Table of Contents

List of Tables

List of Figures

1.0 Background

Saskatchewan Watershed Authority (SWA) developed The *Lake Stewardship Program* in September 1997 to support stewardship groups throughout Saskatchewan. The mandate of the program is to foster communication, collect and share information, and help develop partnerships between stewardship groups and other agencies to protect and preserve water quality and aquatic life.

The Authority provides support to individual stewardship groups based on their specific needs and interests which may include water quality monitoring, environmental education, and community outreach. Stewardship group activities depend on the groups' size, interest, goals, and objectives.

Lake stewards are ambassadors for their lake and community. Knowledge of community achievements and challenges enable stewards to effectively tailor environmental awareness and educational outreach programs to the needs of their community. The *Lake Stewardship Program* will improve understanding and decision making within the watershed and foster relationships between various agencies and stewardship groups to ensure source water protection.

2.0 Jackfish and Murray Lakes

Jackfish and Murray lakes are important recreational water bodies that are located approximately 40 kilometers north of North Battleford, Saskatchewan. In 1932, a control structure was erected on the outlet at the south end of Jackfish Lake to regulate the water level at 529.59 meters above sea level (masl). Desirable summer water levels are between 529.44 and 529.59 masl. When water levels are 529.59 masl, the maximum depth in Jackfish Lake is 4.9 meters (m) with an average depth of 3.3 m. In contrast, Murray Lake has a maximum depth of 8.5 m and a mean depth of 4.5 m. The surface area of Jackfish and Murray lakes are 82 and 13 square kilometers respectively.

In 1998, the *Stewards of Jackfish and Murray Lakes* (SJML) became an incorporated group under the Non-profit Corporations Act. In 1997, an agreement was signed with Sask Water which provided technical, administrative, and financial assistance to support the activities of the group. At this time water sampling commenced at Jackfish and Murray lakes, which continues under the Saskatchewan Watershed Authority's *Lake Stewardship Program*. As a result, water quality monitoring has been conducted for eight consecutive years and provides the most current and comprehensive water quality data from these lakes. This report presents the results from the 2003 and 2004 water quality monitoring program.

2.1 Stewardship Activities

The *Stewards of Jackfish and Murray Lakes (SJML)* has been an extremely proactive and productive group. The SJML have pursued both educational and scientific programs to understand, protect, and enhance the water quality of Jackfish and Murray lakes.

- In 2002, the group organized two shoreline cleanups at Lehman's Creek and provided a barbecue for all volunteers to celebrate.

- Nature Saskatchewan sponsored a Home Visit workshop instructed by Dr. Dennis Lawson, a groundwater geologist and northern environmental specialist. The Home Visit program empowers residents with the knowledge to assess shoreline property for erosion and/or pollution problems and determine best management practices. This enabled trained SJML members to help their neighbours and community identify and apply best management practices on their property. The Home Visit program ensures interested shoreline residents protect their property and water quality.

- The SJML have used Water Watchdog kits to educate community children on the importance of water quality monitoring and assessment. Water Watchdog kits are a fun hands-on educational toolkit for children. The kits promote water quality monitoring, stewardship activities, and environmental awareness.

- The SJML has also been an instrumental partner to various organizations including Saskatchewan Wetland Conservation Corporation, Fish and Wildlife Development Fund, Prairie Farm Rehabilitation Administration, and Environment Canada on riparian habitat enhancement projects within the watershed. Projects focused on reducing the impacts of livestock on riparian areas and water quality by providing remote watering stations or limited stream access. These projects provided an optimal balance between economics and environmental concerns.

After six consecutive years of water sampling SJML pursued additional research to further investigate lake water quality. In 2002 and 2003, research on Jackfish Lake was undertaken by Dr. Jeff Hudson of the University of Saskatchewan and Dr. Marlene Evans from Environment Canada. Dr. Jeff Hudson and Matthew Bogard examined parameters including; lake level, salinity, total phosphorus, chlorophyll *a*, secchi disk depth, and climate. Dr. Marlene Evans collected sediment cores to examine historical trends in nutrient concentrations. Research and water quality monitoring conducted will provide valuable knowledge for stewards to work towards their mission of maintenance and enhancement of water quality in Jackfish and Murray lakes.

2.2 Projects

Since 1990, Jackfish and Murray lakes have experienced a severe decline in lake levels. In 2004, during the open water season Jackfish Lake levels ranged between 528.35 and 528.33 meters, approximately one meter below regulated levels.

Consequently, the University of Saskatchewan was asked by the SJML to investigate the source of the declining water levels and its effect on the water quality. Bogard and Hudson (2004) concluded warmer average air temperatures in the North Battleford region have increased lake evaporation. This, in combination with reduced inflows, has resulted in decreased lake levels. Dr. Dennis Lawson made a presentation on July 5, 2003 at the SJML Annual General Meeting which identified that under drought conditions groundwater from the Thickwood Hills may contribute up to 100% of inflow into Jackfish and Murray lakes. Typically this groundwater would provide only 20% of the total amount of water flowing into these lakes. As a result, inflows and precipitation in the region were decreased under drought conditions and consequently lake levels dropped.

Sediment cores may be used to examine historical trends in water quality parameters such as: total phosphorus, chlorophyll, and salinity. Current nutrient concentrations at the top of the sediment core may be compared to historic concentrations at the base of the core. This information explains whether high nutrient concentrations are a natural phenomenon seen throughout the length of the sediment core or conversely if nutrient concentrations increase with development and human activity in the watershed towards the top of the core. Dr. Marlene Evans presented the results from this study in April 2005. Research conducted by the University of Saskatchewan and Environment Canada will complement the *Lake Stewardship Program* in understanding the changes in water quality experienced in Jackfish and Murray lakes.

2.3 Purpose and Scope

Water quality monitoring is a key component of any lake stewardship activity. Water quality monitoring can serve three primary purposes for local groups and residents:

1. to understand the characteristics of a lake,
2. to understand how activities around a lake can impact water quality, and
3. as a means of assessing water quality.

The scope and purpose of the water quality monitoring program is to assess the current water quality conditions in Jackfish and Murray lakes. The program is designed to collect water quality data representative of the lake that may be used to establish changes or trends in water quality over time.

2.4 Water Sampling Procedure

2.4.1 Baseline Station

Saskatchewan Watershed Authority personnel facilitated the collection of all field measurements and water sampling at Jackfish and Murray lakes in 2003 and 2004. The water quality monitoring program for Jackfish and Murray lakes included one baseline sampling station in the center of each lake at its deepest point (Figure 1). These stations are referred to as baseline station. The baseline sampling station's global positioning satellite (G.P.S.) co-ordinates were referenced so that the same location was sampled each time. Sample location consistency enables current and historic water quality data to be compared. Samples collected from Jackfish and Murray lakes in 2003 were grab

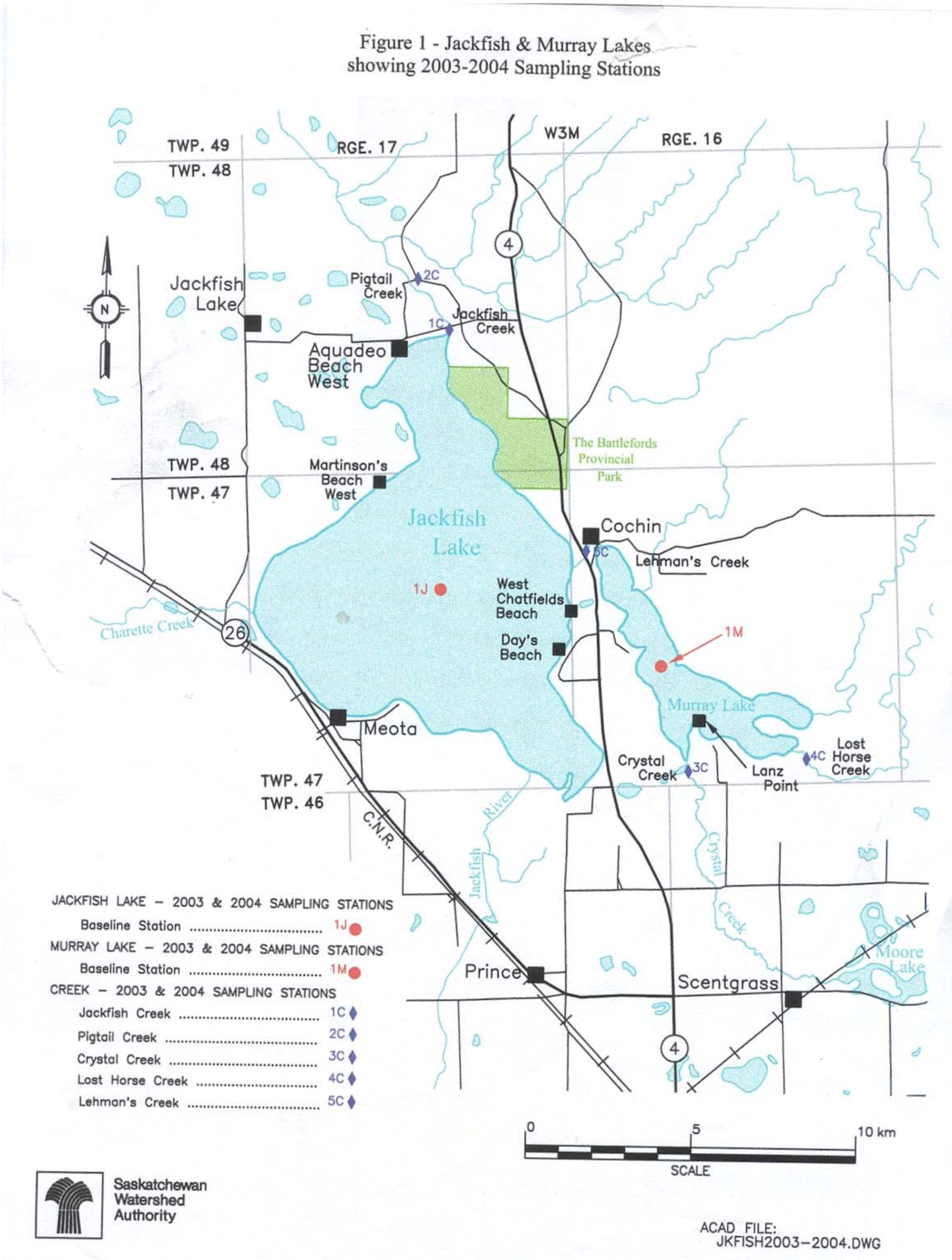

Figure 1 Jackfish and Murray Sampling Locations, 2003 - 2004

samples collected from just beneath the water surface. In 2004 water samples collected from the baseline stations included discrete top and bottom water samples taken using a horizontally orientated Van Dorn water sampler and an integrated water sample taken from the surface to two times the secchi depth. Sample collection and field monitoring of the baseline stations were conducted five times during 2003; March 25, June 2, July 8, August 25, and September 22. In 2004, sampling was conducted four times; March 14, June 14, July 14, and August 11.

2.4.2 Creek Stations

The five tributaries monitored were Jackfish, Pigtail, Lost Horse, Crystal, and Lehman creeks. In 2003, Crystal and Lost Horse creeks were sampled April 28, May 26, June 23, and July 28. Jackfish, Pigtail, and Lehman creeks were also sampled on October 6. In 2004, all of the creeks were sampled on April 12, June 14, July 14, and August 11, with the exception of Lost Horse Creek which could not be sampled on April 12.

2.4.3 Field Measurements

Field measurements were taken at the baseline and creek stations and included air temperature, water temperature, cloud cover, wind speed, secchi disk transparency, pH, turbidity, conductivity, and dissolved oxygen. Dissolved oxygen, conductivity, and temperature were measured using a YSI 85D oxygen/temperature/conductivity meter. Calibrations were made using standard reference solutions. pH was determined using a hand held WTW 330i pH meter; calibrated using a two-point calibration with reference solutions at pH 7 and 10. Turbidity was determined using a Lamotte Model 2020 nephelometric turbidity meter. Calibrations were performed with reference solutions of 1.0 and 10 NTU.

