2005 Windermere Lake Water Quality Monitoring Program and Literature Review

Prepared for:
Regional District of East Kootenay
19-24th Avenue South
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November 9, 2005

Regional District of East Kootenay
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Attention: Mr. Stephen McInnis, Manager of Engineering and Environmental Services

RE: Windermere Lake Water Quality Literature Review 2005

Dear Mr. Stephen McInnis,

Please find attached four hard copies of the Lake Windermere Water Quality Literature Review - 2005. The following report provides a review, summary and consolidation of existing Windermere Lake water quality literature. Trends and changes in water quality over the last several years are identified within the report. Recommendations for further sampling are based on developing and implementing a five-year community based water quality monitoring program.

If you have any comments or questions, please do not hesitate to contact us.

Sincerely,
Masse & Miller Consulting Ltd.

Sylvie Masse, M.Sc., R.P.Bio.

Heidi McGregor, B.Sc.

Executive Summary

Masse & Miller Consulting Ltd. was retained by the Regional District of East Kootenay (RDEK) to conduct a review, summarization and consolidation of existing water quality literature on Lake Windermere, as well as, provide recommendations for future sampling. Recommendations for future sampling will be integrated within the Healthy Water for Healthy Communities – Lake Windermere (HWHC) project, which was spearheaded by Wildsight (formerly East Kootenay Environmental Society).

This study provides the RDEK, Wildsight and stakeholders with a data collection and sampling regime to monitor Windermere Lake over the next 5 years through the HWHC project. Past and future sampling locations, sampling frequency, sampling methods, sampling protocols, and sample analysis criteria are presented. Trends and changes in water quality over the last several years are identified within the report.

Upland and foreshore development is concentrated at the north end of the lake both on the west side in the District of Invermere and on the east side within the Regional District of East Kootenay. Development on the east side of the lake is serviced almost exclusively by septic systems. Many of these systems are located on soils with limited or poor capability to support septic systems (Urban Systems 2001). Water quality monitoring will be site specific to address historical concerns and shoreline land use issues.

The natural characteristics within the Windermere Lake watershed are important factors that must be included in the interpretation of data. The rapid flushing period of 47 days, high winds and shallow depth with no evidence of seasonal stratification influence the lake's overall sensitivity to additional inputs of nutrients.

Previous water quality studies of Windermere Lake indicate that there is a trend towards eutrophication of the lake. Water quality data collected during the 1980's showed that the lake was oligotrophic (McKean and Nordin 1983), however, further studies conducted in 1999 showed an increase in nutrients within the lake indicating a mesotrophic status (Courtney 1999). Potential causes of the increases include foreshore development at the north end of the lake, contamination from septic fields, surface runoff from urbanization, boating and recreational activities on the lake, and operation of nearby golf courses. Further studies are required to identify the major causes of changes in water quality in Windermere Lake. With the increase in lake nutrients, one would expect an increase in macrophyte productivity. The study conducted in 1999 (Courtney) could not ascertain the expansion of macrophyte beds as most of the beds visible in the air photos were located at the south end of the lake away from most of the developments.

The following summary of goals and recommendations should be considered for inclusion in the future monitoring of Windermere Lake:

- Assess the current condition of Windermere Lake;
- Inform local residents of the condition of the water quality within the lake; and
- Present a monitoring program that follows up on past monitoring focusing on productivity levels, water quality trends, and assessing possible natural and human impacts on the lake. A quality assurance component is included to confirm accuracy of the datasets and maintain consistency with past data methods.

Priority monitoring:

- Monitor the three historical lake sample sites immediately after ice melt and continue monthly through high use periods. Weekly monitoring should occur from mid July to end of August. Parameters of priority are nutrients, dissolved oxygen, temperature, pH, conductivity, clarity, turbidity, chlorophyll *a,* hardness, total sulphide, and sulphate.
- Monitor recreational beaches at minimum Windermere, Athalmer (James Chabot Provincial Park) and Invermere for bacteriology 5 times in 30 days during high use in August. Continued monitoring over high use periods should occur every two weeks.

Additional monitoring

- Monitoring representative water intakes during the winter would be beneficial in determining seasonal fluctuations. Samples should be collected monthly from January to April and must be collected within the system prior to treatment. Parameters of priority are nutrients, temperature, pH, conductivity, total sulphide, sulphate and bacteriology.
- Windermere Creek and the Columbia River inflow should be monitored to determine the extent of variation between inflows and lake water quality. Parameters of priority are nutrients, bacteriology, dissolved oxygen, temperature, pH, conductivity, total sulphide, sulphate and turbidity.
- Eurasian water milfoil should be periodically checked when out sampling.
- An aerial photograph should be taken at least every 5 years to monitor the extent of macrophyte growth.
- If nutrient and water intake monitoring indicates elevated levels a follow up fluorescence survey should be conducted to determine the source of septic inflows into the lake.
- Chlorophyll *a* should be monitored during the summer in August.

Acknowledgements

The authors would like to thank Mr. Stephen McInnis, Manager of Engineering and Environmental Services and Mr. Brian Funke both of RDEK for their assistance during this project. Ms. Jolene Raggett, Ministry of Environment, provided water quality data from the 2002-2003 Upper Columbia Water Monitoring program. Ms. Raggett and Ms. Amanda Fedrigo of Wildsight reviewed the draft report and provided comments and recommendations.

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1 Introduction

Masse & Miller Consulting Ltd. was retained by the Regional District of East Kootenay (RDEK) to conduct a review, summarization and consolidation of existing water quality literature on Windermere Lake, as well as, provide recommendations for future sampling. Recommendations for future sampling will be integrated within the Healthy Water for Healthy Communities – Lake Windermere (HWHC) project, which was spearheaded by Wildsight (formerly East Kootenay Environmental Society) with assistance from local stakeholders.

Windermere Lake has also been recently selected as a pilot project to undergo a Source to Tap Assessment designed by the Ministry of Environment. The primary objective of this assessment is to identify hazards and vulnerabilities of the water supply and to recommend risk management actions to address them (Ministry of Health and Ministry of Environment 2005).

Windermere Lake is an important water source and recreational feature in the East Kootenays. The lake's 36 km shoreline and warm water temperatures make this lake attractive to Calgary cottagers and tourists throughout the summer months. Tourism derived from the lake is part of the growing local economy and the density of residential dwellings along the lake's shoreline is increasing. This community's dependence on the lake for drinking water and recreation has brought forward concerns about the impacts from human activities, and hence, various monitoring efforts have taken place in the past to assess the aquatic health and the state of water quality within Windermere Lake.

Water quality is the basic gauge for measuring aquatic health and ecosystem integrity. A community based monitoring program will capture valuable water quality data within Windermere Lake and develop aquatic knowledge within the local community. A successful program must take into account past data and must incorporate current issues into a comprehensive monitoring program. These assets will translate into more informed land use management and sustainable user based action.

1.1 Project Overview and Scope

This study will provide the RDEK, Wildsight and stakeholders with a data collection and sampling regime to monitor Windermere Lake over the next 5 years through the HWHC project. Past and future sampling locations, sampling frequency, sampling methods, sampling protocols and guidelines, and sample analysis criteria are presented herein. Trends and changes in water quality identified in previous reports are also presented.

Past monitoring programs have focused on determining water quality trends and assessing land use impacts. This report combines past water quality monitoring data and analysis to be incorporated into a community based water quality assessment initiative. The report reviews and summarizes past monitoring data and presents a recommended water monitoring program that can easily be implemented by local community groups.

2 Background

2.1 Location and Physical Characteristics

Windermere Lake is located in the Rocky Mountain Trench at 50 27'00" N and 115 59' 30" W and at an average elevation of 800 m. It is a large and shallow lake with a surface area of 1610 hectares. The lake is 17.7 km long with a mean depth of 3.4 m and a maximum depth of 6.4 m (Urban Systems 2001). It is located 3 hours from Calgary and 1.5 hours from Banff and Lake Louise. A map of Windermere Lake and surrounding area is provided in Figure 1.

Table 1. Windermere Lake physical characteristics (Urban 2001).

Volume	55.19×10^6 m^3
Surface Area	1,610 ha
Littoral Area	~ 1,530 ha
Drainage	1,340 km^2
Maximum Depth	6.4 m
Mean Depth	3.4 m
Length	17.7 km
Average Width	1.1 km
Shoreline perimeter	36.3 km

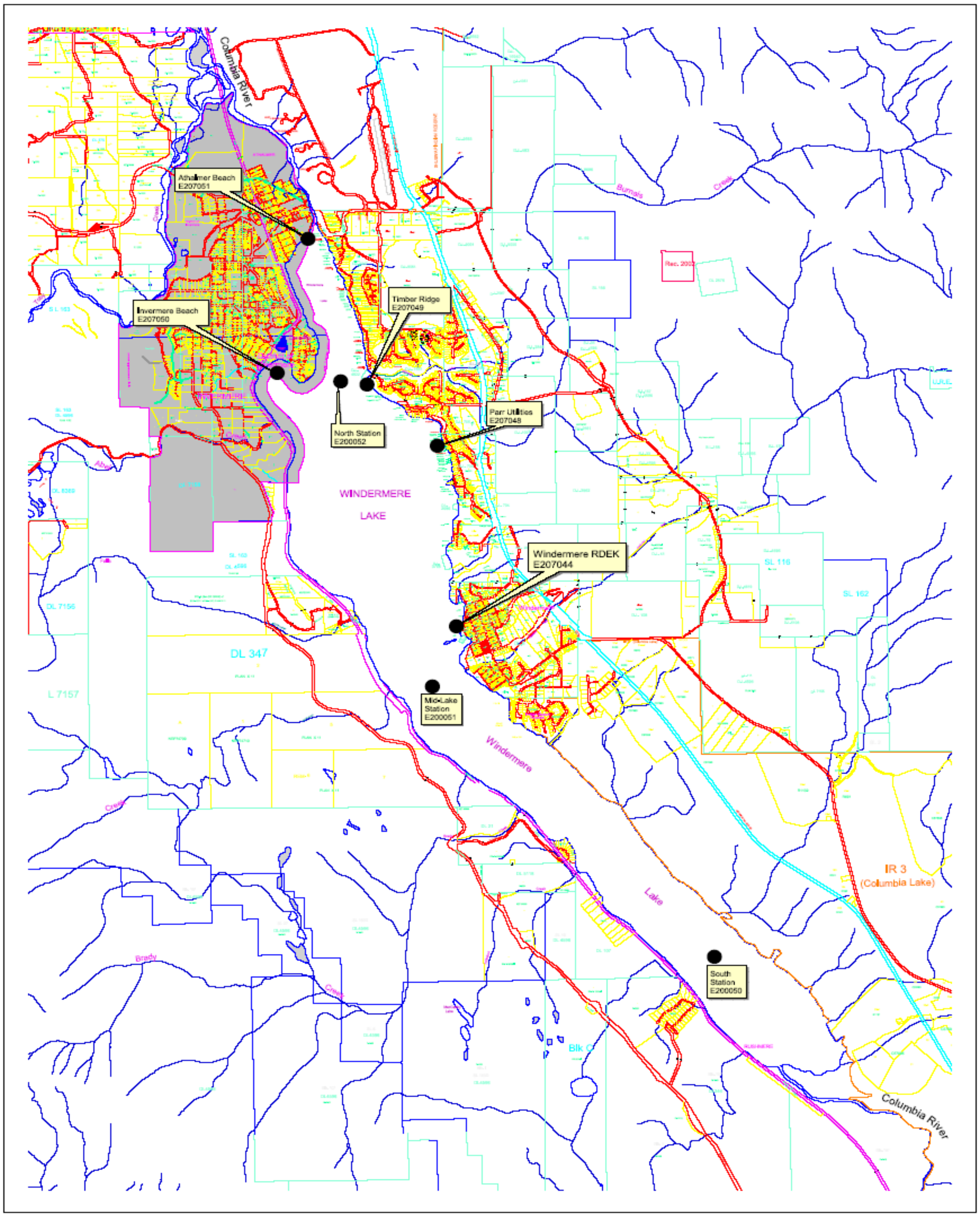
2.2 Hydrology and Watershed Physical Characteristics

Windermere Lake is characterized by a rapid flushing period of 47 days and due to the generally shallow depths it does not stratify during summer (Courtney 1999). Lake stratification is the separation of a lake into three layers; the epilimnion (top), metalimnion (middle), and the hypolimnion (bottom). Water reaches its densest form at 4oC and once surface water temperatures increase it forms a separate less dense layer at the top. Mixing of the layers occurs during the spring and fall as the water at the surface reaches 4oC forcing the entire water column to mix.

The main watersheds contributing water to Windermere Lake consist of the Columbia River, Windermere Creek, Madias Creek, Abel Creek, Goldie Creek, Johnston Creek and Holland Creek.

The Columbia River enters Windermere Lake at the south end and provides the majority of the inflow. This portion of the river connects Columbia Lake to Windermere Lake and, therefore, Columbia Lake's outflow is a factor in assessing the state of water quality entering Windermere Lake. McKean and Nordin (1985) found little difference except elevated turbidity levels between the water quality within this section of the Columbia River and Windermere Lake.

