Lakes of the Carvel Pitted Delta

-Stony Plain Region-

Summer Field Program - 2022

Cover image: Unnamed lakes PL21 and PL22 on Kilini Creek. Photograph taken by David Trew, 2022.

Table of Contents

Report prepared August 2023

Introduction

There are several dozen small kettle lakes located on the post-glacial landscape of Parkland County known as the Carvel Pitted Delta. These unique lakes and their watersheds primarily drain into the Sturgeon River sub-watershed, but some are located in the Modeste sub-watershed and drain towards the North Saskatchewan River. There are approximately 25 named lakes and 70 unnamed lakes in this area. The geographic extent of the Carvel Pitted Delta is described in the "*Mayatan Lake Watershed Management Plan" (2016)*.[1] These small lakes and their associated landscapes are considered to have unique ecological value by local and provincial governments, as well as by conservation agencies. They provide ecosystem services and habitat to support fish, wildlife, and waterfowl populations. They also provide extensive opportunities for nature pursuits, education and outdoor recreation.

North Basin of Mere Lake. Photograph taken by David Trew, 2022.

The small watersheds of these lakes continue to change, mostly as a result of human encroachment. The lakes are now surrounded by varying proportions of forested, agricultural and recreational land, and by rural residential developments. Some lake watersheds have been extensively impacted by human activities, while some on private lands remain relatively undisturbed. The Carvel Pitted Delta and its "hummocky" landscapes also play a significant role in regional groundwater recharge, as described in "*Summary of Groundwater Conditions in the Sturgeon River Basin" (2019)*. [2]

Water quality data from lakes in this region remain somewhat limited and have typically been based on short term research projects or fisheries assessments. Hydrologic and bathymetric data are also limited; only six named lakes are monitored for summer water levels, and water balances have only been prepared for three (S. Figliuzzi, P.

[1] Logan, M., D. O. Trew and D. Mussel. 2016. Mayatan Lake Watershed Management Plan. North Saskatchewan Watershed Alliance, Edmonton, AB. 97 pp.

[2] Oiffer, A. 2019. Summary of Groundwater Conditions In The Sturgeon River Basin. Prepared for the North Saskatchewan Watershed Alliance, Edmonton, AB. 39 pp.

Eng.).[3,4,5] Given the large number of small lakes in this unique geologic setting and the growing interest amongst partners, the concept of a regional synoptic lake survey has evolved.

In 2020, a preliminary project to assess and update lake water quality information in the Carvel Pitted Delta was initiated by the Alberta Lake Management Society (ALMS) and the University of Alberta. During that first project, twelve lake basins were selected and sampled to assess mid-summer water quality. That preliminary work has been summarized in a research paper published by Von Gunten et al. (2021)[6].

In 2021, ALMS and the Mayatan Lake Management Association (MLMA) undertook an expanded water quality survey on 44 of these lakes. The goal of this second survey was to expand the regional understanding of lake water quality and aquatic ecosystem health. Twenty-one named lakes and 23 unnamed lakes were sampled, several for the first time. Unnamed lakes were assigned an identification code and recorded as PL# (PL = Parkland Lake). Results from this survey can be found in "*Lakes of the Carvel Pitted Delta – Stony Plain Region: Summer Field Program 2021*".[7] Many photographs from the 2021 survey can also be found on the ALMS website.[8]

The littoral zone and riparian edge at PL5. Photo taken by David Trew, 2022.

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[3] Logan, M., B. Milholland, D.O. Trew and S. Figliuzzi. 2012. Mayatan Lake State of the Watershed Report. North Saskatchewan Watershed Alliance, Edmonton, AB. 88pp.

[4] Regier, J. and D.O. Trew. 2016. Jackfish Lake State of the Watershed Report. North Saskatchewan Watershed Alliance, Edmonton, AB. 181 pp.

[5] Gordy, M., J. Regier, B. Muldoon and D.O. Trew. 2018. Hubbles Lake State of the Watershed Report. North Saskatchewan Watershed Alliance, Edmonton, AB. 159 pp.

[6] Von Gunten, K., D.O. Trew, B. Smerdon, D. Alessi. 2021. Controls on natural phosphorus in small lakes in central Alberta, Canada. Canadian Water Resources Journal. https://doi.org/10.1080/07011784.2022.2107435

[7] Peter, B., C. Sinn, D.O. Trew, and W. Neilson. 2022. Lakes of the Carvel Pitted Delta – Stony Plain Region: Summer Field Program 2021. Alberta Lake Management Society and Mayatan Lake Management Association. 30 pp.

[8] Alberta Lake Management Society. https://alms.ca/carvel-pitted-delta/.

In 2022 a third community-based water quality survey project was implemented by ALMS and the MLMA. In this survey, 50 lakes were sampled once each between early August and mid-October. Twenty-seven named lakes and twenty-three unnamed lakes were investigated. The primary goal of the project was to extend the regional overview of lake water quality, with the intent of stimulating more community interest and supporting future lake management discussions. The scope of work was expanded over that of 2021 to include lake bathymetry, isotope testing to identify groundwater inputs, microcystin measurements, testing for aquatic invasive species and light extinction measurements. The sampling methodology also evolved from the single grab sampling approach associated with the LakeKeeper program (2020, 2021) to that of a composite sampling approach based on vertically integrated samples.

The 2022 survey was a collaborative effort supported by several partners including ALMS, MLMA, the Land Stewardship Centre of Canada (LSCC), the North Saskatchewan Watershed Alliance (NSWA), the Stony Plain Fish and Game Association (SPFGA), Parkland County and the Department of Earth Sciences, University of Alberta. Thirty-one private landowners were also engaged in the project and graciously provided lake access.

A reflection of clouds in the water at Little Mere Lake. Photograph taken by David Trew, 2022.

Historical Context

Some of these small lakes were first sampled in the late 1940s by Dr. R. B. Miller, Dept of Zoology, University of Alberta, and were described in a GOA publication entitled: "*Preliminary Biological Surveys of Alberta Watersheds*".[9] The emphasis of these lake surveys was to evaluate sportfish capability. Certain water quality and biological data were gathered, lake depths were measured manually and fish species were determined.

During the 1950s and 1960s coarse-scale testing on some of these lakes was conducted by the Alberta Geological Survey as part of efforts to characterize province-wide surface water chemistry patterns. The Alberta Fish and Wildlife Division conducted further evaluations of sportfish capability (under the Canada Land Inventory) and initiated trout stocking programs on certain lakes during the 1960s-70s.

Detailed water quality sampling was initiated on a few lakes by Alberta Environment between the 1970s and 1990s, providing preliminary nutrient and phytoplankton data. During this same period, several lakes were investigated as part of post-graduate student research programs at the University of Alberta. Data for seven of these lakes were first published by Prepas and Trew (1983) in their paper "*Evaluation of the Phosphorus-Chlorophyll Relationship for Lakes off the Precambrian Shield in Western Canada*".[10] These lakes included Eden, Hasse, Hubbles, Mink, Roi (Gerharts), Sauer and Star.

Lily beds at PL23. Photographed by David Trew, 2022.

In 1986 an extensive fisheries inventory was undertaken on 34 lakes by R. L. & L. Environmental Services Ltd., under contract to Fish and Wildlife Division.[11] The survey included water quality testing, vegetation mapping, lake substrate mapping, fish sampling and recommendations for fisheries management. Each lake was sampled once during August 1986.

Six lakes are also described in detail in the "*Atlas of Alberta Lakes"* published by the University of Alberta Press in 1990. These lakes included Eden, Hasse, Hubbles, Jackfish, Sauer and Spring.[11]

During the 2000s, further monitoring has been conducted on 5 of the named lakes by ALMS, providing summer data on major ion chemistry, temperature/dissolved oxygen, nutrients, and general trophic conditions. These lakes include Mayatan, Jackfish, Mink, Spring and Hubbles. The conditions of three lakes were investigated more extensively as part of watershed planning work conducted by the NSWA (2012-2018). These lakes included Mayatan Lake, Jackfish Lake and Hubbles Lake.

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[9] Miller, R.B. and W.H MacDonald. 1949. Preliminary Biological Surveys of Alberta Watersheds (1947-49). Department of Lands and Forests, Government of the Province of Alberta, Edmonton AB. 139 pp.

[10] Prepas, E. E. and D. O. Trew. 1983. Evaluation of the Phosphorus-Chlorophyll Relationship for Lakes off the Precambrian Shield in Western Canada. Journal of the Fisheries Research Board of Canada. Vol 40, Number 1, pp 27-35.

[11] R.L. &L. Environmental Services Ltd. 1987. County of Parkland Fisheries Inventory. Prepared for Alberta Fish and Wildlife Division and Alberta Recreation, Parks and Wildlife Foundation

[11] Prepas, E.E. and P. Mitchell. 1990. Atlas of Alberta Lakes. University of Alberta Press, Edmonton, AB. 675 pp.

Winter lake sampling has also been conducted by MLMA over the past three years under the ALMS Winter LakeKeepers program.[12] In February and March 2021, eighteen basins were sampled to assess late winter dissolved oxygen conditions and other water quality parameters. During the following winter (2022) seven basins were sampled, and in 2023 nineteen basins were sampled.[13]

Looking through the trees at PL15. Photograph taken by David Trew, 2022.

Methods

The lakes selected for sampling in 2022 are illustrated in Figure 1. Each lake was sampled once between August 9th and October 17th, 2022. Given the finite resources available, the sampling design was intended to capture lakes during the period of relatively high water temperatures. Under such conditions, it was anticipated that the deeper lakes would be thermally stratified and display low surface nutrient and algal concentrations, whereas shallow lakes would likely be well mixed and display higher nutrient and algal concentrations.

[12] Sinn, C., B. Peter. 2021. Winter LakeKeepers Report 2020-2021. Alberta Lake Management Society, Edmonton, AB. https://alms.ca/wp-content/uploads/2021/12/WLK_2020-2021_Final_20211202.pdf

[13] Sinn, C., B. Peter. 2022. Winter LakeKeepers Report 2021-2022. Alberta Lake Management Society, Edmonton, AB. https://alms.ca/wp-content/uploads/2022/11/WLK_2021-2022_Final_2022-11-10.pdf

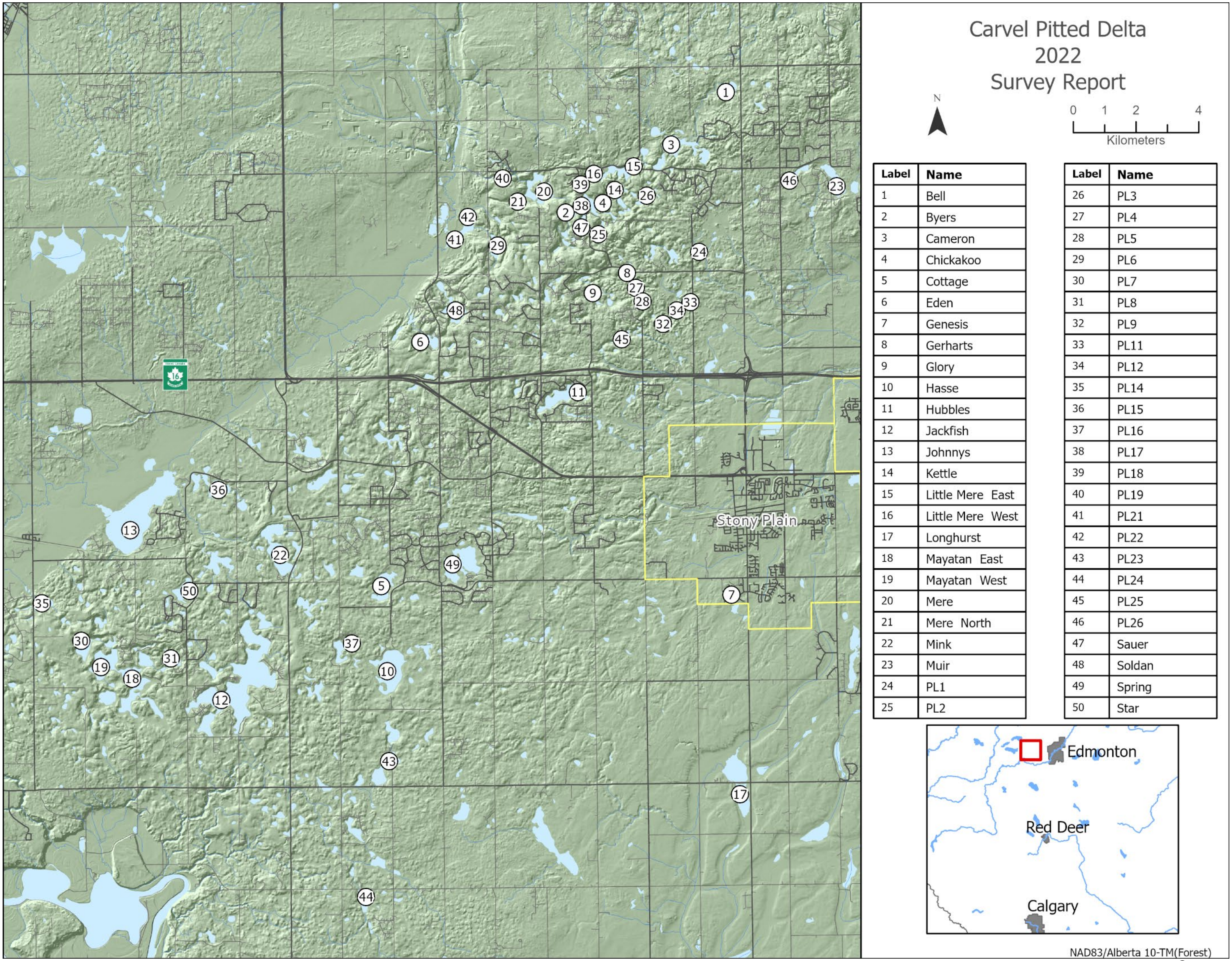
New bathymetric surveys were conducted on 33 lakes during 2022 to improve our regional understanding of lake volumes and areas. A canoe-mounted Garmin chart plotter (EchoMap 95sv UHD2) was used in conjunction with a Garmin sonar transducer (GT56UHD-TM). Each lake was sounded by traversing it numerous times to build a contour map of its bottom using the mapping software included with the EchoMap. Several hundred to several thousand soundings were accumulated for each lake. The individual depth measurements were exported from the GARMIN unit to a GIS-compatible file format and then processed in ESRI ArcGIS to generate smoothed geo-referenced contours. These data will be used to calculate surface areas, volumes and to develop color-coded depth maps.

Physical – chemical profile measurements were recorded at the deepest location of each lake. These locations were generally kept consistent for lakes sampled in both the 2021 and 2022 survey seasons, although some profile locations were adjusted in 2022 if a deeper location was identified through the new bathymetric surveys.

Water quality data collected at the profile location included:

- Water Clarity: measured using a Secchi disk (Secchi depth).
- Light extinction profiles for PAR (Photosynthetically Active Radiation): measured using an Apogee Instruments MQ-510 Full-Spectrum Underwater Quantum PAR meter. Readings were recorded at 0.1 m, 0.5 m, 1.0 m and then every meter until 1% of surface penetrating irradiance was recorded.
- Temperature, Dissolved Oxygen, Conductivity profiles: measured using a YSI ProSolo probe. Readings were recorded at 0.1 m, 0.5 m, 1.0 m and then every meter until lake bottom.
- A discrete sample was collected approximately 1.5 m above the lake bottom, using a horizontal Van Dorn device, in order to determine Total Phosphorus concentrations near the sediments.

Dave Mussell and Walt Neilson collecting underwater video footage at PL12.
Photo by David Trew, 2022.



Label	Name	Label	Name
1	Bell	26	PL3
2	Byers	27	PL4
3	Cameron	28	PL5
4	Chickakoo	29	PL6
5	Cottage	30	PL7
6	Eden	31	PL8
7	Genesis	32	PL9
8	Gerharts	33	PL11
9	Glory	34	PL12
10	Hasse	35	PL14
11	Hubbles	36	PL15
12	Jackfish	37	PL16
13	Johnnys	38	PL17
14	Kettle	39	PL18
15	Little Mere East	40	PL19
16	Little Mere West	41	PL21
17	Longhurst	42	PL22
18	Mayatan East	43	PL23
19	Mayatan West	44	PL24
20	Mere	45	PL25
21	Mere North	46	PL26
22	Mink	47	Sauer
23	Muir	48	Soldan
24	PL1	49	Spring
25	PL2	50	Star

Figure 1. Map showing the 50 lakes sampled in the Carvel Pitted Delta during the summer of 2022. Unnamed lakes have been assigned an arbitrary code indicated by PL#.

The physical profile data from 2020 and 2021 indicated that many of these lakes were thermally stratified at shallow depths, likely a reflection of their sheltered locations on the landscape, limited exposure to winds and limited fetch. Shallow stratification and meromixis had also been reported for these lakes by Prepas and Trew (1983).

Conventional integrated euphotic zone sampling would require sampling to depths that would frequently penetrate nutrient-rich waters in the anoxic hypolimnia of stratified lakes, or close to bottom in the shallower basins. Close inspection of the profile data suggested that restricting vertically integrated sampling to a depth of 2.5 m would provide a comparable survey approach for all lakes.

Water was therefore collected using a vinyl tube with a one-way valve from the surface to the 2.5 m depth level in each lake to represent a vertically integrated sample of the surface water layer. Five sample units were collected at each of three locations and combined to make a whole-lake composite based on 15 sample units. There were some exceptions. Because of extensive shallowness, Muir Lake and PL2 were only sampled to 2 m. Longhurst, Cameron and Genesis lakes were far too shallow to collect vertically integrated water samples, therefore five grab samples were taken from a depth of 0.5 m at each of the three sites using a Van Dorn device. At one small lake (PL18) samples were collected from the shore as boat access was not possible. Water column profiles, Secchi depth and discrete bottom samples could not be collected from this latter site.

The surface composite sample was decanted into various analytical bottles, preservatives added as required, and these bottles were subsequently submitted for the analysis of routine water chemistry and nutrients to Bureau Veritas in Edmonton. Discrete bottom samples for Total Phosphorus analysis were also submitted to Bureau Veritas. Chlorophyll-*a* samples were filtered in the field, frozen and submitted to Innotech Alberta in Vegreville. Samples for stable isotope analyses were also taken from this composite and delivered to the Dept of Earth Sciences, University of Alberta. Triplicate Samples for Aquatic Invasive Species were collected following AEPA protocols using a horizontal tow net at the same three sites that were used for water quality composite sampling. Samples were preserved and delivered to AEPA for analysis. Samples for phytoplankton and zooplankton taxonomy have been preserved and are in storage.

Walter Neilson and a recently collected sample of zooplankton from Johnnys Lake. Photograph taken by David Trew, 2022.

The raw lake data collected during this project have been uploaded to the Gordon Foundation's DataStream, which provides open access and long-term storage. Data can be viewed and downloaded from: https://lakewinnipegdatastream.ca.

This report provides a regional overview and synopsis for 50 lakes but does not include comparisons to historical water quality data or detailed assessments for individual waterbodies. More information on this project can be found at https://alms.ca/carvel-pitted-delta/.

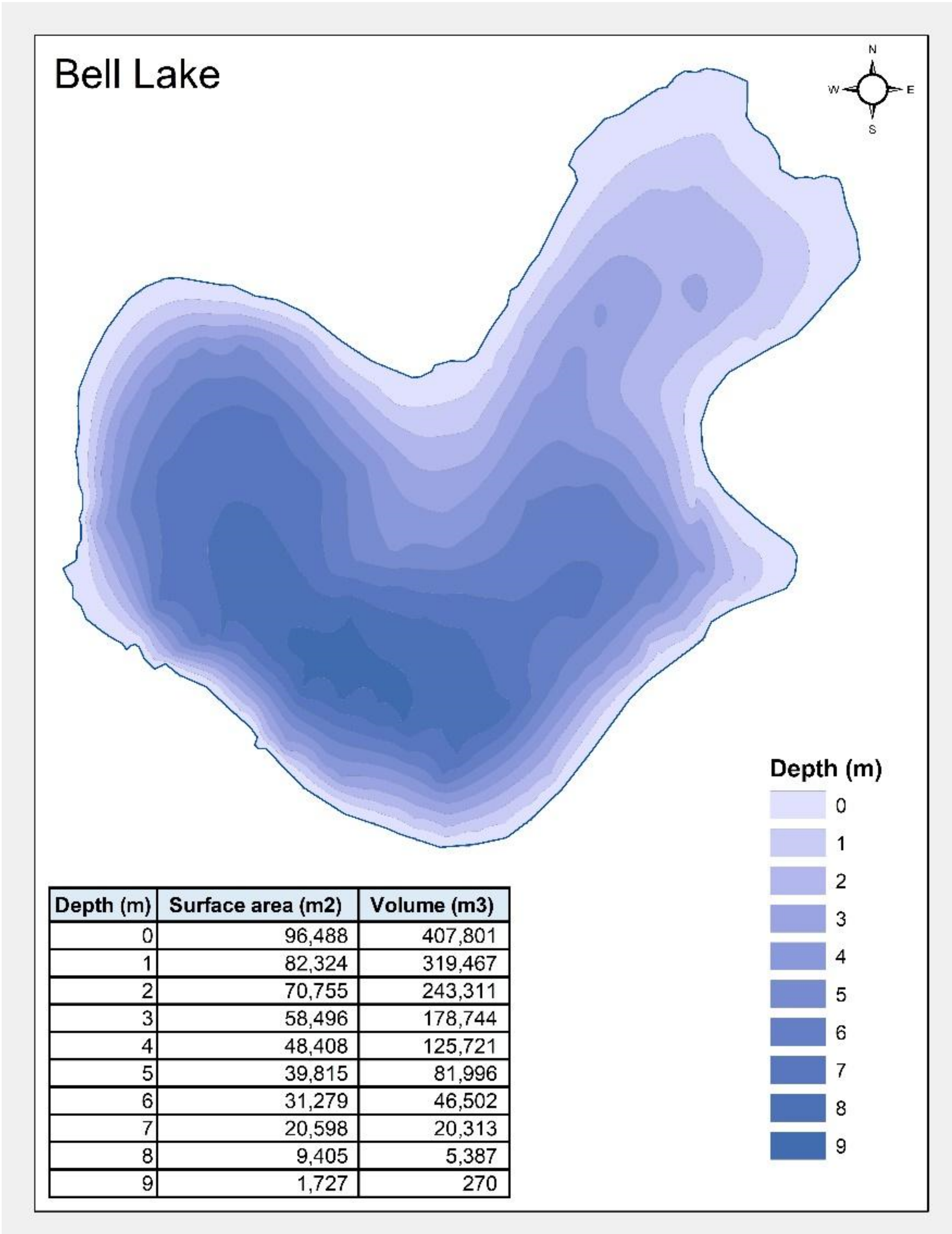
Bathymetry

New bathymetric data were collected for the following 33 lakes during the summer of 2022, using the Garmin instrumentation.

