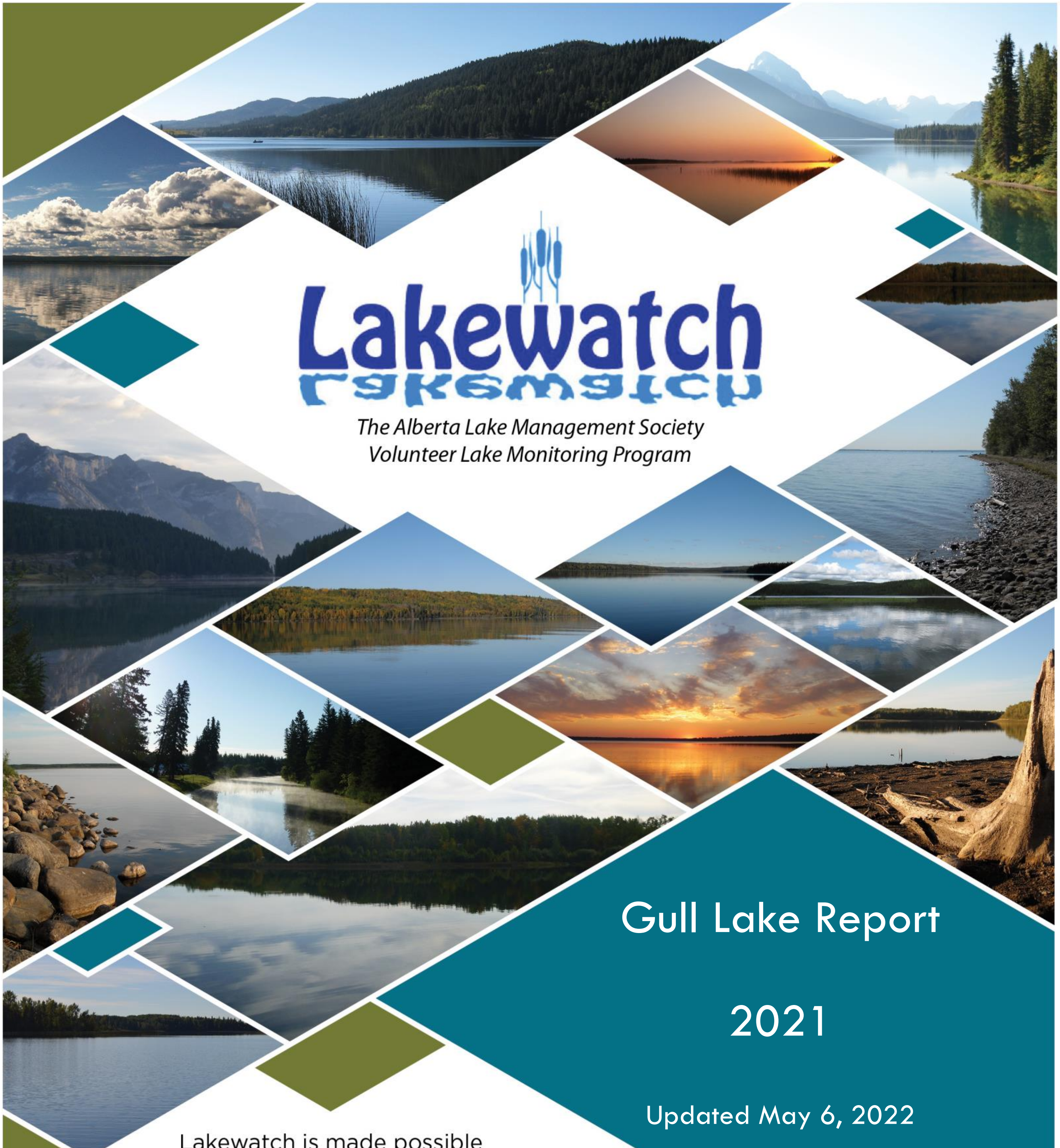


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Gull Lake Report

2021

Updated May 6, 2022

Lakewatch is made possible with support from:

Alberta, LICA Environmental Stewards, Pigeon Lake Watershed Association, MD 61 Wainwright, Alberta Ecotrust, Discover Hardisty – More Than You Imagine, Municipal District Bonnyville No. 87

Classification: Protected A

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

LakeWatch has several important objectives, one of which is to collect and interpret water quality data from Alberta's Lakes. Equally important is educating lake users about aquatic environments, encouraging public involvement in lake management, and facilitating cooperation and partnerships between government, industry, the scientific community and lake users. LakeWatch reports are designed to summarize basic lake data in understandable terms for the widest audience, and are not meant to be a complete synopsis of information about specific lakes. Additional information is available for many lakes that have been included in LakeWatch, and readers requiring more information are encouraged to seek those sources.

ALMS would like to thank all who express interest in Alberta's aquatic environments, and particularly those who have participated in the LakeWatch program. These leaders in stewardship give us hope that our water resources will not be the limiting factor in the health of our environment.

If you require data from this report, please contact ALMS for the raw data files.

ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Jim Moorehead for their commitment to collecting data at Gull Lake. We would also like to thank Keri Malanchuk and Brittany Onysyk, who were summer technicians in 2021. Executive Director Bradley Peter and Program Manager Caleb Sinn were instrumental in planning and organizing the field program. This report was prepared by Caleb Sinn and Bradley Peter.

GULL LAKE

Photo of Gull Lake by Ageleky Bouzetos, 2016.

Gull Lake has a large surface area (80.6 km^2) and is considered to be a shallow lake (mean depth = 5.4 meters; Figure 1). The lake is situated approximately 17 km east of the town of Lacombe and 136 km south from the city of Edmonton. As this lake is situated between two large cities (Edmonton and Calgary), it is heavily populated and visited frequently. The surrounding region of Gull Lake was settled in 1805. At the turn of the 20th century, a lumber industry was established at the lake. A steamboat was used for the sawmill operation as well as for the transportation of passengers. By 1908, the lake served as a hydroelectric reservoir; however, in 1910, the dam was destroyed. Following the destruction of the dam, Gull Lake water levels continually decreased and were a cause for concern. Although the community of Gull Lake had a dam built at the outlet in 1921, the water level nonetheless continued to decrease. The dam is now located approximately 1.6 km from shore, and the water level dropped, on average, ~6 cm/yr from 1924 to 1968. By 1977, a pipeline and canal was built, diverting water from the Blindman River to increase water levels when they fell below a specified target. The diversion pumps were operated in 2010 and water was transferred into Gull Lake. The lake is known for its clear water and sandy beaches. It also supports moderate sport fishing of predominantly northern pike, walleye, and whitefish.

Gull Lake supports many recreational activities such as boating, swimming, fishing, and sailing. There are many cottages along the lake's shoreline and new subdivisions and commercial campgrounds are being proposed in upland areas within the watershed. Aspen Beach Provincial Park lies on the southwest shore of the lake, which was established in 1932, making it one of the first parks of the Alberta park system. The Provincial Park contains two campgrounds, a boat launch, beaches, and day use areas. There are marinas and boat launches located in various subdivisions around the lakeshore. The remaining majority of the watershed is used for agricultural activities and cattle production. Gull Lake lies within two of Alberta's natural subregions: the Boreal Forest natural region on the northern half and the Parkland natural region on the southern half. They are within the Dry Mixedwood and Central Parkland sub-regions respectively. The dominant trees are trembling aspen, balsam poplar, white spruce, and willow in between large cultivated areas.

The watershed area for Gull Lake is 211.16 km^2 and the lake area is 86.31 km^2. The lake to watershed ratio of Gull Lake is 1:2. A map of the Gull Lake watershed area can be found at http://alms.ca/wp-content/uploads/2016/12/Gull.pdf.

WATER CHEMISTRY

ALMS measures a suite of water chemistry parameters. Phosphorus, nitrogen, and chlorophyll-a are important because they are indicators of eutrophication, or excess nutrients, which can lead to harmful algal/cyanobacteria blooms. One direct measure of harmful cyanobacteria blooms are Microcystins, a common group of toxins produced by cyanobacteria. See Table 2 for a complete list of parameters.