Figure 1. Map of Windermere Lake and surrounding area.



Windermere Lake - Water Quality Monitoring Program

● Monitoring Sites

North Station E200052
Mid-Lake Station E200051
South Station E200050
Athalmer Beach E207051
Invermere Beach E207050
Timber Ridge E207049
Parr Utilities E207048
Windermere RDEK E207044

Scale 1:50000

500 0 500 Meters

Mapping by: Masse & Miller Consulting Ltd.

November 9, 2005

N W E S

Another tributary entering this section of the Columbia River is Fairmont Creek. It drains a small area (6.5 km2) on the western slope of Fairmont Ridge in the Stanford Range and enters the Columbia River 10 km upstream of Windermere Lake (McKean and Nordin 1985).

Windermere Creek drains 85 km^2 on the western slopes of the Stanford Range. The creek enters Windermere Lake at Windermere.

Madias Creek flows in a westerly direction and enters Windermere Lake at the southern tip of the lake. Abel Creek drains into Windermere Lake on the northwest shoreline 2 km from the lake's outflow and it is moderately steep with a uniform ditch like channel cross section (Griffith 1994). Goldie Creek is situated 2 km south of Abel Creek on the west side of Windermere Lake, with the lower end having lower gradients. Johnston Creek is situated on the southwest side of the lake and the creek runs through a swamp upstream of the railroad (Griffith 1995). Holland Creek drains into Windermere Lake on the northeast side and large sections of the creek dry up during low flows. Little information is available on the water quality within these creeks.

The relatively low basin elevation of tributary streams flowing into Windermere Lake and gentle topography surrounding the lake result in relatively small peak discharges (Westcott 2000), however, the Athalmer area is prone to flooding. Athalmer is located on the northwest side of the Lake in close proximity to the lake's point of outflow to the Columbia River. Water levels at this site have reached levels as high as 1.7 m above the winter water level (McKean and Nordin 1985). Water Survey of Canada operated a gauging station on the Columbia River at Athalmer (18NA004) in the past and due to flooding concerns in this area, they should be requested to resume monitoring water discharge at this site by freshet 2006. The data collected could also assist with the interpretation of water quality parameters within the monitoring program.

2.3 Fisheries

Windermere Lake has a high diversity of sport and coarse fish species present. Sport fish include: bull trout (*Salvelinus confluentus*), rainbow trout (*Oncorhynchus mykiss*), kokanee (*O. nerka*), mountain whitefish (*Prosopium williamsoni*), westslope cutthroat trout (*O. clarki lewisi*), burbot (*Lota lota*), dolly varden (*Salvelinus malma*), and largemouth bass (*Micropterus salmoides*). Coarse species include: chislemouth chub (*Acrocheilus alutaceus*), torrent sculpin, largescale sucker (*Catostomus macrocheilus*), northern sqawfish (*Ptychocheilus oregonensis*), pumpkinseed *(Lepomis gibbosus*), redside shiner (*Richardsonius balteatus*), sunfish (Lepomis sp.), and longnose sucker (*Catostomus catostomus*). Although there is a high diversity of fish in the lake the numbers are low. The competition by many coarse fish and the lack of recruitment habitat cause low fisheries productivity (Urban Systems 2001).

The Department of Fisheries and Oceans (DFO) has raised concerns about shoreline development impacts on the fish populations within Windermere Lake (pers. comm. Ms. Coopper). A number of properties have historically constructed retaining walls along the foreshore, affecting fisheries habitat, which is no longer an acceptable practice. DFO suggested that the development of a foreshore zoning plan would be beneficial and would identify the extent of acceptable development as well as provide restrictions within sensitive habitats. Furthermore the location of critical fish habitat has not yet been identified and should be located.

2.4 Forestry

Monitoring data relating harvesting activities with the state of water quality is limited within the inflowing watersheds. Westcott's 1999 report reviews possible forestry impacts on Windermere Creek. The stream channel was reported to be disturbed in areas, which was the result of both natural processes and anthropogenic activities. Anthropogenic activities included cutblocks, logging roads, gavel pits and the clearing of riparian vegetation. Activities in the upper watershed were found to have no significant impacts on the middle or lower watershed due to flows going subsurface at mid elevations.

2.5 Mining

Mining activity has occurred within the Columbia Valley since the 1860s. Gypsum mining is occurring in the Windermere Creek drainage, with annual production rates of 500,000 tons, and the a grand total production to date of 14,000,000 million tons (Westcott 1999).

Mining activities within Jumbo Creek and Toby Creek include the old Mineral King Mine and the old Paradise Mine. Water quality in both creeks was assessed in 1976 downstream of the mines and showed that there were little effects from the tailings (MoE 1981). Further sampling was conducted by MoE in 2002 and 2003, but results have not been released. Toby Creek enters the Columbia River downstream of Windermere Lake and therefore does not affect water quality in the lake. Little information is available on mining activity impacts on Windermere Lake's inflowing watersheds.

2.6 Recreational

Most of the properties along Windermere Lake's shoreline are privately owned. Public access points include Athalmer Beach within James Chabot Provincial Park, Invermere Beach, Windermere Beach, Kinsmen Beach, and Sunshine Ranch. The foreshore development includes private wharves, floating structures, marinas, swimming, fishing and boating (Urban Systems 2001).

The East side of Lake Windermere Foreshore Policy ensures that the lake remains a public resource and that providing access to waterfront residents and the community is important (Urban Systems 2001).

Heavy boat traffic occurs between July 10 and August 31 on Windermere Lake (Urban Systems 2001). Possible impacts from boating activities include increased turbidity levels, and fuel emissions and spills.

Several golf courses are located within the Windermere Lake area. The following golf courses are located upstream of the lake (from headwaters to south end of lake): Th'Flats (in Canal Flats), Fairmont Mountainside, Fairmont Riverside and Coy's. Adjacent to the lake are Windermere Valley and Copper Point, which may expand in future. Panorama's Grey Wolf golf course utilizes Toby Creek which drains directly into the Columbia Wetlands downstream of Windermere Lake. Golf courses can affect water quality and quantity of nearby streams with the use of fertilizers, pesticides, herbicides and irrigation requirements. This can affect water levels in local streams and/or water table, which could also affect water levels in the lake in the long term.

2.7 Agriculture

The undeveloped land on the east side of the lake beyond Highway 93/95 and most of the land on the west side of the lake is part of the Agricultural Land Reserve (ALR). Phosphorus loading and surface runoff from agricultural lands are potential sources of nutrients for the lake (Urban Systems 2001). Livestock can also affect water quality in nearby streams and the lake with increased erosion and bacteriological contamination. Proper management of livestock was recommended in the Lake Windermere Management Strategy report (Urban Systems).

2.8 Rail Line

Canadian Pacific Railway (CPR) owns many of the lots along the west side of Windermere Lake where the rail line is located, and subsequently control access to the lake along these sections.

2.9 Native Reserve

Five bands are located within the traditional territory of the Ktunaxa Kinbasket Tribal Council in the Columbia Valley. The Columbia Lake Indian Reserve #3 is situated along the southeast quarter of the shoreline. The Columbia Lake and Shuswap bands have communities within the inflowing watershed land. First Nation concerns revolve around environmental, socio-economic, heritage and treaty negotiation-related issues (MoF 1995).

2.10 Water Use

Windermere Lake is used for domestic consumption, industrial use, irrigation, fisheries and recreation. There are currently a total of 36 water licenses on Windermere Lake. This water is drawn from the lake for irrigation, land improvement, water intakes and domestic supply. A list of water licenses is included in Appendix 1 of this report.

3 Literature Review

Various studies have been conducted over the years on Windermere Lake. Water quality monitoring was completed over several years from 1971 to 1989 by the Ministry of Environment (MoE 1981; McKean and Nordin 1983), as well as in 1999, which was mandated by the Regional District of East Kootenay (Courtney). Three mid lake stations have been established since 1971 with surface and near bottom samples collected at each site. These sites include the North Station (200052), Mid-Lake Station (200051) and South Station (200050). Due to concerns of potential leachate originating from foreshore developments a lake leachate detection study was conducted in 1985 with a fluorometer system (Wiens and Noone 1987). A sediment core was obtained from the Windermere Lake substrate in 1998 to assess historical changes in algal communities (McDonald 2000). Furthermore a Management Strategy for the lake was developed in 2001 to address the growing concerns due to accelerated development around the lake (Urban Systems). More recently, samples were collected by the MoE at three water intakes in 2002 and 2003, however, this data has not been released. The following section provides a summary for each report. References are listed sequentially based on publication date.

Ministry of Environment. 1981. Kootenay Air and Water Quality Study Phase II. Water Quality in the Upper Columbia River Basin. Aquatic Studies Branch. Victoria B.C.

MoE's Kootenay Air and Water Quality Study Phase II report summarizes historical water quality data in Windermere Lake and its tributaries. This report focuses on datasets from provincial monitoring sites collected from 1975 to 1978. Windermere Lake was found to contain clear, well oxygenated water, low in nutrients and with low biological productivity.

Localized water quality hotspots were identified and as of 1978 the only significant discharge of effluent into the Columbia River was from the Radium Waterworks District's sewage treatment plant at Radium Hot Springs. This discharge is located downstream from Lake Windermere and therefore does not impact water quality within the lake.

The water quality in Fairmont Creek was found to be affected by effluents from Fairmont Hotsprings Resort's septic tank and sauna bath. The chlorinated hot spring swimming pool water discharged into Fairmont Creek was found to be hot, highly mineralized and very low in fecal coliforms. The septic tank effluent was high in fecal coliforms. However, these discharges were not considered a concern for water quality in Windermere Lake due to the high dilution capacity of the Columbia River entering the lake (MoE 1981). On the other hand, water quality monitoring in Fairmont Creek downstream of the resort resulted in concluding that the highly mineralized waters originating from the hot springs rendered lower Fairmont Creek unsuitable for domestic use, some industrial uses and for irrigation of some sensitive crops. The resort's effluent contained chlorine residual. Water quality levels downstream were also found to be unfit for aquatic life for a number of factors. Large increases in water temperature and precipitation of carbonates in the streambed and chlorine levels resulted in unsuitable water quality conditions for aquatic life downstream of the resort. High arsenic levels (up to 0.11mg/L) were also found in the hot springs and the MoE recommended an arsenic survey be conducted during low flows to determine their levels in the hot spring water and Fairmont Creek. They also recommended sampling for fecal coliforms and total chlorine residual during low flows downstream of the resort.

Windermere Creek was found to be very hard (415-855 mg/L CaCO3) and potentially unsuitable for domestic or some industrial uses. A maximum of 120 mg/L CaCO3 is recommended for consumption. Surface runoff from the Western Gypsum Ltd. gypsum quarry was found to enter the creek causing high levels of dissolved solids, hardness and sulphate.

Water quality in Windermere Lake was found to be alkaline and medium hard to hard. The waters were well oxygenated, clear, and very low in color, nutrients, suspended solids and turbidity. Chlorophyll *a* measurements suggested that Windermere Lake was oligotrophic and had low biological productivity.

McKean, C.J.P. and R.N. Nordin 1985. Upper Columbia Planning Unit Water Quality Assessment: Volume 1, Columbia and Windermere Lakes, Columbia River Between and Lakes and Windermere Creek. Resource Quality Section, Water Management Branch.

McKean and Nordin's 1983 report focused on the water quality within Columbia Lake, Windermere Lake, Toby Creek, and Windermere Creek from 1972 to 1983. Data collected within Windermere Lake demonstrated oligotrophic conditions. McKean and Nordin identified areas of concern along Windermere Lake as being questionable for development due to unstable soils and/or soils with unsuitable porosity for septic systems. An integrated assessment of both soils and water quality was incorporated into the analysis to account for the potential for input of nutrients, suspended sediments and fecal contaminants to the lakes.

The rating of soils for their potential to transmit phosphorus from septic tank drain fields to the lake was based on soil characteristics, existing on-site waste disposal facilities, and distance to the lake. The soils consisted mainly of fine textured lacustrine materials, which have low porosity and pose moderate constraints to use due to slow groundwater flow. The study concluded that most areas adjacent to Windermere Lake were unsuitable for septic tank absorption. The most important and common landscape limitations included soil perviousness, drainage, existing processes, steep slopes, high water table levels and groundwater contamination potential. An inspection of septic tank fields and a scan of the lakeshore between Windermere and Invermere with a fluorometer designed to detect septic plumes was recommended.

Monitoring results of Windermere Creek and inflows indicated that the nutrient loads from the septic tank discharges and agriculture within the Windermere Creek watershed were not influencing the water quality of the creek. Little information was available on the water quality from other small creeks entering Windermere Lake. The available data indicated that nitrogen and phosphorus concentrations in some creeks were slightly higher than in the lake itself, but because of the very small flows the effects on the lake were considered minimal.

The groundwater entering the lake on the east shore was sampled once with a groundwater sampler. Ammonia (918 ug/L) was the only high value detected. The pH values ranged from 7.6 to 8.8. Maximum pH values at all three lake sites exceeded the recommended range for Drinking Water Quality Guidelines - aesthetic objective set out by Health Canada. Additional sampling was recommended.

