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1.0 Background

Saskatchewan Watershed Authority (SWA) developed the *Lake Stewardship Program* in September 1997 to support stewardship groups throughout Saskatchewan. The mandate of this 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 Good Spirit Lake

Good Spirit Lake is a popular recreational lake, located approximately 60 kilometers northeast of Yorkton, Saskatchewan. Development around the lake includes a number of villages, hamlets, and resort communities, as well as Good Spirit Lake Provincial Park located on the southwest side of the lake. It is a large lake with a surface area of approximately 44 square kilometers. Based on regulated water levels between 484.25 and 484.4 meters (m), the maximum depth is 6 m. In 2004, during the open water season water levels fluctuated between 483.54 and 483.68, with a maximum depth of approximately 4.5 m.

In 1998, *Friends of Good Spirit Lake* became an incorporated group under the Non-Profit Corporations Act. In the same year, an agreement was signed with Sask Water (now Saskatchewan Watershed Authority) which provides technical, administrative, and financial assistance to support the activities of the group. Water sampling was started in 1997 at Good Spirit Lake and continues currently under the Saskatchewan Watershed Authority *Lake Stewardship Program*. As a result, water quality monitoring has been conducted for eight consecutive years providing the most current and comprehensive water quality data for Good Spirit Lake.

2.1 Stewardship Activities

Water quality concerns initiated the formation of the *Friends of Good Spirit Lake*. Consequently, stewardship activities have focused on water quality monitoring and educational outreach. Since monitoring began in 1997 volunteers from the group have been instrumental in sample collection. Educational outreach initiatives focused on the distribution of Water Watchdog Kits to cottagers, beach communities, and Good Spirit Bible Camp. Water Watchdog kits are a fun-hands-on educational toolkit for children. These kits were used to educate community children on water quality monitoring, stewardship activities, and environmental awareness.

In 2005, *Friends of Good Spirit Lake* plan to produce information packages for lake residents, campers, and visitors. These information packages will outline lake activities which support an enjoyable stay while protecting the lake environment. The Green Guest Guide, produced by the Living-By-Water project may be incorporated into this information package. Provincial Park staff will distribute information packages with park passes and camping permits. The group is also perusing a project which would employ a local artist to design a map of Good Spirit Lake. The intent of the map is to foster a sense of pride in lake goers and consequently, promote more environmentally friendly actions.

2.1.1 Projects

Following six years of water quality monitoring *Friends of Good Spirit Lake* sought additional information on the history of their water quality. Sediment core sampling is an ideal method of examining historical trends in water quality. Each layer of sediment tells a story about the water quality at the time of deposition. Sediment at the top of the core explains the current water quality conditions with each layer below details how it has changed over time. Consequently, changes in water quality may be correlated with development and activities in the watershed. Dr. Marlene Evans from Environment Canada collected sediment cores from Good Spirit Lake in March 2003. The results of this study were presented to *Friends of Good Spirit Lake* in April 2005. This research conducted by Environment Canada will complement the *Lake Stewardship Program,* and enable stewards to further understand historic changes in Good Spirit Lake water quality.

2.2 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 Good Spirit Lake. 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.

2.3 Water Sampling Procedure

Saskatchewan Watershed Authority personnel facilitated the collection of all field measurements and water sampling at Good Spirit Lake in 2003 and 2004. A sampling station was established near the point of maximum depth near the center of the lake (Figure 1). This station is 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. Samples collected in 2003 and 2004 from the baseline station 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. The 2003 and 2004 baseline water quality information was collected from the same baseline location as used in previous years. Sample collection and field monitoring at the baseline station was conducted five times during 2003: February 17, May 20, July 9, August 19, and October 15. In 2004, sampling was again conducted five times on: March 2, May 25, July 12, August 31, and November 3.

2.3.1 Field Measurements

Field measurements were taken at the baseline station 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.

2.3.2 Laboratory Analysis

Baseline samples were analyzed for nutrients, major ions, chlorophyll *a*, dissolved and suspended solids, and bacteria (See Tables 6 to 11). All water samples were collected in plastic bottles and shipped in coolers to the Provincial Laboratory in Regina, Saskatchewan.

