The Alberta Lake Management Society Volunteer Lake monitoring report

Pine Lake

2008 Report

Completed with support from:

Alberta Environment

Alberta Lake Management Society

Address: P.O. Box 4283
Edmonton, AB T6E4T3
Phone: 780-702-ALMS
E-mail: info@alms.ca

> *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, Théo Charette and Ron Zurawell. We would like to thank John Rancourt and Leah Codom for their efforts in collecting data in 2008. We would also like to thank Lisa Brodziak and Sophie Damlencour who were summer interns with ALMS in 2008. 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. Al Sosiak (Limnologiest, AENV) prepared the original report, which was updated by Sarah Lord for 2008. Alberta Environment and the Beaver River Watershed Alliance (BRWA) were major sponsors of the Lakewatch program.

Pine Lake

Pine Lake (**Figure 1**) is a small eutrophic lake southeast of Red Deer, Alberta. Pine Lake is subject to cyanobacterial blooms, and public concern over deteriorating water quality prompted the Alberta government to initiate a lake restoration program in 1991. The Pine Lake Restoration Program was designed as a pilot project for future lake and watershed projects in Alberta.

An advisory committee that represented all members of the community directed early planning and problem diagnosis by the Alberta government. A diagnostic study in 1992 (Sosiak and Trew, 1996) determined that approximately 61% of the total phosphorus (TP) loading was from sediment release and other internal sources, compared to about 36% from surface runoff and determined that algal growth in Pine Lake was mainly limited by the supply of phosphorus. Four critical areas for watershed restoration were identified on four streams affected by livestock operations and sewage release (Sosiak and Trew, 1996). These streams contributed 72% of the phosphorus loading from streams in 1992.

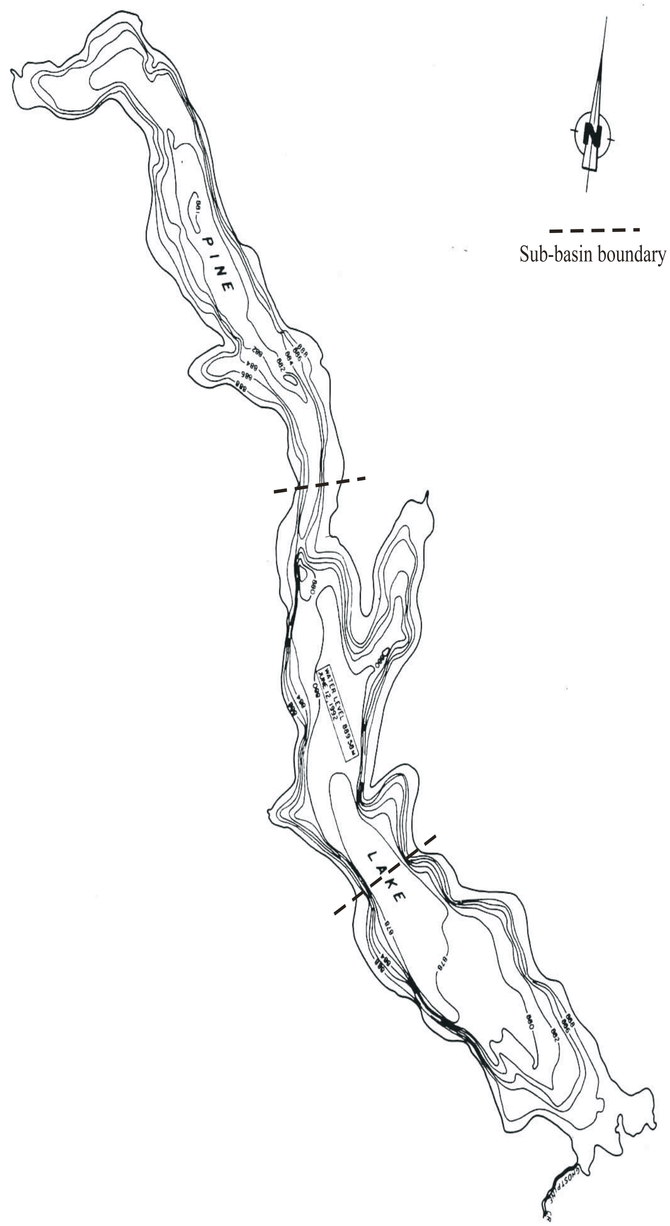

Figure 1. Bathymetry of Pine Lake (Sosiak and Trew, 1996)

