Lakes of the Carvel Pitted Delta

-Stony Plain Region-

Summer Field Program - 2023

Cover image: A small unnamed Lake (PL33) near the Yellowhead Highway. Photographed by David Trew, 2023.

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Report prepared November 2024

Introduction

There are many 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 31 named lakes and over 100 unnamed lakes in this area. The geographic extent of the Carvel Pitted Delta is described in the report "*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.

The scenic shoreline of unnamed lake PL5. Photographed by David Trew, 2023.

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 the report "*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 eight 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. Mussell. 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, thirteen 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. (2022)[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]

A view from the north shore of Mere Lake. Photographed by David Trew, 2023

[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. 2022. 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 (33 lakes), 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 2021 and 2022 surveys were 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.

In 2023, the MLMA in partnership with ALMS and the Land Stewardship Centre of Canada (LSCC) undertook a fourth year of field work. In continuation of the synoptic survey approach, 27 additional lakes were sampled in late summer for lake water quality and groundwater isotopes. Bathymetric data were collected on two additional lakes.

A small unnamed kettle lake (PL45) near Hubbles Lake. Overhead drone photograph taken by Dave Mussell, 2023.

We acknowledge the support of over 50 local landowners who graciously made access to these locations possible during the 2020 to 2023 field programs.

Originally conceived as a regional lake survey, a variety of different waterbody types have been documented over the four years of work. These have included deep kettle lakes, shallow pothole lakes, marl ponds and permanent wetlands. The diverse morphometric characteristics of these waterbodies will be analyzed in a future report.

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.

In 1986 an extensive fisheries inventory was undertaken on 33 named and unnamed 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.

A shallow unnamed lake (PL43). Photographed by David Trew 2023

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.[12]

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.[4,5,6].

[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

[12] Mitchell, E. and E. Prepas. 1990. Atlas of Alberta Lakes. University of Alberta. 675 pp.

Winter lake sampling has also been conducted by MLMA over the past three years under the ALMS Winter LakeKeepers program.[13] 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.[14]

The project team would like to acknowledge the many contributions made to our understanding of the state of water resources in the Carvel Pitted Delta and the adjacent areas of central Alberta by researchers from the University of Alberta who, for over seven decades, have studied water quality, fisheries, aquatic plants and animals, wetlands, groundwater, and other biophysical attributes of the area.

The littoral zone and riparian edge at unnamed lake PL36 near Soldan Lake. Photographed by David Trew, 2023.

[13] 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

[14] 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

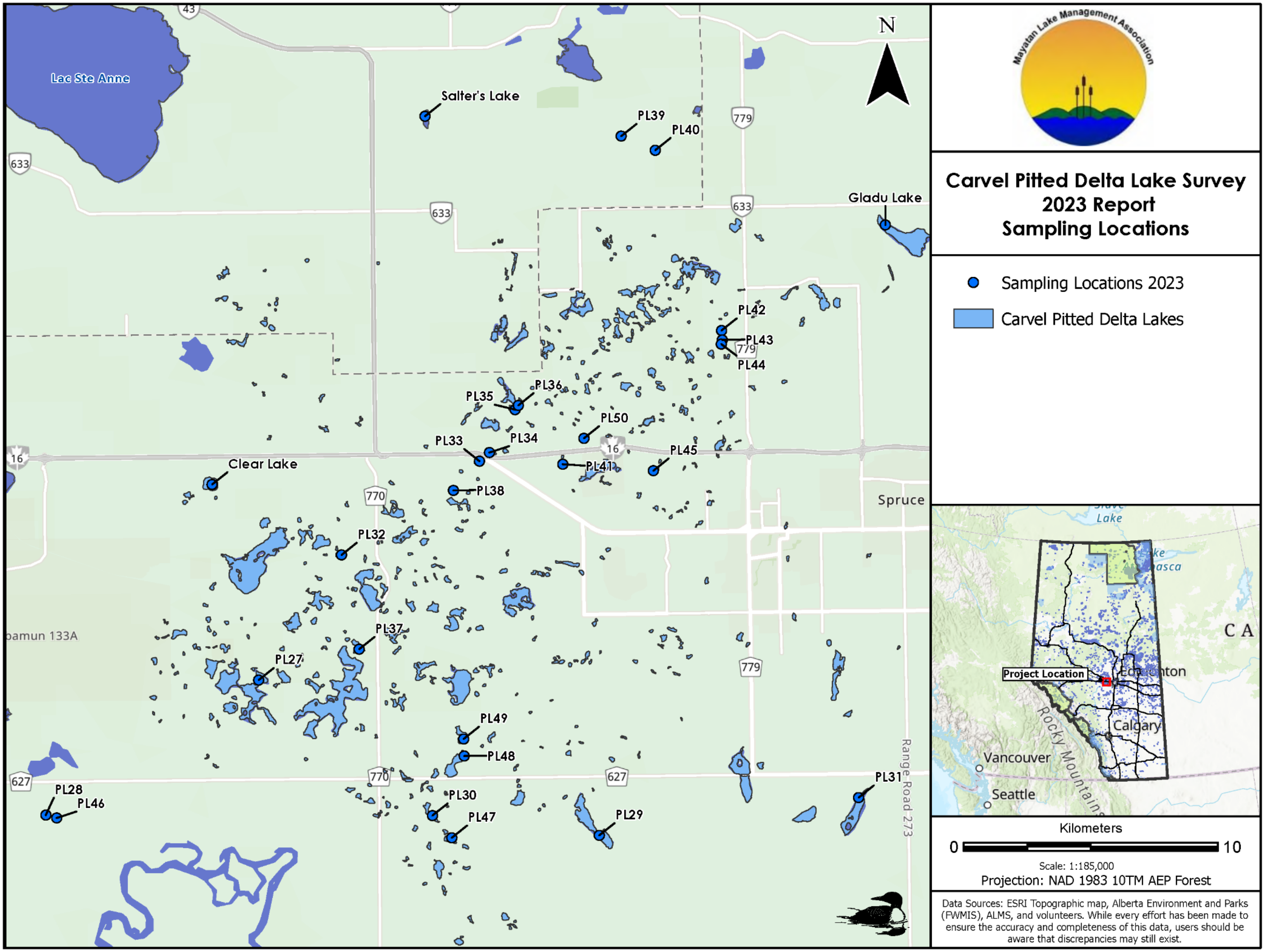

Figure 1. Map showing the 27 lakes sampled in the Carvel Pitted Delta during the summer of 2023. Unnamed lakes have been assigned an arbitrary code indicated by PL#.

Methods

The 27 lakes selected for sampling in 2023 are illustrated in Figure 1. Each lake was sampled once between July 17th and October 4th, 2023. 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.

New bathymetric surveys were conducted on two lakes during 2023 (Mayatan and Salter's) to refine 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 mean depths, and to develop color-coded depth maps.

Physical profile measurements were recorded at the deepest location of each lake, subsequently referred to as the profile location. 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 sampler, to determine Total Phosphorus concentrations near the sediments.

Dave Mussell sampling an unnamed waterbody (PL43) from shore. Photograph taken by David Trew, 2023.

The physical profile data from 2020 and 2021 had 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 at PL42, PL43, PL44, and PL50, grab samples were taken from shore using an extendable sampling pole. At PL29 and PL31, composite samples were collected from a depth of 0.5m using a Van Dorn sampler.

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. Sub-samples for stable isotope analyses were also taken from these composite samples and delivered to the Dept. of Earth Sciences, University of Alberta. Samples for phytoplankton and zooplankton taxonomy have been preserved and are in storage. 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: these three aquatic invasive species were not detected in any of the 49 lakes sampled.

Aquatic invasive species samples were not collected during the 2023 sampling season.

A tranquil morning on the forest trail into an unnamed waterbody, PL29. Photograph taken by David Trew, 2023.

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 additional information for 27 lakes in the Carvel Pitted Delta 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/.

Looking east across an unnamed lake (PL32) near Mink Lake. Photographed by David Trew, 2023.

Physical Characteristics

Most of the lakes sampled in the 2023 summer field program (Figure 2) were comparatively small, with surface areas ranging from 0.57 hectares (PL43) to 112.02 hectares (Gladu Lake). The median size of all sampled lakes was 5.76 hectares. The lakes sampled in 2023 were generally much smaller than those sampled in 2022.

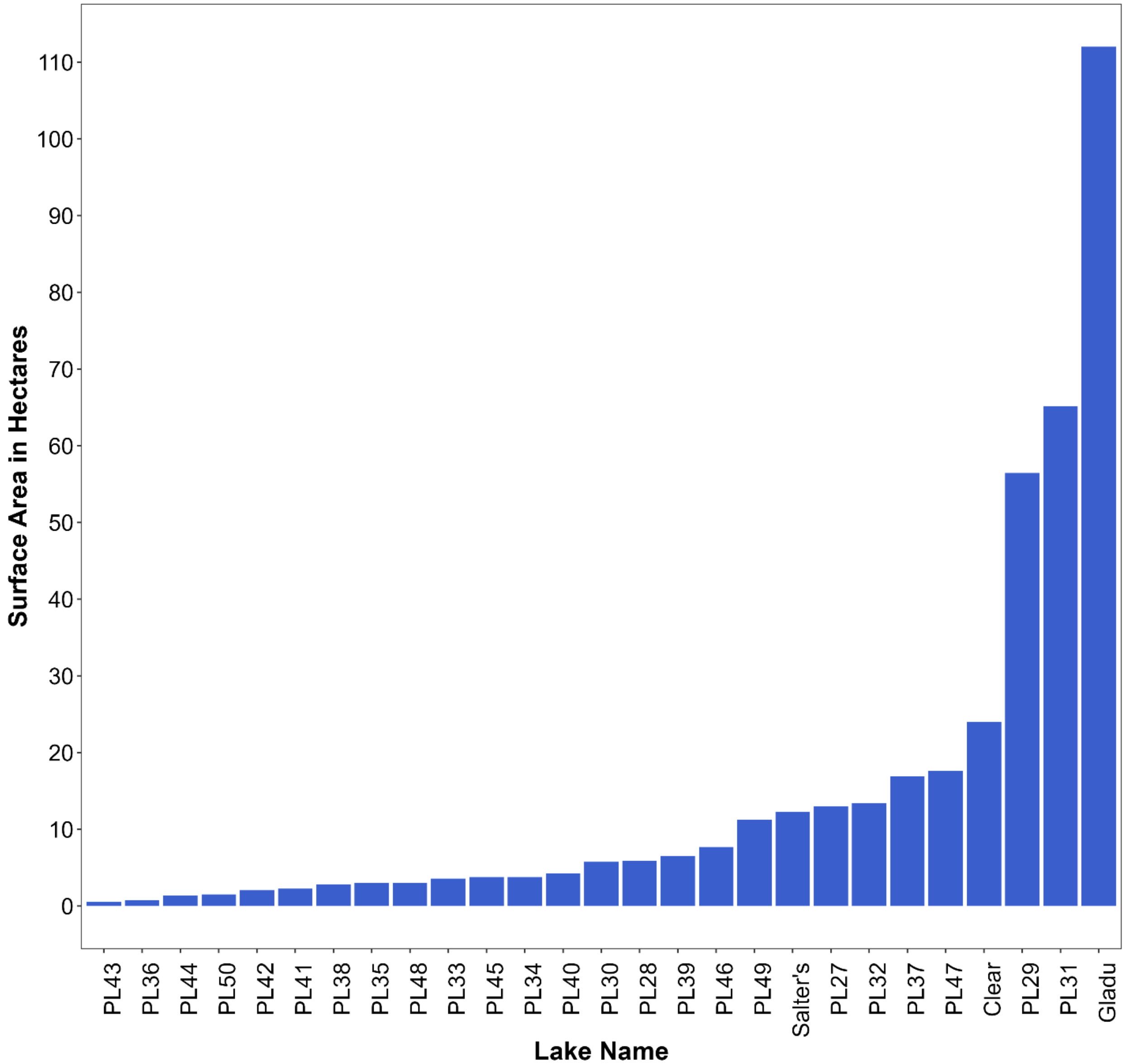

Figure 2. The surface areas (ha) of 27 lakes in the Carvel Pitted Delta. Surface areas calculated in Google Earth by ALMS (2024).

Most lakes sampled in 2023 were relatively shallow compared to the lakes sampled in 2022. Maximum depths were recorded at each profile sample location and ranged from approximately 1.0 m to 9.7 m (Figure 3). Maximum depths in the very shallow waterbodies (including Gladu, PL29, PL31, PL42, PL43, and PL44) were estimated at 1.0 m, based on spot measurements.

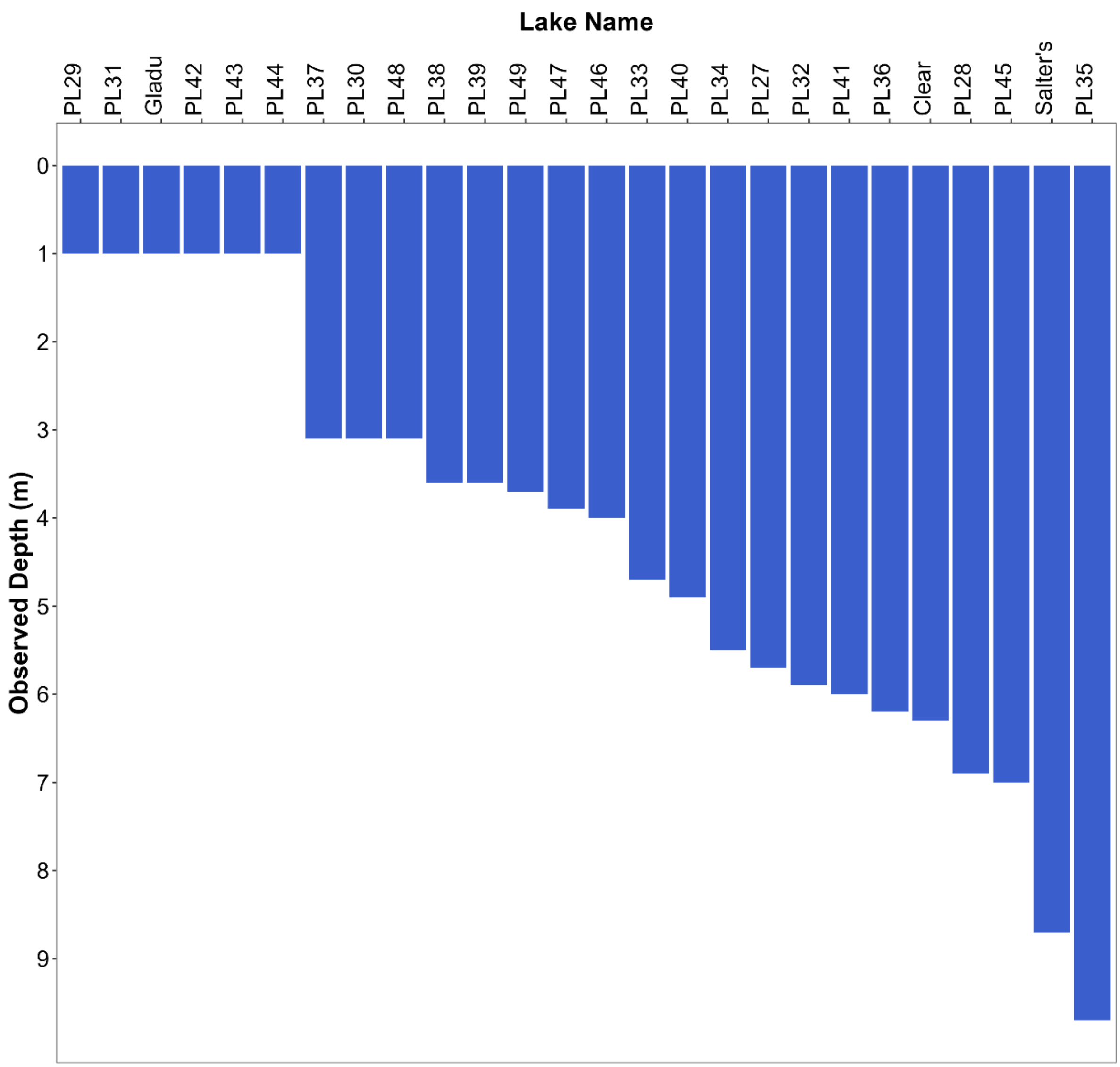

Figure 3. Maximum observed depths (m) recorded or estimated for 26 lakes using a weighted measuring tape. A maximum depth for PL50 was not recorded or estimated.

