	8660
Potassium	4.0	mg/kg wwt	3170	2080	1170	2360	3330	1230
Rubidium	0.050	mg/kg	7.64	2.46	3.36	5.79	6.23	3.67
Rubidium	0.010	mg/kg wwt	1.00	0.305	0.468	0.876	0.841	0.521
Selenium	0.050	mg/kg	0.057	0.075	<0.050	<0.050	<0.050	0.110
Selenium	0.010	mg/kg wwt	<0.010	<0.010	<0.010	<0.010	<0.010	0.016
Sodium	20	mg/kg	1560	5400	1110	1260	5020	1320
Sodium	4.0	mg/kg wwt	205	671	155	191	678	187
Strontium	0.050	mg/kg	66.3	153	158	279	143	125
Strontium	0.010	mg/kg wwt	8.72	19.0	22.0	42.2	19.3	17.7
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0062	0.0067	0.0061	0.0097	0.0041	0.0126
Thallium	0.00040	mg/kg wwt	0.00081	0.00083	0.00085	0.00147	0.00056	0.00179
Tin	0.10	mg/kg	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Tin	0.020	mg/kg wwt	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	0.580	0.784	0.292	0.392	0.289	0.590
Uranium	0.00040	mg/kg wwt	0.0762	0.0975	0.0406	0.0592	0.0390	0.0837
Vanadium	0.10	mg/kg	3.67	4.02	1.58	2.53	2.45	5.71
Vanadium	0.020	mg/kg wwt	0.483	0.500	0.220	0.383	0.331	0.809
Zinc	0.50	mg/kg	14.2	13.1	7.97	8.83	14.1	14.3
Zinc	0.10	mg/kg wwt	1.87	1.63	1.11	1.34	1.91	2.03
Zirconium	0.20	mg/kg	0.50	0.66	0.26	0.36	0.32	0.74
Zirconium	0.040	mg/kg wwt	0.066	0.082	<0.040	0.054	0.044	0.106

Appendix Table D-1. Lab results from the Tachick Lake macrophyte samples continued.

Sample			WEST93-1	WEST93-2	WEST93-3	WEST93-4
Date Sampled			**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**	**30-Aug-2023**
Time Sampled			**15:00**	**15:00**	**15:00**	**15:00**
	Lowest Detection Limit	**Units**				
Physical Tests (Matrix: Biota)						
Moisture	0.50	%	92.7	90.3	91.3	94.0
Anions and Nutrients (Matrix: Biota)						
Total Nitrogen	0.01	%	2.46	2.91	2.57	3.8
Metals (Matrix: Biota)						
Aluminum	2.0	mg/kg	330	633	32.6	1940
Aluminum	0.40	mg/kg wwt	24.1	61.6	2.83	116
Antimony	0.010	mg/kg	0.021	0.025	0.015	0.083
Antimony	0.0020	mg/kg wwt	<0.0020	0.0024	<0.0020	0.0049
Arsenic	0.020	mg/kg	1.09	1.13	2.28	6.58
Arsenic	0.0040	mg/kg wwt	0.0797	0.110	0.198	0.393
Barium	0.050	mg/kg	114	70.0	427	433
Barium	0.010	mg/kg wwt	8.30	6.82	37.1	25.8
Beryllium	0.010	mg/kg	0.012	0.021	<0.010	0.090
Beryllium	0.0020	mg/kg wwt	<0.0020	0.0020	<0.0020	0.0053
Bismuth	0.010	mg/kg	<0.010	<0.010	<0.010	0.025
Bismuth	0.0020	mg/kg wwt	<0.0020	<0.0020	<0.0020	<0.0020
Boron	1.0	mg/kg	24.5	16.8	15.3	16.4
Boron	0.20	mg/kg wwt	1.78	1.63	1.33	0.98
Cadmium	0.0050	mg/kg	0.0295	0.0369	0.0255	0.150
Cadmium	0.0010	mg/kg wwt	0.0022	0.0036	0.0022	0.0089
Calcium	20	mg/kg	21200	15700	68400	11800
Calcium	4.0	mg/kg wwt	1540	1530	5930	705