The average total phosphorus (TP) concentration for Gull Lake was 17 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. This value falls on the lower range of historical averages. TP changed very little through the season ranging between 16 – 29 µg/L (Figure 1).

Average chlorophyll-*a* concentration in 2021 was 7.3 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. Chlorophyll-*a* was lowest during the June 29th sampling event at 3.7 µg/L, and then rose slightly and ranged between 7.4 – 9.1 µg/L over the rest of the season.

The average TKN concentration was 1.9 mg/L (Table 2) and displayed steady levels through the season, but increased slightly to the seasonal maximum of 2.2 mg/L on September 21st (Figure 2).

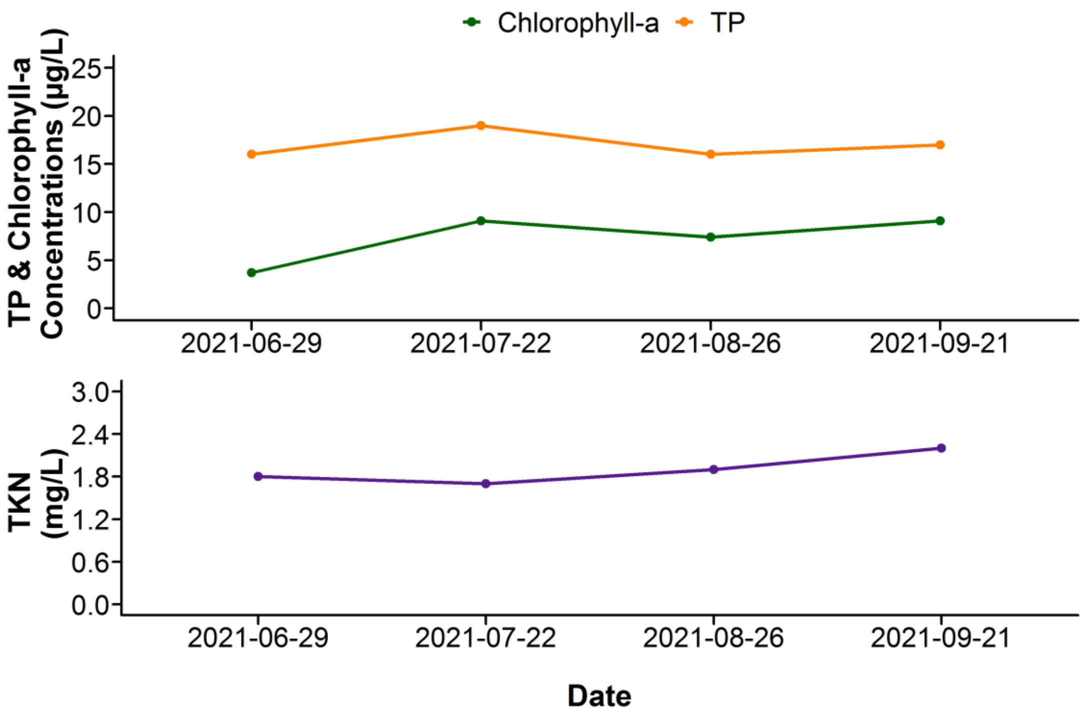


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Gull Lake.

Average pH was measured as 9.16 in 2021, buffered by high alkalinity (702 mg/L $CaCO_3$) and bicarbonate (600 mg/L HCO_3). Aside from bicarbonate, major ions with higher relative abundance were calcium, magnesium, sulphate and carbonate, and together contributed to a high conductivity of 1400 µS/cm (Figure 2, top; Table 2). Gull Lake displayed moderate to higher ion levels compared to other LakeWatch lakes sampled in 2021, with the exception of calcium, where Gull Lake displayed the lowest level of any lake in 2021 (Figure 2, bottom). Low calcium levels were likely due to a 'whiting' event which caused calcium to precipitate out of the water column in 2021.

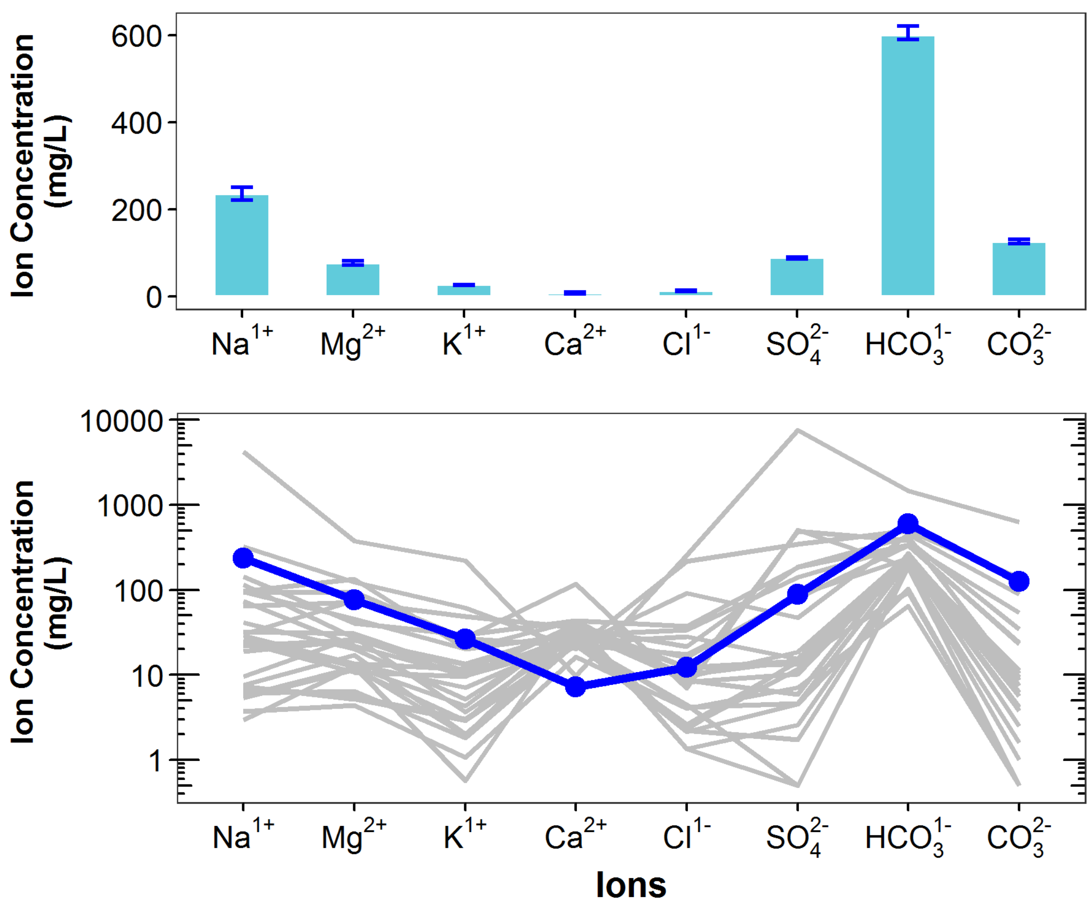


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Gull Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Gull Lake (blue line) compared to 25 lake basins (gray lines) sampled through the LakeWatch program in 2021 (note $\log_{10}$ scale on y-axis of bottom figure).

METALS

Metals will naturally be present in aquatic environments due to in-lake processes or the erosion of rocks, or introduced to the environment from human activities such as urban, agricultural, or industrial developments. Many metals have a unique guideline as they may become toxic at higher concentrations. Where current metal data are not available, historical concentrations for 27 metals have been provided (Table 3).

Metals were not measured at Gull Lake in 2021, but Table 3 displays historical metal concentrations.

WATER CLARITY AND EUPHOTIC DEPTH

Water clarity is influenced by suspended materials, both living and dead, as well as dissolved colored compounds in the water column. During the melting of snow and ice in spring, lake water can become turbid (cloudy) from silt transported into the lake. Lake water usually clears in late spring, but then becomes more turbid with increased algal growth as the summer progresses. The easiest and most widely used measure of lake water clarity is the Secchi depth. Two times the Secchi depth equals the euphotic depth – the depth to which there is enough light for photosynthesis.