- Bell Lake
- Byers Lake
- Cameron Lakes
- Cottage Lake
- Eden Lake
- Genesis Lake
- Gerhart's Lake
- Glory Lake
- Kettle Lake
- Little Mere Lake (East)
- Little Mere Lake (West)
- PL01
- PL02
- PL03
- PL04
- PL05
- PL06
- PL07
- PL08
- PL09
- PL11
- PL12
- PL14
- PL15
- PL17
- PL19
- PL21
- PL22
- PL23
- PL24
- PL25
- PL26
- Soldan Lake

The new bathymetric data will be processed during 2023 and results of this work will be published in a future ALMS report. An example of a finalized bathymetric map (Bell Lake) showing volume and area data for each depth stratum is presented in Figure 2. Bathymetric work will be conducted on additional lakes during the summer of 2023.

Dave Mussell and Dr. Brian Smerdon collecting bathymetric data readings from PL21. Photograph taken by David Trew, 2022.



Depth (m)	Surface area (m2)	Volume (m3)
0	96,488	407,801
1	82,324	319,467
2	70,755	243,311
3	58,496	178,744
4	48,408	125,721
5	39,815	81,996
6	31,279	46,502
7	20,598	20,313
8	9,405	5,387
9	1,727	270

Figure 2. Bathymetric map of Bell Lake illustrating the 0-9 m depth contours. Surface area (m^2) and volume (m^3) data are shown for each depth interval.

Physical Characteristics

All the lakes of the Carvel Pitted Delta sampled in this project (Figure 1) were comparatively small, with surface areas ranging from 0.30 hectares (PL18) to 281.0 hectares (Jackfish Lake; Figure 3). The median size of all sampled lakes was 19.0 hectares.

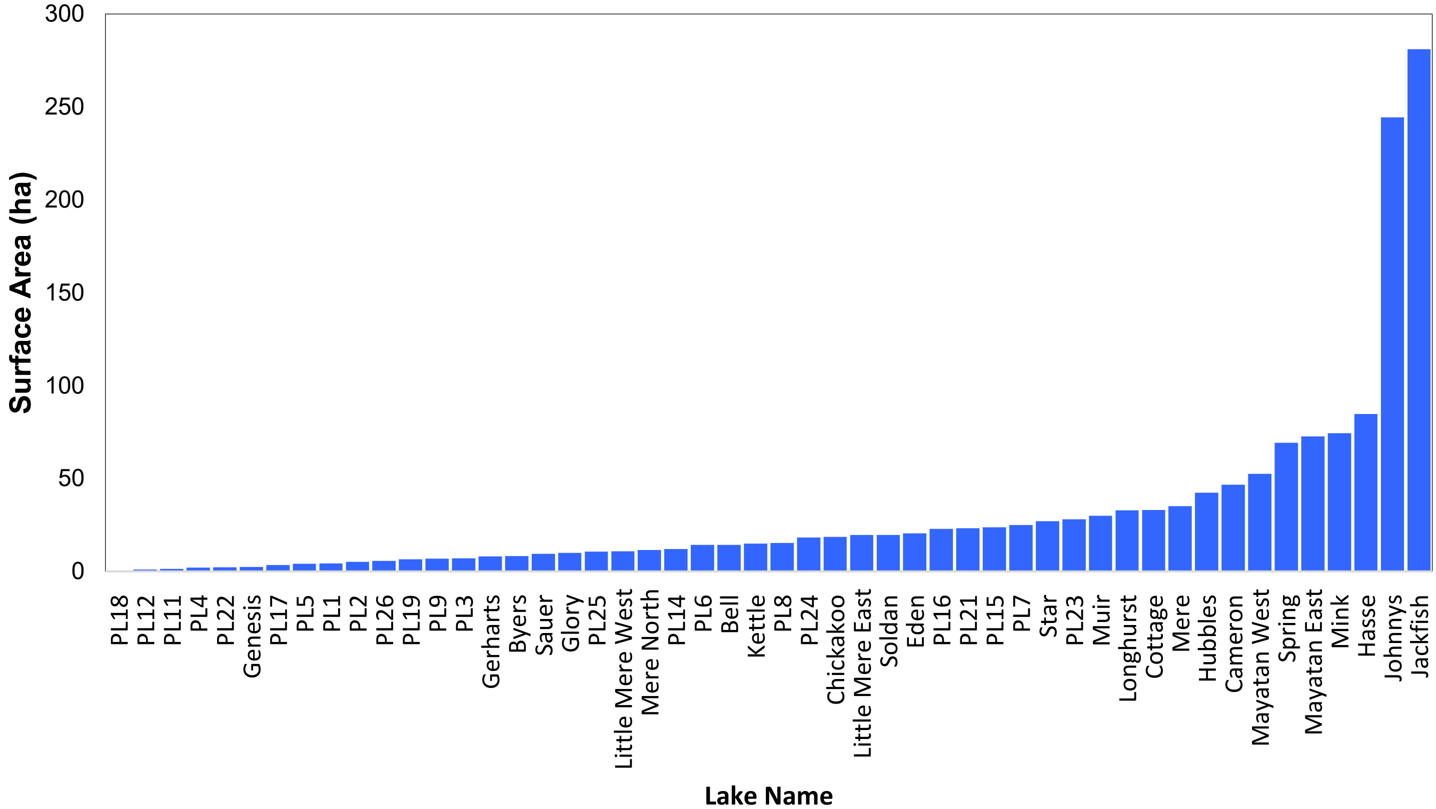


Figure 3. Surface areas (ha) of 50 lakes in the Carvel Pitted Delta. Data provided by NSWA (2021) and ALMS (2023).

Despite their small sizes, many of the lakes are relatively deep. Depths were recorded at each profile sample location and ranged from 1.0 m to 22.5 m (Figure 4). As the new bathymetric data are further evaluated, these maximum depth estimates may be modified.

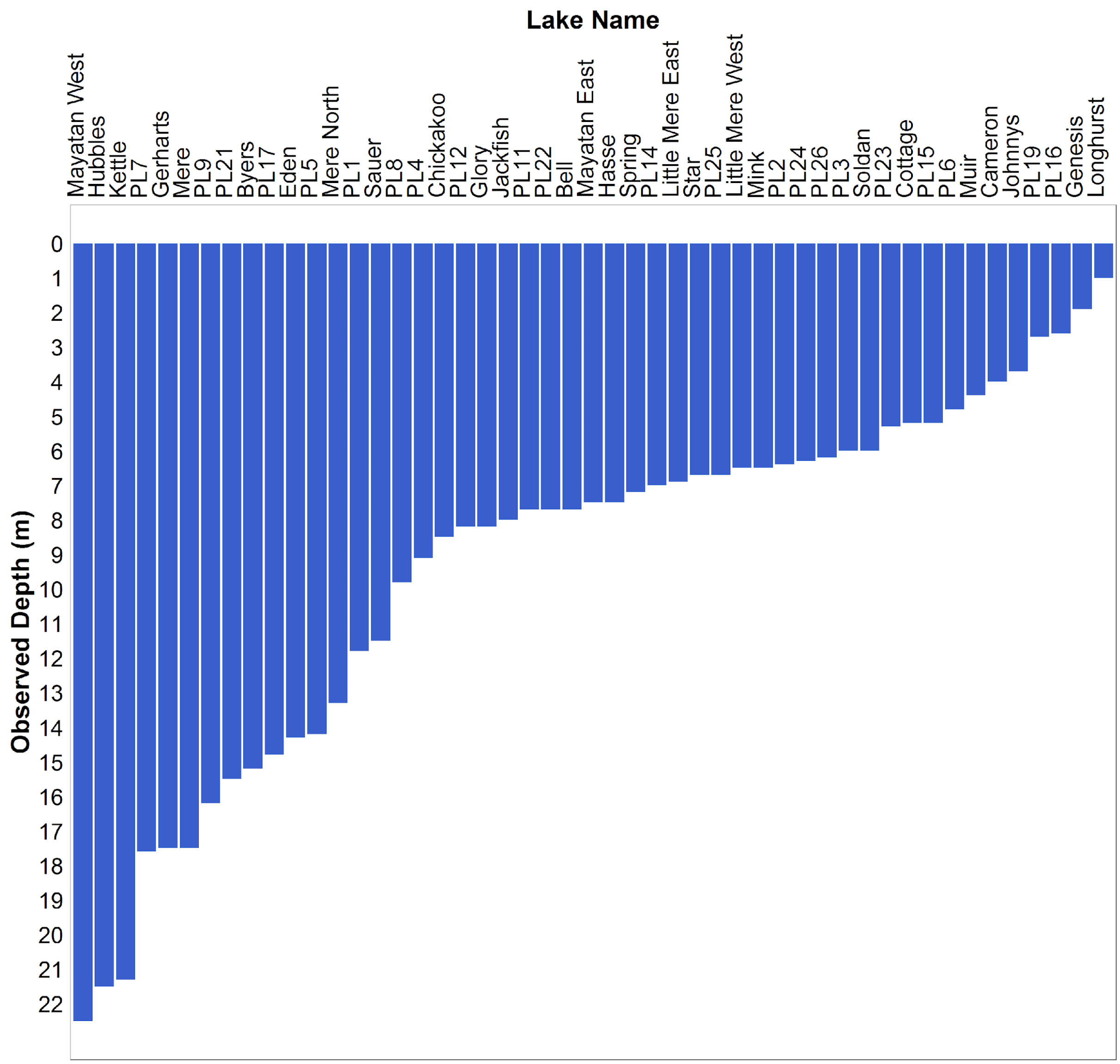


Figure 4. Maximum observed depths (m) recorded for 49 lakes at each sampling site, using a weighted measuring tape or derived from the new bathymetric surveys. PL18 has not been included.

Water Levels

Water level records in this region extend back to 1968, with the exception of Spring Lake which extends back to 1937. These data, collected by Alberta Environment and Protected Areas, are not available for each lake in the Carvel Pitted Delta. However, sufficient data exist for six of the lakes to outline general water level trends. Note that two of the original lakes (Johnnys and Star) were discontinued in 2002, and Mayatan Lake was recently added (2017).

Changes in individual elevation measurements for each lake were calculated against the elevation recorded at a common point in time (May 9, 1994), thus allowing for a comparative depiction of elevation changes for all lakes, for the entire period of record, on one graph (Figure 5). The data suggest that lakes in the region generally experienced higher water levels from the mid 1970s to the late 1990s, followed by declining and lower water levels from the late 1990s until present.

These general water level changes reflect climate patterns (local temperature and precipitation) as recorded at the Edmonton Stony Plain Weather Station during the same period, and are discussed in more detail in NSWA's *Jackfish Lake State of the Watershed Report* (Regier et al. 2015). Note that the effects of watershed change and water use would also have to be assessed for each lake in order to develop a complete understanding of individual lake level changes.

When looking at individual lake levels for the full period of record five lakes appear to show a similar four-decade cycle (see individual lake level graphs in the Appendices). Hasse, Mink and Spring increased from the late 1960s and after four decades have returned to lower levels again but appear to be approximately 0.5 m below that of the 1960s. Jackfish and Hubbles also increased from late 1960s and after four decades have returned to lower levels, but appear similar to the elevations of the late 1960s. In 1976, Chickakoo experienced a rapid one-meter increase from that of the late 1960s, but since then has experienced a steady decline and now sits at an elevation approximately 2.5 m below that of the 1960s. Star and Johnnys, although discontinued, appear to have followed the other lakes in the rising water levels of the mid 1970s and appear to have sustained those levels into the late 1990s.

These changes in the Carvel Pitted Delta region are also typical of patterns observed across the larger North Saskatchewan watershed in recent decades. Buendia and Trew (2017) analyzed data for 36 lakes in the North Saskatchewan watershed between 1985-2016 and reported that 69% of lakes had decreasing or “likely decreasing” water levels.[14]

Changes in lake levels can have important implications for lake water quality and aquatic habitat. Generally, the loss of water from a lake may result in changes to the mixing regime of the water column, altered flushing and chemical cycling rates, varied littoral/riparian zone proportions and their ecological/habitat characteristics, and negative effects on overwinter dissolved oxygen conditions.

[14] Buendia, C. and D. O. Trew. (2017). NSWA Technician Bulletin. Lake Level Trends in Alberta – Preliminary Results. North Saskatchewan Watershed Alliance. Accessed via www.nswa.ab.ca. May 2023.

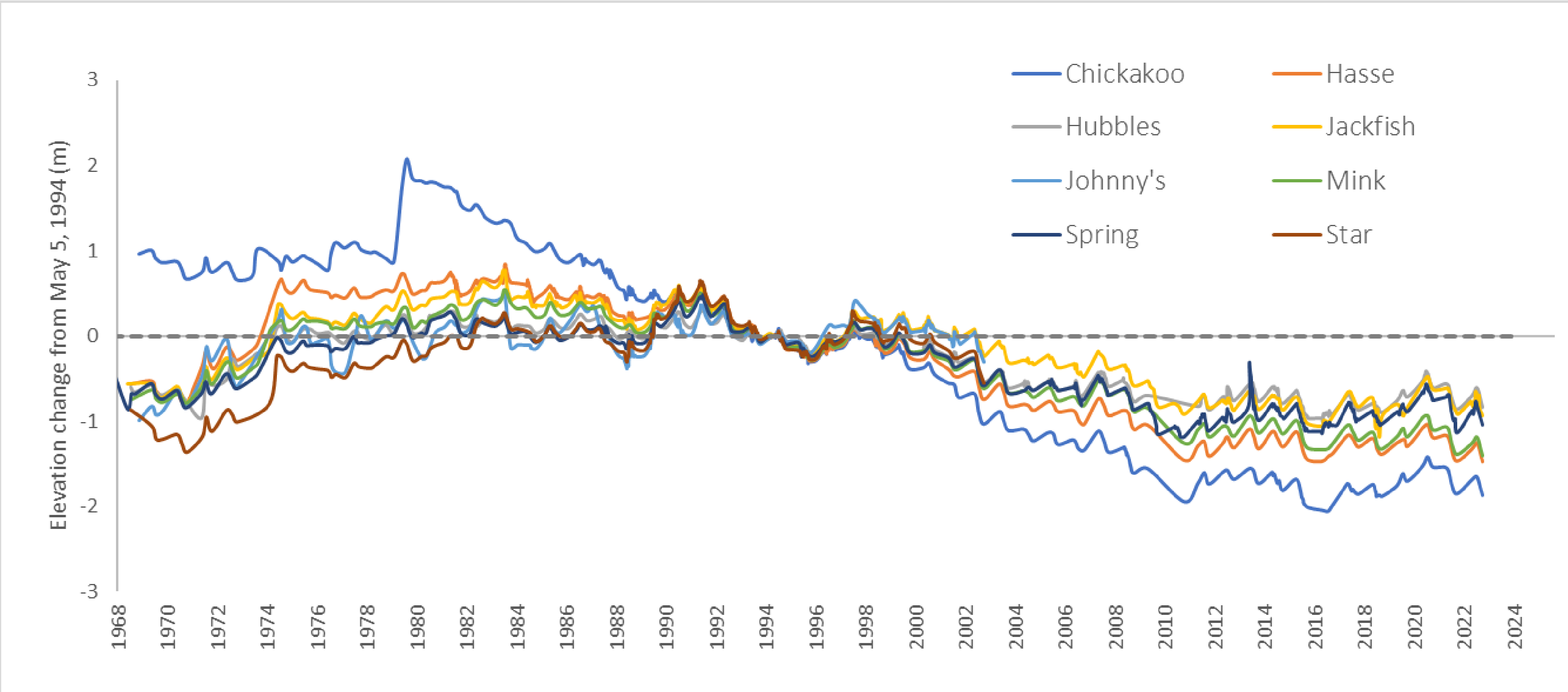


Figure 5. The difference (m) in water levels compared to 1994 levels for eight lakes within the Carvel Pitted Delta region. Water level elevations in meters above sea level were obtained from Alberta Environment and Protected Areas for the period 1968-2022. The difference in water levels was calculated by subtracting the elevation on May 9, 1994 from the observed elevation. Figure and data prepared by S. Figliuzzi, P. Eng.

Temperature

Sampling occurred between early-August and mid-October; therefore, a range of surface water temperatures was observed (Figure 6). The shallow lakes generally displayed warmer and more uniform vertical conditions. A pattern of strong thermal stratification was observed in the deeper lakes. During thermal stratification, a warm surface layer (epilimnion) becomes distinct from a cooler bottom layer (hypolimnion) due to the formation of a thermal density gradient (thermocline). In these deep lakes, the thermocline was often established between 4 – 8 m. Thermal stratification has important implications for fisheries habitat and nutrient cycling. As lakes in Alberta cool during autumn, vertical mixing becomes more common. Lake surface area, lake shape and the surrounding landscape can also influence the degree to which a lake will stratify or mix.

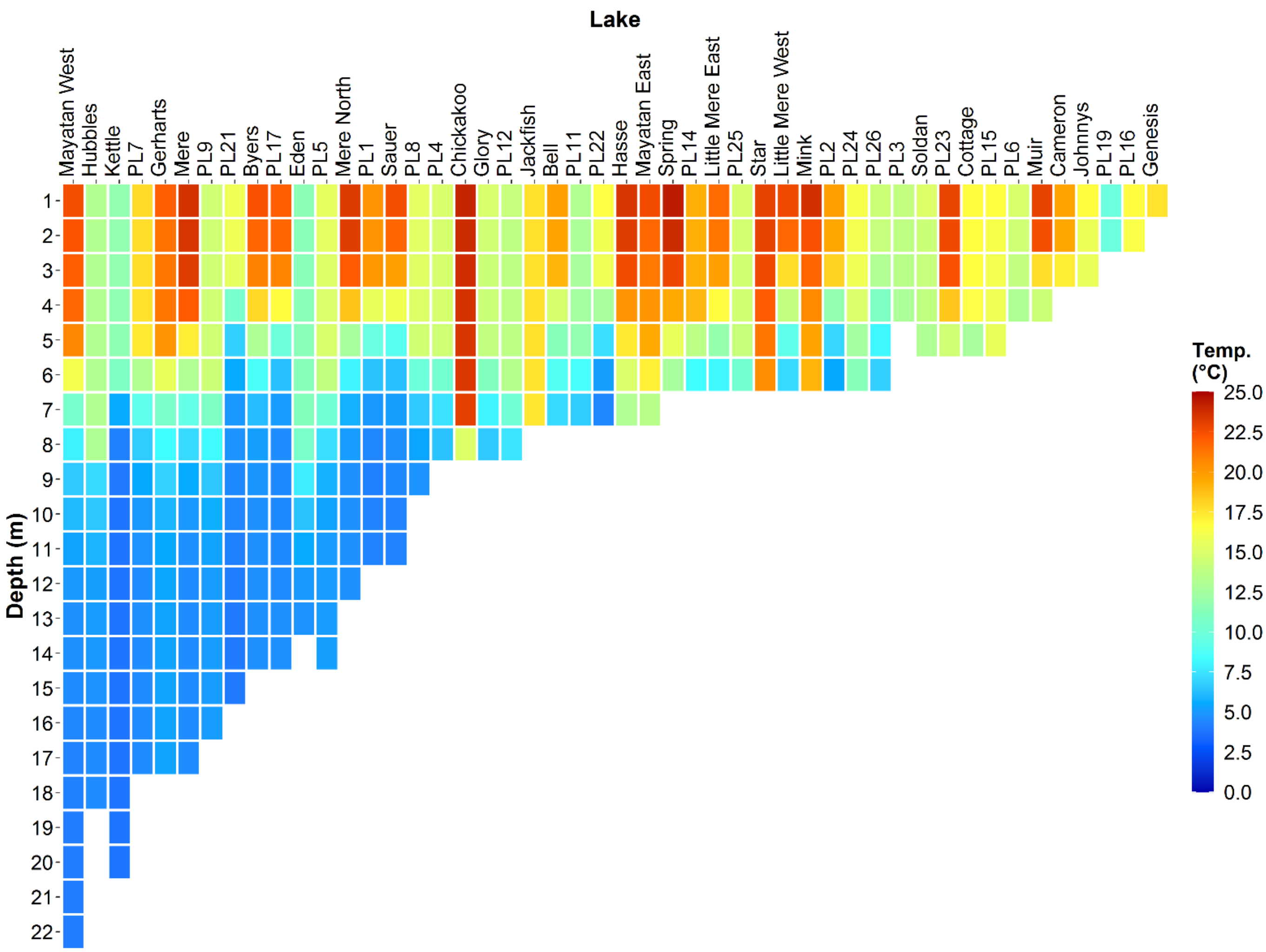


Figure 6. Temperature (°C) profiles for 48 lakes sampled between August 9th and October 17th, 2022. Coloured boxes reflect the temperature measured at that specific depth measurement. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1 m depth for visual purposes. Longhurst Lake and PL18 have not been included in this figure.

