The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Minnie Lake

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2009 Report

Completed with support from:

Alberta Lake Management Society

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> *Water is integral to supporting and maintaining life on this planet as it moderates the climate, creates growth and shapes the living substance of all of Earth's creatures. It is the tide of life itself, the sacred source.*
>
> David Suzuki (1997) The Sacred Balance

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 these 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 and Cindie Kissel for their efforts in collecting data in 2009. We would also like to thank Noemie Jenni and Cristen Symes who were summer interns with ALMS in 2009. 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 logistics planning and training aspects of the program. Doreen LeClair and Chris Rickard were responsible for data management. Théo Charette (ALMS President) and Jill Anderson (Program Manager) were responsible for program administration and planning. Théo Charette, Ron Zurawell (Limnologist, AENV), Lori Neufeld, and Sarah Lord prepared the original report, which was updated by Sarah Lord for 2009. Alberta Environment and the Beaver River Watershed Alliance (BRWA) were major sponsors of the Lakewatch program.

Minnie Lake

Minnie Lake (**Figure 1**) is a small lake located west of Bonnyville, in the Lakeland region of Alberta. The lake is 2 km long and 0.6 km wide, with a surface area of 0.84 km^2. Mean depth was 8.3 m and the deepest basin of the lake was 23.8 m (**Figure 2**) when the lake surface was at 553.75 m elevation, although water levels have dropped by 2.35 m since those measurements were taken (**Figure 3**) and therefore maximum depth is currently 21.45 m.

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

The shoreline of the lake hosts two campsites (including Minnie Lake Provincial Recreation Area), private cabins and recreational properties, agricultural land, and boreal forest.

Minnie Lake is spring-fed by the Beverly channel aquifer and surface runoff from precipitation, and is the secondary water source for the village of Glendon. 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, recreational activities, fisheries, and wildlife, especially as one of the proposed wells would be directionally drilled to pump oil from directly underneath the lake. The Save Minnie Lake

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

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.

Results

Water Level

Water levels have been recorded at Minnie Lake since 1981. Water levels have declined more than 3 m since that time, from a maximum of 554.5 m asl (meters above sea level) in 1981 to the minimum recorded historical level of 551.4 m asl in December 2008 (**Figure 3**). A brief rebound in water levels occurred in 1997, which was an exceptionally wet year, but when precipitation returned to normal rates the decline in water levels continued. Spring-fed lakes tend to maintain stable water levels, and if water levels decline, it may be due to changes in the groundwater levels, withdrawal of lake water, or a combination of the two.

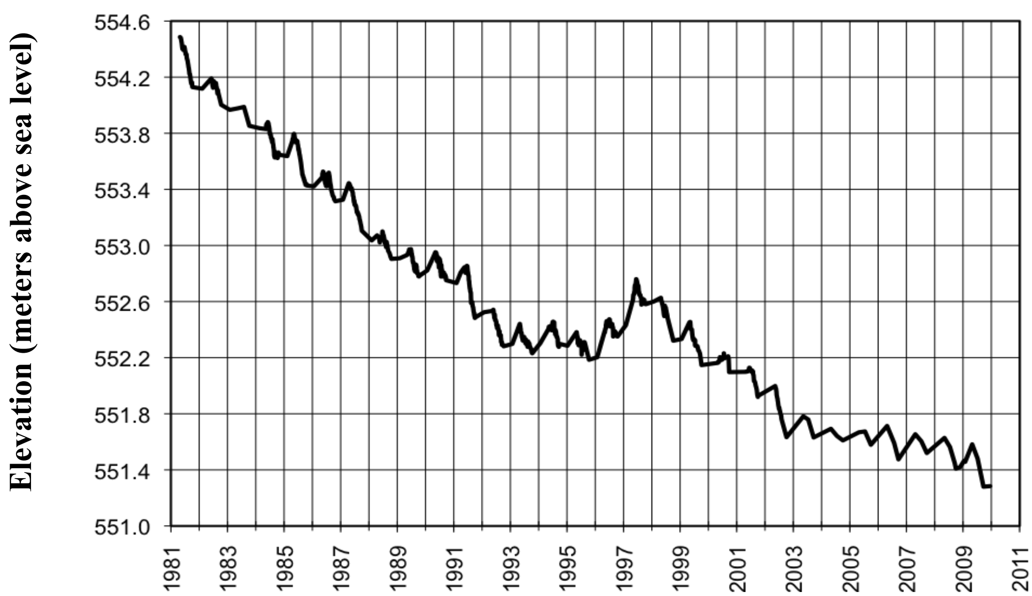

Figure 3. Historical water levels (m asl) in Minnie Lake, Alberta 1981 – 2009.

