The water quality of Chestermere Lake: A state of the knowledge report

Prepared for:

The Town of Chestermere

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April 2001

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3.0 Executive Summary

Excessive macrophyte (aquatic vegetation) growths continue to cause problems for recreational users of Chestermere Lake, Alberta. Fortunately, several scientific studies have been undertaken in the past 30 years on the ecology of Chestermere Lake. The lake was historically managed as a balancing reservoir for the WID; but due to heavy recreational use, the lake managers now maintain a constant water level. Complaints from the recreational users prompted Chestermere Town Council to form the Weed and Water Committee to study the vegetation problem and implement strategies to find some solutions. To effectively begin planning weed management strategies, the past scientific reports must first be identified and summarized for discussion. The purpose of the following report is to identify and summarize all available biological, water and sediment chemistry information available on Chestermere Lake. Raw water data were augmented with AENV data to create a 30-year water quality summary. This document will serve as a starting point for all future management considerations.

Chestermere Lake is a 261 ha offstream storage reservoir, 7 km east of the city of Calgary, Alberta in Municipal District # 44. The reservoir was created in 1903 by the Canadian Pacific Railroad as part of the Western Headworks Canal system linking water from the Bow River to over 800 ranchers up to 90 kms away. The lake has an elongate oval shape with a drainage basin area of 5 km^2. The 12.3-km shoreline around Chestermere Lake has been heavily developed with over 400 lots and over 3300 permanent residents.

The reservoir receives a high rate of inflow which decreases residence times to around 11 days. Water quality is generally good, with nutrients and chlorophyll *a* values in the mesotrophic (middle) range of lake productivity. Lake water is occasionally polluted with coliform bacteria, organics and heavy metals during periods of high runoff, from Calgary urban runoff inputs and Nose Creek upstream. Alberta Environment modeling data (1994) suggested that water quality had decreased during the study period of 1983-1993. While the reservoir is able to decrease concentrations of influent nutrients, coliforms and metals, particulate-bound metals may be accumulating in the lake sediments. Late summer algal blooms are an occasional problem.

Past steps of small-scale sediment removal to curb nuisance plant growth have failed. Dominant aquatic vegetation include Sago Pondweed (*Potamogeton pectinatus*) and Richardson's Pondweed (*P. richardsonii*), less numerous is Coontail (*Ceratophyllum demersum*), Northern Water Milfoil (*Myriophyllum exalbescens*), Flat Stemmed Pondweed *(P. zosteriformis*), Star Duckweed (*Lemna trisulca*) and macrophytic algae (*Chara spp*.) (Alberta Environmental Protection 1994).

The lake purifies inflowing water by effectively trapping and storing particulate bound contaminants while decreasing nutrient concentrations as waters pass through the reservoir. Shallow shoreline depth, nutrient-rich sediments and continuous sediment accumulations are likely providing the necessary combination of factors for accelerated aquatic vegetation growth.

4.0 Introduction

Algal blooms and excessive macrophyte (aquatic weed) growth continue to cause problems for recreational users of Chestermere Lake, Alberta. From as far back as 1969, abundant growth of submersed aquatic vegetation has been noted (Thompson 1971). Since that time, surface water and lake sediment have been studied by several researchers (Masuda 1972, Exner 1978, AEP 1984, Reid Crowther 1991, AEP 1992, AEP 1993, Sosiak 1994, Cross 1996-1999 and McEachern 2000). To date, this body of information has not been incorporated into a single document. The purpose of the following report is to identify and summarize all available water and sediment chemistry research on Chestermere Lake, so that this document may serve as a reference for future projects, such as implementing weed control strategies for the lake.

4.1 Site Description

Chestermere Lake is a 261 ha offstream storage reservoir, 7 km east of the city of Calgary, Alberta (Tp 24 R28 W4) in Municipal District # 44. The lake has an elongate oval shape (5.12 km long by 0.77 km wide) with a drainage basin area of 5 km^2 (Mitchell and Prepas 1990) and lies in the Foothills Fescue Prairie Ecoregion (Poston et al. 1990). This arid region of southern Alberta is characterized by hot summers, cold winters and temperatures modified by Chinook winds. Annual precipitation in the area is 432 mm and evapotranspiration exceeds precipitation by 34 mm/year (Environment Canada, 1982). The geology underlying Chestermere Lake is a bedrock of sandstone, shale and coal, with a surficial layer of till left from the melting of the Pleistocene ice sheets (Hardy 1967). Soils of the area are thin Orthic Black Chernozemics. Lake sediments consist of bottom mud and organic sand and silt underlain by sand and silt with thicknesses ranging from 0.5m to 1.5m (Ouellet and MacLeod 1990).

The 12.3-km shoreline around Chestermere Lake has been heavily developed with over 400 lots and some 3330 permanent residents (Town of Chestermere year 2000 estimate). Chestermere Lake provides excellent recreational opportunities such as canoeing, boating, water-skiing, swimming, windsurfing, fishing, ice fishing, skating and snowmobiling for its residents and others from neighbouring communities such as Calgary. The lakeshores slope steeply to a historical maximum depth of 7 m (Thompson, 1971).

Aquatic weeds have been a nuisance in the lake for recreational users for some time. The dominant weeds are Sago Pondweed (*Potamogeton pectinatus*) and Richardson's Pondweed (*P. richardsonii*); less numerous species present include Coontail (*Ceratophyllum demersum*), Northern Water Milfoil (*Myriophyllum exalbescens*), Flat Stemmed Pondweed *(P. zosteriformis*), Star Duckweed (*Lemna trisulca*) and macrophytic algae (*Chara spp*.) (Alberta Environmental Protection 1994). Mechanical weed harvesters are used during the summer months on the lake.

Fishing at Chestermere Lake is popular in both the winter and the summer. Fish common to Chestermere Lake include northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), white sucker (*Catostomus commersoni*), longnose sucker (*Catostomus catostomus*), with rare occurrences of Lake Whitefish (*Coregonus clupeaformis*) and rainbow trout (*Salmo gairdnerii*).