The average euphotic depth of Gull Lake in 2021 was 2.82 m, corresponding to an average Secchi depth of 1.41 m (Table 2). Euphotic depth varied over the season, ranging from as deep as 6.1 m on June 29th to as shallow as 0.8 m on July 22nd (Figure 3). Generally, relatively lower water clarity levels as seen at Gull Lake in 2021 would indicate significantly increase algal growth, although chlorophyll-a levels were quite low for the lake. Rather, the low water clarity was due to the presence of a 'whiting event,' which changes the water chemistry such that calcium carbonate forms in high abundance, and precipitates giving the change in water colour and clarity. See Photos 1 & 2 below to see what whiting event looks like from space, and on the water.

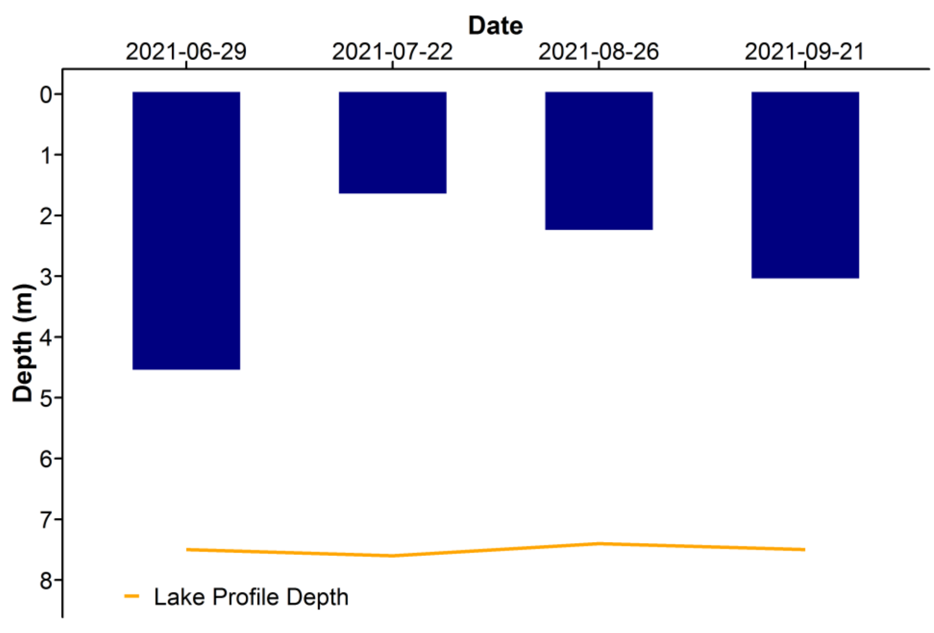


Figure 3. Euphotic depth values measured four times over the course of the summer at Gull Lake in 2021.

Photo 1. Bright blue water at Gull Lake in summer 2021 as a result of a 'whiting event.'

Photo 2. 'Whiting event' at Gull Lake (top right) compared to Sylvan Lake (bottom left) on August 29th, 2021. Satellite imagery from the European Space Agency's Sentinel 2 satellites.

WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen (DO) profiles in the water column can provide information on water quality and fish habitat. The depth of the thermocline is important in determining the depth to which dissolved oxygen from the surface can be mixed. Please refer to the end of this report for descriptions of technical terms.

Surface temperatures of Gull Lake varied throughout the summer, with the June 29th sampling date having the warmest temperatures at 22.4°C (Figure 4a). The lake was mixed during all sampling trips, except the June sampling event, in which the lake displayed slight stratification. The lake cooled as the season progressed, with the September whole-column temperature being approximately 13°C.

Gull Lake was well oxygenated in all sampling dates, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 4b). However, whole lake levels were distinctly lower during the July 22nd sampling event. The solar radiation levels were quite low for a sustained period leading up to July 22nd (Figure 6), indicating that the relatively lower oxygen levels may have been caused by significant smoky or cloudy conditions, which would have inhibited phytoplankton production of oxygen due to reduced light. The ALMS technician did note during sampling that smoke had been heavy in the area in the previous days.

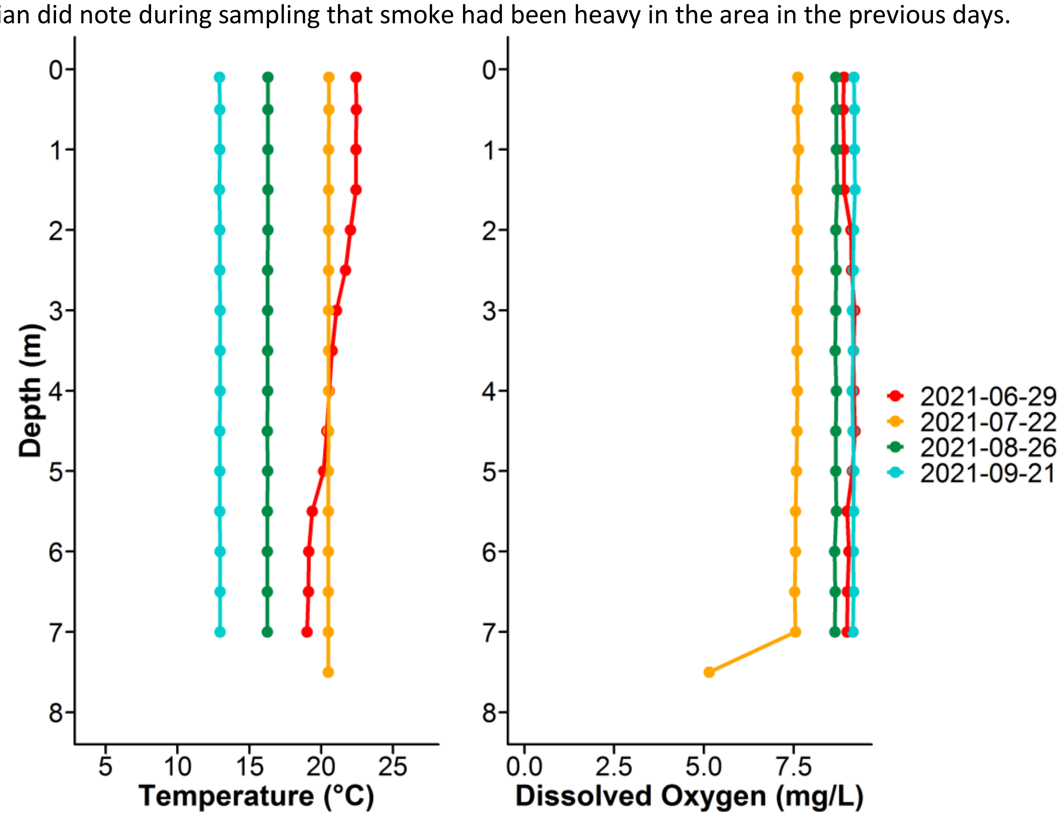


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Gull Lake measured four times over the course of the summer of 2021.

MICROCYSTIN

Microcystins are toxins produced by cyanobacteria (blue-green algae) which, when ingested, can cause severe liver damage. Microcystins are produced by many species of cyanobacteria which are common to Alberta's Lakes, and are thought to be one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 10 μg/L. Blue-green algae advisories are managed by Alberta Health Services. Recreating in algal blooms, even if microcystin concentrations are not above guidelines, is not recommended.

Microcystin levels in Gull Lake fell below the recreational guideline of 10 μg/L during every sampling event in 2021. Even though low levels of microcystin were detected, caution should always be observed when recreating around cyanobacteria.

Table 1. Microcystin concentrations measured four times at Gull Lake in 2021.

