THE ALBERTA LAKE MANAGEMENT SOCIETY
VOLUNTEER LAKE MONITORING PROGRAM

2010 Minnie Lake Report

COMPLETED WITH SUPPORT FROM:

Beaver River Watershed Alliance

Government of Alberta

LICA
Lakeland Industry & Community Association

Alberta Lake Management Society's Lakewatch Program

Lakewatch has several important objectives, one of which is to collect and interpret water quality data on Alberta Lakes. Equally important is educating lake users about their aquatic environment, 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 a lay 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 people prove that ecological apathy can be overcome and give us hope that our water resources will not be the limiting factor in the health of our environment.

Acknowledgements

The Lakewatch program is made possible through the dedication of its volunteers and Lakewatch Chairs, Al Sosiak and Ron Zurawell. We would like to thank Garry Kissel for his efforts in collecting data in 2010. We would also like to thank Bradley Peter and Emily Port who were summer interns with ALMS in 2010. Project Technical Coordinator Jill Anderson was instrumental in planning and organizing the field program. Technologists Shelley Manchur, Mike Bilyk, Brian Jackson, and John Willis were involved in the training aspects of the program. Doreen LeClair and Chris Rickard were responsible for data management. Jill Anderson (Program Manager) was responsible for program administration and planning. Théo Charette, Ron Zurawell, Lori Neufeld, and Sarah Lord prepared the original report, which was updated for 2010 by Bradley Peter and Arin Dyer. Alberta Environment, the Beaver River Watershed Alliance (BRWA), and the Municipal District of Wainwright were major sponsors of the Lakewatch program.

MINNIE LAKE:

Figure 1 – Minnie Lake, Alberta. Photo by the Save Minnie Lake Committee, 2008.

Minnie Lake (Figure 1) is a small lake located west of Bonnyville and north-east of Glendon within the Beaver River Watershed. The lake is 2 km long and 0.6 km wide, with a surface area of 0.84 km^2. Mean depth is 8.3 m and maximum depth is 21.45 m, though water levels have decreased since these values were calculated.

The shoreline of the lake hosts two municipal campsites, private cabins and recreational properties, agricultural land, and boreal forest.

Figure 2 – Bathymetric map of Minnie Lake, Alberta (Trew 1986). Each contour represents 1 m elevation.

Minnie Lake is spring-fed by the Beverly channel aquifer and surface runoff from precipitation. In 2006-2007, the lake experienced a winterkill, which decimated stocks of northern pike and yellow perch that previously supported a recreational fishery. Fish populations have not recovered to date.

In 2008, Canadian Natural Resources Ltd. had planned to drill 15 wells on 8 well pads less than 1.5 km from the lake, in addition to one well pad already present. Local residents expressed concern about the effects of drilling and other oil extraction activities on water quality in the lake and its aquifer, especially as one of the proposed wells would be directionally drilled to pump oil from directly underneath the lake. The Save Minnie Lake Committee was formed in 2008 after discussions with CNR representatives provided insufficient answers for community members. The Municipal District of Bonnyville has since rescinded the development approval permit for the well pad that would have allowed directional drilling.

WATER LEVELS:

Water levels at Minnie Lake have continued to decline since measurements began in 1981 (Figure 3). In 1981, water levels were at a historical maximum of 554.5 metres above sea level (m asl). In 1986, the Minnie Lake Stabilization Plan was drawn up in response to water level declines observed in the early 1980's. The decline was attributed to a combination of drought (which reduced aquifer replenishment by surface runoff) and municipal withdrawals by the village of Glendon, which had been withdrawing water directly from Minnie Lake since 1964. The plan suggested that a halt in municipal withdrawals combined with a one-time addition of water (of approximately 10% of total water volume in Minnie Lake) from other sources, to raise water level back to the desired level of 554.5 m asl. In 2009, however, water levels reached another historical minimum of 551.2 m asl, three meters lower than in 1981. As spring-fed lakes tend to maintain stable water levels, the continued decline in water level may be due to water withdrawal or changes in groundwater levels.