2.3.3 Stewardship Involvement

Volunteers are essential to the water monitoring program providing transportation to sampling locations, sample collection assistance, and local knowledge. In 2003 and 2004 Ray Riesz, Lloyd Wilson, and Bill Anaka assisted Saskatchewan Watershed Authority technologist Rob Walcer with baseline sampling on Good Spirit Lake.

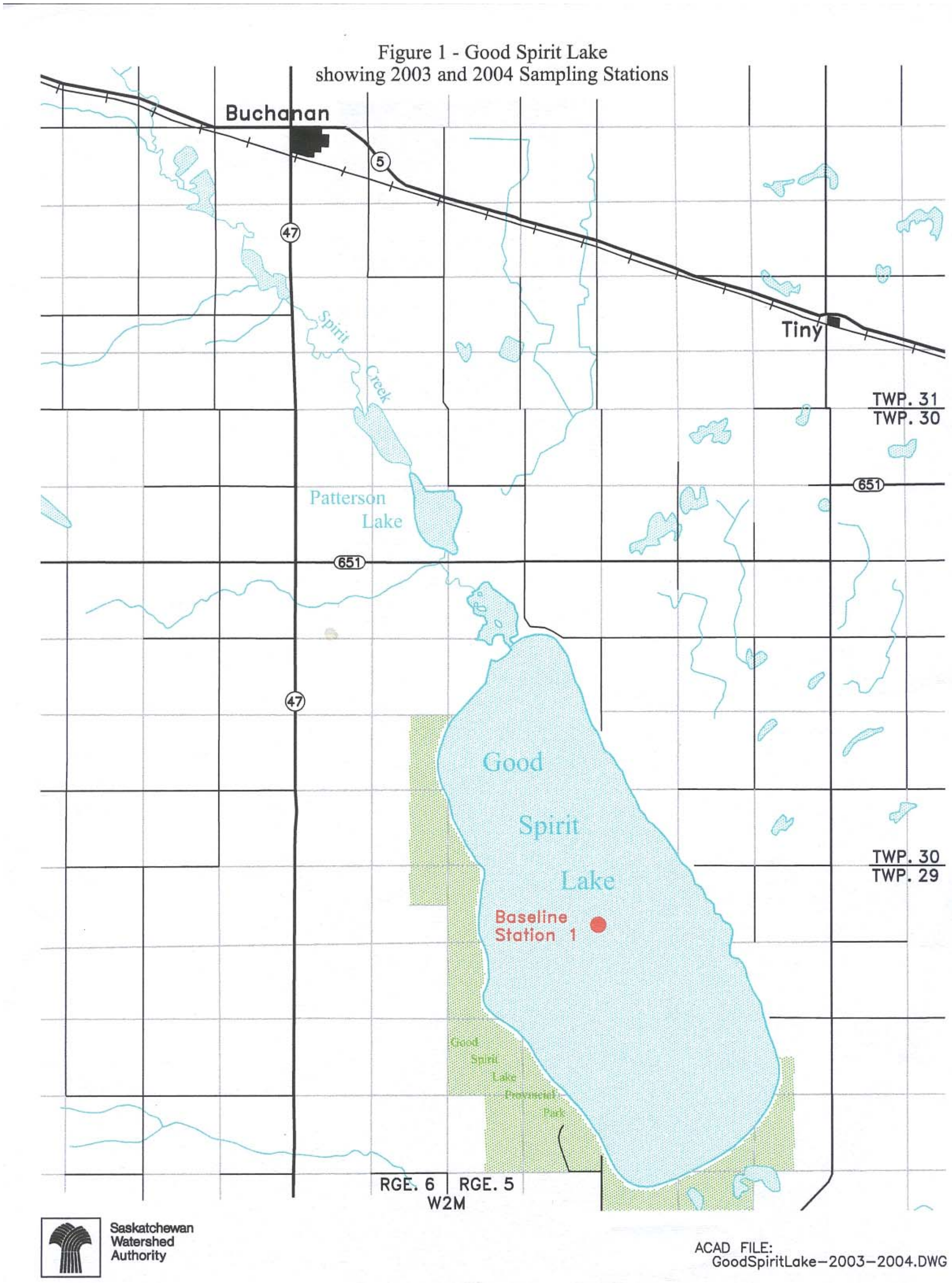

Figure 1 Good Spirit Lake 2003 and 2004 Sampling Station

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 Field Measurements

Field water quality parameters measured at Good Spirit Lake have been summarized in Tables 2 to 5. There are five important field measurements to examine when assessing water quality: dissolve oxygen and temperature profiles, conductivity, secchi disk transparency depth, and turbidity.