2.4.4 Laboratory Analysis

Baseline and creek samples were analyzed for nutrients, major ions, chlorophyll *a*, dissolved and suspended solids, and bacteria. (See Tables 6 to 10 and 15 to 33). All water samples were collected in plastic bottles and shipped in coolers to the Provincial Laboratory in Regina, Saskatchewan for analysis.

2.4.5 Stewardship Involvement

Volunteers are essential to the water monitoring program providing transportation to sampling locations, sample collection assistance and local knowledge. In 2003, Howard and Bunny Libbey assisted Saskatchewan Watershed Authority technologists Bill Andresen and Sheldon Ofukany with baseline sampling on Jackfish and Murray lakes. Bunny Libbey, Phyllis Lowes, and Mary Deshaye collected water samples from the five tributary creeks.

In 2004, Howard and Bunny Libbey continued to assist Sheldon Ofukany with baseline sampling on Jackfish Lake. Ralph Smith assisted with sampling the Murray Lake baseline station. The five tributary creeks were sampled by Sheldon Ofukany of the Saskatchewan Watershed Authority.

3.0 Trophic Status

Trophic status is a lake classification system based on the amount of nutrients in the lake and its' resulting biological productivity. Several water quality parameters are measured and used as indicators to determine the trophic status of a lake. The most commonly used "trophic indicators" include nutrients, chlorophyll *a*, and secchi disk transparency (water clarity). Nutrient additions increase biological productivity, which may be measured as chlorophyll *a*, which in turn decreases water clarity, measured by secchi disk transparency. As a result, biological productivity is used to determine lake trophic status. There are four trophic states: oligotrophic, mesotrophic, eutrophic and hypertrophic, which range from low to extreme biological productivity respectively. Oligotrophic lakes have low inputs if nutrients, organic matter and sediment and consequently, little biological productivity. In contrast, eutrophic lakes are very productive with high levels of nutrients, organic matter and sediments. Lakes on the prairies are typically classified as eutrophic lakes due to high nutrient concentrations. As a result, the Water Quality Index has been employed to more accurately assess the quality of water in recreational lakes throughout Saskatchewan.

4.0 Water Quality Index Summary

The Water Quality Index (WQI) is an effective means for summarizing a large number of water quality parameters. Similar to the UV index or an air quality index, it provides an indication of the overall water quality for watershed health.

The advantage of the WQI is that it summarizes key water quality parameters in a single index and is especially meaningful to people who want to know about the state of their local water body. The index also allows water quality data to be reported in a consistent manner.

Values for various water quality parameters (*e.g.,* dissolved oxygen, nutrients, and fecal coliform bacteria) are compared to specific water quality objectives. The results of the comparisons are combined to provide a water quality ranking (*e.g.,* Good, Fair, Poor) for individual water bodies. To assess overall watershed health the Saskatchewan Watershed Authority has selected seventeen parameters to be incorporated into the water quality index including nutrients, minerals, metals, pesticides, and bacteria. The parameters and their corresponding objectives used in the Water Quality Index are shown in Table 1.

The index is based on three components that relate to water quality objectives:

Scope - How many? - The number of water quality variables that do not meet objectives in at least one sample during the time period under consideration, relative to the total number of variables measured.

Frequency - How often? – The number of individual measurements that do not meet objectives, relative to the total number of measurements made in all samples for the time period of interest.

Amplitude - How much? - The amount by which measurements which do not meet objectives depart from those objectives.

Water Quality Index (WQI) values range between 1 and 100. One represents the worst water quality and 100 represents the best water quality. Once the WQI value has been calculated the value can be further simplified by assigning it to one of several descriptive categories:

Excellent: (WQI value 95-100) – water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels. These index values can only be obtained if all measurements are within objectives virtually all of the time.

Good: (WQI value 80-94) – water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.

Fair: (WQI value 60-79) – water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.

Marginal: (WQI value 45-59) – water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.

Poor: (WQI value 0-44) – water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

5.0 Results

5.1 Baseline Stations

Field measurements for Jackfish and Murray lakes are summarized in Tables 2 to 5 and 11 to 14, respectively. Dissolved oxygen, conductivity, secchi disk depth, and temperature are important field parameters used to assess water quality in Jackfish and Murray lakes.

Dissolved oxygen concentrations are variable based on time, weather, and temperature. Consequently, sampling needs to be repeated within the same time frame each year to enable year to year comparisons. Dissolved oxygen levels of 1 or 2 mg/L will not support fish populations. The Saskatchewan *Surface Water Quality Objectives* (1997) sets a minimum dissolved oxygen concentration of 5 mg/L for the protection of all stages of warm water biota. In Jackfish Lake, under winter conditions dissolved oxygen concentrations were depleted to approximately 1.0 mg/L. Jackfish Lake is a shallow lake with excessive weed growth. As a result, during the winter months oxygen levels may be depleted by decomposition of vegetative matter and respiration by biota. Depleted oxygen levels can lead to winter fish kills in Jackfish Lake. In contrast, Murray Lake is deeper than Jackfish Lake and winter dissolved oxygen levels remain close to the 5 mg/L required by aquatic biota for survival. Consequently, Murray Lake is typically less susceptible to winter fish kills resulting from anoxia than Jackfish Lake (Tables 3, 5, 12, and 14).

Conductivity is a measure of waters ability to conduct an electric current, which depends on the concentration of dissolved ions in solution. It is determined by the concentration of specific ions and lake temperature. Conductivity is influenced by watershed geology and soil composition. Evaporative losses from Jackfish and Murray lakes have increased the conductivity in both lakes by concentrating ions in the lake water. However, Jackfish Lake, a large shallow lake has experienced greater evaporative losses than Murray Lake, which has a greater mean depth and smaller surface area. Murray Lake also receives surface inflow from watershed tributaries. In contrast, Jackfish Lake receives minimal surface inflow from tributaries and Murray Lake via Lehman creek. As a result, Jackfish Lake conductivity levels are twice those found in Murray Lake (Tables 3, 5, 12, and 14).

Turbidity is the measure of water clarity. A reduction or lack of water clarity is caused by solids suspended in the water including clay, silt, and plankton (small plants and animals). Sources of turbidity are soil erosion, waste discharge, urban runoff, boating, algal growth, or abundant bottom feeders that stir up bottom sediment. Increases in turbidity may decrease light penetration, destroy or modify fish habitat, and increase water temperature which decreases oxygen concentrations. In situ field turbidity measurements may characterize actual lake turbidity levels better than laboratory analysis conducted after the sampling event. The turbidity levels in Jackfish Lake ranged from 1.21 to 10.50 NTU, while for Murray Lake, the turbidity levels ranged from 0.83 to 8.70 NTU in 2003 and 2004 (Tables 2,4, 11, and 13).

The secchi disk transparency reading is a measure of water transparency. Transparency is affected by suspended sediment, algae, and water colour. The Saskatchewan *Surface Water Quality Objectives* (1997), state that for bathing waters the secchi disk should be visible at 1.20 meters (m). In Jackfish Lake during the open water seasons of 2003 and 2004 secchi disk depths ranged from 1.20 to 3.25 m. The 3.25 m secchi disk reading for Jackfish Lake on July 14, 2004 was atypical for this lake as secchi disk readings are generally less than 2 meters. In the last eight years of monitoring the secchi disk reading has never been greater than 2 meters. During the open water seasons of 2003 and 2004, Murray Lake secchi disk reading ranged between 1.30 and 2.80 m (Tables 11 and 13).

5.2 Creek Stations

Jackfish and Murray lakes have five tributary creeks which are monitored for water quality to assess nutrient and bacteria contributions from the surrounding watershed. Tables 20 to 33 summarize the data collected from these creeks in 2003 and

2004. During the open water season, total phosphorus concentrations in the creeks ranged from a low of 0.03 mg/L in Lehman's Creek to a high 0.39 mg/L in Lost Horse Creek. For contact recreation the Saskatchewan *Surface Water Quality Objectives* (1997) states that the density of fecal coliform bacteria should not exceed 200 organisms per 100mL of water (orgs/100mL), nor should the total coliform bacteria exceed a density of 5,000 orgs/100mL. In the creeks, total coliform bacteria levels ranged from less than 10 orgs/100mL to 3,000 orgs/100mL. It may be concluded that tributary creeks are nutrient rich with moderate bacteria levels.

5.3 Jackfish Lake Water Quality Index

The WQI value for Jackfish Lake ranged from 54.7 to 63.3 giving the lake a rating of marginal to fair (Figure 2). Of the 17 parameters that were measured pH, TDS, sodium, and sulphate exceeded the WQI objectives.

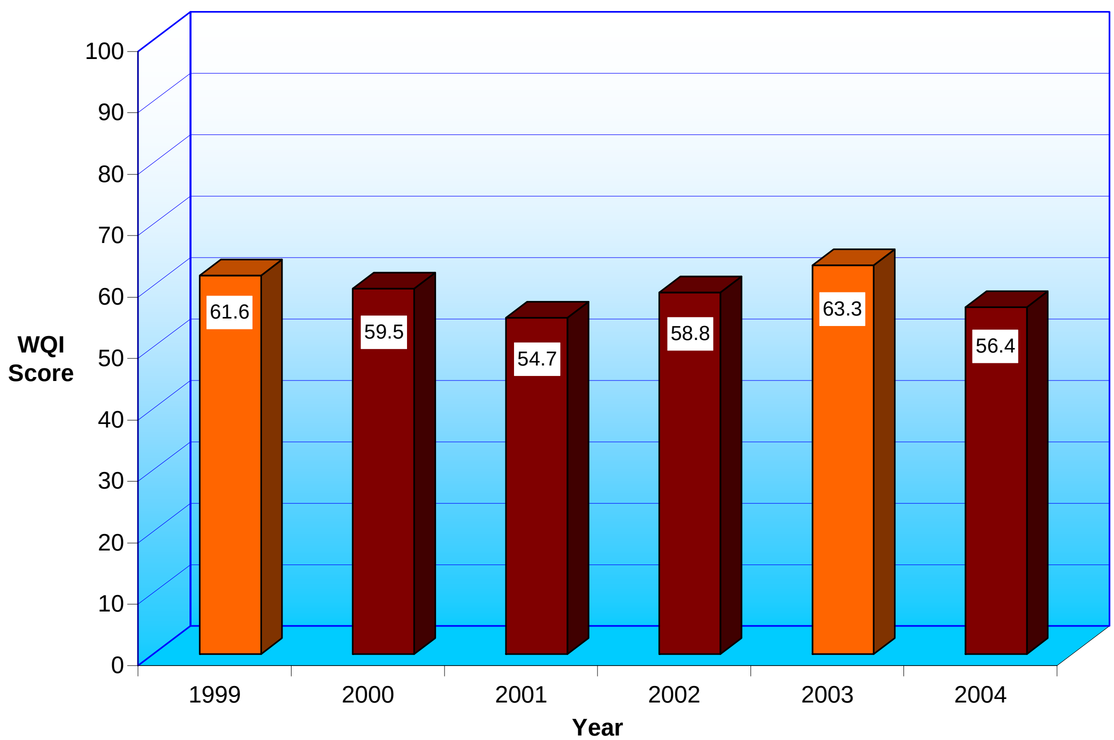

Figure 2 Water Quality Index Scores for Jackfish Lake Baseline Station, 1999 - 2004

Jackfish Lake is an alkaline prairie lake with pH values ranging from 8.7 and 9.1 pH units in the open water seasons. TDS levels ranged between a low of 1,831 mg/L in 2000 to a maximum value of 4,557 mg/L in 2004. Saline lakes are characterized by a TDS level of more than 3,000 mg/L, and consequently Jackfish Lake is weakly saline. Increase sodium and sulphate concentration are associated with saline conditions and consequently exceed water quality objectives. The WQI objective for dissolved sodium is 100 mg/L. Dissolved sodium levels in Jackfish Lake have range from between 306 and 629 mg/L, which is three to six times higher than the objective. The WQI objective for sulphate is 500 mg/L. The sulphate levels in Jackfish Lake reached more than four times that level, ranging from 1,067 to 2,142 mg/L.