Additional monitoring of nitrogen and phosphorus originating from septic tile fields along the littoral of Windermere Lake was recommended due to their potential to increase algal and macrophyte growth. McKean and Nordin recommended future monitoring to include tissue, groundwater, and sediment sampling in areas influenced by septic effluent, and at several control sites. The determination of site locations was recommended by using the fluorometer method.

Fairmont Creek downstream of Fairmont Hotsprings and Windermere Creek downstream of the gypsum quarry were found to be questionable sources of domestic water. Fairmont Creek had high concentrations of calcium, magnesium, sulphate and possibly arsenic while Windermere Creek had high concentrations of calcium and sulphate. Both sources had hardness values that were considered poor to unacceptable for water consumption or use. Frequently sulphate levels exceeded the criteria for taste (150 mg/L) and occasionally for health (500 mg/L). McKean and Nordin recommended that hardness and sulphate be monitored at Windermere Creek and Fairmont Creek. In 1983 there were 5 domestic water licenses downstream of the gypsum quarry on Windermere Creek.

A review of chlorophyll *a* collected in 1976 and in 1982 clearly showed that Windermere Lake was oligotrophic. From this data McKean and Nordin developed a relationship between chlorophyll *a* and phosphorus. However, based on the phosphorus concentrations present in the lake, the model predicted higher chlorophyll *a* levels than what was present which was explained by the high flushing rate of the lake.

Wiens, J.H. and F.A. Noone. 1987. Windermere Lake Leachate Detection Study. Ministry of Environment and Parks, Waste Management Branch.

This report provides results of a leachate detection study that was completed on a portion of the east side of Windermere Lake. Portions of the developed shoreline of Windermere Lake were scanned with a fluorometer system to detect leachate inflows from onsite wastewater disposal. Site specific samples of near shore lake water were also obtained. The fluorometer method is based on the fluorescence properties of water and wastewater constituents, which are detected through the use of an ultra-violet light source and filtered to known wavelengths. Positive fluorometer responses were most frequent along the developed shorelines where the landscape unit was composed of lacustrine materials ranging in texture from silts to gravels. The coarser textured lacustrine deposits along the shoreline of Windermere Lake were found to contribute to the subsurface discharge of effluent into the lake.

Additional leachate detection surveys combined with groundwater flow directions were advised at this time. Wiens and Noone recommended sampling for water chemistry, and particularly sampling for fecal coliforms in future leachate detection studies.

Griffith, R. P. 1994. A Reconnaissance Survey of Windermere Lake. Report prepared for: Mica Fisheries Compensation Program, B.C. Hydro/ B.C. Environment.

The Reconnaissance Survey consisted of a fisheries inventory of tributary streams and Windermere Lake. The inventory included sampling for fish, water chemistry in the lake, and also addressed relevant enhancement/ management implications.

The most abundant species captured in the gill netting survey in Windermere Lake was Kokanee, but northern pikeminnow, bull trout, largemouth bass, burbot, and mountain whitefish were also captured. The authors concluded that the apparent abundance of kokanee seemed to discount any possibility of serious water quality constraints for salmonid production. Even though rainbow trout were periodically stocked, no rainbow trout were captured within the lake, which indicated low natural recruitment of this species.

Major tributary streams entering Windermere Lake were also surveyed and Windermere Creek was found to be the only significant system for fisheries values having a major spawning/recruitment area for kokanee. Rainbow trout and bull trout were also caught upstream of the kokanee spawning reach. A good westslope cutthroat trout population was sampled 3 km upstream of Windermere Lake in the Windermere Creek.

Rainbow trout and Eastern brook trout were caught in Abel Creek and a single brook trout and redside shiner were caught in Brady Creek. No fish were found in Johnston Creek, and Holland Creek and the eight unnamed tributaries had little to no fish habitat.

Griffith found the limitations to fisheries population growth could be due to the excessively steep and swift flows in accessible tributary streams further limiting spawning opportunities. The principle tributary sections for bull trout recruitment appeared to be Windermere Creek. No practical opportunities for enhancement were identified.

Courtney, R. F. 1999. Windermere Lake: Water Quality Monitoring Program. EnviResource Consulting. Report prepared for: Regional District of East Kootenay

This study included assessments of water quality and macrophyte abundance within Windermere Lake.

Water quality results indicated that Windermere Lake was becoming more eutrophic and the north end exhibited higher indices of increased eutrophication through oxygen, pH and total dissolved phosphorus readings.

Macrophyte abundance was compared using aerial photography dating from 1951 and 1995. Macrophyte beds appeared to be fairly constant throughout that period, however, the beds that were visible on the aerial photos were located at the south end of the lake away from development and may not be truly indicative of potential impacts on plant growth within the lake. The dataset established in this study provide useful background information on macrophyte abundance within Windermere Lake. Eurasian water milfoil population status was also assessed during this study and was not identified within Windermere Lake in 1999.

Recommendations for future sampling included top and near bottom samples for the North, Mid-Lake and South Stations, as well as the mouth of Windermere Creek. One pre-freshet and a minimum of four weekly mid-July to mid-August samples were recommended.

Westcott, F. 1999 Benthic Macroinvertebrates in Windermere Creek: Species Identification and Community Interpretation Fall 1998

The benthic invertebrate community structure was assessed in Windermere Creek in 1998. Westcott found the present combination of urban and industrial land uses within the Windermere Creek drainage were likely contributors to increased disturbances to the creek itself and may have synergistic effects on the benthic invertebrate communities, particularly at the creek mouth.

Westcott concluded Windermere Creek was slightly impacted at its mouth as species diversity and abundance both decreased in comparison to upper sections of the creek.

McDonald, L.E. 2000. Windermere Lake: Water Quality Changes Over the Past 300 Years as determined From a Bottom Sediment Core. British Columbia Ministry of Environment, Lands, and Parks, Pollution Prevention Kootenay Region.

A sediment core was obtained from Windermere Lake in 1998 and was analyzed for fossil algal remains. Analysis of the sediment core indicated a slow sedimentation rate within Windermere Lake. This was probably due to the rapid flushing rate of the lake and the presence of wetlands upstream of the lake trapping sediments otherwise destined for Windermere Lake.

Changes in the diatom communities within the core sample were found to correspond to an increase in settlement around the lake. A total of 1290 lots were subdivided on the east side of the lake from 1940 to 1986, of which 623 (48%) were established between 1947 and 1957. The diatom community change observed in the core was not strong, however, it did suggest a subtle change in water quality, probably an increase in nutrients, and was circumstantially associated with accelerated settlement since 1950.

Furthermore the author found there had been a slight increase in algal production (eutrophication) since about 1960. Other changes in specific pigments indicated a shift in the algal community away from diatom dominance and toward green, blue-green and chrysophyte types over this period.

Westcott, F., M. Tilling and S. Masse, 2000. Water Resources Inventory Report: Physical, Chemical and Biological Characteristics of Windermere Creek, 1999

This study monitored four sites within the Windermere Creek watershed. Three sites were along the mainstem of Windermere Creek and one on a major tributary. The upstream mainstem site was located above the North Fork tributary, 10 km from the confluence with Windermere Lake. A second mainstem site was located 0.5 km from Windermere Lake, and the third just prior to its confluence with Windermere Lake. The fourth site was situated on the north tributary to Windermere Creek, just prior to its confluence with the mainstem.

Automated monitors were capturing water quality and quantity data at the three mainstem sites. Continuous parameters monitored at these sites included water temperature, turbidity, specific conductance, and water level.

Basic, which included water temperature, pH, conductivity and turbidity, and stratified samples, which included TSS, TDS, dissolved oxygen, hardness, alkalinity, nutrients and dissolved metals were collected at all three mainstem sites. Data analysis found Windermere Creek to be hard with high concentrations of calcium and magnesium. Conductivity levels were above the Water Quality Guidelines for Irrigation and total suspended solids (TSS) also exceeded the Water Quality Guidelines along the mainstem of Windermere Creek. Iron and dissolved aluminum sporadically exceeded the Freshwater Aquatic Life Guidelines at the North Fork and below mine sites. However, none of these elevated levels were evident health risks.

Fecal coliform samples exceeded Drinking Water Guidelines during spring and fall sampling. Fecal coliform counts were the highest at 0.5 km from Windermere Lake within the Town of Windermere. These results could have been caused by septic inflows, storm water runoff, or from domestic pets.

The change in benthic invertebrate species composition and abundance showed some indication that aquatic degradation was occurring at the lower site near the mouth.

The three hydrometric stations found Windermere Creek to have high flows in late May and early June with several distinct peaks. Fall and summer flows were unseasonably high in 1999 due to high levels of precipitation.

Urban Systems Ltd. 2001. Lake Windermere Management Strategy. Report prepared for: District of Invermere

Urban Systems Ltd. summarized monitoring results from 1971 to 1989 and 1999 and the lake's productivity and carrying capacity for development was determined. The document reviewed the status of Windermere Lake relating to water quality, lake habitat, weed growth, upland development, public access, and marinas and boat launches to determine the lake's carrying capacity to support additional development. The analysis incorporated trophic status, water quality sensitivity rating, chemical and physical analysis, water quality objectives, watershed characteristics, fisheries and aquatic plant data.

This report reviewed historical water quality data to assess the status of productivity within the lake. The trophic status was determined and historical data incorporated into the analysis. Chlorophyll *a* and phosphorus concentrations were the primary parameters used in this assessment and concluded that Windermere Lake was oligotrophic tending to mesotrophic.

Urban Systems concluded that weed growth within the lake was primarily due to the physical characteristics of the system. Windermere Lake has over 95% of its surface area at a depth that light can penetrate to a sufficient degree to support plant growth. This, coupled with frequent winds and adequate nutrients such as nitrogen and phosphorus, ensures that Windermere Lake is highly susceptible to extensive aquatic plant growth.

Management strategies for Windermere Lake were also developed and included some of the following recommendations:

- Establishment of a community group;
- Refinement of the carrying capacity measurements for the lake;
- Initiation of a water quality monitoring program for Windermere Lake, which included water quality assessment of the lake as well as the inlets and outlets and a fluorometer study of the near shore;
- Improvements of upland developments sewage systems;
- Development of a foreshore and lake environmental inventory;
- Restriction of marina developments and recreational use in sensitive areas of the lake;
- Monitoring of weed growth in Windermere Lake and development of a management strategy to control the growth outside of sensitive areas;

- Improvement of lake access to the public;
- Revisions of status of all marinas around the lake and prohibition of the establishment of new or the expansion of existing marinas until an environmental inventory of the lake has been completed; and
- Relocation of the boat launch north of the Columbia River bridge as it is located in an environmentally sensitive area and should be moved to a different location.

Ministry of Environment. 2003. Upper Columbia Monitoring Program. Kootenay Region.

The MoE conducted a water quality monitoring program on the upper portion of the Columbia River in 2002 and 2003. The purpose of the study was to assess the state of water quality, determine if the water quality objectives were being met, and assess land use impacts on the upper portion of the Columbia River. The study monitored three sewage treatment plants (STPs), a decommissioned mining site, three Windermere Lake water intakes and 2 beach sites.

The three STPs monitored were Fairmont Hotsprings, Radium Hot Springs, and Edgewater. Each site's effluent was monitored along with upstream and downstream sites on the Columbia River.

The old Mountain Minerals mine site was monitored to determine if the abandoned tailings were impacting the water quality in Toby Creek. Toby Creek was sampled upstream and downstream of the tailings. Water flow passing through the abandoned site was also tested to determine if the site was discharging into the creek.

Windermere Lake water quality was one focus of the program. Sites incorporated into the study were Parr Utilities, Timber Ridge, and Windermere Holdings water intakes. Water intakes were selected to capture water quality from three different systems extracting water from the northern section of the lake. Water intakes were monitored for total suspended solids, total sulphide, sulphate, bacteriology, nutrients, and phytoplankton. Monitoring occurred during August 2002, January 2003, and April 2003. Athalmer Beach (James Chabot Provincial Park) and Invermere Beach bacterial levels were monitored during August of 2002.

Water quality data for Parr Utilities, Timber Ridge, and Windermere Holdings were provided to us by MoE, however, a full analysis of the results has not been completed yet.

Ministry of Health Services and Ministry of Environment. 2005. Comprehensive Drinking Water Source to Tap Assessment Guideline. Province of British Columbia.

Windermere Lake has recently been selected to undergo a Source to Tap assessment developed by the Ministry of Health and the Ministry of Environment. The first two modules were selected for completion by mid October 2005. The first module involves the delineation and characterization of the drinking water source and includes all drainages contributing water to the lake. Characterization of the watershed and waterbody include an evaluation of the water source and it's land base. Water quality and quantity are a component of the analysis and will rely on historical data.

The second module involves completing a contaminant source inventory. This will provide useful information on potential sites that may impact water quality in Windermere Lake and identifying management strategies that could alleviate these impacts.

4 Water Quality Assessment

4.1 Trophic Status of Windermere Lake

The main goals of past monitoring programs and studies within Windermere Lake were to determine the state of water quality and assess changes in productivity within the lake. The trophic status of a lake can be affected by changes in productivity, which can be a good indicator of potential impacts from human developments.