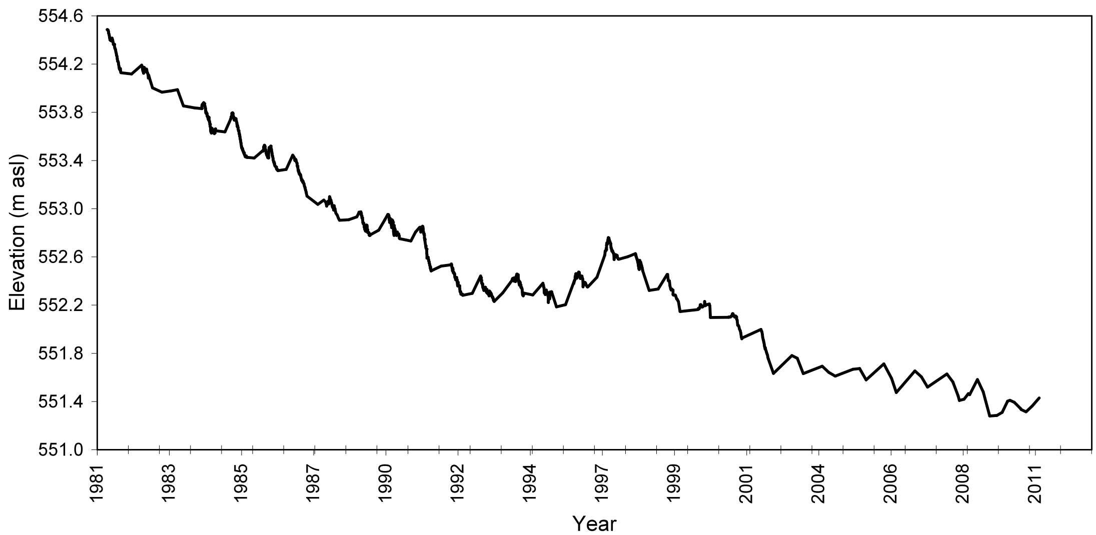

Figure 3 – Water levels for Minnie Lake recorded in meters above sea level (m asl). Data obtained from Alberta Environment.

WATER CLARITY AND SECCHI 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 disk depth.

Compared to many Alberta lakes, water clarity at Minnie Lake is quite good. An average secchi disc depth of 4.70 m was obtained for the summer of 2010 (Table 1). A seasonal maximum of 5.00 m was seen on both August 11th and September 1st, while a seasonal minimum of 4.00 m was measured on September 23rd. Average secchi disc depth for

2010 was higher than in 2008 (4.50 m) and 2009 (2.19 m). Higher-than-normal secchi disc depths were common in 2010, as temperatures were mild and tended not to promote large algae blooms.

WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen 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.

Water temperature at Minnie Lake fluctuated greatly at the surface yet remained stratified at deeper depths for the entire summer (Figure 3a). In mid-June, surface water temperature was 17.59 °C and stratification was observed between 4.0-9.0 m. In mid-July, surface water temperatures had increased to 20.19 °C, and stratification moved deeper, spanning between 5.0-10.5 m. In early-August, surface water temperature increased even more to 22.77 °C, and the size of the stratified zone became larger, stretching between 4.5-11.0 m. On September 1st, surface water temperature began to decline, measuring 17.19 °C, and the size of the stratified zone decreased as well, occurring between 6.5-11.0 m. Finally, on September 23rd, surface water temperatures were only 11.29 °C and weak stratification persisted between 9.0-11.0 m. As no turn-over events were observed, Minnie Lake is possibly meromictic (does not mix every year). This is a function of Minnie Lake's size, depth, and shape, and contributes to the cold anoxic waters seen near the lakebed.