The reservoir was created in 1903 by the Canadian Pacific Railroad as part of the Western Headworks Canal system linking water from the Bow River to over 800 ranchers up to 90 kms away (Thompson, 1971). Downstream from the reservoir, the towns of Gleichen, Rockyford, Standard and Strathmore draw their drinking water supply from the canal. Since 1963, stormwater from the city of Calgary has been added to the Headworks, but a moratorium on additional water was imposed in 1983 (Colborne 1988; cited in Mitchell and Prepas 1990). Historic details of the canal development and town settlement can be found in Thompson (1971) and Peake (1982), respectively. The canal system is managed today by the Western Irrigation District (WID), which maintain the constant water levels on Chestermere Lake. The lake receives approximately 179 x 10^6 m^3 water/day; resulting in a retention time of about 11 days, with lower retention times during high-flow periods (Mitchell and Prepas 1990).

Approximately 55% of the influent water exits the reservoir from Canal A in the southeast corner nearest the inflow, while the rest spills from Canal B in the north end (Mitchell and Prepas 1990) (Figure 1). From October to April the lake is drawn down to a depth of 1.5m and the canals are closed to any water flow to prevent ice damage to the headgates and private docks. Water quality in the lake is generally good, with mean summer Total Phosphorus (TP) concentrations of 32 µg/L and Total Nitrogen (TN) 335 µg/L (McEachern 2000). Algal blooms do occur in the lake. Most recently, a TP doubling in August of 1999 was likely responsible for a bloom which sent chlorophyll *a* values from 5 µg/L to 27 µg/L (McEachern 2000). Both TP and chlorophyll *a* mean summer values average at the upper end of mesotrophic (moderate) productivity. Anoxic conditions under winter ice cover result in release of phosphorus from sediment and subsequently high TP concentrations in the water (Exner 1978).

5.0 Methods and Materials

As much scientific information as possible from a variety of sources was gathered on Chestermere Lake. First, the reports were summarized with the specific details of what was collected, when, who the researchers were, the authors affiliated organization, and their major findings. Then, water and sediment raw data were taken from each report and augmented with data from Alberta Environment to create a 30-year water quality history of Chestermere Lake. The summary of the 30-year water quality history follows the literature survey summaries.

Figure 1: The 261-ha reservoir at Chestermere Lake, Alberta. Water flows in from the southwest and exits from Canal A in the southeast or Canal B in the north.

6.0 Results[1]

6.1 Literature Survey

Thompson 1971. A researcher with Alberta Fish and Wildlife Division collected physical, chemical and biological data on Chestermere Lake to provide a basis for future management recommendations. This report provided the first detailed site description of Chestermere Lake including morphometry, management and geology. Physical and chemical parameters were examined between May 6 and September 22, 1969 and numerous samples of water quality, plankton, bottom fauna, flora and fish were taken. During this period, the lake did not stratify and had surface temperatures ranging from 8.9^{o}C in the spring to 17.8 ^{o}C in late summer. Dissolved oxygen levels ranged between 11-7 mg/L and lake water was never less than 70% saturated.

Bottom sampling found a bottom material consisting mostly of muck, detritus, fine sand, gravel and aquatic plants (mostly Pondweeds (*Potamogeton*)). Diatoms were the most abundant phytoplankton while the copepod *Cyclops* and the cladoceran *Daphnia* were the most abundant zooplankton. Gill and seine nets produced 638 fish composed of 75% yellow perch, 12% pike, 11% white suckers and 2% longnose suckers. More detailed fauna and fish population characteristics can be found in the Thompson report.

Masuda 1972. This report was written by an Alberta Environment Pollution Control researcher to follow up on a previous study from 1971, which warned of high bacteria in Chestermere Lake. A City of Calgary report had found high bacteriological counts, which resulted in both swimming and consumption advisories on Chestermere Lake. Masuda collected over one hundred bacteriological and several “grab” water chemistry samples that fall (1971) and spring (1972) from the Lake and the WID canal. Highest total coliform levels recorded in the lake were 41 organisms/100 ml and fecal coliforms were 2.2/100 ml.

Exner 1978. An Alberta Environment researcher sampled water and sediment chemistry along the WID canal and Chestermere Lake in early May 1978, to determine the cause of profuse weed growth in the canal system. Exner speculated that water quality variability in the system was due to stormwater inputs from the city of Calgary. Profiles of water samples showed higher concentrations of TP nearest the sediment, likely due to liberation following macrophyte breakdown and anoxic conditions under winter ice cover. Early spring TP average concentrations were 0.65 mg/L, which greatly exceed 0.05 mg/L, the Alberta chronic water quality guideline for the protection of aquatic life (AENV 1999). Sediment TP concentrations averaged 1199 mg/kg (ppm) in May and 974 mg/kg in June. Algal assays of aquatic growth potential (the ability of individual water samples to support growth) showed that inlet water was markedly more productive than outlet water, especially during the early summer period.

[1] All references to water quality guidelines refer to the Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (1999) unless otherwise stated.

Environmental Management Associates 1990. This water quality study on Eagle Lake included 9 weeks of data on nitrogen, phosphorus and suspended sediments from Chestermere Lake in the spring of 1990. Mean TP concentration was 0.052 mg/L and TN concentration was 1.516 mg/L (a miscalculation in their report for TN may have lead to an inaccurate conclusion). These previously unpublished data were presented in the Reid Crowther (1991) report (see below).

Ouellet and MacLeod 1990. This Engineering Company examined lakebed sediment stratigraphy that was exposed during a sewer/water line excavation. The excavation was located in the north basin of the lake, where the lake is crossed by Highway 1A. Lakebed sediment stratigraphy consisted of bottom mud and organic sand/silt underlain by sand and silt. These previously unpublished results were presented in the Reid Crowther (1991) report.

Reid Crowther 1991. This local Engineering firm was hired to specifically address the problem of dense, persistent growths of rooted aquatic plants in the lake, and to propose methods for weed control. Several options were explored including bypassing inflows, dredging, full depth removal, root layer removal, lake deepening, bottom barriers, direct plant management (harvesting, rotovating and herbicides) and some biological controls (grass carp, crayfish and spikerush). However, they warned that dredging alone would not solve the weed problem, and that the control of nutrient-rich sediments flowing into the lake must first be signficantly decreased.