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. Dissolved oxygen concentrations in Good Spirit Lake ranged from 3.13 to 13.55 mg/L. Low concentrations are typically observed under winter condition when oxygen addition is limited. During the open water season dissolved oxygen remained well mixed throughout the water column (Tables 3 and 5) with surface concentrations between 7.30 and 13.55 mg/L, exceeding the 5 mg/L objective set for the protection of all stages of warm water biota. In February 2003 and March 2004, the dissolved oxygen levels did drop below 5 mg/L. In 2003, the winter sample showed reduced dissolved oxygen levels throughout the water column whereas in 2004, the dissolved oxygen was not depleted below 5 mg/L until a depth of 3 metres. However, in both years, the dissolved oxygen levels were restored once the ice was off the lake and the lake was once again open to the atmosphere. Temperature and dissolved oxygen profiles did show that Good Spirit Lake is well mixed throughout the water column.

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. In 2003, the conductivity for the baseline station on Good Spirit Lake ranged from 950 to 1,186 µS/cm (Tables 2 and 3) at the surface. In 2004, Good Spirit Lake conductivity ranged from 930 to 1,266 µS/cm (Tables 4 and 5) at the surface.

The secchi disk 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 1.2 m. In Good Spirit Lake, secchi disk readings were similar in 2003 and 2004, ranging between 0.3 and 0.6 meters (Tables 2 and 4). Limited secchi depth is primarily affected by lake turbidity.

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. Good Spirit Lake is an exposed, shallow lake with a sandy bottom. During the open water seasons of 2003 and 2004 turbidity values ranged between 10.52 and 43.80 NTU. Agitation of the lake bottom by wind and wave action may be one contributing factor to the high turbidity levels and reduced secchi disk readings experienced in Good Spirit Lake.

5.2 Good Spirit Lake Water Quality Index

The Water Quality Index (WQI) value for Good Spirit Lake ranged from 69.6 to 91.8 giving the lake a rating of fair to good (Figure 2). Of the 17 parameters that were measured pH, TDS, and total phosphorous exceeded the WQI objectives the most.