The advisory committee later formed the Pine Lake Restoration Society, a non-profit organization with representatives from all stakeholders, which raised funds and worked with technical advisors from the Alberta government. The Pine Lake Restoration Society implemented a four-year work plan in 1995 that addressed phosphorus loading from all sources. The main objective of the restoration program was to restore Pine Lake to a "natural" level of algal productivity. The Pine Lake Restoration Society and other individuals in the basin completed beneficial management practices (BMPs) projects at various agricultural sites. Other organizations also improved wastewater treatment at a resort and two camps near the shoreline of Pine Lake.

Following an evaluation of the different alternatives to remove or treat phosphorus released from lake sediments, hypolimnetic withdrawal was selected as the preferred method of treatment. Hypolimnetic withdrawal has been successfully used to reduce TP concentration in various lakes, mainly in Europe, but has never been attempted in Alberta. Two different designs for the Pine Lake system were prepared and evaluated and, following public notice and licensing, the system was installed in September 1998.

The system at Pine Lake consists of a weir that maintains head and regulates lake level, and a gravity-fed pipeline that withdraws cool, phosphorus-rich water from near the bottom of the lake (called the hypolimnion) of the south basin and discharges through a vault with control valves to a stilling basin on Ghostpine Creek. Locations and other details on the projects and results of water quality sampling to 2001 are in Sosiak (2002).

This report presents results of an update of volunteer sampling of Pine Lake in 2008. The Lakewatch sampling program is designed to monitor changes in water quality in Pine Lake following the completion of watershed and lake projects in 1998. Although the Alberta government sampled individual sub-basins of Pine Lake prior to 2003, key variables were seldom significantly different among sub-basins (Sosiak 2002). Accordingly, Lakewatch volunteers collected a single euphotic zone composite sample from the entire lake on each sampling date during June to September starting in 2003. This change also ensured a consistent sampling approach was used throughout Lakewatch. This report consists of a comparison of 2008 results to data collected by the Alberta government and Lakewatch since 1978. The composite sampling was supplemented by meter measurements of temperature, dissolved oxygen, conductivity, and pH throughout the water column, at the same location sampled previously in the middle basin of Pine Lake.

Water Level

Water levels in Pine Lake have been monitored since 1965 (**Figure 2**). Under the approval to operate the hypolimnetic withdrawal system, the Pine Lake Restoration Society tries to maintain water levels within a range (**Figure 2**) that was recommended in the engineering report for the system. The weir operator for the Society accomplishes this by adding or removing boards to the weir at the lake outfall and by operating the control valves. There was sufficient water to operate the hypolimnetic withdrawal system in 1999, 2000, 2003, and 2005, 2006, and briefly in 2001. However, there was not sufficient water to operate the system during 2002, which was one of the worst droughts that have occurred in this region, or in 2004 when lake levels were still low following the drought. During planning for the project, it was assumed that there would be insufficient water to operate the system three years of 10 (Sosiak, 1997). Water levels were maintained within the target levels for all but a brief period in the spring of the 2006 operating season

(**Figure 2**), although they increased to 889.722 m in April 2006. Water levels were at the lower target level at 889.4 m on November 4, 2006. This recovery in lake levels from the low levels during 2001 to 2003 was probably a result of above average precipitation in 2004 and 2005.