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 eight lakes to outline general water level trends. (Note that two of the original lakes (Johnnys and Star) were discontinued in 2002, but re-established in 2024, and Mayatan Lake was added to the network in 2017).

Changes in individual elevation measurements for each lake were calculated against the elevation recorded at a common point in time (May 9, 1994). This allows for a comparative depiction of elevation changes for all eight lakes, for the entire period of record, on one graph (Figure 4). The data suggest that lakes in the region generally experienced higher water levels from the early 1970s to the early 1990s, followed by declining and lower water levels from the late 1990s until present.

These general water level changes reflect local climate patterns (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 and Trew 2015).[5] The 1970s were generally cooler and wetter, and the last two decades have generally been warmer and drier. 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 (see Appendix, Figures 1 to 8) six lakes appear to show a similar pattern (Hasse, Hubbles, Jackfish, Mink, Spring, Star). All lakes increased from the late 1960s and after six decades have returned to lower levels again; they now appear to be approximately 0.5 m below the levels recorded in the 1960s. Johnnys Lake appears to have followed the rising water level trends of the 1970s and has sustained those levels into the present (2024). Chickakoo Lake experienced a rapid one-meter increase in the 1970s, but since then has experienced a steady decline and now sits at an elevation approximately 1.0 m below that of the 1960s.

Seven of the eight lakes reached historic recorded lows in 2024.

These changes in the Carvel Pitted Delta region are also typical of patterns observed across the larger North Saskatchewan River 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.[15]

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.

[15] 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.

Northern Pike (Esox lucius) in unnamed lake PL4. Underwater photograph taken by Dave Mussell, 2023.

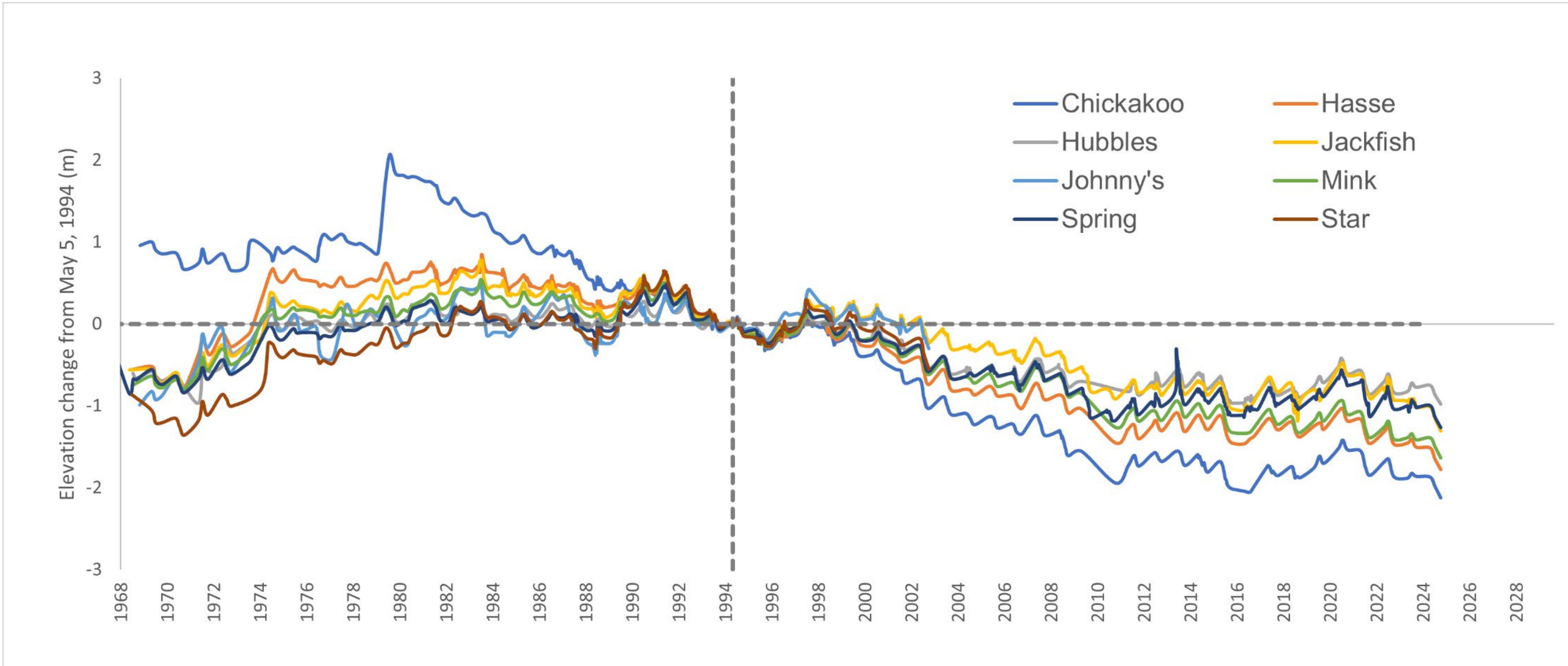

Figure 4. The differences (m) in water levels compared to May 5, 1994 levels for eight lakes within the Carvel Pitted Delta region. Water level elevations in meters above sea level were obtained from Alberta Environment and Protected Areas for the period 1968-2024. The difference in water levels was calculated by subtracting the elevation on May 5, 1994 from the observed elevation. Figure and data prepared by S. Figliuzzi, P. Eng.

Temperature

Sampling in 2023 occurred between mid-July and early-October; therefore, a moderate range of surface water temperatures was observed (Figure 5). As in 2022, a pattern of 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 deeper lakes, the thermocline was often established between 3 – 5 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 influence the degree to which a lake will stratify or mix.

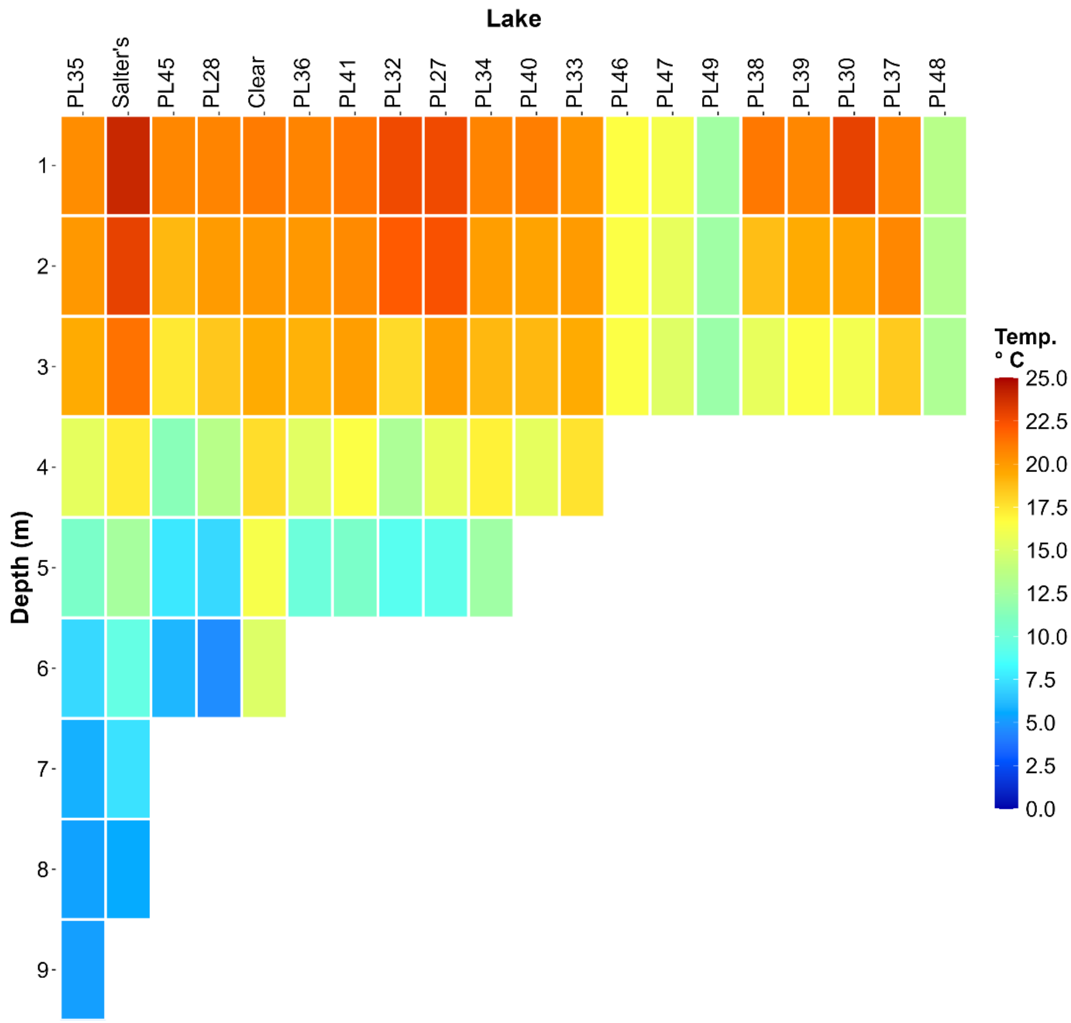

Figure 5. Temperature (°C) profiles for 20 lakes sampled between July 17th and October 4th, 2023. Coloured boxes reflect the temperature measured at that specific depth. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1 m depth for visual purposes. Gladu, PL29, PL31, PL42, PL43, PL44, and PL50 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 6). Dissolved oxygen concentrations in the deeper lakes were strongly influenced by thermal stratification. Declining dissolved oxygen concentrations were frequently observed at a depth of approximately 3.0 m. Very low oxygen or anoxic conditions were regularly observed below that depth.

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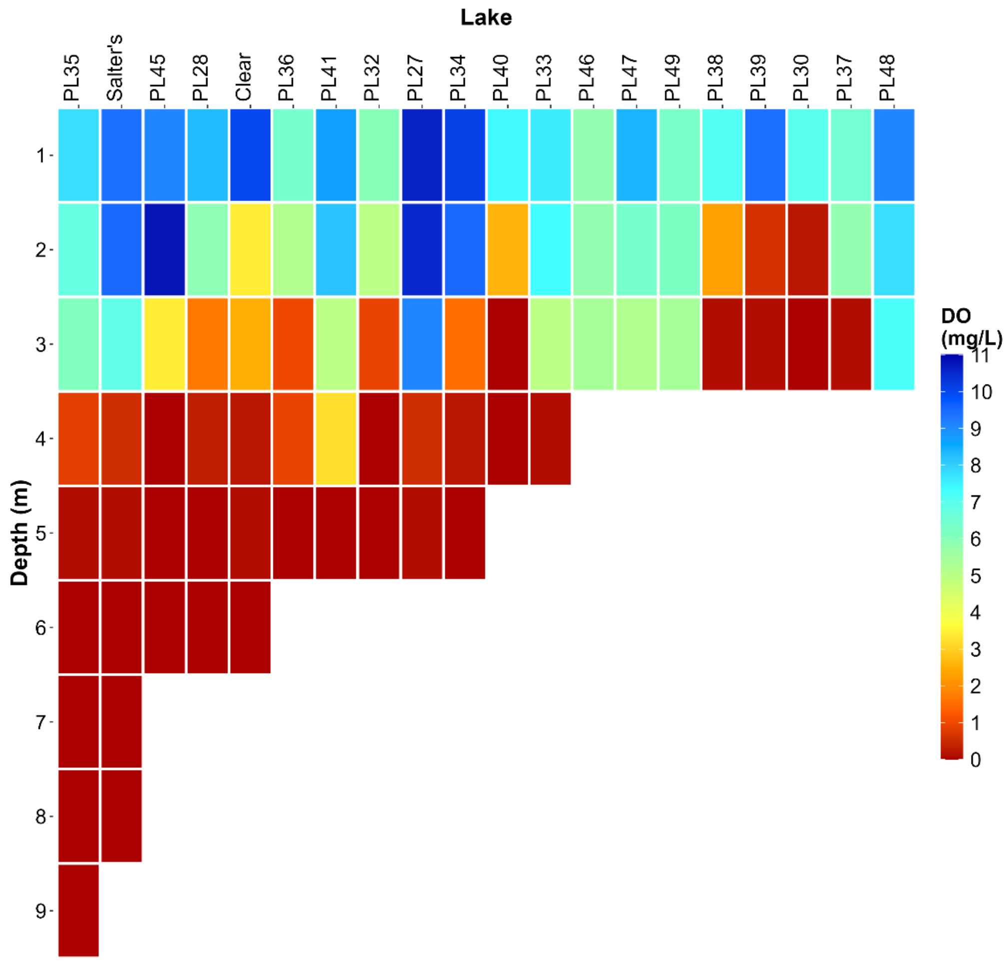


Figure 6. Dissolved oxygen (mg/L) profiles for 20 lakes sampled between July 17th and October 4th, 2023. Coloured boxes reflect the dissolved oxygen measured at that specific depth. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1 m depth for visual purposes. Gladu, PL29, PL31, PL42, PL43, PL44, and PL50 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 displayed a very wide range in the lakes sampled in 2023 (Figure 7), ranging from 8.0 µg/L at PL42 to 360 µg/L at PL39. Based on total phosphorus concentrations one lake was tentatively classified as oligotrophic, seven lakes as mesotrophic, twelve lakes as eutrophic and seven lakes as hypereutrophic. When visualized on the regional map, an interesting grouping of lake types can be observed (Figure 8). The northeastern portion of the region contains a mixture of high quality oligotrophic and mesotrophic lakes. 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 the large and very shallow waterbodies (PL 29, PL31, Gladu) tend to exhibit higher TP concentrations

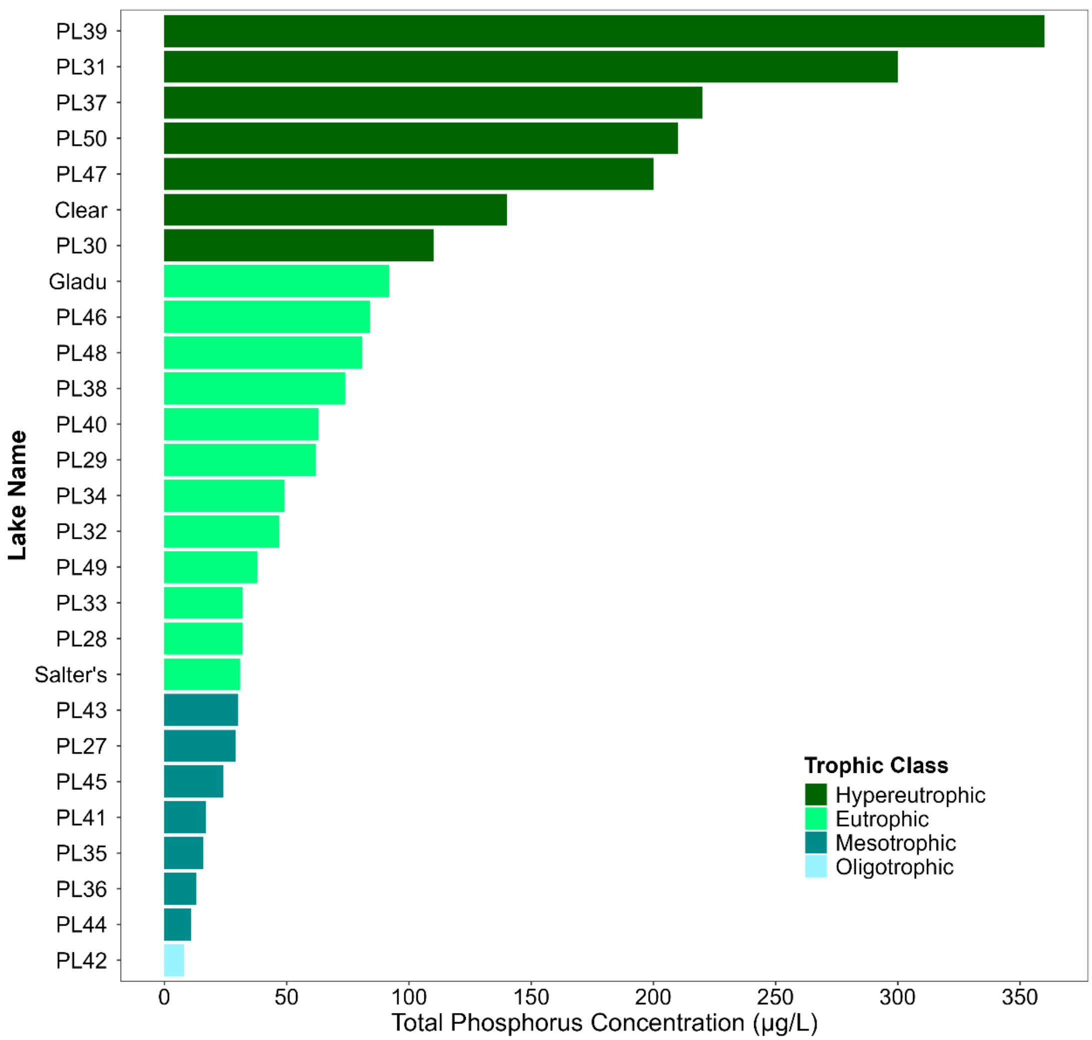


Figure 7. Total phosphorus concentrations for all 27 lakes sampled between July 17th and October 4th, 2023. Vertically integrated samples were collected to a depth of 2.5 m except for the six shallow lakes as previously noted. Trophic categories have been defined as oligotrophic (<10 µg/L), mesotrophic (10 - 30 µg/L), eutrophic (30 - 100 µg/L), and hypereutrophic (>100 µg/L).

