ENVIRONMENTAL PROTECTION DIVISION

ENVIRONMENTAL SUSTAINABILITY AND
STRATEGIC POLICY DIVISION

MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for the Little Qualicum River Community Watershed

TECHNICAL REPORT

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EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of the Little Qualicum River, British Columbia, and proposes water quality objectives designed to protect existing and future water uses. The water quality assessment for the river and its tributaries and an evaluation of the watershed form the basis for the objectives.

The Little Qualicum River community watershed, with an area of 24,718 ha, is located near the community of Qualicum Beach, British Columbia, and provides that community with its drinking water. The water uses to be protected in the Little Qualicum River include drinking water, irrigation, primary and secondary contact recreation, aquatic life, and wildlife. Forestry roads provide recreational access to the upper watershed, and a range of activities including hunting and hiking occur in those areas. As well, there are considerable agriculture and residential uses occurring throughout the lower watershed. These activities, as well as forestry and wildlife, all have the potential to affect water quality in the river.

Water quality monitoring was conducted between 2004 and 2007, and in 2011-12. The results of this monitoring indicated that the overall state of the water quality is quite good, with occasional slightly elevated turbidity levels. All chemical, physical and biological parameters met provincial water quality guidelines with the exception of: temperature and total suspended solids (TSS) (also called non-filterable residue), which exceeded the aquatic life guideline on occasion; and turbidity, total organic carbon, true colour, and *Escherichia coli*, which exceeded the drinking water guidelines on occasion. In order to maintain and protect water quality in the Little Qualicum River, ambient water quality objectives were set for these parameters, and for total phosphorous, in the watershed.

Future monitoring recommendations include attainment monitoring every 3-5 years, depending on available resources and whether activities, such as forestry or development, are underway within the watershed. This monitoring should be conducted for one year during the summer low flow and fall flush period (five weekly samples in 30 days), and monthly from May through September for total phosphorous only, at all four monitoring

sites to ensure water quality is protected throughout the watershed and help determine the source of exceedances, should they occur.

Variable	Objective Value
Turbidity	2 NTU max March - September 5 NTU max October – February ≤1 NTU at intake 95% of time
Temperature (throughout watershed)	Short term (< 5 years): ≤17^{o}C maximum average weekly
Total Suspended Solids (TSS)/ Non Filterable Residue (throughout watershed)	26 mg/L max 6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Total Organic Carbon	≤4.0 mg/L maximum
True colour	15 TCU maximum
Total Phosphorus (throughout watershed)	0.010 mg/L maximum 0.005 mg/L average (based on a minimum of monthly samples collected from May – Sept)
Escherichia coli	≤10 CFU/100 mL (90th percentile) (based on a minimum 5 weekly samples collected over a 30-day period)

Designated water uses: drinking water, irrigation, primary and secondary contact recreation, aquatic life, and wildlife.

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AKNOWLEDGEMENTS

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Deborah Epps, Environmental Impact Assessment Biologist
Environmental Protection Division
Ministry of Environment

Burke Phippen, RPBio.
BWP Consulting Inc.
Kamloops, BC

1.0 INTRODUCTION

The British Columbia (BC) Ministry of Environment (MOE) is conducting a program to assess water quality in priority watersheds. The purpose of this program is to accumulate the baseline data necessary to assess both the current state of water quality and long-term trends, and to establish ambient water quality objectives on a watershed specific basis. Water quality objectives provide goals that need to be met to ensure protection of designated water uses. The inclusion of water quality objectives into planning initiatives can help protect watershed values, mitigate impacts of land-use activities, and protect water quality in the context of both acute and chronic impacts to human and aquatic ecosystem health. Water quality objectives provide direction for resource managers, serve as a guide for issuing permits, licenses, and orders by MOE, and establish benchmarks for assessing the Ministry's performance in protecting water quality. Water quality objectives and attainment monitoring results are reported out both to local stakeholders and on a province wide basis through forums such as State of the Environment reporting.

Vancouver Island's topography is such that the many watersheds of the MOE's Vancouver Island Region are generally small (<500 km^2). As a result the stream response times can be relatively short and opportunities for dilution or settling are often minimal. Rather than developing water quality objectives for these watersheds on an individual basis, an ecoregion approach has been implemented. The ecoregion areas are based on the ecosections developed by Demarchi (1996). However, for ease of communication with a wide range of stakeholders the term "ecoregion" has been adopted by Vancouver Island MOE regional staff. Thus, Vancouver Island has been split into six terrestrial ecoregions, based on similarities in characteristics such as climate, geology, soils, and hydrology (Figure 1).

Fundamental baseline water quality should be similar in all streams and all lakes throughout each ecoregion. However, the underlying physical, chemical and biological differences between streams and lakes must be recognized. Representative lake and stream watersheds within each ecoregion are selected (initially stream focused) and a three year monitoring program is implemented to collect water quality and quantity data, as well as biological data. Standard base monitoring programs have been established for use in streams and lakes, to maximize data comparability between watersheds and among ecoregions, regardless of location. Watershed objectives will be developed for each of the representative lake and stream watersheds, and these objectives will also be applied on an interim basis to the remaining lake and stream watersheds within that ecoregion. Over time, other priority watersheds within each ecoregion will be monitored for one year to verify the validity of the objectives developed for each ecoregion and to determine whether the objectives are being met for individual watersheds.

Figure 1. Map of Vancouver Island Ecoregions.

Partnerships formed between the MOE, local municipalities, other stakeholders and stewardship groups are a key component of the water quality network. Water quality sampling conducted by the public works departments of local municipalities and stewardship groups has enabled the Ministry to significantly increase the number of watersheds assessed and the sampling regime within these watersheds. Stronger relationships with local government and interest groups provide valuable input, local support and, ultimately, a more effective monitoring program.

The Little Qualicum River provides a significant source of drinking water to the local community and has very high fisheries values, with steelhead, rainbow trout, cutthroat trout, all five species of pacific salmon, Dolly Varden, kokanee, and smallmouth bass present at some point during the year (FISS, 2013). It is also one of the few streams in B.C. where brown trout can be found (FISS, 2013). Anthropogenic land uses within the watershed include timber harvesting, agriculture, rural residential, urban residential (in the lower watershed) and recreation. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in Little Qualicum River.

This report examines the existing water quality of Little Qualicum River from 2004-2012 and 2011-12, and recommends water quality objectives for this watershed based on potential impacts and water quality parameters of concern. The Little Qualicum River was designated as a community watershed in 1995, as defined under the *Forest Practices Code of British Columbia Act* ("the drainage area above the downstream point of diversion and which are licensed under the *Water Act* for waterworks purposes"). This designation was grandparented and continued under the *Forest and Range Practices Act* (FRPA) and Regulations in 2004 and infers a level of protection. As the majority of the Little Qualicum River community watershed is on private land, the FRPA does not apply to most of the watershed. However, the MOE uses other tools, such as water quality objectives, and legislation, such as the *Private Managed Forest Land Act* and the *Drinking Water Protection Act*, to ensure that water quality and human health within these watersheds is protected and managed in a consistent manner.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

Little Qualicum River is a fourth-order stream 18.2 km in length from Cameron Lake to the outlet into Georgia Strait just north of the Town of Qualicum Beach, B.C. The community watershed portion is 24,718 ha in area, ranging in elevation from near sea level at the Little Qualicum Waterworks District water intake to about 1,580 m elevation at Mt. Moriarty (Figure 2). Other steep, high mountains including Mt. Arrowsmith (1,820 m) border the watershed. The Little Qualicum Waterworks District intake is located approximately 850 m upstream from the mouth of the Little Qualicum River.

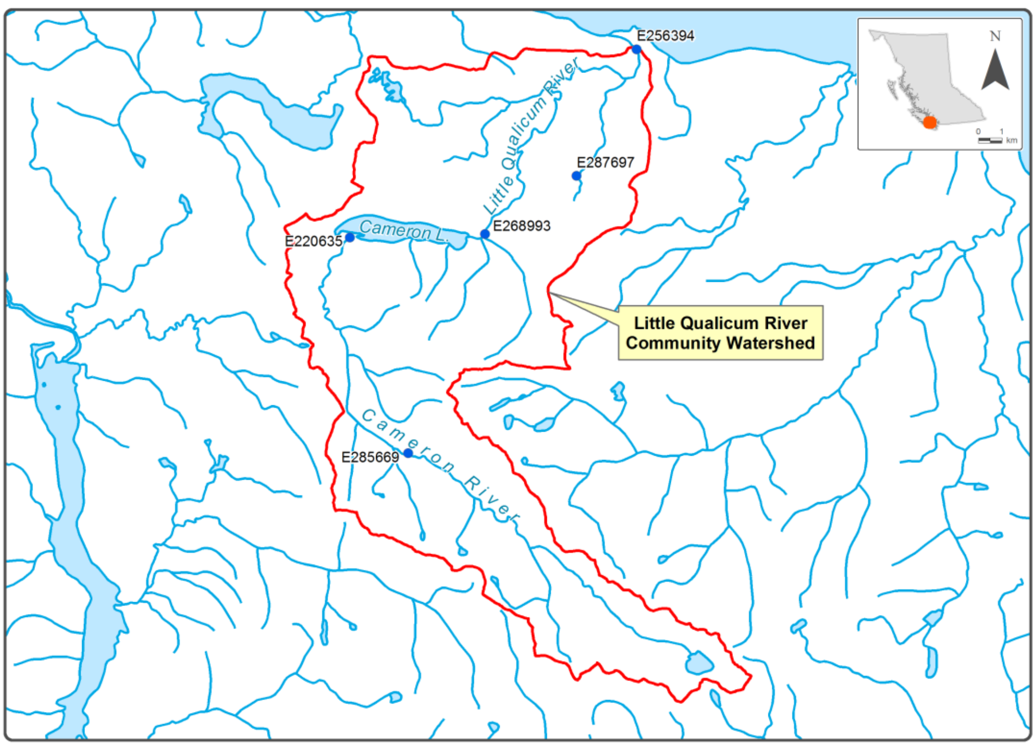

Figure 2. Little Qualicum River Community Watershed and location of water quality monitoring sites.