Alberta Environmental Protection 1993. In February of 1992, Alberta Environment (AENV) began a pilot scale project on behalf of the Village Weed Committee to evaluate the effectiveness of sediment removal, extent of summer weed growth, and water quality. Three plots were excavated and 13 591 m^3 of sediment were removed during February 1992. The use of conventional heavy equipment to remove sediment was described as highly successful in this interim report. In that summer, the excavated sites produced decreased plant biomass (mean 4.4 g/m^2 wet mass) as compared to control sites (mean 22.7 g/m^2 wet mass). AENV also found that macrophyte cover and density increased along a south to north gradient. Mean wet mass of macrophytes in the south of the lake was 55 g/m^2 and 108 g/m^2 in the north basin. Detailed plant biomass estimates and sediment accumulation data are each reported in companion documents prepared by Golder Associates (1994) and Environmental Management Associates (1992), respectively. Richardson and Sago pondweeds (*Potamogeton richardsonii* and *P. pectinatus*) were most abundant with flat-stemmed pondweed, coontail and watermilfoil present. Macrophyte density and distribution data obtained from a compact airborne spectrographic imager were ambiguous and require further interpretation to be useful.

Seven euphotic zone composite water sample grabs were taken from May-October for nutrients, ions and major metals. Water quality variables did not exceed Water Quality Guidelines for Recreation except for high fecal coliforms following storm events. Sediment cores collected at 38 sites in January and February were tested for TP, total zinc and total lead, total organic carbon and texture (% sand, silt and clay). Phosphorus, lead and zinc were correlated with % clay in the sediments, and concentrations decreased further away from the inflow canal.

Alberta Environmental Protection 1994. This report presents the second year (summer of 1993) of weed monitoring following sediment removal from 3 test plots in the lake. As in 1992, macrophyte biomass varied greatly throughout the lake, and biomass was again greater in the north basin than the south basin. However, there was no significant difference between control and dredged site dry biomass (289 g/m^2 control and 183 g/m^2 dredged). While the method of sediment removal was deemed successful, macrophytes were not controlled for various reasons. Sediment accumulation was found to be 4.5 to 32 g/m^2/day and, assuming 210 days of open water, 0.9 to 6.7 kg/m^2/year. This would translate to a sedimentation rate of 1 to 5 mm of sediment over the whole basin per year (not including other contributions such as Nose Creek).

Fecal coliform levels in the WID canal greatly exceeded the CCME Guideline for Irrigation Water Quality in the canal, and exceeded the Guideline for Recreational Water Quality and Aesthetics in lake water, following major storm events in Calgary. The report concluded that sediment removal does not provide a long-term solution for controlling macrophyte biomass, as biomass between the dredged and control sites did not differ after two summer seasons. The author suggested that continued sediment loading from storm sewers and other contributions such as Nose Creek are likely providing a suitable rooting medium for macrophytes within the lake.

Sosiak 1994. An Alberta Environment researcher sampled Chestermere Lake during the summer of 1992 and 1993 to determine the impact of Calgary stormwater on canal and reservoir water quality. Nutrients, coliforms, metals and several physical parameters were analyzed from water collected with automated samplers. Sosiak performed a median test and trend test on 11 years of AENV data from Chestermere Lake (1983-1993). He found significant trends of increasing concentrations of nitrate/nitrite, dissolved calcium, and decreasing Secchi disk depths.

Total phosphorus loading to Chestermere Lake was calculated with the FLUX (Walker 1990) computer program for 1992 and 1993. Half of the 6928 kg TP load (1992) and 6609 kg TP load (1993) from the WID were retained in the lake (i.e. the lake "treated" 1.3 g/m^2/year of TP) (Table 1). Water quality variables were within the CCME Guidelines for both Freshwater Aquatic Life and Recreational Water Quality except after major storm events in Calgary. Total phenols, chromium, iron and lead and an organic compound (DEHP) exceeded the CCME Guidelines for Freshwater Aquatic Life following major storm events in Calgary. Fecal coliforms exceeded the Guideline for Irrigation Water Quality in the Canal upstream of Chestermere Lake. Fecal coliforms greatly exceeded the Guideline for Recreational Water Quality in Chestermere Lake following a large storm event in Calgary.

Table 1: Total Phosphorus loading rates and retention within Chestermere Lake as reported in Sosiak (1994).

	1992	1993
TP influent load	6 928 kg	6 609 kg
TP loading rate	2.65 g/m^2/yr	2.53 g/m^2/yr
TP retained	3 390 kg	2 881 kg
TP load retained	1.3 g/m^2/yr	1.1 g/m^2/yr
% retention	58%	44%

Cross 1997. Cross has been monitoring the water quality along the WID canal, including the inflow and outflows of Chestermere Lake. The results in this report come from the 1996 and 1997 summer field sampling seasons. Changes within Chestermere Lake are determined by comparing water quality entering the lake to the water exiting the lake from Canal A and Canal B. Upstream and downstream concentrations of total and dissolved phosphorus decreased as waters traveled through the lake. Nitrate and nitrite decreased markedly from the inflows to the outflows. As well, fecal coliforms, *E. coli* and metal concentrations were lower at the outflows than the inflow.

Cross 1998. Cross again sampled upstream and both downstream canals of Chestermere Lake in 1998. Total phosphorus concentrations tended to decrease as water flowed through the lake in May and June, then increase from July to September. Nitrate and nitrite were attenuated significantly through the lake as these nutrients were biologically incorporated and transformed. Fecal coliforms, *E. coli* bacteria and metals all decreased from the inflow to the outflows.

Cross 1999. Cross again sampled both upstream and both downstream canals (A and B) of Chestermere Lake in 1999. Similar results to the 1998 study (above) were reported.

McEachern 2000. Chestermere Lake was a participant in the Alberta Lake Management Society's *Lakewatch* Program for 1999. University of Alberta scientists and local volunteers collected water twice monthly from May to September 1999. This report is a data summary of nutrients (nitrogen and phosphorus), major cations and anions, alkalinity, hardness, chlorophyll *a*, conductivity, pH, dissolved oxygen and redox potential. The results are compared to results from the other *Lakewatch* candidates and to earlier Chestermere Lake data from *The Atlas of Alberta Lakes* (Mitchell and Prepas 1990).