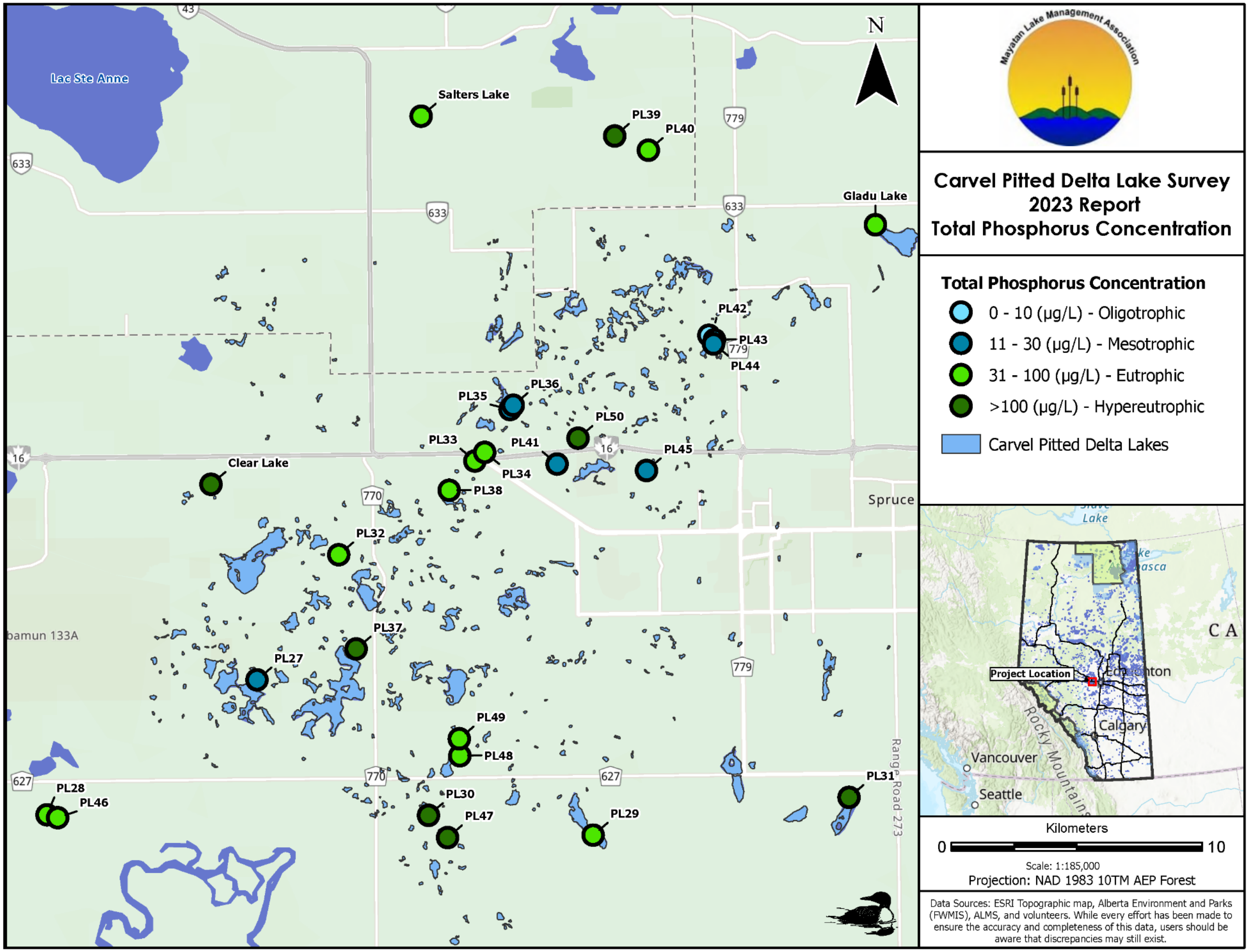


Figure 8. Trophic categories based on Total Phosphorus concentrations have been defined as oligotrophic (<10 µg/L), mesotrophic (11-30 µg/L), eutrophic (31-100 µg/L), and hypereutrophic (>100 µg/L).

Samples collected from near the bottom of each lake revealed concentrations of total phosphorus that were much higher than surface concentrations (Figure 9). An exception is for lakes which were well mixed on the date of sampling, such as PL49, PL48, and PL46, or for lakes which had low surface total phosphorus concentrations, such as PL36 and PL41. Geochemical controls on phosphorus availability appear to vary widely across the region (Von Gunten et al. 2022).

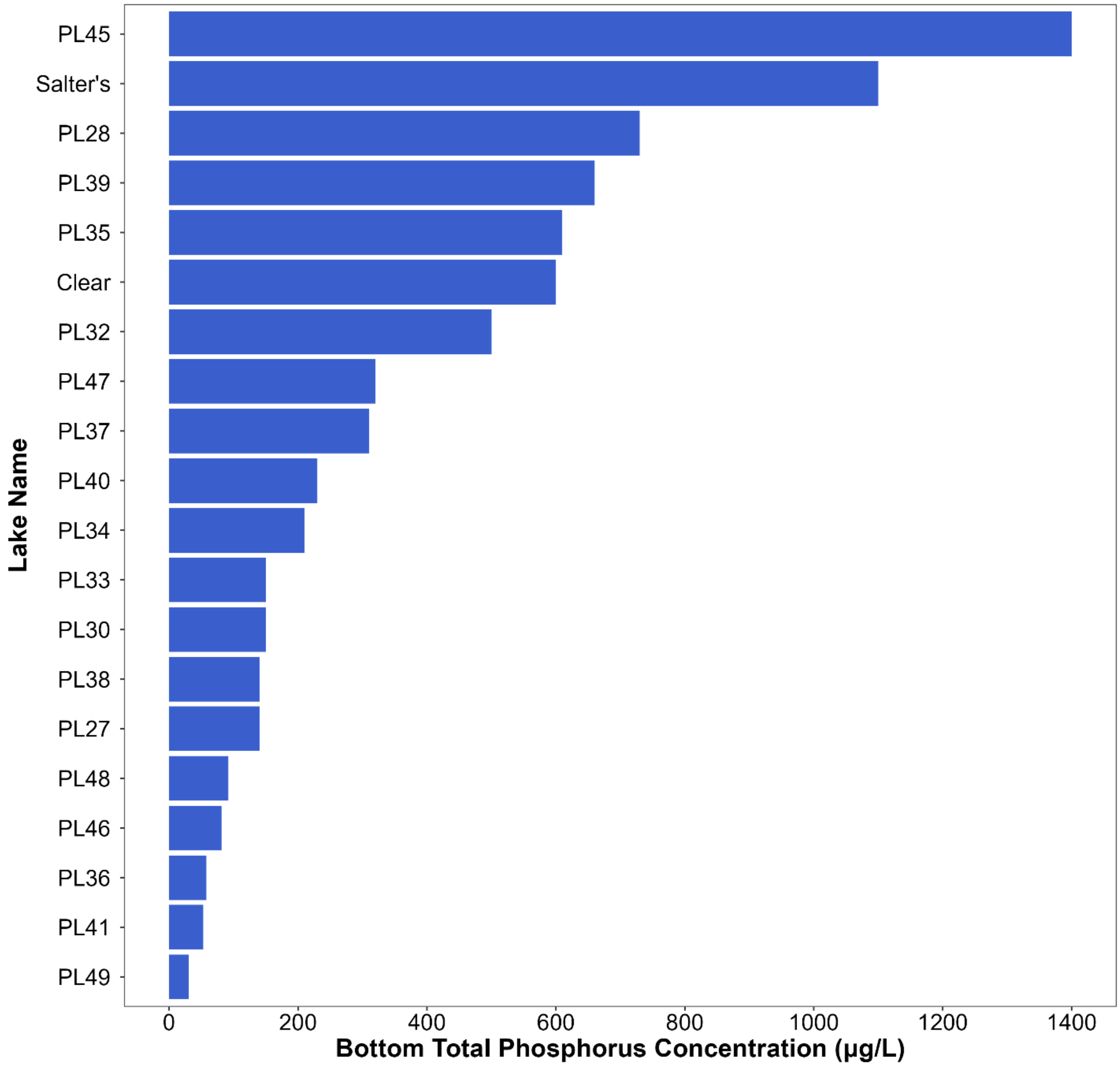


Figure 9. Bottom total phosphorus concentrations for 20 lakes sampled between July 17th and October 4, 2023. Bottom samples are not available for Gladu, PL29, PL31, PL42, PL43, PL44 and PL50.

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 sampled in 2023 again spanned the full range of trophic states based on their chlorophyll-*a* concentrations (Figure 10). Five lakes were tentatively classified as oligotrophic, five lakes as mesotrophic, seven lakes as eutrophic and 10 lakes as hypereutrophic. The northeastern region contained a mixture of oligotrophic and mesotrophic lakes (Figure 11).

Note that PL31 and PL29 are classified as eutrophic based on total phosphorus concentrations, but as oligotrophic/mesotrophic based on chlorophyll-*a* concentrations. Both these waterbodies have the characteristics of permanent wetlands, and are dominated by the growth of macrophytes as opposed to planktonic algae, resulting in low concentrations of chlorophyll-*a* in the water column. PL42, PL43, and PL44 represent unique marl ponds with low total phosphorus concentrations, higher calcium concentrations, and low chlorophyll-*a.*

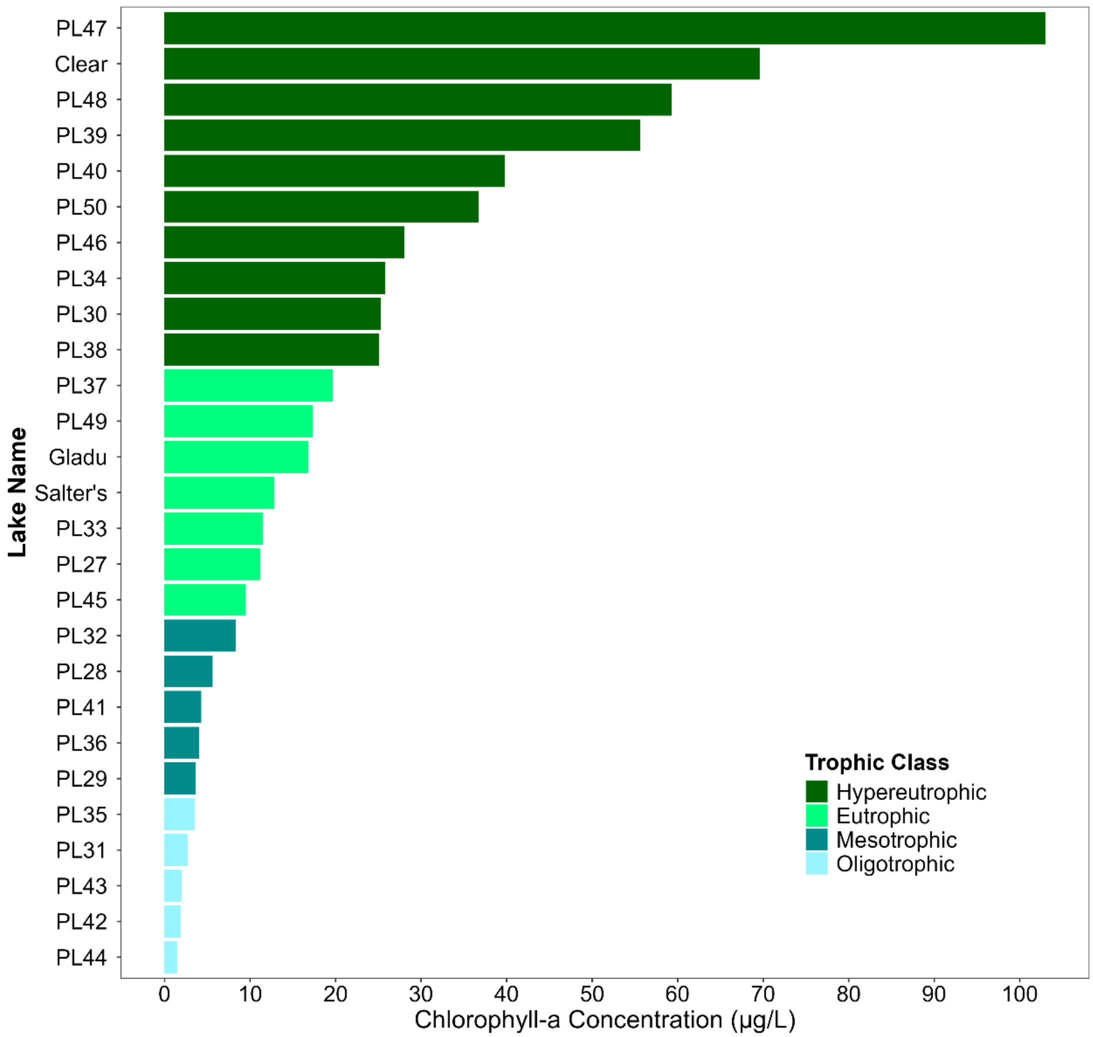


Figure 10. Chlorophyll-*a* concentrations for all 27 lakes sampled between July 17th and October 4th 2023. Trophic categories have been defined as oligotrophic (<3.5 µg/L), mesotrophic (3.5-9 µg/L), eutrophic (9-25 µg/L), and hypereutrophic (>25 µg/L).

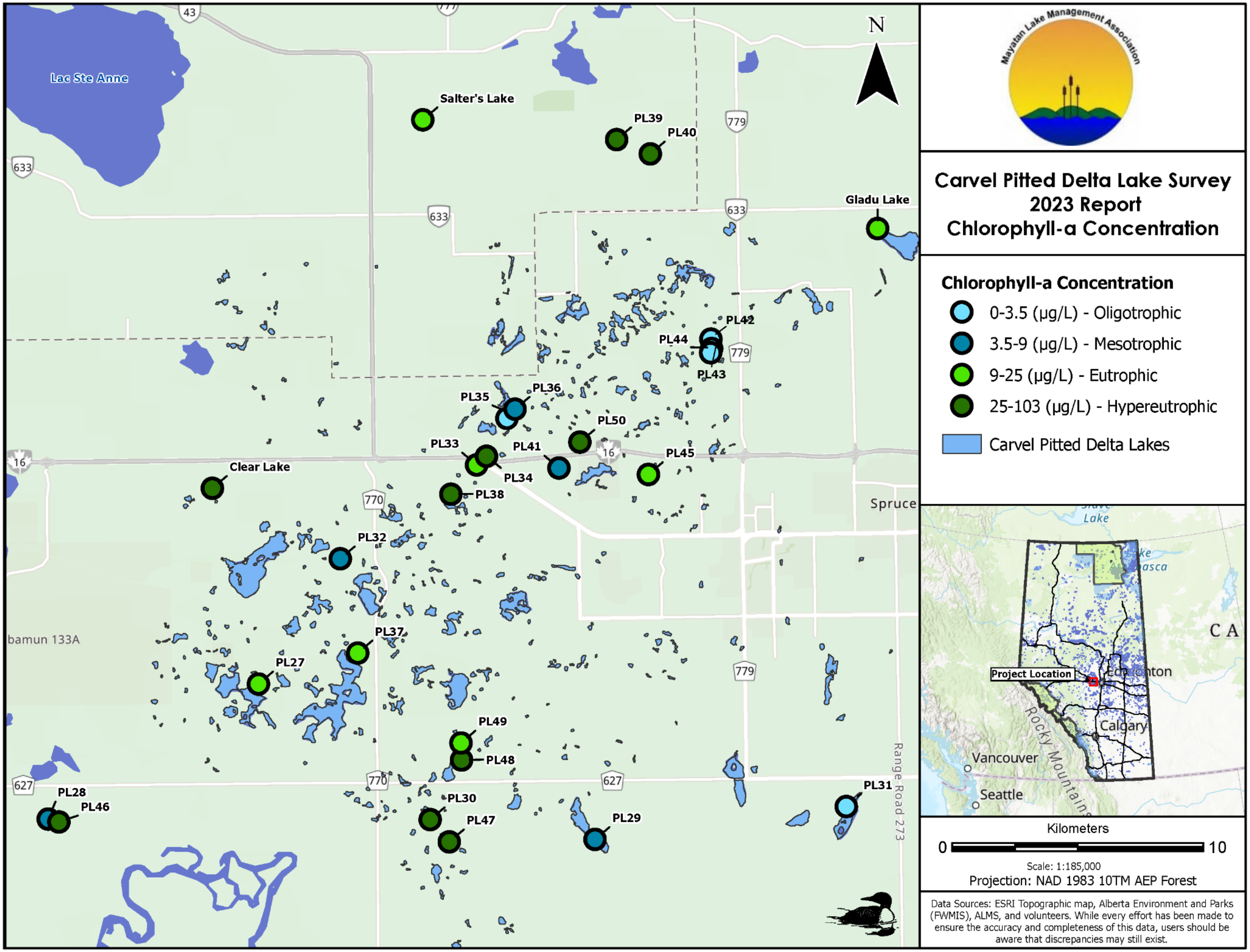


Figure 11. Chlorophyll-a concentrations (µg/L) for each lake sampled in the Carvel Pitted Delta. Trophic categories for chlorophyll-*a* have been defined as oligotrophic (<3.5 µg/L), mesotrophic (3.5-9 µg/L), eutrophic (9-25 µg/L), and hypereutrophic (>25 µg/L).

