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The Alberta Lake Management Society Lakewatch Program

2003 Report on the water quality of

Frog Lake

> *And you really live by the river? What a jolly life!"*
> *"By it and with it and on it and in it," said the Rat. "It's brother and sister to me. What it hasn't got is not worth having, and what it doesn't know is not worth knowing." Kenneth Grahame The Wind in the Willows*
> *"The world's supply of fresh water is running out. Already one person in five has no access to safe drinking water." BBC World Water Crisis Homepage*

A note from the Lakewatch Coordinator Preston McEachern

Lakewatch has several important objectives, one of which is to document and interpret water quality in Alberta Lakes. Equally important are the objectives of educating lake users about their aquatic environment; enhancing public involvement in lake management; and facilitating a link between aquatic scientists and lake users. The Lakewatch Reports are designed to summarize basic lake data in understandable terms for a lay audience, and are not meant to be a complete synopsis of information about specific lakes. Substantial additional information is generally available on the lakes that have participated in Lakewatch and readers requiring more information are encouraged to seek these sources.

Since 2002, Lakewatch Reports have undergone a substantial change in format from previous years. I am no longer the author as much as an editor including text and figures from others who have done an excellent job describing lakes throughout Alberta. I have attempted to give due credit to these outstanding people and apologize for blatant plagiarism where it occurs. As editor, feel free to castrate me for errors. I have included easily accessible information that is likely to have been updated in recent years and readers are encouraged to help update these reports by sending new information to me.

Another exciting event occurred in 2003. Laboratory analyses have been switched from the University of Alberta Limnology Lab to the Alberta Research Council lab in Vegreville. The ARCV has a very broad spectrum of analyses possible and their detection levels are very good. Thus, we have added metals to our suite of analyses in 2003.

I would like to thank all people who share my love for aquatic environments and particularly those who have helped in the Lakewatch program. These people prove that ecological apathy can be overcome and give us hope that water will not be the limiting factor in the health of our planet.

Acknowledgements

The Lakewatch program is made possible through the dedication of its volunteers and Alberta Environment employees. The Frog Lake volunteer was Herb Lehr. Lakewatch would not have occurred without the dedication of his time and of course watercraft. Mike Bilyk and John Willis from Alberta Environment were instrumental in training people. We also thank Yaw Okiere, Alberta Environment, for providing the hydrology section of this report which was completed for another project. Financial support from the Lakeland Industry and Community Association (LICA) and the Prairie Farm Rehabilitation Association (PFRA) was essential in 2003. Jean-François Bouffard was the field coordinator and was an excellent addition to the program.

1.0 INTRODUCTION

Frog Lake is a very large (surface area 58 km^2) and deep (maximum depth 28 m) lake located about 200 km east of the city of Edmonton, in the Eastern North Saskatchewan River Basin (http://www.nswa.ab.ca/know.html). Frog Lake has 4 distinct islands (Fig. 1) that are protected bird sanctuaries, which host nesting sites for one of the largest cormorant colonies in Alberta. Pelicans, various cranes, bald eagles, ducks, geese, and a whole host of other birds make Frog Lake their home. One of the few lakes in Alberta that remains natural, there are only a few fisherman or campers that have enjoyed the beauty of this lake. Frog Lake is very important source of subsistence fisheries as it is almost completely surrounded by Indian reserves and metis settlements. The Puskiakiwenin Indian Reserve 122 and Unipouheos Indian reserve 121 occupy the western shore of Frog Lake, whereas the Fishing Lake Metis Settlement occupies most of the eastern shore.

Fig. 1: Bathymetry of Frog Lake. Each contour represents 20 feet.

Frog Lake's watershed is quite large (613 km^2) and is about 10 times larger than the lake surface. The majority of the land cover in the watershed is natural land (86% of watershed area), and only about 14% if the watershed is cleared. The land cover in Frog Lake's watershed has remained relatively unchanged over the past 15 years (Ducks Unlimited, unpublished 1986 and 1998 data).