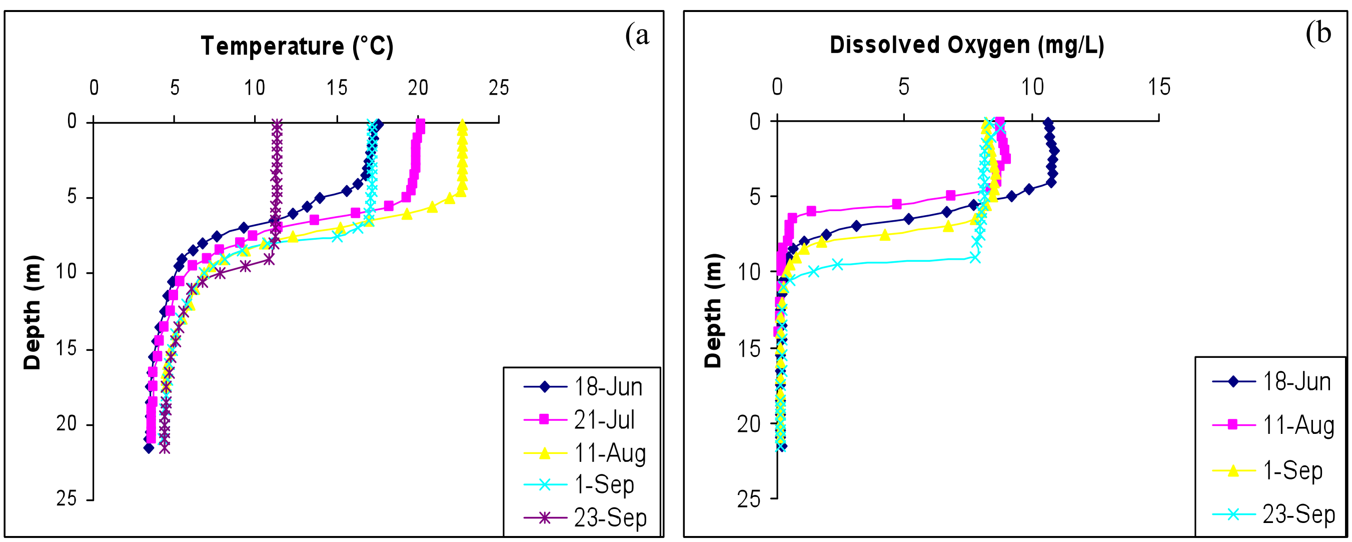

Figure 3 – a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles measured at Minnie Lake over the course of the summer in 2010.

Dissolved oxygen in Minnie Lake changed little over the course of the summer (Figure 3b). Due to the absence of lake-mixing, anoxia was observed on each sampling trip, starting as early as 6.00 m. The July 21st dissolved oxygen profile was excluded due to probe malfunction. Surface dissolved oxygen concentrations ranged from 10.67 mg/L on June 18th and 8.21 mg/L on September 1st.

WATER CHEMISTRY:

ALMS measures a suite of water chemistry parameters. Phosphorous, 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 1 for a complete list of parameters.

Based on average total phosphorous measured in 2010 (38.8 µg/L), Minnie Lake would be considered eutrophic (Table 1). Total phosphorous measured 62 µg/L at the start of the summer and declined to a minimum of 24 µg/L on September 1st as the algae consumed nutrients in the water column (Figure 4). Total nitrogen, however, remained quite steady throughout the summer, with a minimum of 1.53 mg/L on September 1st and a maximum of 1.73 mg/L on August 11th. Because nitrogen changed very little while phosphorous declined, it is likely that the system is phosphorous limited. Average chlorophyll-*a* levels throughout the summer were very low (3.44 µg/L; Table 1), so low that if trophic status was based on chlorophyll-*a,* Minnie Lake would be considered oligotrophic. While chlorophyll-*a* levels are typically low at Minnie Lake (Table 1), the temperatures in 2010 were uncommonly mild, resulting in very low algal biomass. A seasonal maximum chlorophyll-*a* concentration of 7.58 µg/L was seen on July 26th (Figure 4).