The primary tributary to Cameron Lake is the Cameron River, which is a third-order stream 31.2 km long that drains the upper portion of the watershed. Named tributaries to the Cameron River include Copp Creek, Kammat Creek and Yellow Creek. Named tributaries to the Little Qualicum River below Cameron Lake are Kinkaide Creek, Lockwood Creek, McBey Creek and Whiskey Creek. Named lakes within the watershed (Table 1) are all located upstream from Cameron Lake (the largest lake in the watershed). Cameron Lake is large (surface area 477.4 ha, perimeter 13,626 m) and deep (maximum depth 43 m), while the other lakes are all much smaller.

Table 1. Summary of named lakes within the Little Qualicum River watershed.

Name	Surface area (ha)	Elevation (m)
Cameron Lake	477.4	184
Labour Day Lake	74	905
Peak Lake	5.2	1,060
Kammet Lake	7.6	890
Henry Lake	4.6	950
St. Mary Lake	2.5	1,030

The lower portion of the watershed falls within the Coastal Douglas-fir (moist maritime, CDFmm) biogeoclimatic zone, changing at about 150 m elevation to Coastal Western Hemlock (Eastern very dry maritime, CWHxm1), which gives way to the Mountain Hemlock (windward moist montane, MHmm1) biogeoclimatic zone above 1,100 m and small areas above 1,300 m of Coastal Mountain-heather Alpine (CMAunp). The Little Qualicum River watershed transitions from the Leeward Island Mountains (LIM) ecoregion above Cameron Lake to the Nanaimo Lowland (NAL) ecoregion (see Figure 1) in the lower portion of the watershed.

2.2 HYDROLOGY AND PRECIPITATION

The nearest climate station to the watershed for which normal climate data were available was the Qualicum River station (elevation 7.6 m) (Environment Canada Climate Station 1026565). Average daily temperatures between 1971 and 2000 ranged from 3.0°C in January to 16.8°C in July (Figure 3). Average total annual precipitation between 1971 and 2000 was 1,314 mm, with only 50 mm (water equivalent) (4%) of this falling as snow. Temperatures at higher elevations in the watershed would be cooler than recorded at sea level, thus a larger portion of the annual total precipitation would have occurred as snowfall in the higher-elevation terrain of the watershed. Most precipitation (1,031 mm, or 78%) fell between October and March.

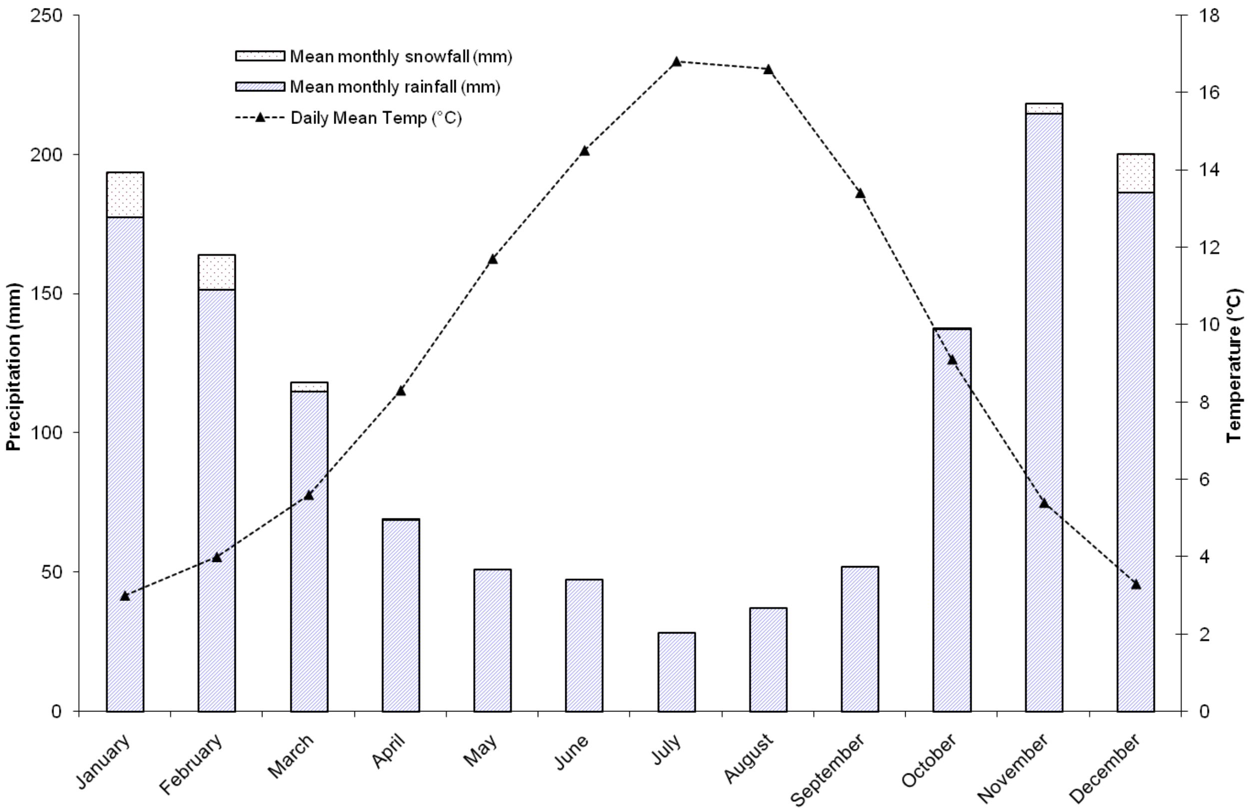

Figure 3. Climate data (1971-2000) for Qualicum (Environment Canada Climate Station 1026565).

Water Survey Canada (WSC) operated a hydrometric station on Little Qualicum River at the outlet of Cameron Lake for about 44 years, from 1913 to 1922 and again from 1960 to 2001 (WSC, 2013). As well, they operated a hydrometric station on the Little Qualicum River near Qualicum Beach, for about 26 years between 1960 and 1986, and began operating this station again in August 2012. Minimum, maximum and average daily flows for these sites are shown in Figure 4 and Figure 5. On average, flows were about 35% higher near Qualicum Beach than they were at the outlet of Cameron Lake. In the Little Qualicum River near Qualicum Beach, flows ranged between a low of 0.736 m^3/s on September 7, 1966 to a maximum of 257 m^3/s on January 15, 1961. Flows are very low during the summer months, especially August and September, although storage on Cameron Lake and releases by the Department of Fisheries and Oceans (DFO) augment these low flows.

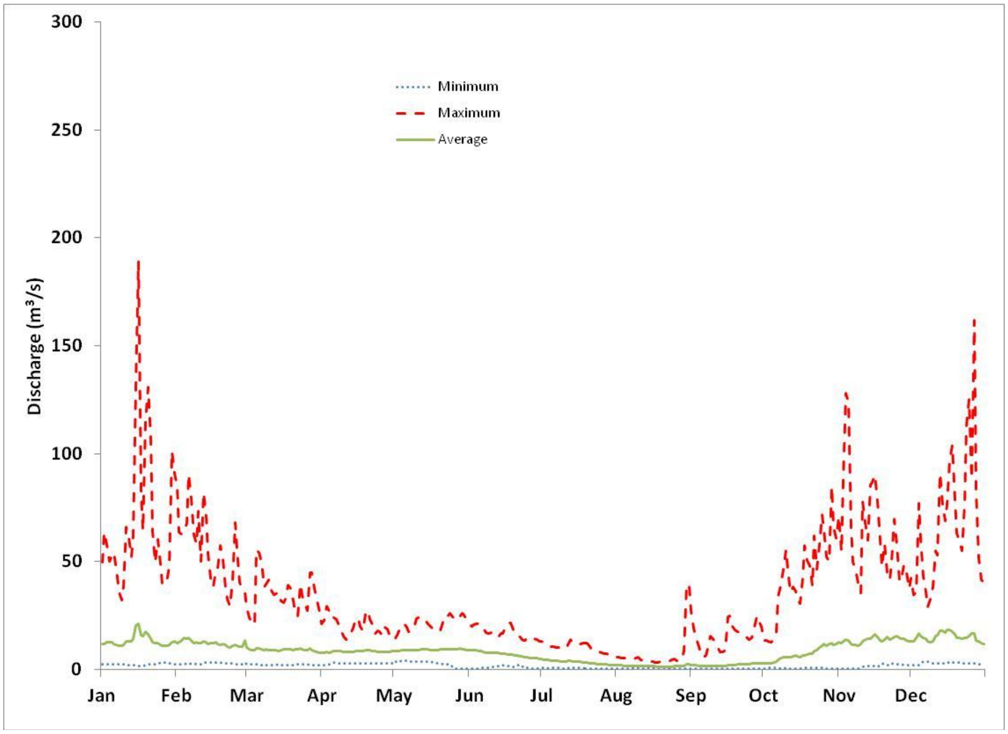

Figure 4. Minimum, maximum and average daily discharge data for Little Qualicum River below Cameron Lake (WSC Station 08HB004) between 1913 and 2001 (WSC, 2013).