Date	Microcystin Concentration (μg/L)
29-Jun-21	0.18
22-Jul-21	0.13
26-Aug-21	0.16
21-Sep-21	0.16
Average	0.16

INVASIVE SPECIES MONITORING

Dreissenid mussels pose a significant concern for Alberta because they impair the function of water conveyance infrastructure and adversely impact the aquatic environment. These invasive mussels can change lake conditions which can then lead to toxic cyanobacteria blooms, decrease the amount of nutrients needed for fish and other native species, and cause millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities. Spiny water flea pose a concern for Alberta because they alter the abundance and diversity of native zooplankton, as they are aggressive zooplankton predators. Through over-predation, they will impact higher trophic levels such as fish. They also disrupt fishing equipment by attaching in large numbers to fishing lines.

Monitoring involved sampling with a 63 μm plankton net at three sample sites, to look for juvenile mussel veligers and spiny water flea in each lake sampled. In 2021, no mussels or spiny water flea were detected at Gull Lake.

Eurasian watermilfoil is a non-native aquatic plant that poses a threat to aquatic habitats in Alberta because it grows in dense mats preventing light penetration through the water column, reduces oxygen levels when the dense mats decompose, and outcompetes native aquatic plants. Eurasian watermilfoil can look similar to the native Northern watermilfoil, thus genetic analysis is ideal for suspect watermilfoil species identification.

No suspect watermilfoil was observed or collected from Gull Lake in 2021.

WATER LEVELS

There are many factors influencing water quantity. Some of these factors include the size of the lake's drainage basin, precipitation, evaporation, water consumption, ground water influences, and the efficiency of the outlet channel structure at removing water from the lake. Requests for water quantity monitoring should go through Alberta Environment and Parks Monitoring and Science division.

Water levels at Gull Lake in 2021 remain below the historical average, and have been declining since 2015.

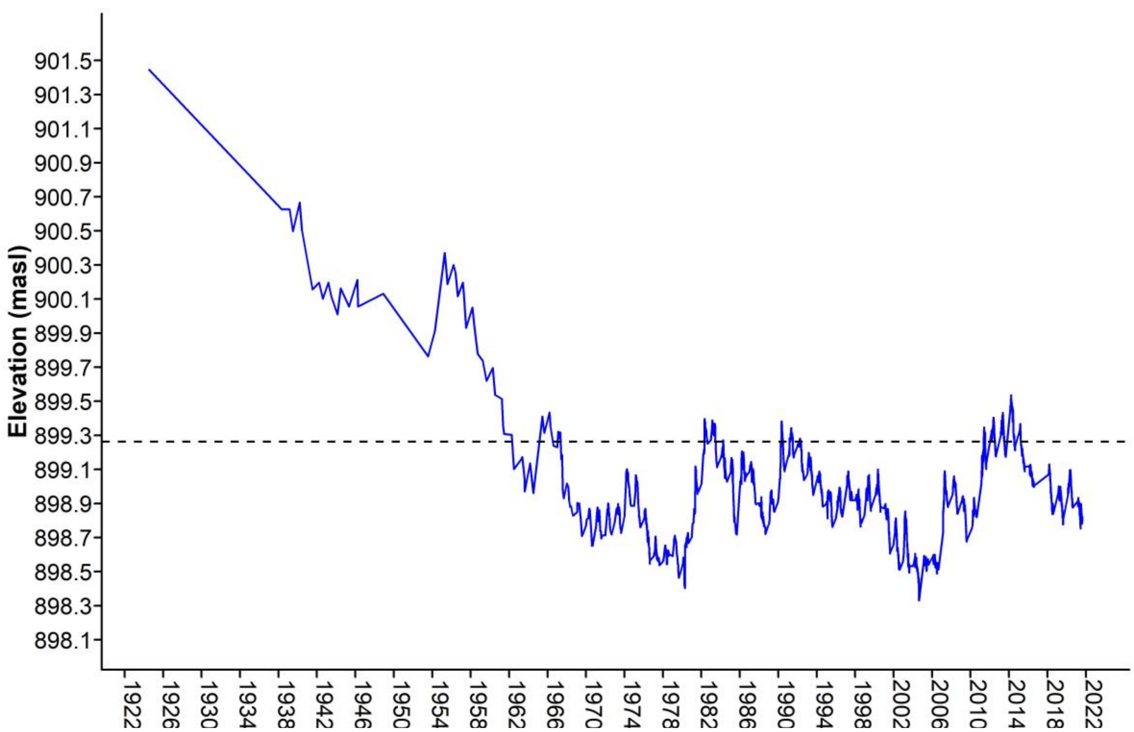


Figure 5. Water levels measured at Gull Lake in metres above sea level (masl) from 1922-2021. Data retrieved from Environment Canada and Alberta Environment and Parks. Black dashed line represents historical yearly average water level.

WEATHER & LAKE STRATIFICATION

Air temperature will directly impact lake temperatures, and result in different temperature layers (stratification) throughout the lake, depending on its depth. Wind will also impact the degree to which a lake mixes, and how it will stratify. The amount of precipitation that falls within a lake's watershed will have important implications, depending on the context of the watershed and the amount of precipitation that has fallen. Solar radiation represents the amount of energy that reaches the earth's surface, and has implications for lake temperature & productivity.

Gull Lake experienced a warmer, slightly drier, windier summer with slightly less solar radiation compared to normal (Figure 6). Slight stratification during the June 29th sampling event occurred during the hottest spell in the summer which followed a few calm days. Following the warm spell in June, whole lake temperatures followed the decreasing trajectory of temperature from July till the end of September.