Dissolved Oxygen

Dissolved oxygen concentrations [DO] can vary greatly both among and within lakes due to factors such as depth, water column mixing, temperature and biological activity (Figure 7). Dissolved oxygen concentrations in the deeper lakes were strongly influenced by thermal stratification. Very low oxygen or anoxic conditions were regularly observed below the thermocline. Low dissolved oxygen concentrations were also observed at a depth of approximately 3.0 m in many of the shallower lakes sampled. Chickakoo, Cameron and Glory lakes displayed low oxygen values throughout the water column. Chickakoo and Cameron lakes also exhibited very low phytoplankton chlorophyll-*a* (Figure 11); shading of phytoplankton by the extensive standing crops of duckweed (Lemna sp.) observed in those two lakes may have contributed to the low [DO]. The littoral zone of Glory Lake supports a large population of white water lilies with floating leaves which may have an effect on diurnal oxygen levels.

Note that the 5.0 m and 6.0 m panels within the Gerharts Lake and PL7 profiles are coloured grey. Interestingly, dissolved oxygen concentrations at these depths displayed sharp peaks of 13.22 mg/L and 22.82 mg/L respectively. Elevated [DO] readings at the transition point between the surface and bottom layers usually indicates the presence of a thin but highly concentrated layer of phytoplankton, supported by high nutrient water from the hypolimnion, and adequate light penetration down to the thermocline depth (see Figure 14).

Figure 7. Dissolved oxygen (mg/L) profiles for 48 lakes sampled between August 9th and October 17th, 2022. Coloured boxes reflect the dissolved oxygen concentration measured at that specific depth measurement. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1.0 m depth for visual purposes. Longhurst Lake and PL18 have not been included in this figure.

Total Phosphorus

Phosphorus represents one of the most important nutrients controlling the growth of phytoplankton in lakes. Surface total phosphorus concentrations [TP] displayed a very wide range in the lakes of the Carvel Pitted Delta (Figure 8), ranging from <3.0 µg/L at PL9 and PL12 to 410 µg/L at Cameron Lake. Based on total phosphorus concentrations fourteen lakes were tentatively classified as oligotrophic, thirteen lakes as mesotrophic, fifteen lakes as eutrophic and eight lakes as hypereutrophic. When visualized on the regional map, some interesting grouping of lake types can be observed (Figure 9). The southwestern portion of the region contains a mixture of high quality oligotrophic and mesotrophic lakes, as does the northeastern portion. These patterns may reflect differences in land cover types and the extent of human encroachment within individual lake watersheds. The natural influences of groundwater on lake chemistry and lake flushing rates may also be important for understanding the diverse phosphorus attributes of these lakes (Von Gunten et al. 2021)[6]. Note that larger scale maps of phosphorus and other parameters are included in the Appendices.

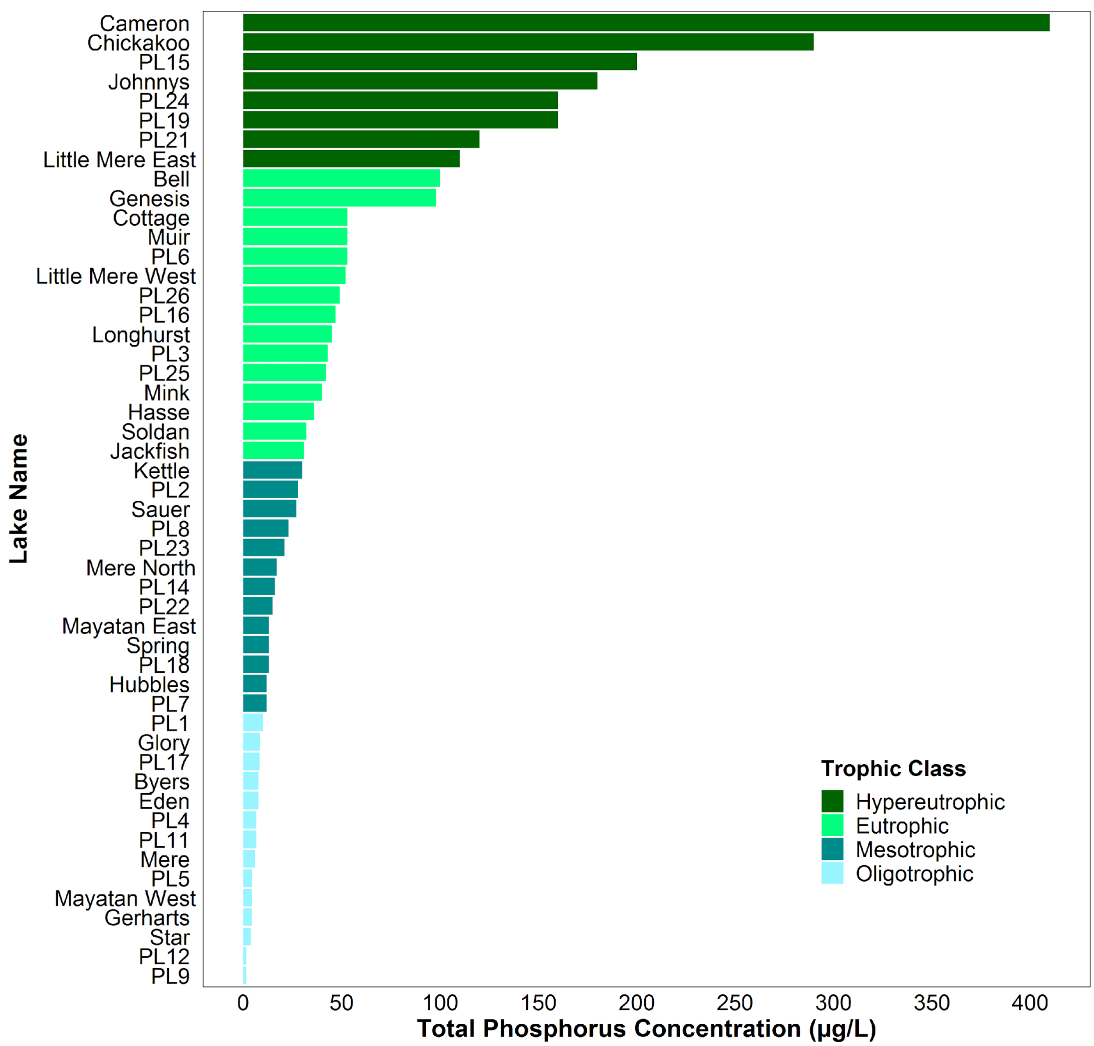


Figure 8. Total phosphorus concentrations for all 50 lakes sampled between August 9th and October 17th, 2022. Composite samples were generally collected to 2.5 m depth except for the six shallow lakes as previously noted. Trophic categories have been defined as oligotrophic (<10 µg/L), mesotrophic (10 - 30 µg/L), eutrophic (30 - 100 µg/L), and hypereutrophic (>100 µg/L).

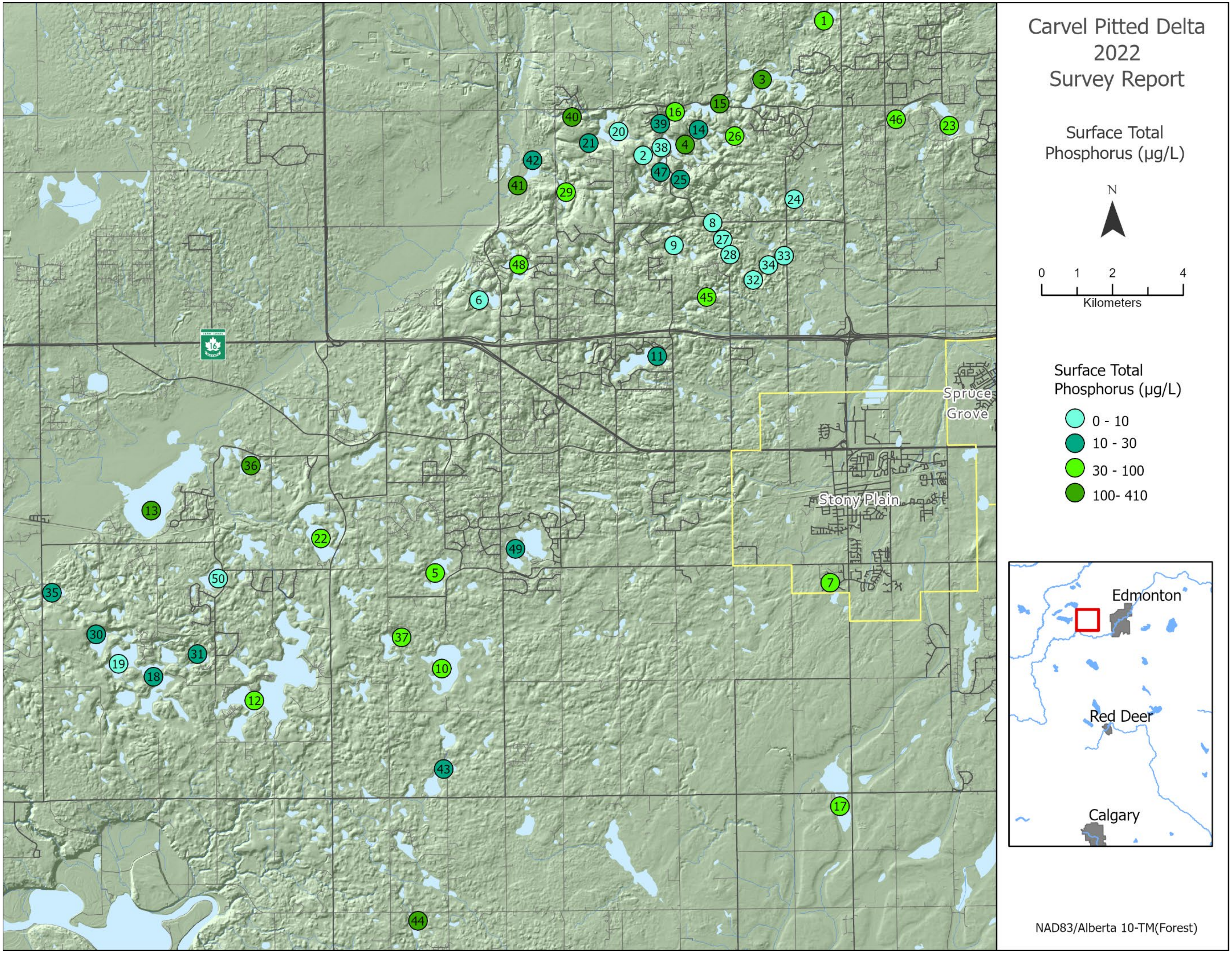


Figure 9. Total phosphorus values sorted into trophic categories for each lake sampled in the Carvel Pitted Delta region. Different colours represent different trophic categories, from oligotrophic (0-10 µg/L), to mesotrophic (10-30 µg/L), to eutrophic (30-100 µg/L), to hypereutrophic (>100 µg/L). The maximum observed phosphorus value was 410 µg/L. See Figure 1 for a description of lake labels and names.

Samples collected from near the bottom of each lake revealed concentrations of total phosphorus that were much higher than surface concentrations (Figure 10), a common observation in Alberta lakes. This is particularly evident in deep lakes with thermal stratification, such as Byers Lake, Mere Lake North and PL17. Geochemical controls on phosphorus availability appear to vary widely across the region (Von Gunten et al. 2021).

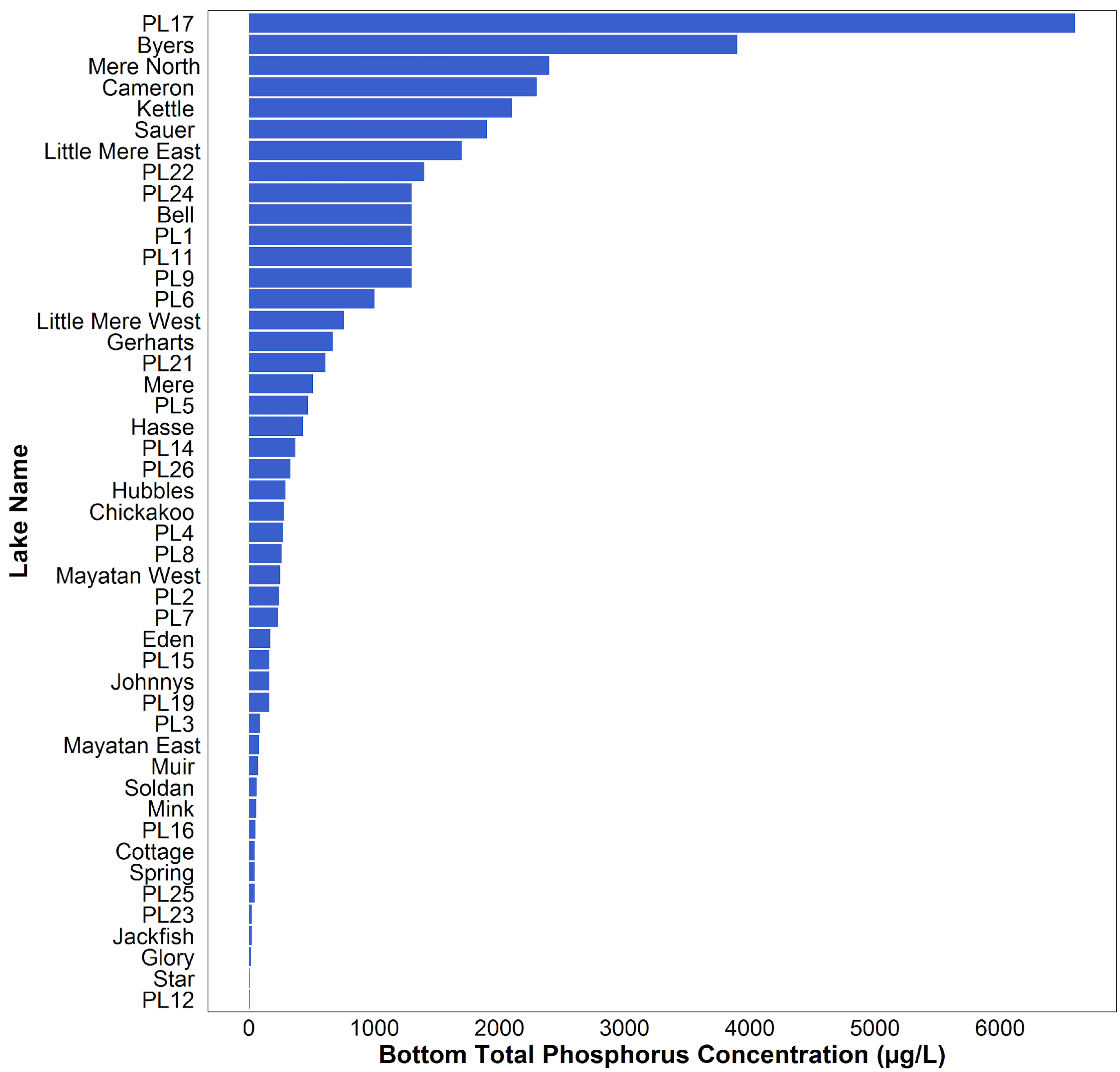


Figure 10. Bottom total phosphorus concentrations from 47 lakes sampled between August 9th and October 17th, 2022. Bottom samples were not collected from Genesis Lake, Longhurst Lake or PL18.

Chlorophyll-*a*

Chlorophyll-*a* is a photosynthetic pigment and is used as an indicator of the biomass of phytoplankton (algae and cyanobacteria) in a lake. In general, lakes with low phosphorus concentrations tend to display low concentrations of chlorophyll-*a,* as phosphorus is considered the primary nutrient limiting the growth of phytoplankton. The lakes of the Carvel Pitted Delta again spanned the full range of trophic states based on their chlorophyll-*a* concentrations [Chl-*a*] (Figure 11). Fourteen lakes were tentatively classified as oligotrophic, fourteen lakes as mesotrophic, eleven lakes as eutrophic and eleven lakes as hypereutrophic. As observed for total phosphorus, the southwestern and northeastern regions both contained a mixture of high quality oligotrophic and mesotrophic lakes (Figure 12).

Note that the [Chl-*a*]: [TP] ratio varies naturally from lake to lake, and within the growing season, so that independent trophic classifications based on these two variables may not always align. The two lakes showing the largest deviations from the general pattern were Chickakoo Lake and Cameron Lake: both had very high [TP] and very low [Chl-*a*]. Overall, chlorophyll-*a* concentrations ranged from 1.1 µg/L at Glory Lake to 117 µg/L at Johnnys Lake and PL15.

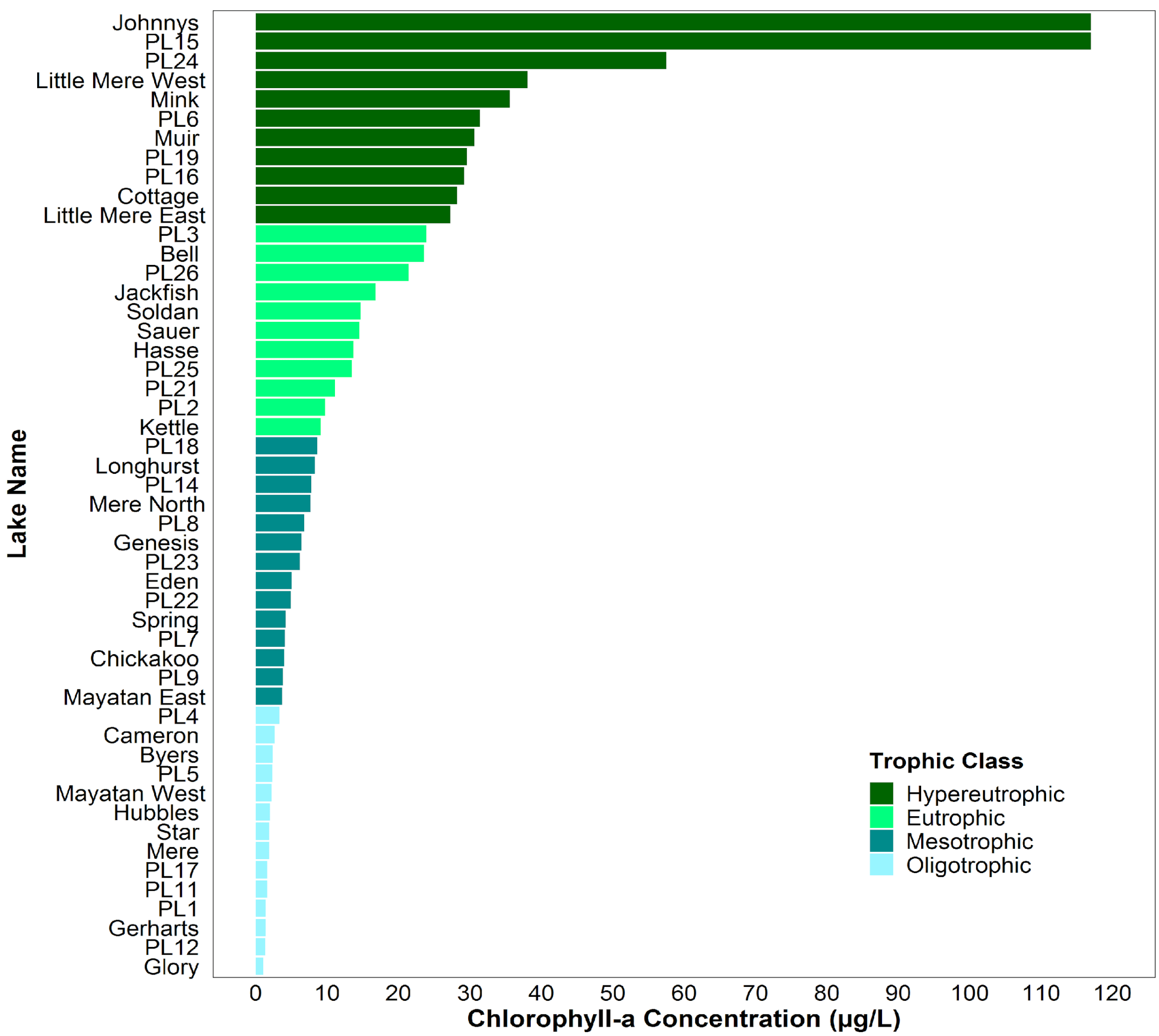


Figure 11. Chlorophyll-*a* concentrations for all 50 lakes sampled between August 9th and October 17th 2022. Trophic categories have been defined as oligotrophic (<3.5 µg/L), mesotrophic (3.5 - 9 µg/L), eutrophic (9 - 25 µg/L), and hypereutrophic (>25 µg/L).