McEachern reported good water quality on average, with mean summer concentrations of TP = 32 µg/L and TN = 335 µg/L . However, nutrient chemistry was quite variable, such as the TP doubling in August that was likely responsible for an algal bloom of an unusually large, eyeball-shaped colonial protozoan (*Ophrydium*) which increased chlorophyll *a* values from 5 µg/L to 27 µg/L (McEachern 2000). As well, the lake stratified in late summer and dissolved oxygen concentrations dropped from 8.4 to 5.5 mg/L. Ion concentrations were similar to 1983, with exception of doubled sodium and chloride values.

6.2 Thirty-Year Water Quality Summary[2]

6.2.1 Nutrients and Chlorophyll

Surprisingly, nitrogen and phosphorus concentrations followed different yearly trends until about 1983. Phosphorus concentrations were very high and variable in the lake until 1983 when they suddenly dropped and became much less variable (staying around <50 µg/L) (Figure 2). Soluble reactive phosphorus followed a similar trend.

[2] In the following figures, data have been interpolated between years when data were not collected.

Chlorophyll levels average 6.6 mg/L, which is typical for mesotrophic lakes (Figure 2). However, Chestermere is subject to infrequent late summer algal blooms, which can persist for several weeks (McEachern 2000).

Ammonia concentrations were, on average, quite high until 1978, when they decreased and stabilized (<100 µg/L) (Figure 3). Total kjeldahl nitrogen (the sum of inorganic nitrogen species) has increased significantly since 1978 and continues to fluctuate between sampling periods. Nitrate and nitrite/nitrate has been fairly constant since the early 1970s with concentrations between 20-100µg/L.

Total organic carbon, dissolved organic carbon and dissolved inorganic carbon were all very low across the 30-year sampling period (Figure 4).

6.2.2 Alkalinity, hardness, carbon and physical parameters

Alkalinity, hardness and bicarbonate correlate well with each other and show little variation over the 30-year sampling period. Less data exist for dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total organic carbon (TOC), however these concentrations are very low with little variation (Figure 4). Conductivity, pH, turbidity, colour, non-filterable residue (NFR), filterable residue (FR), total residue (TR), total dissolved solids (TDS), total suspended solids (TSS) all fluctuate widely and their 30-year data summary of means, min and max are presented in Table 2.

Table 2: Selected water quality parameters summarized with maximum, minimum and mean.

	pH	Conductivity[1]	Turbidity	Colour	NFR[2]	FR	TR	TDS	TSS
Mean	8.09	332.92	7.3	5.46	28.76	188.48	199.8	237.3	51.3
Max	8.7	644	135	15	300	380	300	302	231
Min	6.92	235	0.7	0	0.8	3	146	138	5.1

[1]Units: conductivity (µsiemens/cm); turbidity (nephelometric turbidity units); colour (true relative units); NFR, FR, TDS, TSS (mg/L).
[2]NFR: Non-filterable residue; FR: Filterable residue; TR: Total residue; TDS: Total dissolved solids; TSS: Total suspended solids.

Temperature, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD) and secchi disk depth are summarized in Table 3. Temperature and dissolved oxygen follow predictable seasonal patterns, with warmer late summer temperatures causing lake stratification and lower oxygen concentrations each year.

Figure 2: Thirty-year data summary for Total Phosphorus (TP), Soluble Reactive Phosphorus and Total Dissolved Phosphorus (TDP) for Chestermere Lake, Alberta. Yearly means are presented with standard error bars.

Figure 3: Thirty-year data summary for nitrate (NO_3), Nitrate/Nitrite (NO), Total Kjeldahl Nitrogen (TKN) and Ammonia (NH_4) for Chestermere Lake, Alberta. Yearly means are presented with standard errors bars.

Figure 4: Thirty-year data summary for Total Organic Carbon (TOC), Dissolved Inorganic Carbon (DIC), Dissolved Organic Carbon (DOC), Alkalinity, Hardness and Bicarbonate. Yearly means are presented with standard error bars.

Table 3: Selected water quality parameters summarized with maximum, minimum and mean.

	Temp[1] (surface)	Dissolved Oxygen (DO)	Biological Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)	Secchi
Mean	12.82	9.17	1.10	18.29	2.69
Max	21.5	13	2.3	40	5.75
Min	0	1.86	0.1	9	0.5

[1]Units: temperature (^{o}C); dissolved oxygen, BOD and COD (mg/L); Secchi (m).

6.2.3 Salinity

The salinity of freshwaters is dominated by the cations calcium, magnesium, sodium and potassium and the anions carbonate, sulfate and chloride. Large concentrations of these ions in water such as Chestermere Lake result in “hard” water. Magnesium and potassium were consistently low through the 30-year sampling period, while calcium and sodium were quite variable (Table 4). Sulfate varied between 15-85 µg/L with a maximum in 1978. Chloride was very high in 1978. The greatest carbonate contribution was from inorganic species, as both organic species were very low. All ions showed normal seasonal and temporal variation in the 30-year data summary, with no ascertainable trends other than a slight overall increase in calcium in the last 10 years.

Table 4: Selected anions and cations summarized with maximum, minimum and mean.

	Mg (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Cl (mg/L)	SO_4 (mg/L)	Chl *a* (mg/L)
Mean	15.45	14.92	1.234	35.72	6.65	44.68	6.62
Max	37	34	6	63	41.5	84	27.1
Min	8	1	0.45	19	1	14	0.21

6.2.4 Bacteria

Fecal coliform collections were present in most collections from 1992 and 1993 (Figure 5). Coliform counts were greater than 20 organisms/100 mL on more than half of the samplings (24/45) and over 200 organisms/100 mL on 1 occasion, at 2 sites.

Figure 5: Fecal Coliform data collected at Chestermere Lake 1992-93.

7.0 Discussion

7.1 Literature Survey

Thompson 1971. The field data collected from the summer of 1969 is the first documented study of the ecology of Chestermere Lake. Unfortunately, water quality data were limited to a suite of drinking water quality analyses. No phosphorus or chlorophyll *a* data were presented; however, plankton biomass collected suggested lake productivity in the eutrophic range. Thompson further collected a full suite of phytoplankton, zooplankton, bottom fauna and fish. He concluded that key spawning and feeding habitats of perch and pike need to be identified and protected to ensure continued natural reproduction. To date, this work has not yet been done and will likely be a necessary precursor to sediment dredging or other large-scale lake manipulation.