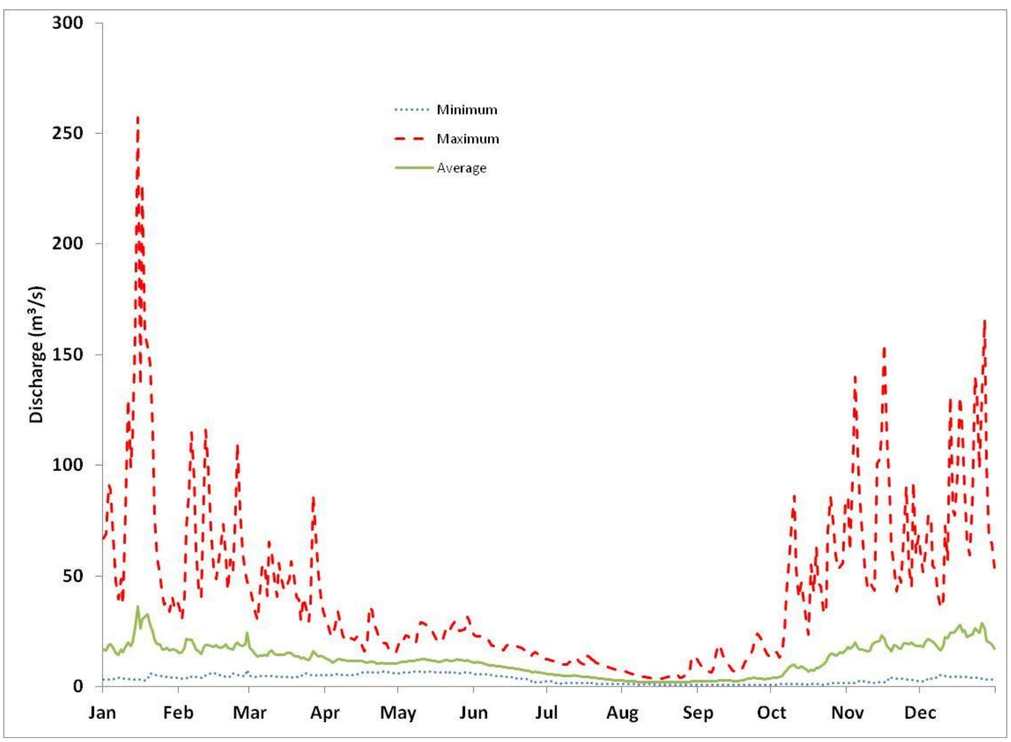

Figure 5. Minimum, maximum and average daily discharge data for Little Qualicum River near Qualicum Beach (WSC Station 08HB029) between 1960 and 1986 (WSC, 2013).

3.0 WATER USES

3.1 WATER LICENSES

Nine water licenses have been issued for the Little Qualicum River (Table 2). The majority of the licensed volume (4,018.50 dam^3/year (cubic decametres/year, where 1 $dam^3 = 1{,}000\ m^3$)) is for use by DFO to maintain minimum summer flows to support fish populations. The Little Qualicum Waterworks District is another significant licensee (389.94 dam^3/year). The remaining licenses are for other domestic use and irrigation.

Table 2. Summary of licensed water withdrawals from within the Little Qualicum River community watershed.

Use	No. of licences	Total volume of licences (dam^3/year)	Principal Licensee
Waterworks - Local Authority	2	389.94	Little Qualicum Waterworks District
Enterprise	1	3.32	
Conservation - Use of Water	1	4,018.50	DFO
Irrigation	2	197.36	Various
Domestic	3	2.49	Various
Total	9	4,611.6	

3.2 FISHERIES

The Little Qualicum River supports an extremely diverse and important fish population. Historically, it has been an important spawning and rearing ground for steelhead (*Oncorhynchus mykiss)*, although recent escapements have been between 10% and 20% of estimated capacity (BCCF, 2008a). A project to increase rearing habitat in the Little Qualicum River by constructing large woody debris (LWD) structures was undertaken in 2004 (Craig, 2005). As well, an experimental fish culture program entitled the Living Gene Bank worked to capture steelhead smolts from the Little Qualicum River, rear them to adults at the hatchery in Duncan, B.C., and then spawn them and return their progeny to the river to increase genetic diversity (BCCF, 2008b). This program ended in 2005 after providing six years (2000 – 2005) of supplementation. No steelhead or cutthroat are currently stocked in the Little Qualicum River (McCulloch, pers. comm., 2013).

Other species utilizing the river include chinook (*O. tshawytscha*), pink (*O. gorbuscha*), coho (*O. kisutch*), sockeye (*O. nerka*) and chum (*O. keta*) salmon, rainbow trout (*O. mykiss*), cutthroat trout (*O. clarkii*), brown trout (*Salmo trutta*) (originally stocked in the river in 1935-36, and one of the few viable populations of this species in B.C.) and Dolly Varden (*Salvelinus malma malma*). Kokanee (*O. nerka*) and smallmouth bass (*Micropterus dolomieu*) may also be found (FISS, 2013). The Little Qualicum River fish hatchery releases a large number of chinook and chum each year. The fish hatchery also maintains a 4.2 km long spawning channel in the lower Little Qualicum River, utilized by a number of species. The Little Qualicum Falls, about 12 km from the mouth of the Little Qualicum River, act as a barrier to upstream fish migration.

3.3 RECREATION

Forestry roads permit access to the upper watershed, and it is likely that recreationalists utilize these areas for hiking, ATV use, hunting, and other activities. No specific studies have been conducted on recreational use in the upper watershed, so it is difficult to quantify or qualify this use. The Cameron River is a popular destination for kayakers as well, boasting numerous Class IV rapids (LiquidLore, 2013).

The 440 ha Little Qualicum Falls Provincial Park, straddling the upper portion of the Little Qualicum River as well as the southern shore of Cameron Lake, is a popular recreation destination. Park facilities include a campground with 93 vehicle-accessible campsites (open annually from May 1 to September 30), as well as two day-use areas. There is no boat launch in the provincial park, but the nearby privately-owned Cameron Lake Resort provides a boat launch for their guests. Swimming is encouraged in Cameron Lake, as well as upstream from 75 m above the middle canyon bridge in Little Qualicum River (swimming is not permitted below this point due to dangerous currents associated with the waterfalls). Boating, fishing and sail boarding on Cameron Lake are all popular activities. There are a large number of hiking trails within the park and along the river that are popular throughout the year (especially in summer) (Almond, pers. comm., 2013).

The 44 ha Little Qualicum River Regional Park (solely owned and managed by the Regional District of Nanaimo) runs along both sides of the river immediately below the Provincial Park and includes an unmaintained trail system. Current recreational use of this park is limited, as there are no formally developed trails (other than a short path that leads from Meadowood Way into the nearby Provincial Park), and future development will be limited by steep banks, swamps and sensitive riparian habitat (RDN, 2012). There is a BC Hydro corridor passing through the park, but a gate controls vehicular access to the park from the corridor. A private gravel road passes through the park and across a bridge over the Little Qualicum River through an easement within the Regional Park. The road is gated on weekends, during the summer when there is high fire risk, and when there is heavy snowfall, but is used by local residents to access the Alberni Highway (Highway 4) during the week (RDN, 2012). ATV users access the river from this bridge, as well as along the BC Hydro corridor, and utilize the nearby gravel pit operated by Ozero (RDN, 2012). An RDN management study (RDN, 2012) makes recommendations to minimize impacts to water quality in the Little Qualicum River from the Regional Park.

The 301 ha MacMillan Provincial Park straddles Highway 4 along Cameron Lake and along the upper Little Qualicum River downstream of the lake for about 4.5 km. This includes the very popular Cathedral Grove stand of old growth forest that in 1992 received an estimated 300 000 visitors each year (BCMOELP, 1992), a number which is likely much higher today.

There is also a trail system in the lower portion of the watershed near the estuary. Much of the estuary is protected, consisting of: the Qualicum National Wildlife Area, managed by the Canadian Wildlife Service of Environment Canada; the Parksville-Qualicum Beach Wildlife Management Area, managed by the province; and the Little Qualicum Estuary Regional Conservation Area, managed by the Regional District of Nanaimo and Ducks Unlimited Canada (RDN and DUC, 2010).

3.4 FLORA AND FAUNA

The Little Qualicum River watershed provides habitat to a wide variety of wildlife species including blacktail deer (*Odocoileus hemionus columbianus*), black bear (*Ursus americanus*), cougar (*Puma concolor*), and numerous other small mammals and birds. The endangered Vancouver Island marmot (*Marmota vancouverensis*) has been found in the sub-alpine portions of both Mount Moriarty and near Labour Day Lake (BCCDC, 2013). Another species of concern, the anguinae sub-species of ermine (*Mustela erminea anguinae*), has been observed in the lower portion of the watershed (BCCDC, 2013). Populations of Roosevelt elk (*Cervus elaphus roosevelti*), marten (*Martes americana*), fisher (*Martes pennant*), and river otter (*Lontra canadensis*) can also be found within the watershed. The Little Qualicum River estuary is home to a wide variety of birds, with over 220 species being reported (MABF, 2001).

A number of rare plant species are also found within the Little Qualicum River watershed. Species on the BC Conservation Data Centre (CDC) red list (composed of species legally considered endangered or threatened) include *Rubus nivalis* (snow bramble) and *Allium crenulatum* (Olympic onion). Blue-listed plant species (considered species of concern) include *Senecio macounii* (Macoun’s groundsel), *Viola howellii* (Howell’s violet), *Glyderia occidentalis* (western mannagrass), *Nothochelone nemorosa* (woodland penstemon), *Draba lonchocarpa* var. *vestita* (lance-fruited draba), and the *Aster paucicapitatus* (Olympic mountain aster) (BCCDC, 2013).

3.5 DESIGNATED WATER USES

Designated water uses are those identified for protection in a specific watershed or waterbody. Water quality objectives are designed for the substances or conditions of concern in a watershed so that their attainment will protect the most sensitive designated uses. The preceding discussion demonstrates that water uses to be protected include drinking water, irrigation, primary and secondary contact recreation, aquatic life, and wildlife.

4.0 INFLUENCES ON WATER QUALITY

Due to the large volume of Cameron Lake, the residence time is such that impacts occurring to water quality above the lake are mitigated to a large extent by the time the water leaves the lake due to settling and precipitation. An exception to this occurs during sediment events in the Cameron valley upstream from Cameron Lake. During these events, clay-sized particles passed through the lake outlet, while silt-sized particles and larger (0.002 mm and larger) are retained in the lake (Horel, 1998; Sweeten *et al*. 2003). Therefore, while turbidity in the lower creek is occasionally affected by sedimentation events in the upper watershed, most significant impacts on water quality within Little Qualicum River are likely to be from activities occurring within the lower portion of the watershed, downstream from Cameron Lake.

4.1 LAND OWNERSHIP

The upper watershed (upstream from Cameron Lake, as well as the McBey Creek and Lockwood Creek sub-basins which drain into the Little Qualicum River just downstream from Cameron Lake) consists primarily of land within Managed Forest 19, which is managed by Island Timberlands. Land use and ownership for the upper watershed is summarized in Table 3 (from Horel, 1998; Epps, pers. comm., 2013).

Table 3. Summary of land ownership in upper Little Qualicum River watershed (upstream from Cameron Lake) (from Horel, 1998, Epps, pers. comm.., 2013).