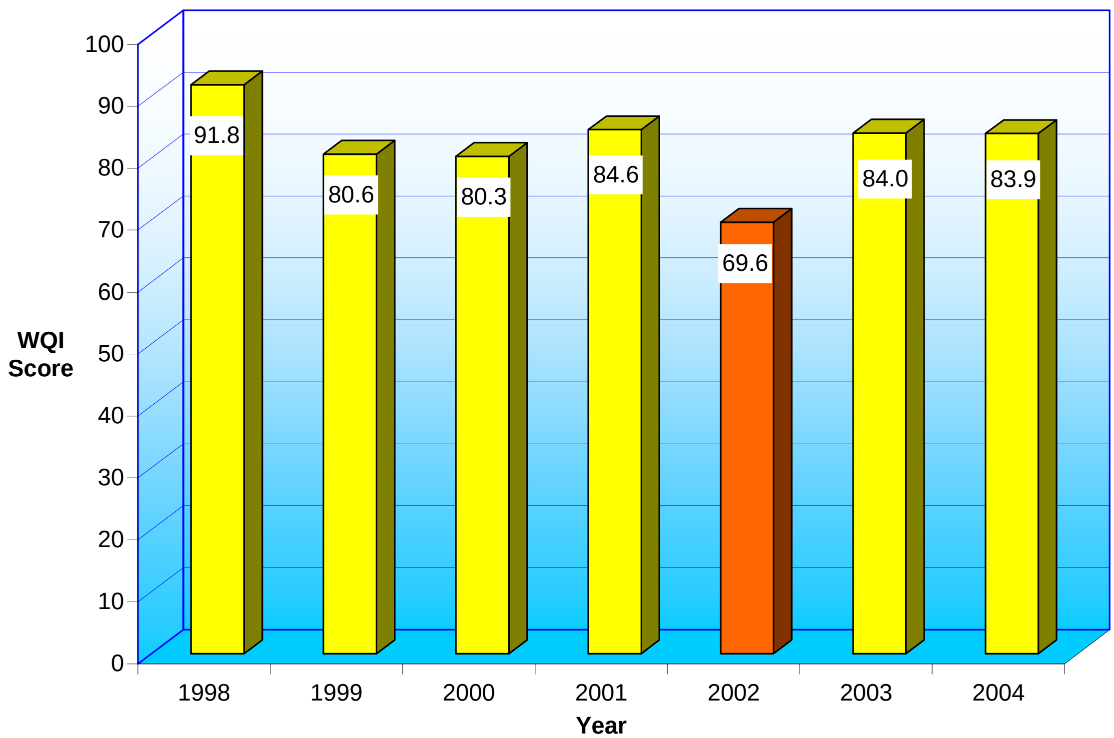

Figure 2 Good Spirit Lake Water Quality Index Score for 1998 - 2004

Good Spirit Lake has fair to good water quality. In all monitored years, with the exception of 2002, Good Spirit Lake had good water quality. Good water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels. The WQI was consistently triggered by three parameters: pH, total dissolved solids (TDS), and total phosphorus. These parameters showed only marginal deviations from the WQI objectives. As a result, the WQI score was maintained relatively constant between 80.3 and 91.8.

The Saskatchewan *Surface Water Quality Objectives* (1997) sets a pH range of 6.5 to 8.5 as optimal for surface waters. In the last seven years the pH of Good Spirit Lake has ranged from 7.45 to 9.10. In 2003, Good Spirit Lake's pH ranged from 7.9 to 8.9 (Table 6) and from 8.1 to 8.9 in 2004 (Table 6).

Cations (calcium magnesium, sodium, and potassium) and their associated anions (bicarbonate, sulphate, and chloride) are the main ions which contribute to the total dissolved solids (TDS) of a water supply. The quantity 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 additions. A high mineral concentration can restrict the use of the water, depending on the specific minerals present and their individual concentration. The Saskatchewan *Surface Water Quality Objectives* (1997) recommends TDS below 1,000 mg/L for livestock watering and 700 mg/L for irrigation. The water quality objective for TDS is 700 mg/L. Total dissolved solid concentrations ranged between 791 to 1,071 mg/L in Good Spirit Lake (Tables 6 and 7) in 2003 and 2004.

In Saskatchewan, the bacteriological quality of the water is assessed using traditional bacterial indicators such as fecal streptococci or fecal and total coliforms. Fecal coliform bacteria are present in the lower intestine of warm blooded animals and are rare in unpolluted waters; their presence is used as an indicator of sewage or human fecal contamination. For contact recreation, the Province sets water quality objectives using fecal coliform bacteria as an indicator of microbial water quality. For contact recreation, the Saskatchewan *Surface Water Quality Objectives* (1997) state that the density of fecal coliform bacteria should not exceed 200 organisms per 100mL of water. Since 1998, only one sample taken July 17, 2002 exceeded the objective with 410 orgs/100mL. The following sample collected on September 3, 2002 showed fecal coliform bacteria levels were well below the objective at 40 orgs/100mL. This peak may have resulted from a bird or animal defecation or other such natural processes. All other samples collected have had less than 50 orgs/ 100mL. As a result, Good Spirit Lake has good bacteriological water quality for contact recreation.

In 2002, the WQI score decreased to 69.6 triggered by five parameters: pH, TDS, total phosphorus, fecal coliform bacteria, and chlorophyll *a*. Similar to previous years, pH and TDS values slightly exceeded WQI objectives. Samples collected in September and October exceeded the WQI total phosphorus objective of 0.1 mg/L, with values of 0.17 and 0.13 mg/L respectively. The objective for fecal coliform bacteria for contact recreation is 200 organisms per 100mL of water (200 orgs/100mL). The 2002 July sample was 410 orgs/100mL. Chlorophyll *a* levels in October were 71.97 µg/L which exceeded the WQI objective of 50 µg/L.