Masuda 1972. Masuda showed a reduction in coliform counts from the inflow to the outflows during the summer of 1971. Other concentrations that decrease as water flows through the lake included turbidity and oxygen demand. Masuda concluded that bacteriologically, the lake is similar to other Alberta surface waters and that it was safe for swimming but not drinking. Masuda further concluded that ecologically, the surface water quality was within established Alberta guidelines for surface waters. His bacteriological conclusions may have been somewhat optimistic. While he did collect numerous samples, the samplings were focused on the later summer and fall periods, where he may have missed summer storm other runoff events. More recent data (Sosiak 1994) concluded that the lake has very high bacteriological counts immediately following larger storm events in Calgary, which quickly return to normal within days of the events.

Exner 1978. This report was the first to document complaints from the residents and pursue a reason for the dense macrophyte and filamentous algal growths at Chestermere Lake. Exner suggested that most nutrient loading occurs in quick pulses in the spring, and that the lake retains the most nutrients during this time because macrophytes are in a rapid growth period. This study indicated that phosphorus might be liberated from bottom sediments during winter ice cover and periods of anoxia. The liberation of phosphorus had a negative impact on water quality. Finally, Exner attributed numerous areas along the WID canal banks, which show excessive erosion or slumping, liberating sediment and causing downstream turbidity and sedimentation problems in Chestermere Lake.

Environmental Management Associates 1990. This data provided by EMA reported water quality results from only 9 collections in the spring of 1990. EMA concluded that the nitrogen and phosphorus concentrations were below those considered to be conducive to excessive plant growth. However, a miscalculation of TN in their report may have lead to this conclusion. They further suggest that plants are drawing their nutrient supply from benthic lake sediments.

Reid Crowther 1991. Several weed control options were explored by this engineering firm including bypassing inflows, dredging, root layer removal, bottom barriers and some biological controls. Each solution presented unique sociological, economic and environmental challenges for further exploration. However, they warned that dredging alone would not solve the vegetation problem, unless the control of nutrient-rich sediments flowing into the lake was significantly decreased.

AEP 1993, 1994. Macrophyte growth, water quality and sediment quality data were collected in this study following the removal of sediment at 3 test plots. The dredging project had no long-term success at eliminating macrophyte growth and, within one year of dredging, enough sediment had redistributed and/or settled to allow significant macrophyte re-establishment. Apart from elevated fecal coliform counts following a large summer storm, no other water quality variables exceeded the Recreation Guidelines.

Sosiak, 1994. Sosiak's median and trend testing found significant trends of increasing concentrations of nitrate/nitrite, dissolved calcium, and decreasing secchi disk depths. All three of these indicate water quality and clarity had decreased between 1983-1993. Other data that suggested poorer water quality (albeit not significantly), were TP, TDP, chlorophyll *a*, conductivity, dissolved sodium, fecal coliforms and total coliforms. However, Chestermere Lake did retain half of the TP loading from the WID canal, exclusive of TP from atmospheric deposition, diffuse runoff to the lake or sediment release. The WID canal water upstream of Chestermere Lake exceed the Guideline for Irrigation Water Quality for fecal coliforms and should not be used for irrigation following storm events. Chestermere Lake water greatly exceeded the Guideline for Recreation Water Quality for fecal coliforms and should not be used for recreation following large storm events. Total phenols, chromium, iron, lead and an organic compound were found to occasionally exceed Guidelines for Freshwater Aquatic Life following major storm events in Calgary.

Cross, 1997-1999. Cross concluded that Chestermere Lake plays a significant role treating pollutants from the inflowing canalwater. Nutrient concentrations decrease as particles settle out across the lake and are incorporated by plants, immobilized, biologically transformed and/or released to the atmosphere (nitrogen only). Coliform bacteria die and heavy metal concentrations decrease (such as aluminum, iron and lead) as water passes through the lake and particulate bound metals settle. Strong wind events and other sediment disruptions may cause resuspension, which counteract the treatment.

Poorest regulatory compliance of Chestermere Lake water was with the Guidelines for Protection of Freshwater Aquatic Life, as several metals exceeded the limit (zinc, iron, copper, chromium, aluminum, and cadmium). Coliform bacteria levels were mostly compliant with Irrigation and Recreation Guidelines, but rarely complied with Drinking Water Quality Guidelines.

McEachern 2000. This *Lakewatch* report showed nutrient and algal concentrations within Chestermere Lake consistent with those of a mesotrophic lake. However, the potential for algal blooms and lowered dissolved oxygen levels were demonstrated in late summer with an unusual algal bloom. The peculiar "eyeball" shaped protozoan was identified as the colonial ciliate *Ophyridium*, also identified were *Nitzschia* diatoms (Sosiak *pers. comm.*). Unfortunately, detailed taxonomy or cell count information does not exist for the 1999 bloom.

Nutrient and salinity concentrations were similar to or lower than values in *The Atlas of Alberta Lakes* (Mitchell and Prepas 1990), with the exception of sodium and chloride, which were double the 1983 Atlas values. An increase in these two ions may be due to roadsalting and other anthropogenic contributions. McEachern recommended further monitoring of chloride to determine if concentrations are increasing. His *Lakewatch* report accurately emphasized the dichotomy of Chestermere Lake: its need as a balancing reservoir for irrigation and its recreational function in a cottage community. However, a recent agreement between the WID and Town of Chestermere to maintain a constant water level in the reservoir through the summer months may have eliminated the dichotomy altogether. McEachern speculated that the ultimate solution between the Alberta Government and the Town of Chestermere Lake may serve as a precedent for other lake associations concerned with watershed protection, shoreline development and water use.