In 1986 the Minnie Lake Stabilization Plan was drawn up in response to water level declines observed in the early 1980s. 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. However, the continued decline in water level shows that the halt in municipal withdrawals, and all other water level management efforts, have been insufficient to offset changes in groundwater levels and non-municipal withdrawals.

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.

Thermal stratification in Minnie Lake was observed during the summer 2009 (**Figure 4**). On 25 June, a thermocline was observed at 5 m depth, and water temperature decreased from 18.9°C at the surface to 4.3°C at to the lake bottom. The thermocline depth was slightly deeper on 15 July, and surface water temperature was 18.2°C. On 5 August, the surface water temperature reached a seasonal maximum of 20.2°C and the thermocline occurred at 5 m depth. Surface waters returned to 18.3°C by 20 August, and the thermocline remained at 5.5 m depth. Minnie Lake is a partially meromictic lake (water column does not completely mix in all years) with a residence time of 12.3 years (Trew 1986), and the strong thermocline on all sampling dates shows that the lake did not overturn during the sampling period.

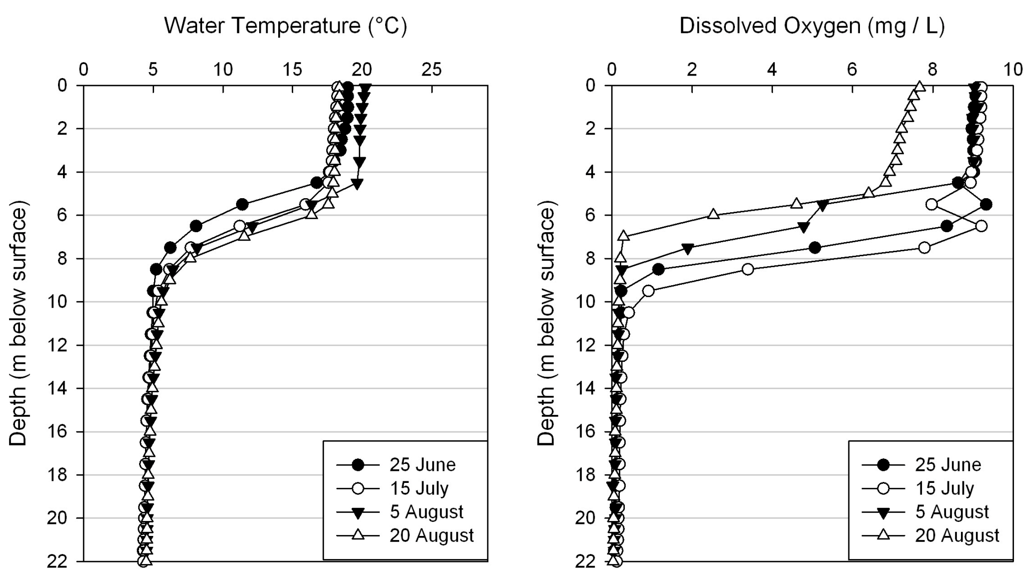

Figure 4. Water temperature (°C) and dissolved oxygen (mg/L) profiles for Minnie Lake during the summer of 2009.

Dissolved oxygen (DO) concentrations in upper layers of surface waters of Minnie Lake were ≥ 7 mg/L on all sampling dates through the summer, well within the acceptable range for surface water quality (DO ≥ 5.0 mg/L) (**Figure 4**). DO concentrations declined rapidly at a depth of 4.5 m on 25 June and 15 July. The boundary between well-oxygenated and poorly-oxygenated layers of water remained at 5.5 m on 5 August and 20 August. On all sample dates, DO was near zero (e.g. anoxic) below the boundary down to the lakebed. Deep-water anoxia is common in summer, and the decomposition of organic matter produced during the open water season continues on into the winter months, which in turn, leads to low winter oxygen concentrations as decomposition consumes oxygen.

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.