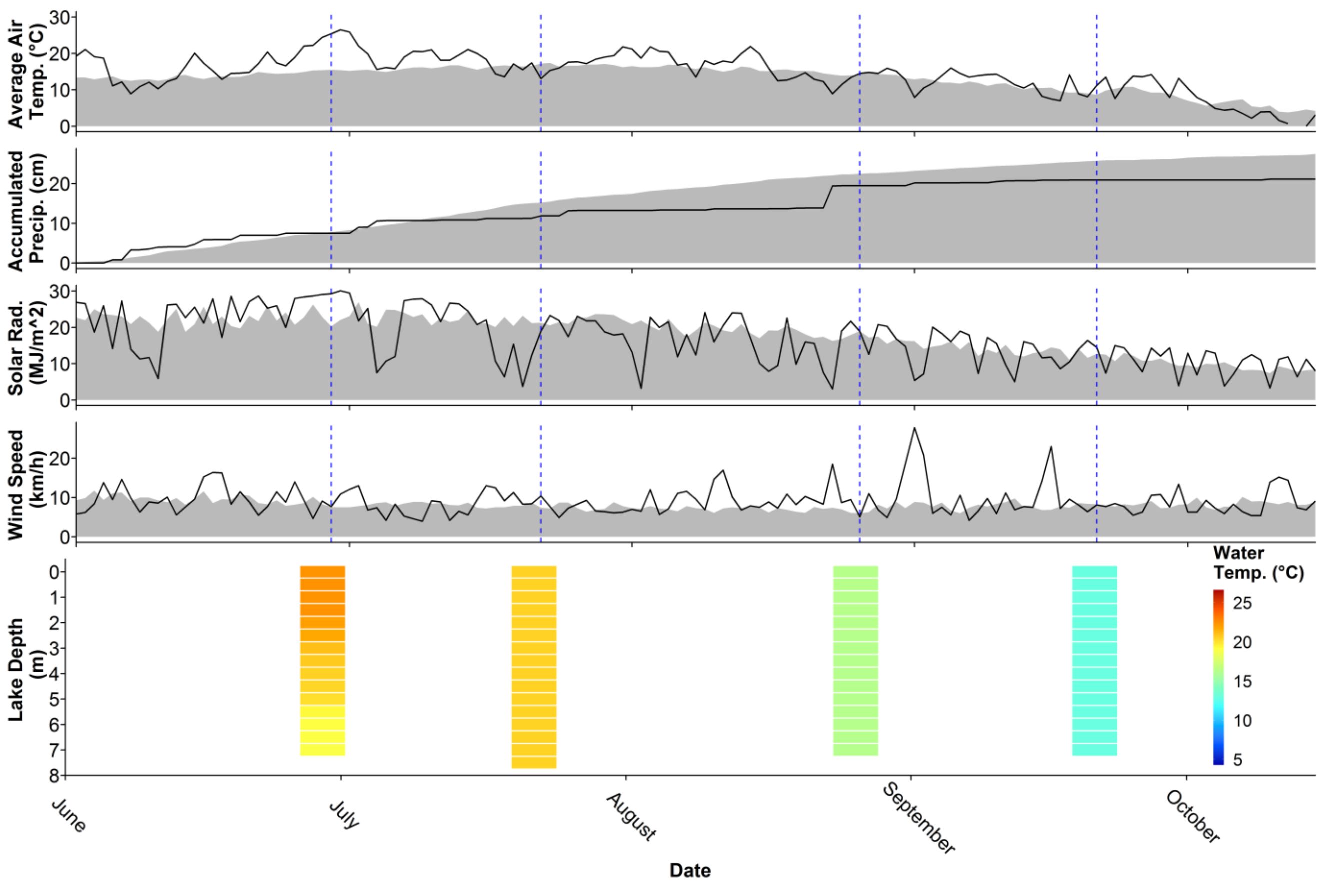


Figure 6. Average air temperature (°C), accumulated precipitation (cm) solar radiation (MJ/m^2), and wind speed (km/h) measured from Lacombe CDA 2, with Gull Lake temperature profiles (°C) at the bottom. Black lines indicate 2021 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Gull Lake over the summer. Further information about the weather data provided is available in the LakeWatch 2021 Methods report. Weather data provided by Agriculture, Forestry and Rural Economic Development, Alberta Climate Information Service (ACIS) https://acis.alberta.ca (retrieved April 2022).

Table 2a. Average Secchi depth and water chemistry values for Gull Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	1983	1984	1985	1987	1988	1989	1990	1991	1992	1993	1994	1995
TP (µg/L)	42	41	26	25	56	49	46	45	47	45	52	47
TDP (µg/L)	/	/	/	/	/	22	/	/	/	/	/	21
Chlorophyll-*a* (µg/L)	7.4	6	6.9	1	12.3	9	8.4	7	9.5	9	13.4	7.4
Secchi depth (m)	2.95	3.12	4.8	6	2.36	2.46	2.3	2.83	2.5	2.43	1.97	2.42
TKN (mg/L)	/	/	/	/	/	1.7	/	/	/	/	/	1.4
NO_2-N and NO_3-N (µg/L)	25	25	25	10	9	2	10	2	746	6	2	2
NH_3-N (µg/L)	/	/	/	/	/	30	/	/	/	/	/	12
DOC (mg/L)	/	/	/	/	/	22	/	/	/	/	/	20
Ca^{2+} (mg/L)	9	9	6	9	10	11	12	12	12	12	12	11
Mg^{2+} (mg/L)	55	61	64	63	70	67	66	67	66	63	66	67
Na^{+} (mg/L)	174	187	190	187	202	199	181	184	190	188	195	198
K^{+} (mg/L)	18	18	19	18	17	19	17	17	18	18	19	19
SO_4^{2-} (mg/L)	69	64	68	90	77	75	75	72	75	75	79	84
Cl^{-} (mg/L)	3	3	4	4	3	4	4	10	4	4	4	4
CO_3^{2-} (mg/L)	78.7	77.4	73.9	65	90	82.1	83	80	79.5	72.5	78.5	75.3
HCO_3^{-} (mg/L)	583	612	620	631	632	631	588	598	696	710	718	651
pH	9.17	9.13	9.1	9	9.09	9.06	9.14	9.11	9.11	9.09	9.05	9.08
Conductivity (µS/cm)	1137	1128	1179	1177	1238	1214	1150	1158	1186	1195	1203	1213
Hardness (mg/L)	251	273	279	281	312	304	298	307	304	290	302	304
TDS (mg/L)	694	720	731	746	781	773	726	738	752	746	769	779
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	609	630	632	626	669	655	620	624	638	642	655	659

Table 2b. Average Secchi depth and water chemistry values for Gull Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	1996	1997	1998	1999	2006	2008	2010	2011	2012	2015	2016	2021
TP (µg/L)	43	38	45	47	36	47	42	39	43	26	16	17
TDP (µg/L)	/	/	18	18	16	17	14	14	17	9	6	6
Chlorophyll-*a* (µg/L)	6.4	5.8	6.3	8.9	8.5	9.7	7	7.8	10	8.5	8.8	7.3
Secchi depth (m)	2	1.9	2.27	1.89	1.86	2	2.87	2.17	1.96	1.68	2.02	1.43
TKN (mg/L)	/	/	1.5	1.5	1.6	1.7	1.7	1.5	1.5	1.4	1.5	1.9
NO_2-N and NO_3-N (µg/L)	/	/	2	5	3	3	8	3	2	2	2	8
NH_3-N (µg/L)	/	/	18	17	24	19	26	25	18	25	25	42
DOC (mg/L)	/	/	20	/	23	/	20	/	20	21	21	22
Ca^{2+} (mg/L)	12	12	10	11	6	10	/	/	/	9	8	7
Mg^{2+} (mg/L)	61	65	66	65	74	67	/	/	/	64	68	76
Na^{+} (mg/L)	191	199	206	205	228	208	228	188	194	194	210	235
K^{+} (mg/L)	19	20	20	20	22	20	22	/	21	21	23	26
SO_4^{2-} (mg/L)	79	79	78	83	89	80	95	78	95	82	65	88
Cl^{-} (mg/L)	4	4	6	5	7	7	7	7	8	9	9	12
CO_3^{2-} (mg/L)	85.2	66.1	86.9	83.8	112	99	76	97.7	77.6	92.6	101.5	125
HCO_3^{-} (mg/L)	630	650	626	630	643	617	688	597	630	624	638	600
pH	9	8.82	9	9.02	9.17	9.07	9.01	9.16	9.09	9.08	9.16	9.16
Conductivity (µS/cm)	1242	1190	1250	1188	1320	1273	1298	1240	1227	1280	1300	1400
Hardness (mg/L)	280	296	296	296	312	301	290	273	263	288	300	330
TDS (mg/L)	766	770	786	782	853	795	842	754	775	788	808	878
Microcystin (µg/L)	/	/	/	/	0.09	0.24	0.14	/	0.21	0.21	0.28	0.16
Total Alkalinity (mg/L $CaCO_3$)	658	643	658	654	713	670	691	652	647	666	695	702

Table 3. Concentrations of metals measured in Gull Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Note that metal sample collection method changed in 2016 from composite to single surface grab at the profile location.

Metals (Total Recoverable)	2012	2015	2016	Guidelines
Aluminum µg/L	45.2	84	17.3	100[a]
Antimony µg/L	0.2735	0.2995	0.308	/
Arsenic µg/L	7.085	7.05	6.31	5
Barium µg/L	48.3	35.05	36.6	/
Beryllium µg/L	0.0015	0.004	0.004	100[c,d]
Bismuth µg/L	0.0021	0.0005	0.001	/
Boron µg/L	161.5	156	155	1500
Cadmium µg/L	0.018	0.009	0.005	0.37[b]
Chromium µg/L	0.2445	0.205	0.06	/
Cobalt µg/L	0.07665	0.0895	0.066	50,1000[c,d]
Copper µg/L	0.881	0.84	0.96	2.20[b]
Iron µg/L	32.6	59.7	28.1	300
Lead µg/L	0.10525	0.132	0.113	7[b]
Lithium µg/L	42.95	42.35	45.5	2500[d]
Manganese µg/L	2.535	3.425	2.48	140[e]
Molybdenum µg/L	4.065	3.965	3.65	73
Nickel µg/L	0.28	0.5	0.428	150[b]
Selenium µg/L	0.146	0.03	0.24	1
Silver µg/L	0.0034	0.002	0.001	0.25
Strontium µg/L	109	65.65	60.4	/
Thallium µg/L	0.000775	0.001775	0.0012	0.8
Thorium µg/L	0.005775	0.010275	0.0031	/
Tin µg/L	5	0.0095	0.021	/
Titanium µg/L	1.415	2.94	1.26	/
Uranium µg/L	2.61	2.74	2.59	15
Vanadium µg/L	1.49	1.12	1.42	100[c,d]
Zinc µg/L	0.995	0.85	2.9	30[f]