In 2004, water quality samples where collected from the surface, integrated, and bottom of the water column to assess the variation within the water column (Tables 7 to 11). Results showed that there were no significant difference in water quality parameters measured at the top, integrated, and bottom of the water column. Surface samples were indicative of conditions throughout the water column and consequently, may be used to assess lake water quality. In 2005, only surface water sampling will be resumed at the baseline station to maintain monitoring activities while minimizing associated cost and time constraints.

6.0 Discussion and Recommendations

Good Spirit Lake has good quality water which meets the Saskatchewan Surface *Water Quality Objectives* (1997) for contact and non-contact recreation. Good Spirit Lake did not experience summer stratification and was well-mixed with temperature and dissolved oxygen conditions maintained throughout the water column. During the open water season dissolved oxygen concentrations were maintained at concentrations sufficient to protect fish populations and other aquatic life. In 2004, winter dissolved oxygen levels are greater than 5 mg/L required for the protection of aquatic life.

Good Spirit Lake has good quality water which should be preserved for the enjoyment of future generations. Residents and other lake users who are interested in the preservation and enhancement of Good Spirit Lake are encouraged to become actively involved in the *Friends of Good Spirit Lake*. 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. This handbook provides excellent tips and facts focused on shoreline landscaping, erosion, construction, and septic systems.

7.0 References

Kipp, Sarah & Callaway, Clive. (2003). *On The Living Edge: Your Handbook For Waterfront Living.* Saskatchewan/Manitoba Edition. Federation of British Columbia Naturalist: British Columbia.

Wetzel, Robert G. (2001). *Limnology: Lake and River Ecosystems, 3rd Edition.* Academic Press: San Diego, CA.

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)	6.5-8.5
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 Coliforms (units/100mL)	200
Total Phosphorus (mg/L)	0.1
Dissolved Nitrate & Nitrite (mg/L)	1
Total Dissolved Solids (mg/L)	700
Chlorophyll *a* (µg/L)	50

Table 2 Field Measurements at Good Spirit Lake Baseline Site, 2003

Field Data	Feb 17	May 20	July 9	Aug 19	Oct 15
Surface Parameters					
Air Temperature (ºC)	-15	na	16	na	6
Water Temperature (ºC)	0.4	11.7	18.4	24.4	7.6
Dissolved Oxygen (mg/L)	3.13	8.70	7.30	8.34	9.31
pH (pH units)	7.45	8.51	8.82	9.07	8.98
Conductivity (µS/cm)	1,186	950	974	1,040	965
Secchi Disk (meters)	na	0.60	0.40	0.40	0.40
Turbidity (NTU)	4.62	10.52	15.30	15.80	22.00

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

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
17/02/03	0	3.13	0.4	1,186
	1	2.81	0.6	1,208
	2	2.60	2.6	1,197
	3	2.16	2.9	1,196
	4	2.45	4.0	1,202
20/05/03	0	8.70	11.7	950
	1	8.70	11.6	950
	2	8.79	11.6	951
	3	8.68	11.6	952
	4	8.60	11.6	952
09/07/03	0	7.30	18.4	974
	1	7.20	18.4	974
	2	6.96	18.4	974
	3	7.23	18.4	974
	4	6.98	18.4	974
19/08/03	0	8.34	24.4	1,040
	1	8.06	24.0	1,039
	2	6.95	23.6	1,039
	3	6.47	23.3	1,041
	4	5.70	23.1	1,042
15/10/03	0	9.31	7.6	965
	1	9.27	7.5	966
	2	9.42	7.5	967
	3	9.26	7.5	967
	4	9.41	7.5	967

Table 4 Field Measurements from Good Spirit Lake Baseline Station, 2004

Field Data	March 2	May 25	July 12	Aug 31	Nov 3
Surface Parameters					
Water Temperature (ºC)	0.3	8.1	20.1	14.1	2.4
Dissolved Oxygen (mg/L)	6.62	10.19	8.90	7.91	13.55
pH (pH units)	na	na	na	8.8	8.3
Conductivity (µS/cm)	1,266	946	942	930	1,018
Secchi Disk (meters)	na	0.5	0.4	0.3	0.3
Turbidity (NTU)	2.6	na	18.5	43.8	39.8