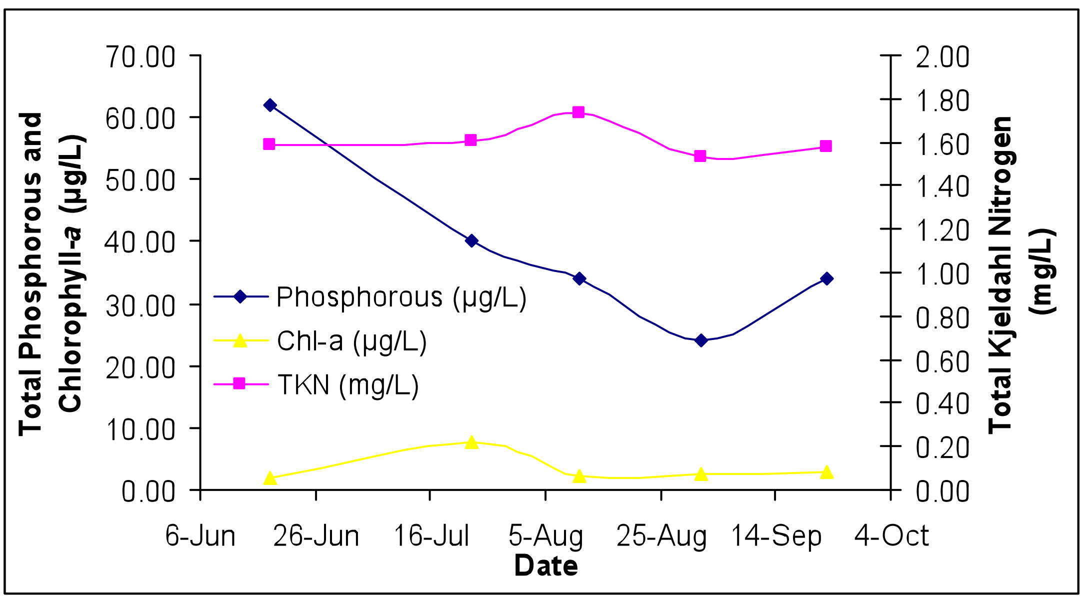

Figure 4 – Total phosphorous (µg/L), chlorophyll-*a* concentration (µg/L), and total Kjeldahl nitrogen (mg/L) measured over the course of the summer at Minnie Lake.

Average pH at Minnie Lake measured 8.65, well above neutral (7.0; Table 1). High bicarbonate ion concentrations (412 mg/L) help to buffer the lake against changes to pH. Other dominant ions include magnesium (123.3 mg/L), sodium (97.2 mg/L), and sulphate

(408.7 mg/L). Hardness, conductivity, and total dissolved solids (TDS), all have shown an increasing trend since 1978. Metals were measured twice during the summer of 2010, and all but arsenic fell within their recommended guidelines (Table 2). Quality assurance and quality control samples have been performed in 2011 to confirm levels of arsenic measured in Minnie Lake.

Table 1 – Average secchi depth and water chemistry values for Minnie Lake as measured in 2010. Water quality data from previous years provided for comparison.

Parameter	**1978**	**1979**	**1985**	**2008**	**2009**	**2010**
TP (μg/L)	/	/	21	40	42.3	38.8
TDP (μg/L)	/	/	11	23.8	22.5	27
Chlorophyll-*a* (μg/L)	/	/	6	5.3	4.03	3.4
Secchi depth (m)	/	/	4.2	4.5	2.2	4.7
TKN (μg/L)	/	/	1153	1504	1533	1608
NO_2 and NO_3 (μg/L)	/	/	6	33.3	8.25	12.1
NH_3 (μg/L)	/	/	50	62	35.8	99.2
DOC (mg/L)	/	/	13.2	18.3	19.5	19.6
Ca (mg/L)	29	30	19.4	26.6	25.7	21.8
Mg (mg/L)	90	87	91	120.3	121.3	123.3
Na (mg/L)	62	61	68	94.2	96.6	97.2
K (mg/L)	11.7	9.4	13.1	23.3	19.1	18.6
SO_4^{2-} (mg/L)	223	211	197	398.7	421	408. 7
Cl^- (mg/L)	3	3	4.4	7.1	6.93	7.5
CO_3 (mg/L)	/	/	21	25.7	31.3	23
HCO_3 (mg/L)	340	398	368	408.3	389.7	412
pH	8.9	8.6	8.6-8.9	8.6	8.8	8.6
Conductivity (μS/cm)	922	981	992	1340	1232	1370
Hardness (mg/L)	442	435	422	561.7	563.7	562.3
TDS (mg/L)	614	611	595	897.3	914	902. 7
Microcystin (μg/L)	/	/	/	0.11	0.11	0.08
Total Alkalinity (mg/L $CaCO_3$)	324	316	338	378.3	371.7	376