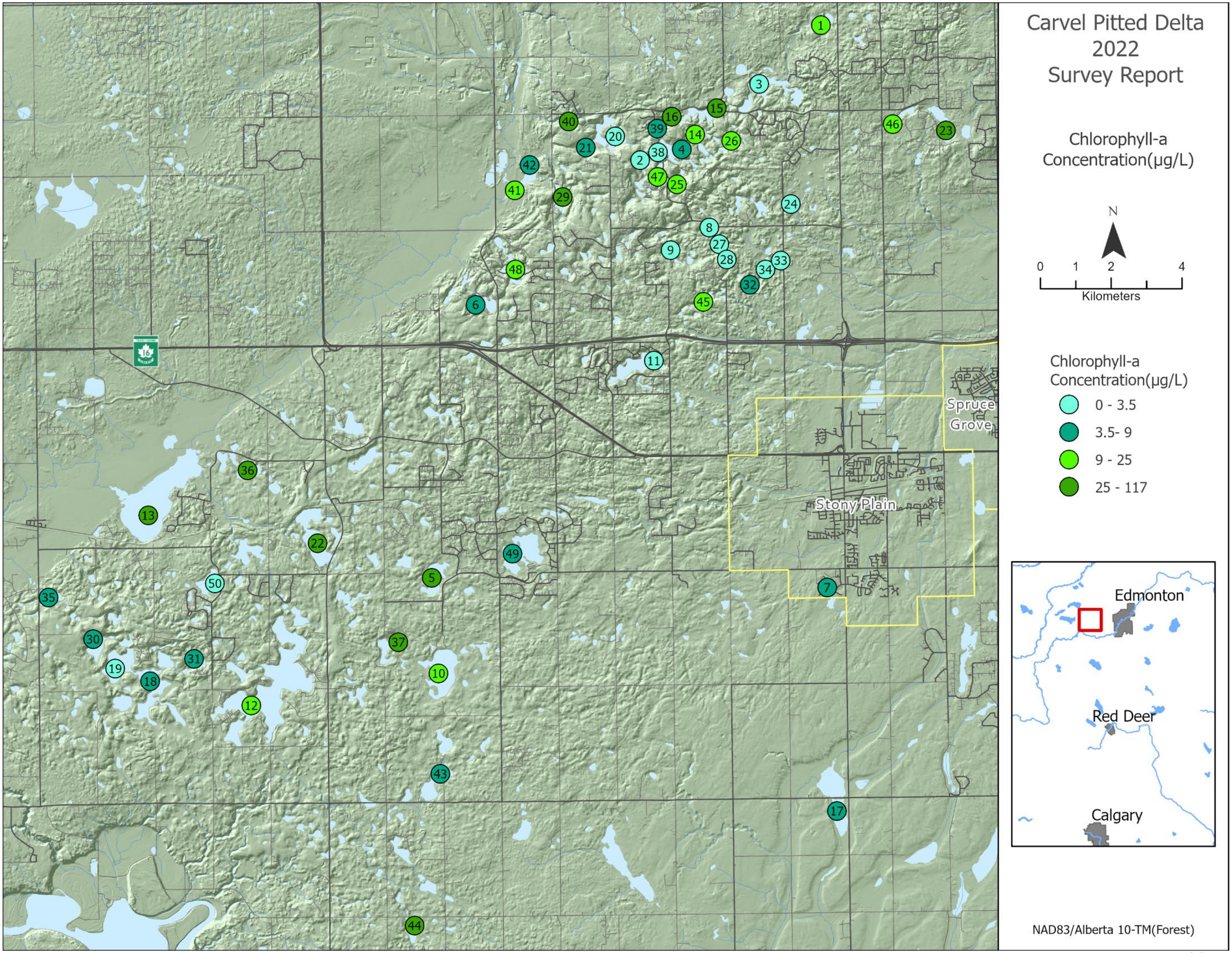


Figure 12. Chlorophyll-a concentrations (µg/L) sorted into trophic categories for each lake sampled in the Carvel Pitted Delta. Different colours represent different trophic categories, from oligotrophic (0-3.5 µg/L), to mesotrophic (3.5-9 µg/L), to eutrophic (9 -25 µg/L), to hypereutrophic (>25 µg/L). The maximum observed chlorophyll-a value was 117 µg/L at Johnnys Lake and PL15. See Figure 1 for a description of lake labels and names.

Microcystin

Microcystin is the most common cyanobacterial (blue-green algal) toxin found in Alberta. Although it is detectable in most lakes during the summer months, higher concentrations of microcystin can pose significant health risks to humans and wildlife. The current Health Canada recreational guideline for microcystin toxin is 10 µg/L[15]. Microcystin was below the detection limit (0.1 µg/L) in 30 lakes but detected in 20 lakes (Figure 13). Microcystin concentrations were highest at Bell Lake and PL24, where high concentrations of chlorophyll-*a* were also observed. Microcystin concentrations at PL24 (13.41 µg/L) exceeded the Health Canada guideline. Unfortunately, a small number of dead waterfowl were noted at PL24 on that sampling date. Caution should always be observed when recreating in Alberta lakes to limit exposure to cyanobacteria.

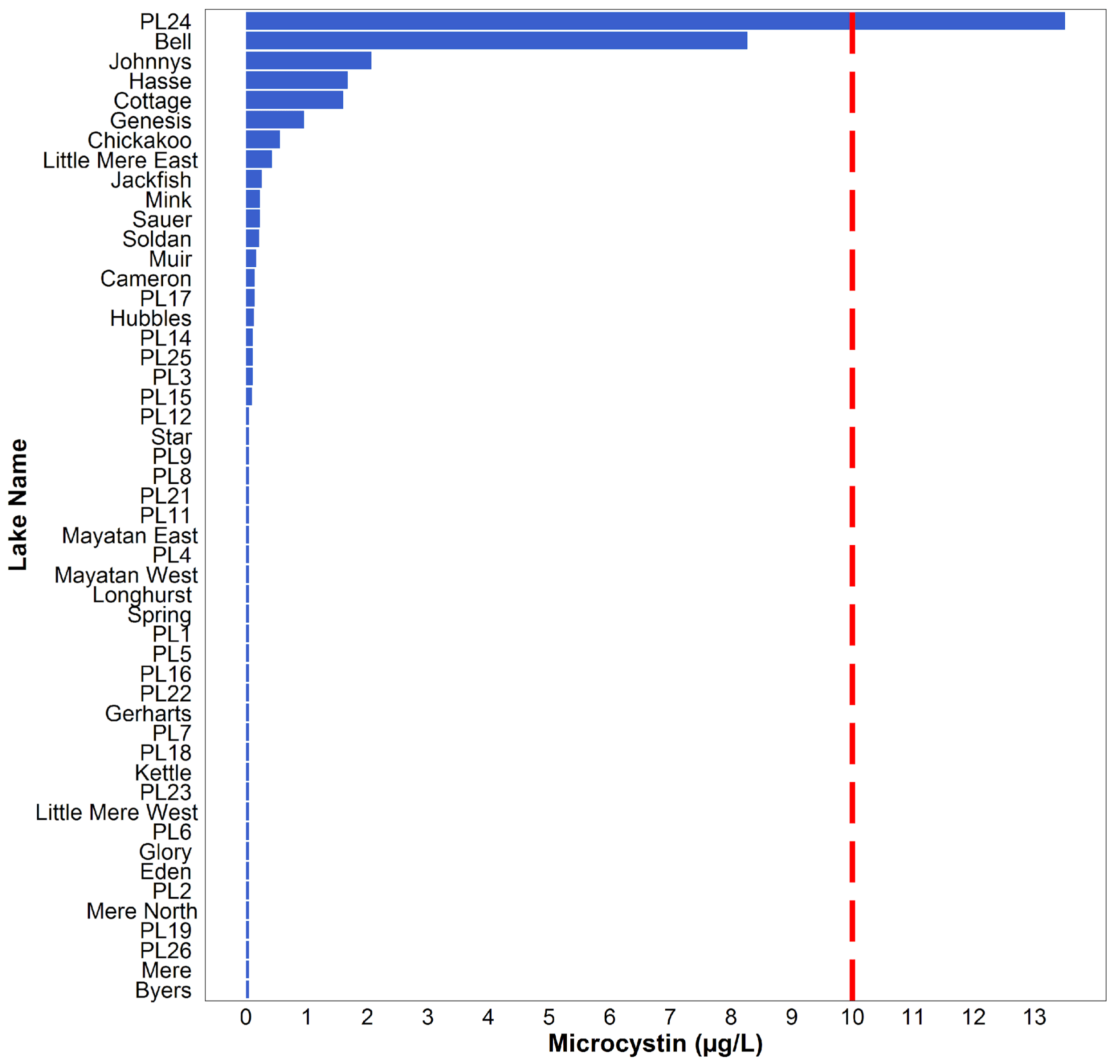


Figure 13. Microcystin concentrations for all 50 lakes sampled between August 9th and October 17th 2022. The Health Canada recreational guideline of 10 µg/L is indicated with a red vertical dashed line. Concentrations of microcystin above the minimum detection limit (0.1 µg/L) are evident on the graph beginning at PL15.

[15] Health Canada. 2022. Guidelines for Canadian recreational water quality. Cyanobacteria and their toxins. Guideline Technical Document. 71 pp.

Photosynthetically Active Radiation

Photosynthetically active radiation (PAR) is defined and measured in lakes by the penetration of light wavelengths between 400 and 700 nm. PAR is important for the growth of phytoplankton and macrophytes in lake ecosystems. PAR measurements can be obtained using specialized probes which record PAR levels as µmol/m2/s. Incident PAR at the surface will vary depending on daily weather conditions. Subsurface penetration depends on several factors, including suspended material (turbidity), the colour of the water and the amount of phytoplankton biomass in the water column. The attenuation of PAR within a water column is calculated as the extinction coefficient (Figure 14). Rapid light extinction was recorded at lakes with higher dissolved organic carbon concentrations [DOC] and chlorophyll-*a* concentrations (Johnnys, PL19, PL15). Very low light extinction was observed in the clear, oligotrophic lakes.

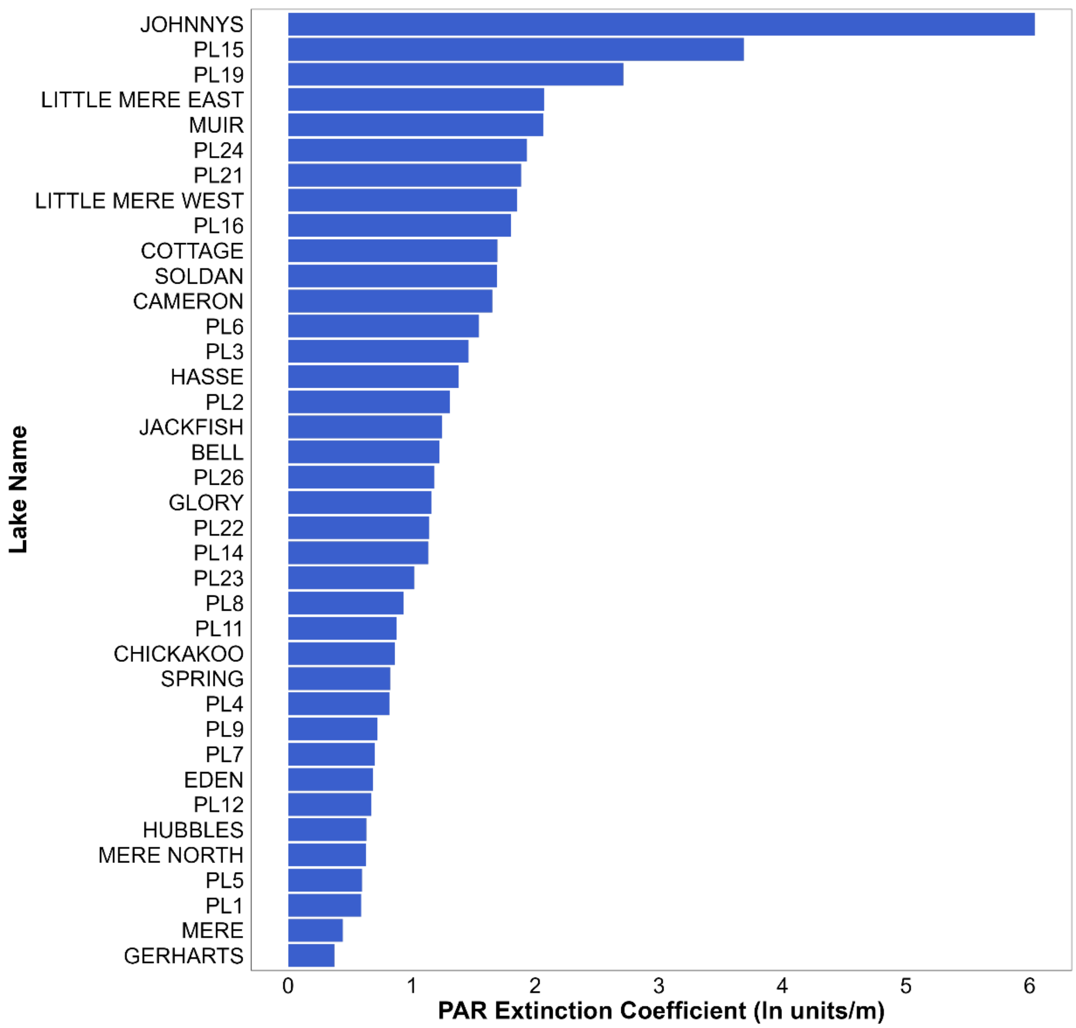


Figure 14. The PAR extinction coefficient (ln units/meter) calculated between 0.5 and 3.0 m for 38 lakes. The extinction coefficient was calculated as the natural log of PAR at depth ‘a’ minus the natural log of PAR at depth ‘b’ divided by the depth interval.

Euphotic Zone Depth

The euphotic zone is considered the primary photosynthetic zone in lakes and is conventionally defined as the depth to which 1% of surface penetrating irradiance remains. This zone can be measured directly using PAR extinction or estimated using a Secchi disk (calculated as 2 x Secchi Depth). See Appendix Table 1 for Secchi depths.

In the 38 lakes with measured PAR data, euphotic zone depths ranged from 0.6 m at Johnnys Lake to 8.5 m in Hubbles Lake (Figure 15). The minimum euphotic zone depth (at Johnnys Lake) coincided with the highest observed chlorophyll-*a* concentration (117 µg/L), indicating that a phytoplankton bloom significantly impacted water clarity on that sampling date. The clear, oligotrophic lakes typically displayed the deepest euphotic zones.

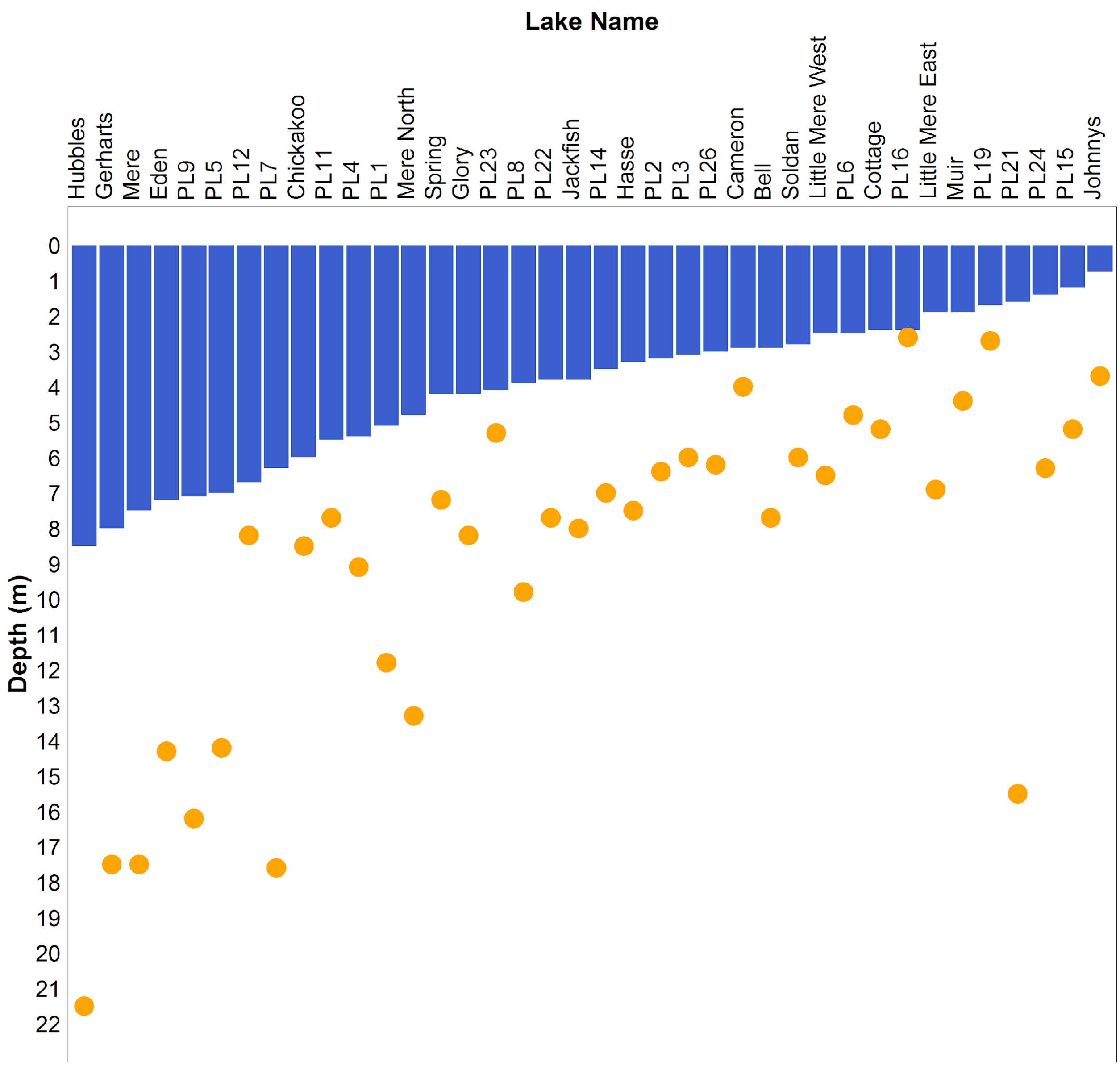


Figure 15. Euphotic zone depths (blue bars) measured for 38 lakes in the Carvel Pitted Delta. The euphotic zone was calculated as the depth to which 1% of the surface penetrating irradiance was observed. Lake bottom depths at the profile sites are indicated by yellow dots.

Major Ions

Groundwater, local geology and human activity can all impact the concentrations of major cations and anions in lake water. When comparing major ions across the sampled lakes, sulphate (SO_4^{2-}) displayed the highest variation in concentrations, ranging from <1.0 mg/L at Byer's Lake, PL2, PL3 and PL19 to 1200 mg/L at Mink Lake (Figure 16, Figure 17). Most lakes displayed carbonate (CO_3^{2-}) concentrations that fell below the laboratory detection limit (DL= 1 mg/L). For graphing purposes, these lakes were assigned a value representing 50% of the DL, or 0.5 mg/L.

The lakes of the Carvel Pitted Delta region display a very wide range of ionic concentrations and proportions, indicative of unique and differing water types. All lakes displayed alkaline characteristics, except PL18 which was slightly acidic and had been noted as such in the 2020 and 2021 surveys. In general, major ion concentrations in the southern region tend to be higher than major ion concentrations in the northern region.

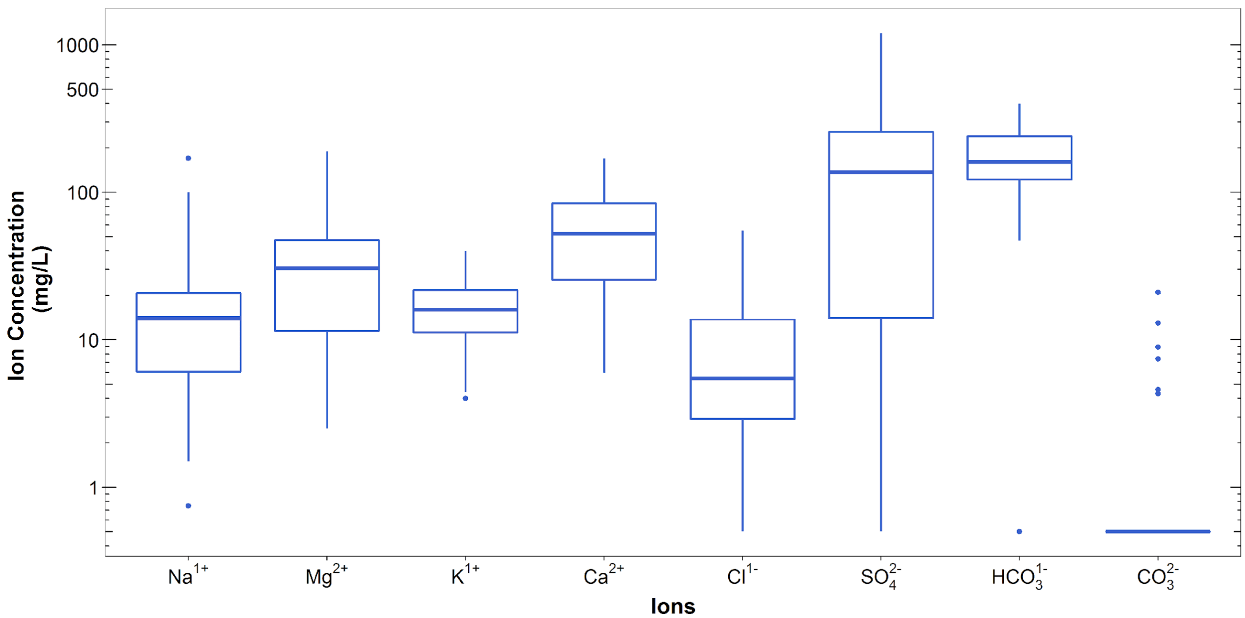


Figure 16. The distribution of major ions concentrations (mg/L) represented as box plots measured from composite samples collected at 49 lakes and a grab sample collected at PL18. Note that the y-axis represents a logarithmic scale of ion concentrations.

Left to Right: Samplers David Trew, Walt Neilson, Dave Mussell, and Dr. Brian Smerdon. 2022.