Three other variables; total phosphorus, dissolved oxygen, and total ammonia exceeded their objectives less than three times in the six years analyzed. Total phosphorus concentrations exceeded the 0.10 mg/L objective once in 2000 and 2001 at 0.12 mg/L. Winter sampling in 2003 and 2004 revealed dissolved oxygen levels less than the 5.0 mg/L objective for the protection of aquatic life under ice conditions. In 2004, all samples exceeded the calculated total ammonia objective. As a result, the WQI score decreased from 63.3 in 2003 to 56.4 in 2004.

5.4 Murray Lake Water Quality Index

The WQI value for Murray Lake ranged from 61.7 to 74.4 giving the lake a rating of fair (Figure 3). Of the 17 parameters that were measured pH, TDS, sodium, and sulphate exceeded the WQI objectives.

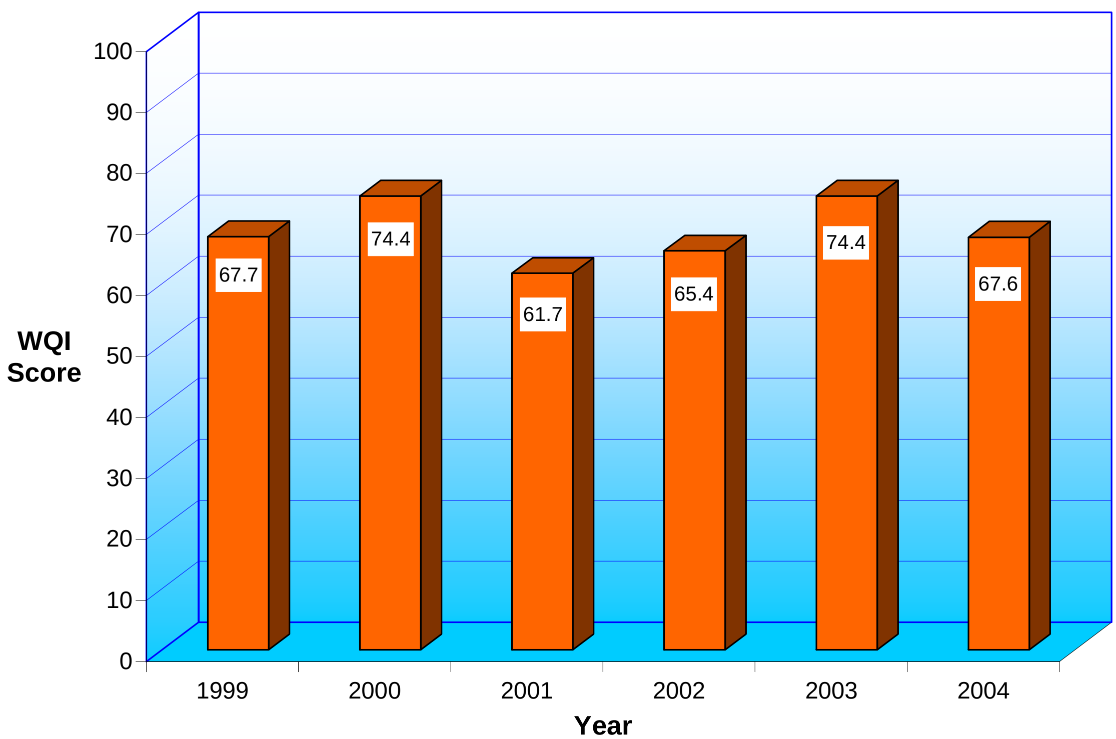

Figure 3 Water Quality Index Scores for Murray Lake Baseline Station, 1999 - 2004

Total dissolved solids and sodium concentrations consistently exceed WQI objectives. Typical TDS levels are twice the 700 mg/L objective set for irrigation ranging from 1,138 to 1,748 mg/L. Sodium concentrations ranged from 119 to 207 mg/L moderately exceeding the 100 mg/L objective. Sulphate concentrations have increased from an average 487 mg/L in 1999 to 569 mg/L in 2004, exceeding the 500 mg/L objective in all samples since July 2001. Murray Lake is an alkaline lake with pH levels between 8.10 and 9.01 pH units. Total phosphorus concentrations exceeded the 0.10 mg/L objective in a single sample from 1999, 2001, and 2003. In contrast, two of the three samples collected in 2002, had a total phosphorus concentration of 0.14 mg/L. In 2004, the WQI score decreased slightly to 67.6 triggered by two additional parameters; ammonia and dissolved oxygen concentrations under winter conditions.

6.0 Discussion and Recommendations

Until the early 1990s the control structure on Jackfish Lake maintained the lake level at 529.44 masl, the full supply level (FSL). On November 1, 2004 the lake level was measured at 528.33 more than a meter below the FSL. Hudson and Boghard (2004) concluded that evaporation and decreased inflows have resulted in the decreasing lake level. Evaporative losses have affected not only water quantity but also quality. Salts and minerals within Jackfish and Murray Lakes have been concentrated by this process increasing total dissolved solids (TDS) levels. As a result, Jackfish Lake is classified as weakly saline while, Murray Lake is considered sub-saline.

Lake productivity, the amount of plant growth and biological production is often phosphorus dependent. As a result, lake monitoring programs often emphasize changes in phosphorus levels when assessing water quality. Although phosphorus concentrations only moderately exceed the WQI objective, precautions should be followed to prevent further phosphorus enrichment. Shoreline residents can minimize phosphorus additions by using phosphate free soaps and detergents at their residence and ensuring holding tanks are working properly and emptied regularly.

All plants and algae contain the photosynthetic pigment, chlorophyll *a*, used to absorb light energy and produce living matter. In the laboratory chlorophyll *a* is easily extracted from algae and measured. As a result, chlorophyll *a* is used to determine the amount of algae in a water sample. Although Jackfish and Murray lakes are nutrient rich, they are not plagued by algae blooms and generally have low chlorophyll *a* concentrations. Lower algal biomass may be the result of saline conditions. Nutrients may also be sequestered by macrophyte weeds limiting algal growth. Macrophyte growth is quite significant at Jackfish and Murray lakes.

Ammonia-nitrogen is considered the preferred form of nitrogen for uptake by aquatic plants and algae. Typically concentrations are low in healthy lakes at less than 1 mg/L. Decomposing organic material produces total ammonia as a byproduct. High levels of ammonia can be toxic to aquatic life if the pH is greater than 8, as the unionized form of ammonia becomes present in higher concentrations. As a result, in eutrophic lakes ammonia concentration can reach toxic levels due to conditions such as: decomposing organic matter, high temperatures, and pH. Jackfish Lake is a shallow alkaline lake with excessive plant growth and is therefore susceptible to elevated levels of unionized ammonia.

In 2004, Jackfish and Murray lakes were tested for metal concentrations including: mercury, aluminum, and arsenic. In both Jackfish and Murray lakes, mercury and aluminum concentrations were below the detection limit of <0.02 µg/L for both parameters (Tables 7 and 16).

Arsenic is widely distributed throughout the earth's crust. Minerals containing arsenic are widely distributed and naturally occurring. Natural weathering processes result in arsenic release from the watershed into over-land runoff, streams, and lakes. Additional sources of arsenic are industrial manufacturing, pesticides, weed killers, and certain laundry detergents (CCME). Aquatic arsenic concentrations are dependent on watershed geochemistry and human activities.

The Saskatchewan *Surface Water Quality Objectives* (1997), state that for the protection of aquatic life, wildlife, and the use of water for livestock watering, arsenic concentrations should be below 0.05 mg/L. The drinking water quality standard in Saskatchewan for arsenic is 0.025 mg/L. Arsenic concentrations in Jackfish and Murray lakes ranged between 0.022 and 0.029 mg/L and 0.006 and 0.012 mg/L, respectively (Tables 7, 8, 15, and 16).

Arsenic concentrations in Jackfish Lake are currently within *Saskatchewan Water Surface Quality Objectives (1997)* for the protection of aquatic life and wildlife. However, Jackfish Lake does have elevated concentrations of arsenic when compared to the adjacent Murray Lake. Sediment cores could be used to determine whether arsenic concentrations are naturally elevated in Jackfish Lake or if they correspond with human activities in the watershed. Arsenic concentrations should be monitored in order to advice stakeholders if concentrations exceed water quality objectives.

Jackfish and Murray lakes are important recreational areas which should be maintained and enhanced for the enjoyment of future generations. Residents and other lake users are encouraged to become actively involved in the *Stewards of Jackfish and Murray Lakes* dedicated to the stewardship of these lakes. The Saskatchewan Watershed Authority encourages lake users to follow healthy shoreline living practices outlined in *On the Living Edge – Your Handbook for Waterfront Living*, published by Nature Saskatchewan (See References). This handbook provides excellent tips and facts focused on shoreline landscaping, erosion, construction, and septic systems.

7.0 References

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8.0 Appendix A - Water Quality Summary Tables

Table 1 Water Quality Index Objectives

Parameter	Objective
Total Arsenic (µg/L)	50
Dissolved Chloride (mg/L)	100
Total Chromium (mg/L)	0.02
Mercury (µg/L)	0.1
Total Ammonia (mg/L)	calculated
Dissolved Oxygen (mg/L)	5
pH (units)	6.5 to 8.5
Dissolved Sodium (mg/L)	100
2’4-D (µg/L)	4
MCPA (µg/L)	0.025
Total Aluminum (mg/L)	5
Sulphate (mg/L)	500
Fecal Coliform Bacteria (units/100mL)	200
Total Phosphorus (mg/L)	0.1
Dissolved Nitrate and Nitrite (mg/L)	1
Total Dissolved Solids (mg/L)	700
Chlorophyll *a* (µg/L)	50

Table 2 Field Measurements from Jackfish Lake Baseline Site, 2003

Field Data	March 24	June 2	July 8	Sept 22
Surface Parameters				
Air Temperature (ºC)	4	20	20	14
Water Temperature (ºC)	1.75	16.90	17.70	10.00
Dissolved Oxygen (mg/L)	1.01	8.22	6.82	2.90
pH (pH units)	8.50	8.96	9.09	9.33
Conductivity (µS/cm)	4,134	3,660	3,290	3,680
Secchi Disk (meters)	2.8	1.5	1.3	1.2
Turbidity (NTU)	2.30	8.96	8.90	10.50

Table 3 Dissolved Oxygen, Temperature, and Conductivity Profiles for Jackfish Lake, 2003

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
2/6/03	0	8.22	16.9	3,660
	1	8.12	16.8	3,660
	2	8.08	16.8	3,550
	3	8.01	16.8	3,548
8/7/03	0	6.82	17.7	3,290
	1	6.62	17.7	3,220
	2	6.01	17.7	3,220
	3	6.00	17.9	3,230
22/9/03	0	2.90	10.0	3,680
	1	na	9.9	3,686
	2	na	9.8	3,684
	3	na	9.8	3,696
	3.5	na	9.8	3,694

Table 4 Field Measurements from Jackfish Lake Baseline Site, 2004

Field Data	**March 15**	**June 14**	**July 14**	**Aug 11**
Surface Parameters				
Air Temperature (ºC)	0	16	na	na
Water Temperature (ºC)	0.6	13.9	20.0	18.0
Dissolved Oxygen (mg/L)	0.90	8.81	7.39	6.92
pH (pH units)	9.60	9.16	9.04	9.10
Conductivity (µS/cm)	4,459	3,529	3,618	3,558
Secchi Disk (meters)	1.70	1.10	3.25	1.75
Turbidity (NTU)	2.23	4.35	1.21	2.86

Table 5 Dissolved Oxygen, Temperature, and Conductivity Profiles for Jackfish Lake, 2004

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
15/3/04	0	0.90	0.6	4,459
	1	1.55	0.8	4,535
	2	1.08	2.1	4,346
	3	1.17	2.8	4,623
	3.4	3.21	3.1	4,634
14/6/04	0	8.81	13.9	3,529
	1	8.26	13.3	3,524
	2	7.91	13.0	3,513
	3	7.64	12.8	3,603
	3.6	7.63	12.7	3,607
14/7/04	0	7.39	20.0	3,618
	1	7.29	19.9	3,622
	2	6.97	19.8	3,622
	3	6.37	19.6	3,613
	3.7	5.26	19.0	3,634
11/8/04	0	6.92	18.0	3,558
	1	6.68	18.0	3,603
	2	6.56	17.9	3,640
	3	6.53	17.9	3,642
	3.6	6.47	17.8	3,645