7.2 Thirty-Year Water Quality Summary[3]

7.2.1 Nutrients and Chlorophyll

Several of the reports reviewed concluded that much of the nutrient loading into Chestermere is rapidly incorporated into the biological community or settled out as nutrient-laden particles. The differences in concentration between the inflow and outflow is as much as 50% (AEP 1993, AEP 1994, Sosiak 1994, Cross 1997, Cross 1998 and Cross 1999). On occasion, nutrient concentrations are elevated due to sediment resuspension on windy days, and to a much lesser extent, during local inputs of low quality runoff water. It is likely that the shallow north end of the lake is functioning like a wetland, playing a significant role in nutrient retention, immobilization, incorporation and transformation. Higher plant biomasses in the north end support this theory. Chlorophyll *a* (an indication of phytoplankton biomass) remains within the mesotrophic (middle) range of algal production, as reported in Sosiak (1994).

The large improvements in water quality (especially TP and ammonia) shown during the early 1980s are more likely due to improved water chemistry lab techniques with increased detection limits and not to any actual water quality betterment. However, it is interesting to note that lake residents were connected to a Calgary sewer main in 1983. Further, Sosiak (1994) detected an 11-year trend (1983-1993) of increasing of nitrate+nitrite, suggesting a greater impairment of water quality. If this trend continues, then weed problems can be expected to increase, as will the frequency of noxious algal blooms and the further impairment of water quality. Further sampling is advised to monitor these trends.

7.2.2 Physical

The delineation of Chestermere Lake morphology was originally undertaken by the Alberta Department of Agriculture's Water Resources Division on June 11, 1970 (Thompson, 1971). AENV continues to use this morphometry in recent reports with the only changes being a metric conversion of the contour units. It may be useful to update the lake contour information due to the immense sediment loading that the lake has received since 1970.

[3] I acknowledge that there are likely some strong seasonal trends in water quality at Chestermere Lake, however, our dataset was not large enough to show these. Instead, we have focused on the yearly trends to show how water quality has changed in the past 30 years.

Alkalinity, hardness and bicarbonate all correlate well with each other and are positively related to the amount of Bow River water diverted into the canal, which is rich in $CaCO_3$ from the glacial headwaters.

The results of pH, conductivity, turbidity and colour represent the natural range of variability expected following periods of short-term high volume runoff following spring runoff and summer storms. The very high values are short-lived.

Temperature and dissolved oxygen concentrations follow predictable seasonal patterns. Warm temperatures cause lake stratification and lower oxygen levels in late summer each year (5.5 mg/L, McEachern 2000). Elevated BOD and COD values would suggest a risk of oxygen depletion in the water column, however BOD values remained low and COD values were moderate over the 30-year sampling period.

7.2.3 Salinity

Low magnesium and potassium concentrations are normal for this area. The variability seen in sodium and chloride levels are most likely due to road salting and other anthropogenic inputs, while the calcium variation is attributed to inputs from the Bow River diversion. Bow River water is naturally high in calcium derived from its glaciolacustrine origins. The increase in calcium shown here is a continuation of an upward trend first reported in Sosiak (1994). The sulfate high concentrations (especially in 1978) are commonly seen under ice cover by liberation under anaerobic conditions during the breakdown of plant and other biomass processes.

7.2.4 Bacteria

Coliform counts exceeded the Guideline for Irrigation use on 6 occasions and exceeded the Guideline for Recreational Use (Table 5) on one occasion, at two sampled sites. The cause of elevated coliforms in Chestermere Lake is likely municipal runoff from the City of Calgary, and contributions from the Nose Creek watershed. Residential runoff has been shown to be as polluted with fecal coliforms and other pathogens as dilute sewage (Qureshi and Dutka 1979). This runoff can pose significant health risks when it reaches recreational use waters. Several Canadian cities with urban beaches have instituted beach closure policies based on rainfall activity, such as along Ottawa's Rideau River. Beaches of the Rideau River are closed for 24 or 48 hours, following rainfall events of more than 10 and 20 mm, respectively, in the preceding 24 hours (Corber 1988; as cited in Health and Welfare Canada 1992.). This effectively closes beaches when the risk to recreational users is the greatest. The Town of Chestermere Lake could impose a similar guideline to protect their recreational users, by using the City of Calgary's rainfall data.

Table 5: Selected *Canadian Water Quality Guidelines* Maximum Acceptable Concentration (MAC) for ecological parameters.

Parameter	Drinking Water	Freshwater Aquatic Life	Agriculture: Livestock	Agriculture: Irrigation
Calcium	---	---	1000 mg/L	---
Fecal Coliforms[1]	0/100mL	---	---	100/100mL
Total Coliforms[2]	10/100mL	---	---	1000/100mL
Nitrate	45 mg/L	Avoid prolific growth	---	---
Nitrate + Nitrite	---	---	100 mg/L	---
Nitrite	3.2 mg/L	0.06 mg/L	10 mg/L	---
Total Phosphorus	---	---	---	0.05 mg/L

[1]Water for direct contact recreation (e.g., swimming) should not exceed 200/100 mL MAC and or raw produce irrigation (e.g., vegetables) should not exceed 20/100 mL MAC.
[2]Regulatory agencies have moved away from using Total Coliform data and now employ more direct indicators such as Fecal Coliforms and *E. coli*.

8.0 Conclusions

Chestermere Lake is somewhat unusual. It has a very small drainage basin area, which should theoretically give it a large retention time. However, large inflows from upstream and shallow depth give it a retention time of only days. Due to the short retention times, the lake functions as a shallow riverine system. The dense and prolific aquatic plant community help to remove large amounts of influent pollutants (sediment, heavy metals, bacteria and nutrients), which is typically the role of wetlands. Overall, the current water quality indicates mesotrophic status, however shallow depths, accelerated biological activity and large inputs of nutrient rich sediment cause prolific weed growth all across the lake, which suggests eutrophic status. Sedimentation will continue to be a problem for the reservoir, providing a continual nutrient-laden substrate for aquatic weed growth.

9.0 Recommendations

The Weed and Water Committee of Chestermere Town Council should continue with further monitoring, including:

1. Depth contour mapping to update the 1970 data;
2. Sample sediment depth and determine accurate sediment contours and sediment loading across the lake;
3. Continue water quality sampling to monitor increase in urban runoff to the Headworks Canal. Particular attention should be given to nutrients (total phosphorus, nitrate+nitrite), fecal coliforms, *E. coli* and chloride; and
4. Sample sediments for possible heavy metal contamination (aluminum, cadmium, chromium, copper, iron and zinc). This information will be necessary in the future to assess disposal options for dredged material.
5. Issue a warning regarding the potential hazard of fecal coliform bacteria contamination to recreational users following storm events in Calgary.