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on 2016 avg. water hardness (as CaCO3) with CCME equation
[c] Based on CCME Guidelines for Agricultural use (Livestock).
[d] Based on CCME Guidelines for Agricultural Use (Irrigation).
[e] Based on CCME Manganese variable calculation (https://ccme.ca/en/chemical/129#_aql_fresh_concentration), using 2016 avg. water hardness (as CaCO3) and avg. pH
[f] Based on 2016 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation
A forward slash (/) indicates an absence of data or guidelines

LONG TERM TRENDS

Trend analysis was conducted on the parameters total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth to look for changes over time in Gull Lake. In sum, a significant increasing trend was observed in TDS, significant decreasing trends were observed in TP and Secchi depth, and no significant trends were detected for chlorophyll-*a*. Secchi depth can be subjective and is sensitive to variation in weather; therefore, trend analysis must be interpreted with caution. Data is presented below as both line and box-and-whisker plots. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

Table 4. Summary table of trend analysis on Gull Lake data from 1983 to 2021.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1983-2021	Decreasing
Chlorophyll-*a*	1983-2021	No Change
Total Dissolved Solids	1983-2021	Increasing
Secchi Depth	1983-2021	Decreasing

Definitions:

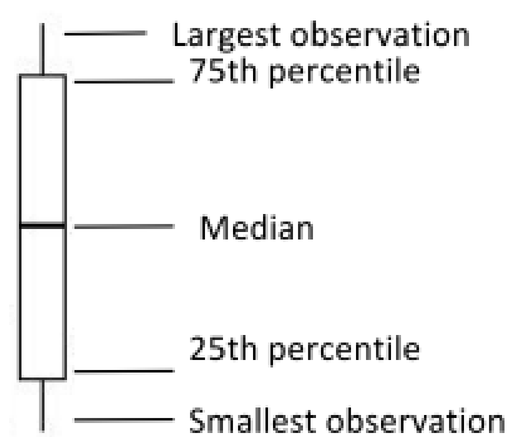
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

Box and Whisker Plot: a box-and-whisker plot, or boxplot, is a way of displaying all of our annual data. The median splits the data in half. The 75th percentile is the upper quartile of the data, and the 25th percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.



Total Phosphorus (TP)

Trend analysis of TP over time showed that it has significantly decreased in Gull Lake since 1983 (Tau = -0.47, p = <0.001).

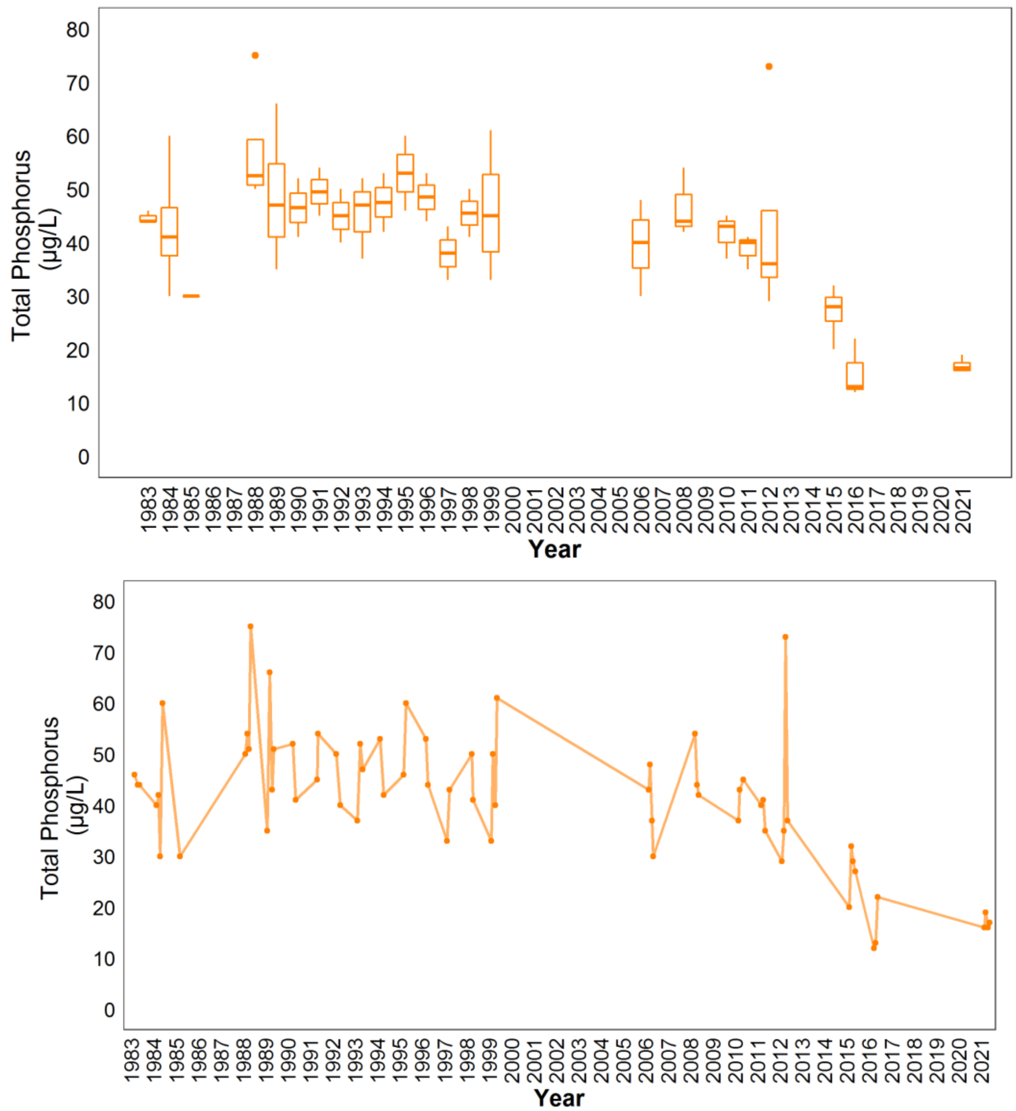


Figure 6. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1983 and 2021 (n = 67). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* has not significantly changed over time at Gull Lake (Tau = -0.05, p = 0.55). Chlorophyll-*a* trends follow TP trends with a positive correlation over time (r = 0.52, $p = 7.33 \times 10^{-6}$).