Note: TP = total phosphorous, TDP = total dissolved phosphorous, Chl-*a* = chlorophyll-*a*, TKN = total Kjeldahl nitrogen. NO_{2+3} = nitrate+nitrite, NH_3 = ammonia, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, SO_4 = sulphate, Cl = chloride, CO_3 = carbonate, HCO_3 = bicarbonate. A forward slash (/) indicates an absence of data.

Table 2 - Concentrations of metals measured in Minnie Lake on July 21st and September 23rd 2010. Values shown for 2010 are an average of those dates. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	**2008**	**2009**	**2010**	**Guidelines**
Aluminum µg/L	13.7	13	14.26	100[a]
Antimony µg/L	0.382	0.375	0.392	6[e]
Arsenic µg/L	9.15	9.33	9.56	5
Barium µg/L	20.6	18.7	18.5	1000[e]
Beryllium µg/L	<0.003	<0.003	0.005	100[d,f]
Bismuth µg/L	0.0073	0.0057	0.00385	/
Boron µg/L	162	205.5	159.5	5000[e,f]
Cadmium µg/L	0.0124	0.0187	0.01725	0.085[b]
Chromium µg/L	0.494	0.394	0.169	/
Cobalt µg/L	0.111	0.092	0.0972	1000[f]
Copper µg/L	0.332	2.09	0.6815	4[c]
Iron µg/L	10.9	43.6	16.1	300
Lead µg/L	0.0274	0.0544	0.0851	7[c]
Lithium µg/L	74.1	101.5	84.05	2500[g]
Manganese µg/L	8.61	6.36	5.905	200[g]
Molybdenum µg/L	0.799	0.727	0.746	73[d]
Nickel µg/L	0.271	0.665	0.3805	150[c]
Selenium µg/L	0.2	0.292	0.232	1
Silver µg/L	0.0022	0.0082	0.0029	0.1
Strontium µg/L	74	69.7	55	/
Thallium µg/L	0.0026	0.0029	0.00555	0.8
Thorium µg/L	0.0628	0.00215	0.01825	/
Tin µg/L	0.0308	<0.03	0.015	/
Titanium µg/L	0.667	0.691	1.0995	/
Uranium µg/L	2.3	2.08	2.16	100[e]
Vanadium µg/L	1.31	1.22	1.165	100[f,g]
Zinc µg/L	1.58	1.34	1.165	30

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5; calcium ion concentrations $[Ca^{+2}]$ ≥ 4 mg/L; and dissolved organic carbon concentration [DOC] ≥ 2 mg/L.
[b] Based on water Hardness of 300 mg/L (as $CaCO_3$)
[c] Based on water hardness > 180mg/L (as $CaCO_3$)
[d] CCME interim value.
[e] Based on Canadian Drinking Water Quality guideline values.
[f] Based on CCME Guidelines for Agricultural use (Livestock Watering).
[g] Based on CCME Guidelines for Agricultural Use (Irrigation).
A forward slash (/) indicates an absence of data or guidelines.

A Brief Introduction to Limnology

Indicators of Water Quality:

Water samples are collected in Lakewatch to determine the chemical characteristics that characterize general water quality. 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:

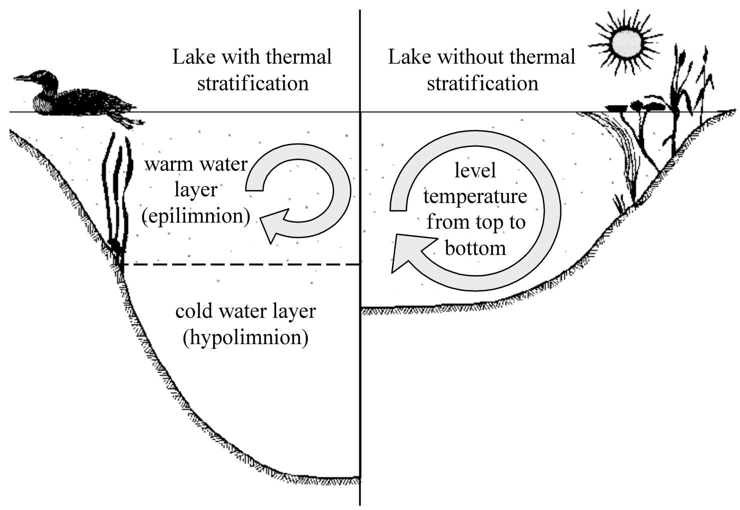

Figure A: Difference in the circulation of the water column depending on thermal stratification.

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 often 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 near 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 $mg \bullet L^{-1}$ and should not average less than 6.5 $mg \bullet L^{-1}$ over a seven-day period. However, the guidelines also require that dissolved oxygen concentrations remain above 9.5 $mg \bullet L^{-1}$ 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 rather than suspended algae. In these lakes, chlorophyll *a* and nutrient values taken from water samples do not include productivity from large aquatic plants. The result, in lakes like Chestermere which are dominated by larger plants known as macrophytes, can be 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 TRANSPARENCY :

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. A measure of the transparency or clarity of the water is performed with a Secchi disk with an alternating black and white pattern. To measure the clarity of the water, the Secchi disk is lowered down into the water column and the depth where the disk disappears is recorded. The Secchi depth in lakes with a lot of algal growth will be small while the Secchi depth in lakes with little algal growth can be very deep. However, low Secchi depths are not caused by algal growth alone. 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 low Secchi depths despite low algal growth and nutrient concentrations.

The euphotic zone or the maximum depth that light can penetrate into the water column for actively growing plants is calculated as twice the Secchi depth. Murky waters, with shallow Secchi depths, can prevent aquatic plants from growing on the lake bottom. Conversely, aquatic plants can ensure lakes have clear water by reducing shoreline erosion and stabilizing lake bottom sediments. In Alberta, many lakes are shallow and bottom sediments contain 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 insects, depend on aquatic plants for food and shelter.

TROPHIC STATE:

Trophic state is classification of lakes into four categories of 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 (Table 2)**.

A majority of lakes in Alberta contain naturally high levels of chlorophyll *a* (8 to 25 µg/L) due to our deep fertile soils. These lakes are usually considered fertile and are termed eutrophic. 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.

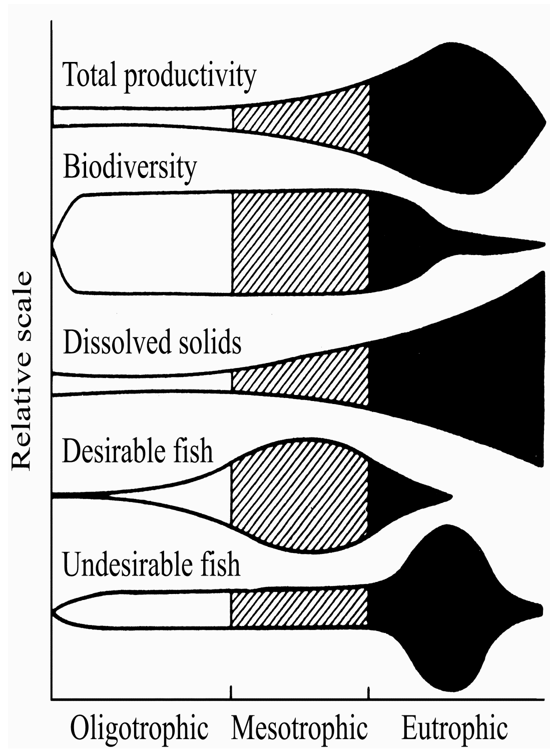

Figure B: Suggested changes in various lake characteristics with eutrophication. From "Ecological Effects of Wastewater", 1980.

Table A - Trophic status classification based on lake water characteristics.

Trophic state	Total Phosphorus (µg•L^{-1})	Total Nitrogen (µg•L^{-1})	Chlorophyll *a* (µg•L^{-1})	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.