Table 6 Jackfish Lake Surface Baseline Parameters, 2003

Parameters	Mar 25	June 2	July 8	Aug 25	Sept 22
Nutrients (mg/L)					
Dissolved Organic Carbon	73	32	29	38	37
Nitrate, as Nitrogen	0.15	0.02	<0.02	0.03	0.03
Ammonia, as Nitrogen	0.05	0.02	0.04	na	0.04
Total Kjedahl Nitrogen	2.8	2.2	2.4	2.7	2.7
Total Phosphorous	0.10	0.09	0.08	0.08	0.09
Ortho-Phosphate, as P	0.08	0.05	0.05	0.06	0.06
Solids (mg/L)					
Total Dissolved	4,073	3,231	3,284	3,519	3,496
Suspended, Fixed	4	5	4	6	8
Suspended, Volatile	2	8	4	11	11
Suspended, Total	6	13	9	17	19
Bacteria (orgs/100 mL)					
Fecal Coliform	<10	<10	<10	<10	<10
Fecal Streptococci	<10	<10	30	10	30
Total Coliform	<10	100	<100	<10	<10
Majar Ions					
Alkalinity, Total	968	784	796	836	842
Alkalinity, Phenol	102	102	104	138	138
Bicarbonate	932	708	717	683	691
Calcium	13	11	11	10	9.2
Carbonate	122	122	125	166	166
Chloride	57	44	48	48	48
Hardness, Total	1,746	1,333	1,391	1,503	1,521
Iron	na	na	0.027	na	0.052
Magnesium	416	317	331	359	350
Manganese	na	na	0.002	na	0.004
Potassium	70	51	53	55	60
Sodium	512	409	428	474	470
Sulphate	1,951	1,569	1,571	1,724	1,687
Other					
Chlorophyll *a* (µg/L)	6.85	7.52	<0.20	0.75	4.14
Conductivity (µS/cm)	4,250	3,510	3,620	3,740	3,740
pH (pH units)	8.9	9.0	9.0	9.1	9.1
Turbidity (N.T.U.)	na	4.25	5.42	4.86	10.10
Biochemical Oxygen Demand (mg/L)	na	1.8	1.4	1.5	1.6
Chemical Oxygen Demand (mg/L)	na	96.0	86.9	102.0	101.0
Metals					
Preserved Mercury (µg/L)	na	na	<0.05	na	<0.05
Aluminum (mg/L)	na	na	0.022	na	0.024
Arsenic (mg/L)	na	na	0.026	na	0.029

Table 7 Jackfish Lake Surface Baseline Parameters, 2004

Parameters	Mar 15	June 14	July 14	Aug 11
Nutrients (mg/L)				
Dissolved Organic Carbon	46.5	178.0	33.7	33.4
Nitrate, as Nitrogen	<0.02	<0.04	<0.04	0.20
Ammonia, as Nitrogen	0.33	0.11	0.15	0.24
Total Kjedahl Nitrogen	3.0	2.4	2.3	2.6
Total Phosphorous	0.10	0.07	0.07	0.09
Ortho-Phosphate, as P	0.08	0.05	0.05	0.08
Solids (mg/L)				
Total Dissolved	4,557	3,170	3,128	3,163
Suspended, Fixed	4	2	1	3
Suspended, Volatile	2	4	2	7
Suspended, Total	6	6	3	10
Bacteria (orgs/100 mL)				
Fecal Coliform	<2	10	10	10
Fecal Streptococci	1,110	10	10	<10
Total Coliform	2	100	10	<10
Major Ions (mg/L)				
Alkalinity, Total	1,083.8	772.0	771.0	774.0
Alkalinity, Phenol	127	92	98	104
Bicarbonate	1,012	717	702	691
Calcium	11	12	12	12
Carbonate	152	110	118	125
Chloride	67.0	39.0	41.0	40.7
Hardness, Total	1,959	1,397	1,335	1,377
Magnesium	469	332	317	327
Potassium	75	53	52	52
Sodium	629	441	433	444
Sulphate	2,142.0	1465.7	1453.1	1471.1
Other				
Chlorophyll *a* (µg/L)	3.62	2.01	1.04	4.38
Conductivity (µS/cm)	4,760	3,540	3,500	3,550
pH (pH units)	8.9	9.0	9.0	9.1
Turbidity (N.T.U.)	2.39	3.80	1.20	2.60
Biochemical Oxygen Demand (mg/L)	<2.0	<2.0	<2.0	3.3
Chemical Oxygen Demand (mg/L)	115.0	88.2	83.9	86.9
Metals				
Preserved Mercury (µg/L)	na	<0.02	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02	<0.02
Arsenic (mg/L)	na	0.023	0.022	0.024

Table 8 June 14, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	June 14		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	178.0	175.0	177.7
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.11	0.12	0.14
Total Kjedahl Nitrogen	2.4	2.5	2.4
Total Phosphorous	0.07	0.08	0.08
Ortho-Phosphate, as P	0.05	0.05	0.05
Solids (mg/L)			
Total Dissolved	3,170	3,148	3,155
Suspended, Fixed	2	4	3
Suspended, Volatile	4	6	6
Suspended, Total	6	9	9
Bacteria (orgs/100 mL)			
Fecal Coliform	10	<10	<10
Fecal Streptococci	10	<10	10
Total Coliform	100	<10	30
Major Ions (mg/L)			
Alkalinity, Total	772	771	770
Alkalinity, Phenol	92	92	92
Bicarbonate	717	716	715
Calcium	12	12	12
Carbonate	110	110	110
Chloride	39.0	38.9	39.0
Hardness, Total	1,397	1,364	1,385
Magnesium	332	324	329
Potassium	53	51	52
Sodium	441	441	439
Sulphate	1465.7	1455.1	1458.5
Other			
Chlorophyll *a* (µg/L)	2.01	2.08	1.42
Conductivity (µS/cm)	3,540	3,530	3,530
pH (pH units)	9	9	9
Turbidity (N.T.U.)	3.8	5.1	6.2
Biochemical Oxygen Demand (mg/L)	<2.0	<2.0	2.1
Chemical Oxygen Demand (mg/L)	88.2	91.8	87.2
Metals			
Preserved Mercury (µg/L)	na	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02
Arsenic (mg/L)	na	0.024	0.024

Table 9 July 14, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	**July 14**		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	33.7	33.9	33.9
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.15	0.15	0.18
Total Kjedahl Nitrogen	2.3	2.1	2.7
Total Phosphorous	0.07	0.08	0.07
Ortho-Phosphate, as P	0.05	0.06	0.05
Solids (mg/L)			
Total Dissolved	3,128	3,135	3,121
Suspended, Fixed	1	2	2
Suspended, Volatile	2	3	2
Suspended, Total	3	5	3
Bacteria (orgs/100 mL)			
Fecal Coliform	10	10	10
Fecal Streptococci	10	<10	<10
Total Coliform	10	<10	<10
Major Ions (mg/L)			
Alkalinity, Total	771	773	772
Alkalinity, Phenol	98	98	97
Bicarbonate	702	704	705
Calcium	12	12	12
Carbonate	118	118	116
Chloride	41	41	40.9
Hardness, Total	1,335	1,339	1,302
Magnesium	317	318	309
Potassium	52	51	51
Sodium	433	431	430
Sulphate	1,453.1	1,459.8	1,457.5
Other			
Chlorophyll *a* (µg/L)	1.04	1.04	1.04
Conductivity (µS/cm)	3,500	3,500	3,500
pH (pH units)	9	9	9
Turbidity (N.T.U.)	1.2	1.4	1.5
Biochemical Oxygen Demand (mg/L)	<2	<2	<2
Chemical Oxygen Demand (mg/L)	83.9	82.5	83.6
Metals			
Preserved Mercury (µg/L)	na	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02
Arsenic (mg/L)	na	0.021	0.021

Table 10 August 11, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	August 11		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	33.4	33.2	33.0
Nitrate, as Nitrogen	0.20	0.15	0.18
Ammonia, as Nitrogen	0.24	0.14	0.16
Total Kjedahl Nitrogen	2.6	2.2	2.2
Total Phosphorous	0.09	0.08	0.08
Ortho-Phosphate, as P	0.08	0.07	0.07
Solids (mg/L)			
Total Dissolved	3,163	3,147	3,159
Suspended, Fixed	3	1	2
Suspended, Volatile	7	2	2
Suspended, Total	10	4	4
Bacteria (orgs/100 mL)			
Fecal Coliform	10	<10	<10
Fecal Streptococci	<10	<10	<10
Total Coliform	<10	<10	<10
Major Ions (mg/L)			
Alkalinity, Total	774	776	778
Alkalinity, Phenol	104	106	106
Bicarbonate	691	688	691
Calcium	12	12	12
Carbonate	125	127	127
Chloride	40.7	40.5	40.8
Hardness, Total	1,377	1,405	1,360
Magnesium	327	334	323
Potassium	52	53	52
Sodium	444	426	440
Sulphate	1,471.1	1,466.6	1,473.1
Other			
Chlorophyll *a* (µg/L)	4.38	10.00	4.38
Conductivity (µS/cm)	3,550	3,550	3,540
pH (pH units)	9.1	9.1	9.1
Turbidity (N.T.U.)	2.6	3.0	3.3
Biochemical Oxygen Demand (mg/L)	3.3	<2.0	<2.0
Chemical Oxygen Demand (mg/L)	86.9	93.0	87.0
Metals			
Preserved Mercury (µg/L)	na	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02
Arsenic (mg/L)	na	0.025	0.024

Table 11 Field Measurements from Murray Lake Baseline Site, 2003

Field Data	March 25	June 2	July 8	Sept 22
Surface Parameters				
Air Temperature (ºC)	4	22	20	14
Water Temperature (ºC)	0.66	17.20	18.80	10.90
Dissolved Oxygen (mg/L)	5.39	7.69	7.18	8.51
pH (pH units)	8.12	8.51	8.76	9.01
Conductivity (µS/cm)	1,933	1,524	1,559	1,708
Secchi Disk (meters)	2.8	1.3	1.3	1.5
Turbidity (NTU)	1.00	2.60	8.70	3.03

Table 12 Dissolved Oxygen, Temperature, and Conductivity Profiles for Murray Lake Baseline Site, 2003

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
2/6/03	0	7.69	17.2	1,524
	1	7.58	17.1	1,525
	2	7.53	17.1	1,525
	3	7.46	17.1	1,523
	4	7.40	17.1	1,523
	5	7.33	17.1	1,523
	6	7.30	16.1	1,405
	6.5	7.30	16.3	1,356
8/7/03	0	7.18	18.8	1,559
	1	7.08	18.7	1,560
	2	7.03	18.7	1,561
	3	6.96	18.7	1,558
	4	6.90	18.7	1,558
	5	6.81	18.0	1,558
	6	6.80	17.1	1,425
	6.5	6.80	17.3	1,375

Table 12 Dissolved Oxygen, Temperature, and Conductivity Profiles for Murray Lake Baseline Site, 2003 continued

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
22/9/03	0	8.51	10.9	1,708
	1	8.38	10.7	1,723
	2	8.32	10.7	1,752
	3	8.39	10.7	1,754
	4	8.29	10.6	1,755
	5	6.01	10.6	1,750
	6	5.30	10.6	1,748
	6.5	1.62	10.5	1,735

Table 13 Field Measurements from Murray Lake Baseline Site, 2004

Field Data	**March 15**	**June 14**	**July 14**	**Aug 11**
Surface Parameters				
Water Temperature (ºC)	0.5	14.3	22.3	18.7
Dissolved Oxygen (mg/L)	4.27	7.42	8.01	7.44
pH (pH units)	8.92	8.77	8.72	8.80
Conductivity (µS/cm)	1,131	1,533	1,536	1,534
Secchi Disk (meters)	na	2.00	2.00	2.25
Turbidity (NTU)	0.83	1.55	2.94	1.58