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

Date (d/m/y)	Depth (m)	Dissolved Oxygen (mg/L)	Water Temperature (ºC)	Conductivity (µS/cm)
2/3/04	0	6.62	0.3	1,266
	1	6.68	0.5	1,267
	2	5.92	2.9	722
	3	2.95	3.7	745
	4	1.95	4.6	800
25/5/04	1	10.19	8.1	946
	2	10.25	8.2	946
	3	10.29	8.1	946
	4	10.25	8.1	946
12/7/04	0	8.90	20.1	942
	1	8.69	19.8	942
	2	8.41	19.7	943
	3	8.49	19.6	943
	4	4.75	18.8	950
31/8/04	0	7.91	14.1	930
	1	7.87	14.3	931
	2	7.60	14.3	931
	3	7.81	14.3	931
	4	7.45	14.3	931
3/11/04	0	13.55	2.4	1,018
	1	13.60	2.3	1,020
	2	13.33	2.3	1,029
	3	13.02	2.3	1,034
	4	13.23	2.3	1,035

Table 6 Summary of Good Spirit Lake Baseline Surface Parameters, 2003

Parameters	Feb 17	May 20	July 9	Aug19	Oct 15
Nutrients (mg/L)					
Dissolved Organic Carbon	37	28	20	30	29
Nitrate, as Nitrogen	0.04	0.02	<0.02	<0.04	0.02
Ammonia, as Nitrogen	0.57	0.17	0.04	0.03	0.03
Total Kjedahl Nitrogen	2.9	3.0	3.3	3.5	3.3
Total Phosphorous	0.04	0.09	0.10	0.10	0.15
Ortho-Phosphate, as P	<0.02	<0.02	0.03	0.05	0.06
Solids (mg/L)					
Total Dissolved	1,008	791	818	792	847
Suspended, Fixed	1	8	9	6	16
Suspended, Volatile	4	21	32	32	36
Suspended, Total	4	29	41	38	52
Bacteria (orgs/100 mL)					
Fecal Coliform	<10	10	<10	<100	30
Fecal Streptococci	<10	160	80	<100	100
Total Coliform	<10	20	<100	<100	200
Major Ions (mg/L)					
Alkalinity, Total	292	234	248	224	234
Alkalinity, Phenol	na	10	16	28	18
Bicarbonate	356	261	264	205	242
Calcium	51	42	40	33	34
Carbonate	na	12.0	19.2	33.6	21.6
Chloride	10	7	7	10	9
Hardness, Total	654	508	516	519	538
Iron	<0.100	na	0.039	0.023	0.041
Magnesium	128	98	101	106	110
Manganese	0.040	na	0.025	na	0.019
Potassium	33	25	26	27	28
Sodium	30	24	24	27	28
Sulphate	433	322	337	350	374
Other					
Chlorophyll *a* (µg/L)	3.00	na	<0.20	13.91	30.21
Conductivity (µS/cm)	1,211	1,026	1,111	1,044	1,084
pH (pH units)	7.9	8.5	8.7	8.9	8.8
Turbidity (N.T.U.)	na	20.80	16.24	15.23	20.00
Biochemical Oxygen Demand (mg/L)	na	3.3	3.8	2.7	4.6
Chemical Oxygen Demand (mg/L)	na	100	126	128	134
Metals					
Preserved Mercury (µg/L)	<0.05	na	na	<0.05	<0.05
Aluminum (mg/L)	<0.005	na	na	<0.005	<0.005
Arsenic (mg/L)	na	na	na	0.003	0.003