Water clarity in Minnie Lake was measured four times during the summer of 2009. Minnie Lake was neither exceptionally turbid nor exceptionally clear compared to other lakes in Alberta, with average Secchi depth of 2.19 m over the summer (**Table 1**). In June, Secchi depth was 2.25 m and light penetrated 8.0 m or ~10% of the total lake depth, which allowed for algal growth in the top 4.5 m of the lake. On 15 July, Secchi depth remained at 2.25 m, but by early August decreased to 1.25 m. Water clarity recovered to its seasonal maximum of 3.0 m Secchi depth in late August. This pattern of water clarity dynamics is typical of highly productive Alberta lakes, when algal growth during summer months causes reduced water clarity. Water clarity begins to increase in late summer as lower temperatures limit growth, and the dying algae fall out of the water column and settle on the lakebed where they are decomposed by anaerobic bacteria.

Water Chemistry

Based on lake water characteristics Minnie Lake is considered mesotrophic (see *A Brief Introduction to Limnology* at the end of this report). In 2009, Marie Lake had moderate concentrations of total phosphorus (average TP = 42.3 μg/L), total nitrogen (average TN = 1541 μg/L), and algal biomass (average chlorophyll *a* = 4.03 μg/L) (**Table 1**). Total phosphorous declined over the summer, from 49 μg/L on 25 June to a low of 34 μg/L on 20 August (**Figure 5**), as algal growth consumed nutrients in the water column. Total nitrogen remained comparatively steady, fluctuating from a maximum of 1.695 mg/L on 5 August and a minimum of 1.44 mg/L on 25 June. Chlorophyll *a* (a measure of algal biomass) increased steadily from 3.48 μg/L on 25 June to 7.02 μg/L on 5 August, and then declined to a seasonal minimum of 1.82 μg/L on 20 August.

During the summer 2009, Minnie Lake was well buffered from acidification with an average pH = 8.8, which is well above that of pure water (i.e., pH 7). Dominant ions include sulphate, bicarbonate, and magnesium (**Table 1**). Attention had previously been drawn to the high sulphate and relatively high magnesium concentrations (Trew 1986), which make Minnie Lake a relatively undesirable municipal water source, due to the need for extra water treatment options. Water in Minnie Lake is now harder and more alkaline than in 1978, with higher ion concentrations (e.g. sulphate concentration has doubled since 1985), than reported in historical sampling.

The average concentrations of various metals (as total recoverable concentrations) in Minnie Lake were measured twice in the summer of 2009. All concentrations were within CCME guidelines for the Protection of Freshwater Aquatic Life, except for arsenic, which at 9.33 µg/L exceeded the 5.0 µg/L guideline (**Appendix 1**).