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[16]. Microcystin was below the detection limit (0.1 µg/L) in 14 lakes but detected in 13 lakes (Figure 12). Microcystin concentrations were highest at PL47 (18.29 µg/L), Clear Lake (15.43 µg/L), and PL39 (13.47 µg/L) where high concentrations of chlorophyll-*a* were also observed. Microcystin concentrations at these three lakes also exceeded the Health Canada Guideline. Caution should always be observed when recreating in the more productive Alberta lakes to limit exposure to cyanobacteria.

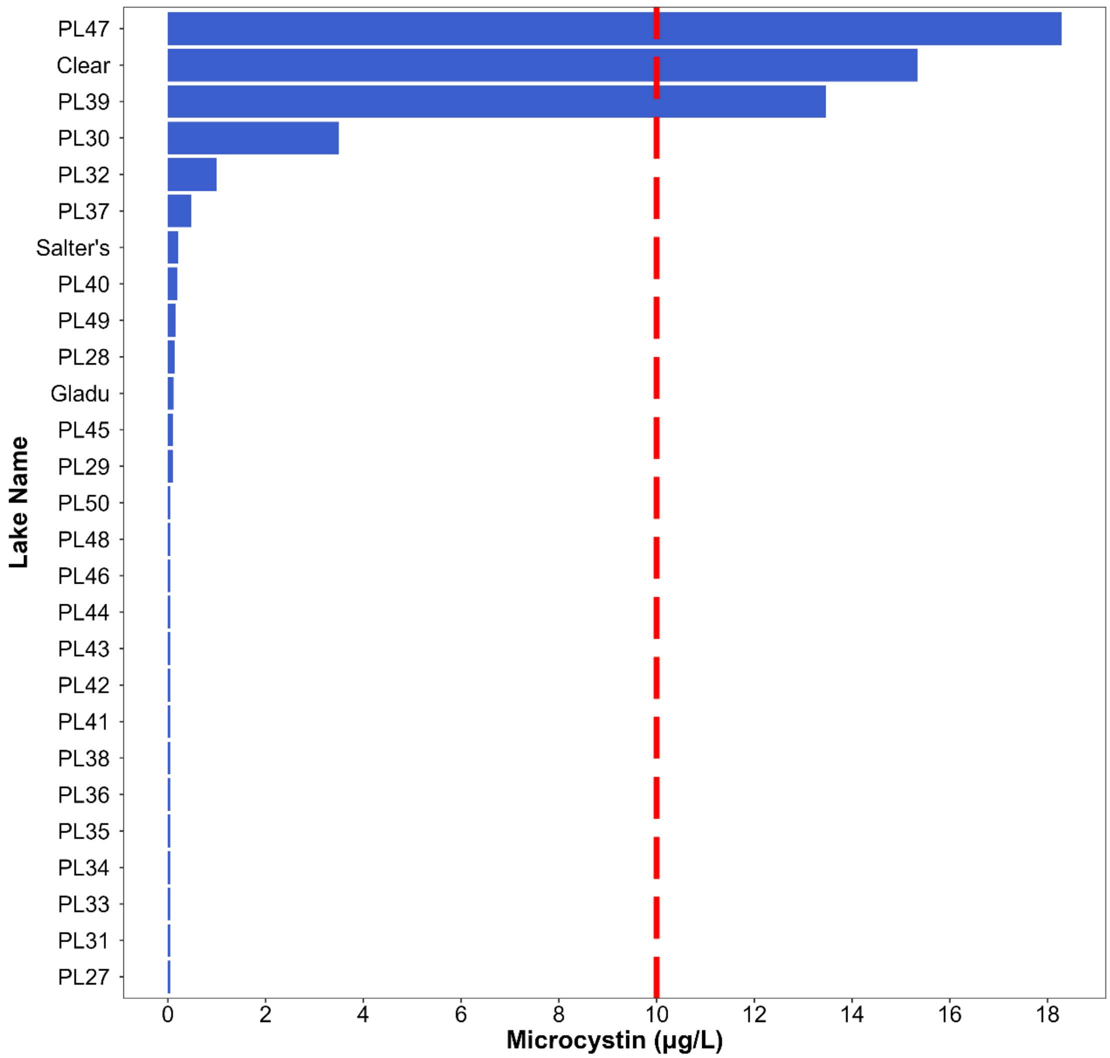


Figure 12. Microcystin concentrations for all 27 lakes sampled between July 17th and October 4th 2023. The Health Canada Recreational Guideline of 10 µg/L is indicated with a red vertical dashed line.

[16] 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 13). As expected, rapid light extinction was recorded in lakes with higher chlorophyll-*a* concentrations (PL47, PL48, Clear) and dissolved organic carbon concentrations [DOC] (PL30). Very low light extinction was observed in the lakes with low chlorophyll-*a*.

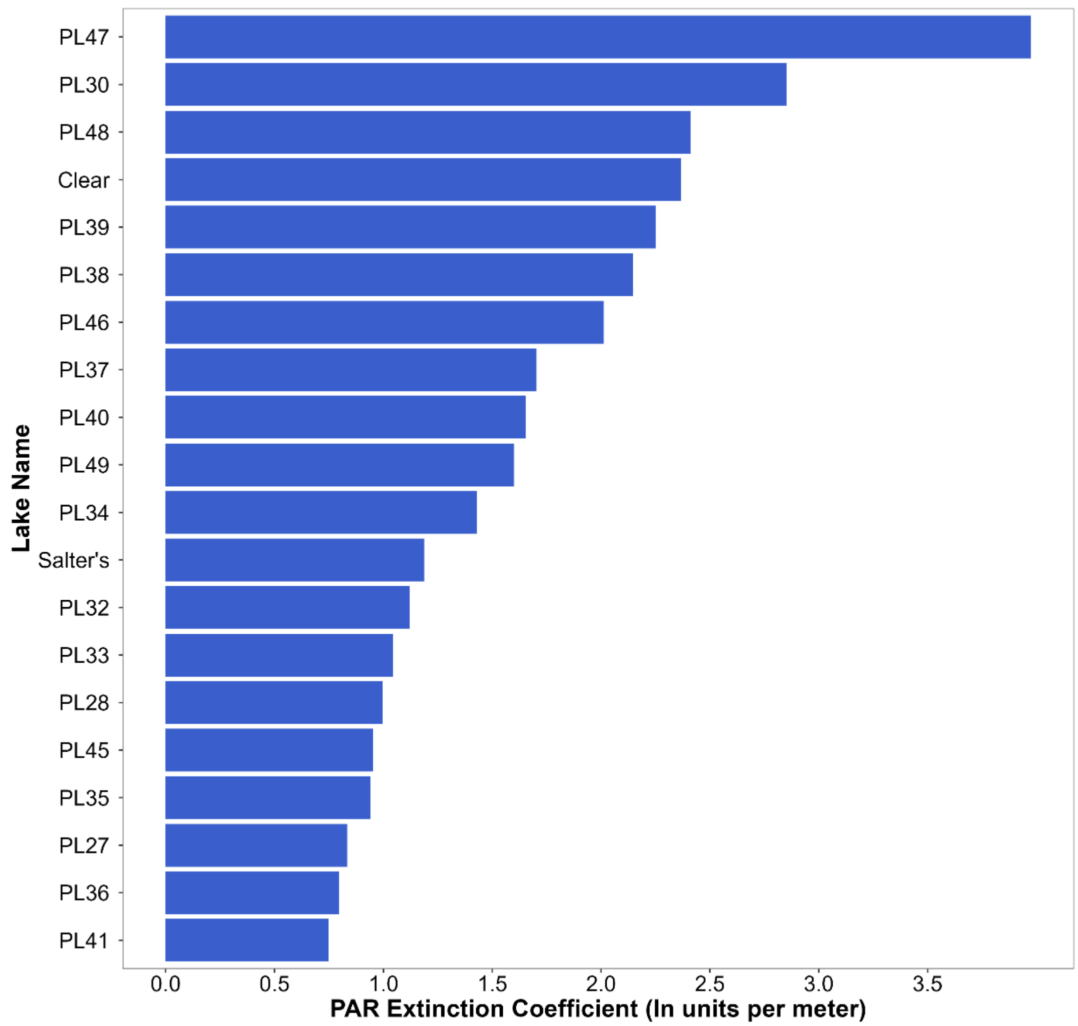


Figure 13. The PAR extinction coefficient (ln units/meter) calculated between 0.5 and 3.0 m for 20 lakes. The extinction coefficient was calculated as the natural log of PAR at depth 'a' minus the natural log of PAR at depth 'b' divided by the depth interval. Gladu, PL29, PL31, PL42, PL43, PL44, and PL50 have not been included in this figure.

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 20 lakes with measured PAR data in 2023, euphotic zone depths ranged from 1.2 m at PL47 to 4.8 m in PL41 Lake (Figure 14). The minimum euphotic zone depth (at PL47) coincided with the highest observed chlorophyll-*a* concentration (103 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.

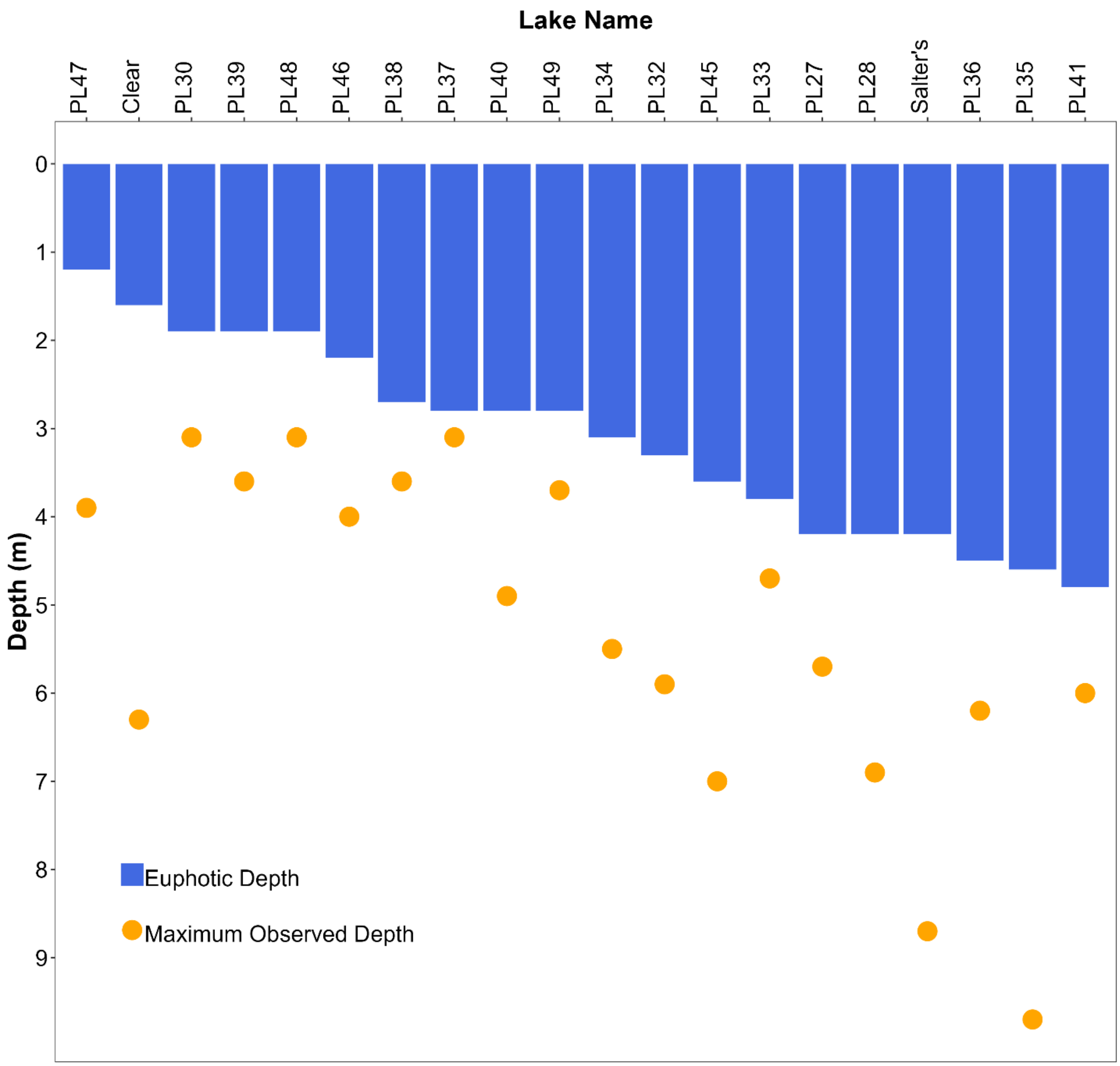


Figure 14. Euphotic zone depths (blue bars) measured for 20 lakes in the Carvel Pitted Delta. The euphotic zone was calculated as the depth to which 1% of the surface penetrating irradiance was observed. Maximum observed depths at the profile sites are indicated by yellow dots. Gladu, PL29, PL31, PL42, PL43, PL44, and PL50 have not been included in this figure.

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 lakes sampled in 2023, sulphate (SO_4^{2-}) displayed the highest variation in concentrations, ranging from <1.0 mg/L at PL35, PL38, PL41, PL50, to 880 mg/L at PL46 (Figure 15, Figure 16). 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 PL35, PL41, PL46, and PL47 which were slightly acidic and two which were close to neutrality (PL33, PL36). In general, major ion concentrations in the southern region tend to be higher than major ion concentrations in the northern region.