Table 14 Dissolved Oxygen, Temperature, and Conductivity Profiles for Murray Lake, 2004

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
15/3/04	0	4.27	0.5	2,126
	1	4.29	1.3	2,114
	2	3.60	1.8	2,117
	3	2.69	2.2	2,095
	4	1.07	2.6	2,118
	5	0.64	2.8	2,132
	6	2.22	3.5	2,115
	7	3.60	3.5	2,048
14/6/04	0	7.42	14.3	1,533
	1	7.84	13.9	1,532
	2	7.40	13.5	1,526
	3	7.02	13.4	1,530
	4	7.13	13.3	1,527
	5	7.41	13.2	1,527
	6	6.20	13.2	1,527
	7	1.61	13.2	1,506
14/7/04	0	8.01	22.3	1,536
	1	8.22	21.3	1,529
	2	7.84	20.9	1,530
	3	7.38	20.4	1,524
	4	8.01	19.3	1,528
	5	7.16	19.0	1,526
	6	6.80	18.5	1,516
	6.8	4.32	18.2	1,530
11/8/04	0	7.44	18.7	1,534
	1	7.02	18.7	1,532
	2	6.97	18.6	1,528
	3	6.71	18.5	1,528
	4	6.81	18.4	1,529
	5	6.57	18.3	1,531
	6	6.30	18.3	1,532
	7	0.20	18.0	1,526

Table 15 Murray Lake Surface Baseline Parameters, 2003

Parameters	Mar 25	June 2	July 10	Sept 22
Nutrients (mg/L)				
Dissolved Organic Carbon	32	16	14	17
Nitrate, as Nitrogen	0.05	<0.02	<0.02	0.02
Ammonia, as Nitrogen	0.20	0.02	0.03	0.03
Total Kjedahl Nitrogen	1.7	1.3	1.4	1.6
Total Phosphorous	0.08	0.06	0.12	0.07
Ortho-Phosphate, as P	0.04	0.02	0.04	0.05
Solids (mg/L)				
Total Dissolved	1,748	1,326	1,408	1,402
Suspended, Fixed	1	2	4	4
Suspended, Volatile	2	3	4	5
Suspended, Total	3	6	7	9
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	<10	<10	<10
Fecal Streptococci	<10	170	10	<10
Total Coliform	10	<10	<100	20
Major Ions (mg/L)				
Alkalinity, Total	438	370	366	354
Alkalinity, Phenol	14	22	22	30
Bicarbonate	500	398	393	359
Calcium	50	40	38	30
Carbonate	16.8	26.4	26.4	36
Chloride	20	13	14	15
Hardness, Total	833	631	643	656
Iron	na	na	0.012	0.008
Magnesium	172	129	133	141
Manganese	na	na	0.006	0.003
Potassium	na	20	21	22
Sodium	198	150	156	161
Sulphate	791	550	627	638
Other				
Chlorophyll *a* (µg/L)	9.23	4.71	<0.20	14.13
Conductivity (µS/cm)	2,000	1,680	1,720	1,720
pH (pH units)	8.5	8.7	8.7	8.8
Turbidity (N.T.U.)	na	1.85	3.23	3.35
Biochemical Oxygen Demand (mg/L)	na	1.8	1.5	1.0
Chemical Oxygen Demand (mg/L)	na	47.8	40.0	47.6
Metals				
Preserved Mercury (µg/L)	na	na	<0.05	<0.05
Aluminum (mg/L)	na	na	<0.005	<0.005
Arsenic (mg/L)	na	na	0.010	0.012

Table 16 Murray Lake Surface Baseline Parameters, 2004

Parameters	**Mar 15**	**June 14**	**July 14**	**Aug 11**
Nutrients (mg/L)				
Dissolved Organic Carbon	19.2	85.7	16.3	16.2
Nitrate, as Nitrogen	<0.02	<0.04	<0.04	0.36
Ammonia, as Nitrogen	0.26	0.03	<0.02	0.04
Total Kjedahl Nitrogen	1.7	1.2	1.3	1.3
Total Phosphorous	0.07	0.04	0.04	0.05
Ortho-Phosphate, as P	0.05	<0.02	<0.02	0.03
Solids (mg/L)				
Total Dissolved	1,699	1,233	1,216	1,223
Suspended, Fixed	2	1	2	1
Suspended, Volatile	2	2	3	3
Suspended, Total	4	3	5	5
Bacteria (orgs/100 mL)				
Fecal Coliform	<2	<10	<10	<10
Fecal Streptococci	40	10	<10	<10
Total Coliform	<2	50	30	<10
Major Ions (mg/L)				
Alkalinity, Total	429.4	328.0	332.0	332.0
Alkalinity, Phenol	11.2	17.0	22.0	26.0
Bicarbonate	497	359	351	342
Calcium	39	40	38	37
Carbonate	13.4	20.4	26.4	31.2
Chloride	17.0	11.9	12.2	11.9
Hardness, Total	818	598	581	587
Magnesium	175	121	118	120
Potassium	26	20	19	20
Sodium	207	141	135	141
Sulphate	725.0	519.7	516.8	519.5
Other				
Chlorophyll *a* (µg/L)	10.37	3.33	6.23	7.33
Conductivity (µS/cm)	2,070	1,510	1,500	1,520
pH (pH units)	8.5	8.6	8.8	8.8
Turbidity (N.T.U.)	0.796	1.300	2.400	2.600
Biochemical Oxygen Demand (mg/L)	<2	<2	<2	<2
Chemical Oxygen Demand (mg/L)	46.3	38.9	48.6	46.3
Metals				
Preserved Mercury (µg/L)	na	<0.02	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02	0.02
Arsenic (mg/L)	na	0.006	0.007	0.008

Table 17 June 14, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	June 14		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	85.7	86.0	86.6
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.03	0.03	0.03
Total Kjedahl Nitrogen	1.2	1.4	1.3
Total Phosphorous	0.04	0.05	0.06
Ortho-Phosphate, as P	<0.02	<0.02	<0.02
Solids (mg/L)			
Total Dissolved	1,233	1,230	1,228
Suspended , Fixed	1	2	2
Suspended, Volatile	2	3	3
Suspended, Total	3	5	5
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	<10	<10
Fecal Streptococci	10	<10	<10
Total Coliform	50	130	100
Major Ions (mg/L)			
Alkalinity, Total	328	330	329
Alkalinity, Phenol	17	16	17
Bicarbonate	359	364	360
Calcium	40	39	40
Carbonate	20.4	19.2	20.4
Chloride	11.9	11.9	11.9
Hardness, Total	598	587	598
Magnesium	121	119	121
Potassium	20	20	20
Sodium	141	140	139
Sulphate	519.7	516.9	515.6
Other			
Chlorophyll *a* (µg/L)	3.33	4.45	6.15
Conductivity (µS/cm)	1,510	1,510	1,520
pH (pH units)	8.6	8.6	8.6
Turbidity (N.T.U.)	1.3	1.5	1.8
Biochemical Oxygen Demand (mg/L)	<2	<2	<2
Chemical Oxygen Demand (mg/L)	38.9	40.4	42.4
Metals			
Preserved Mercury (µg/L)	<0.02	<0.02	<0.02
Aluminum (mg/L)	<0.02	<0.02	<0.02
Arsenic (mg/L)	0.006	0.006	0.006

Table 18 July 14, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	July 14		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	16.3	16.3	16.1
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	<0.02	<0.02	<0.02
Total Kjedahl Nitrogen	1.3	1.2	1.6
Total Phosphorous	0.04	0.04	0.04
Ortho-Phosphate, as P	<0.02	<0.02	<0.02
Solids (mg/L)			
Total Dissolved	1,216	1,220	1,218
Suspended, Fixed	2	3	3
Suspended, Volatile	3	3	4
Suspended, Total	5	6	7
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	<10	<10
Fecal Streptococci	<10	<10	<10
Total Coliform	30	<10	<10
Major Ions (mg/L)			
Alkalinity, Total	332	331	332
Alkalinity, Phenol	22	22	21
Bicarbonate	351	350	354
Calcium	38	39	38
Carbonate	26.4	26.4	25.2
Chloride	12.2	12.2	12.1
Hardness, Total	581	583	581
Magnesium	118	118	118
Potassium	19	19	19
Sodium	135	137	137
Sulphate	516.8	518.2	515.0
Other			
Chlorophyll *a* (µg/L)	6.23	7.33	3.86
Conductivity (µS/cm)	1,500	1,490	1,500
pH (pH units)	8.8	8.8	8.7
Turbidity (N.T.U.)	2.4	2.3	2.4
Biochemical Oxygen Demand (mg/L)	<2.0	2.1	<2.0
Chemical Oxygen Demand (mg/L)	48.6	39.3	41.7
Metals			
Preserved Mercury (µg/L)	na	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02
Arsenic (mg/L)	na	0.006	0.006

Table 19 August 11, 2004 Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	**August 11**		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	16.2	16.2	16.5
Nitrate, as Nitrogen	0.36	0.25	0.27
Ammonia, as Nitrogen	0.04	0.04	0.04
Total Kjedahl Nitrogen	1.3	1.3	1.3
Total Phosphorous	0.05	0.05	0.05
Ortho-Phosphate, as P	0.03	0.03	0.03
Solids (mg/L)			
Total Dissolved	1,223	1,220	1,227
Suspended, Fixed	1	2	1
Suspended, Volatile	3	3	4
Suspended, Total	5	5	5
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	<10	<10
Fecal Streptococci	<10	<10	<10
Total Coliform	<10	<10	<10
Major Ions (mg/L)			
Alkalinity, Total	332	332	332
Alkalinity, Phenol	26	26	26
Bicarbonate	342	342	342
Calcium	37	37	37
Carbonate	31.2	31.2	31.2
Chloride	11.9	12.0	12.0
Hardness, Total	587	578	587
Magnesium	120	118	120
Potassium	20	19	20
Sodium	141	141	143
Sulphate	519.5	519.9	521.6
Other			
Chlorophyll *a* (µg/L)	7.33	7.33	7.33
Conductivity (µS/cm)	1,520	1,520	1,510
pH (pH units)	8.8	8.8	8.8
Turbidity (N.T.U.)	2.6	3.1	2.6
Biochemical Oxygen Demand (mg/L)	<2	<2	<2
Chemical Oxygen Demand (mg/L)	46.3	50.8	47.9
Metals			
Preserved Mercury (µg/L)	na	<0.02	<0.02
Aluminum (mg/L)	na	<0.02	<0.02
Arsenic (mg/L)	na	0.008	0.008

Table 20 Crystal Creek Field and Laboratory Surface Water Quality Data, 2003

Surface Parameters	**April 28**	**May 26**	**June 23**	**July 28**
Field Measurements				
Air Temperature (ºC)	6	22	na	20
Water Temperature (ºC)	4	16	na	na
Dissolved Oxygen (mg/L)	14	5	na	na
pH (pH units)	9.0	8.1	na	na
Conductivity (µS/cm)	610	1,340	na	na
Laboratory Analyzed Parameters				
Nutrients (mg/L)				
Dissolved Organic Carbon	10	17	21	32
Nitrate, as Nitrogen	0.06	<0.02	<0.02	<0.02
Ammonia, as Nitrogen	0.34	0.05	0.10	0.23
Total Kjedahl Nitrogen	1.7	1.5	2.1	2.9
Total Phosphorous	0.13	0.08	0.07	0.29
Ortho-Phosphate, as P	0.03	0.02	0.02	0.16
Solids (mg/L)				
Suspended, Fixed	14	3	2	26
Suspended, Volatile	6	3	2	8
Suspended, Total	21	6	4	34
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	30	790	560
Fecal Streptococci	<10	200	260	4390
Total Coliform	300	<100	>700	2,000
Other				
Chlorophyll *a* (µg/L)	42.31	na	9.33	5.13
Turbidity (N.T.U.)	9.62	2.85	1.49	9.89
Biochemical Oxygen Demand (mg/L)	4.5	3.2	2.2	2.5
Chemical Oxygen Demand (mg/L)	28.9	47.3	68.6	85.2