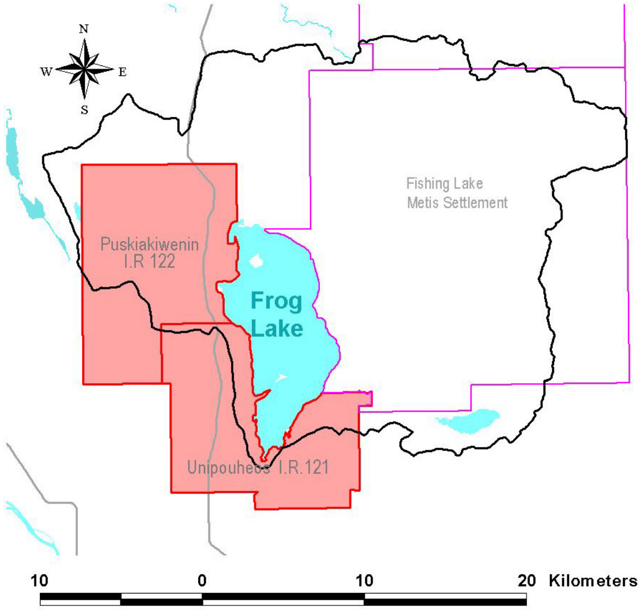

Fig. 2: Frog Lake Watershed

2.0 WATER QUALITY

Water quality information has been collected from Frog Lake over the past two years through a partnership involving the Alberta Lake Management Society, Alberta Environment, the Lakeland Industry & Community Association, and the Fishing Lake Metis Settlement (Herb Lehr). The focus of water sampling has been on parameters important for

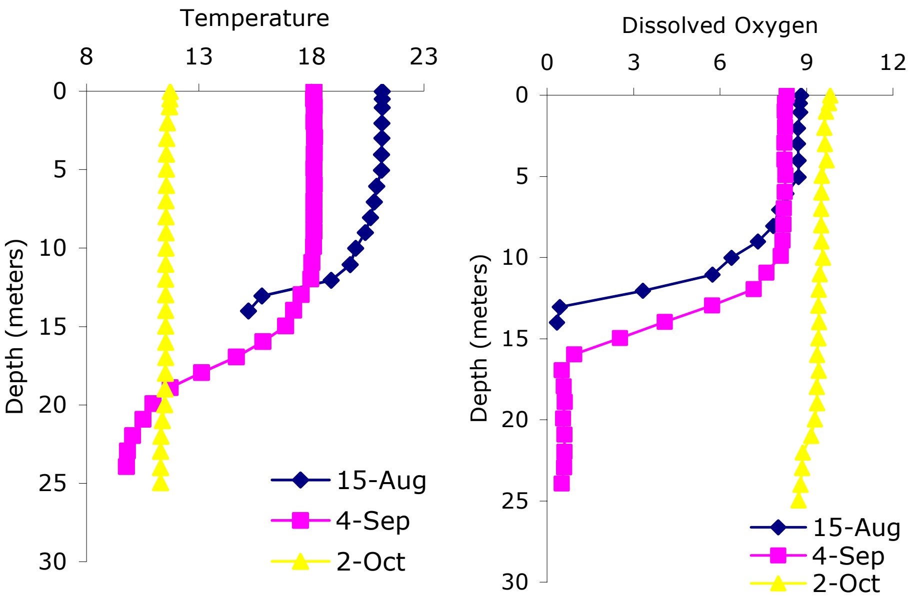

Fig. 3: Temperature and dissolved oxygen profiles for Frog Lake, summer 2003.

recreation and aesthetics, such as nutrients and water greenness (i.e., algal biomass), parameters that indicate lake hydrologic changes (i.e., ions), and total metals.

2.1 Water Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen profiles in the water column can provide information on water quality and fish habitat. Please refer to the end of this report for descriptions of technical terms.