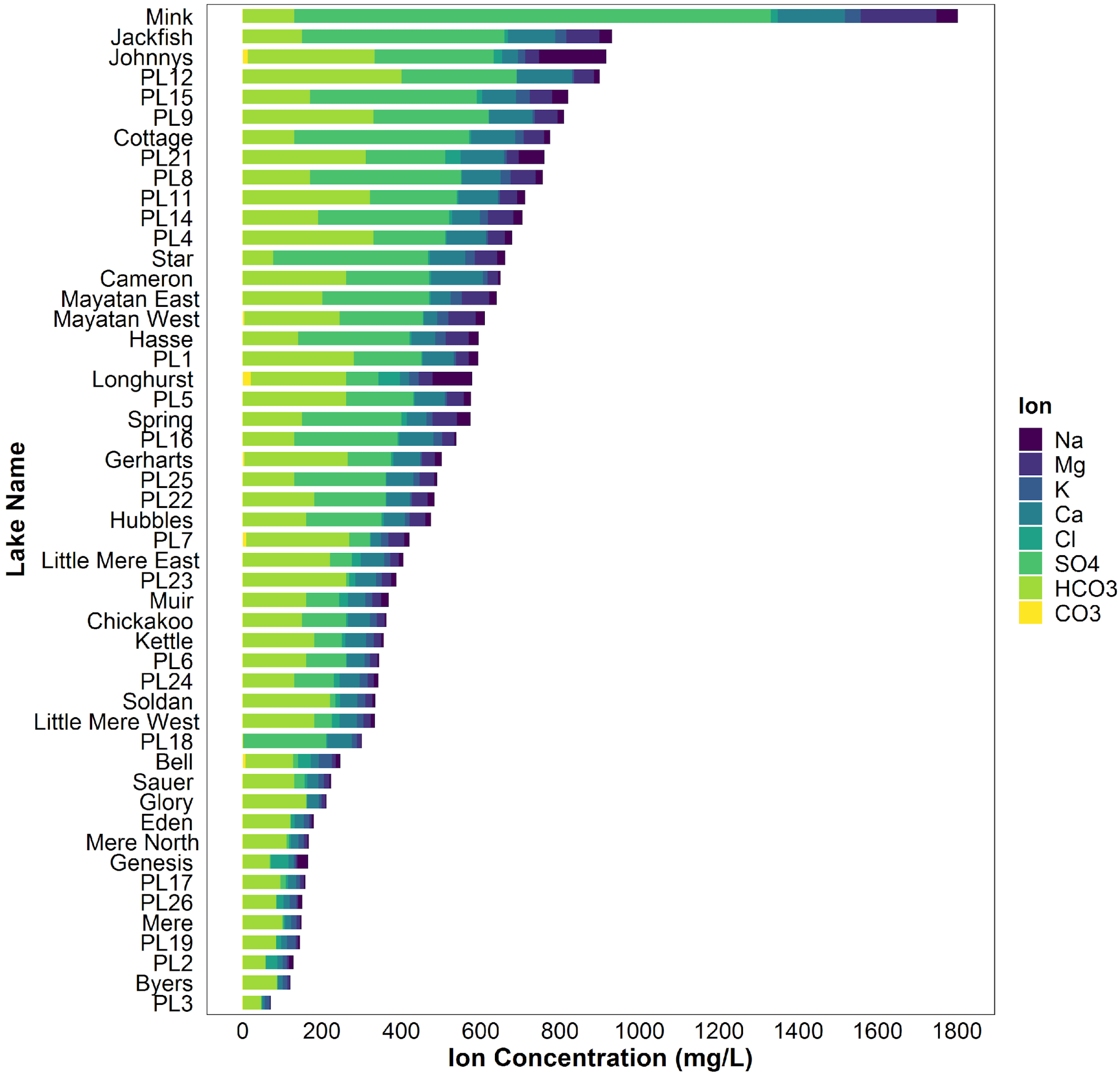


Figure 17. The distribution of major ions, presented as a stacked bar graph (mg/L) from composite samples collected at 49 lakes between August 9th and October 17th, 2022. A grab sample was taken from the shore at PL18.

Conductivity

Conductivity is a measure of the capacity of water to conduct an electrical current and is used as an indicator of the major ion content of lake water. Lakes with higher concentrations of major ions tend to have higher conductivities than lakes with lower concentrations of major ions. Conductivity was measured using two methods: in composite samples collected from the surface water layer and returned to the analytical lab, and as *in situ* vertical profiles using the YSI probe. Conductivity values measured in the lab ranged from 91 µS/cm at PL3 to 2200 µS/cm at Mink Lake (Figure 18). When visualized on the regional map, clustering is again evident (Figure 19). Lakes in the northern region generally have lower conductivities than lakes in the southern region. However, within the northern region, the distinct cluster of oligotrophic lakes demonstrated higher conductivities compared to most other lakes in this region.

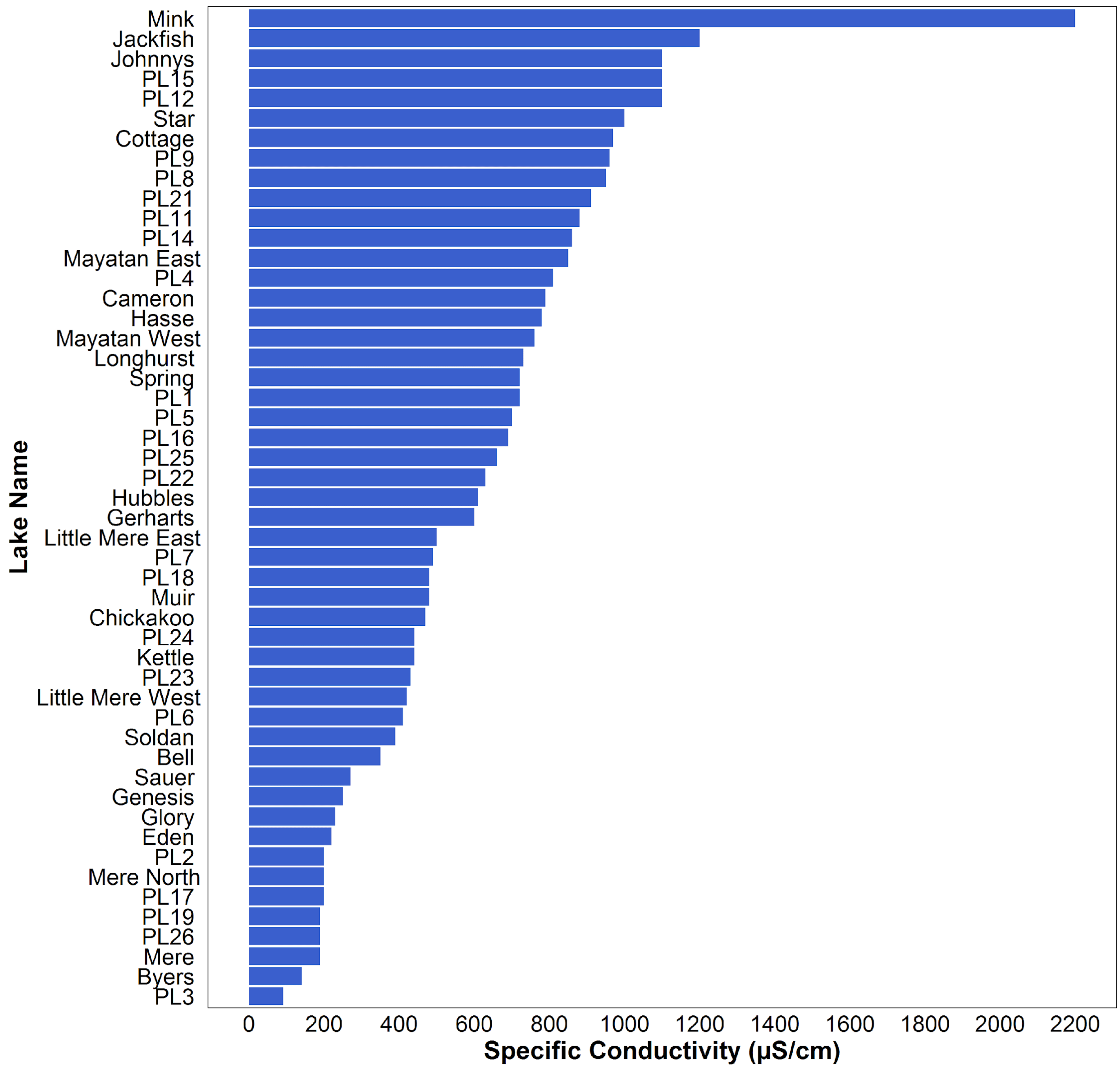


Figure 18. Conductivity (µS/cm) measured from composite samples collected from 49 lakes between August 9th and October 17th, 2022. A grab sample was taken from shore at PL18.

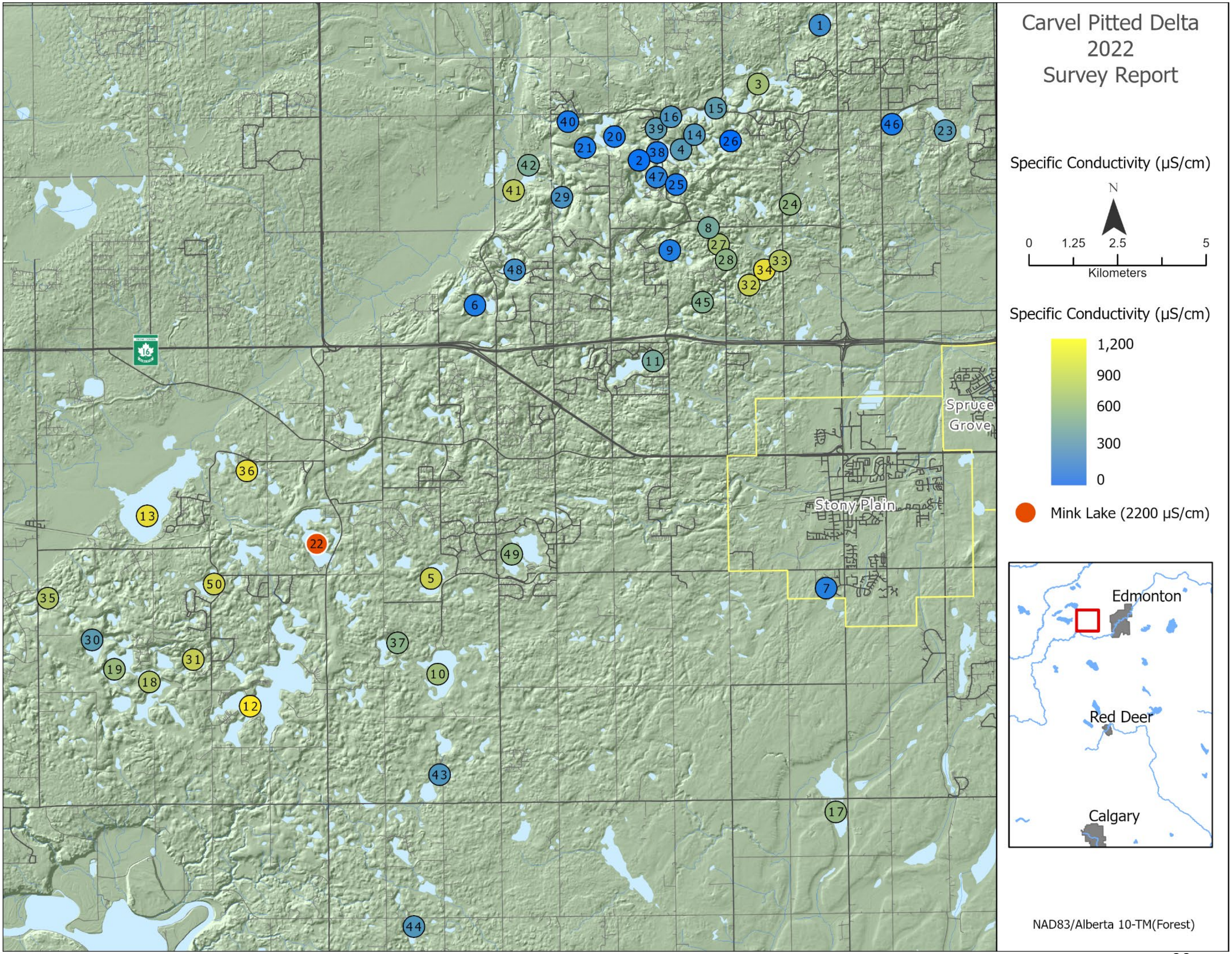


Figure 19. Conductivity values for 50 lakes in the Carvel Pitted Delta region. Conductivity values range from 91 µS/cm at PL3 to 2200 µS/cm at Mink Lake. See Figure 1 for a description of lake labels and names.

Based on the *in situ* profile measurements, the lakes again displayed a wide range of conductivities and vertical patterns. Conductivity values remained fairly consistent from the surface to the bottom in shallow lakes (Figure 20). The highest conductivity values were often seen at the bottom of the deeper lakes, where a combination of thermal stratification, decomposition processes, anoxia at the sediment water-interface and groundwater inflows may all influence ionic content. This pattern can be observed in several of the oligotrophic lakes of the northern region (Gerharts, PL4, PL5, PL9) as well as PL21 and PL22. Certain deep lakes showed more uniform patterns, however they were sampled later in the season when thermal stratification was somewhat weakened (Hubbles, Kettle).

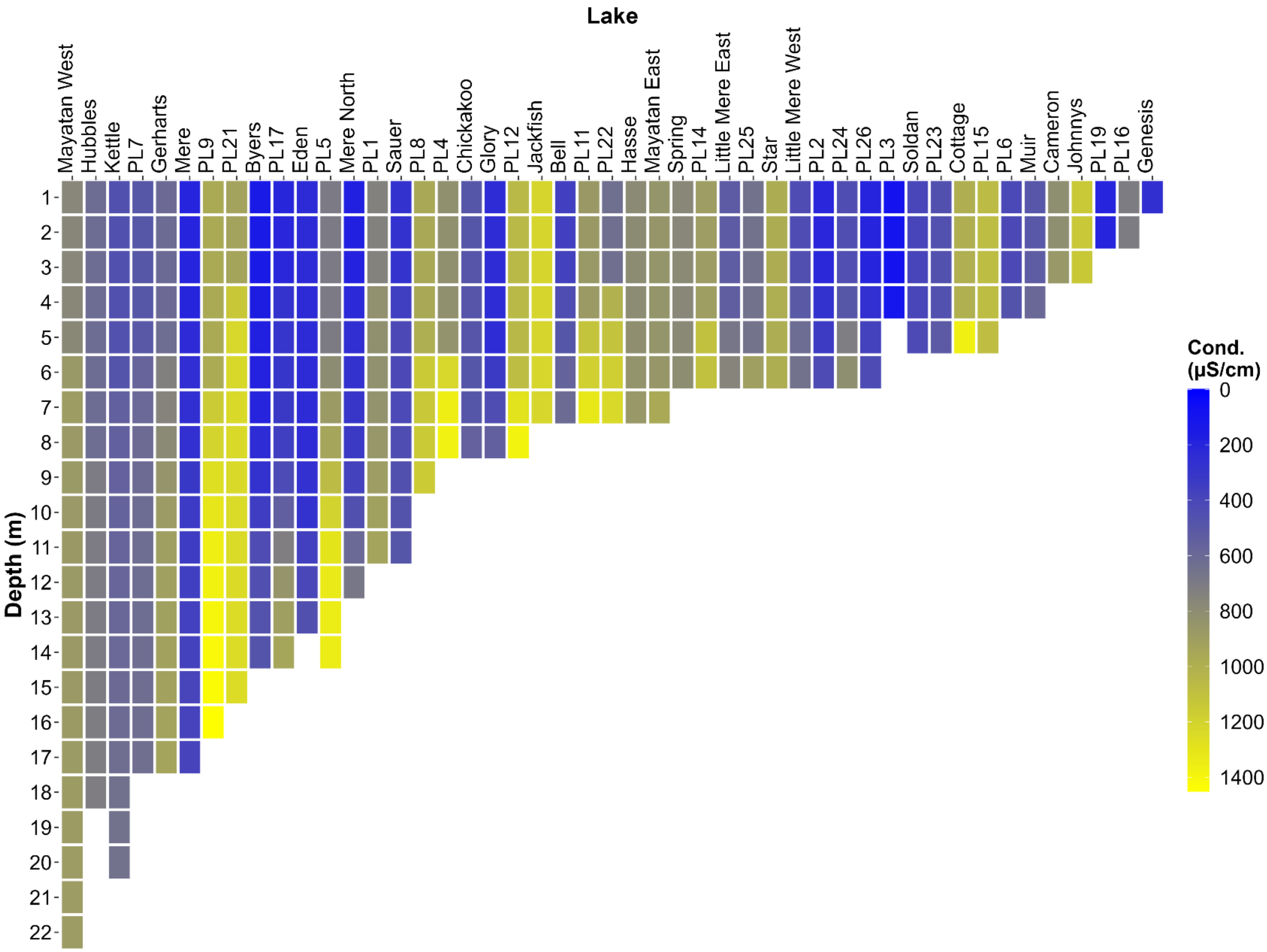


Figure 20. Conductivity (µS/cm) profiles for 47 lakes sampled between August 9th and October 17th, 2022. Coloured boxes reflect the conductivity measurements at each specific depth. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1 m depth for visual purposes. Mink Lake has been excluded from this figure due its high conductivity values. Profiles were not taken at Longhurst Lake and PL18.

Groundwater

Stable isotopes of oxygen and hydrogen may be used to describe the movement of water into and out of lakes.[16] Heavier isotopes tend to remain in the liquid phase, while lighter isotopes tend to move into the gaseous phase. These characteristics are useful to trace the movement of water molecules through the hydrologic cycle. For example, as a lake experiences evaporation, heavier isotopes (e.g. oxygen-18) tend to remain in the lake, while lighter isotopes (e.g. oxygen-16) tend to evaporate.

During 2021 and 2022, each of the lakes was sampled for the stable isotopes of water. Samples were submitted to Dr. Brian Smerdon at the University of Alberta for analysis. These results will be used to estimate the throughflow index that describes the fraction of total water inflows that are lost by evaporation. These data and interpretation of results will help differentiate lakes that are dominated by precipitation and local runoff compared to lakes that may be more influenced by groundwater. These isotopic data will be further analyzed during 2023 and published in a future report.

The oxygen isotope ratio is denoted as $\delta^{18}O$ in parts per thousand (‰). In 2021, the oxygen isotope ratios varied from -5 to -15 ‰. The variation between each lake can be caused by differences in water sources and the effect of evaporation acting on the lake. When mapped, the spatial pattern reveals a grouping of isotope ratios that fall into 3 categories, where the less negative values (e.g., -5 ‰ $\delta^{18}O$) are lakes undergoing more evaporation than lakes with more negative values (e.g., -15 ‰ $\delta^{18}O$) (Figure 21). It is likely that the lakes with more negative values are better connected to a groundwater source. These preliminary results suggest that the oligotrophic lakes of the northeast are less evaporated and may have a more significant groundwater supply.

The tan coloured fens near PL1 as seen from a drone. Photo supplied by Mike Myshak.

[16] Gibson, J. J., S. J. Birks, and Y. Yi. 2016a. "Stable isotope mass balance of lakes: a contemporary perspective." Quaternary Science Reviews 131: 316-328. doi:10.1016/j.quascirev.2015.04.013

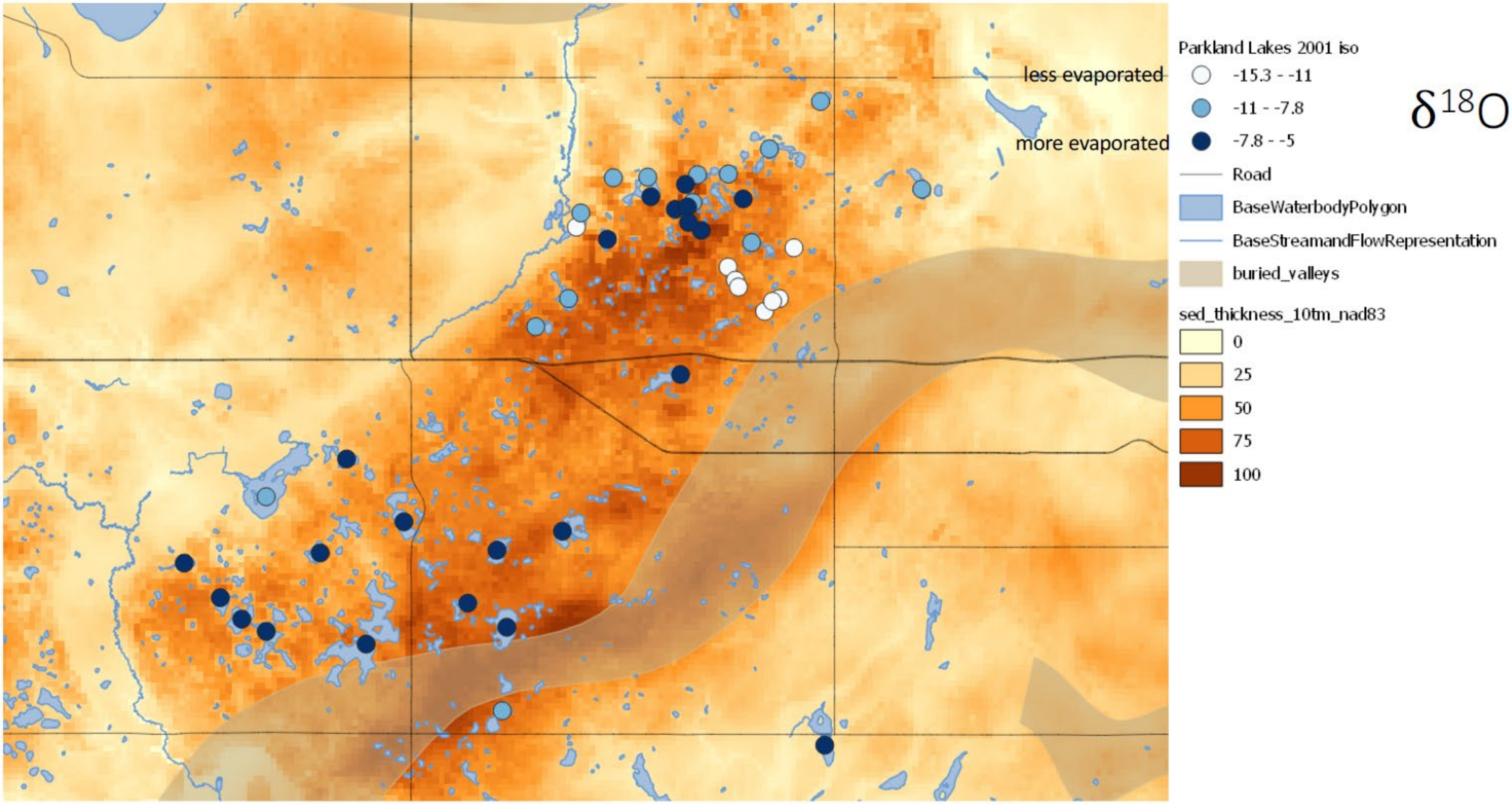


Figure 21. The oxygen isotope ratio ($\delta^{18}O$) in parts per thousand (‰) for lakes sampled in the Carvel Pitted Delta during the 2021 sampling season.