Table 21 Crystal Creek Field and Laboratory Surface Water Quality Data, 2004

Surface Parameters	**April 12**	**June 14**	**July 14**	**Aug 11**
Field Measurements				
Air Temperature (ºC)	8	16	25	na
Water Temperature (ºC)	4.0	15.4	21.0	na
Dissolved Oxygen (mg/L)	na	7.83	1.33	na
pH (pH units)	na	8.45	7.46	na
Conductivity (µS/cm)	na	1,651	1,614	na
Turbidity (NTU)	na	0.90	0.81	na
Laboratory Analyzed Parameters				
Nutrients (mg/L)				
Dissolved Organic Carbon	19.0	103.6	29.6	27.6
Nitrate, as Nitrogen	0.45	<0.04	<0.04	0.22
Total Kjedahl Nitrogen	1.6	1.6	2.3	2.0
Total Phosphorous	0.18	0.05	0.23	0.15
Ortho-Phosphate, as P	0.08	0.02	0.18	0.10
Solids (mg/L)				
Suspended, Fixed	2	1	1	1
Suspended, Volatile	3	2	2	1
Suspended, Total	5	3	3	1
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	10	130	50
Fecal Streptococci	90	40	50	80
Total Coliform	330	30	200	210
Other				
Chlorophyll *a* (µg/L)	6.34	3.93	na	6.08
Turbidity (N.T.U.)	4.70	5.20	0.85	<0.20
Biochemical Oxygen Demand (mg/L)	4.2	<2.0	2.0	<2.0
Chemical Oxygen Demand (mg/L)	52.9	63.9	81.5	76.1

Table 22 Jackfish Creek Field and Laboratory Surface Water Quality Data, 2003

Surface Parameters	April 28	May 26	June 23	July 28	Aug 25	Oct 6 04
Field Measurements						
Air Temperature (ºC)	7	24	na	na	na	na
Water Temperature (ºC)	6	19	na	na	na	na
Dissolved Oxygen (mg/L)	12	na	na	na	na	na
pH (pH units)	8.0	8.4	na	na	na	na
Conductivity (µS/cm)	850	940	na	na	na	na
Laboratory Analyzed Parameters						
Nutrients (mg/L)						
Dissolved Organic Carbon	19	15	14	26	22	14
Nitrate, as Nitrogen	0.03	<0.02	0.05	<0.02	0.03	0.03
Ammonia, as Nitrogen	0.12	<0.02	0.05	0.14	0.23	na
Total Kjedahl Nitrogen	1.6	1.3	1.3	1.9	3.0	1.4
Total Phosphorous	0.19	0.15	0.11	0.19	0.24	0.12
Ortho-Phosphate, as P	0.11	0.08	0.08	0.09	0.05	0.07
Solids (mg/L)						
Suspended, Fixed	11	6	4	5	137	12
Suspended, Volatile	4	4	3	6	28	4
Suspended, Total	15	10	7	11	165	16
Bacteria (orgs/100 mL)						
Fecal Coliform	<10	20	60	<100	30	10
Fecal Streptococci	10	<10	490	<10	30	<10
Total Coliform	200	200	200	<100	100	10
Other						
Chlorophyll *a* (µg/L)	13.68	na	1.75	1.16	15.18	9.66
Turbidity (N.T.U.)	11.62	3.21	3.39	2.56	74.1	13.00
Biochemical Oxygen Demand (mg/L)	2.3	3.4	2.1	2.1	2.0	1.4
Chemical Oxygen Demand (mg/L)	53.0	38.4	43.6	62.1	86.9	38.0

Table 23 Jackfish Creek Field and Laboratory Surface Water Quality Data, 2004

Surface Parameters	April 12	June 14	July 14	Aug 11
Field Measurements				
Air Temperature (ºC)	na	16	25	na
Water Temperature (ºC)	na	15.8	25.2	na
Dissolved Oxygen (mg/L)	na	4.78	8.24	na
pH (pH units)	na	8.45	8.43	na
Conductivity (µS/cm)	na	1,524	1,449	na
Turbidity (NTU)	na	4.35	6.25	na
Laboratory Analyzed Parameters				
Nutrients (mg/L)				
Dissolved Organic Carbon	21.0	151.1	35.7	32.7
Nitrate, as Nitrogen	<0.04	<0.04	<0.04	0.21
Total Kjedahl Nitrogen	1.8	2.3	2.5	3.2
Total Phosphorous	0.20	0.17	0.27	0.24
Ortho-Phosphate, as P	0.07	0.09	0.11	0.08
Solids (mg/L)				
Suspended, Fixed	24	3	1	10
Suspended, Volatile	7	4	2	5
Suspended, Total	31	8	3	15
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	110	260	<10
Fecal Streptococci	400	270	30	10
Total Coliform	10	2,000	240	10
Other				
Chlorophyll *a* (µg/L)	6.81	9.55	5.63	7.33
Turbidity (N.T.U.)	8.8	3.5	2.1	5.6
Biochemical Oxygen Demand (mg/L)	2.8	2.8	2.3	3.2
Chemical Oxygen Demand (mg/L)	57.1	90.9	94.5	95.6

Table 24 Lehman's Creek, Main Bridge Site #5AC, Field and Laboratory Surface Water Quality Data, 2003

Surface Parameters	**May 26**	**June 23**	**July 28**	**Aug 25**
Field Measurements				
Air Temperature (ºC)	23	na	na	na
Water Temperature (ºC)	17	na	na	na
Dissolved Oxygen (mg/L)	8	na	na	na
pH (pH units)	8.6	na	na	na
Conductivity (µS/cm)	1,440	na	na	na
Laboratory Analyzed Parameters				
Nutrients (mg/L)				
Dissolved Organic Carbon	15	15	21	24
Nitrate, as Nitrogen	<0.02	<0.04	<0.02	0.03
Ammonia, as Nitrogen	0.02	0.11	0.06	0.10
Total Kjedahl Nitrogen	1.4	1.6	1.8	2.0
Total Phosphorous	0.06	0.07	0.07	0.09
Ortho-Phosphate, as P	0.02	0.03	0.04	0.06
Solids (mg/L)				
Suspended, Fixed	5	8	2	3
Suspended, Volatile	4	2	2	3
Suspended, Total	8	11	4	6
Bacteria (orgs/100 mL)				
Fecal Coliform	10	630	<10	20
Fecal Streptococci	70	1,000	200	90
Total Coliform	<100	1,100	<100	<10
Other				
Chlorophyll *a* (µg/L)	na	<0.20	<0.20	4.35
Turbidity (N.T.U.)	3.55	2.78	1.05	0.85
Biochemical Oxygen Demand (mg/L)	1.7	2.1	1.2	0.8
Chemical Oxygen Demand (mg/L)	41.4	48.4	52.0	58.7

Table 25 Lehman's Creek Field and Laboratory Surface Water Quality Data, 2004

Surface Parameters	**April 12**	**July 14**	**Aug 11**
Field Measurements			
Air Temperature (ºC)	7	25	na
Water Temperature (ºC)	5	22	na
Dissolved Oxygen (mg/L)	na	8.53	na
pH (pH units)	na	8.7	na
Conductivity (µS/cm)	na	1,497	na
Turbidity (NTU)	na	2.5	na
Laboratory Analyzed Parameters			
Nutrients (mg/L)			
Dissolved Organic Carbon	14.0	16.5	16.8
Nitrate, as Nitrogen	0.29	<0.04	0.21
Total Kjedahl Nitrogen	1.8	1.2	1.3
Total Phosphorous	0.24	0.04	0.03
Ortho-Phosphate, as P	0.06	<0.02	0.02
Solids (mg/L)			
Suspended, Fixed	9	1	1
Suspended, Volatile	7	1	2
Suspended, Total	16	2	2
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	50	<10
Fecal Streptococci	1,900	20	60
Total Coliform	300	40	10
Other			
Chlorophyll *a* (µg/L)	47.89	1.71	2.74
Turbidity (N.T.U.)	6.3	2.2	1.7
Biochemical Oxygen Demand (mg/L)	7.0	2.3	<2.0
Chemical Oxygen Demand (mg/L)	40.3	44.6	50.8

Table 26 Lehman's Creek, NE of Bridge, Bacteria Data, 2003

Surface Parameters	**May 26**	**June 23**	**July 28**	**Aug 25**
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	50	na	10
Fecal Streptococci	20	190	na	150
Total Coliform	100	300	na	20

Table 27 Lehman's Creek, NE of Bridge, Bacteria Data, 2004

Surface Parameters	**April 12**	**June 14**	**July14**	**Aug 11**
Bacteria (orgs/100 mL)				
Fecal Coliform	10	na	10	20
Fecal Streptococci	1,000	na	<10	220
Total Coliform	500	na	<10	10

Table 28 Lehman's Creek, SW of Bridge, Bacteria Data, 2003

Surface Parameters	**May 26**	**June 23**	**July 28**	**Aug 25**
Bacteria (orgs/100 mL)				
Fecal Coliform	30	150	<100	20
Fecal Streptococci	70	1,700	10	80
Total Coliform	<100	>100	<100	100

Table 29 Lehman's Creek, SW of Bridge, Bacteria Data, 2004

Surface Parameters	**April 12**	**June 14**	**July 14**	**Aug 11**
Bacteria (orgs/100 mL)				
Fecal Coliform	<10	na	20	20
Fecal Streptococci	800	na	40	40
Total Coliform	900	na	20	50

Table 30 Lost Horse Creek Field and Laboratory Surface Water Quality Data, 2003

Surface Parameters	**Apr 28**	**May 26**	**Jun 23**	**Jul 28**	**Aug 25**
Field Measurements					
Air Temperature (ºC)	5	23	na	na	na
Water Temperature (ºC)	3	17	na	na	na
Dissolved Oxygen (mg/L)	13	7	na	na	na
pH (pH units)	8.0	8.2	na	na	na
Conductivity (µS/cm)	420	na	na	na	na
Laboratory Analyzed Parameters					
Nutrients (mg/L)					
Dissolved Organic Carbon	10	13	15	21	24
Nitrate, as Nitrogen	0.03	<0.02	<0.04	0.02	0.03
Ammonia, as Nitrogen	0.03	0.02	0.16	0.15	0.34
Total Kjedahl Nitrogen	0.7	1.1	1.6	1.9	4.4
Total Phosphorous	0.10	0.11	0.26	0.2	0.39
Ortho-Phosphate, as P	0.06	0.04	0.20	0.09	0.20
Solids (mg/L)					
Suspended, Fixed	6	11	10	10	9
Suspended, Volatile	3	4	6	17	10
Suspended, Total	8	15	15	26	19
Bacteria (orgs/100 mL)					
Fecal Coliform	210	240	640	<10	<10
Fecal Streptococci	150	1,440	340	10	<10
Total Coliform	360	300	>200	<100	<10
Other					
Chlorophyll *a* (µg/L)	2.78	na	18.22	5.47	16.72
Turbidity (N.T.U.)	5.54	5.60	4.42	0.93	4.26
Biochemical Oxygen Demand (mg/L)	1.5	2.5	2.1	7.8	3.4
Chemical Oxygen Demand (mg/L)	25.6	35.3	43.0	na	66.8

Table 31 Lost Horse Creek Field and Laboratory Surface Water Quality Data, 2004

Surface Parameters	June 14	July 14	Aug 11
Field Measurements			
Air Temperature (ºC)	16	16	na
Water Temperature (ºC)	13.9	21.1	na
Dissolved Oxygen (mg/L)	6.49	4.24	na
pH (pH units)	8.52	8.02	na
Conductivity (µS/cm)	705	767	na
Turbidity (NTU)	3.50	6.26	na
Laboratory Analyzed Parameters			
Nutrients (mg/L)			
Dissolved Organic Carbon	76.8	13.6	15.4
Nitrate, as Nitrogen	<0.04	<0.04	0.22
Total Kjedahl Nitrogen	0.9	1.0	2.6
Total Phosphorous	0.08	0.11	0.39
Ortho-Phosphate, as P	0.04	0.07	0.08
Solids (mg/L)			
Suspended, Fixed	4	4	28
Suspended, Volatile	2	3	17
Suspended, Total	7	7	45
Bacteria (orgs/100 mL)			
Fecal Coliform	170	130	100
Fecal Streptococci	140	30	180
Total Coliform	1,500	280	3,000
Other			
Chlorophyll *a* (µg/L)	2.15	4.44	148.75
Turbidity (N.T.U.)	4.3	4.6	21.0
Biochemical Oxygen Demand (mg/L)	<2.0	<2.0	6.2
Chemical Oxygen Demand (mg/L)	28.9	33.4	64.1