Land Owner/manager	% of watershed	# of hectares
Private/Island Timberlands	74%	10,353
Parks/Provincial Gov’t	8%	1,056
Crown and private/others	18%	2,580
Total	100%	13,989

Lands within the Agricultural Land Reserve (ALR) are found in the lower portion of the watershed (Figure 6), and are generally not directly adjacent to the mainstem of the Little Qualicum River. However, agricultural activity also occurs outside of the ALR, and sediment from cleared land, nutrients from fertilizer use, pesticides, and animal waste can all be transported from farmland into the river.

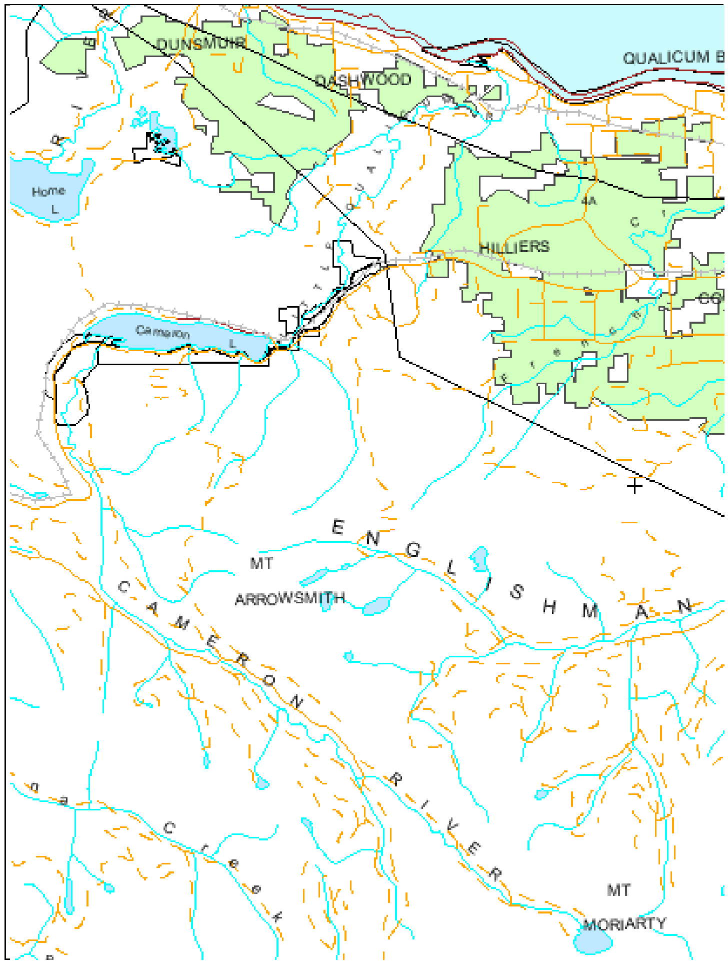

Figure 6. Little Qualicum watershed, showing outlines of Agricultural Land Reserve (in green).

There is a significant amount of rural residential development in the lower portions of the watershed, including the Little Qualicum River Village subdivision (located north of the Little Qualicum Falls Provincial Park), Qualicum River estates (located south of Highway 19) and residential lots near the Old Island Highway 19A (near the mouth of the river). Thus, potential sources of contamination associated with households (such as septic fields), as well as fecal material from domestic animals, may affect water quality in the Little Qualicum River. As well, there is some urban development in the lower watershed near the Old Island Highway. Urbanization, particularly in the lower watershed, can impact water quality in many ways, including road runoff, storm water, nutrients from lawn fertilizers, proliferation of impervious surfaces and increased sediment loadings from land disturbance.

Significant erosion has occurred along the stream banks of the lower Little Qualicum River, as much of the streambank has been historically logged, leaving immature conifers and deciduous trees that are prone to undercutting (Poulin, 2005). Restoration work, including streambank armoring with rip-rap, boulder groynes, and large woody debris on a 130 m stretch of the lower Little Qualicum River in August 2005, was conducted to minimize streambank erosion and siltation problems (Steelhead Review, 2005).

Finally, there are two highway crossings in the lower Little Qualicum River watershed: the Inland Island Highway (Highway 19) crosses the river about midway between the Little Qualicum Falls Provincial Park and the mouth of the river (about 10 km upstream from the mouth of the river; and the Old Island Highway (Highway 19A), a major highway and local thoroughfare with high traffic volume, crosses the Little Qualicum River approximately 1.5 km upstream from the mouth of the river. The Alberni Highway (Highway 4) runs along the entire south side of Cameron Lake and parallel to Cameron River upstream of the lake for about 7 km. Runoff from the highways can also impact the Cameron River and Little Qualicum River with increased sediment loads and contaminants such as polycyclic aromatic hydrocarbons from vehicles.

4.2 LICENSED WATER WITHDRAWALS

The majority (4,018.5 dam^3/year) of the overall maximum licensed water withdrawal volume (4,611.6 dam^3/year) from the Little Qualicum River is licensed to DFO, allowing them to augment summer low flows to protect fish habitat. This license works in concert with a storage license issued to DFO on Cameron Lake permitting the storage of 5,006,8 dam^3/year. DFO and MOE determined that a minimum flow of 2.378 m^3/s was required to support the fish resource in the Little Qualicum River, which DFO releases through their storage on Cameron Lake. Low-flows (below 60% of the mean annual discharge (MAD)) occur in the Little Qualicum River between the months of June and September. As natural mean monthly flows in the Little Qualicum River occasionally fall below 10% MAD (usually in August or September), extractive licensed demands are only allowed for the period when the mean monthly flow is above 60% of MAD, unless storage is developed (Pirani and Bryden, 1996). This excludes licenses for rural, residential domestic use. Licensed low-flow demand is approximately 28.9 l/second (including extractions by the Little Qualicum Waterworks District), which should be met by a requirement in the DFO licence to provide up to 283 l/second for other water licensed water uses when necessary (Pirani and Bryden, 1996). Irrigation licensees are required to have storage (a reservoir or dugout) capable of storing the total volume of water to be used, as well as additional capacity for evaporation and other losses. As summer low-flows are regulated by the dam on Cameron Lake, and water withdrawals other than domestic use are not permitted during the dry summer months unless storage has been developed, water licenses should not impact flows in the Little Qualicum River.

There are also approximately 234 drinking water wells within the Little Qualicum River watershed (including 15 community wells, for various campgrounds, resorts and subdivisions), the majority of them downstream from Highway 4 (David, 2012). Interactions between ground and surface waters are such that when water levels decrease significantly in an aquifer, surface water flows can also decrease. A surface water stress analysis conducted by Waterline Resources Inc. and Kerr Wood Leidal for the RDN, which considered the consumptive demand and the minimum conservation flow required versus the average natural river flow plus storage for a given watershed, concluded that there is a moderate stress on surface flows in the Little Qualicum River (David *et al*. 2012).

4.3 FOREST HARVESTING AND FOREST ROADS

Forestry activities can impact water quality both directly and indirectly in several ways. The removal of trees can decrease water retention times within the watershed and result in a more rapid response to precipitation events and earlier and higher rain on snow events in spring. The improper construction of roads can change drainage patterns, destabilize slopes, and introduce high concentrations of sediment to streams.

No coastal watershed assessment procedure (CWAP) has been conducted for the Little Qualicum River watershed as a whole. However, a CWAP was conducted in 1998 for the Cameron Watershed, from the upper reaches as far downstream as Cameron Lake (Horel, 1998). There has been extensive logging in the upper watershed during the

1960's and '70's, and surface erosion is a significant concern in the upper watershed. This is primarily due to high road density, high density of stream crossings, large amounts of riparian harvesting, and a high ranking for landslide effects (Table 4). In a 2001 update to the original CWAP, Horel (2001) found that no new landslides had occurred in the upper watershed since the previous report, that ECA's had declined (no logging had occurred since 1998 in any of the sub-basins listed in Table 4 except for Cameron River), and that there was no significant change in road densities. A number of recommendations were made to address stability and erosion concerns on existing roads, as well as to utilize other measures (*e.g.* grass seeding, sediment basins, erosion blankets, and ditch checkdams) to decrease runoff to Cameron River and its tributaries.

Most streamside roadways within the watershed have a vegetated buffer between them and the river, reducing runoff and therefore decreasing the amount of turbidity and suspended solids entering the river. However, the high density of roads within the watershed suggests that, in some areas, runoff from these roads has the potential to impact turbidity levels in the river, particularly during periods of road grading or road construction. Potential impacts from these roads will decrease as roads are deactivated and reclaimed.

Table 4. Summary of harvesting activities in the Cameron River watershed to the end of 1997 (from Horel, 1998, 2001).

			Sub basin				
		Total Watershed	McBey Ck	Lockwood Ck	Cameron Lk	Cameron River (1997)	Cameron River (est. to 2005)
Total Basin Area	ha	15,818	1,091	1,429	2,081	11,217	11,356
Weighted ECA	ha	2,921	82	320	195	2,324	2,189
Weighted ECA	%	18	8	22	9	21	19
Total road length	km	321	10	28	16	268	283.4
Effective road density	km/km^2	2	0.9	2	0.8	2.4	2.5
Natural landslides	No.	54	5	1	9	39	39
Post-logging landslides	No.	42	0	4	1	37	37

The cumulative effect of the large number of small-scale disturbances associated with road construction and forest harvesting has the potential to impact water quality to a certain degree, especially with respect to turbidity levels during rain events. Improvements in harvesting practices over the past 20 years, coupled with increased legislation (for example, the *Water Act* and the *Private Managed Forest Land Act*), should decrease the potential for impacts to water quality as hydrologic recovery continues.

4.4 RECREATION

Recreational activities can affect water quality in a number of ways. Erosion associated with off highway vehicles, direct contamination of water from vehicle fuel, and fecal contamination from human and domestic animal wastes (*e.g.*, dogs or horses) are typical examples of potential effects. As no specific studies have been conducted on recreation within the Little Qualicum River watershed, the relative impacts of recreational activities cannot be discussed. However, with the ease of access in the lower watershed, the presence of two large provincial parks and a regional park within the watershed boundaries, and the proximity to population centres, it is likely that some recreational impacts occur within the watershed.