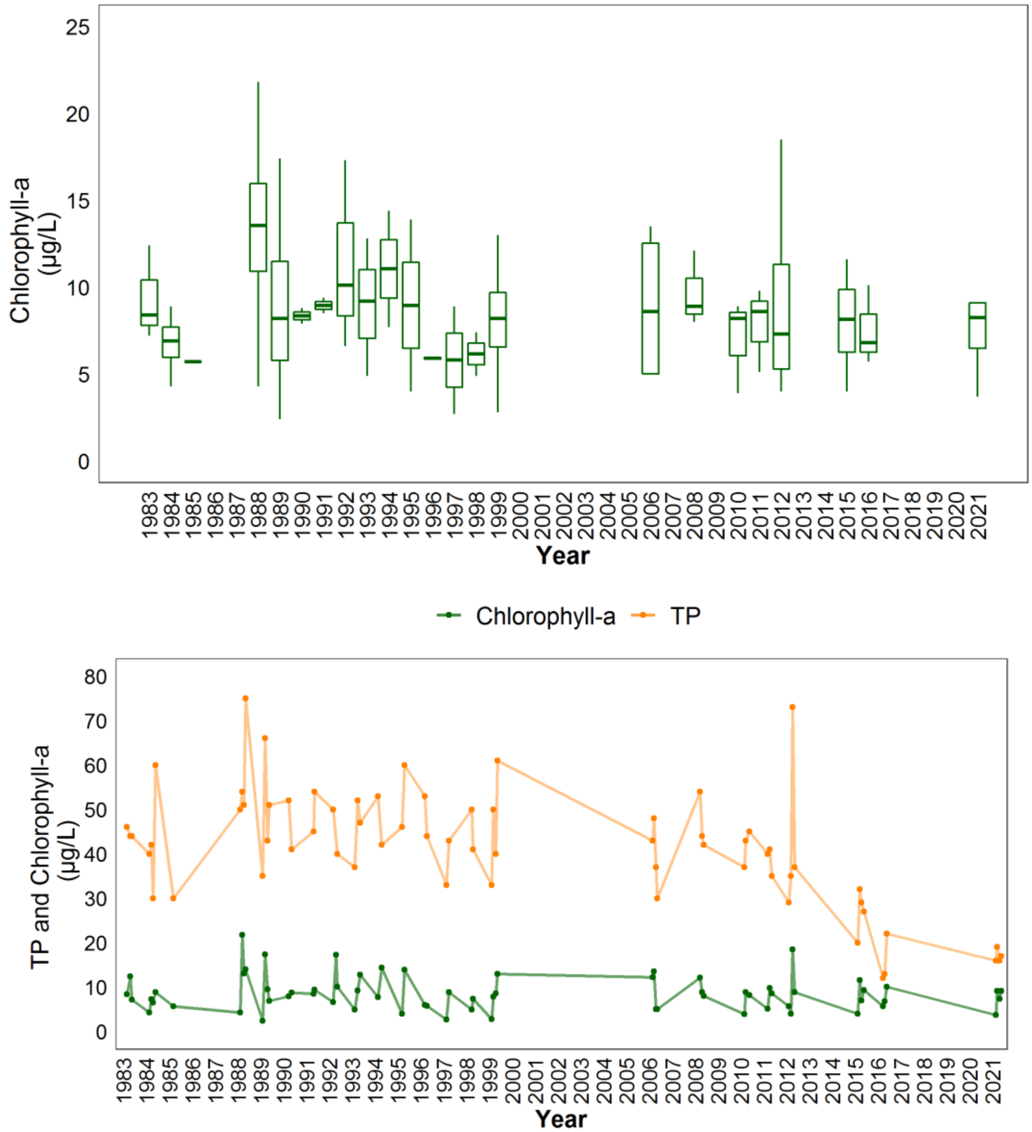


Figure 7. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2021 (n = 68). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2021 (Tau = 0.48, p = <0.001) in Gull Lake. In addition, the boxplot of TDS over time indicates that the median TDS level in 2021 is the highest in the historical record (Figure 8).

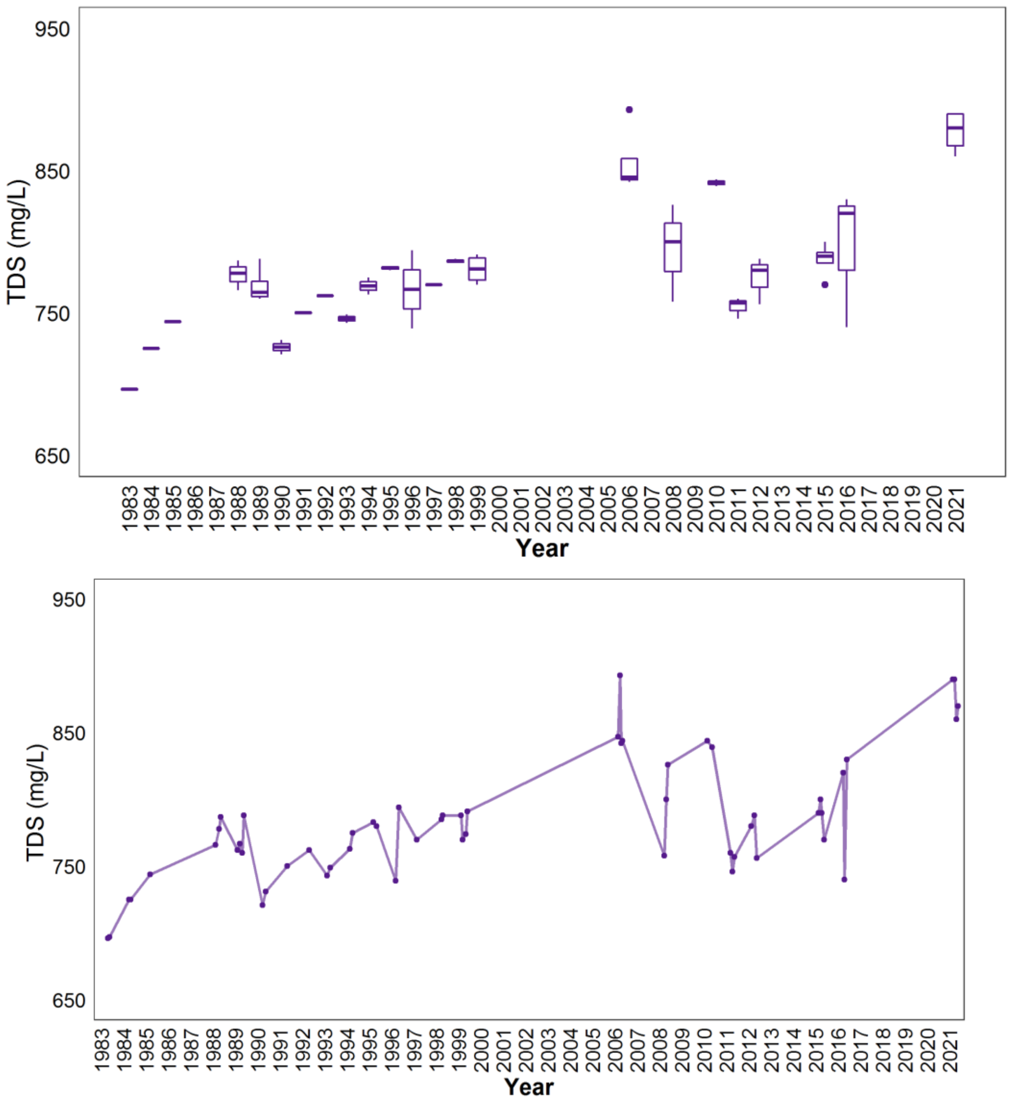


Figure 8. Monthly TDS values measured between June and September over the long term sampling dates between 1983 and 2021 (n = 57). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant increasing trend of TDS in Gull Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Gull Lake indicates that alkalinity (bicarbonate, carbonate), sulphate, and sodium are likely the key parameters that drove the historical increase in TDS (Figure 9). Of these parameters, alkalinity and sodium appear to follow the changes in TDS the closest over time, likely because they are in the highest abundance relative to all other ions. Chloride and potassium also display significantly increasing trends over time, but their trends display a more stable increasing trajectory over time relative to TDS, as well as alkalinity, sodium, and sulphate.