The trophic status is a measure of a lake's productivity and it's sensitivity to additional inputs of nutrients. Increased nutrient loading may lead to increased algal and plant growth which is a process termed eutrophication. There are a total of three trophic categories: nutrient poor lakes are categorized as oligotrophic, moderately productive lakes as mesotrophic and nutrient rich lakes as eutrophic. Although eutrophication is a natural process of aging, human activities can accelerate this process by increasing nutrient inputs into the lake.

Parameters reviewed and goals of the proposed community based monitoring program will aim at assessing Windermere Lake's trophic status.

4.2 Inflows to Windermere Lake

Inflowing streams can affect water quality in Windermere Lake. The Columbia River portion south of Windermere Lake is the largest inflow to the lake contributing to water quality. Past studies have found little difference between the water quality upstream of Windermere Lake and the lake's water quality.

Windermere Creek enters the southeast section of the lake. Past water quality monitoring indicated that the nutrient loads from septic tanks, permitted discharges, and agriculture were not influencing water quality (McKean and Nordin 1985). Further assessments completed in 1999 found turbidity and total suspended solids levels to exceed the Water Quality Guidelines in Windermere Creek and also found calcium and magnesium concentrations to be high. Fecal coliform samples were found to exceed Drinking Water Guidelines during spring and fall sampling and were highest 0.5 km from Windermere Lake within the Town of Windermere, which could originate from septic inflows, storm water runoff, or domestic pets (Westcott 2000).

Other inflows have had little to no water quality monitoring in the past. From the existing data, the results show that in some creeks nitrogen and phosphorus concentrations were slightly higher than in the lake itself. Due to the small amount of flows these creeks should not have a significant effect on Windermere Lake's nutrient loads.

4.3 Windermere Lake Water Quality

Parameters monitored in past programs are listed with an overview of historical findings and interpretation. A description of the parameter, summary of data, and methodology are provided herein.

4.3.1 Temperature and Dissolved Oxygen

Temperature is a measurement of the intensity of heat stored in a volume of water (RISC 1998). High water temperatures increase the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impact many species (RISC 1998). Temperature strongly influences dissolved oxygen as oxygen solubility decreases with increasing water temperature. The amount of dissolved oxygen in a lake is also related to photosynthesis and respiration rates as well as mechanical actions such as wind. Photosynthesis releases oxygen in the day light hours and the consumption of oxygen during the night results in lower pre-dawn levels. As a lake becomes more eutrophic, the diurnal fluctuation in dissolved oxygen concentration becomes more extreme. Dissolved oxygen concentration greater than 100% saturation occur in areas of rapid photosynthesis and below 100% where respiration is dominant. Inputs into the lake from sewage and manure can reduce dissolved oxygen levels due to the decomposition process and the demand for oxygen (Urban Systems 2001).

Lakes that are unproductive (oligotrophic) have enough oxygen to support life at all depths throughout the year. If lakes are becoming more productive (eutrophic) more oxygen is being consumed near the bottom of the lake due to the deposition of organic matter and decomposition processes.

Windermere Lake Status

Historical water temperature data shows that there is no thermal stratification in Windermere Lake during the summer due to the generally shallow waters present (Courtney 1999). Historical data from 1973 to 1983 indicates that dissolved oxygen concentrations were generally high with mean levels of 10.2 mg/L, 10.2 mg/L and 9.5 mg/L at the South, Mid-Lake and North Stations respectively (McKean and Nordin 1985).

The physical characteristics of Windermere Lake, such as the shallow waters and wind action, can cause irregular dissolved oxygen depth profiles and can result in a thorough mixing of the water column. This would cause dissolved oxygen levels to more closely approach 100%, which are common conditions around the lake. Data comparison and analysis with other lakes within the Kootenay Region must consider these physical characteristics. The North Station, which is the closest to urban development, exhibited increases in dissolved oxygen saturation, which could be indicative of increased photosynthetic activity and hence potentially increased eutrophication (Courtney 1999). Oxygen production during the summer can lead to oxygen depleted waters in the fall/winter when the macrophytes and algae die off and decomposition rates increase (Courtney 1999). Further references to macrophyte abundance would aid in confirming this observation. Water quality guidelines recommend a minimum instantaneous total of 5 mg/L for aquatic life (fish) (RISC 1998).

Future Monitoring

Monitoring for dissolved oxygen should be conducted during the summer when oxygen levels would be most affected by photosynthetic processes. Winter/fall data should also be captured as this is when dissolved oxygen is affected by decomposition processes, which could lead to oxygen depletion (Countney 1999). The top 1 m and near bottom samples provide the most reliable results due to the shallow depth of Windermere Lake and the fact the lake does not stratify. Water temperature and dissolved oxygen should be monitored at the three mid lake sites established by MoE (North Station, Mid-Lake Station and South Station) as well as the beach sites and the two major inflows (Columbia River and Windermere Creek). Measurements can be taken with a handheld meter equipped with an extension cable long enough to capture near bottom conditions. If this is not possible samples should be collected with a Van Dorn sampler for the near bottom mid lake sample sites and analyzed on site once at the surface.

4.3.2 Alkalinity and Hardness

Alkalinity is the measurement of the water's ability to neutralize acids (RISC 1998). Alkalinity levels within a water body often indicate the presence of carbonate, bicarbonates, or hydroxides (RISC 1998) and results are expressed in terms of an equivalent amount of calcium carbonate. High alkalinity values can result in excessive hardness and high concentrations of sodium salts. Water with low alkalinity has little capacity to buffer acidic inputs and is susceptible to acidification, however, values over 20 mg/L have been determined to have low sensitivity (MoE, 1998). Past Lake Windermere monitoring programs have not found values under 20 mg/L.

The hardness of water is a measure of the metallic ions in water. Hardness levels are generally due to the presence of calcium and magnesium in the water and are reported in terms of calcium carbonate and in units of milligrams per liter (mg/L). Waters with values exceeding 120 mg/L are considered hard, while values below 60 mg/L are considered soft (RISC 1998). Soft water may have a corrosive effect on metal plumbing, while hard water may result in scale deposits in the pipes (RISC 1998). If the water has a hardness of greater than 500 mg/L, then it is normally unacceptable for most domestic purposes and must be treated (RISC 1998).

Windermere Lake Status

Alkalinity was measured at three stations (North, Mid-Lake and South) in 1999 and was considered a parameter with limited usefulness at detecting effects of lakeshore development (Courtney 1999) as it is more a product of the parent material of the watershed (RISC 1998). It would not be expected to be sensitive to changes in lakeshore development. McKean and Nordin (1985) found Windermere Lake to be alkaline (pH 8.5), with moderate dissolved materials (alkalinity 100 mg/L, and hardness 125 mg/L), which indicates that the lake has low sensitivity to acid input. The geology of the area appears to have the greatest effect on the dissolved residue concentration and the metamorphosed sedimentary rock surrounding the lake is the source of this dissolved material (McKean and Nordin 1985).

Calcium, which is a contributor to hardness, was found to increase by 87% from 1959 to 1983 in the sediment core sample obtained in 1998 (McDonald 2000). These increases were also found to coincide with an increase in development around the lake and could be in part due to increased runoff on exposed soils with high calcium carbonate content. Calcium carbonate can also bind with phosphorus, which may explain the accelerated increase in phosphorus in the core sample over the same period (McDonald 2000).

The maximum values for pH obtained for the samples collected at the water intakes (Parr Utilities, Timber Ridge and Windermere) in April of 2003 were found to exceed the Drinking Water Guidelines for aesthetic objectives with values of 8.64 pH, 8.59 pH, 8.54 pH respectively.

Future Monitoring

Alkalinity should not be included in future monitoring as it is not responsive to shoreline development. Hardness, on the other hand, should continue to be monitored at the mid lake sample sites, lake inflows and water intakes due to the increase of calcium observed in the sediment core over the years.

4.3.3 Turbidity

Turbidity is a measure of water clarity or the amount of suspended particulate matter in a water body. Materials that contribute to turbidity include biotic factors (such as plankton and algae) and abiotic factors (such as suspended sediments) (RISC 1998). Turbidity levels increase during freshet but these increases are usually of low consequence to aquatic life as organisms have developed high tolerance levels for short-term turbidity increases. Increased turbidity, however, can interfere with the disinfection of drinking water and is aesthetically unpleasant.

Windermere Lake Status

The highest turbidity values in 1999 occurred during freshet as turbidity values are often elevated during spring runoff. Turbidity measurements did not show any consistent trend from year to year and were highly variable. Variations in turbidity did not appear to be affected by shoreline development but were rather influenced by other factors such as freshet and proximity to inlets (Courtney 1999).

Turbidity can be measured with a secchi disk, which consists of a black and white plate that is lowered into the water until the two colours can no longer be distinguished. The secchi depth measurements in Lake Windermere averaged approximately 4 m over a number of years of sampling (Urban Systems 2001). This indicates clear water conditions and light penetration depths which encourage aquatic growth over 95% of the lake bottom (Urban Systems 2001). Changes in values can be caused by increased abundance of free floating algae, erosion of the shoreline or erosion from site development near the lake, recirculation of bottom sediment from motorboat activity, discolouration of the water from wetland runoff and/ or plant decomposition.

Turbidity and secchi depth measurements were not taken in MoE's 2002-2003 Upper Columbia monitoring program.

Future Monitoring

Even though there were no apparent trends in turbidity values, turbidity should continue to be incorporated into the monitoring program and should be monitored in conjunction with other parameters. The Water Quality Guidelines require a maximum value of 1 NTU for drinking water. Lake measurements are often not reflective of the turbidity value at water intakes. Turbidity should be measured at the mid lake stations, lake inflows and water intakes.

Water clarity measurements using secchi depth is a good method of obtaining information on changes in water clarity and is a good educational tool for community monitoring programs. Readings can be obtained at any time with no cost to the program beyond the purchase of the secchi depth device. Secchi disk measurements should be completed at the mid lake stations.

4.3.4 Total Suspended Solids (TSS)

TSS is a measure of the particulate matter that is suspended within the water column. Non-filterable residue values are reported in mg/L. High concentrations of non-filterable residue increase turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills and settling of suspended solids can cause impairment to spawning habitat by smothering fish eggs (RISC 1998). Suspended solids also interfere with water treatment processes. Criteria for TSS are referenced against background data. Background data must be representative of the same site during the same season.

Windermere Lake Status

Historical data for Windermere Lake indicated that TSS values ranged between 6 and 40 mg/L during freshet (McKean and Nordin 1985). This variation from year to year could be due to different amounts of watershed runoff entering the lake during freshet and the fact that samples may not have been collected during peak flows as the timing of freshet varies from year to year. TSS was also analyzed during the 2003 monitoring program with most results less than the detection limits of 4 mg/L. These sample results, however, could not be compared to historical data as they were taken from the water intakes and not directly from the lake.

Future Monitoring

TSS is not a priority parameter to monitor in this community based program. Windermere Lake water clarity measurements can be captured using a secchi disk and turbidity measurements. TSS data is useful for the selection and maintenance of filtration systems. It would be beneficial to add TSS to the project if additional laboratory funding is available. If added it should follow the sample site locations, monitoring protocol at all of the lake sites, lake inflows and water intakes.

4.3.5 Chloride

Chloride can be a good indicator of contamination from industry, road salting and municipal wastewater. Courtney (1999) found chloride to be a poor indicator of lakeshore development for Windermere Lake and concluded that variations were rather generally associated with watershed characteristics and climate.

Windermere Lake Status

Chloride levels were measured in Windermere Lake in 1999 and 1970s and levels were found to be generally lower in 1999 compared to the 1970s (Courtney 1999).

Future Monitoring

Chloride can be added to capture the trend component of monitoring and can also be indicative of wasterwater contamination. However it is not a priority variable due to limited background data. It could be assessed in certain periods throughout the program but does not need to be monitored in all samples.

4.3.6 Sulphate and Sulphide

The amount of sulphate in the water is often related to the types of minerals found in the watershed. Sulphate can be reduced to hydrogen sulphide in lakes with a low oxygen content (anaerobic conditions). This can result in foul odours and taste in the water.

Sulphate depth profiles are a useful way to assess the trophic status of a lake. Sulphate levels are influenced by the amount of oxygen in the hypolimnion. Sulphate, being an oxidized form of sulphur, will be abundant in oligotrophic lakes and can show an increase at the mud-water interface. In oligotrophic lakes sulphate levels remain constant at all depths with a slight increase near the bottom of the lake. Mesotrophic lakes have intermediate levels of sulphate in the hypolimnion. In eutrophic lakes sulphate levels are the lowest near the bottom of the lake (Mackie, 2001).

Windermere Lake Status

Total sulphide and dissolved sulphate were monitored in three of the water intakes on the east side of Windermere Lake in 2002 and 2003. Historical sulphate and sulphide levels are not available for comparison. Total sulphide levels were found to be low often below detection levels. Dissolved sulphate samples, on the other hand, exceeded the Aquatic Life Water Quality Guidelines requirement of 50 mg/L average over 30 days at Parr Utilities and Windermere during winter monitoring and spring freshet. The 30 day averages during winter monitoring at Parr Utilities and Windermere were 57.9 mg/L and 54.4mg/L respectively. Parr Utilities and

Windermere 30 day dissolved sulphate values during freshet were 72.3mg/L and 71.4mg/L respectively.