In Frog Lake, a layer of warm water forms over a layer of cold water during the summer. This phenomenon is called "thermal stratification" and is common in deeper lakes. During thermal stratification, the warm top layer does not mix with the bottom cold layer. During the summer of 2003, the thermal layer in Frog Lake occurred between 12 and 15 m. Because oxygen-using decomposition occurs at the bottom of the lake and the cold, bottom layer has no access to the oxygen from the atmosphere, a decrease in oxygen concentration occurred in the cold-water layer. The entire lake began mixing again in the beginning of October as temperatures were not different with depth. Because oxygen-rich water circulated all the way to the bottom of Frog Lake at this time, the entire water column was well-airated.

2.2 Water clarity

Water clarity is influenced by suspended materials, both living and dead, as well as some coloured dissolved compounds in the water column. During the melting of snow and ice in spring, lake water can become cloudy from silt transported into the lake. Lake water usually clears in late spring but then becomes more turbid with increased algal biomass as the summer progresses. The easiest and most widely used measure of lake water clarity is by lowering a black and white disk, called a Secchi disk, in the water until it is no longer visible.

Frog Lake's water was fairly clear during the summer of 2003: Secchi disk depth averaged over two meters. Clarity was highest in October at 3.5 m and lowest in August at 2.25 m, when algae are most abundant. Although no data is available, water clarity is likely quite clear during spring and early summer before algae become more abundant in late summer.

Table 1: Historical chemical characteristics of Frog Lake water.

	Ice-on		Ice-off		
Parameter	Mar 1986	Feb 2004	May 1976	Jun 1978	Aug-Oct 2003
Total P (µg/L)	12	-	-	-	18
TDP (µg/L)	-	-	-	-	7.3
Chla (µg/L)	-	-	-	-	6.1
Secchi (m)	-	-	-	-	2.8
Total N (mg/L)	920	1302	-	-	1156
NO_{2+3} (µg/L)	41	71	29	2	23
NH_4 (µg/L)	29	156	-	-	26
Mercury (total)	nd	-	-	-	-
Ca (mg/L)	25	18	-	25	18
Mg (mg/L)	51	66	36	43	64
Na (mg/L)	55	87	41	73	75
K (mg/L)	14	18	12	12	17
SO_4 (mg/L)	67	100	48	73	91
Cl (mg/L)	7	11	7	28	11
CO_3 (mg/L)	14	25	-	11	35
HCO_3 (mg/L)	360	444	-	377	386
TDS (mg/L)	410	-	347	413	500
Conductivity	691	902	540	574	-
pH	8.7	8.7	8.7	8.6	8.9
Total Alkalinity (mg/L $CaCO_3$)	319	405	276	266	375

Notes: "nd" = below detection limit.

2.3 Water chemistry

Due to deep and fertile soils, lakes in Alberta are naturally nutrient-rich and are prone to algal blooms. Frog Lake has moderate nutrient concentrations and algal biomass compared to other lakes throughout Canada; it is considered meso-eutrophic (see details on trophic status classification at end of this report). In the Alberta context, Frog Lake is less fertile than a typical lake, likely because its watershed has remained relatively pristine. In 2003, water greenness (algal biomass measured as chlorophyll *a*), nitrogen and phosphorus concentrations increased from August to September (Fig. 4). This pattern of increase in water greenness and nutrients over the summer is typical for Alberta lakes. Metal concentrations were low and none surpassed provincial and federal Water Quality Guidelines for the Protection of Aquatic Life. Only pH and total N surpassed guidelines, which

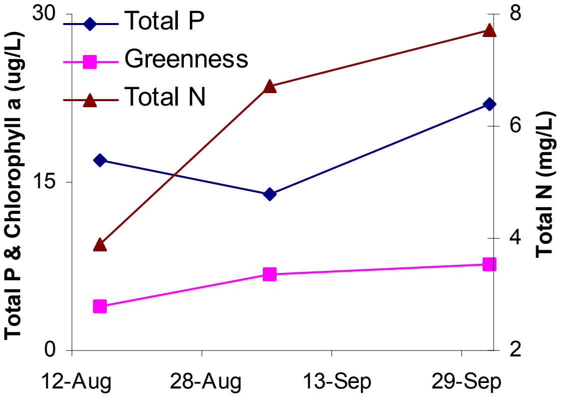

Fig. 4: Total phosphorus, algal biomass (chlorophyll *a*) and total nitrogen for Kehewin Lake, summer 2003.

is not surprising since these parameters are naturally high in Alberta Lakes.