As the only boat launch on the lake is located on private land (the Cameron Lake Resort), access to the lake for boating purposes is strictly controlled; however, there is the potential for fuel spills from boats to impact water quality. Toilet facilities and waste receptacles are available in the Provincial Parks, which should minimize impacts from improperly disposed of waste. It is likely that some fecal coliforms will be shed by bathers. ATV access to the river in the Little Qualicum River Regional Park could result in turbidity events, as well as potential contaminants from fuel. Recreational use of the upper watershed (Cameron River) is likely limited to kayakers due to fast flowing water and frequent canyons, although it is possible that ATV’s are also able to access the river at some point.

4.5 WILDLIFE

Wildlife can influence water quality through the deposition of fecal material which may include pathogens such as *Giardia lamblia*, which causes giardiasis or “beaver fever”, and *Cryptosporidium* oocysts which cause the gastrointestinal disease, cryptosporidiosis (Health Canada, 2004). Microbiological indicators, such as *Escherichia coli,* are used to assess the risk of fecal contamination to human health. Fecal contamination of water by animals is generally considered to be less of a concern to human health than contamination by humans because there is less risk of inter-species transfer of pathogens. However, without specific source tracking methods, it is impossible to determine the origins of coliforms.

The watershed contains valuable wildlife habitat and provides a home for a wide variety of warm-blooded species. Therefore, the risk of contamination from endemic wildlife exists.

4.6 MINING

Mining activities can potentially impact water quality through the introduction of metals and other contaminants (*e.g.*, sulphate) to the watershed. The leaching of acidic waste rock or adit discharges can also impact downstream water quality. Mining activities generally include road construction and land-clearing, which can change water movement patterns and result in increased turbidity levels. There are no active or inactive mines located within the watershed boundaries, but there are a number of prospects in the upper watershed that contain gold, silver, cobalt, copper, lead, molybdenum, nickel, and zinc (MINFILE, 2013). The likelihood of these sites being developed for mining activities is not known, but any activities would have to undergo impact assessments to ensure that water quality is not impacted.

5.0 STUDY DETAILS

Initially (between 2004 and 2007), one water quality monitoring site was established within the Little Qualicum River watershed: Environmental Monitoring System (EMS) Site E256394 is the Little Qualicum River at the Waterworks intake (Figure 2). In 2011, four additional sites were added to the monitoring program: Site E285669 is located on the Upper Cameron River about 13 km upstream from Cameron Lake and accessed off of the Cameron Main forestry road; Site E220635 is on the Cameron River just upstream from Cameron Lake; Site E268993 is on the Little Qualicum River 1.2 km downstream from Cameron Lake; and Site E287697 is on Whiskey Creek, a tributary to the Little Qualicum River. The program consisted of four phases: collecting water quality data, gathering information on water use, determining land use activities that may influence water quality, and establishing water quality objectives.

Water quality data were collected from 2004 to 2007 at E256394 (Little Qualicum River at intake) and from 2011 to 2012 at all five sites. Drinking water is one of the designated water uses in the Little Qualicum River and so water quality variables relevant to the protection of raw drinking water supplies were included. Based on the current knowledge of potential anthropogenic impacts to watershed (generally associated with timber harvesting, agriculture, recreation and rural and urban residential development), natural features (wildlife), and the lack of authorized waste discharges directly to the river within the watershed, the following water quality variables were included:

- Physical: pH, temperature, specific conductivity, true color, turbidity, non-filterable residue (total suspended solids);
- Carbon: dissolved organic carbon, total organic carbon, total inorganic carbon;
- Nutrients: total phosphorus, orthophosphate, nitrate, nitrite, ammonia, total Kjeldahl nitrogen;
- Total and dissolved metals concentrations, hardness;
- Microbiological indicators: fecal coliforms, *Escherichia coli;*
- Biological: benthic invertebrates, chlorophyll *a*.

Water samples were collected approximately once a month between 2004 and 2007, and again from April 2011 through March 2012, with sampling frequencies increased to five times in 30 days during the summer low-flow (August – September) and fall high-flow (October-November) periods. Samples were collected in strict accordance with Resource Inventory Standards Committee (RISC) standards (BC MOE, 2003) by trained personnel, including Town of Qualicum staff. Samples were sent to Maxxam Analytics Inc. in Burnaby, BC (and Cantest Laboratories for microbiological analysis prior to Cantest being purchased by Maxxam) for all laboratory analyses except taxonomic identification of benthic invertebrates. Taxonomic identifications were done by Fraser Environmental Services of Surrey, B.C .

Weekly field monitoring for temperature, dissolved oxygen, specific conductivity, and turbidity was also conducted by stewardship groups using a YSI ProPlus handheld meter and LaMott turbidity meter at all sites during the summer low flow and fall flush periods in 2011 and 2012.

Summary statistics were calculated on all available data, and 90th percentiles were calculated using data from a minimum of 5 weekly samples in 30 consecutive days for each site. Data are summarized in Appendix I.

An automated water quality/quantity monitoring station was also installed at the E256394 Little Qualicum River intake site from April 2011 to March 2012 to measure and log water temperature, turbidity, conductivity and water level. Here, a YSI 600 OMS sonde turbidity sensor was installed within the stream flow and polled every 15 minutes. HOBO temperature loggers were installed at two sites (E285669 Upper Cameron River and E220635 Cameron River upstream of Cameron Lake) in June 2011 and remain in the river to date. These temperature loggers collect hourly temperature data.

5.1 QUALITY ASSURANCE / QUALITY CONTROL

Quality assurance and quality control was verified by collecting duplicate and blank samples. Duplicate (or triplicate) co-located samples were collected by filling two (or three) sample bottles in as close to the same time period as possible (one right after the other) at a monitoring location, and then calculating the relative percent difference (or relative standard deviation) between the laboratory results reported for the various samples. The maximum acceptable percentage difference between duplicate samples is 25%, and the maximum acceptable relative standard deviation for triplicates is 18%. However, this interpretation only holds true if the results are at least 10 times the detection limits for a given parameter, as the accuracy of a result close to the detection limit shows more variability than results well above detection limits. As well, some parameters (notably bacteriological indicators and chlorophyll *a*) are not homogeneous throughout the water column and therefore we expect to see a higher degree of variability between replicate samples. For blanks, the Guidelines for Interpreting Water Quality Data (RISC, 1997) state that contamination has occurred when 5% or more of the blanks show any levels above the method detection limit. If the blanks are within the guidelines, the data are to be considered clean and the real sample data are to be treated as uncontaminated.

Results of the QA/QC analyses are summarized in Appendix II. Triplicate samples were taken for chlorophyll *a* in mid-September. At each site the relative standard deviation for chlorophyll *a* triplicate results was above the maximum acceptable level of 18%; however, this is not a concern as this parameter is not naturally homogeneously distributed. Duplicate samples were collected at the intake site on October 18, 2011 and analyzed for *E. coli*. The relative percent difference between the samples was 55% (Appendix II Table 32), well above the acceptable limit of 25% for duplicate samples but, as with chlorophyll *a*, *E. coli* is not homogeneous throughout the water column. Finally, duplicate samples were collected at the intake site on November 1, 2004 and analyzed for metals and total suspended solids concentrations. The relative percent differences between samples were generally low, but for six of the 27 parameters, the 25% threshold for acceptability was exceeded (Appendix II Table 33). However, in all of those instances, measured concentrations were less than 10 times the detection limits. Variability noted in all duplicate and triplicate samples is within the expected range for the parameters measured and the concentrations at which these were present. Based on these samples, the data can be considered to be within acceptable limits for data quality.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

There are two sets of guidelines that are commonly used to determine the suitability of drinking water. The BC MOE water quality guidelines (available at http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html) are used to assess water at the point of diversion of the natural stream into a waterworks system. These BC guidelines are also used to protect other designated water uses such as recreation and habitat for aquatic life. Water quality guidelines provide the basis for the development of water quality objectives for a specific waterbody, which can be integrated into an overall fundamental water protection program designed to protect all uses of the resource, including drinking water sources.

The BC *Drinking Water Protection Act* sets minimum disinfection requirements for all surface supplies, as well as requiring drinking water to be potable. The Vancouver Island Health Authority (VIHA) determines the level of treatment and disinfection required based on both the source and end-of-tap water quality. As such, VIHA requires all surface water supply systems to provide two types of treatment processes. Currently the Little Qualicum Waterworks District disinfects drinking water with chlorination (Norman, pers. comm., 2013). To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, the Little Qualicum Waterworks District may be required to provide additional disinfection, such as UV or ozone, and/or treatment, such as filtration. Some measure of natural filtration is already in place, as the District uses a "wet well" for their intake, so that water passes into the well through the gravel riverbed which filters out some turbidity (Norman, pers. comm., 2013).

The following sections describe the characteristics considered in assessing the water quality of the Little Qualicum River.

6.1 PH

pH measures the concentration of hydrogen ions (H^+) in water. The concentration of hydrogen ions in water can range over 14 orders of magnitude, so pH is defined on a logarithmic scale between 0 and 14. A pH between 0 and 7 is acidic (the lower the number, the more acidic the water) and a pH between 7 and 14 is alkaline (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5 (McKean and Nagpal, 1991). Corrosion of metal plumbing may occur at both low and high pH outside of this range, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range.

The pH at all of the sites was generally slightly alkaline, with values ranging from 7.2 pH units to 8.0 pH units, and an average of between 7.6 pH units and 7.8 pH units at all of the sites (Appendix I). All pH values were well within the drinking water guideline, suggesting that pH is not presently a concern within the Little Qualicum River watershed. Therefore, no objective is proposed for pH in the Little Qualicum River.