The sediment core sample showed that sulphate levels began to decline around 1950 (McDonald 2000). The presence of algal pigments specific to the purple-sulphur bacteria in the core sample would suggest, however, the presence of sulphur in sufficient quantities for their growth. Windermere Lake is known to receive large quantities of sulphate from the hot springs upstream and the gypsum deposits in Windermere Creek (McDonald 2000). The presence of purple-sulphur bacteria in Windermere Lake is of concern due to its properties to generate odorous by-products of organic decay like methane, ammonia and hydrogen sulphide (McDonald 2000).

Future Monitoring

It is recommended to continue to monitor both total sulphide and dissolved sulphate at the mid lake sample sites, lake inflows and water intakes.

4.4 Windermere Lake Nutrients

Assessing the level of nutrients is an important factor in determining lake productivity. Lake water quality is strongly influenced by the relative abundance of nutrients. A moderate amount of nutrients enhances the lake ecosystem by providing a food source for living organisms. Too few nutrients and the lake is unable to sustain life, too many nutrients and the lake suffocates in the overproduction of life forms. Nutrients can migrate into the lake from surface runoff as well as groundwater inflows.

Phosphorus is usually the most limiting nutrient for plant and algae growth in lakes and is measured in it's dissolved form. Total phosphorus levels include all forms of organic and inorganic phosphorus. Portions of this phosphorus component are not immediately biologically available (RISC 1998). Forms of phosphorus that are biologically available for plant growth include total dissolved phosphorus, ortho-phosphorus and soluble reactive phosphorus and therefore are better indicators of trophic status within the lake. Increased levels of phosphorus are generally associated with increasing levels of eutrophication. Soil types and land use inputs influence phosphorus levels and potential sources include storm water runoff, agriculture, golf courses and wastewater systems. Groundwater phosphorus concentrations can become elevated when the soil phosphorus holding capacity is exceeded.

Nitrogen is also an essential nutrient for aquatic plant growth, but it is not usually limiting as it is found in much greater concentrations than phosphorus. Total nitrogen is composed almost entirely of organic nitrogen. Ammonia and nitrite/nitrate are forms of nitrogen that are immediately biologically available. Ammonia can be produced by the degradation of organic compounds and can indicate the presence of wastewater effluent. This ammonia is further transformed into nitrite-nitrate when it is exposed to air. This process is termed nitrification, which is a chemical process performed by bacteria under aerobic conditions, which oxidizes the ammonia into nitrite first and then into nitrate.

Windermere Lake Status

The sediment core sample obtained in 1998 showed that phosphorus appeared to have steadily increased since about 1800, almost doubling by 1983 (McDonald 2000) potentially indicating an increase in nutrient inputs. Samples taken from each of the three mid-lake stations during the 1999 monitoring program also suggested an increase in phosphorus levels since 1989 (Courtney 1999). These levels appeared to be higher at the North and Mid-Lake Stations and lowest at the South Station, however, the differences were not statistically significant (Courtney 1999). The study completed in 1983 (McKean and Nordin 1985) also showed an increase in phosphorus. Again this trend was not statistically significant but the author commented that if the data were part of a long-term trend study it would have been highly significant. It may, however, be reflective of annual variability and several more years of data would be required to assess any significant long-term trends.

More recent data is available from the 2003 monitoring program conducted by MoE, which monitored orthophosphate, dissolved phosphorus, and total phosphorus at three water intakes (Parr Utilities, Windermere and Timber Ridge). Total phosphorus levels were found to exceed the Water Quality Guidelines for both drinking water (0.01 mg/L) and aquatic life (0.008 mg/L) at all three water intakes. The data obtained at Parr Utilities, Windermere, and Timber Ridge maximum values were 0.057 mg/L, 0.032 mg/L, and 0.022 mg/L respectively during freshet. Unfortunately, these results cannot be compared to historical data as samples were taken from the water intakes and not directly from the lake. Further monitoring at the water intakes would be required to identify trends and assess additional exceedances to Water Quality Guidelines.

Ammonia levels recorded at the three mid lake stations were below detection limits. The data did not show any decline in water quality due to ammonia concentration (Courtney 1999). The ammonia that could be present in the lake would readily be nitrified into nitrite and then nitrate due to the good oxygen saturation in the lake. Historical nitrate+nitrite data was found to be below detection limits of 0.02 mg/L (McKean and Nordin 1985). Most of the 1999 results were also below the detection limits, even though the detection limit was lowered to 0.003 mg/L.

Organic nitrogen was the most abundant form of nitrogen present in the lake. Based on 1999 data, it appeared that nitrogen levels had increased (Courtney), which could be indicative of increased eutrophication.

The nitrogen to phosphorus weight ratio in the lake water can be used for evaluating the limiting effects of nutrients. McKean and Nordin (1985) found the annual mean total N to P ratio for Windermere Lake was 21:1. This ratio indicates that phosphorus is the nutrient most likely to be limiting algal and non-rooted vascular plant growth (McKean and Nordin 1985).

Soil holding capability was assessed in the report by Wiens and Noone (1987), which outlined the variability of soils along the shoreline. This information along with residential dwelling locations aid in determining the best site for monitoring groundwater inflows. Some additional sampling of this type should be considered if groundwater is suspected of causing a significant nutrient input to the lake (McKean 1983). Groundwater entering the lake on the east shore of Windermere Lake was analyzed for nutrients in September and October 1982. The only high value found was for ammonia at 0.918 mg/L.

Future Monitoring

Nutrient levels should continue to be monitored at all three lake sites at surface and above bottom depths as they are a good indicator of trophic status and gauge of human related activities. These sites allow for comparison of background data and capture sections of the lake that are indicative of highly developed areas especially at the northern end. Samples should also be collected at the two water inflows and water intakes. Variables to be included in the program are ammonia nitrogen, nitrate/nitrite, organic nitrogen, total nitrogen, ortho-phosphorus, total dissolved phosphorus, and total phosphorus. Ammonia would be more useful to measure near the shore where impacts of potential contamination from domestic wastewater in groundwater is more likely to occur and before the nitrification process occurs. However, it should also continue to be included in the mid lake samples as it is required to calculate total organic nitrogen.

4.4.1 Chlorophyll *a*

Chlorophyll *a* is a measure of the phytoplankton or periphyton biomass present in a body of water (RISC 1998). It is reported as µg/L for plankton species and mg/m^2 for attached species. This variable directly relates to the productivity and trophic status of the body of water. High chlorophyll *a* concentrations are a direct result of high nutrient inputs and/or high light inputs in streams that are light limited. Values below 3 µg/L (plankton) are considered to indicate low productivity (oligotrophic waters) and values greater than 15 µg/L are generally considered to indicate high productivity (eutrophic waters) (RISC 1998).

Windermere Lake Status

Chlorophyll *a* analyses were completed in 1976 and 1982. From this data McKean and Nordin (1985) developed a relationship between phosphorus concentrations and chlorophyll *a*, as they are directly proportional to each other. Spring overturn values for phosphorus are usually required, but because of the shallow depth of Windermere Lake, the mean summer phosphorus concentration could be utilized. It was found that Windermere Lake had slightly less chlorophyll *a* than predicted by the model probably due to the high flushing rates. Based on McKean and Nordin's model, phosphorus concentrations indicate that Windermere Lake is oligotrophic tending to mesotrophic (Urban Systems 2001).

Future Monitoring

Future monitoring of chlorophyll *a* will assist in determining changes in trophic status and aquatic ecosystem health and should be monitored at the three lake stations in August. Samples should be obtained at the surface within the first meter of the water column.

4.5 Windermere Lake Bacteriology

Bacteriology monitoring captures the degree of contamination from human and animal wastes. Recreational and drinking water health is often monitored using bacterial monitoring. The total coliform group (of micro-organisms) includes: fecal coliforms, common to the intestinal tract of both humans and warm-blooded animals, and non-fecal coliforms that are naturally present in soils and on vegetation (RISC 1998). Enterococcus and *E. coli* (which are sub-groups of fecal coliform) are specific to fecal contamination of water because feces of warm-blooded animals are the only source of these bacteria (RISC 1998). Coliform results are reported as Colony Forming Units (CFU) counted in 100 milliliters of water submitted or Most Probable Number (MPN) per 100 mL of water. Tests for both total and fecal coliforms were conducted in past monitoring programs.

Windermere Lake Status

Past monitoring data at recreational beaches found low values of fecal coliforms. These values were well below the acceptable guidelines of 200 CFU/100mL (McKean and Nordin 1985). However, values indicated that water did require treatment for domestic purposes, as values were greater than 0 CFU/100mL.

Future Monitoring

Bacteriological monitoring is currently completed at beach sites by the Interior Health Authority (IHA). Samples have been collected by Wildsight during 2005 and were analyzed for fecal coliforms. Continued sampling at the beach sites is recommended, however, we would also recommend analyzing for *E. coli* and Enterococcus since they have been shown to be more strongly related to gastrointestinal illnesses and are better indicators of the presence of pathogens. Water quality at water intakes must also be monitored under the Drinking Water Protection Act. According to the Act water supplied for drinking must be monitored at its source, in its system and at the tap. Parameters to be analyzed are set by the regulation and include total coliform and fecal coliform or *E. coli* and must be completed 4 times per month at the tap and once per month at the source. Cooperation with the water purveyors would be a good way to obtain additional data at little extra cost. Additional samples could be collected by the purveyors as per the recommended frequency since they are collecting samples at least once per month. Bacteriological sampling at the mid lake stations may not be as useful as the bacteria are usually short lived and would be more prevalent at the beach sites and closer to the shore.

Sampling should therefore be conducted at the beach sites and at the three water intakes (Parr Utilities, Windermere and Timber Ridge). These samples should be analyzed for fecal coliforms, *E. coli* and Enterococcus. Beach samples should be taken at the surface up to 3m from the shore.

4.6 Windermere Lake Sediments

Sampling of sediments would be a useful tool at identifying possible contaminants entering the lake. Such contaminants can include oils and greases from motorboat activities and pesticides and herbicides potentially used on the surrounding agricultural lands, golf courses and residences.

Windermere Lake Status

The sediment core collected in 1998 indicated that the diatom communities were increasing in relation to the settlement around the lake since about 1960. Other changes in specific pigments indicated a shift in the algal community away from diatom dominance and toward green, blue-green and chrysophyte types over this period (McDonald 2000). Sediment samples were collected during mid winter at the north end of Windermere Lake, in the 2002-2003 monitoring program conducted by MoE, however, results were not available.

Future Monitoring

Further sediment sampling during winter months would be beneficial to the program. This is beyond the scope of a community based monitoring program. A qualified consultant with experience in sediment sampling study design, monitoring protocol and analysis should be involved in the program development for this portion of the project.

Sediment samples would aid in assessing impacts from pesticides and motorized recreational use along the lake. Future sediment sampling should continue at minimum at the north end site. Additional samples from the south end site could help link pesticide inflows from local golf maintenance practices.

The presence of hydrocarbons in the sediment samples should be analyzed as a method of assessing impact from motorized boat activity on the lake. Sediment samples should also be analyzed for pesticides. This assessment should reflect possible pesticides used on the golf courses and current shoreline lawn maintenance techniques. Golf course pesticide management plans should be consulted to determine types of pesticides used and season.

Sediment samples can be collected with the use of an Ekman Grab or a Ponar Grab. Once the sample has been retrieved the top layer of the sample should be retained for analysis. Further details on sediment monitoring protocols can be found in the MoE's Resource Inventory Standards Committee Sediment Sampling Document. Lake and Stream Bottom Sediment Sampling Manual (MOE, 1997) can be obtained from http://srmwww.gov.bc.ca/risc/pubs /aquatic/ lake-stream /index.htm

4.7 Windermere Lake Water Quantity

Little information is available on water quantity for Lake Windermere. A Water Survey of Canada used to operate a water station at the south end of the lake at Athalmer (station 08NA004).

Windermere Lake status

Water quantity is not currently monitored in Windermere Lake. Increased demands on water resources throughout the Windermere Lake drainage could have an impact on water levels in the lake over the long term. Such demands include an increasing population with greater demands for water, resort developments and golf courses with high irrigation requirements.

Future Monitoring

Reinstating the Water Survey of Canada monitoring station would be a benefit to the program and identifying long-term impacts of increasing demands on water supplies. An inventory of water licenses and quantities utilized for both surface water and groundwater wells within the Windermere Lake watershed should be compiled and their impacts assessed cumulatively.

4.8 Windermere Lake Aquatic Macrophytes

Macrophytes are indicators of lake productivity. The changes in diversity and abundance of macrophytes within a lake can be used as a tool to determine changes in trophic status.

Windermere Lake status

An assessment of macrophyte abundance was completed by Courtney in 1999. The assessment was based on a review of aerial photography, and comparing the extent of macrophyte beds to historical air photos. It appeared that the major macrophyte beds remained fairly constant. The shallow waters throughout most of the lake and warm temperatures ensures that macrophytes are abundant in Windermere Lake. The use of macrophyte diversity and abundance can assist in determining changes in trophic status and water quality health especially at the north end of the lake where development is more prevalent.