Frog Lake is well-buffered from acidification: its pH of 8.5-9.0 is well above that of pure water (i.e., pH 7). Dominant ions include bicarbonate, sodium, magnesium, and sulphate. Over the years, water quality has remained fairly stable, except for perhaps a slight increase in salinity (measured as total dissolved solids). Many lakes in the area have increased in salinity over the past two decades due to reduced precipitation and freshwater inflows.

Table 3: Frog Lake exceedances to Alberta and CCME Surface Water Quality Guidelines for the Protection of Aquatic Life. If monitoring data do not exceed guidelines, problems are unlikely. If the guidelines are exceeded, a detailed assessment might be required to determine the extent, cause, and potential adverse effect arising from the exceedance. Guidelines are sometimes exceeded due to natural causes, such as heavy runoff or extreme weather conditions.

Water quality parameter	Guideline value (µg/L)	Number of values beyond guidelines
Aluminum	100	0
Ammonia	1370	0
Arsenic (total)	5	0
Cadmium[1]	0.085	0
Copper	7	0
Iron	300	0
Lead	7	0
Nickel	150	0
Nitrite	60	0
Oxygen, dissolved	5.0	0
pH	6.5-9.0	1
Total N	1000	10
Total P	50	0
Selenium	1	0
Silver	0.1	0
Zinc	30	0

[1] value at hardness = 300 mg/L

3.0 WATER BALANCE

3.1 Available data

Monitoring of Frog Lake levels by Alberta Environment began in 1968. The lake level data are miscellaneous and for that reason an average of about four readings per year are taken. The available records show the level of the lake was fairly stable between 1968 and 1981, fluctuating about 574.5 metres above sea level (masl). The lake levels have been declining since 1981. As at August 5, 2004, the recorded water level on Frog Lake was 571.524 masl; this represents a drop in lake level of 3 metres. The maximum level during the period of record was 575.321 masl, giving a maximum difference in lake levels of 3.9 metres. Figure 3 shows the recorded lake levels.

The lake is not regulated and there is also no gauge station at the outlet. The bathymetry of the lake was prepared in September 1968 by Water Resources division of the Ministry of Agriculture.

Some of the meteorological stations in the vicinity of Frog Lake have period of record that does not cover the entire duration of the lake level measurement. There are also no published data on lake evaporation for these stations. The meteorological station in Cold Lake, which is about 60 km north-east of Frog Lake, was therefore used in this study. This station has a complete record of precipitation and lake evaporation, and is found to be representative of the climatic conditions within the Frog Lake basin.

Licensed diversions and consumptive use within the Frog Lake basin are based on Water Act licencing records in the regional office.

3.2 Inflows

Stream Flows
Currently there are no measurements for the several feeder tributaries into the lake hence the inflows were estimated using a nearby hydrometric gauge site that has similar basin characteristics. Water Survey of Canada gauge station on Atimoswe Creek near Elk Point (05ED002) was used to estimate all the surface runoff into Frog Lake. The inflows were scaled linearly from the Atimoswe Creek to the Frog Lake drainage basin.

Direct Precipitation on the Lake
A continuous precipitation record for the Cold Lake Meteorological Station (3181680) was used. Total monthly precipitation data was used for each time step.

Return Flows
There are no return flows in the basin hence the model considered that component to be zero.

3.3 Outflows

Diversions or Water Rights
The current licenses were considered in the model by apportioning the annual volumes to equivalent monthly values. It assumed that the current total amount of all the allocations took effect from 1993.

Lake Evaporation
Lake evaporation data for Cold Lake was used in the model. The data on Cold Lake evaporation is part of an internal report published in 1999 by the Water Sciences Branch of Alberta Environment. The data provides a fairly good approximation of the meteorological conditions because both lakes are in the same geographic area.