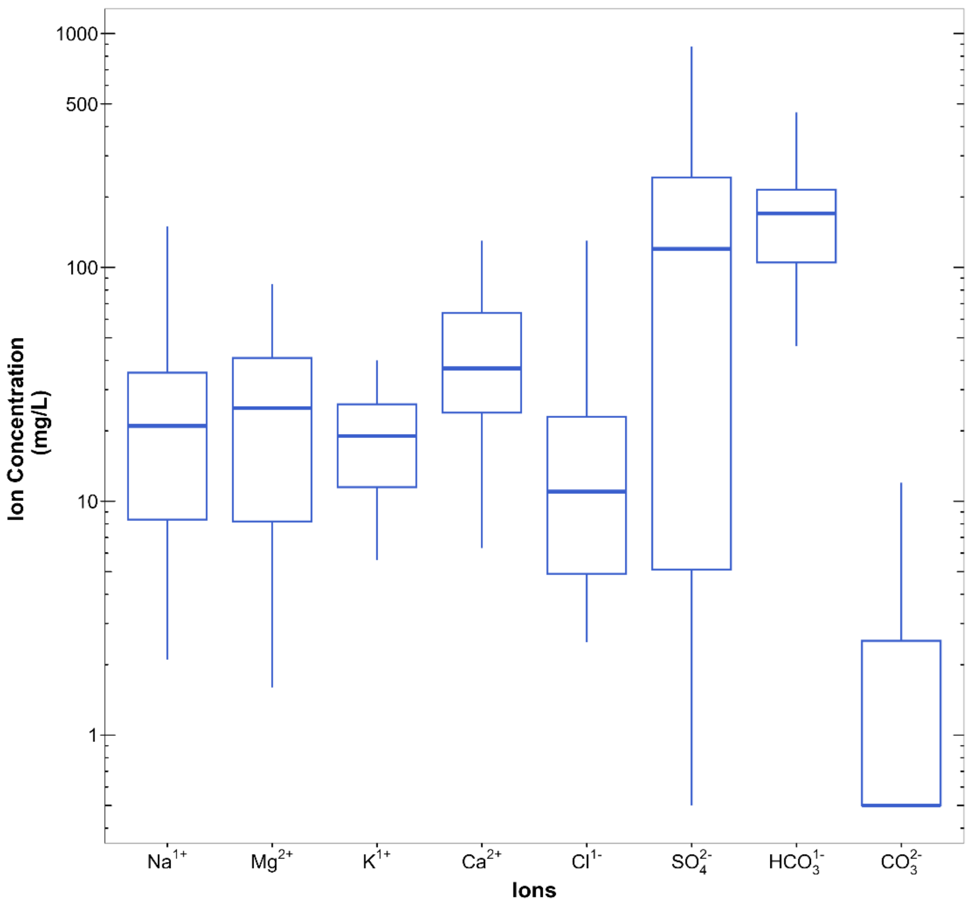


Figure 15. The distribution of major ion concentrations (mg/L) represented as box plots measured from samples collected at 27 lakes. Note that the y-axis represents a logarithmic scale of ion concentrations.

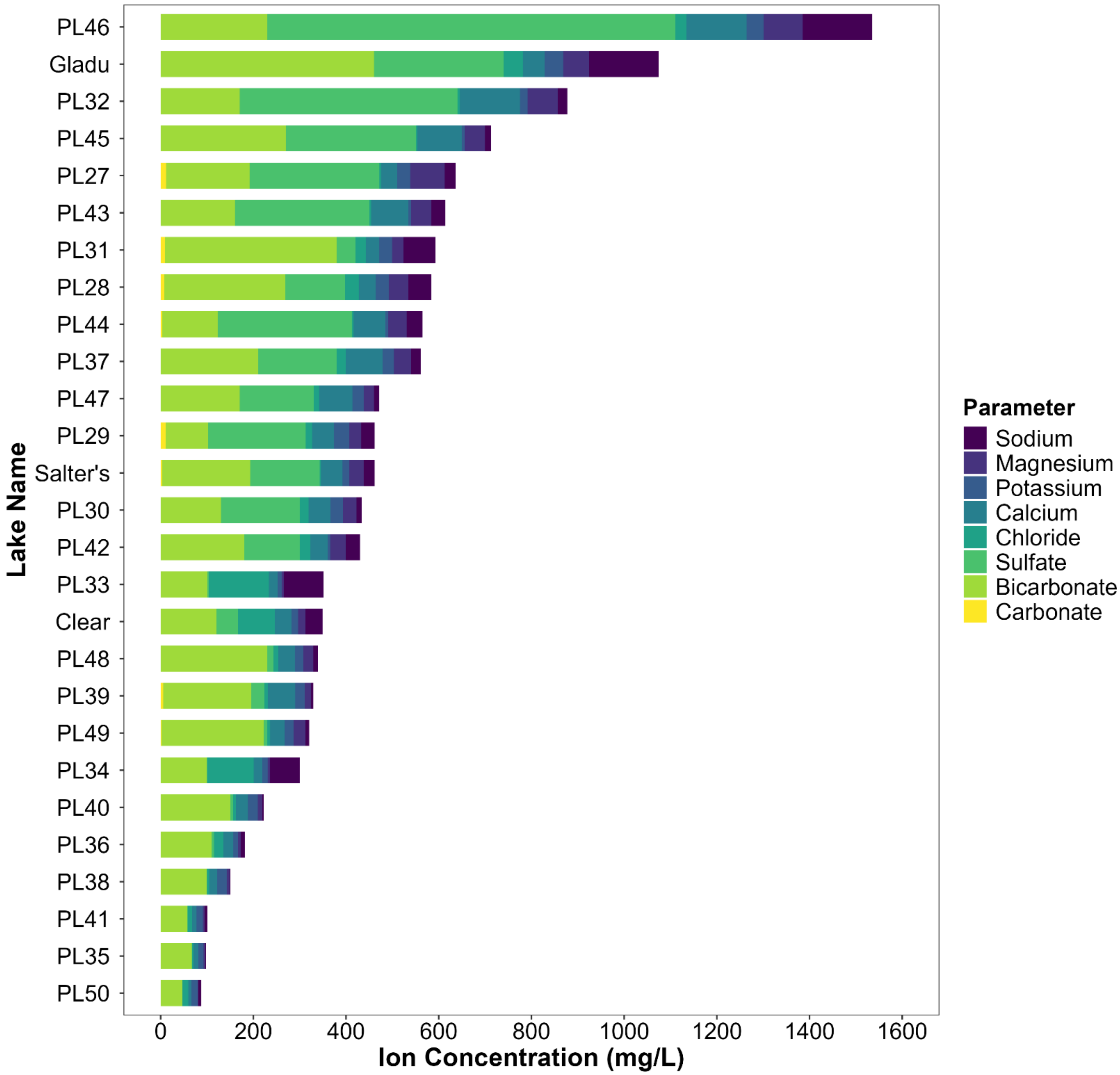


Figure 16. The distribution of major ion concentrations presented as a stacked bar graph (mg/L) from composite samples collected at 27 lakes between July 17th and October 4th, 2023.

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. Conductivity was measured using two methods: in composite and/or grab 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 110 µS/cm at PL35 to 1800 µS/cm at PL46 (Figure 17). When visualized on the regional map, lakes in the northern region generally have lower conductivities than lakes in the southern region, although some exceptions were noted in both 2022 and 2023 (Figure 18).[17]

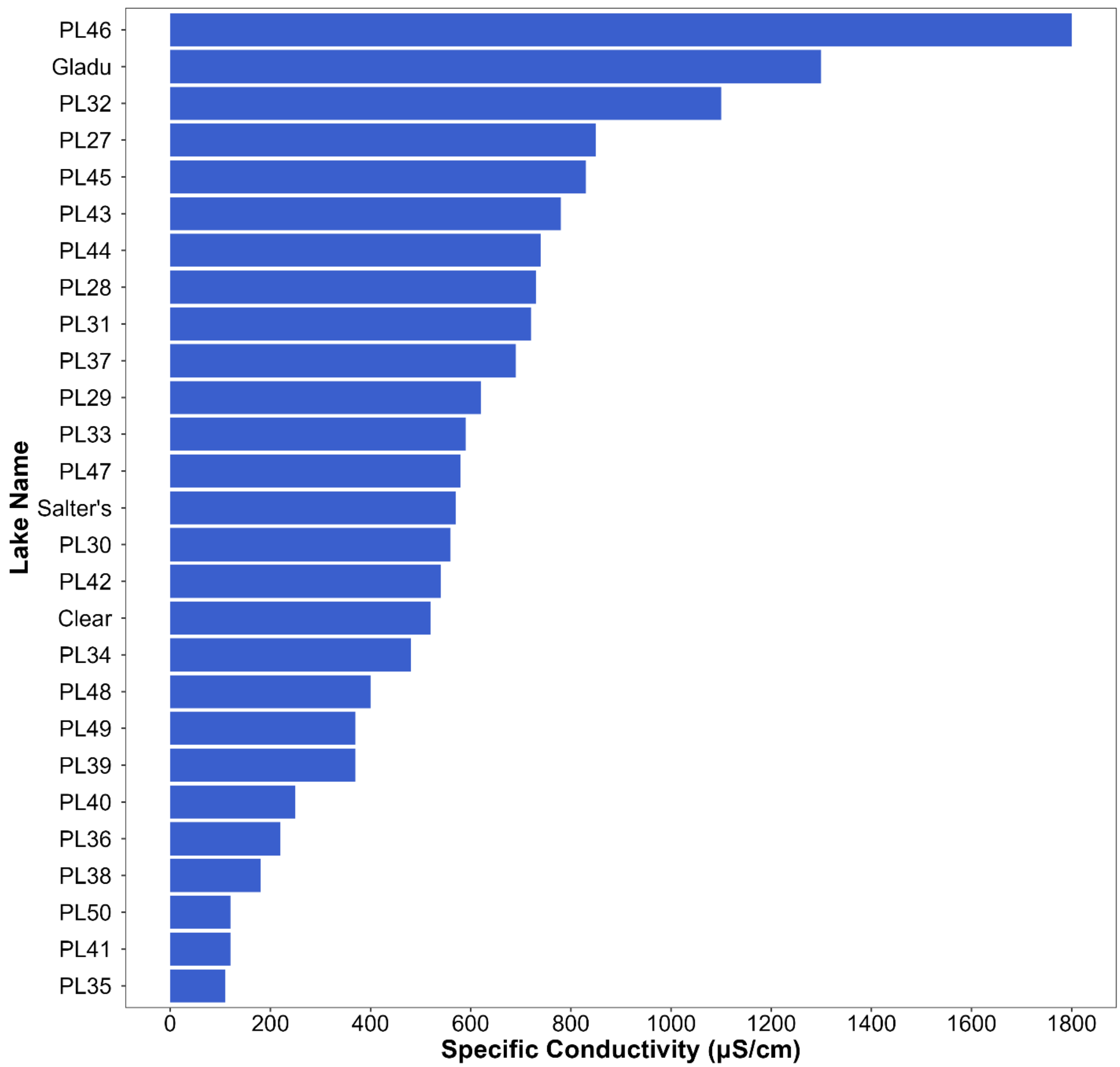


Figure 17. Specific conductivity (µS/cm) measured in composite samples collected from 27 lakes between July 17th and October 4th, 2023.

[17] Peter, B, D.O. Trew, C. Sinn, D. Mussell, and W. Neilson. 2023. Lakes of the Carvel Pitted Delta – Stony Plain Region: Summer Field Program 2022. Alberta Lake Management Society and Mayatan Lake Management Association. 53 pp.

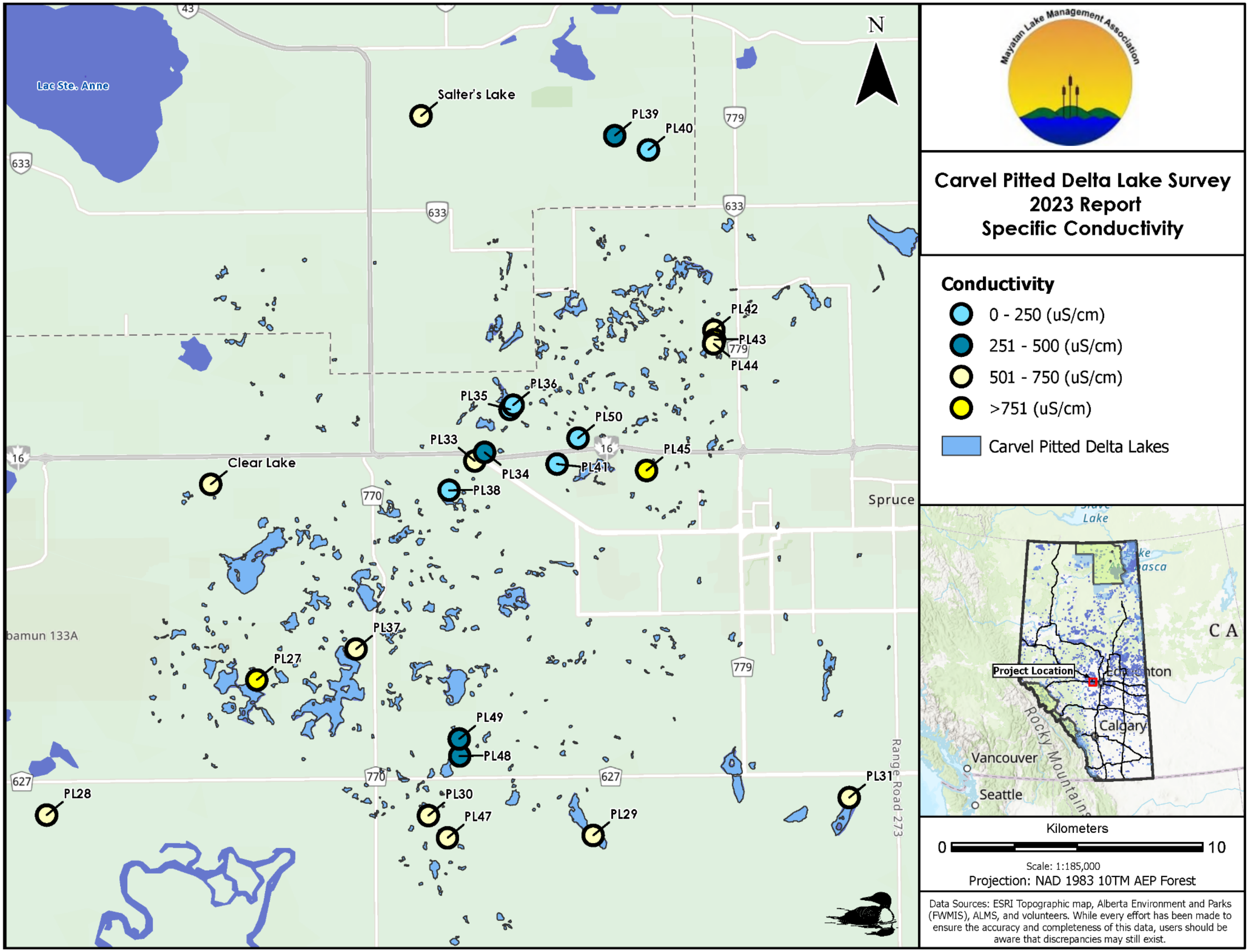


Figure 18. Specific conductivity values for 27 lakes in the Carvel Pitted Delta region.

Based on the *in-situ* profile measurements, the lakes again displayed a wide range of conductivities and vertical patterns (Figure 19). Conductivity values tended to increase with depth in most lakes, where a combination of thermal stratification, decomposition processes, anoxia at the sediment water-interface and groundwater inflows may all influence ionic content. PL32 and PL46 had higher conductivities, measuring 1100 µS/cm 1800 µS/cm respectively. These values are similar to the upper ranges of conductivities measured in 2022. These lakes are situated in the southern region and within watersheds with higher degrees of historic human impact.