Table 7 Summary of Good Spirit Lake Baseline Surface Parameters, 2004

Parameters	Mar 2	May 25	July 12	Aug 31	Nov 3
Nutrients (mg/L)					
Dissolved Organic Carbon	41.0	29.3	31.7	26.5	29.8
Nitrate, as Nitrogen	0.03	<0.04	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.54	0.05	0.05	0.08	0.08
Total Kjedahl Nitrogen	3.3	2.8	3.4	3.4	4.3
Total Phosphorous	0.08	0.09	0.10	0.14	0.17
Ortho-Phosphate, as P	0.06	<0.02	0.02	0.03	0.05
Solids (mg/L)					
Total Dissolved	1,071	825	804	817	886
Suspended, Fixed	1	9	10	19	20
Suspended, Volatile	4	27	33	66	56
Suspended, Total	5	36	43	84	76
Bacteria (orgs/100 mL)					
Fecal Coliform	<2	<10	<10	40	10
Fecal Streptococci	<10	20	<10	50	na
Total Coliform	4	<10	<100	200	10
Major Ions (mg/L)					
Alkalinity, Total	296	226	228	234	242
Alkalinity, Phenol	na	14	24	20	10
Bicarbonate	361	242	220	237	271
Calcium	48	37	37	35	39
Carbonate	na	16.8	28.8	24.0	12.0
Chloride	13.0	9.6	9.6	9.5	10.6
Hardness, Total	758	545	529	532	579
Magnesium	155	110	106	108	117
Potassium	39	27	26	27	29
Sodium	34	25	24	24	26
Sulphate	421.0	357.1	352.3	352.9	381.1
Other					
Chlorophyll *a* (µg/L)	2.09	35.55	4.45	41.96	7.44
Conductivity (µS/cm)	1,390	1,048	1,038	1,048	1,080
pH (pH units)	8.1	8.6	8.9	8.8	8.6
Turbidity (N.T.U.)	1.7	10.0	16.0	38.0	38.0
Biochemical Oxygen Demand (mg/L)	<2.0	3.7	3.9	4.3	4.1
Chemical Oxygen Demand (mg/L)	114	125	125	162	163
Metals					
Preserved Mercury (µg/L)	na	na	<0.02	na	na
Aluminum (mg/L)	na	na	<0.02	na	na
Arsenic (mg/L)	na	na	0.001	na	na

Table 8 May 25, 2004 Good Spirit Lake Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	**May 25**		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	29.3	29.8	29.7
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.05	0.05	0.06
Total Kjedahl Nitrogen	2.8	3.1	2.7
Total Phosphorous	0.09	0.14	0.09
Ortho-Phosphate, as P	<0.02	<0.02	<0.02
Solids (mg/L)			
Total Dissolved	825	831	820
Suspended, Fixed	9	9	8
Suspended, Volatile	27	29	28
Suspended, Total	36	38	36
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	<10	<10
Fecal Streptococci	20	<10	<10
Total Coliform	<10	<10	<10
Major Ions (mg/L)			
Alkalinity, Total	226	224	224
Alkalinity, Phenol	14	14	14
Bicarbonate	242	239	239
Calcium	37	38	37
Carbonate	16.8	16.8	16.8
Chloride	9.6	9.9	9.4
Hardness, Total	545	564	554
Magnesium	110	114	112
Potassium	27	29	28
Sodium	25	26	25
Sulphate	357.1	357.8	352.4
Other			
Chlorophyll *a* (µg/L)	35.55	38.41	40.39
Conductivity (µS/cm)	1,048	1,049	1,049
pH (pH units)	8.6	8.6	8.6
Turbidity (N.T.U.)	10.0	8.8	8.8
Biochemical Oxygen Demand (mg/L)	3.7	2.0	4.3
Chemical Oxygen Demand (mg/L)	125	128	121

Table 9 July 12, 2004 Good Spirit Lake Comparison Between Surface, Integrated, and Bottom Parameters

	July 12		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	31.7	30.6	30.5
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.05	0.04	0.04
Total Kjedahl Nitrogen	3.4	3.5	3.4
Total Phosphorous	0.10	0.11	0.14
Ortho-Phosphate, as P	0.02	<0.02	0.02
Solids (mg/L)			
Total Dissolved	804	801	807
Suspended, Fixed	10	12	18
Suspended, Volatile	33	32	43
Suspended, Total	43	44	62
Bacteria (orgs/100 mL)			
Fecal Coliform	<10	<10	<10
Fecal Streptococci	<10	<10	30
Total Coliform	<100	<100	<100
Major Ions (mg/L)			
Alkalinity, Total	228	228	230
Alkalinity, Phenol	24	24	21
Bicarbonate	220	220	229
Calcium	37	37	38
Carbonate	28.8	28.8	25.2
Chloride	9.6	9.7	9.6
Hardness, Total	529	533	531
Magnesium	106	107	106
Potassium	26	26	26
Sodium	24	24	24
Sulphate	352.3	348.4	349.5
Other			
Chlorophyll *a* (µg/L)	4.45	11.25	8.87
Conductivity (µS/cm)	1,038	1,040	1,043
pH (pH units)	8.9	8.8	8.8
Turbidity (N.T.U.)	16	16	22
Biochemical Oxygen Demand (mg/L)	3.9	3.7	5.5
Chemical Oxygen Demand (mg/L)	125	126	139
Metals			
Preserved Mercury (µg/L)	<0.02	<0.02	<0.02
Aluminum (mg/L)	<0.02	0.02	0.02
Arsenic (mg/L)	0.001	0.001	0.001