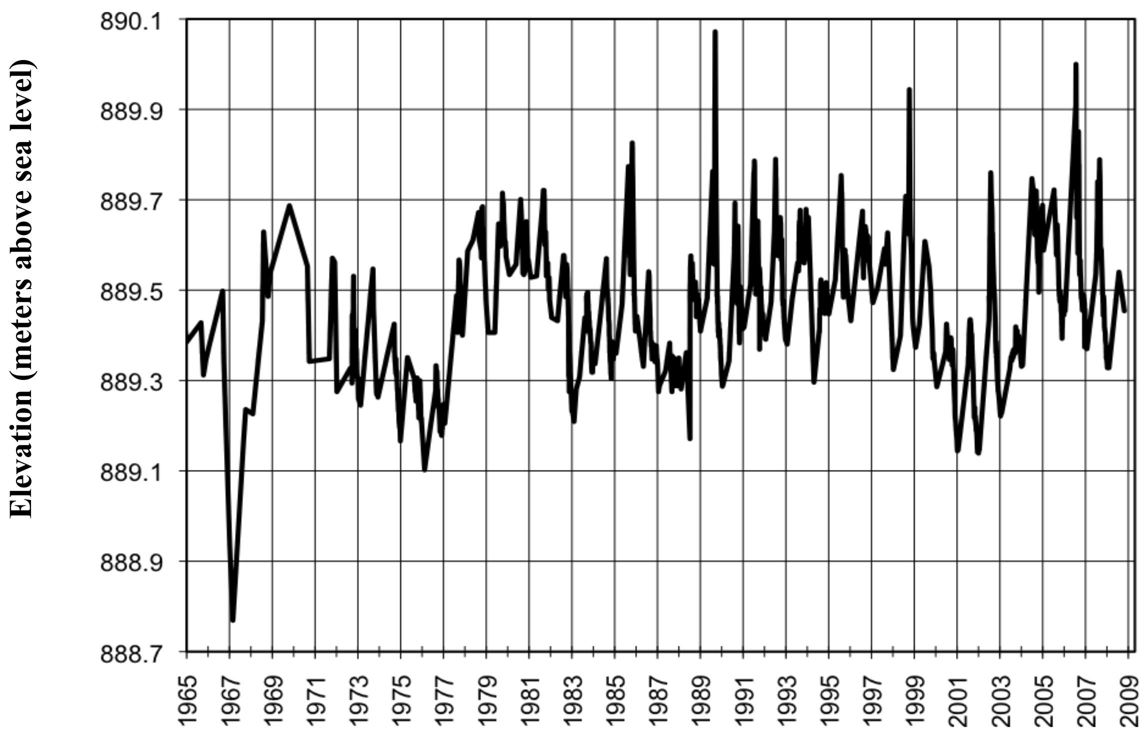

Figure 2. Historical water levels (meters above sea level (asl)) in Pine Lake, Alberta 1965 – 2009.

Results

Water temperature and dissolved oxygen

No significant thermal stratification was observed in Pine Lake during the summer of 2008 (**Figure 3**). Surface water temperature was 17.4°C on 23 June, and increased to 19.3°C by 22 July. On 22 July, a slight thermocline was present at 8 m depth, but the mild temperature differential had disappeared by 22 August while surface water temperature remained constant. On 10 July, the surface waters cooled to 15.9°C and the lake was perfectly isothermic. This profile shows that Pine Lake is a polymictic lake, and that lake water layers were well-mixed for most of the summer of 2008.

Dissolved oxygen (DO) concentrations in upper layers of surface waters of Pine Lake were ≥ 5 mg/L on all sampling dates through the summer except 22 August, within the acceptable range for surface water quality (DO ≥ 5.0 mg/L) (**Figure 3**). DO concentrations were 11.46 mg/L at the surface, and declined gradually to 2.56 mg/L at the lake bed on 23 June. Surface water oxygen concentration, and the intensity of the corresponding chemocline, increased through the summer. On 22 July a strong chemocline was present at 6 m depth, and bottom waters were anoxic below 9 m depth. On 22 August, surface water DO concentrations fell below provincial guidelines, but chemocline depth remained constant. On 10 September the chemocline disappeared and DO was relatively constant at all depths except within 1 m of the lake bed, indicating the lake had completely mixed prior to sampling. 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).