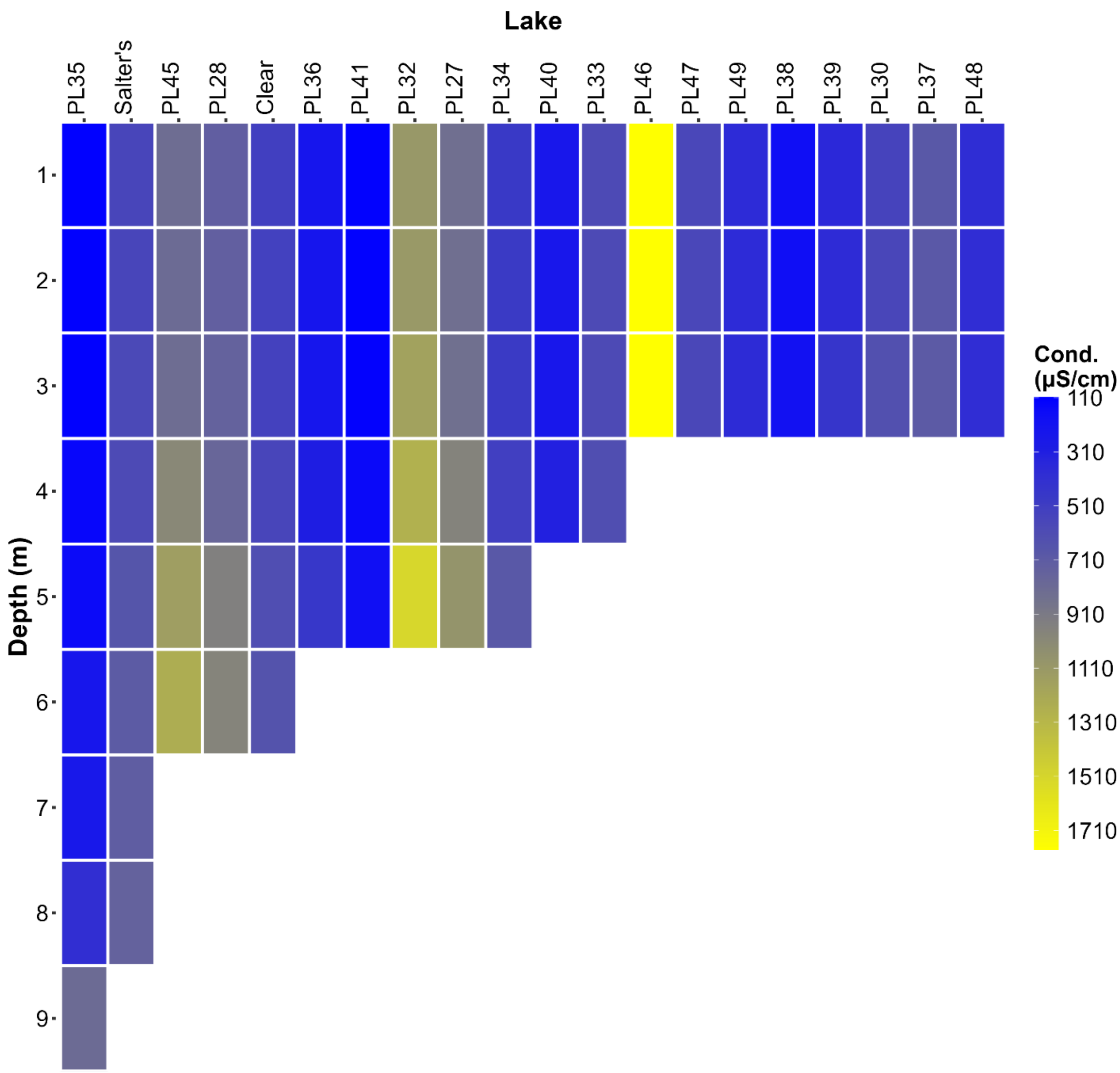


Figure 19. Conductivity (µS/cm) profiles for 20 lakes sampled between July 17th and October 4th, 2023. Coloured boxes reflect the conductivity measurements at each specific depth. Note that while 0.1 m and 0.5 m readings are available for each lake, this figure begins at 1 m depth for visual purposes. Gladu, PL29, PL31, PL42, PL43, PL44, and PL50 have not been included in this figure.

Groundwater

Stable isotopes of oxygen and hydrogen may be used to describe the movement of water into and out of lakes.[18] 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, 2022 and 2023 each of the lakes was sampled for the stable isotopes of hydrogen and oxygen. Samples were submitted to Dr. Brian Smerdon, Dept. of Earth Sciences, University of Alberta for analysis. These results have been used to estimate the through-flow index that describes the fraction of total water inflows that are lost by evaporation. These data and interpretation of results help differentiate lakes that are dominated by precipitation and local runoff compared to lakes that are more influenced by groundwater. These isotopic data will be further analyzed and published in a future report.

The oxygen isotope ratio is denoted as $\delta^{18}O$ in parts per thousand (‰). Between 2021-2023, 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 20). It is likely that the lakes with more negative values (indicated in red) are better connected to a groundwater source. These results suggest that the oligotrophic lakes of the northeast are less evaporated and have a more significant groundwater supply.

An overhead drone photograph of Gerharts Lake. Photograph taken by Dave Mussell, 2023

[18] 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

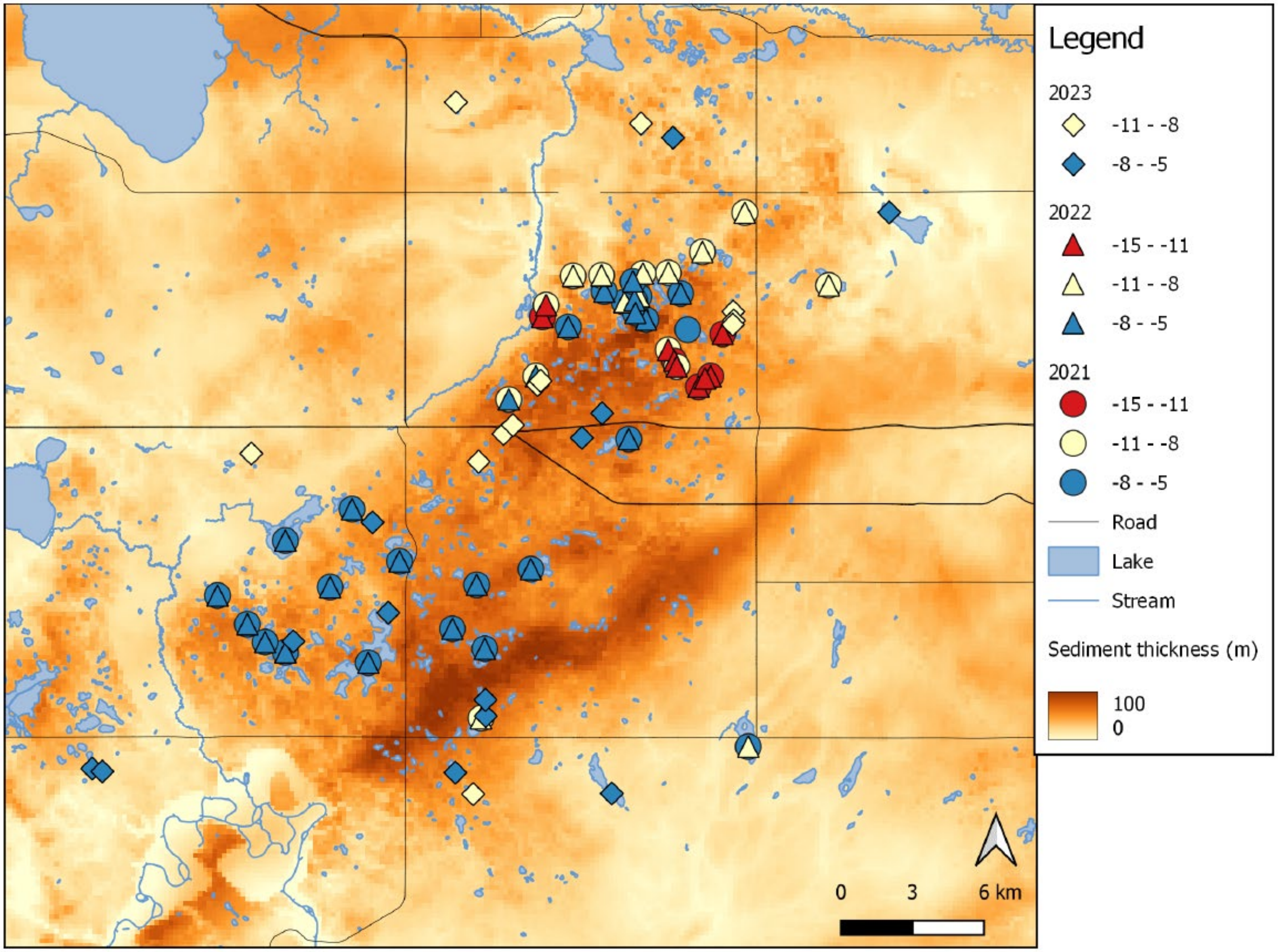


Figure 20. The oxygen isotope ratio ($\delta^{18}O$) in parts per thousand (‰) for 77 lakes sampled in the Carvel Pitted Delta between 2021-2023. It is likely that the lakes with more negative values (indicated in red) are better connected to a groundwater source.

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 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 2024 is built on that of the four previous years to achieve a better understanding of the general limnology of the lakes in the study area. Another priority for 2024-25 is to summarize the available information for all 77 lakes sampled to date. This summary will include information on water quality, bathymetry, watershed delineations, land cover, and groundwater. The project team will be developing additional communication tools including an enhanced video of the Carvel Pitted Delta featuring interviews with landowners and project partners. Both products are intended to inform and motivate local landowners, the general public, and decision-makers with Parkland County and the Government of Alberta.

The lush cattail growth on the shores of Clear Lake. Photographed by David Trew, 2023.

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) and the Land Stewardship Centre of Canada (LSCC). 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, Jenna Maccagno and Dr. Dan Alessi, University of Alberta, conducted the lake water isotope components of the study. 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 acknowledge the assistance of Devon Shouldice of ALMS for the preparation of the maps in this report and the assistance of Dr. Eric Neilson in the preparation of the detailed regional map which has been utilized in many public briefings. Once again, the many landowners who enabled access to these lakes are gratefully acknowledged. The ongoing support and encouragement of Parkland County Council and staff are also gratefully acknowledged.

This report was prepared by Bradley Peter (ALMS), David Trew (MLMA), Dave Mussell (MLMA), Walter Neilson (MLMA) and Dr. Brian Smerdon (University of Alberta)

A view from the south shore of Mere Lake. Photographed by David Trew, 2023

Appendix

Appendix Table 1. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 27 lakes sampled in the Carvel Pitted Delta region.

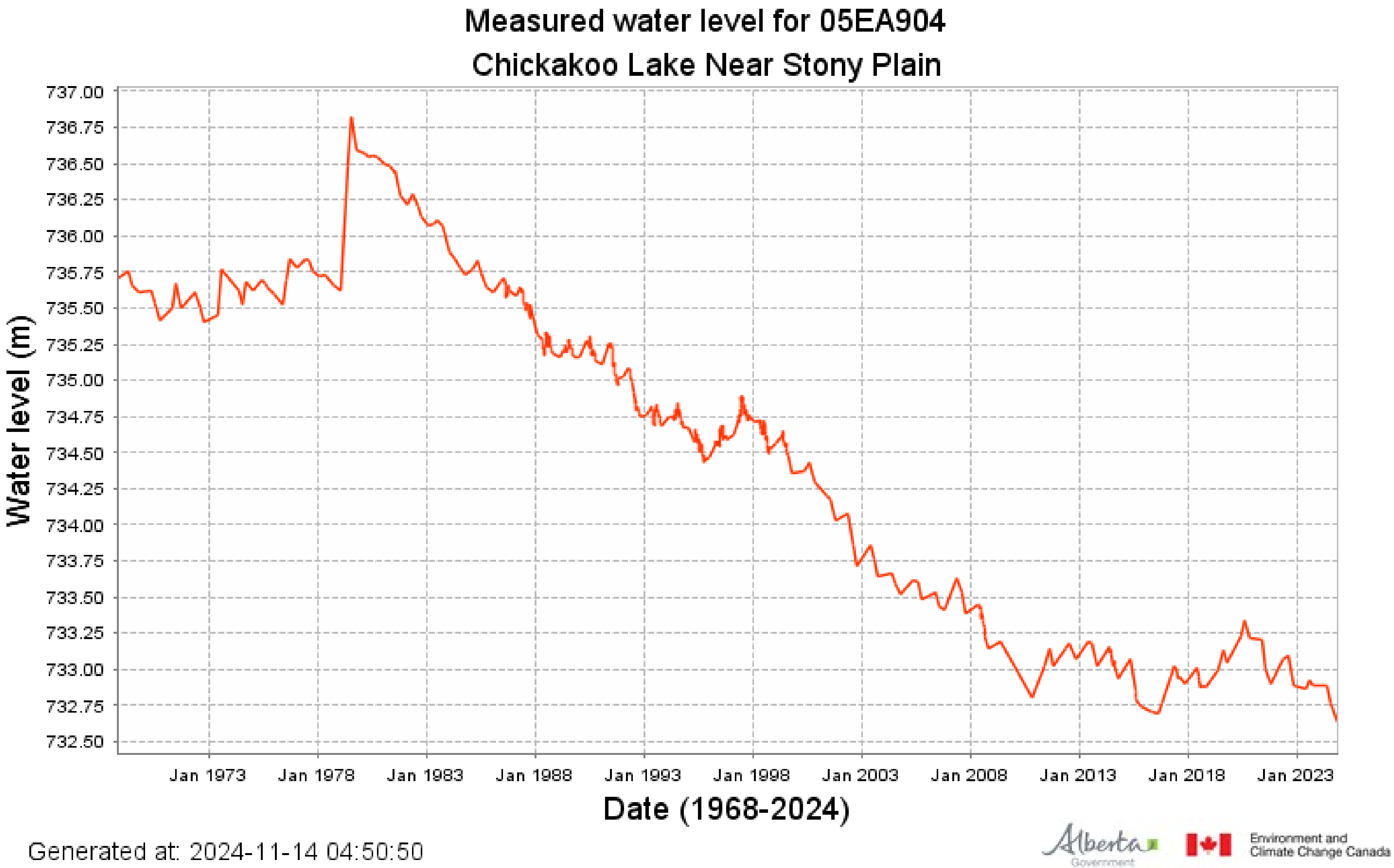
Table	Clear	Gladu	PL27	PL28	PL29	PL30	PL31	PL32	PL33
Sample Date	2023-07-20	2023-09-19	2023-07-17	2023-07-20	2023-07-21	2023-07-24	2023-07-24	2023-07-25	2023-07-31
Ca^{2+} (mg/L)	36	47	35	37	47	47	28	130	19
Chl-*a* (µg/L)	69.6	16.8	11.2	5.60	3.60	25.3	2.70	8.30	11.5
Cl^{-} (mg/L)	80	41	3.2	29	14	19	23	5.1	130
CO_3^{2-} (mg/L)	0.5	0.5	12	8.3	11	0.5	9.3	0.5	0.5
Cond. (µS/cm)	532	1236	842	734	682	537	720	1103	590
DOC (mg/L)	22	46	16	26	30	36	54	36	8.7
Hardness (mg/L)	160	350	400	270	220	230	170	590	67
HCO^{3-} (mg/L)	120	460	180	260	92	130	370	170	100
K^{+} (mg/L)	14	40	28	28	33	27	28	16	8.3
Max. Obs. Depth (m)	6.3	0.7	5.7	6.9	1	3.1	0.9	5.9	4.7
Mg^{2+} (mg/L)	16	56	75	42	26	29	25	65	4.8
Microcystin (µg/L)	15.34	0.11	0.05	0.14	0.10	3.50	0.05	0.99	0.05
Na^{+} (mg/L)	37	150	23	49	29	12	69	21	86
NH_3-N (µg/L)	57	96	25	120	75	45	180	170	20
NO_3+NO_2 (µg/L)	2.1	2.1	2.1	5.2	2.1	2.1	2.1	2.1	2.1
pH	7.34	8.1	8.66	8.42	8.9	8.01	8.45	8.03	7.17
Secchi Depth (m)	0.6	0.7	1.3	2.7	1	0.7	0.9	2.1	2.4
Si^{4+} (mg/L)	5.8	21	0.77	1.2	9.3	6.6	8.9	9.8	1.2
SO_4^{2-} (mg/L)	46	280	280	130	210	170	41	470	3.1
Surface Area (ha)	23.98	112.02	12.99	5.9	56.46	5.76	65.13	13.42	3.58
TDP (µg/L)	290	860	550	450	430	370	410	800	300
TKN (mg/L)	3.3	3.6	1.8	1.5	1.6	2.8	3	2.4	1.1
TN (mg/L)	3.3	3.6	1.8	1.5	1.6	2.8	3	2.4	1.1
Total Alkalinity (mg/L)	99	380	170	230	94	110	320	140	83
TP (µg/L)	140	92	29	32	62	110	300	47	32
TP Bottom (µg/L)	600	NA	140	730	NA	150	NA	500	150
TSS (mg/L)	16	3.4	4	1.1	1.6	8.3	1.2	1.9	2.6

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 27 lakes sampled in the Carvel Pitted Delta region.