Lake Outflows

There are neither measured outflows nor a control structure at the outlet of Frog Lake. An outlet configuration, based on a trapezoidal weir of bottom width 20 m and side slope of 30°, was assumed to be representative of the lake outlet. A geodetic elevation of 574.4 m was also assumed for bottom of the outlet based on graphical plots of the miscellaneous lake level measurements from 1968-2003.

Groundwater

Groundwater can act as a source of inflow or a sink. In this analysis, the influence due to groundwater was not considered directly. However the runoff into the lake is estimated using recorded stream flow, which includes a component of groundwater.

3.4 Lake Bathymetry

The lake bathymetry is based on a digitized map from a hydrographic survey conducted in September 1968 by Water Resources division of the Ministry of Agriculture. Since the hydrographic survey did not provide the water level on the day of survey, it was assumed that the highest level at the periphery of the lake represents the water level on the day of survey. The hydrographic survey was therefore converted from a temporal elevation to Geodetic by adding the 574.282 m; which is the recorded water level on the same day of survey. The accuracy of this conversion is about ±1.0 m.

3.5 Results

Figure 5; shows the simulated and recorded water levels for Frog Lake. The simulated water levels compare fairly well with the observed lake levels. In general, there is a downward trend for both the simulated and the observed lake levels. A table of the model results on annual basis is in Appendix A. In general, the table shows that in many years there is not enough precipitation and surface runoff to make up for the losses from the lake in evaporation.

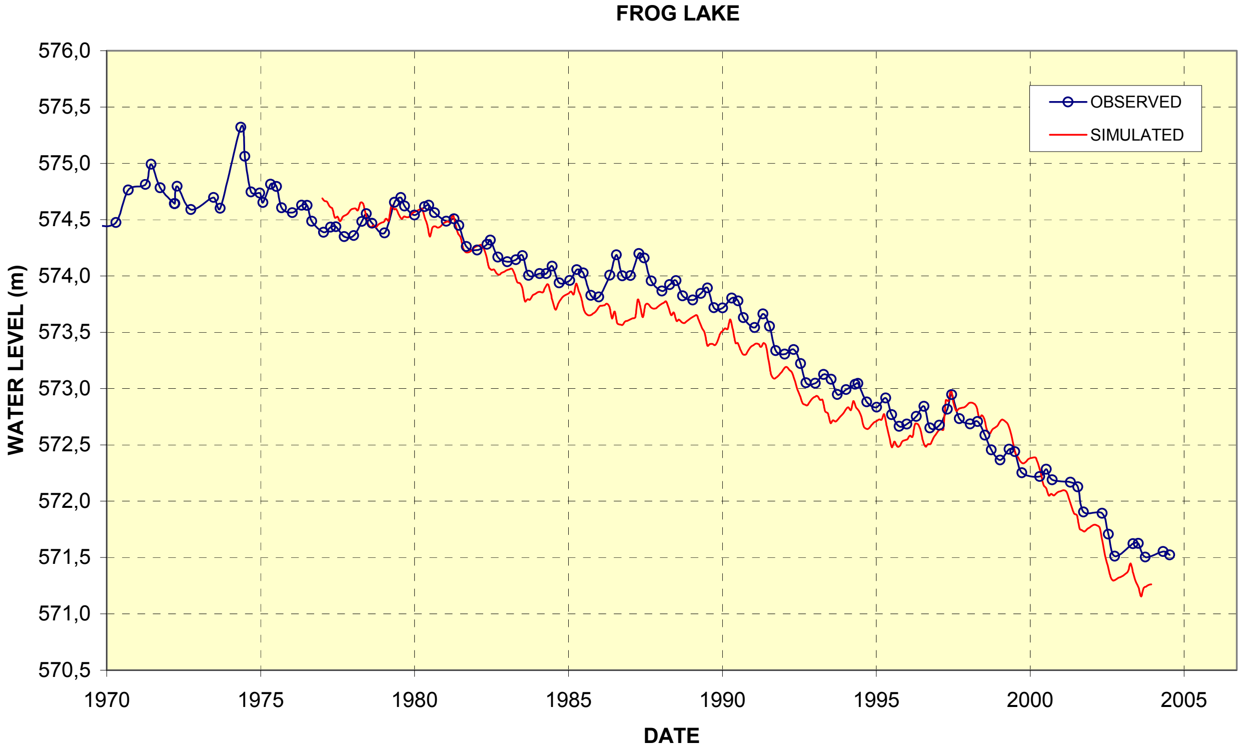

Fig. 5: Observed and simulated water levels of Frog Lake.