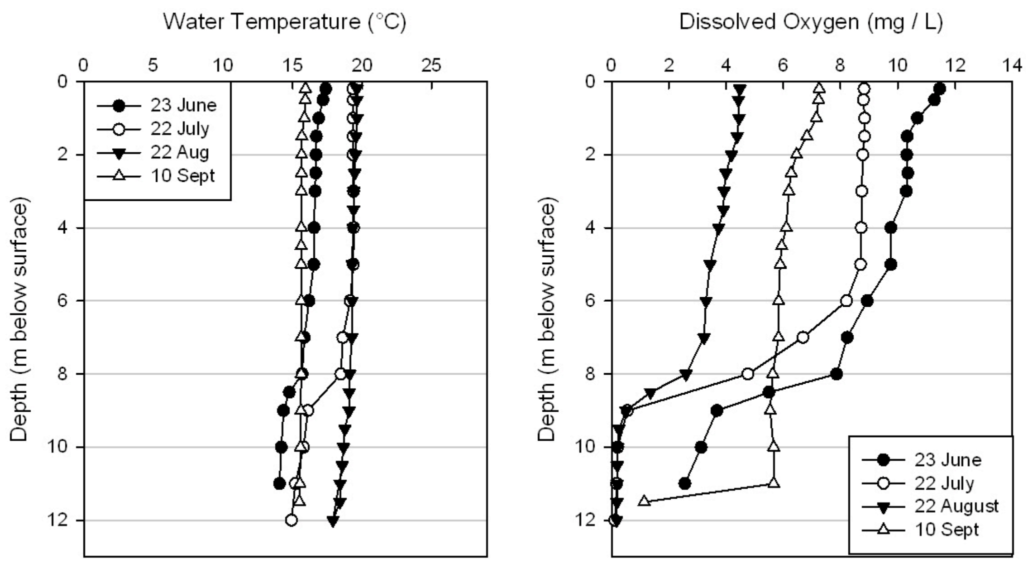

Figure 3. Water temperature (°C) and dissolved oxygen (mg/L) profiles for Pine Lake during the summer of 2008.

Water clarity and Secchi Disk Depth

Water clarity is influenced by suspended material, both living and dead, as well as some coloured dissolved compounds in the water column. The most widely used measure of lake water clarity is the Secchi disk depth. Following the period of ice and snowmelt, a lake can have low clarity due to spring runoff and the inflow of suspended sediments into the lake. Lake water usually Pines in the spring but then becomes more turbid due to algal growth taking place throughout the summer open water season.

Water clarity on Pine Lake was measured four times during the summer of 2008. Pine Lake was relatively turbid compared to other lakes in Alberta, with average Secchi disk depth = 1.2 m (**Table 1**). On 23 June, light penetrated 1.25 m or only ~11% of the total lake depth, which allowed for algal growth in the top 2.5 m of the lake. By 22 July, Secchi disk depth had decreased to 0.8 m, but recovered to 1.6 m by 22 August. Water clarity declined again by 10 September, with a Secchi disk depth of 1.25 m. This pattern of water clarity dynamics is typical of highly productive Alberta lakes, when algal growth during July and August causes reduced water clarity. Water clarity recovers in September as lower temperatures limit growth, and dying algae fall out of the water column and settle on the lakebed where they are decomposed by anaerobic bacteria. The drop in water clarity on 10 September relative to 22 August may have been caused by the recent fall turnover, which resuspended particulates in the hypolimnion.

Water chemistry

Based on lake water characteristics, Pine Lake is considered hypereutrophic (see *A Brief Introduction to Limnology* at the end of this report). Average total phosphorus (TP = 78.8 μg/L) was within the eutrophic range, while total Kjeldahl nitrogen (TN = 1907 μg/L) and chlorophyll *a* (chl *a* = 37.15 μg/L) were within the hypereutrophic range in 2008 (**Table 1**).

Total phosphorous varied over the summer, from a minimum of 67 μg/L on 22 August to a maximum of 92 μg/L on 10 September (**Figure 4**). Total nitrogen remained relatively steady, fluctuating from a maximum of 2.02 mg/L on 22 July and a minimum of 1.75 mg/L on 23 June. Chlorophyll *a* (a measure of algal biomass) concentrations closely tracked the changes in phosphorous concentrations, increasing from 19.0 ug/L on 23 June to the seasonal maximum of 54.1 ug/L on 22 July, then declined to 24.5 ug/L on 22 August, before recovering to 51 μg/L on 10 September. As the depletion of phosphorous was not accompanied by a significant decrease in nitrogen, algal growth in Pine Lake is phosphorous-limited and not nitrogen-limited.