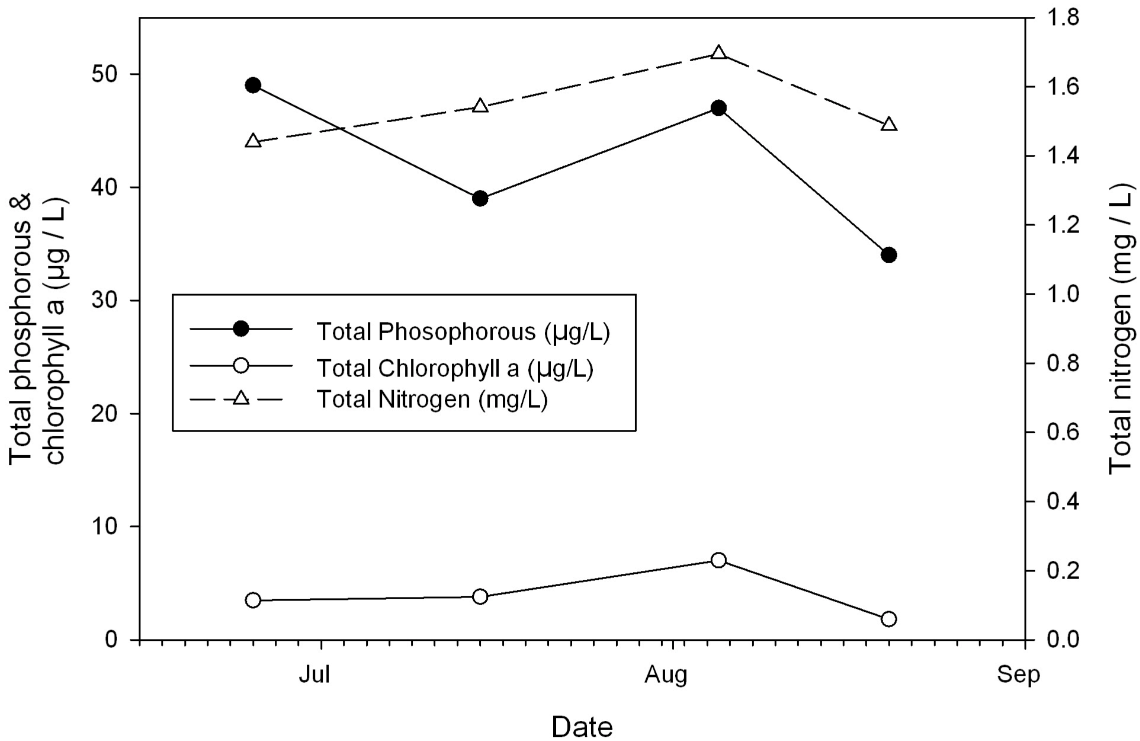

Figure 5. Total phosphorous, chlorophyll *a* (a measure of algal biomass), and total nitrogen concentrations for Minnie Lake during the summer of 2009.

Table 1. Mean water chemistry and Secchi depth values for Minnie Lake. Historical values for 3 August 1978, 20 June 1979, and 31 July 1985 are compiled from Trew (1986).

Parameter	1978	1979	1985	2008	2009
TP (μg/L)	-	-	21	40	42.3
TDP (μg/L)	-	-	11	23.8	22.5
Chlorophyll-*a* (μg/L)	-	-	6	5.3	4.03
Secchi depth (m)	-	-	-	4.5	2.19
TKN (μg/L)	-	-	1153	1504	1533
$NO_{2,3}$ (μg/L)	-	-	6	33.3	8.25
NH_4 (μg/L)	-	-	50	62	35.8
Dissolved organic C (mg/L)	-	-	13.2	18.3	19.5
Ca (mg/L)	29	30	19.4	26.6	25.7
Mg (mg/L)	90	87	91	120.3	121.3
Na (mg/L)	62	61	68	94.2	96.6
K (mg/L)	11.7	9.4	13.1	23.3	19.1
SO_4^{2-} (mg/L)	223	211	197	398.7	421
Cl^- (mg/L)	3	3	4.4	7.1	6.93
TDS (mg/L)	614	611	595	897.3	914
pH	8.9	8.6	8.6 – 8.9	8.6	8.8
Conductivity (μS/cm)	922	981	992	1340	1232
Hardness (mg/L)	442	435	422	561.7	563.7
HCO_3 (mg/L)	340	398	368	408.3	389.7
CO_3 (mg/L)	-	-	21	25.7	31.3
Total Alkalinity (mg/L $CaCO_3$)	324	316	338	378.3	371.7

Note: TP = total phosphorous, TDP = total dissolved phosphorous, Chla = chlorophyll *a*, TKN = total Kjeldahl nitrogen, NO_{2+3} = nitrate+nitrite, NH_4 = ammonium, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, SO_4 = sulphate, Cl = chloride, CO_3 = carbonate, HCO_3 = bicarbonate.

*Atlas of Alberta Lakes (Mitchell and Prepas, 1990).

Appendix 1

The concentrations of metals were measured twice in Minnie Lake in summer 2009; mean values are presented here. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (total)	2008	2009	Guidelines
ALUMINUM µg/L	13.7	13.0	100[a]
ANTIMONY µg/L	0.382	0.375	6[e]
ARSENIC µg/L	9.15	9.33	5
BARIUM µg/L	20.6	18.7	1000[e]
BERYLLIUM µg/L	<0.003	<0.003	100[d,f]
BISMUTH µg/L	0.0073	0.0057	
BORON µg/L	162	205.5	5000[e,f]
CADMIUM µg/L	0.0124	0.0187	0.085[b]
CHROMIUM µg/L	0.494	0.394	
COBALT µg/L	0.111	0.092	1000[f]
COPPER µg/L	0.332	2.09	4[c]
IRON µg/L	10.9	43.6	300
LEAD µg/L	0.0274	0.0544	7[c]
LITHIUM µg/L	74.1	101.5	2500[g]
MANGANESE µg/L	8.61	6.36	200[g]
MOLYBDENUM	0.799	0.727	73[d]
NICKEL µg/L	0.271	0.665	150[c]
SELENIUM µg/L	0.200	0.292	1
STRONTIUM µg/L	74.0	69.7	
SILVER µg/L	0.0022	0.0082	
THALLIUM µg/L	0.0026	0.0029	0.8
THORIUM µg/L	0.0628	0.00215	
TIN µg/L	0.0308	<0.03	
TITANIUM µg/L	0.667	0.691	
URANIUM µg/L	2.30	2.08	100[e]
VANADIUM µg/L	1.31	1.22	100[f,g]
ZINC µg/L	1.58	1.34	30