3.6 Summary

Given that the lake levels can be modelled fairly well using streamflow, precipitation, lake evaporation and water licence data, it suggests that:

- The likely explanation for the decline in the lake levels is purely a natural phenomenon and may be attributed to meteorological drought. An on-going study by the department on Muriel Lake, which has a common basin boundary with Frog Lake, also indicates a trend of decline in lake levels. The same trend has also been noticed on the Upper Therien Lake near St. Paul.
- As at August 5, 2004, the recorded water level on Frog Lake was 571.524m, which corresponds to storage volume of about 47,021 dam^3 (47,021,000 m^3). The estimated mean annual surface runoff and direct precipitation into Frog Lake based on regional data is 29,450 dam^3. Given the mean annual lake evaporation of 36,257 dam^3 and allocations of 141.5 dam^3, there is still sufficient water in Frog Lake to meet the current water supply demand.
- The annual diversions or allocations are negligible compared with evaporation losses. As millimetres of lake level the mean annual evaporation is 614 mm, and the allocations are 2 mm. The average input from surface runoff and precipitation is 499 mm.

A brief introduction to Limnology

Indicators of water quality

Water samples are collected in Lakewatch to determine the water quality of lakes. Though not all encompassing, the variables collected in Lakewatch are sensitive to human activities in watersheds that can cause degraded water quality. For example, nutrients such as phosphorus and nitrogen are important determinants of lake productivity. The concentrations of these nutrients in a lake are impacted (typically elevated) by land use changes such as increased crop production or livestock grazing. Elevated nutrient concentrations can cause increases in undesirable algae blooms resulting in low dissolved oxygen concentrations, degraded habitat for fish and noxious smells. A large increase in nutrients over time may also indicate sewage inputs which in turn may result in other human health concerns associated with bacteria or the protozoan *Cryptosporidium*.

Temperature and mixing

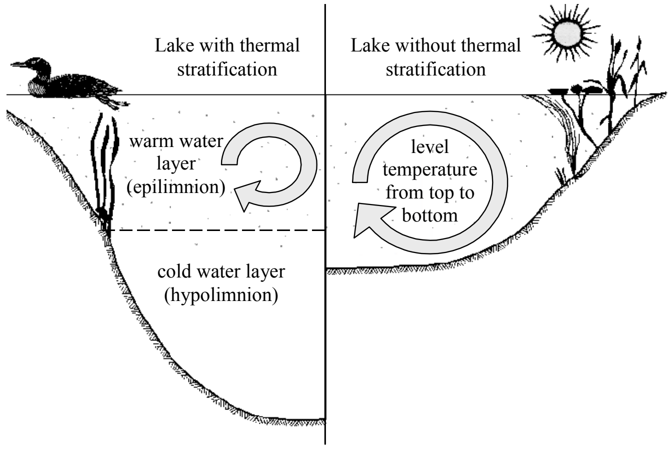

Fig. 1: Difference in the circulation of the water column depending on thermal stratification.

Water temperature in a lake dictates the behavior of many chemical parameters responsible for water quality. Heat is transferred to a lake at its surface and slowly moves downward depending on water circulation in the lake. Lakes with a large surface area or a small volume tend to have greater mixing due to wind. In deeper lakes, circulation is not strong enough to move warm water to depths typically greater than 4 or 5 m and as a result cooler denser water remains at the bottom of the lake. As the difference in temperature between warm surface and cold deeper water increases, two distinct layers are formed. Limnologists call these layers of water the **epilimnion** at the surface and the **hypolimnion** at the bottom. The layers are separated by a transition layer known as the **metalimnion** which contains the effective wall separating top and bottom waters called a **thermocline**. A thermocline typically occurs when water temperature changes by more than one degree within one meter depth. The hypolimnion and epilimnion do not mix, nor do elements such as oxygen supplied at the surface move downward into the hypolimnion. In the fall, surface waters begin to cool and eventually reach the same temperature as hypolimnetic water. At this point the water mixes from top to bottom in what is called a **turnover** event. Surface water cools further as ice forms and again a thermocline develops this time with 4° C water at the bottom and 0° C water on the top.