10.0 Acknowledgements

Many thanks go out to the Edmonton Alberta Environment office for allowing access to their database on Chestermere Lake, the Alberta Lake Management Society for their 1999 field data, Al Sosiak in the Calgary AENV office who shared both his expertise and reports on Chestermere Lake and Patsy Cross at Madawaska Consulting for her WID reports. I am indebted to Shannon Keehn at Alberta Environment and Preston McEachern at the University of Alberta for providing valuable input to this manuscript. This report was improved greatly by comments from Al Sosiak in the Calgary AENV office.

11.0 References

Alberta Environmental Protection. 1984. Unpublished data on Chestermere Lake.

Alberta Environmental Protection. 1993. Chestermere Lake weed study interim report. Prepared by Water resources services and environmental regulatory services, Alberta Environmental Protection. 45 p.

Alberta Environmental Protection. 1994. Chestermere Lake weed study final report. Prepared by Water resources services and environmental regulatory services, Alberta Environmental Protection. 31 p.

Alberta Environment. 1999. Surface water quality guidelines for use in Alberta. Natural Resource Service, Water Management Division, Edmonton. 20 p.

American Water Works Association. 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Maryland, USA.

Canadian Council of Ministers of the Environment. 1999. Canadian environmental quality guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Cross, P.M. 1997. Western irrigation district water quality sampling program 1997. Prepared by Madawaska Consulting for the Western Irrigation District, Calgary, Alberta. 60 p.

Cross, P.M. 1998. Western irrigation district water quality sampling program 1998. Prepared by Madawaska Consulting for the Western Irrigation District, Calgary, Alberta. 70 p.

Cross, P.M. 1999. Western irrigation district water quality sampling program 1999. Prepared by Madawaska Consulting for the Western Irrigation District, Calgary, Alberta. 72 p.

Cross, P.M. 2000. Chestermere Lake: Objectives of the WID program. Presentation at the Living in the Watershed Workshop held at Chestermere Lake, September 30.

Environmental Management Associates. 1990. Data taken from: *Study into management of weeds in Chestermere Lake.* Prepared by Reid Crowther & Partners Ltd., Calgary, Alberta. 44 p. Reid Crowther & Partners Ltd. (1991).

Environmental Management Associates. 1992. Chestermere Lake macrophyte sampling. Environmental Management Associates, Calgary, Alberta. 23 p.

Exner, K. 1978. 1978 investigations into the water quality of the Western Irrigation District Distribution system to Chestermere Lake. Water quality control branch, pollution control division. Alberta Environmental Protection.

Golder Associates. 1994. Chestermere Lake aquatic plant study 1993. Golder Associates, Calgary. 10 p.

Hardy, W.G. 1967. Alberta—A natural history. Evergreen Press Ltd. Vancouver. 343 p.

Health and Welfare Canada. 1992. Guidelines for Canadian Recreational Water Quality. Health and Welfare Canada. 109 p.

Masuda, A. 1972. Chestermere Lake survey 1971-1972. Department of the Environment Division of Pollution Control, Edmonton, Alberta. 19 p.

McEachern, P.M. 1999. Alberta Lake Management Society *Lakewatch* 1999 Report. Prepared by the Alberta Lake Management Society, Edmonton, Alberta.

Mitchell, P. and E. Prepas. 1990. Atlas of Alberta Lakes. University of Alberta Press, Edmonton, Alberta. 675 p.

Ouellet, C.A. and N.R. MacLeod. 1990. Chestermere Lake bed soil evaluation. EBA Engineering Consultants Ltd. Calgary, Alberta.

Peake, E. (Ed.) 1982. Growing through time: Stories of Chestermere Lake. Friesen Printers, Calgary, 228 p.

Poston, B., D. Ealey, P. Taylor and G. McKeating. 1990. Priority migratory bird habitats of Canada's prairie provinces. Canadian Wildlife Service, Edmonton.

Qureshi, A.A. and B.J. Dutka. 1979. Sewage runoff microbiology adds to concern. Water Sewage Works, 126:86-88.

Reid Crowther & Partners Limited. 1991. Study into management of weeds in Chestermere Lake. Prepared by Reid Crowther & Partners Ltd., Calgary, Alberta. 44 p.

Sosiak, A. 1994. Chestermere Lake water quality monitoring. Prepared by the Surface water assessment branch technical services and monitoring division Alberta Environmental Protection, Calgary, Alberta. 19 p.

Sosiak, A. 1998. Changes in contaminant levels in the Bow River following the installation of a containment system at the Canada creosote site. Prepared by the Water Sciences Branch, Water Management Division Natural Resource Service, Calgary, Alberta. 27 p.

Sosiak, A. 1998. Phosphorus budget for Chestermere Lake. Letter to Frank Kosa, Town Manager 14 January.

Sosiak, A. 2001. Personal communication. Water Sciences Branch, Water Management Division Natural Resource Service, Calgary, Alberta.

The Calgary Regional Planning Commission. 1975. Chestermere Lake: an analysis of development and management options. Prepared for the MD of Rockyview by the Calgary Regional Planning Commission, Calgary, Alberta.

Thompson, G.E. 1971. The limnology and fishery management of Chestermere Lake, Alberta. Prepared by the Fish and Wildlife Division, Department of Lands and Forests, Edmonton, Alberta. 39 p.

Underwood McLennan Associates. 1976. Preliminary feasibility study for the supply of water and sewage facilities to the community of Chestermere Lake for the Chestermere Lake Cabin Owners Cooperative Association. Underwood McLellan Associates, Calgary, Alberta.

Walker, W.W. 1990. FLUX. Stream load computations. Version 4.4. Prepared for Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi.

12.0 Glossary

Aerobic: In freshwater systems, an environment that contains oxygen.

Alkalinity: A measure of the hydroxl ion concentration in a solution expressed as a pH value between 7 and 14. Alkalinity is a capacity factor that represents the acid-neutralizing capacity of a system (CCME 1999).