6.2 TEMPERATURE

Temperature is considered in drinking water for aesthetic reasons. The aesthetic guideline is 15°C; temperatures above this level are considered to be too warm to be aesthetically pleasing (Oliver and Fidler, 2001). For the protection of aquatic life in streams the allowable hourly change in temperature is +/-1°C from naturally occurring levels. The optimum temperature ranges for salmonids and other cold water species are based on species-specific life history stages such as incubation, rearing, migration, and spawning. For steelhead, which are present in the Little Qualicum River, the optimum temperature ranges are: 10 – 12°C for incubation; 16 – 18°C for rearing; and 10 – 15.5°C for spawning (Oliver and Fidler, 2001). Chum salmon, which are present in the Little Qualicum River, are the most sensitive salmonid to warmer temperatures (12 – 14°C for rearing). However, the juveniles are not present in the river during the summer months. Steelhead and coho, which have similar temperature thresholds, are the species present in the watershed for the longest periods of time, including the summer (McCulloch, pers. com., 2013). Maturation of the embryos is temperature-dependent, but coho typically emerge by mid-May and steelhead typically emerge by late June.

Water temperatures in the Cameron and Little Qualicum Rivers varied seasonally, with maximum temperatures occurring in late July through the end of August. In 2011 and 2012, (mid August – mid November) field-measured water temperatures in the upper

Cameron River (E285669) ranged from 3.4°C to 13.1°C, from 3.5°C to 13.1°C in the Cameron River upstream from Cameron Lake (E220635), from 8.8°C to 18.7°C in the Little Qualicum River 1.2 km downstream from Cameron Lake (E268993), from 6.6 to 12.7 at the Whiskey Creek site (E287697) and from 6.6°C to 18.4°C at the intake site on the Little Qualicum River (E256394) (Barlak, 2012 and 2013). As expected, water temperatures increased in a downstream direction, with decreases in elevation and increased exposure to ambient air temperatures (especially in Cameron Lake, which has a significant residence time) resulting in warmer water temperatures during the hot summer months. Temperature logger data in the Upper Cameron River ranged from 1.0°C to 11.9°C with a maximum weekly average of 10.5°C (Figure 7); at the Cameron River upstream from Cameron Lake , temperatures ranged from 0.5°C to 14.9°C with a maximum weekly average of 13.4°C (Figure 8). At the automated station at the Little Qualicum River at intake, water temperatures ranged from 2°C to 20°C, with a maximum weekly average of 17.7°C (Figure 9).

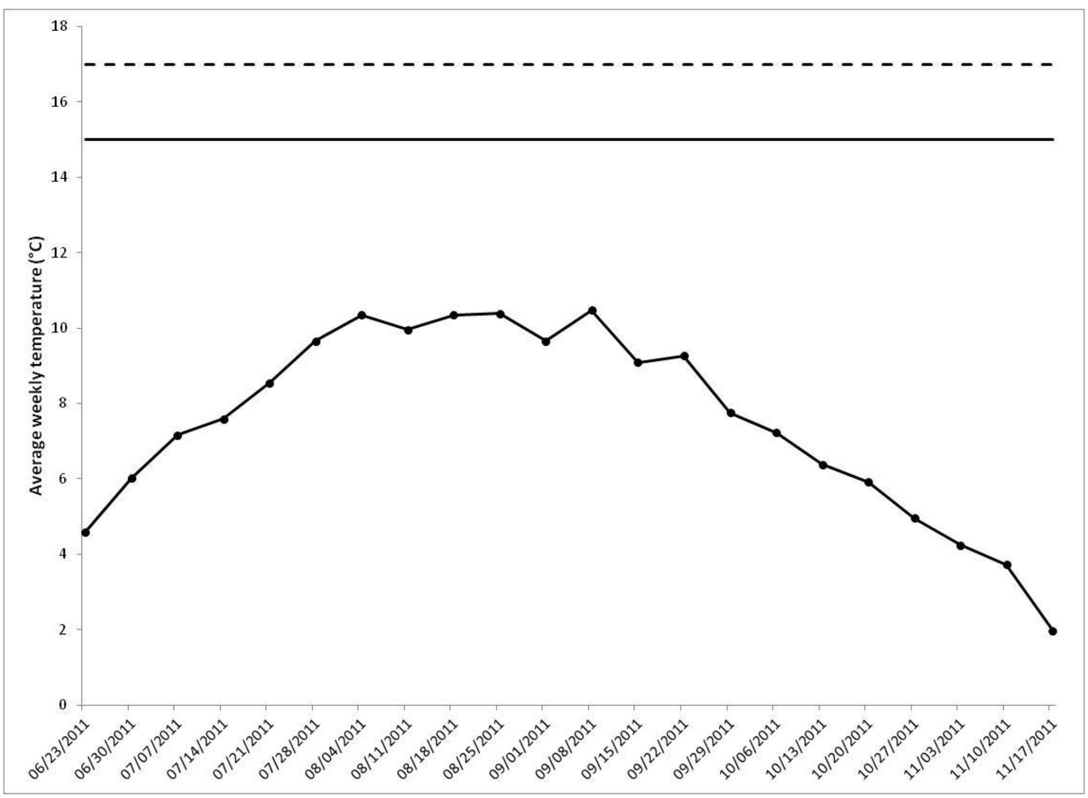

Figure 7. Average weekly temperature measured at E285669 Upper Cameron River between June 23, 2011 and November 17, 2011. Dashed line denotes aquatic life guideline, solid line denotes drinking water guideline.

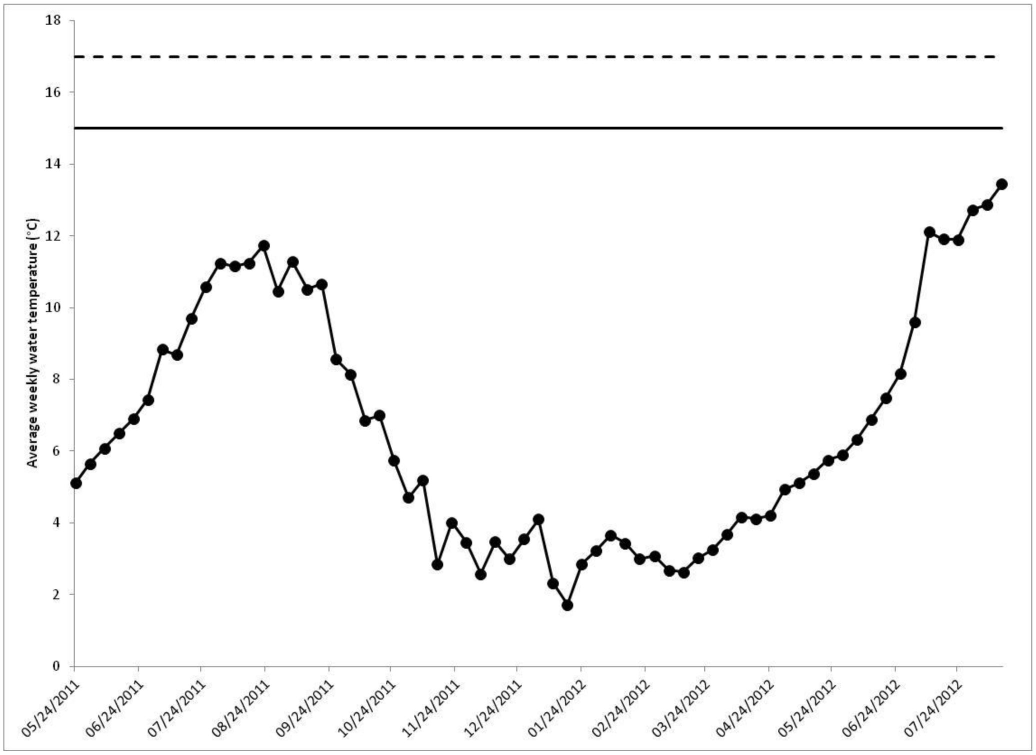

Figure 8. Average weekly temperature measured atE220635 Cameron River upstream from Cameron Lake between May 24, 2011 and August 14, 2012. Dashed line denotes aquatic life guideline, solid line denotes drinking water guideline.

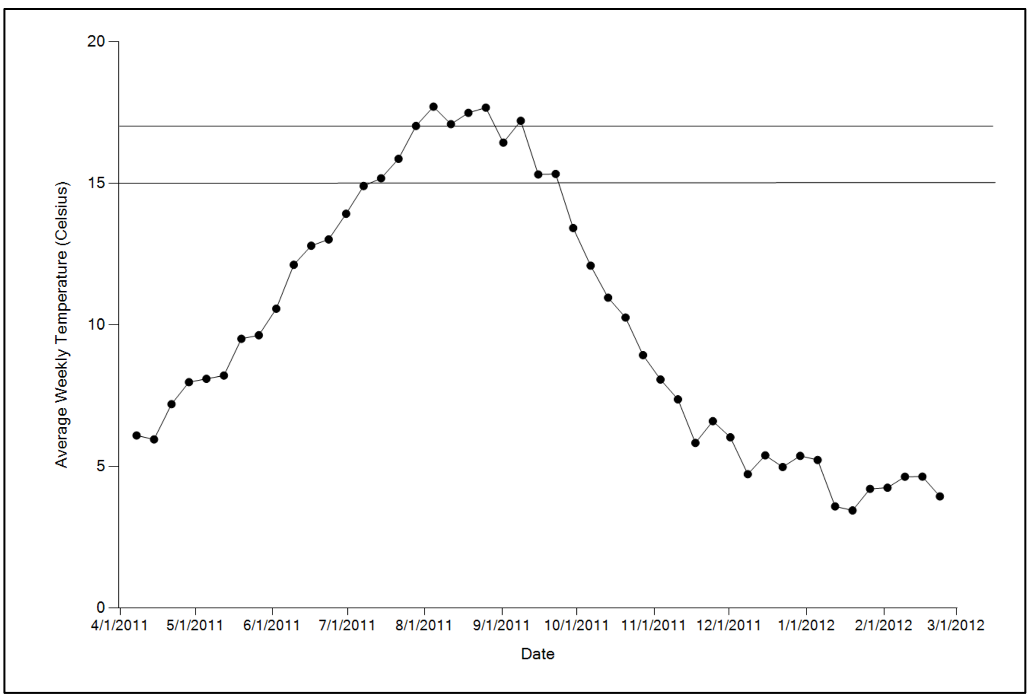

Figure 9. Average weekly temperatures measured at E256394 Little Qualicum River automated water quality monitoring site between April 2011 and March 2012 (from Obee, 2012). Lines denote drinking water (15°C) and aquatic life (17°C) guidelines.