Table 32 Pigtail Creek Field and Laboratory Surface Water Quality Data, 2003

Surface Parameters	**Apr 28**	**May 26**	**Jun 23**	**Jul 28**	**Oct 6**
Field Measurements					
Air Temperature (ºC)	9	24	na	na	na
Water Temperature (ºC)	6	20	na	na	na
Dissolved Oxygen (mg/L)	11	10	na	na	na
pH (pH units)	8.0	8.4	na	na	na
Conductivity (µS/cm)	1,230	1,830	na	na	na
Laboratory Analyzed Parameters					
Nutrients (mg/L)					
Dissolved Organic Carbon	32	34	41	53	32
Nitrate, as Nitrogen	0.02	<0.02	0.07	<0.02	0.07
Ammonia, as Nitrogen	0.09	0.03	0.41	0.20	na
Total Kjedahl Nitrogen	2.1	2.8	4.5	4.7	2.7
Total Phosphorous	0.14	0.07	0.15	0.17	0.15
Ortho-Phosphate, as P	0.09	0.02	0.05	0.06	0.04
Solids (mg/L)					
Suspended, Fixed	3	5	95	8	8
Suspended, Volatile	2	3	52	6	8
Suspended, Total	5	8	147	15	16
Bacteria (orgs/100 mL)					
Fecal Coliform	<10	30	170	1,800	90
Fecal Streptococci	<10	80	510	480	70
Total Coliform	300	<100	>100	1,000	100
Other					
Chlorophyll *a* (µg/L)	5.50	na	6.28	<0.20	27.10
Turbidity (N.T.U.)	0.88	0.92	40.30	7.63	3.80
Biochemical Oxygen Demand (mg/L)	2.2	1.9	3.8	2.6	3.6
Chemical Oxygen Demand (mg/L)	73.8	92.1	145.0	153.0	89.4

Table 33 Pigtail Creek Field and Laboratory Surface Water Quality Data, 2004

Surface Parameters	**April 12**	**July 14**	**Aug 11**
Field Measurements			
Air Temperature (ºC)	na	25	na
Water Temperature (ºC)	na	24.5	na
Dissolved Oxygen (mg/L)	na	2.17	na
pH (pH units)	na	8.03	na
Conductivity (µS/cm)	na	1,681	na
Turbidity (NTU)	na	1.99	na
Laboratory Analyzed Parameters			
Nutrients (mg/L)			
Dissolved Organic Carbon	24.0	43.1	39.2
Nitrate, as Nitrogen	<0.04	<0.04	0.21
Total Kjedahl Nitrogen	1.8	2.8	2.8
Total Phosphorous	0.21	0.15	0.09
Ortho-Phosphate, as P	0.08	0.11	0.05
Solids (mg/L)			
Suspended, Fixed	1	1	2
Suspended, Volatile	2	4	3
Suspended, Total	3	5	5
Bacteria (orgs/100 mL)			
Fecal Coliform	10	50	30
Fecal Streptococci	240	80	70
Total Coliform	210	100	160
Other			
Chlorophyll *a* (µg/L)	4.03	1.70	5.03
Turbidity (N.T.U.)	3.50	0.74	2.90
Biochemical Oxygen Demand (mg/L)	3.0	2.7	2.0
Chemical Oxygen Demand (mg/L)	65.7	111.0	108.0

9.0 Appendix B

9.1 Lake Stewardship Manual

This manual is intended to provide lake stewards with an explanation of the parameters commonly analyzed as part of a water quality monitoring program. Water quality monitoring is a key component of any lake stewardship activity. Monitoring enables local groups and residents to understand the characteristics of their lake and how activities around a lake may impact water quality. This knowledge enables stewards to set goals and objectives to improve and protect lake water quality. Lake stewardship groups may aid in the collection of water quality data, share acquired information, educate the public on sound lake and drainage basin management, foster partnerships with government and research personnel, and develop lake enhancement and protection projects.

The Saskatchewan Watershed Authority, *Lake Stewardship Program* provides technical assistance and guidance in order to facilitate lake stewardship goals and objectives. The *Lake Stewardship Program* may include a water monitoring program. The scope and purpose of water quality monitoring programs are to assess current water quality conditions by collecting representative data which may be used to examine changes or trends in water quality over time. Baseline stations are typically located close to the center of the lake at the deepest point. Shoreline sampling sites, identified by lake stewards, may also be included in the monitoring program to assess localized point or non-point source pollution from the watershed. These cooperative efforts result in a well planned sampling program which over time provides information on temporal changes in water quality resulting from storm events, drought, season, or increased lake use.

In Saskatchewan, *Surface Water Quality Objective* (1997) are set for various uses of water including protection of aquatic life, contact and non-contact recreation, irrigation, livestock, watering, municipal, and domestic uses. As a result, no one set of objectives or guidelines can be used in the assessment of surface water quality. Consequently, water quality parameters are discussed in this manual, in terms of the Saskatchewan *Surface Water Quality Objectives* (1997), for contact and non-contact recreation, as well as the protection of aquatic life.

9.2 Parameter Summary

1. Trophic Status - is a lake classification system based on the amount of nutrients in the lake and its' resulting biological productivity. Several water quality parameters are measured and used as indicators to determine the trophic status of a lake. The most commonly used "trophic indicators" include nutrients, chlorophyll *a*, and secchi disk transparency (water clarity). Nutrient additions increase biological productivity, which may be measured as chlorophyll *a*, which decreases water clarity, measured by secchi disk transparency. As a result, biological productivity is used to determine lake trophic status. There are four trophic states: oligotrophic, mesotrophic, eutrophic, and hypertrophic, which range from low to extreme biological productivity respectively. Oligotrophic lakes have low inputs if nutrients, organic matter and sediment and consequently, little biological productivity. In contrast, eutrophic lakes are very productive with high levels of nutrients, organic matter and sediments.

2. Nutrients - primary productivity, aquatic plant, and algae growth, is dependent on nutrients to stimulate and sustain growth. As a result, the availability of particular essential nutrients such as phosphorus and nitrogen often determines lake productivity.

3. Phosphorus - there are numerous forms of phosphorus. The two most commonly measured forms of phosphorus are total phosphorus (TP) and orthophosphate (PO_4). Total phosphorus is a measure of all phosphorus forms including dissolved and particulate organic phosphates from algae and other organisms, inorganic particulate phosphorus from soil particles and other solids, and polyphosphates from detergents and dissolved orthophosphates. Orthophosphate is the only directly usable form of soluble inorganic phosphorus by aquatic plants and algae.

4. Nitrogen - there are five forms of nitrogen found in freshwater lakes: elemental nitrogen (N_2), organic nitrogen, ammonia (NH_3), nitrate (NO_3) and nitrite (NO_2). Only three forms of nitrogen (ammonia, nitrate, and nitrite) are readily available to aquatic plants and algae for growth. As a result, these three nitrogen compounds, plus total kjeldahl nitrogen (TKN), a measurement of organic and ammonia nitrogen, are usually analyzed in most monitoring programs. Common anthropogenic nitrogen sources include sewage, feedlots, and fertilizers.

   Ammonia-nitrogen is the preferred form of nitrogen for uptake by aquatic plants and algae. Typically concentrations are low in healthy lakes at less than 1 mg/L. Decomposing organic material produces ammonia as a byproduct. High levels of ammonia can be toxic to aquatic life if the pH is greater than 8, as the unionized form of ammonia becomes present in high concentrations. Unionized ammonia concentrations increase with corresponding increases in lake temperature and/or pH. As a result, in eutrophic lakes ammonia concentration can reach toxic levels due to favorable conditions including: decomposing organic matter, high temperatures, and pH.

Nitrate-nitrogen is used by aquatic plants and algae but must be reduced to ammonia prior to use. As a result, ammonia is the preferred form of nitrogen. Nitrate concentrations are less than 0.05 mg/L in healthy lakes, most surface waters are less than 0.3 mg/L. In eutrophic lakes nitrate will be depleted at the top due to algae consumption and high at the bottom from release by decomposing organic material.

Nitrite-nitrogen is readily oxidized to nitrate. As a result, nitrite is typically found at very low concentrations, less than 0.005 mg/L. When nitrite concentrations are high it may indicate organic pollution by sewage systems.

Total Kjehldahl nitrogen is a measure of the organic and ammonia nitrogen. When samples are analyzed for TKN and nitrate the values may be subtracted to estimate the ammonia concentration.

5. Chlorophyll *a* - all plants and algae contain the photosynthetic pigment, chlorophyll *a*, used to absorb light energy and produce living matter. In the laboratory chlorophyll *a* is easily extracted from algae and measured. As a result, chlorophyll *a* is used to determine the amount of algae in a water sample and therefore the intensity of lake primary productivity. This parameter is commonly used as a trophic status indicator.

6. pH - is an important water quality parameter. It affects most chemical and biological reactions within the lake. Extremes in pH or rapid changes in pH can be detrimental to aquatic life. pH is a measurement of the hydrogen ion concentration, expressed on a logarithmic scale, ranging from 0 (acidic) to 14 (alkaline). Waters with a pH of 7 are neutral. The logarithmic scales means that with every unit increase in pH the hydrogen ion concentration increases ten times. Lake pH is influenced by the addition of salts, acids, bases, and increased photosynthesis. Lakes may be acidified by the accumulation of acidic runoff and humic substances drained from igneous deposits in the watershed. Normal rainwater has a pH of 5.6 making it another acidic addition. In contrast, drainage of calcareous or limestone deposits are basic additions. Photosynthesis also depletes the carbon dioxide and hydrogen ions, which increase the pH, and the lake may become more basic. The Saskatchewan *Surface Water Quality Objectives* (1997) sets a pH range of 6.5 to 8.5 as optimal for surface waters.

7. Total Alkalinity - is a measure of water's acid-neutralizing capacity. pH is the measure of acid and base reactions in water, while alkalinity is a measure of the ability of water to resist acid and base reactions through buffering. Lakes with low alkalinity have large daily pH fluctuations indicating they are poorly buffered. The capability of the system to buffer additions is dependent on the carbonate, bicarbonate and hydroxide content. Water with an abundance of buffering materials is more resistant to changes in pH. As a result, soft water lakes have poor buffering capacity and are therefore vulnerable to the addition of acid. A total alkalinity level of 100 to 200 mg/L will stabilize the pH of most

water bodies. Consequently, lakes with total alkalinity levels greater than 200 mg/L are typically well buffered and should resist sudden changes in pH.

8. Conductivity - is a measure of the ability of water to conduct an electric current, which is dependent on the concentration of dissolved ions in solution. Conductivity is variable and is dependent on the geology and soil in the watershed and is determined by the concentration of specific ions and lake temperature. As a result, once the ion concentration is known, changes in conductivity reflect modifications of ion concentrations. Conductivity is corrected to 25°C and reported as specific conductance (umhos/cm @ 25°C) to enable direct comparison of samples collected at different temperatures.

9. Turbidity - is the measure of water clarity. A reduction or lack of water clarity is indicative of turbidity. Turbidity is caused by solids suspended in the water including clay, silt and plankton (small plants and animals). Sources of turbidity are soil erosion, waste discharge, urban runoff, algal growth, or abundant bottom feeders, such as carp, that stir up bottom sediment. Increases in turbidity may decrease light penetration, destroy or modify fish habitat and increase water temperature which decreases oxygen concentrations. As a result, the Saskatchewan *Surface Water Quality Objectives* (1997), state that turbidity should not be increased by more than 25 turbidity unit above ambient values. Turbidity may be measured using a secchi disk or a more precise turbidimeter.