In spring another turnover event occurs when surface waters warm to 4° C. Lakes with this mixing pattern of two stratification periods and two turnover events are called **dimictic** lakes. In shallower lakes, the water column may mix from top to bottom most of the ice-free season with occasional stratification during periods of calm warm conditions. Lakes that mix frequently are **termed polymictic** lakes. In our cold climate, many shallow lakes are **cold monomictic** meaning a **thermocline** develops every winter, there is one turnover event in spring but the remainder of the ice free season the lake is **polymictic.**

Dissolved Oxygen

Oxygen enters a lake at the lake surface and throughout the water column when produced by photosynthesizing plants, including algae, in the lake. Oxygen is consumed within the lake by respiration of living organisms and decomposition of organic material in the lake sediments. In lakes that stratify (see temperature above), oxygen that dissolves into the lake at the surface cannot mix downward into the hypolimnion. At the same time oxygen is depleted in the hypolimnion by decomposition. The result is that the hypolimnion of a lake can become anoxic, meaning it contains little or no dissolved oxygen. When a lake is frozen, the entire water column can become anoxic because the surface is sealed off from the atmosphere. Winter anoxic conditions can result in a fish-kill which is particularly common during harsh winters with extended ice-cover. Alberta Surface Water Quality Guidelines suggest dissolved oxygen concentrations (in the epilimnion) must not decline below 5 mg/L and should not average less than 6.5 mg/L over a seven-day period. However, the guidelines also require that dissolved oxygen concentrations remain above 9.5 mg/L in areas where early life stages of aquatic biota, particularly fish, are present.

General Water Chemistry

Water in lakes always contains substances that have been transported by rain and snow or have entered the lake in groundwater and inflow streams. These substances may be dissolved in the water or suspended as particles. Some of these substances are familiar minerals, such as sodium and chloride, which when combined form table salt, but when dissolved in water separate into the two electrically charged components called ions. Most dissolved substances in water are in ionic forms and are held in solution due to the polar nature of the water molecule. Hydrophobic (water-fearing) compounds such as oils contain little or no ionic character, are non-polar and for this reason do not readily dissolve in water. Although hydrophobic compounds do not readily dissolve, they can still be transported to lakes by flowing water. Within individual lakes, ion concentrations vary from year to year depending on the amount and mineral content of the water entering the lake. This mineral content can be influenced by the amount of precipitation and other climate variables as well as human activities such as fertilizer and road salt application.

Phosphorus and Nitrogen

Phosphorus and nitrogen are important nutrients limiting the growth of algae in Alberta lakes. While nitrogen usually limits agricultural plants, phosphorus is usually in shortest supply in lakes. Even a slight increase of phosphorus in a lake can, given the right conditions, promote algal blooms causing the water to turn green in the summer and impair recreational uses. When pollution originating from livestock manure and human sewage enters lakes not only are the concentrations of phosphorus and nitrogen increased but nitrogen can become a limiting nutrient which is thought to cause blooms of toxic algae belonging to the cyanobacteria. Not all cyanobacteria are toxic, however, the blooms can form decomposing mats that smell and impair dissolved oxygen concentrations in the lake.

Chlorophyll a

Chlorophyll *a* is a photosynthetic pigment that green plants, including algae, possess enabling them to convert the sun's energy to living material. Chlorophyll *a* can be easily extracted from algae in the laboratory. Consequently, chlorophyll *a* is a good estimate of the amount of algae in the water. Some highly productive lakes are dominated by larger aquatic plants, known as macrophytes, rather than suspended algae. In these lakes, chlorophyll *a* and nutrient values taken from water samples do not include productivity from large aquatic plants. As a result, lakes like Chestermere which are dominated by macrophytes can be at a lower trophic state than if macrophyte biomass was included. Unfortunately, the productivity and nutrient cycling contributions of macrophytes are difficult to sample accurately and are therefore not typically included in trophic state indices.