Future Monitoring

Future surveys are recommended to compare current macrophyte abundance to the 1999 data set. Aerial photography should be taken of the lake at least every 5 years and should be taken at the same time period as the 1999 air photos (early September).

4.8.1 Eurasian Water Milfoil

Eurasian water milfoil is an invasive aquatic plant that grows in areas of nutrient rich sediments. The plant flourishes in fertile, fine-textured, inorganic sediments and it acts as an indicator of water high in nutrients. High water temperatures can promote multiple periods of flowering and fragmentation (Courtney 1999).

Windermere Lake Status

Two native water milfoil were found in Windermere Lake in 1985 (McKean and Nordin 1985). Further sampling conducted in 1999 (Courtney) did not detect the presence of Eurasian water milfoil in the lake.

Future Monitoring

A follow up on the Courtney 1999 study of Eurasian water milfoil would aid in assessing the presence of Eurasian water milfoil. Ideally, populations of Eurasian water milfoil should be documented in the community samplers field log book. Community water monitors should be provided with an identification card to be aware of the characteristics of Eurasian water milfoil. Any possible sightings should be recorded and a sample of the plant brought back for identification by an invasive plant biologist as it is difficult to differentiate from the native species. A follow up study of the Eurasian water milfoil population should occur in mid August. The optimum monitoring frequency recommended would be once in the first year of a five-year water quality monitoring program and once in the final year.

The field book should include:

Myriophyllum spicatum: Eurasian water-milfoil is a rooted submersed herb with long branching stems and feather-like whorled leaves; its small reddish flowers are held above the water on a spike. (http://aquat1.ifas.ufl.edu/seagrant/myrspi2.html)

Myriophyllum sibiricum: Common water-milfoil is a submerged aquatic plant, identifiable as a milfoil by its finely dissected, thread-like leaves. It is distinguished from other native milfoils by: leaves and flowers in whorls; the bracts surrounding the male flowers are entire and not longer than the flowers. It is distinguished from the Eurasian Water Milfoil, which it closely resembles, by its less finely divided leaves and larger floral bracts. The native Common Milfoil typically has 5-10 thread-like segments on each side of the midrib; its Eurasian cousin is more finely divided, with 12-24 segments. Plants often turn whitish when dried.

Potamogeton natans: Jointed Pondweed is common in lochs. Floating leaf blades are typically 6-10 cm long. Leaf with a flexible joint where stalk meets blade; easily recognisable even if can't be reached, by leaf blade being at angle to stalk. Other features include floating leaves with long-stalked and submerged leaves are linear, usually without a blade. Floating leaves are broad and submerged leaves are linear.

5 Proposed Activities and Components of the Program

The proposed monitoring program pulls together past findings to be incorporated into a community based sampling regime. Community commitment and understanding of the project goals will assist in ensuring the longterm success of the program. The monitoring program is based on achieving stewardship awareness while capturing baseline data to be analyzed and reported to the community and land use planners.

Water quality monitoring priorities are set to protect the most sensitive designated water use at a specific location. The designated water uses within Windermere Lake are:

- Raw drinking water, public water supply, and food processing;
- Aquatic life and wildlife;
- Agriculture (livestock watering and irrigation); and
- Recreation and aesthetics.

A comprehensive monitoring program is recommended to continue to document and assess anthropogenic inputs into the lake and natural variability. The monitoring program focuses on determining the productivity of the lake, daily consumption requirements and recreational use in Windermere Lake. A long-term data set reflecting future changes in water quality are also of interest.

The main monitoring goal is therefore to assess the state of water quality in Windermere Lake and detect changes in trophic status.

5.1 Proposed Monitoring Plan

5.1.1 Lake Monitoring Sites

The three historical lake sample sites (South Station EMS 0200050, Mid-Lake Station EMS 0200051 and North Station EMS 0200052) should continue to be monitored as they provide a good baseline to compare data to. This will allow continuing to develop the baseline dataset and detect trends in water quality in the lake. These sites will assess the state of water quality of the lake in different sections, which will allow possible impacts to be discerned from land developments since most of the development is occurring at the north end of the lake. If impacts from land developments are occurring, the north end of the lake should be the first area to experience deterioration in water quality. This will help gauge if the changes in water quality are land use related.

Monitoring of these sites should commence immediately after ice melt (pre-freshet) and continue monthly. Timing of the pre-freshet sample must be reassessed yearly since the onset of freshet (period when inflows into the lake are at their peak) varies from year to year. Weekly monitoring should occur during the months of July and August during the greatest uses and should be collected when ambient water temperatures are at their highest. Weekly sampling could start in the latter part of July and extend to the end of August.

The following parameters should be monitored throughout the duration of the program: water temperature, pH, conductivity, dissolved oxygen, turbidity, hardness, total sulphide, sulphate and nutrients (total nitrogen, total organic nitrogen, ammonia, total phosphorus, total dissolved phosphorus and orthophosphorus). Clarity should also be measured at all three mid lake sample sites with a secchi disk.

Samples should be collected at the top and near bottom at all three sample sites; North, Mid-Lake and South Stations. Ideally lake samples should be taken 0.5 m from the surface and 0.5 m from the bottom of the lake. Consistency between sample depths is important in order to compare to past datasets. Even though historical data show that most parameters were similar at both depths, some differences were found for nutrients, especially dissolved phosphorus, on certain dates. It is therefore recommended to continue monitoring the top and bottom depth with the bottom sample analyzed for nutrients, as well as sulphate and sulphide. Field measurements should be completed at both depths since there is no extra cost.

Chlorophyll *a* should also be monitored weekly at the three lake sample sites during the month of August when productivity is at it's highest. Monitoring every two years would be sufficient.

5.1.2 Beach Monitoring Sites

Sampling should be conducted at the recreational beaches that are the most frequented. The following beaches should be monitored for fecal coliforms, *E. coli* and Enterococcus: Windermere Beach, Athalmer Beach (James Chabot Provincial Park) and Invermere Beach. Sampling frequency should consist of 5 times in 30 days during high peak use, since water quality guidelines are based on 5 in 30 day averages, and should also be collected every two weeks during the entire high use period (June – September). Beach samples should be taken at the surface up to 3m from the shore. The presence of people on the beaches should be noted during sampling.

Sampling efforts should be coordinated with IHA, since they collect samples at these locations throughout the summer. IHA however, currently analyzes their samples for fecal coliform only, but adding the analysis of both *E. coli* and Enterococcus would not be very costly since the samples are already being collected and sent to the laboratory. The only additional expense would consist of the laboratory analysis.

5.1.3 Water Intakes

Many shoreline residents outside of the Town of Invermere draw water from Windermere Lake. The higher populated communities use a central intake to provide water for each individual household. The northeast end of the lake has the densest development and community water intake pipes extend out into the lake. Sampling should be conducted at Windermere, Timber Ridge and Parr Utilities as these were also monitored during the 2002-2003 monitoring program completed by MoE.

Monitoring water intakes would provide a means for sampling lake water during winter without having to deal with cutting through the ice. Monthly sampling is therefore recommended at the water intake sites during winter (January through April). The following parameters should be monitored throughout the duration of the program: water temperature, pH, conductivity, dissolved oxygen, turbidity, hardness, total sulphide, sulphate and nutrients (total nitrogen, total organic nitrogen, ammonia, total phosphorus, total dissolved phosphorus and orthophosphorus). In addition bacteriology could also be analyzed since the water purveyors must complete this analysis once per month under the Drinking Water Protection Act. They are currently obligated under the Act to monitor source water for total coliforms, fecal coliforms and turbidity.

Sampling efforts should be coordinated with the water purveyors, since they regularly have to collect samples at these locations. It is also important to ensure samples are taken prior to treatment.

5.1.4 Windermere Lake Inflows

The monitoring of Windermere Lake inflows would also provide useful information on the quality of the water flowing into the lake and may assist in identifying land use impacts. Sampling at these locations should be conducted if there is a sufficient budget. Windermere Creek and the Columbia River inflow should be monitored to determine the extent of variation between inflows and lake water quality.

The following parameters should be monitored throughout the duration of the program: water temperature, pH, conductivity, dissolved oxygen, turbidity, hardness, total sulphide, sulphate and nutrients (total nitrogen, total organic nitrogen, ammonia, total phosphorus, total dissolved phosphorus and orthophosphorus). Bacteriology should also be sampled at these sites as they are in closer proximity to potential contamination from land development and should include fecal coliforms, *E. coli* and Enterococcus. Samples can be collected from shore and must be taken from a well mixed portion of the creek/river.

Samples should be collected monthly starting right after ice melt and continuing until late fall. Weekly samples should also be collected when water temperatures are at their highest from the end of July to the end of August. Samples analyzed for bacteriology should also be collected at low flows during the month of August and should consist of 5 samples in 30 days.

5.1.5 Windermere Lake Macrophytes

Aerial photography of the lake should be conducted once every 5 years to assess the expansion of the macrophyte beds present in Windermere Lake. Eurasian Water Milfoil should be checked periodically throughout the summer months. Incidental observations should be reported by the community water samplers.

5.1.6 Windermere Lake Foreshore

A follow up on the 1985 fluorometry study should be completed along the entire shoreline of the lake where development has occurred. This would provide a means of identifying new areas of concerns and reconfirm hot sports that were identified previously. Water samples should also be collected simultaneously and should be analyzed for pH, conductivity, nutrients and bacteriology.

5.2 Sampling Summary

Table 2. Windermere Lake monitoring program - sample site descriptions.

Sample site	EMS ID number	Location	Sampling Frequency	Season
North Station	200052	Middle of the lake directly in front the outflow from Holland Creek.	monthly weekly	Prefreshet, May, June, Sept., Oct, Nov. end July to end August
Mid Lake Station	200051	Mid way across the lake in front of Windermere town	monthly weekly	Prefreshet, May, June, Sept., Oct, Nov. end July to end August
South Station	200050	Mid way across the lake upstream from Rushmere	monthly weekly	Prefreshet, May, June, Sept., Oct, Nov. end July to end August
Athalmer Beach	E207051	James Chabot Provincial Park	5x in 30 days biweekly	August Periods of high use
Windermere Beach		At Windermere Beach along the shoreline	5x in 30 days Biweekly	August Periods of high use
Invermere Beach	E207050	At Invermere Beach along the shoreline	5x in 30 days biweekly	August Periods of high use
Windermere	E207044		Monthly 5x in 30days for bacteriology)	January –April January
Timber Ridge	E207090		Monthly 5x in 30days for bacteriology)	January –April January
Parr Utilities	E207050		Monthly 5x in 30days for bacteriology)	January –April January
Windermere Creek	E231717	At mouth before junction with Windermere Lake in well mixed water	Monthly 5 in 30 days	Prefreshet, May, June, Sept., Oct, Nov. August for bacteriology
Columbia River		At mouth before junction with Windermere Lake in well mixed water	Monthly 5 in 30 days	Prefreshet, May, June, Sept., Oct, Nov. August for bacteriology
Windermere Lake foreshore		Along developed shore lines	Fluorometry survey	August

Table 3. Windermere Lake water quality monitoring program – yearly schedule.

		January	February	March	April	May	June	July	August	September	October	November	December
Lake Stations General Chemistry And Nutrients	North	-	-	-	1	1	1	2	3	1	1	1	-
	Mid-Lake	-	-	-	1	1	1	2	3	1	1	1	-
	South	-	-	-	1	1	1	2	3	1	1	1	-
Lake Stations Chlorophyll *a*	North	-	-	-	-	-	-	-	4	-	-	-	-
	Mid-Lake	-	-	-	-	-	-	-	4	-	-	-	-
	South	-	-	-	-	-	-	-	4	-	-	-	-
Beaches Bacteriology	Athalmar	-	-	-	-	-	2	2	5 in 30 days	2	-	-	-
	Windermere	-	-	-	-	-	2	2	5 in 30 days	2	-	-	-
	Invermere	-	-	-	-	-	2	2	5 in 30 days	2	-	-	-
Water Intakes General Chemistry and Nutrients	Windermere	1	1	1	1	-	-	-	-	-	-	-	1
	Timber Ridge	1	1	1	1	-	-	-	-	-	-	-	1
	Parr Utilities	1	1	1	1	-	-	-	-	-	-	-	1
Water Intakes Bacteriology	Windermere	5 in 30 days	-	-	-	-	-	-	-	-	-	-	1
	Timber Ridge	5 in 30 days	-	-	-	-	-	-	-	-	-	-	1
	Parr Utilities	5 in 30 days	-	-	-	-	-	-	-	-	-	-	1
Lake Inflows General Chemistry and Nutrients	Windermere Creek	-	-	-	1	1	1	2	3	1	1	1	-
	Columbia River	-	-	-	1	1	1	2	3	1	1	1	-
Lake Inflows Bacteriology	Windermere Creek	-	-	-	-	-	-	-	5 in 30 days	-	-	-	-
	Columbia River	-	-	-	-	-	-	-	5 in 30 days	-	-	-	-

Table 4. Windermere Lake monitoring program – parameters.