Water temperatures remained consistently below the aquatic life guidelines for the incubation and spawning period for salmonids. However, maximum summer water temperatures exceed the guideline for both coho (17°C) and steelhead (19°C) rearing at the intake site. While adult steelhead typically return to the ocean after spawning, most juveniles spend one to two years in freshwater maturing into smolts before entering the ocean. Some salmon species, including coho, also utilize freshwater for up to three years before entering the ocean. The lower portion of the Little Qualicum River is generally wide and shallow, with little riparian cover (including the exposed 4.2 km long spawning channel at the fish hatchery), allowing considerable solar infiltration. Therefore, water temperatures in the lower reaches are likely considerably higher than at upstream locations. Many watersheds on the west coast of Vancouver Island, as well as throughout the Southern Interior, typically have elevated summer water temperatures. However, it is possible that activities such as forest harvesting, agriculture or urban development, activities that have the potential to decrease stream shading if removal of vegetation occurs in riparian areas, and climate change, could exacerbate peak summer water temperature further. ***Due to the high summer temperatures and the high fisheries values of the Little Qualicum River, a short-term (within five years) water quality objective is proposed to protect juvenile salmonids. The average weekly temperature should not exceed 17°C at any time during the year.*** While maximum temperatures may exceed the guideline in some portions of the creek, as long as refuges remain with average temperatures below the guideline, juvenile fish should be protected during periods of elevated temperatures.

The aesthetic drinking water guideline (a maximum of 15°C) was exceeded by a considerable margin during the summer months in the Little Qualicum River. In the Little Qualicum River it is likely that higher summer temperatures above this guideline are, for the most part, a natural occurrence due to the residence time in Cameron Lake. For this reason no objective is proposed at this time for drinking water purposes at the Little Qualicum Waterworks District intake. In the Little Qualicum River system, releases of deep cold water from Cameron Lake could augment low summer flows and decrease maximum temperatures, which would be beneficial both for aquatic life and for drinking water aesthetics. If this were to be implemented, a long term objective for drinking water purposes should be considered.

6.3 CONDUCTIVITY

Conductivity refers to the ability of a substance to conduct an electric current. The conductivity of a water sample gives an indication of the amount of dissolved ions in the water. The more ions dissolved in a solution, the greater the electrical conductivity. As temperature affects the conductivity of water (a 1ºC increase in temperature results in approximately a 2% increase in conductivity), specific conductivity is used (rather than simply conductivity) to compensate for temperature. Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 microsiemens/centimeter (µS/cm)), while interior watersheds generally have higher values. Increased flows resulting from precipitation events or snowmelt tends to dilute the ions, resulting in decreased specific conductivity levels with increased flow levels. Therefore, water level and specific conductivity tend to be inversely related. However, in situations such as landslides, where high levels of dissolved and suspended solids are introduced to the stream, specific conductivity levels tend to increase. As such, significant changes in specific conductivity can be used as an indicator of potential impacts.

In the Little Qualicum River watershed, average specific conductivity measured weekly in the field at the five sites ranged from 85.5 µS/cm (for the intake site between 2004 and 2007) to 136.1 µS/cm for Whiskey Creek (2011-2012) (Table 5). Higher values, especially those seen in Whiskey Creek, are likely an indicator of groundwater (often high in minerals) influences as they did not appear to correspond to higher turbidity levels. At the automated station operated near the intake between April 2011 and March 2012, conductivity (data were not corrected for temperature, and therefore do not represent specific conductivity) ranged between 25 µS/cm and 80 µS/cm, with an average of 55 µS/cm (Obee, 2012). For the 2004-2007 data at the intake site, as well as the automated data collected in 2011-12, specific conductivity values were correlated with flows, with the highest conductivity occurring during summer low flows (when dilution was lowest) and conductivity values dropping during the winter (when dilution from rainfall was highest). For the 2011-2012 field-measured data, specific conductivity increased during the fall at all of the sites relative to the summer data (Barlak, 2012 and 2013). The reason for this increase is unclear at this time but comparison to automated data collected at the intake site suggests this may have been an instrument calibration error (Barlak, 2012). As there is no BC Water Quality Guideline for specific conductivity and the average specific conductivity observed was generally typical of coastal systems, no objective is proposed for specific conductivity in the Little Qualicum River watershed.

Table 5. Summary of results of specific conductivity field analyses within the Little Qualicum River watershed 2004-2012.

		Minimum	Maximum	Average	No. of samples	Jun - Sept Avg	Oct - May Avg
E285669	Upper Cameron River 2011-2012	65.2	110.2	91.5	15	89.4	95.7
E220635	Cameron River U/S Cameron Lake 2011-2012	70.8	136.3	108.0	15	104.4	115.3
E268993	Little Qualicum River 1.2 km d/s Cameron Lake 2011-2012	78.9	133.1	102.7	10	89.4	116.0
E256394	Little Qualicum River at Intake 2004-07	59.0	105.0	85.5	32	93.4	79.3
E256394	Little Qualicum River at Intake 2011-12	84.5	150.4	103.9	15	94.4	122.8
E287697	Whiskey Creek 2011-2012	109.4	199.6	136.1	9	120.4	155.8

6.4 TURBIDITY

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water as nephelometric turbidity units (NTU). Elevated turbidity levels can decrease the efficiency of disinfection, allowing microbiological contaminants to enter the water system. As well, there are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures. The guideline for drinking water that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU when background is <u>less than</u> 5 NTU, and a maximum of 5 NTU (during turbid flow periods) (Caux *et al*., 1997). VIHA's goal for surface source drinking water for systems that do not receive filtration, such as Little Qualicum River, is that it demonstrate 1 NTU turbidity or less

(95% of days) and not above 5 NTU on more than 2 days in a 12 month period when sampled at the intake (Enns, pers. comm., 2009).

Turbidity events can result from non-point sources such as runoff from roads, ditches, and farmland, as well as from landslides (both natural and those resulting from anthropogenic impacts such as timber harvesting or road construction). Sweeten *et al*. (2003) identified a number of turbidity events that occurred in the upper watershed during their 15-year study period (1986-2001); these events affected water quality downstream from Cameron Lake due to small clay particles that did not settle out of the water column while passing through Cameron Lake.

The Little Qualicum Waterworks District (LQWD) has a wet well intake on the Little Qualicum River, as well as significant reservoir storage capacity. When heavy rainfall results in elevated turbidity levels, the LQWD stops drawing water directly from its wet well intake on the Little Qualicum River and instead relies on its storage capacity.

A summary of lab analyzed turbidity measurements for the Little Qualicum River watershed are given in Table 6. Average turbidity was highest at the intake site and lowest in the upper watershed. Higher turbidity levels (those exceeding 1 NTU) at each of the sites occurred almost invariably between the months of November and January, likely as a result of rainfall events washing suspended sediments into the rivers.

Table 6. Summary of results of turbidity lab analyses within the Little Qualicum River watershed.

		Minimum (NTU)	Maximum (NTU)	Average (NTU)	Std Dev	No. of samples
E285669	Upper Cameron River	0.08	4.96	0.45	1.08	30
E220635	Cameron River U/S Cameron Lake	0.02	11.3	0.7	2.1	31
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	0.16	2.5	0.49	0.56	21
E256394	Little Qualicum at intake 2004-07	0.1	7.36	1.23	1.54	32
E256394	Little Qualicum at intake 2011-12	0.17	12.3	1.10	2.24	32

The maximum turbidity values measured at the two Cameron River sites, as well as the intake site on Little Qualicum River, occurred on November 22, 2012, the day after a winter storm deposited 63 mm of rain on the area (as measured at the Environment Canada Qualicum River weather station, Climate ID 1026565) (Table 7). However, the turbidity measured in the Little Qualicum River downstream from Cameron Lake on that day was only 1.32 NTU. Very high turbidity levels were also observed on January 24, 2012. On both dates, turbidity levels increased from the Upper Cameron River site to the Cameron River Upstream from Cameron Lake site, decreased at the Little Qualicum River downstream from Cameron Lake site, and increased again considerably at intake site. This pattern likely reflects the residence time and settling capacity of Cameron Lake, where larger particulate matter entering the lake will generally settle out of the water column by the time the water leaves the lake (Sweeten *et al.* 2003; Horel 1998)). Therefore, the higher turbidity levels measured at the intake likely reflected turbidity introduced into the Little Qualicum River from sources downstream from Cameron Lake.

Table 7. Comparison of turbidity levels at the four monitoring sites on Nov. 22, 2011 and Jan 24, 2012 (the dates when the highest turbidity levels occurred).

Date	E285669 Upper Cameron R	E220635 Cameron R U/S Cameron Lk.	E268993 Little Qualicum River 1.2 km d/s Cameron Lake	E256394 Little Qualicum R at intake
Nov. 22, 2011	4.96	11.3	1.32	12.3
Jan 24, 2012	0.62	3.43	2.5	5.45

Turbidity was also measured at the automated station that operated between April 2011 and March 2012 near the intake site, and the results of these analyses are summarized in Table 8 and Figure 10. Turbidity at the intake exceeded the drinking water guideline of 5 NTU in about 9% of the samples analyzed. Turbidity is notoriously difficult to measure accurately with automated equipment due to the wide variety of factors that can affect measurements, including fish and other aquatic organisms, algae and air bubbles. As all of these factors cause erroneous increases in turbidity (as long as the turbidity probe is properly situated in the water column, it is not possible for it to report turbidity levels lower than are actually occurring), the automated data are likely skewed in an upward direction, and the threshold may have been exceeded by somewhat less than the 9% of samples reported.

Table 8. Summary of automated turbidity data collected between April 2011 and March 2012.