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5; calcium ion concentration $[Ca^{+2}]$ ≥ 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 > 180 mg/L (as $CaCO_3$).
[d] CCME interim value.
[e] Based of Canadian Drinking Water Quality guideline values.
[f] Based of CCME Guidelines for Agricultural Use (Livestock Watering).
[g] Based of CCME Guidelines for Agricultural Use (Irrigation).

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A Brief Introduction to Limnology

Indicators of water quality

The goal of **Lakewatch** is to collect water samples necessary to determine the water quality of lakes. Though not all encompassing, the variables measured in **Lakewatch** are sensitive to human activities in watersheds that may cause impacts to 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 affected (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 fish habitat and production of noxious odors. Large increases in nutrients over time may also indicate sewage inputs, which in turn, may result in other human health concerns such as harmful bacteria or protozoans (e.g. *Cryptosporidium*).

Temperature and mixing

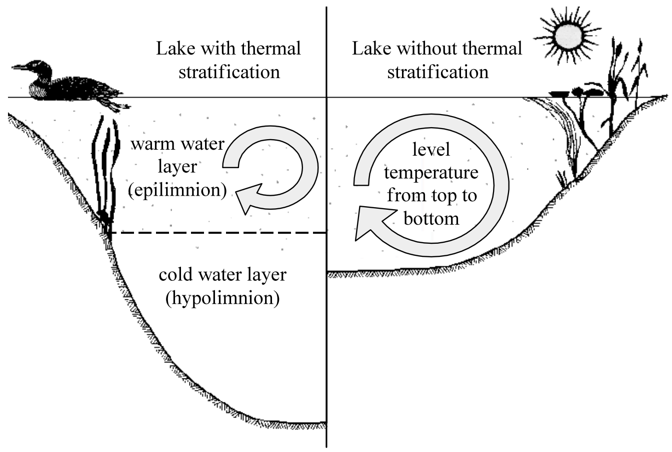

Figure 6: Difference in the circulation of the water column depending on thermal stratification.

Water temperature in a lake dictates the behavior of many chemical parameters responsible for water quality (Figure 6). 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. Larger aquatic plants, known as macrophytes, rather than algae, dominate some highly productive lakes. 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 exist 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-*a*) concentrations, the trophic states are: **oligotrophic**, **mesotrophic**, **eutrophic** and **hypereutrophic**. The nutrient and algal biomass concentrations that define these categories are shown in table 2 and a graph of Alberta lakes compared by trophic state can be found on the ALMS website. A majority of lakes in Alberta are meso- to 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 Figure. 7.

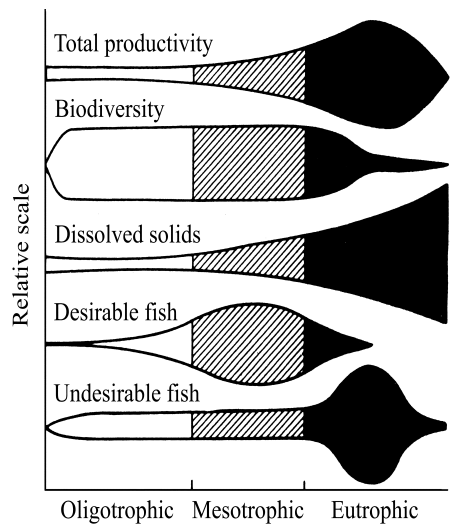

Figure 7: Suggested changes in various lake characteristics with eutrophication. From "Ecological Effects of Wastewater", 1980.

Table 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.