Secchi Disk Depth

Lakes that are clear are more attractive for recreation, whereas those that are turbid or murky are considered by lake users to have poor water quality. Secchi disk depth is the oldest, simplest, and quickest quantitative measure of water clarity. A Secchi disk is a black and white disk that is lowered down through the water column until it can no longer be seen. Secchi disk depth is the midpoint between the depth at which it disappears when lowered and reappears when it is pulled up again. The Secchi disk depth in lakes with high algal biomass will generally be shallow. However, Secchi disk depth is not only affected by algae. High concentrations of suspended sediments, particularly fine clays or glacial till, are common in plains or mountain reservoirs of Alberta. Mountain reservoirs may have exceedingly shallow Secchi disk depths despite low algal growth and nutrient concentrations.

The euphotic zone, calculated as twice the Secchi disk depth, is the portion of the water column that has sufficient light for aquatic plants to grow. Murky waters, with shallow Secchi depths, can prevent aquatic plants from growing on the lake bottom. Aquatic plants are important because they ensure clear lake water by reducing shoreline erosion and stabilizing lake bottom sediments. Many lakes in Alberta are shallow and have bottom sediments with high concentrations of nutrients. Without aquatic plants, water quality may decline in these lakes due to murky, sediment-laden water and excessive algal blooms. Maintaining aquatic plants in certain areas of a lake is often essential for ensuring good water clarity and a healthy lake as many organisms, like aquatic invertebrates and fish, depend on aquatic plants for food and shelter.

Trophic state

Trophic state is a classification system for lakes that depends on fertility and is a useful index for rating and comparing lakes. From low to high nutrient and algal biomass (as chlorophyll) concentrations, the trophic states are: oligotrophic, mesotrophic, eutrophic and hypereutrophic. The nutrient and algal biomass concentrations that define these categories are shown in the following table, a figure of Alberta lakes compared by trophic state can be found on the ALMS website. A majority of lakes in Alberta are meso- to

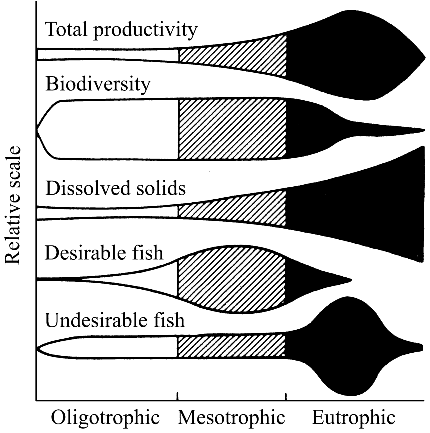

Fig. 2: Suggested changes in various lake characteristics with eutrophication. From "Ecological

eutrophic because they naturally contain high nutrient concentrations due to our deep fertile soils. Thus, lakes in Alberta are susceptible to human impacts because they are already nutrient-rich; any further nutrient increases can bring about undesirable conditions illustrated in Fig 2.

Trophic status based on lake water characteristics.

Trophic state	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Chlorophyll a (µg/L)	Secchi Depth (m)
Oligotrophic	< 10	< 350	< 3.5	> 4
Mesotrophic	10 - 30	350 - 650	3.5 - 9	4 - 2
Eutrophic	30 - 100	650 - 1200	9 - 25	2 - 1
Hypereutrophic	> 100	> 1200	> 25	< 1

Note: These values are from a detailed study of global lakes reported in Nurnberg 1996. Alberta Environment uses slightly different values for TP and CHL based on those of the OECD reported by Vollenweider (1982). The AENV and OECD cutoffs for TP are 10, 35 and 100; for CHL are 3, 8 and 25. AENV does not have TN or Secchi depth criteria. The corresponding OECD exists for Secchi depth and the cutoffs are 6, 3 and 1.5 m.