		Lake sites						Beach sites		Water Intakes			Lake inflows	
	Variable	North Top	North Bottom	Mid Lake Top	Mid Lake Bottom	South Top	South Bottom	Athalmer Beach	Invermere Beach	Parr	Windermere	Timber Ridge	Windermere Creek	Columbia River
Field Measurements	Water Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X
	pH	X	X	X	X	X	X	X	X	X	X	X	X	X
	Conductivity	X	X	X	X	X	X	X	X	X	X	X	X	X
	Dissolved Oxygen	X	X	X	X	X	X			X	X	X	X	X
	Clarity (Secchi Disk)	X		X		X								
General Chemistry	Turbidity	X		X		X				X	X	X	X	X
	TSS (optional)	X		X		X								
	Hardness	X		X		X				X	X	X	X	X
	Total Sulphide	X	X	X	X	X	X			X	X	X	X	X
	Sulphate	X	X	X	X	X	X			X	X	X	X	X
	Total Nitrogen	X	X	X	X	X	X			X	X	X	X	X
Nutrients	Total organic nitrogen	X	X	X	X	X	X			X	X	X	X	X
	Ammonia	X	X	X	X	X	X			X	X	X	X	X
	Total Phosphorus	X	X	X	X	X	X			X	X	X	X	X
	Total Dissolved Phosphorus	X	X	X	X	X	X			X	X	X	X	X
	Orpthophosphorus	X	X	X	X	X	X			X	X	X	X	X
Bacte-riology	Fecal Coliform							X	X	X	X	X	X	X
	E Coli							X	X	X	X	X	X	X
	Enterococcus							X	X	X	X	X	X	X
	Chlorophyll a	X		X		X								

5.3 Protocols

5.3.1 Field Parameters

Field parameters include water temperature, pH, conductivity and dissolved oxygen. Handheld meters can be used for field measurements and must be properly calibrated before use. The bottom sample should be collected with a Van Dorn sampler 0.5 m above the substrate and the samples must be measured immediately with the handheld meters. If the meters have a long enough cable they could be lowered to the bottom location and measured in situ. Field measurements can be taken in situ for lake inflows and in sample container at water intakes.

5.3.2 Clarity Secchi Depth

Due to the maximum depth of the lake being 6.4 m the use of a secchi disk may be questionable as a measurement, however, it can be a good indicator of changes over time. To use the secchi disk lower the plastic black and white disk into the water until the pattern can no longer be seen. Record the depth using the meter increments on the rope attached to the disk. Bring the disk back up until the pattern can be seen again. Record this distance and then average the two. Secchi depth measurements should be completed at the end of sampling to ensure that the bottom sediments are not disturbed.

5.3.3 Water Samples

Samples collected near the surface can be collected at arms length from the boat for the lake sites. Other samples collected in the creeks should be collected in a well mixed area. The near bottom sample will be collected with a Van Dorn sampler 0.5 m above the substrate. Care must be taken not to disturb the substrate as this would affect analytical results.

Samples for general chemistry analysis should be collected in a 1 L general chemistry bottle. Samples analyzed for ammonia nitrogen, nitrate/nitrite, organic nitrogen, total nitrogen, total dissolved phosphorus, and total phosphorus are collected in a 500 ml opaque plastic bottle and preserved with sulphuric acid. The orthophosphate must be collected in an amber glass bottle, which is usually 250 ml in size. Bacteriological samples must be collected in a sterilized container provided by the laboratory.

It is imperative that low-level laboratory detection limits be requested for nutrients on all requisition forms to ensure that these tests are properly carried out. The sampler should ensure that this is clearly identified on the requisition form or that the laboratory is familiar with protocols established for this program.

5.3.4 Chlorophyll a

A 1 L container should be filled with near surface water by reaching out at arms length. Samples should be filtered as soon as collected, however, if this is not possible, samples are to be filtered as soon as they reach the laboratory or stored for as short a time as possible at $4^{o}C$. Ideally the samples should reach the laboratory within a 24-hour period for laboratory filtration. Filtered samples should be capped and kept in a freezer until ready to proceed with the extraction. It is best to check with the laboratory that will be processing the samples as to the sample preparation and storage to ensure best results. ALS laboratories in Vancouver completes analysis for chlorophyll *a*.

5.4 Quality Assurance

Quality assurance is a means to ensure that samples are collected and analyzed adequately with little to no errors. Quality control consists of field protocols, written protocols, training of personnel, use of well maintained and calibrated equipment, the use of quality control samples (blanks, reference samples, spikes, and replicates), and diligent record keeping. A brief summary of this component of the program is included. Refer to http://srmwww.gov.bc.ca/risc/pubs/aquatic/interp/interp2.htm#2 for details.

Blanks are designed to detect contamination that contributes to imprecision and bias. For details about how each blank is prepared, refer to the *`Ambient Fresh Water and Effluent Sampling Manual'* (Cavanagh, *et al.,* 1994a). The different types of blanks are (RISC 1998):

> **Trip blanks** - laboratory provided de-ionized water preserved prior to the sample trip in the same manner as the associated field sample. It remains unopened throughout the duration of the trip. These blanks detect any widespread contamination resulting from the container or preservative during transport and storage.
>
> **Field blanks** - de-ionized water, which is exposed to the sampling environment at the sample site and handled in the same manner as the real sample (e.g., preserved, filtered). These blanks provide information on contamination resulting from the handling technique and from exposure to the atmosphere.
>
> **Equipment blanks** - samples of de-ionized water that is used to rinse sampling equipment. This type of blank is useful in documenting the effectiveness of the cleaning or decontamination of equipment.
>
> **Filtration blanks** (or rinsate blanks) - de-ionized water that is passed through the filtration apparatus in the same manner as the sample. Analysis of the filtrate provides an indication of the types of contaminants that may have been introduced through contact with the filtration apparatus. Filtration blanks are also used as a check for potential cross-contamination through inadequate field filtration/cleaning techniques.

Standard reference samples aim to measure the accuracy of analyses performed by the analyzing laboratory. The variable concentrations in these reference solutions can vary depending on the source of the sample and the variable being tested. It is often desirable to use reference samples that are close to the criterion levels established to protect aquatic life, but preferably close to the range of values expected in the real samples. Therefore, the results present a measure of confidence in the laboratory's ability to provide reliable data in those variable ranges that are critical (RISC 1998).

Spiked samples for each variable being tested can be prepared by spiking aliquots of a single water sample with pre-measured amounts of the variable of interest. The information gained from spiked samples is used to reveal any systematic errors (or bias) in the analytical method (RISC 1998).

The following is a breakdown of the QA/QC sample types.

Summary of quality assurance sample type measures (RISC 1998):

- Field replicates sampling + environmental + analytical precision;
- Spiked samples analytical accuracy;
- Field blank contamination (bias and imprecision) introduced during sample handling in the field and laboratory;
- Trip blank contamination (bias and imprecision) introduced by the container, preservative and/or during transportation;
- Equipment blank contamination (bias and imprecision) introduced through improper cleaning techniques; and
- Filtration blank contamination (bias and imprecision) introduced from the filtration apparatus and inadequate cleaning of apparatus.

At minimum field replicates and field blanks should be collected for quality control. Ten percent of the monitoring program should be quality control samples.

5.5 Data Analysis

All data must be compared to the Canadian Drinking Water Guidelines and exceedances should be highlighted and reported. A spreadsheet outlining the Canadian Drinking Water Quality Guidelines and the Provincial Federal Drinking Water Guidelines maximum acceptable concentration from Health Canada (2003) and the Water Quality Guidelines for protection of aquatic life (WLAP, 1998) is provided in Appendix 2.

Changes in trophic status due to natural causes usually take decades. Therefore rapid alterations in lake water quality levels often indicate unnatural influences entering the aquatic ecosystem. It is important to consider and differentiate seasonal and annual variation and possible analytical error. Past data sets are a key component to data analysis within future monitoring and should be referred to when analyzing new data. A comparison to past results will help distinguish if levels are being affected by land use. It should also be noted that new data can be compared to historical data if they are collected at the same site location, with the same monitoring protocol, and meet the quality assurance requirements. Consistency in the data should be assessed when comparing results to historical data and evaluating trends.

Screening and editing is the initial phase in assessing water quality data. Data review and interpretation should be conducted as an ongoing process throughout the duration of the monitoring program to ensure that the program objectives initially established are continually being met.

5.6 Data Assessment Tools

5.6.1 Trophic Status

Trophic status is a good method of assessing changes in lake productivity and often reflects land use impacts on water quality. The following table provides guidance on interpretation of results and identifying the trophic status of the lake.

Table 5. Trophic status analysis

	Chl *a* (ug/L)	Total P (ug/L)	Total N (ug/L)	Secchi Depth (m)
Trophic Status	Growing season mean	At spring overturn	At spring overturn	Growing season mean
Oligotrophic	0-2	1-10	<100	>6
Mesotrophic	2-5	10-20	100-500	3-6
Eutrophic	>5	>20	500-1000	<3

(Jensen 2003)

5.6.2 Nitrogen/ Phosphorus Weight ratio

The nitrogen to phosphorus weight ratio in the lake water can be used for evaluating the limiting effects of nutrients. The ratio of 21:1 obtained for Windermere Lake indicates that phosphorus is the nutrient most likely to be limiting algal and non-rooted vascular plant growth (McKean and al 1985). Additional inputs of phosphorus into the lake can result in a change of this ratio and an increase in the growth of phytoplankton.

5.7 Field Equipment

The following table provides a list of equipment that should be readily available for field sampling.

Table 6. Field Equipment

General:			
Logbook		Pencils	
Cooler		Waterproof marker	
Rope		Tape	
Camera (film)		Requisitions forms	
Waybills		Shipping labels	
Resealable bags			
Labeled Sample Bottles:			
General chemistry (1 L plastic bottle)		QA sample bottles (replicates, blanks)	
Bacteriology (500 mL sterilized bottle)		Orthophosphorus (250 amber glass bottle)	
Nutrients (500 mL opaque plastic bottle			
Chlorophyll a (1 Lplastic bottle)			
Sampling Equipment:			
Dissolved oxygen meter with extension cable for probe		Van Dorn, rope, and messenger	
Thermometer		PH meter	
Conductivity meter			
Boat Equipment:			
Motor boat		Paddles	
Fuel		Ropes	
Life jackets		Tool kit	
Anchor			
Personal Gear:			
Lunch		Rain gear	
Waders		Survival suit	
Flashlight		Gum boots	
Safety:			
Goggles or safety glasses		First Aid kit	
Rubber gloves			

Recommended Laboratories:

Any laboratory certified by the MoE Standards will ensure accurate results. The following lists provides the names of a few laboratories located in Vancouver.

Maxxam Analytics Ltd.
8577 Commerce Court
Burnaby, BC
V5A 4N5
604-444-4808

ALS Environmental
1988 Triumph St.
Vancouver, BC
V5L 1K5
604-253-4188; 800-665-0243

Cantest Laboratory
4606 Canada Way
Burnaby, BC
V5G 1K5
604-734-7276; 800-665-8566

CARO Environmental Services
102 – 3677 Highway 97N,
Kelowna, BC
V1X 5C3
(250) 765-9646

6 Conclusion

Nutrient enrichment is a concern to residents residing along Windermere Lake along with its implications on the long-term aquatic health of the system. Continued monitoring is required to develop a dataset to reflect the natural variations and land use implications on water quality within Windermere Lake. A community based monitoring program will capture valuable data and increase awareness within the local population on water quality and shoreline issues. Findings from these studies are important tools to land planners in determining future development possibilities within the area.

The 1999 monitoring program provided evidence that Windermere Lake is becoming more enriched or eutrophic. Of the water quality parameters, dissolved oxygen, pH, total organic nitrogen and total dissolved phosphorus showed significant trends indicating Windermere Lake is becoming mesotrophic. The north end of the lake exhibited higher indices of increased eutrophication through oxygen, pH and total dissolved phosphorus readings (Courtney 1999). Future monitoring will continue to assess changes in nutrient loads within the lake. Trophic status will be documented through monitoring regime focusing on productivity levels.

Summary of recommendations:

- A five year monitoring program focusing on lake productivity will assess the state of water quality in Windermere Lake and determine trends.
- Monitoring sites of priority are the three mid lake sample sites (North Station, Mid-Lake Station and South Station) and beach sites (Windermere , Athalmer, and Invermere).
- Parameters of priority are nutrients, bacteriology, dissolved oxygen, temperature, pH, chlorophyll *a*, total sulphide, and sulphate.
- Additional monitoring recommended at three water intakes (Windermere, Timber Ridge and Parr Utilities) are included to capture seasonal variations.
- Further studies are listed to ensure all elements are addressed. These recommendations include inflow monitoring, assessment of macrophyte abundance and chlorophyll *a* analysis.
- A fluorometer survey of the entire lakeshore affected by development is recommended to detect leachate inflows from onsite wastewater disposal.
- Water Survey of Canada should resume monitoring water discharge at the old Columbia River Athalmer (08NA004) site. This data will help with the interpretation of water quality parameters within the monitoring program.
- A professional biologist should be hired to review and amalgamate the data on an annual basis. Yearly reports should be completed to compile that years data and a final report should be completed after five years which should assess changes in water quality and trends over time.