Aquatic Invasive Species

Aquatic invasive species (AIS) pose a threat to the health of Alberta's lakes. AIS represent non-native species that cause harm when introduced into environments outside of their natural range. AIS spread rapidly in new environments where natural predators are absent, and can outcompete native species. Aquatic invasive species can be transmitted from one waterbody to another via recreational activities such as boating, fishing or paddling. The early detection of AIS is critical for a rapid response and a successful management plan.

In 2022, samples were collected from 49 lakes in the Carvel Pitted Delta and submitted to Alberta Environment and Protected Areas for the analysis of three invasive species: the zebra mussel (*Dreissena polymorpha),* the quagga mussel *(Dreissena rostriformis)* and the spiny waterflea (*Bythotrephes longimanus)*.

The results were very encouraging: none of these aquatic invasive species were detected in any of the 49 lakes sampled.

Beds of Chara spp. near the shores of Gerharts Lake. Photo by David Trew, 2022.

Summary

The Carvel Pitted Delta region contains many beautiful small lakes which span an unusually wide range of physical attributes, chemistries and trophic conditions. The region includes deep lakes with low productivities and clear waters, as well as shallow lakes with high nutrient levels and significant amounts of phytoplankton. The results of these surveys clearly suggest that a multitude of natural and human factors are influencing lake water quality over relatively short distances. From a hydrologic perspective this region also constitutes a unique lake assemblage and is positioned within a diverse hydrogeological setting.

The funding partners supported these water quality surveys to initiate the development of an improved information base to support future land and water management discussions, and to encourage local conservation and stewardship activities.

Future Plans

The scope of work planned for the summer and fall of 2023 builds on that of the two previous years to achieve a more complete geographic picture of the hydrology and water quality of the lakes in the study area. The first priority for 2023 is to gather new or updated water chemistry, biological and bathymetric data for some 20 additional lakes, including several lakes previously surveyed by RL&L in 1986, and which have not been sampled since. This will yield a body of scientifically consistent information for a population of approximately 70 lakes in the study area. The second priority for 2023 is to explore and identify watershed information describing the conditions of uplands, wetlands and riparian areas surrounding the lakes in the study area, and to identify organizations that may be able to fill in gaps in that information. The third priority for 2023 is to draw from the collected information to develop new communication and educational resources intended for local landowners, the general public and decision-makers with Parkland County and the Government of Alberta.

Autumn colours at Cameron Lake. Photograph by David Trew, 2022.

Acknowledgements

The MLMA undertook initial project and funding development, and community outreach for this project. ALMS provided advice and guidance for the design of the survey, provided field equipment, facilitated laboratory analysis and undertook data management. Funding was provided by the Alberta Lake Management Society (ALMS), the Land Stewardship Centre of Canada (LSCC), the North Saskatchewan Watershed Alliance (NSWA), Parkland County and the Stony Plain Fish and Game Association (SPFGA). Boats and vehicles were supplied by MLMA volunteers. David Trew, Walter Neilson and Dave Mussell conducted most of the field work and provided other in-kind support for the study. Dr. Brian Smerdon and Dr. Dan Alessi, University of Alberta, conducted the lake water isotope components of the study, metals analyses, and assisted in the field. Dr. Steve Craik provided detailed data assistance in 2021/22. Sal Figliuzzi, P. Eng., provided hydrologic advice and evaluated the lake level data. Dr. Craig Emmerton provided the prototype bathymetric data analysis for Bell Lake, which will be applied to the other lakes. We also acknowledge sampling and data assistance provided by Jeremy Plonkowski. We acknowledge the assistance of Brad Tyssen of the NSWA for the preparation of the maps in this report and the assistance of Eric Neilson in the preparation of the detailed regional map which has been utilized in many public briefings. We acknowledge Pauline Molnar of Invert Solutions for her support on invasive species sampling and analysis. Photograph enhancements were provided by Rocco Macri at Macri Photography. The cooperation of 31 individual landowners who enabled access to many of these lakes is gratefully acknowledged.

This report was prepared by Bradley Peter (ALMS), David Trew (MLMA), Caleb Sinn (ALMS), Dave Mussell (MLMA) and Walter Neilson (MLMA).

Floating leaves of variegated pond lily at PL1. Photograph taken by David Trew, 2022.

Appendix

Appendix Table 1. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 50 lakes sampled in the Carvel Pitted Delta region.

Variable Name	Bell	Byers	Cameron	Chickako o	Cottage	Eden	Genesis	Gerharts	Glory	Hasse
Sample Date	5-Sep-22	9-Aug-22	5-Sep-22	22-Aug-22	13-Sep-22	17-Oct-22	6-Sep-22	29-Aug-22	22-Sep-22	24-Aug-22
Ca (mg/L)	21	13	130	56	110	22	13	68	30	60
Chl-*a* (µg/L)	23.6	2.4	2.7	4.0	28.2	5.0	6.4	1.4	1.1	13.7
Cl^- (mg/L)	31	<1	5.1	4.7	5.9	10	44	5.6	<1	5.3
CO_3^{2-} (mg/L)	7.4	<1	<1	<1	<1	<1	<1	4.3	<1	<1
Cond. (µS/cm)	350	140	790	470	970	220	250	600	230	780
DOC (mg/L)	1.6	15	30	22	24	8.2	27	8.8	11	17
Hardness (mg/L)	95	56	440	220	490	81	48	300	110	390
HCO_3^- (mg/L)	120	87	260	150	130	120	68	260	160	140
K^+ (mg/L)	33	12	12	17	22	14	5.4	4	6.9	26
Mg^{2+} (mg/L)	10	5.6	26	20	51	6.4	3.7	33	9.3	58
Microcystin (µg/L)	8.27	<0.1	0.14	0.56	1.6	<0.1	0.96	<0.1	<0.1	1.68
Na^+ (mg/L)	12	1.5	6.0	5.1	16	5.4	27	18	3.3	26
NH3-N (µg/L)	<15	<15	230	150	210	<15	18	<15	170	16
NO_3+NO_2 (µg/L)	14	15	24	4.3	5	<4.2	15	<4.2	41	4.9
Max. Obs. Depth (m)	7.7	15.2	4.0	8.5	5.2	14.3	1.9	17.5	8.2	7.5
Secchi Depth (m)	1.8	4.0	2.75	4.0	1.25	4.25	1.75	6.2	4.0	1.25
SO_4^{2-} (mg/L)	13	<1	210	110	440	1.6	3.5	110	1.4	280
TDP (µg/L)	27	<3	370	260	22	<3	95	<3	4.7	11
TDS (mg/L)	190	76	540	290	720	120	130	390	140	530
TKN (mg/L)	2.8	1.2	3.0	2.2	2.8	0.72	0.95	0.43	1.0	1.6
Total Alkalinity (mg/L)	110	71	210	120	110	98	55	220	130	120
TP (µg/L)	100	7.8	410	290	53	7.7	98	4.3	8.5	36
TP Bottom (µg/L)	1300	3900	2300	280	47	170	<3	670	<30	430
Surface Area (ha)	14.3	8.3	46.6	18.5	33	20.5	2.43	8.0	9.9	84.8

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 50 lakes sampled in the Carvel Pitted Delta region.

Variable Name	Hubbles	Jackfish	Johnnys	Kettle	Little Mere East	Little Mere West	Longhurst	Mayatan East	Mayatan West	Mere
Sample Date	11-Oct-22	14-Sep-22	12-Sep-22	12-Oct-22	18-Aug-22	18-Aug-22	25-Aug-22	11-Aug-22	11-Aug-22	19-Aug-22
Ca (mg/L)	53	120	39	53	59	43	23	51	34	16
Chl-*a* (µg/L)	2.0	16.8	117	9.1	27.3	38.1	8.3	3.7	2.2	1.9
Cl^- (mg/L)	5.1	7.5	22	8.7	22	19	55	2.9	1.9	3.8
CO_3^{2-} (mg/L)	<1	<1	13	<1	<1	<1	21	<1	4.6	<1
Cond. (µS/cm)	610	1200	1100	440	500	420	730	850	760	190
DOC (mg/L)	6.9	15	49	13	24	20	45	17	16	13
Hardness (mg/L)	300	640	240	210	230	190	200	410	370	77
HCO_3^- (mg/L)	160	150	320	180	220	180	240	200	240	100
K^+ (mg/L)	12	28	18	19	16	17	24	29	28	14
Mg^{2+} (mg/L)	40	83	35	18	21	19	35	68	69	8.8
Microcystin (µg/L)	0.13	0.26	2.07	<0.1	0.43	<0.1	<0.1	<0.1	<0.1	<0.1
Na^+ (mg/L)	15	32	170	6.4	12	10	100	19	23	2.9
NH3-N (µg/L)	29	25	66	470	<15	<15	<15	26	<15	<15
NO_3+NO_2 (µg/L)	<4.2	<4.2	<4.2	19	9.9	6.2	14	5.9	<4.2	22
Max. Obs. Depth (m)	21.5	8.0	3.7	21.3	6.9	6.5	1.0	7.5	22.5	17.5
Secchi Depth (m)	5.25	2.1	0.3	1.5	1.0	1.5	>1	4.0	5.0	4.5
SO_4^{2-} (mg/L)	190	510	300	70	55	45	81	270	210	2.6
TDP (µg/L)	6.1	8.6	34	12	68	22	18	3.3	3.1	<3
TDS (mg/L)	390	860	780	260	300	240	460	540	490	100
TKN (mg/L)	0.88	1.6	4.2	2.3	2.2	2.4	3.1	1.5	1.1	0.97
Total Alkalinity (mg/L)	130	130	280	150	180	150	230	160	210	86
TP (µg/L)	12	31	180	30	110	52	45	13	4.4	6.1
TP Bottom (µg/L)	290	22	160	2100	1700	760	<3	80	250	510
Surface Area (ha)	42.4	281.0	244.4	15.0	19.7	10.8	32.8	72.7	52.5	35.2

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 50 lakes sampled in the Carvel Pitted Delta region.

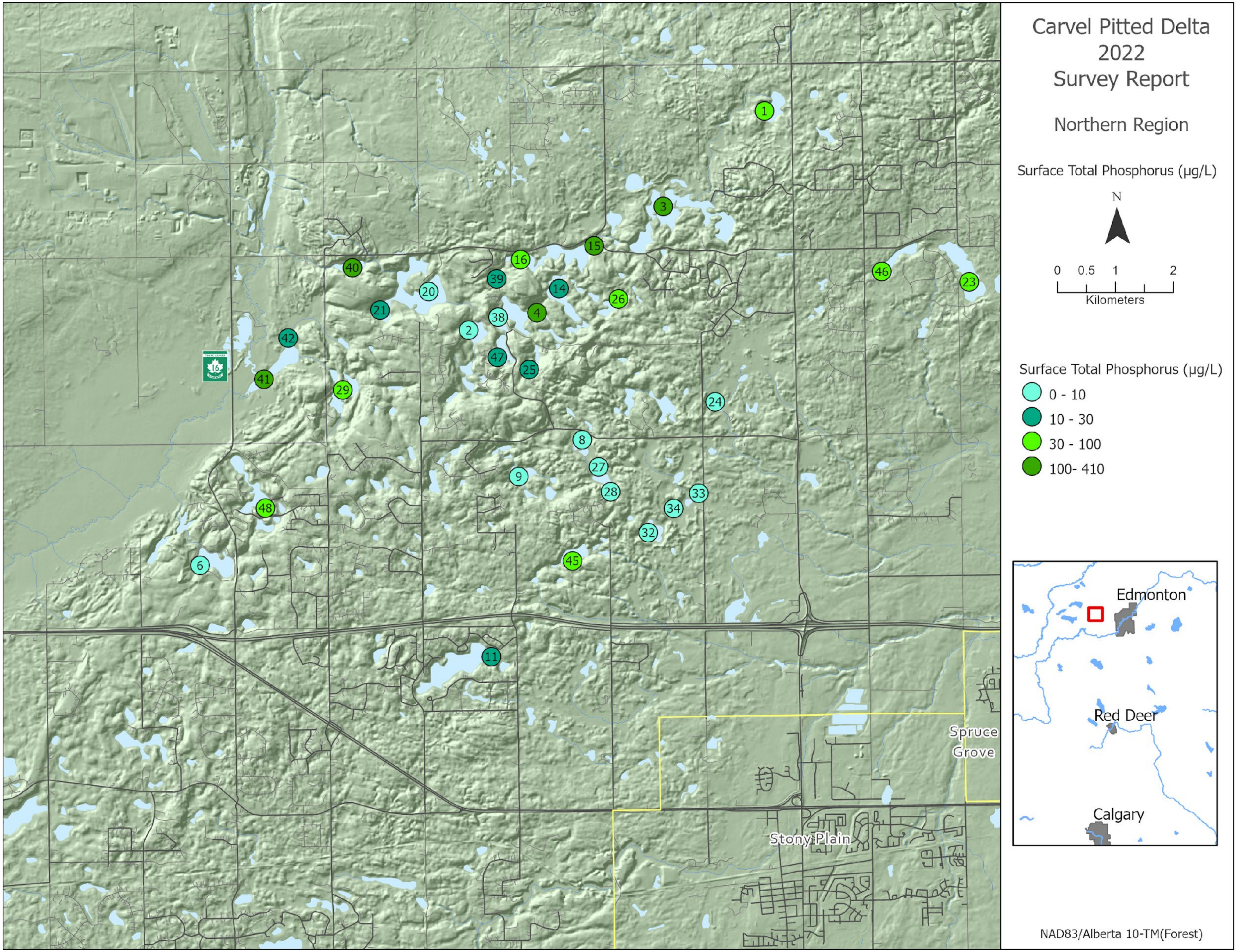
Variable Name	Mere North	Mink	Muir	PL1	PL2	PL3	PL4	PL5	PL6	PL7
Sample Date	22-Aug-22	15-Aug-22	23-Aug-22	29-Aug-22	30-Aug-22	3-Oct-22	23-Sep-22	23-Sep-22	3-Oct-22	16-Sep-22
Ca (mg/L)	20	170	43	79	13	6	100	76	44	25
Chl-*a* (µg/L)	7.7	35.6	30.6	1.4	9.7	23.9	3.3	2.3	31.4	4.1
Cl^- (mg/L)	4.0	18	23	2.9	29	1.7	3.5	3.2	2.3	1.6
CO_3^{2-} (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	8.9
Cond. (µS/cm)	200	2200	480	720	200	91	810	700	410	490
DOC (mg/L)	21	16	23	16	17	13	7.7	8.4	17	16
Hardness (mg/L)	85	1200	200	330	52	25	430	370	190	230
HCO_3^- (mg/L)	110	130	160	280	58	47	330	260	160	260
K^+ (mg/L)	14	40	18	5.5	11	12	4.4	4.6	14	19
Mg^{2+} (mg/L)	8.8	190	22	32	4.5	2.5	43	43	19	40
Microcystin (µg/L)	<0.1	0.23	0.17	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1
Na^+ (mg/L)	3.1	54	19	25	12	0.75	18	19	4.9	13
NH3-N (µg/L)	<15	<15	<15	34	<15	49	27	47	71	43
NO_3+NO_2 (µg/L)	<4.2	<4.2	<4.2	56	<4.2	<4.2	<4.2	<4.2	<4.2	<4.2
Max. Obs. Depth (m)	13.3	6.5	4.4	11.8	6.4	6.0	9.1	14.2	4.8	17.6
Secchi Depth (m)	3.25	0.8	0.8	4.9	2.2	1.25	3.5	4.0	1.0	3.0
SO_4^{2-} (mg/L)	6.8	1200	83	170	<1	<1	180	170	100	53
TDP (µg/L)	5.6	<3	3.8	3.4	10	49	3.2	<3	21	4.6
TDS (mg/L)	110	1700	290	470	98	47	540	470	260	290
TKN (mg/L)	1.3	1.3	1.9	0.98	1.4	1.8	0.78	0.81	2.1	1.3
Total Alkalinity (mg/L)	87	110	130	230	48	39	270	210	130	230
TP (µg/L)	17	40	53	10	28	43	6.7	4.6	53	12
TP Bottom (µg/L)	2400	57	74	1300	240	88	270	470	1000	230
Surface Area (ha)	11.5	74.4	29.9	4.3	5.2	7.1	2.0	4.2	14.2	24.9

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 50 lakes sampled in the Carvel Pitted Delta region.

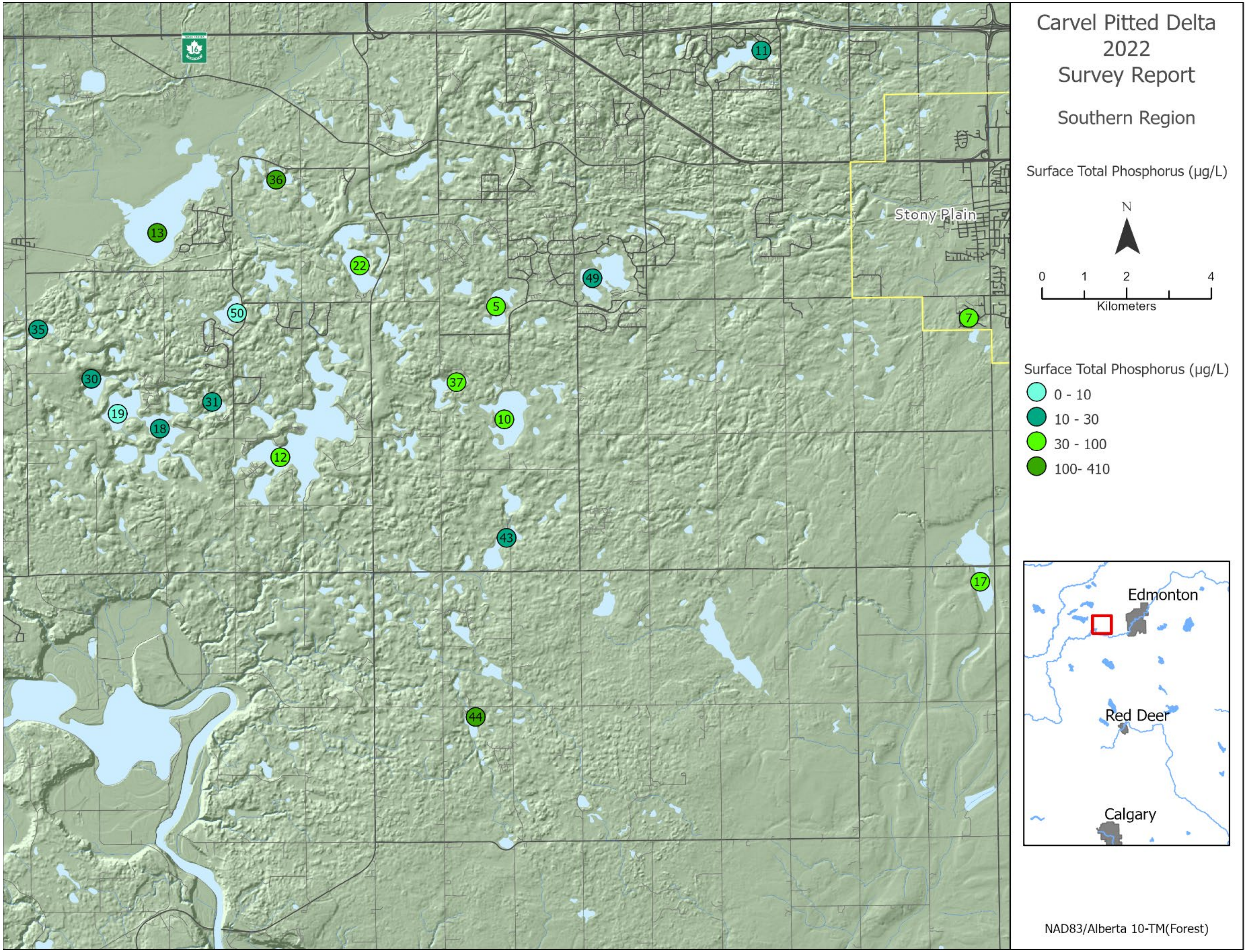
Variable Name	PL8	PL9	PL11	PL12	PL14	PL15	PL16	PL17	PL18	PL19
Sample Date	20-Sep-22	6-Oct-22	7-Oct-22	7-Oct-22	7-Sep-22	12-Sep-22	13-Sep-22	10-Aug-22	10-Oct-22	11-Oct-22
Ca (mg/L)	97	110	100	140	70	86	86	20	62	15
Chl-*a* (µg/L)	6.8	3.8	1.6	1.3	7.8	117	29.2	1.6	8.6	29.6
Cl^- (mg/L)	2.2	<1	3.2	<1	7.4	13	4.7	5.7	2.8	12
CO_3^{2-} (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cond. (µS/cm)	950	960	880	1100	860	1100	690	200	480	190
DOC (mg/L)	19	6.7	9.1	8.0	21	32	21	16	3.1	11
Hardness (mg/L)	500	520	430	560	430	450	340	87	200	59
HCO_3^- (mg/L)	170	330	320	400	190	170	130	95	<1	84
K^+ (mg/L)	26	5.3	4.7	5.0	21	34	22	10	12	22
Mg^{2+} (mg/L)	63	57	43	49	63	56	30	8.8	11	5.3
Microcystin (µg/L)	<0.1	<0.1	<0.1	<0.1	0.11	0.1	<0.1	0.14	<0.1	<0.1
Na^+ (mg/L)	18	17	21	15	24	41	6.4	4.2	2.2	5.9
NH3-N (µg/L)	39	51	33	140	<15	310	45	<15	920	30
NO_3+NO_2 (µg/L)	<4.2	8.1	<4.2	27	5.9	5.8	<4.2	9.1	<4.2	<4.2
Max. Obs. Depth (m)	9.8	16.2	7.7	8.2	7.0	5.2	2.6	14.8	NA	2.7
Secchi Depth (m)	2.0	4.1	5.0	6.5	2.0	0.6	0.9	4.3	NA	0.75
SO_4^{2-} (mg/L)	380	290	220	290	330	420	260	14	210	<1
TDP (µg/L)	12	<3	3.5	<3	12	59	24	4.8	<3	58
TDS (mg/L)	670	670	580	730	610	750	490	110	310	100
TKN (mg/L)	2.0	0.53	0.66	0.66	1.8	3.6	1.9	1.4	1.4	2.2
Total Alkalinity (mg/L)	140	270	260	330	160	140	110	78	<1	69
TP (µg/L)	23	<3	6.6	<3	16	200	47	8.4	13	150
TP Bottom (µg/L)	260	1300	1300	<15	370	160	51	6600	NA	160
Surface Area (ha)	15.3	6.8	1.3	1.1	12.1	23.7	22.9	3.4	0.3	6.5

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 50 lakes sampled in the Carvel Pitted Delta region.