Table 10 August 31, 2004 Good Spirit Lake Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	**August 31**		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	26.5	24.0	23.5
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.08	0.06	0.08
Total Kjedahl Nitrogen	3.4	3.6	3.4
Total Phosphorous	0.14	0.14	0.15
Ortho-Phosphate, as P	0.03	0.03	0.03
Solids (mg/L)			
Total Dissolved	817	821	819
Suspended, Fixed	19	19	22
Suspended, Volatile	66	64	60
Suspended, Total	84	83	82
Bacteria (orgs/100 mL)			
Fecal Coliform	40	<10	10
Fecal Streptococci	50	30	10
Total Coliform	200	20	20
Major Ions (mg/L)			
Alkalinity, Total	234	234	232
Alkalinity, Phenol	20	22	22
Bicarbonate	237	232	229
Calcium	35	35	35
Carbonate	24.0	26.4	26.4
Chloride	9.5	9.6	9.7
Hardness, Total	532	536	536
Magnesium	108	109	109
Potassium	27	27	27
Sodium	24	25	25
Sulphate	352.9	357.3	357.4
Other			
Chlorophyll *a* (µg/L)	41.96	49.38	53.30
Conductivity (µS/cm)	1,048	1,046	1,047
pH (pH units)	8.8	8.8	8.8
Turbidity (N.T.U.)	38	37	37
Biochemical Oxygen Demand (mg/L)	4.3	4.4	4.5
Chemical Oxygen Demand (mg/L)	162	160	157

Table 11 November 3, 2004 Good Spirit Lake Comparison Between Surface, Integrated, and Bottom Parameters

Parameters	**November 3**		
Nutrients (mg/L)	**Surface**	**Integrated**	**Bottom**
Dissolved Organic Carbon	29.8	30.3	30.8
Nitrate, as Nitrogen	<0.04	<0.04	<0.04
Ammonia, as Nitrogen	0.08	0.09	0.06
Total Kjedahl Nitrogen	4.3	4.1	4.3
Total Phosphorous	0.17	0.18	0.17
Ortho-Phosphate, as P	0.05	0.06	0.05
Solids (mg/L)			
Total Dissolved	886	874	874
Suspended, Fixed	20	24	18
Suspended, Volatile	56	58	60
Suspended, Total	76	82	78
Bacteria (orgs/100 mL)			
Fecal Coliform	10	10	10
Total Coliform	10	<10	10
Major Ions (mg/L)			
Alkalinity, Total	242	242	242
Alkalinity, Phenol	10	10	10
Bicarbonate	271	271	271
Calcium	39	38	38
Carbonate	12	12	12
Chloride	10.6	10.2	10.2
Hardness, Total	579	573	564
Magnesium	117	116	114
Potassium	29	29	28
Sodium	26	26	26
Sulphate	381.1	372.0	374.4
Other			
Chlorophyll *a* (µg/L)	7.44	20.78	20.78
Conductivity (µS/cm)	1,080	1,081	1,081
pH (pH units)	8.6	8.6	8.6
Turbidity (N.T.U.)	38	40	37
Biochemical Oxygen Demand (mg/L)	4.1	4.2	4.2
Chemical Oxygen Demand (mg/L)	163	161	163

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. 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* which is 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 Transparency 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. Total Dissolved Solids (TDS) - 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. Total Suspended Solids (TSS) - 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. Total Hardness - 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. Salinity - 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.