10. Secchi Disk Readings - is a measure of water transparency. Transparency is affected by suspended sediment, algae, and water colour. Secchi depth is determined by lowering a weighted black and white disk, 20 cm in diameter, from the shaded side of a boat and averaging the depth were the disk disappears and then reappears from view. Volunteers taking secchi measurements must remember to remove their sunglasses which enhance their ability to look down into the water. The secchi disk reading is a simple measurement that may be used as a trophic status indicator. The Saskatchewan *Surface Water Quality Objectives* (1997), state that for bathing waters the secchi disk should be visible at 1.2 m.

11. Biological Oxygen Demand (BOD 5-Day) - Aerobic bacteria decompose organic matter such as plants and animals. In this process, bacteria breakdown organic matter and oxidize it by adding oxygen. Biological oxygen demand is the quantity of oxygen used in the oxidation of organic matter. When organic matter is decomposed and oxidized, nutrients are released and plant growth is stimulated. This increases the amount of organic material requiring decomposition and leads to an increased biological oxygen demand (BOD). Consequently, when BOD levels are high, oxygen is being consumed by decomposition processes and this limits the oxygen available for other organisms such as invertebrates and fish. Biological oxygen demand can be measured in the laboratory to determine the amount of dissolved oxygen consumed by oxidative processes in water over a 5 day period at 20°C. *Surface Water Quality Objectives* (1997), state the BOD must not exceed a limit which would create dissolved oxygen content of less than 5 mg/L.

12. Chemical Oxygen Demand (COD) - is the quantity of oxygen consumed by biological and non-biological oxidation of organic matter in water. In contrast to BOD, COD may be measured in a matter of hours. As a result, COD is often used to measure the oxygen demand of waste water discharged, including sewage and industrial effluent.

13. Dissolved Oxygen - oxygen is readily dissolved in water and is supplied to surface water through the diffusion of atmospheric oxygen and the production of oxygen by aquatic plants and algae during photosynthesis. Although oxygen is very soluble in water, a number of factors can determine the amount of dissolved oxygen found in a lake including: water temperature, atmospheric pressure (or altitude), wind and wave action (mixing), salinity, respiratory and decomposition processes, and the shape and depth of a lake.

    In lakes, dissolved oxygen levels can fluctuate with depth and taking dissolved oxygen and temperature profiles can provide information on the mixing patterns in the water. Dissolved oxygen and temperature profiles are measured at the baseline monitoring stations. Dissolved oxygen is more soluble in cold water than in warm water. Consequently, dissolve oxygen concentrations may vary throughout the day with temperature. The solubility of oxygen is greater in water than in the atmosphere. As a result, oxygen from the atmosphere diffuses into water. Oxygen diffusion is enhanced by wind and wave action which distributes oxygen throughout the water. Dissolved oxygen concentrations are variable based on time, weather and temperature. Consequently, sampling needs to be repeated within the same time frame to enable year to year comparisons.

    Dissolved oxygen is essential to aquatic life. Fish, invertebrates, and aerobic bacteria all require oxygen for respiration. If dissolved oxygen levels are depleted, aquatic organisms may become stressed or die. Some organisms are more tolerant of low oxygen levels than others. The amount of oxygen required depends on the species and life stage. Dissolved oxygen levels of 1 or 2 mg/L will not support fish populations. The Saskatchewan *Surface Water Quality Objectives* (1997) sets a minimum dissolved oxygen concentration of 5 mg/L for the protection of all stages of warm water biota.

14. Dissolved Organic Carbon (DOC) - is responsible for making lake water look "tea" coloured. DOC is decomposed organic material in the form of humic and fulvic acids which are relatively stable with low solubility. Precipitation, leaching and decomposing from surrounding terrestrial and wetland areas are the primary source of dissolved organic carbon additions to freshwater lakes. Plants and algae within the lake can also provide a contribution to DOC concentrations within a lake. Lake productivity, nutrient cycling, temperature, and light penetration are all affected by DOC concentrations. Currently, research is focused on the attenuation of UV radiation by DOC for the protection of aquatic life.

15. Microbiological Water Quality - the bacterial quality of surface water supplies is of importance for a number of water uses, including contact and non-contact

recreation such as swimming, boating, or fishing. The bacterial quality of a water supply can also be important for irrigation of certain crops, such as fruits and vegetables, and as a supply for domestic or municipal systems. All surface waters are open to the environment and will contain a variety of bacterial species. These organisms play an important role in the decomposition of organic material and recycling of nutrients. While bacteria are present in all surface waters, it is the sanitary quality of the reservoir that is of concern.

In Saskatchewan, the bacterial quality of surface waters is assessed by the presence of indicator organisms, such as total coliform and fecal coliform bacteria. The Saskatchewan *Surface Water Quality Objectives* set guidelines for the number of these organisms acceptable within a surface water body based on the various uses of the water. For contact recreation, the *Surface Water Quality Objectives* (1997) state that the mean density of fecal coliforms should not exceed 200 organisms per 100 mL of water. For non-contact recreation and general surface water quality, the *Surface Water Quality Objectives* state that the density of fecal coliforms should not exceed 1,000 organisms per 100 mL of water, nor should the total coliforms exceed a density of 5,000 organisms per 100 mL of water.

16. <u>Total Dissolved Solids (TDS)</u> - is a measure of the dissolved ions (minerals) in water. The cations (calcium, magnesium, sodium, and potassium), and their associated anions (bicarbonate, sulphate, and chloride) are the main ions that contribute to the total dissolved solids of a water supply. The amount of minerals found in a water supply depends mainly on the types of rock or soil the water comes into contact with and the amount of water lost to evaporation relative to precipitation. A high mineral concentration can restrict the use of the water, depending on the specific minerals present and their individual concentration. TDS can also be used as an indicator of the salinity of a water body. While a high TDS can affect the use of water for irrigation, livestock watering, municipal and domestic uses, it generally does not have a significant impact on lake recreation activities.

17. <u>Total Suspended Solids (TSS)</u> - is organic and inorganic material present in the water including: algae, plant material, micro-organisms, and sand, silt, and clay particles. Total suspended solids can be divided into categories: fixed and volatile suspended solids.

18. <u>Total Hardness</u> - is the concentration of calcium and magnesium ions in the water, expressed as calcium carbonate. Calcium carbonates precipitates from hard waters encrusting water pipes and forming scale deposits when heated. Hard waters are usually found were water drainage is derived from calcareous deposit. In contrast, soft waters have low ions concentration, low salinity, and are usually derived from acidic igneous rock drainage.

19. <u>Salinity</u> - is defined as the sum concentration of all ionic components dissolved in fresh and saline water. Ionic concentration is dependent on ion exchanges with

the atmosphere and watershed including rock, soil, human activity, the ocean, and lake sediment. Four major cations: calcium, magnesium, sodium, and potassium, and four major anions: bicarbonate, carbonate, sulphate, and chloride determine 99% of total ionic salinity. Consequently, other elements such as nitrogen, phosphorus, iron, and manganese contribute little to the total ionic salinity of the water.

20. Cations: Calcium, Magnesium, Sodium & Potassium - The concentration of cations in lake water is primarily determined by the watershed geology. Calcium is derived from the watershed from weathering of rocks and soil, especially limestone. Calcium is readily soluble in water and is one of the most abundant cations in lake water. Magnesium is a component of igneous rock as ferromagnesium minerals and sedimentary rock as magnesium carbonates, and is the eighth most abundant natural element. Industrial and municipal wastes in addition to natural weathering determine calcium and magnesium concentrations. Together calcium and magnesium salts determine the hardness of the water.

    Calcium concentrations are strongly influenced by biological metabolism. In contrast, concentrations of magnesium, sodium and potassium are not modified substantially by biological use. Calcium is an essential nutrient used by algae in physiological process. Magnesium helps form chlorophyll and consequently is a micronutrient required by all plants and algae. Magnesium concentrations are relatively unaffected by biological use because quantities consumed are significantly less than the quantity available. Sodium and potassium may be used by certain types of algae but concentrations remain relatively stable.

21. Anions: Sulphate, Chloride, Bicarbonate & Carbonate - Sulphate is the primary form of dissolved sulfur. Sulfur is required by all living organisms. The cycling of sulphur within a lake is complex and results in variable concentrations spatially and seasonally. Chloride concentrations are also determined by spatial and season distribution, relatively unaffected by biological uptake. In contrast, bicarbonate and carbonate concentrations are determined by the lake's alkalinity and productivity.

22. Elements: Iron & Manganese - Iron and manganese are essential elements to physiological processes of algae, plant and animals. Although these elements are biologically important they also have a role in phosphorus cycling within the lake and affect phosphorus availability. As a result, iron and manganese concentrations are often measured as part of a water quality sampling program.

23. Metals: Mercury, Aluminum, and Arsenic - Mercury, aluminum, and arsenic are metals which naturally occur in all rock types. Natural rock weathering and erosion results in the addition of these elements to lake water. However, the concentration of these metals may be dramatically higher than natural concentration due to human activity causing pollution.

Mercury is used in the chlor-alkali, paint, pulp and paper industries. Products include chlorine, hydrogen, paint pigments, and preservatives, electrical equipment such as thermometers, batteries and lamps. In the lake mercury is transformed by microorganisms into methlymercury. There are two forms of methlymercury: monomethylmercury, and dimethylmercury. The amount of each form is dependent on amount of mercury, presence of microbes, organic carbon concentrations, pH and lake temperature. Dimethylmercury is produced under high pH conditions, while monomethlymercury formation is favoured under acidic conditions. These methylated forms of mercury accumulate in aquatic organisms, such as fish and invertebrates. Mercury is an acute neurotoxin, which negatively affects the biota of a polluted lake. Biological organisms may accumulate mercury directly from the water or through the food chain. Bioconcentration of mercury are high in aquatic organisms due to the rapid uptake of methylmercury by organisms. The concentration of mercury is magnified up the food chain. As a result, organisms at the bottom of the food chain have lower concentrations of mercury accumulated from the water. In contrast, predatory fish, such as lake trout, accumulate higher concentrations of mercury from their food source as well as the water. Consequently, it is said that mercury concentrations are biomagnified up the food chain. The Saskatchewan *Surface Water Quality Objectives* (1997) specifies that mercury concentration should be less than 0.001 mg/L or 1 µg/L for the protection of aquatic life and wildlife.

Aluminum is abundant in the natural environment but typically inorganic and biological processes maintain aluminum in an unreactive form. Acidic precipitation and poorly buffered soils result in reactive aluminum additions from upland soil and rock weathering. The primary source of aquatic aluminum pollution is from effluent produced by industries using aluminum in their processing or alum as a flocculent. Aluminum may enter the lake from local or long distance atmospheric transportation and deposition. The concentration of reactive aluminum increases with water acidity. As a result, decreases in pH and increases in organic carbon result in increased concentrations of aluminum in the lake water. Aluminum is highly reactive and can be toxic to biological organisms at low concentrations. The Saskatchewan *Surface Water Quality Objectives* (1997) for livestock watering, aluminum concentrations should be less than 5 mg/L or 5,000 µg/L.

Arsenic is naturally released into the environment by rock weathering and volcanic release. However, human activities can cause twice as much arsenic to be released into the environment as natural sources. Arsenic is used in many industrial processes and products. Common products which may be used around lakes are pesticides and herbicides containing arsenic. Aquatic arsenic concentrations are dependent on geological chemistry, industrial and human activity in the watershed. In the lake, arsenic is removed from the water and deposited in the sediment by adsorbing to suspended organic matter which settles to the bottom of the lake. Consequently, arsenic may form a wide variety of compounds with elements found in lake water. Arsenic is toxic at low concentrations to aquatic organisms. Aquatic organisms bioaccumulate arsenic in their tissue and organs. Accumulated arsenic concentrations depend on the organism, its age, water temperature and the concentration of arsenic present. In contrast to mercury, there is no evidence of arsenic biomagnification. The Saskatchewan *Surface Water Quality Objectives* (1997), for the protection of aquatic life and wildlife, arsenic concentrations should be less than 0.05 mg/L or 50 µg/L.