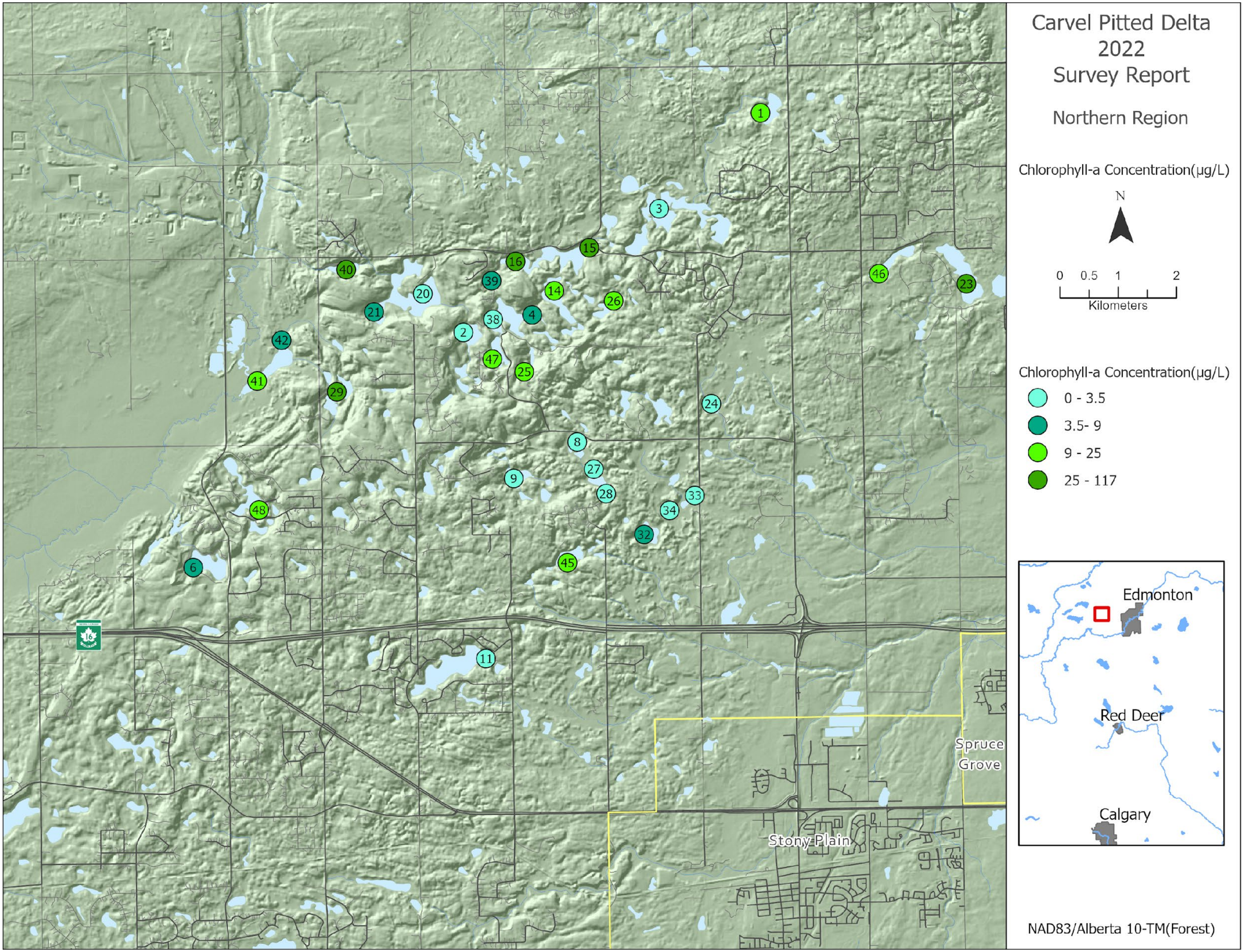
Variable Name	PL21	PL22	PL23	PL24	PL25	PL26	Sauer	Soldan	Spring	Star
Sample Date	9-Sep-22	9-Sep-22	25-Aug-22	14-Sep-22	22-Sep-22	30-Sep-22	10-Aug-22	26-Sep-22	24-Aug-22	15-Aug-22
Ca (mg/L)	110	59	52	51	68	15	27	44	50	89
Chl-*a* (µg/L)	11.1	4.9	6.2	57.5	13.5	21.4	14.5	14.7	4.2	1.9
Cl^- (mg/L)	39	2.4	16	14	2.3	18	7.5	11	13	4.7
CO_3^{2-} (mg/L)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cond. (µS/cm)	910	630	430	440	660	190	270	390	720	1000
DOC (mg/L)	11	23	16	25	18	21	20	16	16	17
Hardness (mg/L)	390	310	230	200	320	55	120	180	380	450
HCO_3^- (mg/L)	310	180	260	130	130	85	130	220	150	77
K^+ (mg/L)	6.2	4.6	14	20	16	17	14	20	16	25
Mg^{2+} (mg/L)	31	40	24	16	36	4.3	13	18	61	56
Microcystin (µg/L)	<0.1	<0.1	<0.1	13.51	0.11	<0.1	0.23	0.22	<0.1	<0.1
Na^+ (mg/L)	64	18	13	11	8	11	5.9	6.9	34	20
NH3-N (µg/L)	20	17	<15	95	110	20	<15	270	<15	<15
NO_3+NO_2 (µg/L)	<21	18	7	17	220	4.8	<4.2	7.1	<4.2	<4.2
Max. Obs. Depth (m)	15.5	7.7	5.3	6.3	6.7	6.2	11.5	6.0	7.2	6.7
Secchi Depth (m)	1.0	2.75	2.1	0.6	2.8	1.75	2.1	1.2	2.5	5.25
SO_4^{2-} (mg/L)	200	180	8.3	100	230	<1	26	14	250	390
TDP (µg/L)	130	10	<3	37	14	24	15	8.2	<3	<3
TDS (mg/L)	620	410	270	280	430	110	160	230	500	630
TKN (mg/L)	2.4	1.3	0.96	2.5	2.0	1.8	2.2	1.8	1.3	0.99
Total Alkalinity (mg/L)	250	150	210	110	110	70	100	180	120	63
TP (µg/L)	120	15	21	160	42	49	27	32	13	3.8
TP Bottom (µg/L)	610	1400	23	1300	46	330	1900	61	47	7.5
Surface Area (ha)	23.3	2.3	28	18.3	10.6	5.7	9.4	19.7	69.2	27.0



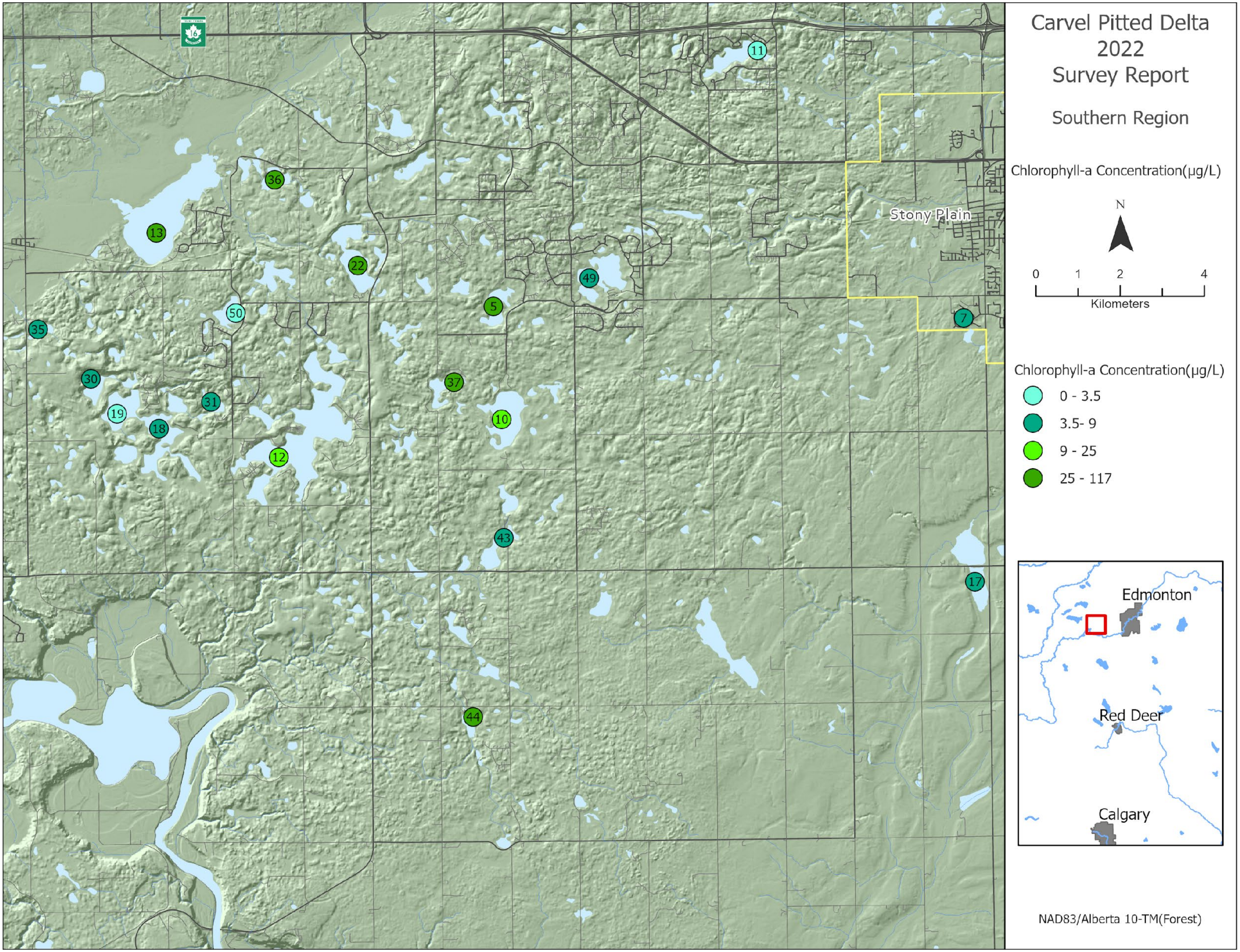
Appendix Figure 1. Total phosphorus concentrations sorted into trophic categories for each lake sampled in the northern region of the Carvel Pitted Delta. Different colours represent different trophic categories, from oligotrophic (0-10 µg/L), to mesotrophic (10-30 µg/L), to eutrophic (30-100 µg/L), to hypereutrophic (>100 µg/L). See Figure 1 for a description of lake labels and names.



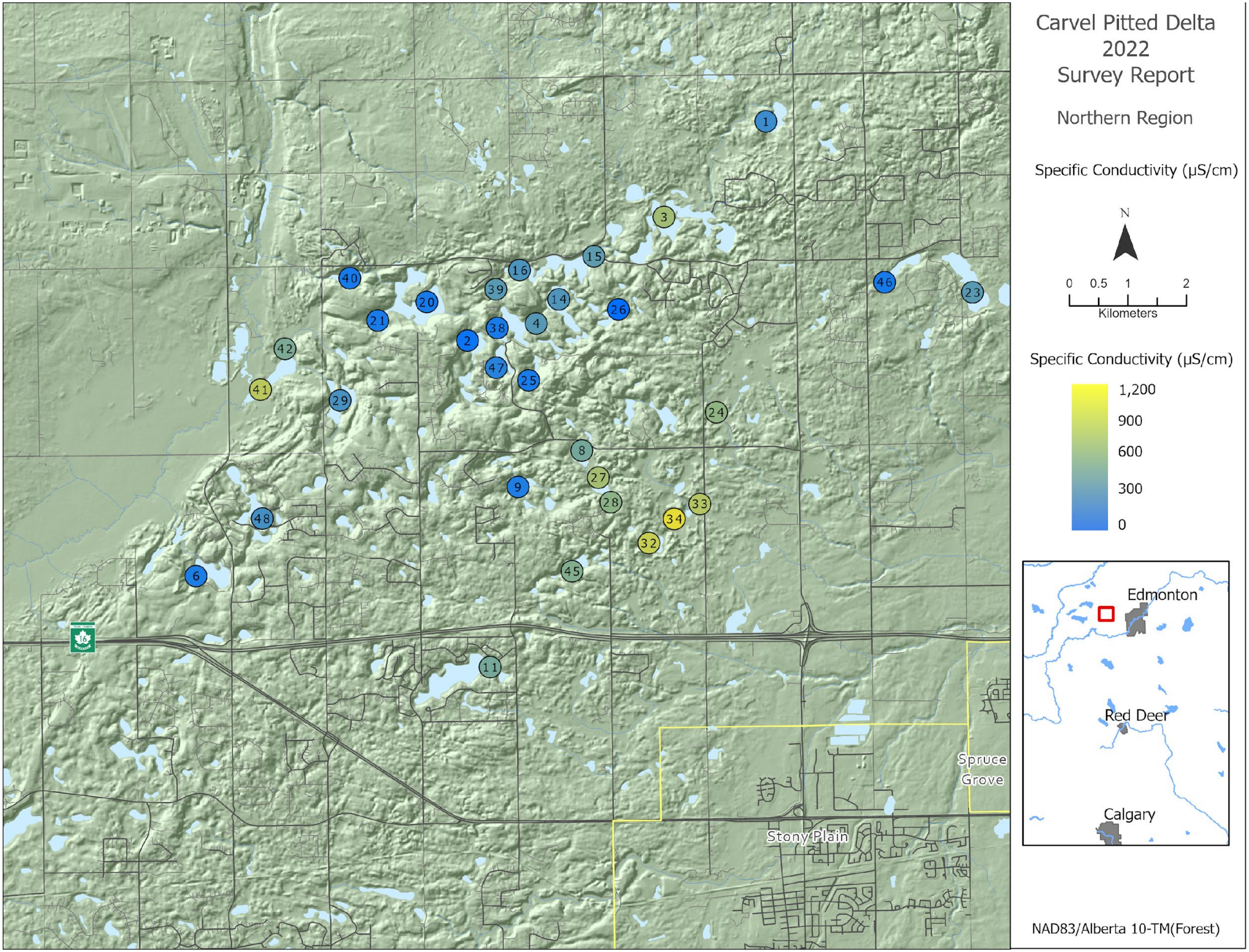
Appendix Figure 2. Total phosphorus concentrations sorted into trophic categories for each lake sampled in the southern region of the Carvel Pitted Delta. Different colours represent different trophic categories, from oligotrophic (0-10 µg/L), to mesotrophic (10-30 µg/L), to eutrophic (30-100 µg/L), to hypereutrophic (>100 µg/L). See Figure 1 for a description of lake labels and names.



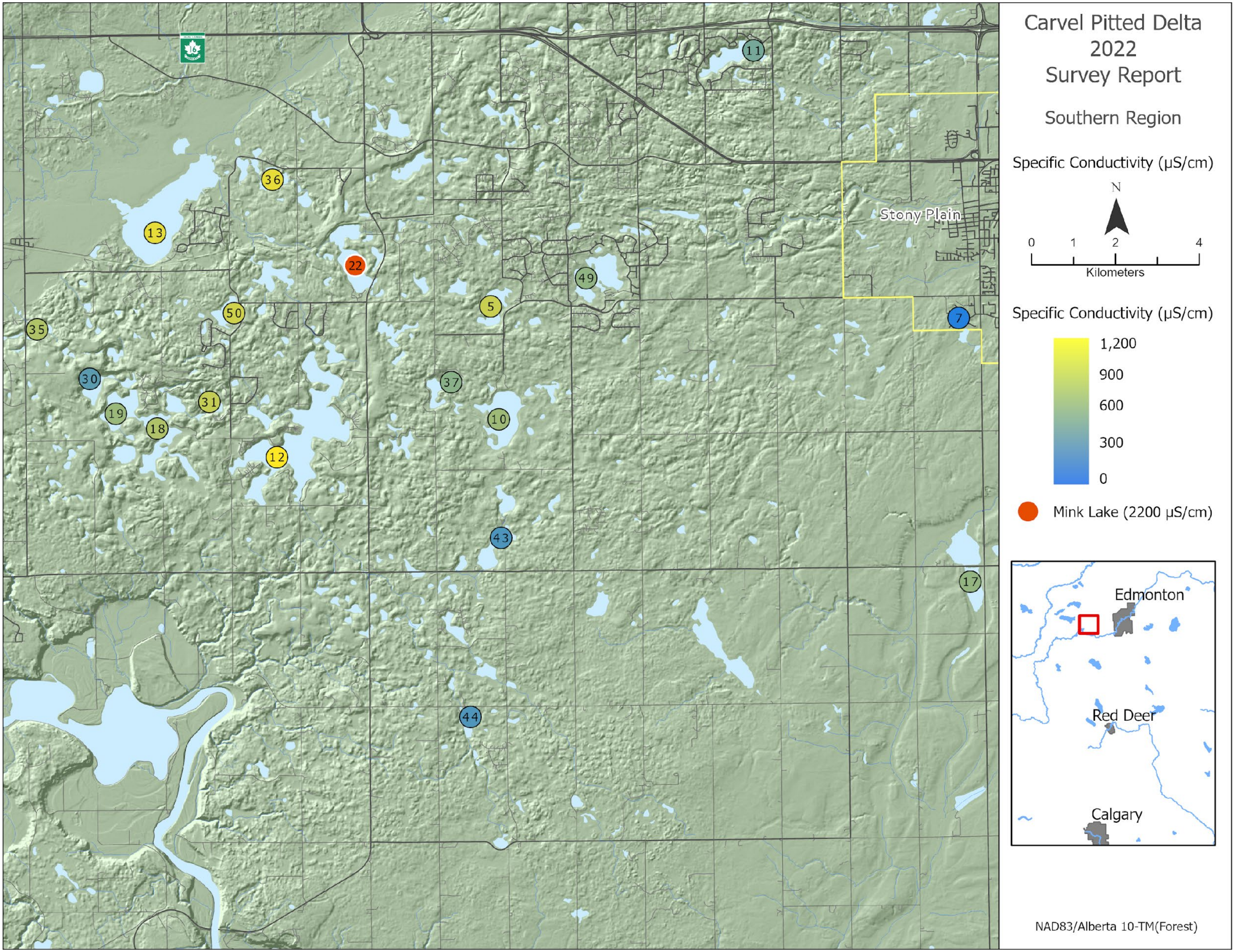
Appendix Figure 3. Chlorophyll-a concentrations (µg/L) sorted into trophic categories for each lake sampled in the northern region of the Carvel Pitted Delta. Different colours represent different trophic categories, from oligotrophic (0-3.5 µg/L), to mesotrophic (3.5-9 µg/L), to eutrophic (9 -25 µg/L), to hypereutrophic (>25 µg/L). See Figure 1 for a description of lake labels and names.



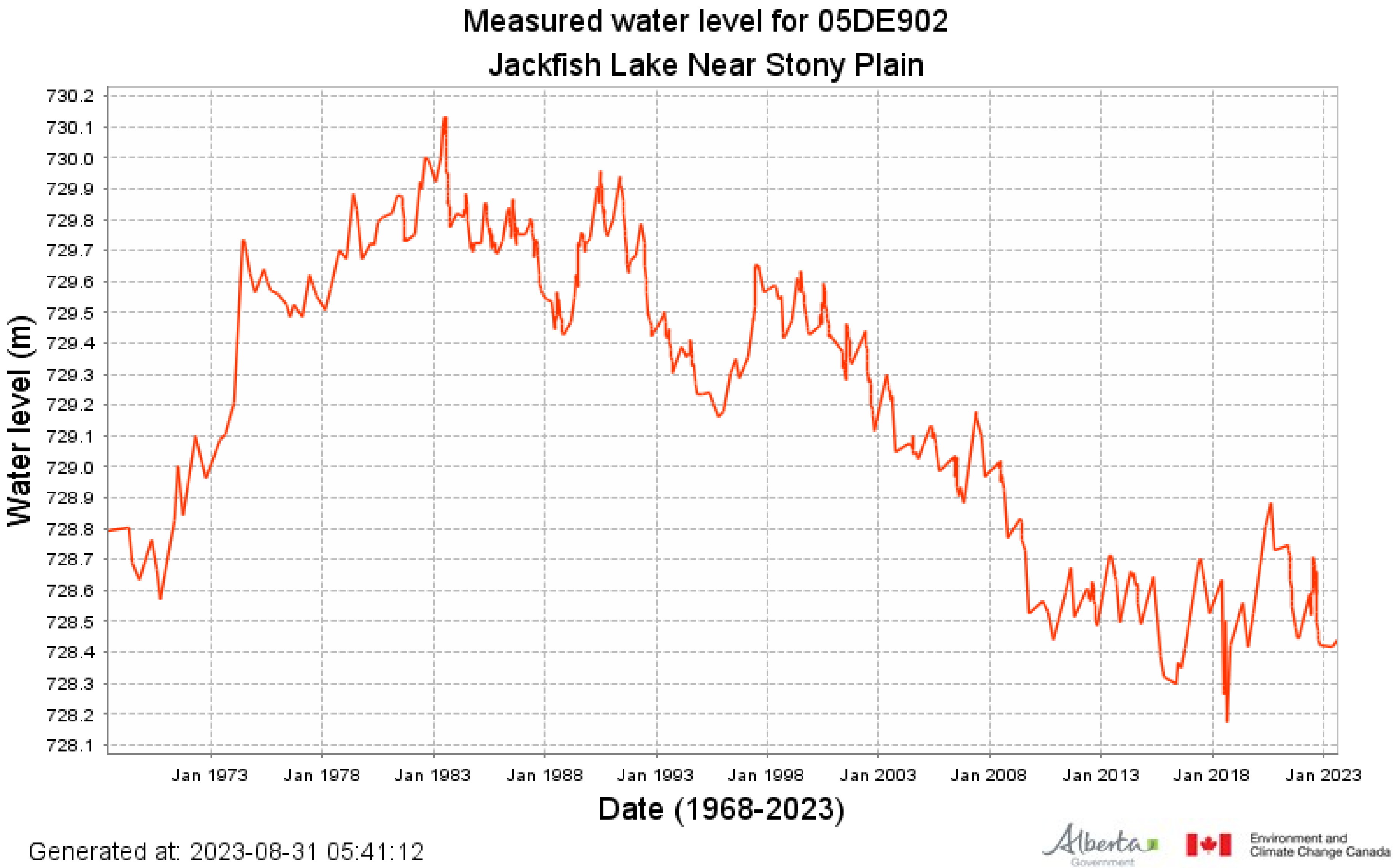
Appendix Figure 4. Chlorophyll-a concentrations (µg/L) sorted into trophic categories for each lake sampled in the southern region of the Carvel Pitted Delta. Different colours represent different trophic categories, from oligotrophic (0-3.5 µg/L), to mesotrophic (3.5-9 µg/L), to eutrophic (9 -25 µg/L), to hypereutrophic (>25 µg/L). See Figure 1 for a description of lake labels and names.