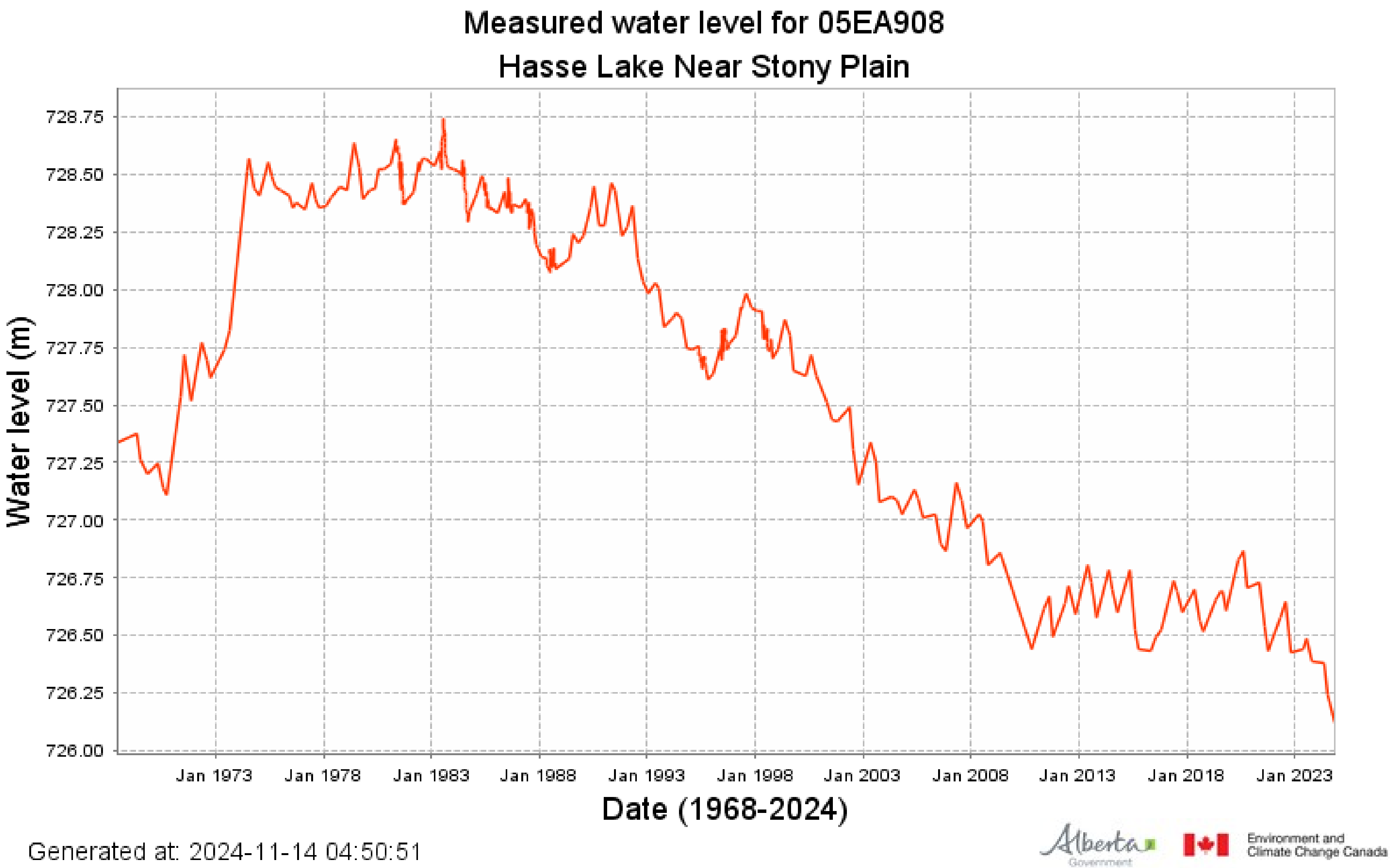
Table	PL34	PL35	PL36	PL37	PL38	PL39	PL40	PL41	PL42
Sample Date	2023-07-31	2023-08-01	2023-08-01	2023-08-03	2023-08-03	2023-08-04	2023-08-14	2023-08-14	2023-08-15
Ca^{2+} (mg/L)	18	10	22	79	17	59	26	9.7	37
Chl-*a* (µg/L)	25.8	3.50	4.00	19.7	25.1	55.6	39.8	4.30	1.90
Cl^{-} (mg/L)	100	3.5	20	19	4.7	7.5	6.1	9.6	23
CO_3^{2-} (mg/L)	0.5	0.5	0.5	0.5	0.5	5.3	0.5	0.5	0.5
Cond. (µS/cm)	488.2	112	230	686	173	3556	242	119	5.32
DOC (mg/L)	8.3	9.8	8.8	18	13	21	26	9.3	27
Hardness (mg/L)	65	39	85	350	68	210	100	37	230
HCO^{3-} (mg/L)	99	67	110	210	99	190	150	57	180
K^{+} (mg/L)	12	11	9.7	25	21	20	21	14	5.6
Max. Obs. Depth (m)	5.5	9.7	6.2	3.1	3.6	3.6	4.9	6	NA
Mg^{2+} (mg/L)	4.9	3.4	7	37	6	14	9.6	3.1	33
Microcystin (µg/L)	0.05	0.05	0.05	0.48	0.05	13.47	0.19	0.05	0.05
Na^{+} (mg/L)	64	2.1	8.2	21	2.4	4.6	3.4	6.1	31
NH_3-N (µg/L)	7.5	24	7.5	1100	41	58	450	560	380
NO_3+NO_2 (µg/L)	2.1	2.1	2.1	190	2.1	2.1	16	2.1	5.6
pH	7.31	6.94	7.1	7.98	7	8.45	7.49	6.83	8.21
Secchi Depth (m)	1	3.1	3.4	2.2	1.7	0.8	1.5	3.2	NA
Si^{4+} (mg/L)	0.17	0.6	1.2	20	1.3	7.1	0.77	0.19	5.5
SO_4^{2-} (mg/L)	1.5	0.5	4.5	170	0.5	29	5.8	0.5	120
Surface Area (ha)	3.8	3.04	0.78	16.89	2.8	6.48	4.29	2.24	2.04
TDP (µg/L)	250	64	120	480	100	240	150	71	350
TKN (mg/L)	1.3	1.1	1	3.7	2.3	2.9	2.5	1.1	1.4
TN (mg/L)	1.3	1.1	1	3.8	2.3	2.9	2.5	1.1	1.5
Total Alkalinity (mg/L)	81	55	86	170	81	160	120	47	140
TP (µg/L)	49	16	13	220	74	360	63	17	8
TP Bottom (µg/L)	210	610	58	310	140	660	230	53	NA
TSS (mg/L)	4.7	0.5	0.5	1.9	3.8	13	5.6	1.1	0.5

Appendix Table 1 continued. Sample date, Secchi depth, water quality parameters, lake surface area, and maximum observed depth for 27 lakes sampled in the Carvel Pitted Delta region.

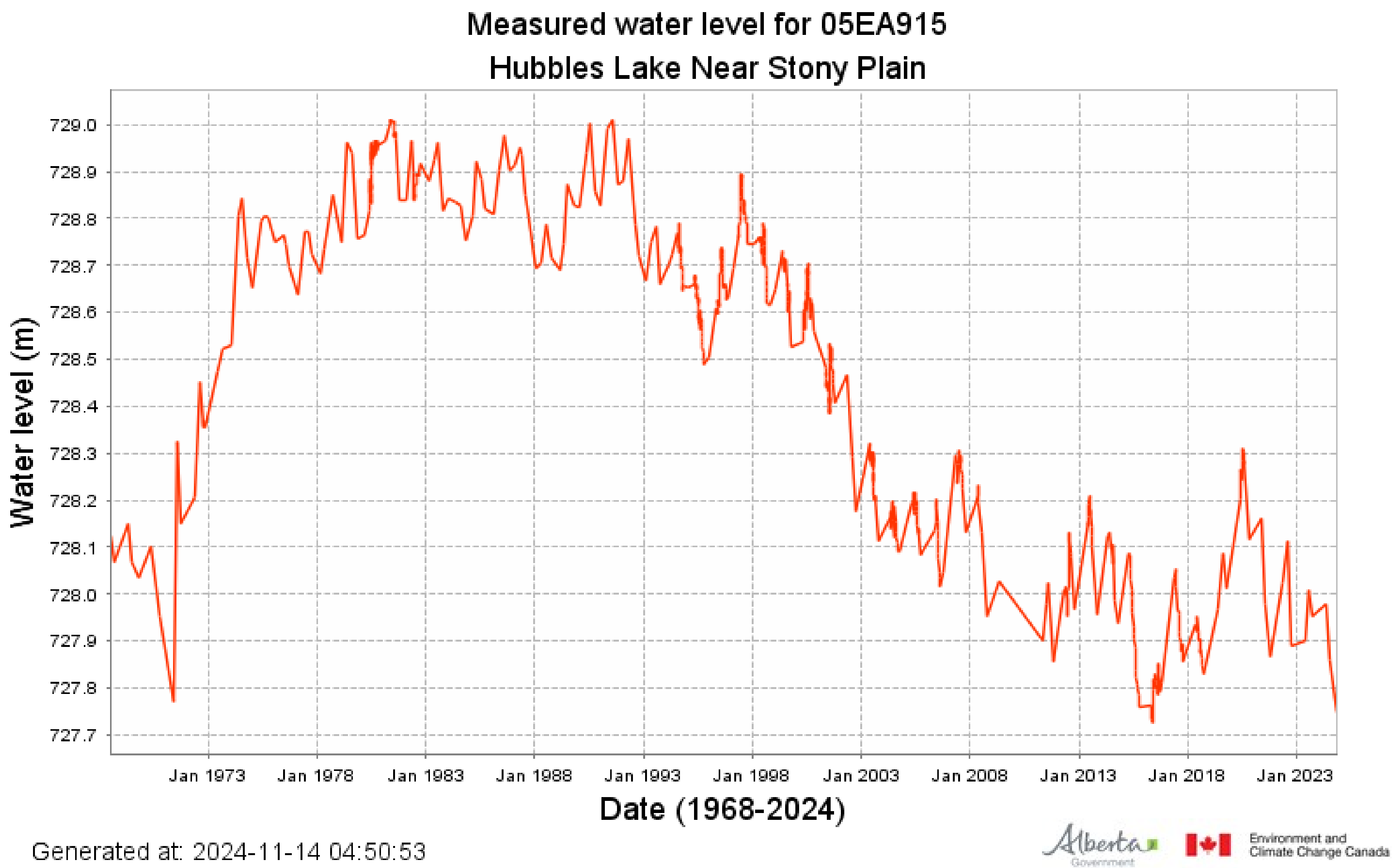
Table	PL43	PL44	PL45	PL46	PL47	PL48	PL49	PL50	Salter's
Sample Date	2023-08-15	2023-08-15	2023-08-30	2023-09-14	2023-09-15	2023-09-26	2023-10-03	2023-10-04	2023-07-25
Ca^{2+} (mg/L)	80	69	97	130	72	35	32	6.3	47
Chl-*a* (µg/L)	2.00	1.50	9.50	28.0	103.0	59.3	17.3	36.7	12.8
Cl^{-} (mg/L)	3.8	2.9	2.6	24	11	11	6.2	13	2.5
CO_3^{2-} (mg/L)	0.5	3.3	0.5	0.5	0.5	0.5	2	0.5	3.2
Cond. (µS/cm)	778	741	827	1778	567	390	375	19	560
DOC (mg/L)	35	30	22	29	31	23	19	15	20
Hardness (mg/L)	380	340	420	680	270	170	180	22	250
HCO^{3-} (mg/L)	160	120	270	230	170	230	220	46	190
K^{+} (mg/L)	5.9	5.9	5.8	36	25	19	19	14	14
Max. Obs. Depth (m)	NA	NA	7	4	3.9	3.1	3.7	NA	8.7
Mg^{2+} (mg/L)	44	40	44	85	22	21	25	1.6	32
Microcystin (µg/L)	0.05	0.05	0.10	0.05	18.29	0.05	0.15	NA	0.21
Na^{+} (mg/L)	30	34	13	150	11	9.4	8.5	5.9	23
NH_3-N (µg/L)	190	120	370	67	220	32	390	1500	27
NO_3+NO_2 (µg/L)	8.6	8.5	8	5.1	28	2.1	2.1	7.4	7.7
pH	8.19	8.29	7.89	6.93	6.8	7.75	8.38	7.4	8.36
Secchi Depth (m)	NA	NA	2.4	0.9	0.5	0.7	1.2	NA	2.3
Si^{4+} (mg/L)	20	21	23	1.3	9.6	18	9.3	1.6	1.7
SO_4^{2-} (mg/L)	290	290	280	880	160	13	8	0.5	150
Surface Area (ha)	0.57	1.39	3.79	7.69	17.63	3.04	11.27	1.53	12.3
TDP (µg/L)	550	530	600	1400	400	240	220	68	370
TKN (mg/L)	2.1	2	2	3	3.9	2.4	2.2	3.4	1.9
TN (mg/L)	2.1	2	2	3	4	2.4	2.2	3.4	1.9
Total Alkalinity (mg/L)	130	110	220	180	140	190	190	38	160
TP (µg/L)	30	11	24	84	200	81	38	210	31
TP Bottom (µg/L)	NA	NA	1400	81	320	92	30	NA	1100
TSS (mg/L)	1.8	0.5	1.5	7.5	17	8.9	4.1	7.5	1.2



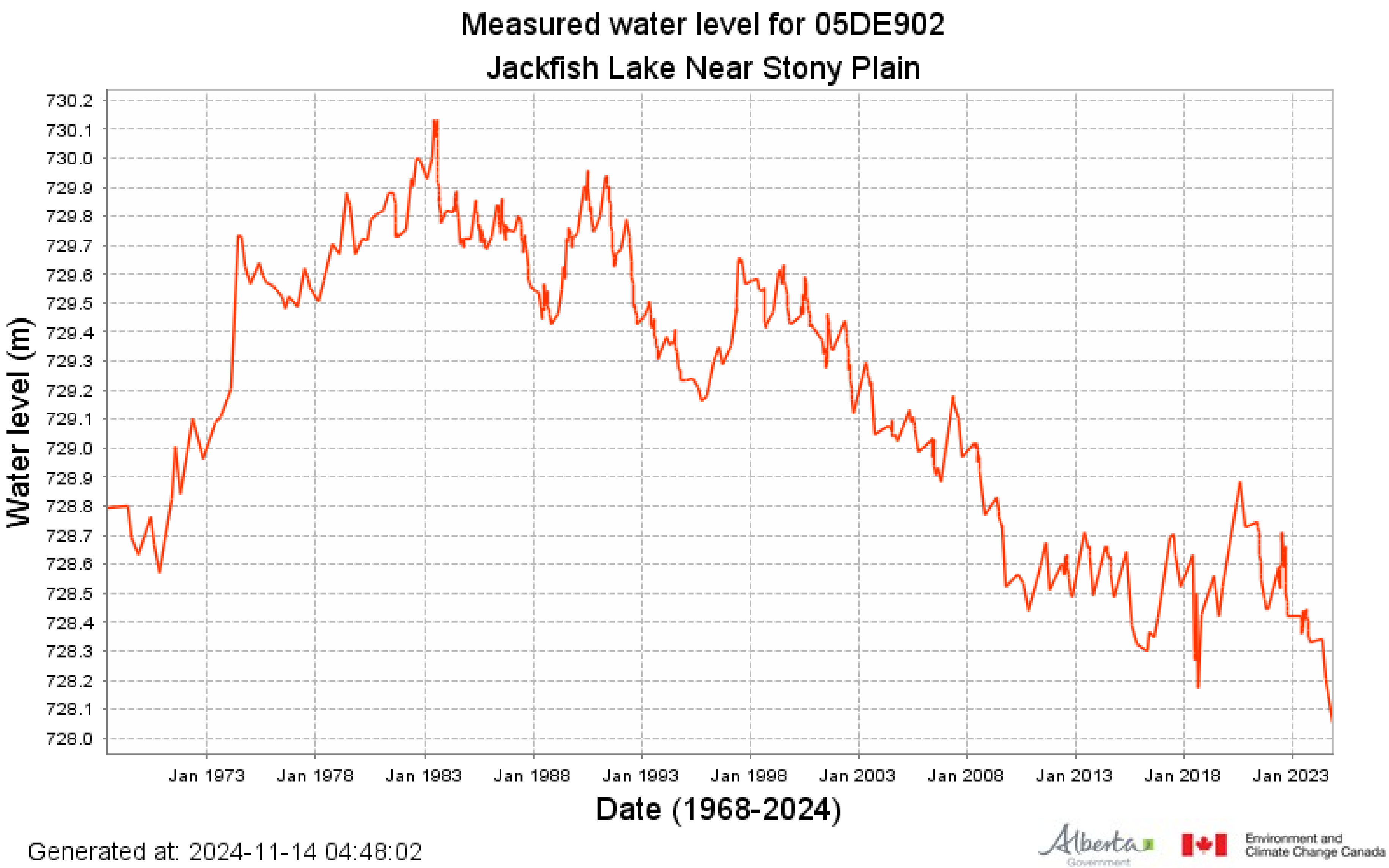
Appendix Figure 1. Water levels in meters above sea level for Chickakoo Lake from 1968-2024. Data obtained from rivers.alberta.ca.