During the summer 2008, Pine Lake was well buffered from acidification with an average pH = 8.5, which is well above that of pure water (i.e., pH 7). Dominant ions include ammonia, sodium, and sulphate (**Table 1**). Ion concentrations in Pine Lake seem to have remained relatively stable since monitoring began in 1979. The average concentrations of various heavy metals (as total recoverable concentrations) in Pine Lake were not measured in the summer of 2008.

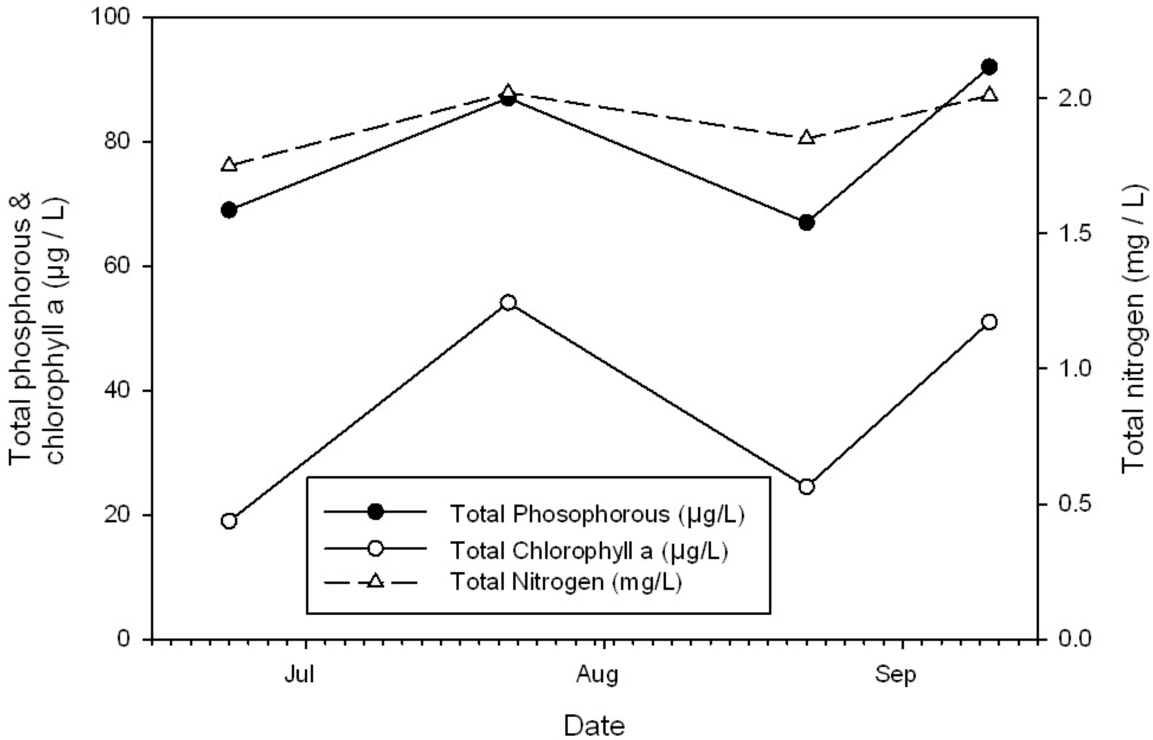

Figure 4. Total phosphorous, chlorophyll a (a measure of algal biomass), and total nitrogen concentrations for Pine Lake during the summer of 2008.

Table 1. Water chemistry values for Pine Lake compared to values from previous years of sampling and those reported in the Atlas of Alberta Lakes (Mitchell and Prepas 1990).