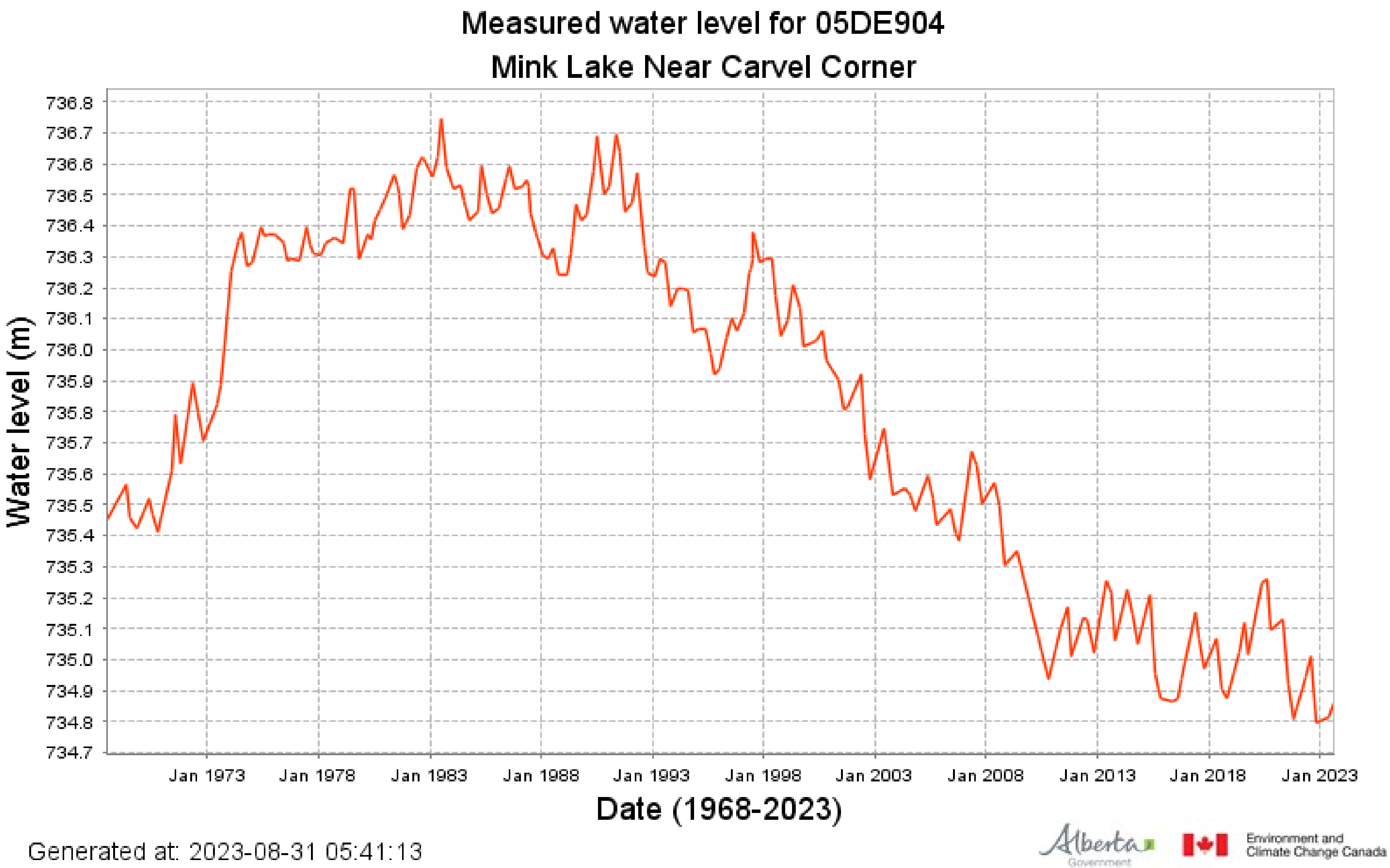
Appendix Figure 5. Conductivity values for lakes in the northern region of the Carvel Pitted Delta. See Figure 1 for a description of lake labels and names.



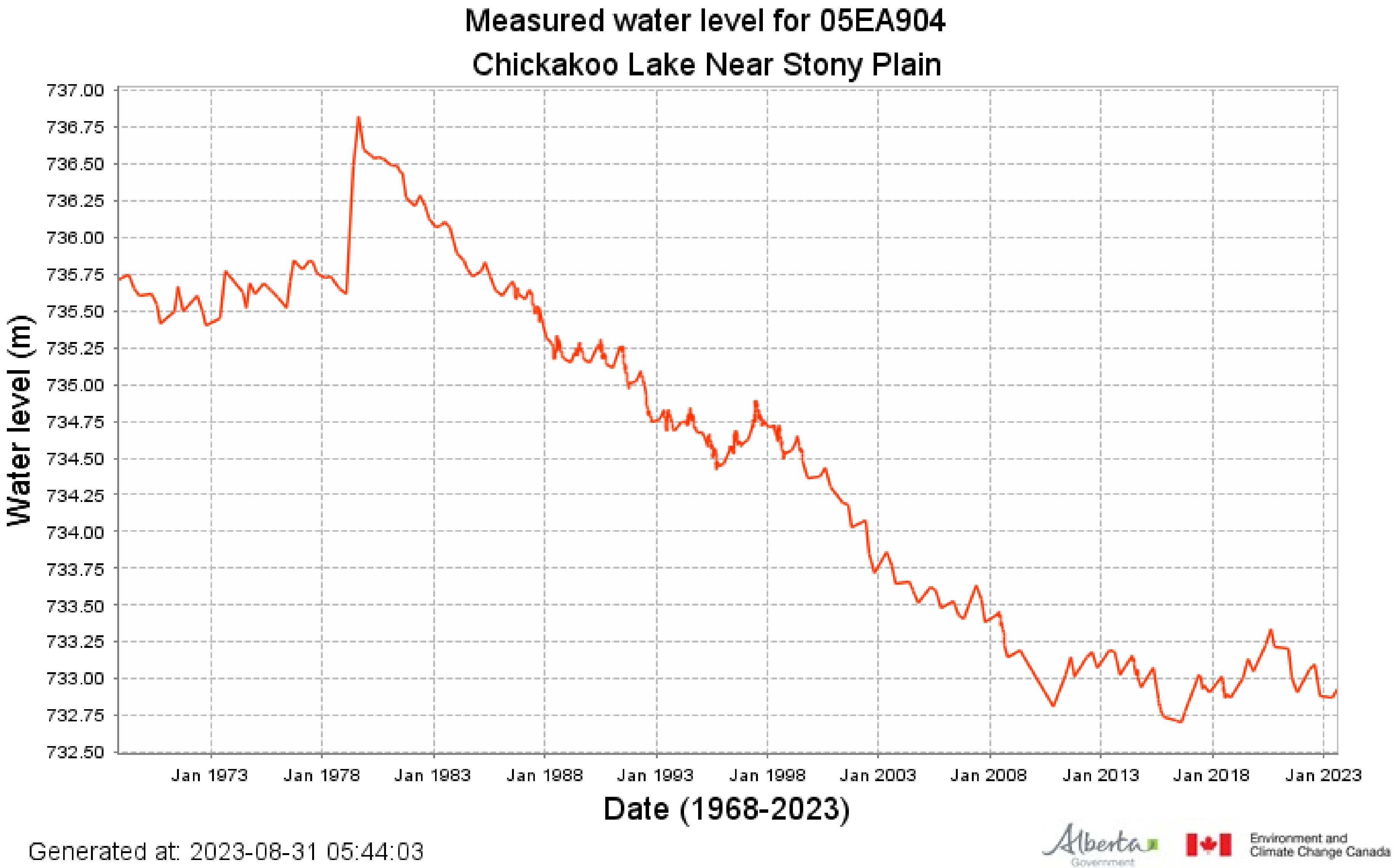
Appendix Figure 6. Conductivity values for lakes in the southern region of the Carvel Pitted Delta. See Figure 1 for a description of lake labels and names.



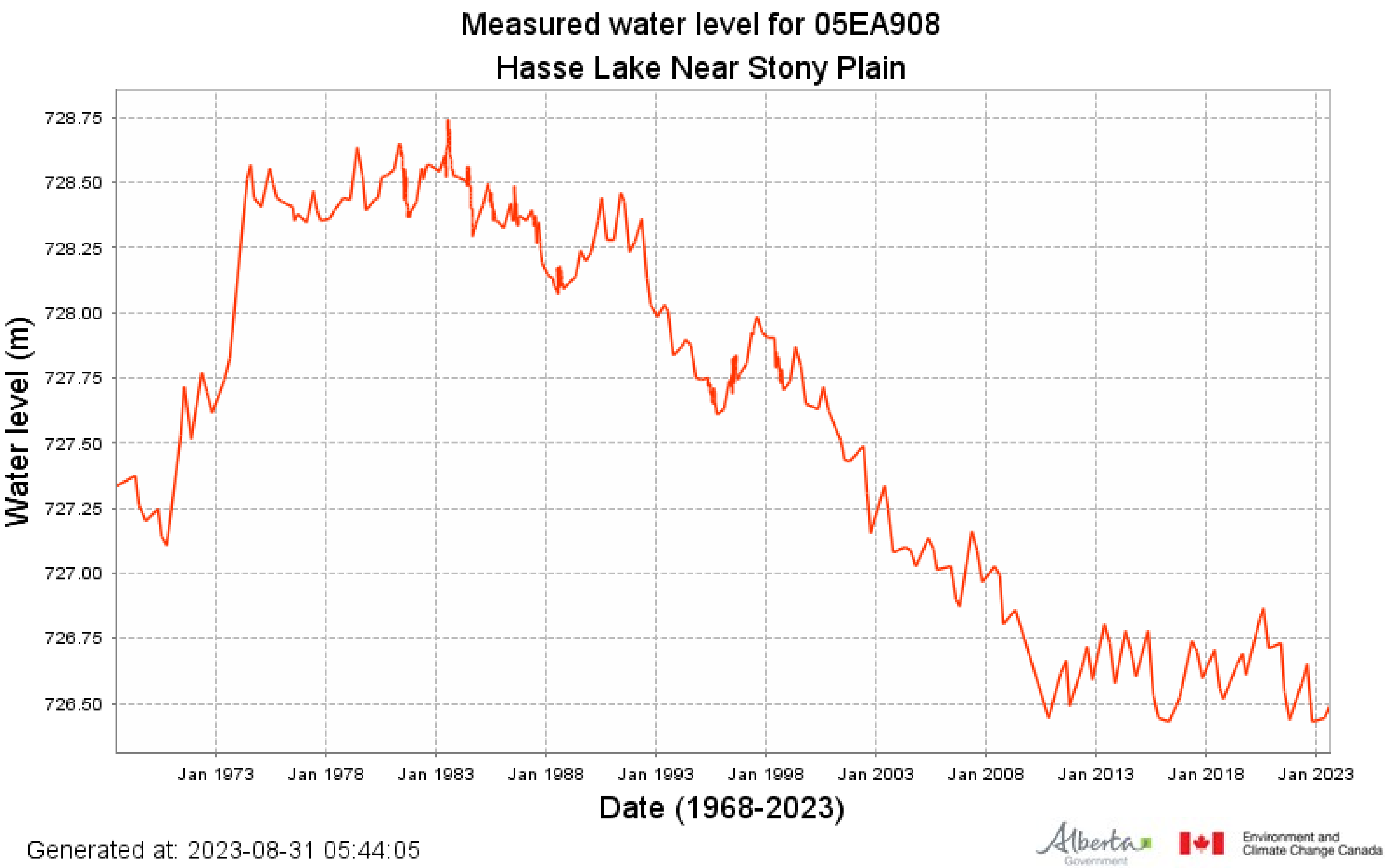
Appendix Figure 7. Water levels in meters above sea level for Jackfish Lake from 1968-2023. Data obtained from rivers.alberta.ca.



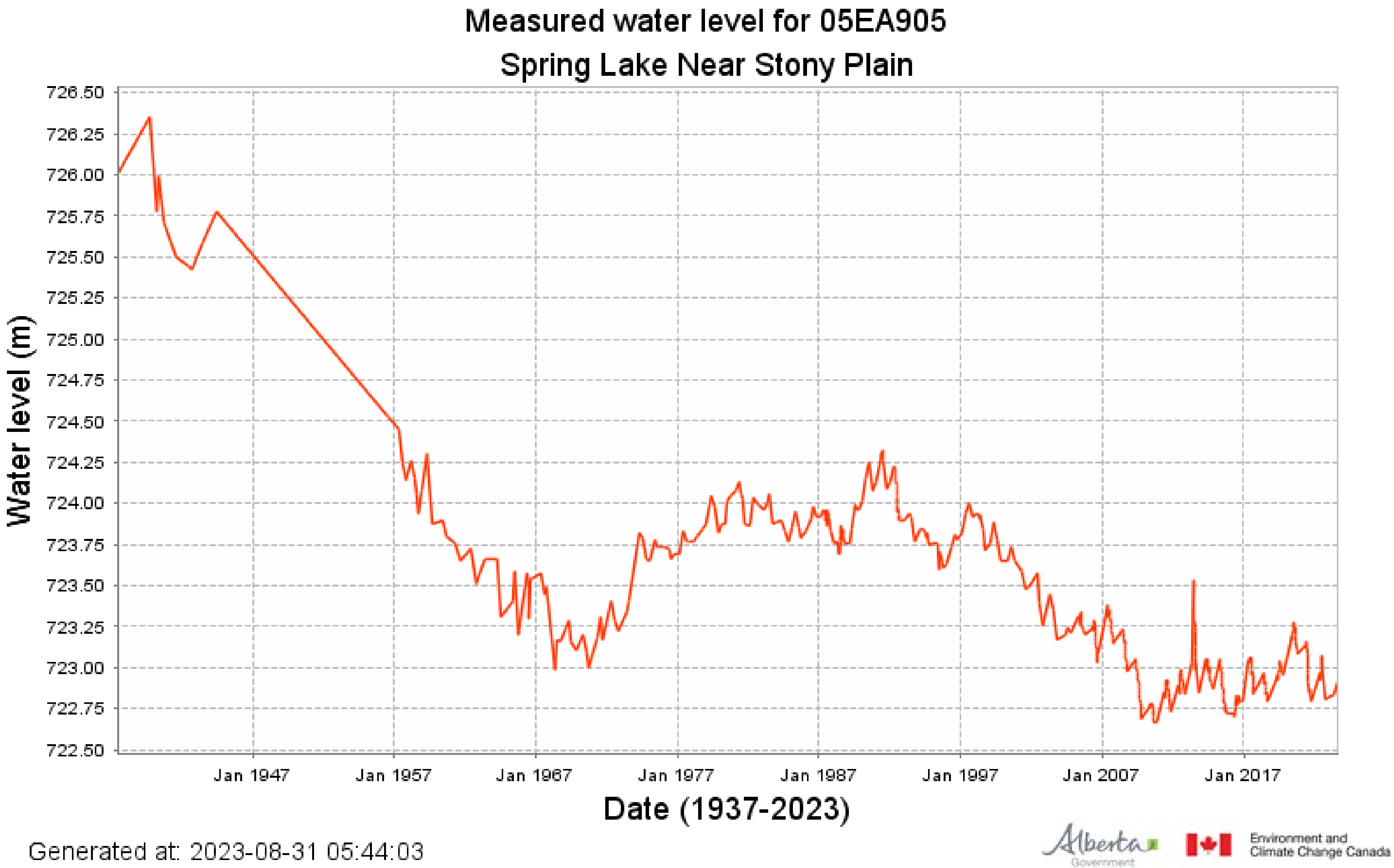
Appendix Figure 8. Water levels in meters above sea level for Mink Lake from 1968-2023. Data obtained from rivers.alberta.ca.



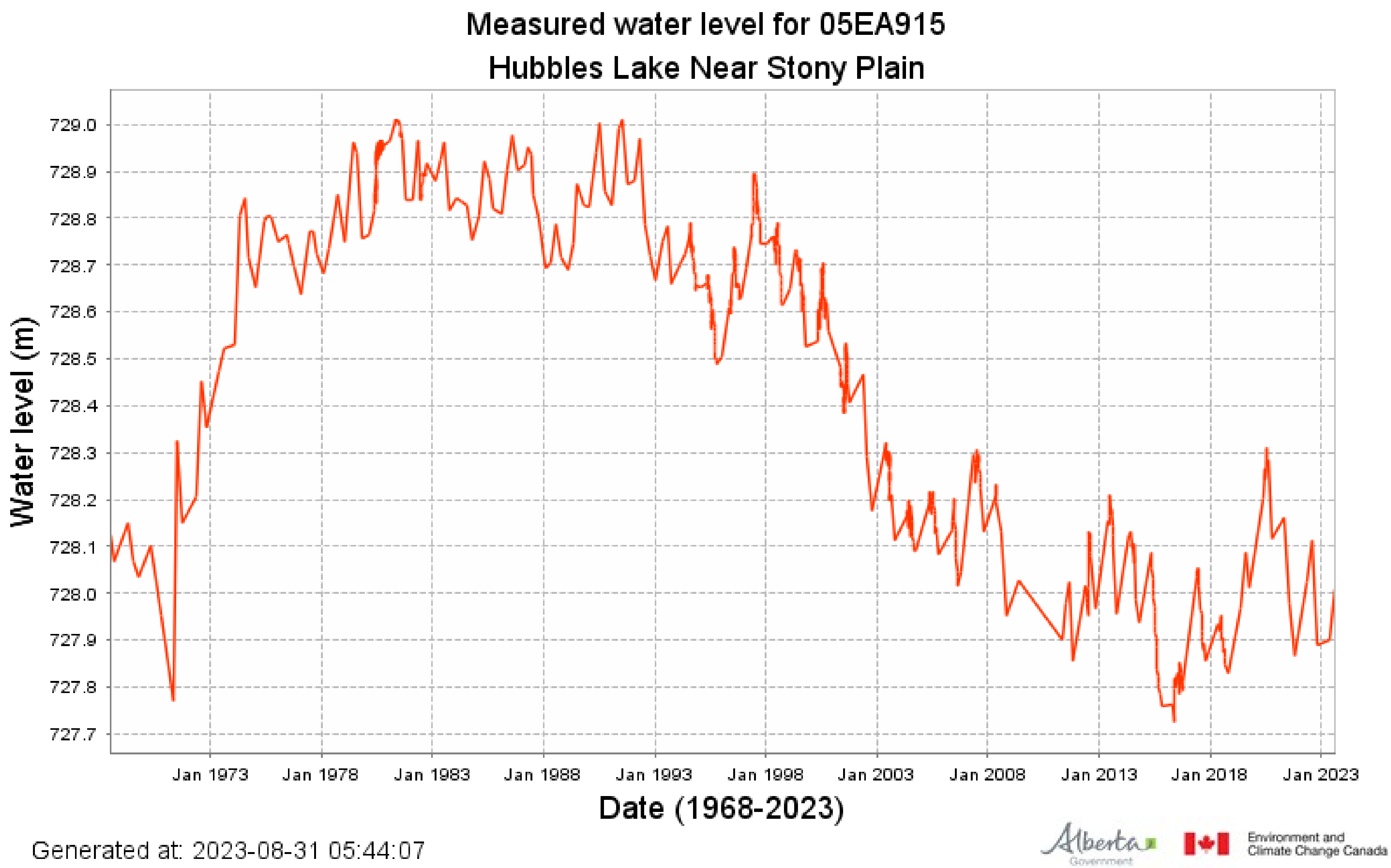
Appendix Figure 9. Water levels in meters above sea level for Chickakoo Lake from 1968-2023. Data obtained from rivers.alberta.ca.



Appendix Figure 10. Water levels in meters above sea level for Hasse Lake from 1968-2023. Data obtained from rivers.alberta.ca.



Appendix Figure 11. Water levels in meters above sea level for Spring Lake from 1937-2023. Data obtained from rivers.alberta.ca.



Appendix Figure 12. Water levels in meters above sea level for Hubbles Lake from 1968-2023. Data obtained from rivers.alberta.ca.