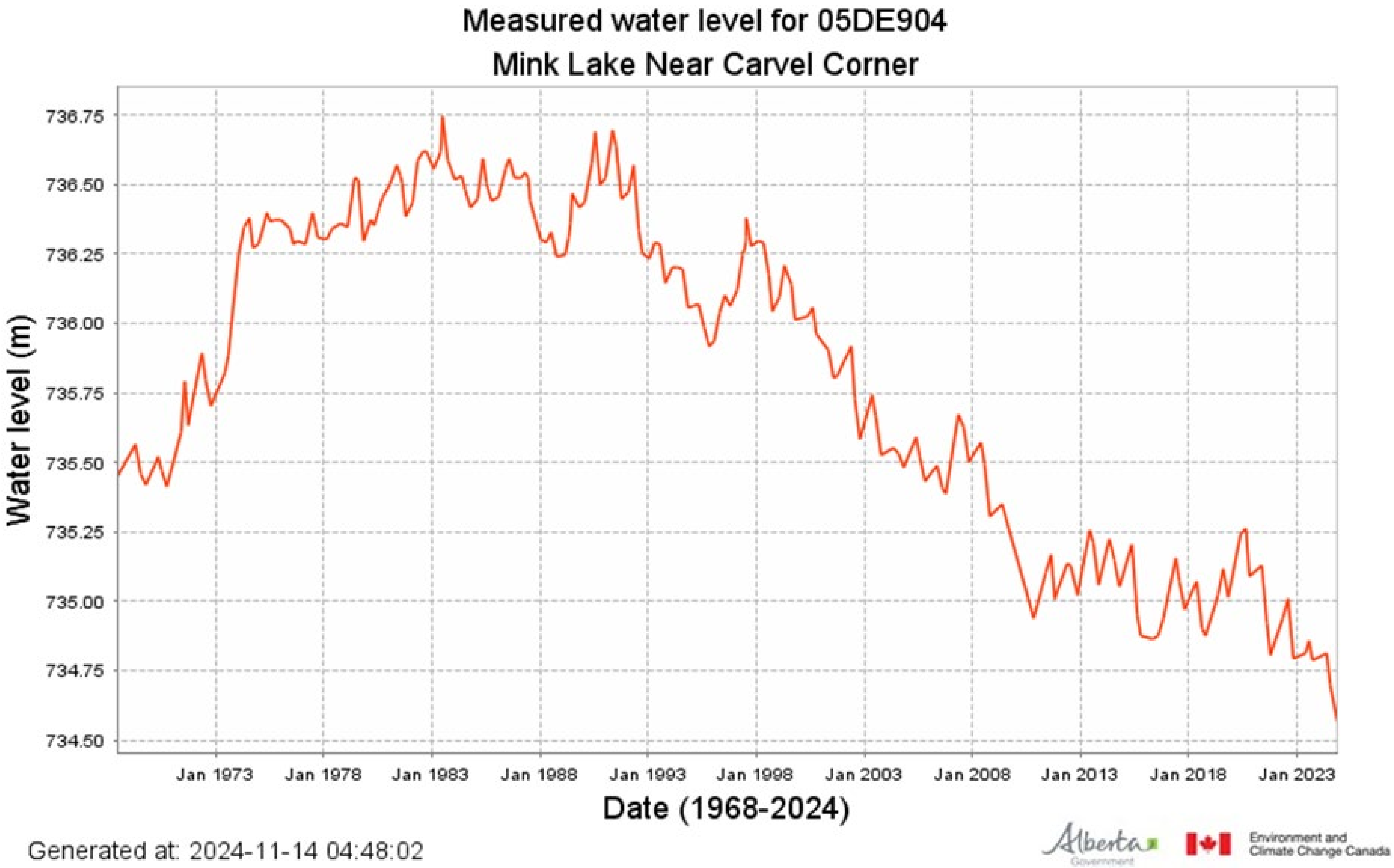
Appendix Figure 2. Water levels in meters above sea level for Hasse Lake from 1968-2024. Data obtained from rivers.alberta.ca.



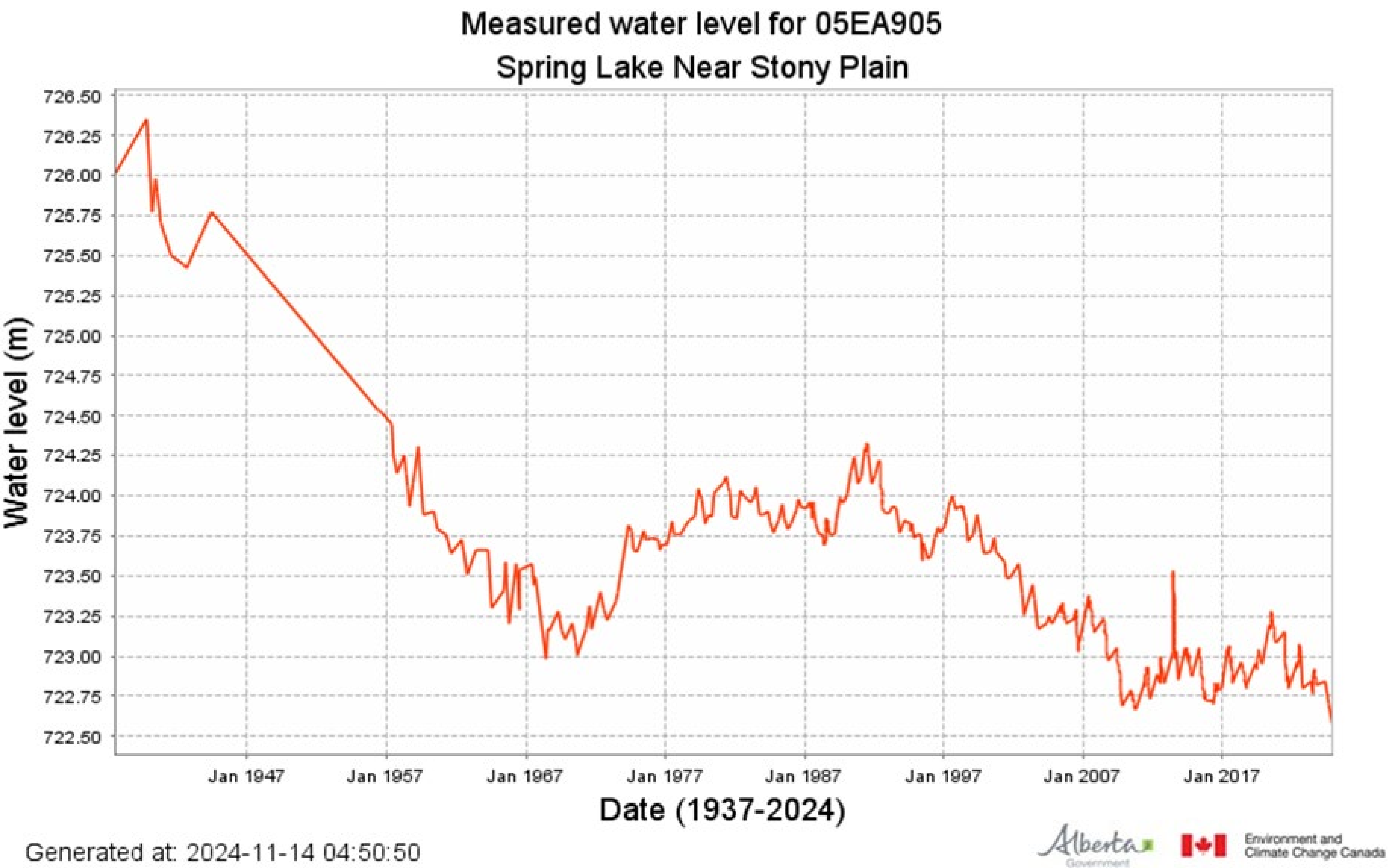
Appendix Figure 3. Water levels in meters above sea level for Hubbles Lake from 1968-2024. Data obtained from rivers.alberta.ca.



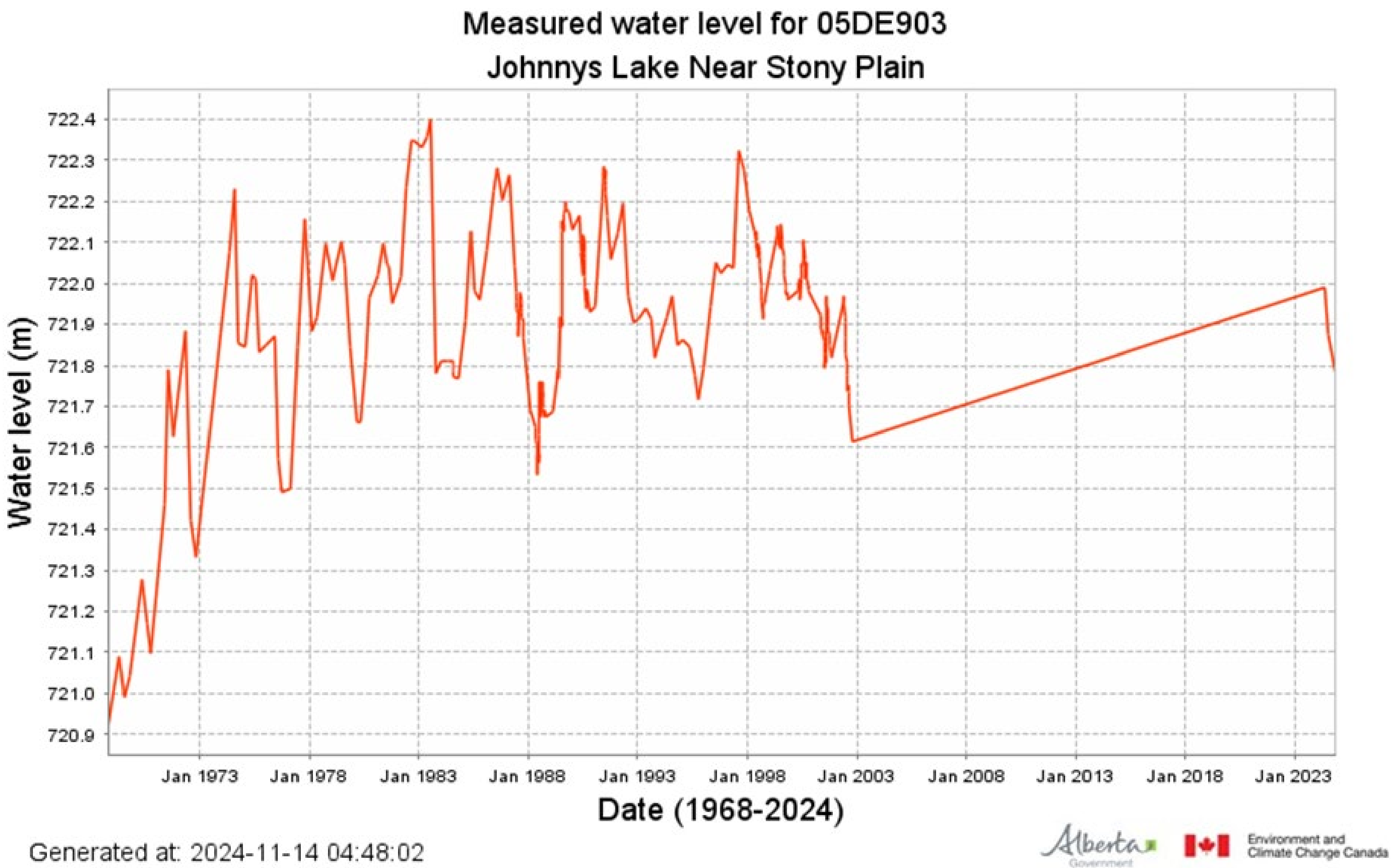
Appendix Figure 4. Water levels in meters above sea level for Jackfish Lake from 1968-2024. Data obtained from rivers.alberta.ca.



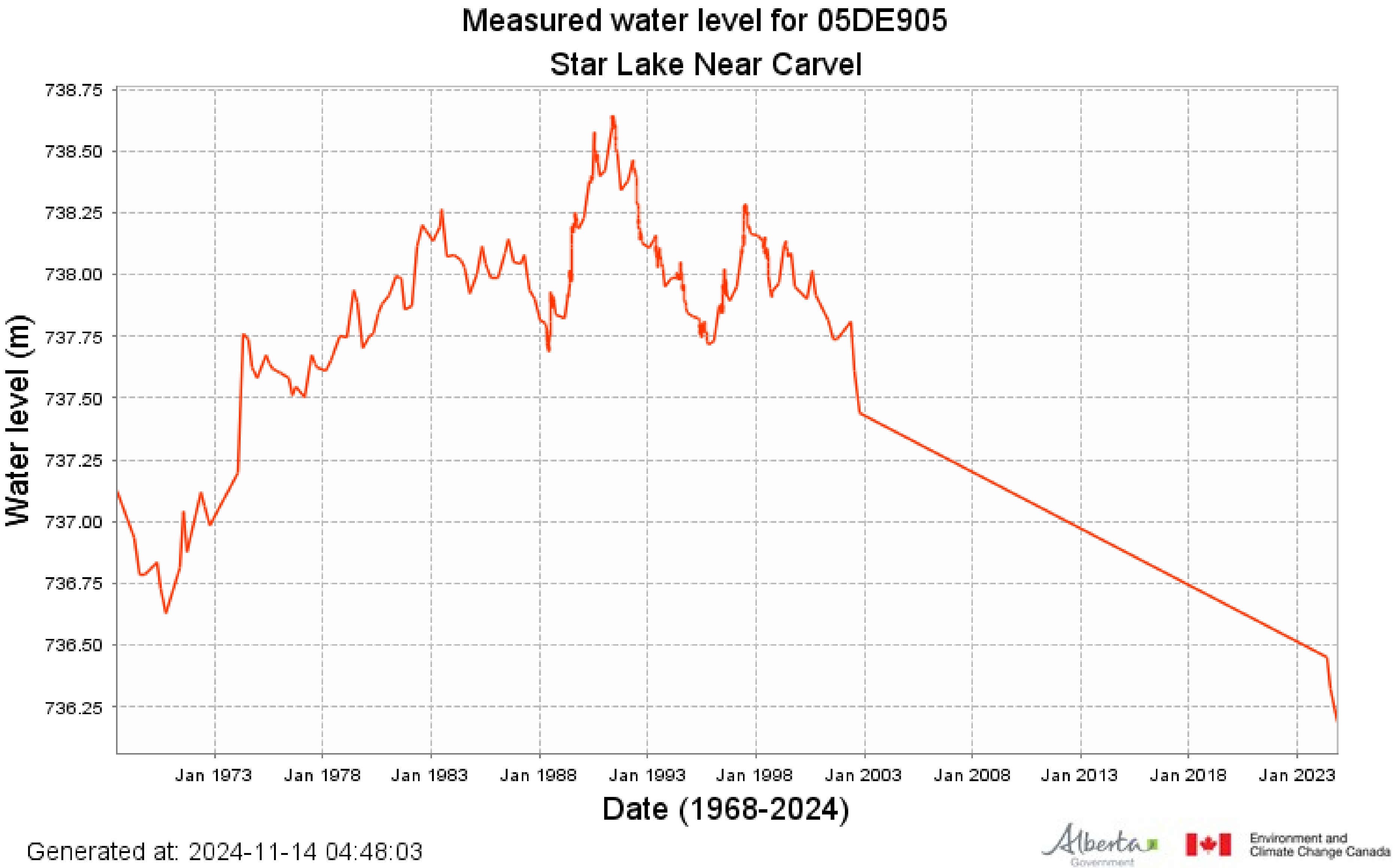
Appendix Figure 5. Water levels in meters above sea level for Mink Lake from 1968-2024. Data obtained from rivers.alberta.ca.



Appendix Figure 6. Water levels in meters above sea level for Spring Lake from 1937-2024. Data obtained from rivers.alberta.ca.



Appendix Figure 7. Water levels in meters above sea level for Johnnys Lake from 1968-2024. Data obtained from rivers.alberta.ca.



Appendix Figure 8. Water levels in meters above sea level for Star Lake from 1968-2024. Data obtained from rivers.alberta.ca.