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8 Glossary of Terms

algae - primitive chlorophyll-containing mainly aquatic eukaryotic organisms lacking true stems and roots and leaves.

alkalinity - is the measure of the ability of water to maintain its pH and neutralize acidic inputs. It is determined primarily by the amount of carbonate, bicarbonate and hydroxide ions in the water.

anthropogenic - effects or processes that are derived from human activities, as opposed to effects or processes that occur in the natural environment without human influences.

aquatic macrophytes - are aquatic plants that are large enough to be apparent to the naked eye; in other words, they are larger than most algae.

bacteriology - The study of a group of single-celled procaryotic organisms called bacteria.

benthic invertebrates - the animals lacking a backbone found in the gravels and sediments at the bottom of a stream. Common benthic invertebrates include worms, snails, water mites, leeches, small crustaceans, and insect larvae. Benthic invertebrates are an important food source for fish and play a major role in the decomposition of organic material, and therefore, affect nutrient availability in the water.

carbonates - a colorless or white crystalline compound, $CaCO_3$, occurring naturally as chalk, limestone, marble, and other forms.

chlorophyll - is a green photosynthetic pigment found in plants, algae, and cyanobacteria.

coarse fish - A freshwater fish, other than trout and salmon.

fecal coliforms - fecal coliforms are a group of bacteria that inhabit the intestinal tract of warm blooded animals. They are found in human and animal sewage and are important because if they are present other harmful microorganisms like *Giardia*, *Salmonella*, and *Cryptosporidium* may be present.

control -The condition downstream from a gauging station that determines the stage/discharge relation. It may be a stretch of rapids, a weir or other artificial structure. In the absence of such features, the control may be a less obvious condition such as a convergence of the channel or even simply the resistance to flow through the downstream reach. A shifting control exists where the stage/discharge relation tends to change because of impermanent beds or banks.

conductivity - is termed specific conductance if standardized to 25°C. It is as measure of the ionic content of the water, and specifically, its ability to conduct an electrical current. Dissolved ions such as sodium, potassium, calcium, magnesium, sulphate and nitrate contribute to the conductivity of the water as do dissolved organic substances.

cross section of a stream - A specified vertical plane through a stream bounded by the wetted perimeter and the free surface.

diatoms - are a major group of eukaryotic algae, and are one of the most common types of phytoplankton. Most diatoms are unicellular, although some form chains or simple colonies. A characteristic feature of diatom cells is that they are encased within a unique cell wall made of silicate. These walls show a wide diversity in form, some quite beautiful and ornate.

discharge, Q - The volume of liquid flowing through a cross section per unit of time. It is not synonymous with "flow".

discharge measurement - The determination of the rate of discharge at a gauging station on a stream, including an observation of "no flow", which is classed as a discharge measurement.

dissolved oxygen - is oxygen dissolved in the water. Oxygen is essential for most aquatic life forms and chemical reactions within streams such that minimum concentrations are necessary for a functioning system. Excessive amounts of oxygen and other supersaturated gasses (caused by high pressures of dam spillways for example) can negatively affect aquatic life through the production of “gas bubble trauma” or the over inflation of swim bladders in fish. Dissolved oxygen concentration is a function of the temperature of the water. With increasing temperature, the solubility of oxygen decreases. At the same time, the respiratory requirements of aquatic organisms increase with increasing temperature, however, there is less oxygen in the water to meet these increased needs, and death can result.

ecosystem integrity - the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of the natural habitat of a region (Karr and Dudley 1981).

epilimnion – is the top-most layer in a thermally stratified lake, occurring above the deeper hypolimnion. It is warmer and typically has a higher pH and dissolved oxygen concentration than the hypolimnion. Being exposed at the surface, it typically becomes turbulently mixed as a result of surface wind-mixing. It is also free to exchange dissolved gases (ie O_2 and CO_2) with the atmosphere.

eutrophic - having waters rich in mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

eutrophication - is the gradual increase and enrichment of an ecosystem by nutrients such as nitrogen and phosphorus.

flow - The movement of water in a channel without reference to rate, depth, etc.

fluorescence - The emission of electromagnetic radiation, especially of visible light, stimulated in a substance by the absorption of incident radiation and persisting only as long as the stimulating radiation is continued.

fluorometer - An instrument for detecting and measuring fluorescence.

gauging station - the complete installation at a measuring site where systematic records of water level and/or discharge are obtained.

hardness – is a measure of the concentration of ions such as calcium and magnesium. The geology of the area will greatly influence both the hardness and the types of ions comprising it. The hardness of the water partly determines the toxicity of metals such as cadmium, copper and zinc, with a decrease in hardness resulting in an increase in toxicity. Hardness itself is not a health concern, but can cause scaling and calcium deposits.

hypolimnion – is the bottom and most dense layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline. Typically, it is non-circulatory and remains cold throughout the year. Typically the hypolimnion is the coldest layer in the summer and the warmest during winter. Being at depth, it is isolated from surface wind-mixing and does not receive enough incoming irradiance (light) for photosynthesis to occur.

lacustrine - of or relating to lakes. Living or growing in or along the edges of lakes.

mesotrophic lakes - are moderately productive lakes, with slightly green water.

metalimnion – is a zone of abrupt temperature change (thermocline) between the warm epilimnion and the cool hypolimnion of a lake.

nutrients - nitrogen and phosphorus are the two most important nutrients required for plant growth. Various chemical forms of these nutrients exist in the water and some are more important than others in determining how much primary production or plant growth will occur. Nitrate and phosphate are the more readily available forms and are most commonly measured.

These nutrient concentrations need to be high enough to support a healthy plant community, which provides the basis of the food chain. Excessive amounts of nutrients, however, can also cause problems. A high amount of plant growth eventually leads to a high amount of dead plant material. Oxygen, required to decompose the organic material, can be significantly depleted to a point where aquatic organisms die. Nitrite is another form of nitrogen commonly measured because of potential health problems for both aquatic organisms and humans. In high concentrations, nitrite can bind to the haemoglobin of blood and prevent its uptake of oxygen. Babies under 3 months of age are especially at risk for developing “blue baby” syndrome, and can die as a result of drinking contaminated water.

oligotrophic - waters that are relatively low in nutrients, cannot support much plant life and also having large amounts of dissolved oxygen throughout.

pH - the concentration of hydrogen ions in the water. The pH of water indicates how basic or neutral it is. A pH of 7 is neutral, above 7 is basic and below 7 is acidic. The pH also influences the toxicity of metals, especially aluminum and iron. At more acidic pH levels, these metals are significantly more toxic.

phytoplankton - refers to the algal or plant-like component of the plankton that drifts in the water column.

photosynthesis - The process in green plants and certain other organisms by which carbohydrates are synthesized from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a byproduct.

primary production - the amount of plant growth, used as a food source for herbivorous animals such as benthic invertebrates and fish.

riparian – the vegetation that grows on the banks of streams. Riparian plants are terrestrial, not aquatic, however, their leaf litter does contribute to the organic matter content of the stream and is often a major source of food for aquatic organisms.

salmonid – any member of the family Salmonidae, which includes the salmon, trout, chars, whitefishes, ciscoes and grayling of North America.

sediment - is any particulate matter that can be transported by fluid flow and which eventually is deposited as a layer of solid particles on the bed or bottom of a body of water or other liquid.

sedimentation - is the deposition by settling of a suspended material.

soil porosity - The volume of water that can be held in a soil. Also refers to the ratio of the volume of voids to the total volume of the soil.

lake turnover - during late summer and autumn, air temperatures cool the surface water causing its density to increase. The heavier water sinks, forcing the lighter, less dense water to the surface. This continues until the water temperature at all depths reaches approximately 4º C (at which temperature water is at it's densest). Because there is very little difference in density at this stage, the waters are easily mixed by the wind. The sinking action and mixing of the water by the wind results in the exchange of surface and bottom waters which is called "turnover." During spring, the process reverses itself. This time ice melts, and surface waters warm and sink until the water temperature at all depths reaches approximately 4º C. The sinking combined with wind mixing causes spring "turnover."

subsurface flow – is the flow of water beneath the surface of the earth.

stream - The generic term for water flowing in an open channel.

temperature - the temperature of the water directly affects the productivity of the system through influencing the chemical reactions occurring within the water as well as the growth of plants and animals. Extremes of either temperature will negatively affect growth, but in our temperate environment, it is more important that temperature is not allowed to rise too high.

thermal stratification – is the vertical variation of temperature in a lake, in which water temperatures decrease with depth, and is most pronounced during the summer.

total coliform - is a non-specific indicator of fecal contamination and can originate from a number of different plant and soil sources.

trophic status – is a measure of a lake's productivity and it's sensitivity to additional inputs of nutrients.

TSS (total suspended solids; non-filterable residue) - the total amount of solids suspended in the water, or those large enough to be caught by a 0.45 μm filter. A close relationship may be established between TSS and turbidity, since they both measure clay, silt and colloidal material suspended in the water.

turbidity - is an optical characteristic of water, in that it is a measure of how much light passes through it. Turbidity is caused by the amount of suspended matter in the water, including clay, silt, fine particles of organic and inorganic matter, and microscopic organisms. High turbidity levels can obscure light availability and reduce plant production as well as negatively affect some animal behaviors such as predator avoidance. Particles can also settle out on the stream bottom and smother aquatic invertebrates as well as developing fish embryos. Turbidity is of a health concern for humans drinking chlorinated water due to the possible reaction of chlorine with organic materials to produce carcinogenic substances.

water quality guidelines – are provincially determined safe levels of substances for the protection of a given water use, including drinking water, aquatic life, recreation and agricultural uses.

watershed - is a region of land where water flows into a specified body of water, such as a river, lake, sea, or ocean.

APPENDIX 1. LIST OF WATER LICENSES

APPENDIX 2. TERMS OF REFERENCE

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Introduction

The RDEK is seeking proposals to undertake a study which will primarily consist of a review, summarization and consolidation of existing Lake Windermere water quality literature and recommendations for further sampling. The study's recommendations will identify sampling requirements to be implemented within the *Healthy Waters for Healthy Communities – Lake Windermere* (HWHC) project spearheaded by Wildsight (formerly East Kootenay Environmental Society) with assistance from stakeholders. The HWHC project will develop tools required and address threats to the sustainable development of Lake Windermere and educate the Lake Windermere community regarding the current lake quality.

Objectives

The objectives of this study are to provide the RDEK, Wildsight and stakeholders a data collection and sampling regime to monitor Lake Windermere over the next 5 years through the HWHC project. The study will identify past and future sampling locations, sampling frequency, sampling methods, sampling protocols and guidelines, and sample analysis criteria. Detailed trends or changes in water quality over the last several years are to be identified.

It is suggested that the completion of the Literature Review Report be within 30 days of award. Proponents are to provide a project schedule outlining milestones such as start date, start meeting, draft submission, and final submission.

Existing / Historical Data

Within the Literature Review Report, Proponents are to summarize the Lake Windermere water quality literature from the last 25 years. A list of literature to be summarized and reviewed which will be available at the RDEK is:

- Urban Systems. 2001. Lake Windermere Management Strategy. Report prepared for: District of Invermere
- McDonald, L.E. 2000. Windermere Lake: Water Quality Changes Over the Past 300 Years as determined From a Bottom Sediment Core. British Columbia Ministry of Environment, Lands & Parks, Pollution Prevention, Kootenay Region.
- Courtney, Rick F. 1999. Windermere Lake: Water Quality Monitoring Program. EnviResource Consulting. Report prepared for: Regional District of East Kootenay.
- Griffith, R.P. 1994. A Reconnaissance Survey of Windermere Lake. Report prepared for: Mica Fisheries Compensation Program, B.C. Hydro / B.C. Environment.

- Wiens, J.H. and F.A. Noone. 1987. Windermere Lake Leachate Detection Study. Ministry of Environment & Parks, Waste Management Branch.
- McKean, C.J.P. and R.N. Nordin 1985. Upper Columbia River Area: Columbia and Windermere Lakes Sub-Basin Water Quality assessment and objectives. Technical Appendix. Resource Quality Section, Water Management Branch, Ministry of Environment. Victoria, B.C.
- McKean, C.J.P. and R.N. Nordin 1983. Upper Columbia Planning Unit Water Quality Assessment: Volume 1, Columbia and Windermere Lakes, Columbia River Between the Lakes and Windermere Creek. Resource Quality Section, Water Management Branch.
- McKean, C.J.P. and R.N. Nordin 1983. Upper Columbia Planning Unit Water Quality Assessment: Volume 1, Columbia and Windermere Lakes, Columbia River Between the Lakes and Windermere Creek. Resource Quality Section, Water Management Branch.
- Ministry of Environment. 1981. Kootenay Air and Water Quality Study Phase II. Water Quality in the Upper Columbia River Basin. Aquatic Studies Branch. Victoria B.C.

Copies of the above literature will be made available to the successful Proponent only. Proponents may schedule an appointment with the RDEK to arrange to review the above literature for preparation of their proposals.

The Proponent is to search for other available literature from various government agencies and interest groups and include them as part of their review within the study.