Anaerobic: In freshwater systems, an environment that is devoid of oxygen.

Anoxic: In freshwater systems, anoxic refers to a lack of dissolved oxygen. Bacterial decomposition of excessive organic matter under winter ice cover frequently causes anoxia.

Anthropogenic: Literally, "human origin", such as sewage inputs into a freshwater system.

Benthic: Refers to the substrate at the bottom of aquatic habitats (e.g., lakes, oceans and rivers). Also describes the life strategy of organisms living in or on that substrate (e.g., clams and oligochaete worms) (CCME 1999).

Biochemical oxygen demand (BOD): The measurement of the decrease in oxygen content (mg/L) of a sample of water over a certain period of time, in the dark, at a certain temperature, which is brought about by the increase in bacterial respiration rate during the breakdown of organic matter. The oxygen demand is measured after 5 d (BOD_5), at which time 70% of the final value has usually been reached (CCME 1999).

Chlorination: The application of chlorine to water, sewage, or other industrial wastes for disinfection or for other biological or chemical results (CCME 1999).

Chlorophyll *a*: A measure of phytoplankton productivity in freshwaters, which is empirically positively correlated with phosphorus concentrations.

Chemical Oxygen Demand (COD): A measurement of the oxygen required to chemically decompose the organic material in a water sample.

Colour: A measure of the degree to which water is stained by dissolved organic compounds (such as humic acids). Lakes with high colour are less transparent to light penetration.

Conductivity: An indication of the ionic strength of freshwater, by measuring its ability to conduct electricity.

Dissolved Oxygen (DO): a measurement of the amount of oxygen available to aquatic organisms. Temperature, salinity, organic matter present, BOD and COD affect DO solubility in water.

Fecal Coliform: Refers to the group of bacteria associated with the feces of warm-blooded animals. They constitute one of three bacteria commonly used to measure possible contamination of water by human or animal wastes. The others are *Escherichia coli* (*E. coli*) and *Enterococcus spp*.

Ecosystem: An ecological system. A natural unit of living and nonliving components that interact to form a stable system in which a cyclic interchange of material takes place between living and nonliving units (CCME 1999).

Eutrophic: Refers to aquatic environments that have abundant nutrients and high rates of productivity. In water bodies such as lakes, ponds and slow-moving rivers, oxygen levels below the surface layer may be depleted. Opposite of oligotrophic (CCME 1999).

Eutrophication: The natural and/or anthropogenic processes by which the nutrient content of natural waters is increased, generally resulting in an increase of biotic productivity and biomass (CCME 1999).

Fauna: Animals of a particular region, considered as a group.

Filterable Residue (FR): Same as TDS, material that passes through a 2.0 µm filter (Standard Methods 1998).

Guidelines: Generic numerical concentrations or narrative statements that are recommended as upper limits to protect and maintain the specified uses of air, water, sediment, soil or wildlife. These values are not legally binding (CCME 1999).

Hardness: The concentration of all metallic cations, except those of the alkali metals, present in water. In general, hardness is a measure of the concentration of calcium and magnesium ions in water and is frequently expressed as mg/L calcium carbonate equivalent (CCME 1999).

Macrophytes: Macroscopic (large) aquatic plants, which can be rooted, submersed, emergent or sessile.

Mesotrophic: Refers to aquatic environments with adequate nutrients and sufficient rates of productivity to sustain aquatic life. (Meso = "middle").

Morphometry: The measurement of the shape of a lake, usually with depth contours.

Nitrogen: A nutrient necessary for the growth and development of animals and plants. Typically the limiting nutrient in terrestrial systems.

Non-Filterable Residue (NFR): Same as TSS; material unable to pass through a 2.0 µm filter (Standard Methods 1998).

Objective: A numerical concentration or narrative statement that has been established by taking into account site-specific conditions to protect and maintain a specified use of a resource, such as water, soil, sediment, or tissue, at a particular site (CCME 1999).

Pathogen: An agent that causes disease, especially a living microorganism such as a bacterium or fungus (Webster's dictionary).

pH: A logarithmic scale used to measure the acidity of water.

Phosphorus: A nutrient necessary for the growth and development of animals and plants. Typically the limiting nutrient in aquatic systems.

Salinity: In fresh waters, the salinity is the sum of the ionic composition of the eight major cations (calcium, magnesium, sodium and potassium) and anions (carbonate, sulfate, chloride and nitrate) in mass or milliequivalents per liter (Wetzel 1975).

Secchi disk: An 8-inch (20 cm) disk with 2 alternating black and white quadrants used to measure water transparency to light penetration. Transparency decreases as color, suspended sediments, or algal abundance increases.

Solids: Matter suspended or dissolved in water which may negatively effect water quality in terms of palatibility, industrial use and aesthetics.

Standard: A legally enforceable numerical limit or narrative statement, such as in regulation, statute, contract, or other legally binding document, that has been adopted from a criterion or objective (CCME 1999).

Stratigraphy: The study of rock, soil or lake sediment layers (strata), especially the distribution, deposition, and age of sedimentary rocks or lake sediments.

Total Dissolved Solids (TDS): Portion of dissolved solids that passes through a 2.0 µm filter (Standard Methods 1998).

Total Coliforms: A group of closely related, mostly harmless bacteria that live in soil and water as well as the gut of animals. The extent to which total coliforms are present in the source water can indicate the general quality of that water and the likelihood that the water is fecally contaminated. Total coliforms are currently controlled in drinking water regulations, because their presence above the standard indicates problems in treatment or in the distribution system. If total coliforms are found, then the public water system must further analyze that total coliform-positive sample to determine if specific types of coliforms (i.e., fecal coliforms or *E. coli*) are present.

Total Kjeldahl Nitrogen (TKN): A measure of the sum of organic nitrogen and ammonia nitrogen (Standard Methods 1998).

Total Residue (TR): Material left behind after evaporation of a sample and oven drying (Standard Methods 1998).

Trophic: Refers to the nutrient availability and productivity status of a waterbody.

Total Suspended Solids (TSS): The portion of dissolved solids that are retained by a 2.0 µm filter (Standard Methods 1998).