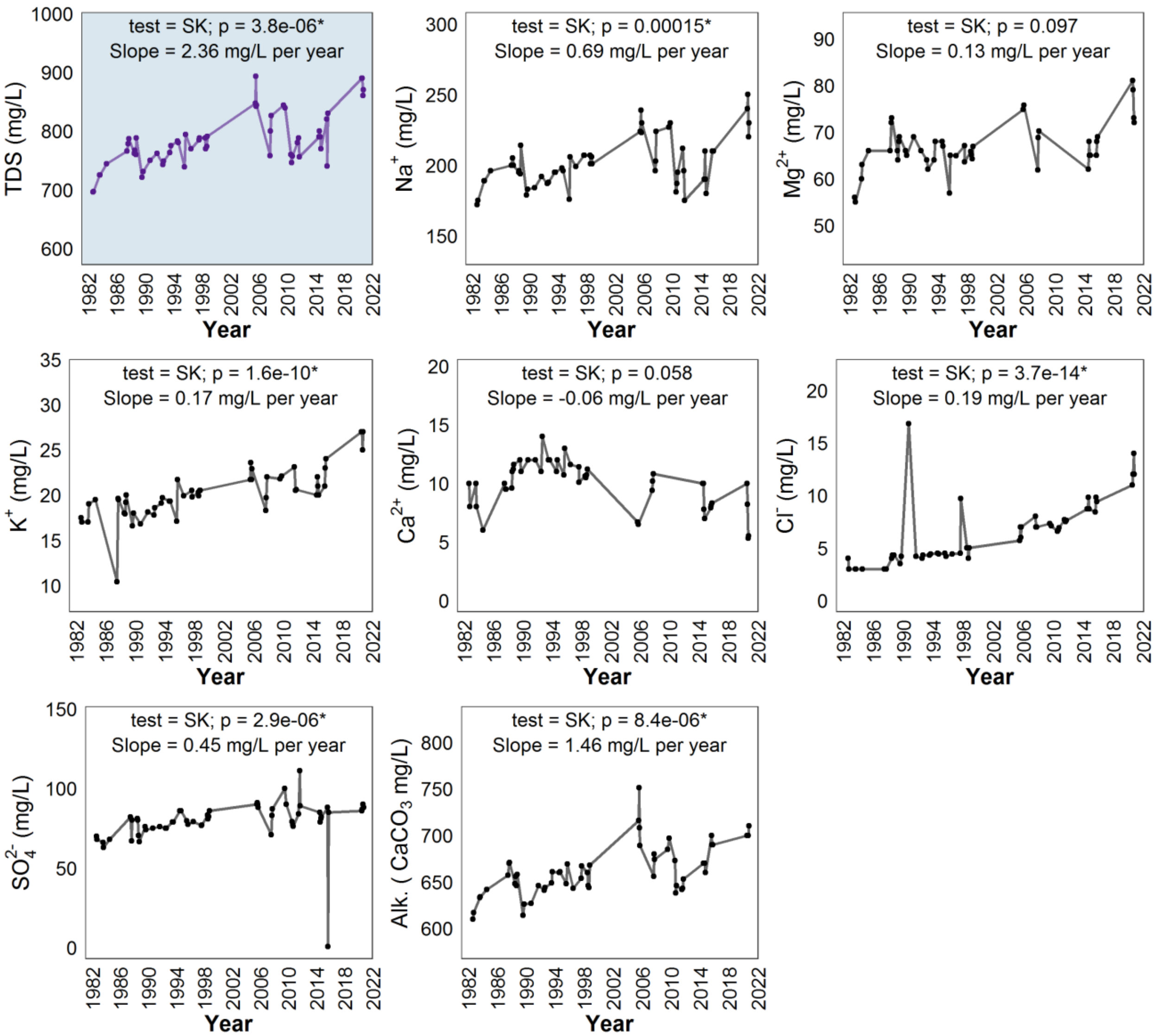
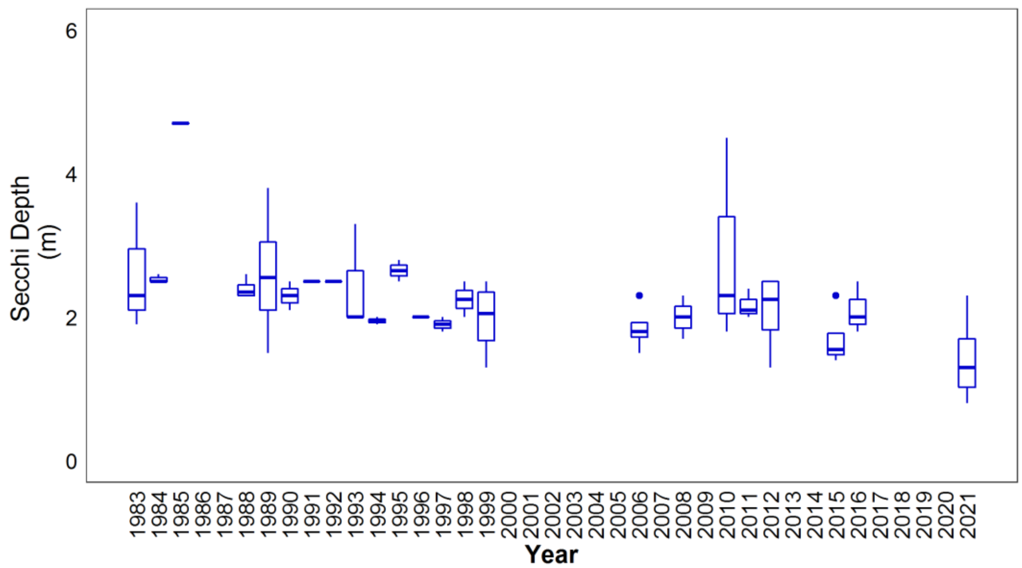


Figure 9. Concentrations of TDS (top left, blue panel), major ions (sodium = Na$^+$, magnesium = Mg^{2+}, potassium = K$^+$, calcium = Ca^{2+}, chloride = Cl$^-$, sulphate = SO$_4^{2-}$), and total alkalinity (Alk., as mg/L CaCO$_3$) measured monthly between June and September on sampling dates between 1983 and 2021. Also represented is the monotonic trend results for each parameter; test used (MK = Mann Kendall, SK = Seasonal Kendall), significance of test (p; assessed as significance when $p < 0.05$, marked with '*' if significant), and the slope of the trend. Test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Note that some ions had insufficient data (*I.D.*) therefore trends were not calculated. The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Secchi depth has significantly decreased (become less clear) in Gull Lake since 1983 (Tau = -0.39, *p* = <0.001). The relatively water clarity levels in 2021 are likely related to the observed lake whiting event.



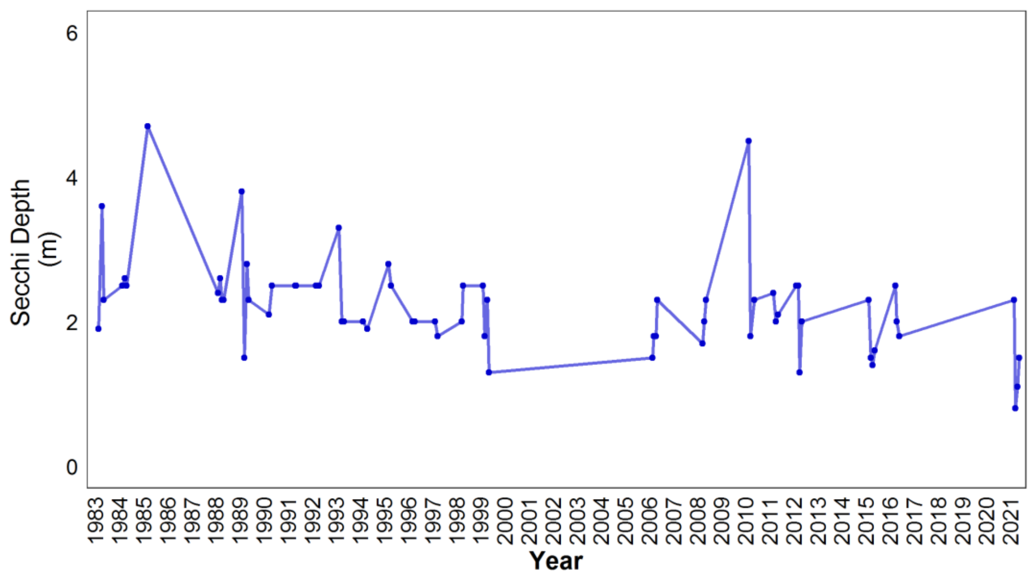


Figure 10. Monthly Secchi depth values measured between June and September over the long term sampling dates between 1983 and 2021 (n = 66). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September, for sampled years from 1983-2021 on Gull Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	-0.47	-0.05	0.48	-0.39
The extent of the trend	Slope (units per Year)	-0.71	-0.02	2.36	-0.03
The statistic used to find significance of the trend	Z	-5.13	-0.60	4.62	-4.58
Number of samples included	n	67	68	57	66
The significance of the trend	*p*	2.96×10^{-7}*	0.55	3.76×10^{-6}*	4.68×10^{-6}*

*$p < 0.05$ is significant within 95%