Parameter	1979	1984	1992	1996	2002	2003	2004	2005	2006	2008
TP ($\mu g \bullet L^{-1}$)	-	56	84.7	104.0	49.3	55	79	70	81.2	78.8
TDP ($\mu g \bullet L^{-1}$)			38.6	57.9	18.4	26.2	26.2	33.3	32.4	33.8
Chl a ($\mu g \bullet L^{-1}$)	11.3	26.3	50.4	22.1	15.6	17.9	37.8	19.3	32.7	37.2
Secchi disk depth (m)	3.4	1.8	1.8	2.1	1.7	3.1	1.7	2.5	1.8	1.2
TKN ($\mu g \bullet L^{-1}$)	1293	1302	2052	1360	1442	1474	1880	1750	1856	1908
TN ($\mu g \bullet L^{-1}$)	-	-	2088	1385	1445	1484	2020	1761	1859	
NO_2+NO_3N ($\mu g \bullet L^{-1}$)	13	<10	36	11	3	10	9.7	11	2	13
NH_4^+ N ($\mu g \bullet L^{-1}$)	-	59	146	120	11	98	136	156	134	135
Ca ($mg \bullet L^{-1}$)		23	25	28	20	21	21.7	21	24	29.1
Mg ($mg \bullet L^{-1}$)		25	25	24	26	24	25	23	23	23.5
Na ($mg \bullet L^{-1}$)		108	99	103	112	124	132	129	128	109
K ($mg \bullet L^{-1}$)		10	9	10	11.5	10	10	10	10.7	9.7
SO_4^{2-} ($mg \bullet L^{-1}$)		84	69	63	90	79	85	78	82.3	68.3
Cl^- ($mg \bullet L^{-1}$)		6	7	8	11	10	11	10	12	12.8
Total Alkalinity ($mg \bullet L^{-1}$ $CaCO_3$)		319	308	313	321	331	341	342	346	319.7
pH	-	-	-	-	-	-	8.8	8.7	8.7	8.5
HCO_3($mg \bullet L^{-1}$)	-	-	-	-	-	-	374	381	387	370

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).

References

Mitchell, P. and E. Prepas. 1990. Atlas of Alberta Lakes. University of Alberta Press.

Vollenweider, R.A., and J. Kerekes, Jr. 1982. Eutrophication of Waters. Monitoring, Assessment and Control. Organization for Economic Co-Operation and Development (OECD), Paris. 156p.

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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

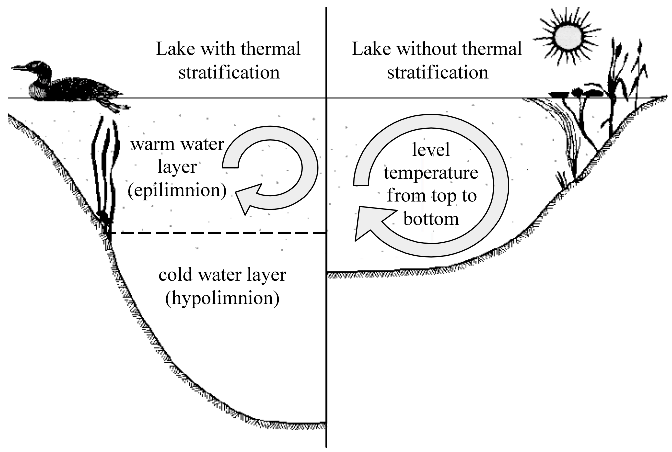

Figure 6: Difference in the circulation of the water column depending on thermal stratification.

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 Pine 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 Pine 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.

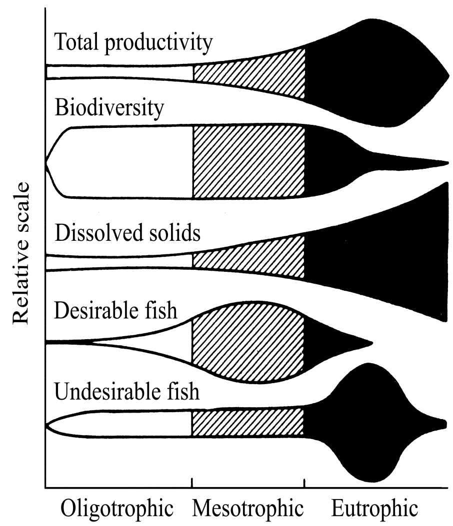

Figure 7: Suggested changes in various lake characteristics with eutrophication. From "Ecological Effects of Wastewater", 1980.

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.