Sample			WEST93-1	WEST93-2	WEST93-3	WEST93-4
Cesium	0.0050	mg/kg	0.0310	0.0562	<0.0050	0.188
Cesium	0.0010	mg/kg wwt	0.0023	0.0055	<0.0010	0.0112
Chromium	0.050	mg/kg	0.433	0.804	0.073	3.33
Chromium	0.010	mg/kg wwt	0.032	0.078	<0.010	0.199
Cobalt	0.020	mg/kg	0.271	0.436	0.125	1.88
Cobalt	0.0040	mg/kg wwt	0.0197	0.0425	0.0108	0.112
Copper	0.10	mg/kg	1.65	2.34	0.86	8.12
Copper	0.020	mg/kg wwt	0.120	0.228	0.074	0.485
Iron	3.0	mg/kg	2130	1360	1400	12500
Iron	0.60	mg/kg wwt	155	132	121	748
Lead	0.020	mg/kg	0.733	0.528	0.115	3.10
Lead	0.0040	mg/kg wwt	0.0534	0.0514	0.0100	0.185
Lithium	0.50	mg/kg	<0.50	<0.50	<0.50	1.35
Lithium	0.10	mg/kg wwt	<0.10	<0.10	<0.10	<0.10
Magnesium	2.0	mg/kg	14000	11300	8510	5560
Magnesium	0.40	mg/kg wwt	1020	1100	738	332
Manganese	0.050	mg/kg	1320	952	17100	22600
Manganese	0.010	mg/kg wwt	96.3	92.7	1480	1350
Mercury	0.0050	mg/kg	0.0070	0.0081	<0.0050	0.0263
Mercury	0.0010	mg/kg wwt	<0.0010	<0.0010	<0.0010	0.0016
Molybdenum	0.020	mg/kg	13.4	10.6	5.50	6.84
Molybdenum	0.0040	mg/kg wwt	0.974	1.03	0.477	0.409
Nickel	0.20	mg/kg	0.97	1.43	0.41	6.41
Nickel	0.040	mg/kg wwt	0.071	0.139	<0.040	0.383
Phosphorus	10	mg/kg	4410	3510	4600	7400
Phosphorus	2.0	mg/kg wwt	321	342	400	442
Potassium	20	mg/kg	27000	15600	25000	31600

Sample			WEST93-1	WEST93-2	WEST93-3	WEST93-4
Potassium	4.0	mg/kg wwt	1970	1520	2170	1880
Rubidium	0.050	mg/kg	4.38	5.18	7.34	11.7
Rubidium	0.010	mg/kg wwt	0.319	0.504	0.637	0.698
Selenium	0.050	mg/kg	<0.050	0.065	<0.050	0.246
Selenium	0.010	mg/kg wwt	<0.010	<0.010	<0.010	0.015
Sodium	20	mg/kg	8490	3390	1790	2200
Sodium	4.0	mg/kg wwt	619	330	155	132
Strontium	0.050	mg/kg	165	119	236	96.0
Strontium	0.010	mg/kg wwt	12.0	11.6	20.5	5.73
Tellurium	0.020	mg/kg	<0.020	<0.020	<0.020	<0.020
Tellurium	0.0040	mg/kg wwt	<0.0040	<0.0040	<0.0040	<0.0040
Thallium	0.0020	mg/kg	0.0042	0.0066	0.0058	0.0141
Thallium	0.00040	mg/kg wwt	<0.00040	0.00064	0.00051	0.00084
Tin	0.10	mg/kg	0.26	<0.10	<0.10	0.12
Tin	0.020	mg/kg wwt	<0.020	<0.020	<0.020	<0.020
Uranium	0.0020	mg/kg	1.13	0.677	0.231	1.12
Uranium	0.00040	mg/kg wwt	0.0824	0.0659	0.0200	0.0672
Vanadium	0.10	mg/kg	2.03	2.74	1.21	9.99
Vanadium	0.020	mg/kg wwt	0.148	0.267	0.105	0.596
Zinc	0.50	mg/kg	21.6	12.3	5.61	31.5
Zinc	0.10	mg/kg wwt	1.57	1.20	0.49	1.88
Zirconium	0.20	mg/kg	0.30	0.43	<0.20	1.38
Zirconium	0.040	mg/kg wwt	<0.040	0.042	<0.040	0.082