	Number of Measurements	Number of Days	Percentage of results	Cumulative Percentage
Turbidity ≤ 1 NTU	13,438	140.0	43.1%	43.1%
Turbidity > 1, ≤ 5 NTU	14,812	154.3	47.5%	90.6%
Turbidity > 5, ≤ 10 NTU	1,345	14.0	4.3%	94.9%
Turbidity > 10, ≤ 50 NTU	1,482	15.4	4.8%	99.6%
Turbidity > 50 NTU	116	1.2	0.4%	100.0%
Total	**31,193**	**325**	**100%**	

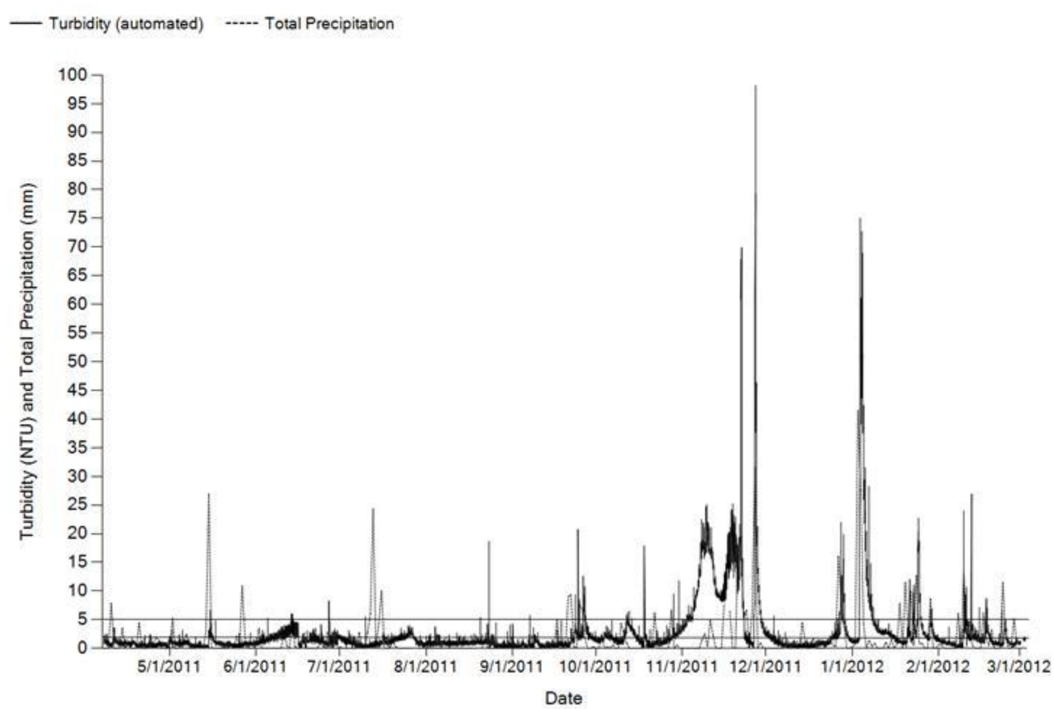

Figure 10. Turbidity (NTU) and total precipitation (mm) in the Little Qualicum River 2011-12. The horizontal lines indicate the Water Quality Objectives of 2 NTU and 5 NTU for the Nanaimo Lowland ecoregion (from Obee, 2012).

In order to try and quantify this potential error, automated data was compared with discrete samples collected at the intake site at the same time (Table 9). In those instances where discrete samples were not collected on the quarter-hour (the automated station measured turbidity once every 15 minutes, on the quarter-hour), an average was calculated for the turbidity reported before and after the discrete sample was collected. For 18 of the 21 discrete samples collected, the automated turbidity value was higher than the reported laboratory value. The average relative percent difference between the turbidity measured in the discrete samples at the laboratory versus those reported by the automated meter was 64%, suggesting that, on average, the turbidity reported by the automated meter was more than twice that reported by the laboratory. This may be due to particulate matter settling in the bottle prior to lab analysis, or, as suggested in Obee (2012) the position of the deployment tube may have caused an excess of bubbles around the automated sonde, possibly affecting the readings. As much as possible, erroneous data points in the automated data were deleted during data correction (Obee, 2012).

Table 9. Comparison of turbidity measured by automated station compared with discrete samples analyzed at the laboratory (data from Obee 2012).

Date	Turbidity (NTU)	Automated turbidity reading prior to discrete sample collection	Automated turbidity reading post discrete sample collection	Average automated turbidity reading	Relative % difference
19/04/2011 16:00	0.5			0.3	-53%
24/05/2011 13:15	0.4			0.7	58%
22/06/2011 11:55	0.8	2.2	2.4	2.3	97%
21/07/2011 14:35	0.7	1.6	1.8	1.7	84%
16/08/2011 12:40	0.4	0.8	1.1	0.9	79%
23/08/2011 12:20	0.7	1.1	1.4	1.3	57%
31/08/2011 6:20	0.5	0.9	2.7	1.8	112%
06/09/2011 12:20	0.3	0.3	0.3	0.3	4%
13/09/2011 12:15	0.3			0.6	68%
15/09/2011 9:45	0.7			0.6	-14%
21/09/2011 11:30	0.5			0.8	45%
18/10/2011 12:15	0.66			1.9	98%
18/10/2011 12:15	0.71			1.9	92%
25/10/2011 12:20	0.64	1.1	0.8	1.0	39%
01/11/2011 12:20	0.67	3.3	3.6	3.5	136%
08/11/2011 11:20	1.1	17.3	17.4	17.3	176%
15/11/2011 11:45	0.89			9.1	164%
22/11/2011 12:00	12.3			20.1	48%
14/12/2011 11:00	0.55			0.5	-19%
24/01/2012 14:00	5.45			10.0	59%
14/02/2012 12:22	1.61	1.6	1.8	1.7	5%

It is important to consider not only the total amount of time the criterion was exceeded, but also how long each exceedance lasted. For example, high turbidity levels for five consecutive hours are more likely to impact drinking water quality than five one-hour events separated by a few hours of low-turbidity water. Table 10 shows a summary of the intensity and duration of turbidity events occurring at the automated station between 2011 and 2012. A turbidity event, for the sake of this summary, is defined as a number of consecutive turbidity values measured at 15-minute intervals exceeding the 5 NTU threshold. The recovery time is the length of time that has passed since the previous turbidity event (*i.e.*, since the turbidity last exceeded 5 NTU). For the sake of brevity and ease of reading, Table 10 includes only the longest-duration events (*i.e.*, events over 5 hours in length) – the remainder of the summary is included as Appendix III, arranged in chronological order. The longest turbidity event was almost 450 hours in length, with a maximum value of almost 70 NTU. Most turbidity events (six of the seven events lasting over five hours) occurred between the months of November and February

Table 10. Summary of duration and intensity of turbidity events occurring at automated station at Little Qualicum River intake (from Obee, 2012)

Event Start Date and Time	Duration (hrs)	Recovery Time (hrs)	Min (NTU)	Max (NTU)	Mean (NTU)	StDev
2011-09-26 13:30:50	13.25	32.25	5.0	12.6	7.0	1.2
2011-11-04 17:15:51	449.75	0.25	5.2	69.9	13.9	7.1
2011-11-26 22:30:51	59.00	0.25	5.2	98.2	22.2	22.4
2011-12-27 20:30:51	16.75	0.25	5.1	22.0	10.5	4.7
2011-12-28 17:30:51	16.00	0.75	5.1	19.9	10.6	4.1
2012-01-03 15:30:51	115.25	3.00	5.0	75.0	24.4	19.0
2012-01-24 12:15:50	28.50	3.00	5.2	22.7	13.2	5.2

Finally, turbidity was also measured by the stewardship groups in 2011 and 2012 at the four monitoring sites as well as at Whiskey Creek (Table 11) (Barlak, 2012 and 2013). Average turbidity was once again lowest in the upper watershed and highest at the intake site and in Whiskey Creek. These readings generally were within MOE QA/QC limits (<25% difference between samples) when compared to lab analyses results, as only four of 40 samples exceeded the MOE QA/QC limits (Barlak, 2012). Those results that were >25% different were attributed to sampling procedure or field equipment procedure, *i.e.*

stirring up sediment while filling a bottle or dust in the turbidity instrument (Barlak, 2012).

Table 11. Summary of turbidity measurements made in the field by stewardship groups at the four monitoring locations and at Whiskey Creek, 2011-2012.

		Minimum	Maximum	Average	Std Dev	No. of samples
E285669	Upper Cameron River	0.0	2.1	0.3	0.4	20
E220635	Cameron River U/S Cameron Lake	0.0	1.2	0.2	0.3	20
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	0.1	2.1	0.5	0.7	10
E256394	Little Qualicum River at Intake	0.2	1.6	0.5	0.4	20
E287697	Whiskey Creek	0.1	0.5	0.2	0.1	9

As mentioned above, turbidity tended to increase in a downstream direction. Turbidity levels are occasionally high throughout the watershed, including at the Upper Cameron River site, suggesting that there are a number of different sources of sediments, including anthropogenic factors, and that turbidity is a concern. Turbidity at the Upper Cameron River site (the site most representative of natural conditions in the watershed) remained low (< 1 NTU for 95% of the discrete sample data) with only minor fluctuations during rain storm events (to a maximum value of < 5 NTU). Therefore, to protect drinking water quality in the Little Qualicum River, ***it is recommended that from October to February (when turbid flows can occur), turbidity measured at the intake should not exceed 5 NTU; during the remainder of the year (clear flow periods, March to September), turbidity should not exceed 2 NTU at any time (1 NTU above ambient levels, as measured at the Upper Cameron River site) and that turbidity measured at the Little Qualicum Waterworks District intake be < 1 NTU 95% of the time.*** It should be noted that turbidity values above 2 NTU are considered likely to affect disinfection in a chlorine-only system (Anderson, pers. comm., 2006). An alternative to the average objective of 2 NTU would be to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency. In accordance with VIHA’s protocol for whether filtration is required, the Town of Qualicum Beach, as water purveyors, should continue to measure turbidity levels at the water intake location to ensure that the existingtreatment methods are appropriate.

6.5 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS), or non-filterable residue or (NFR), include all of the undissolved particulate matter in a sample. This value should be closely correlated with the turbidity value; however, unlike turbidity, it is not measured by optics. Instead, a quantity of the sample is filtered, and the residue is dried and weighed so that a weight of residue per volume is determined. No guideline has been established for drinking water sources at this time. For the protection of aquatic life, the maximum concentration allowed is an induced TSS concentration over background of 25 mg/L at any one time in 24 hours when background is less than or equal to 25 mg/L (clear flows) and an induced TSS concentration of 5 mg/L over background concentrations at any one time for a duration of 30 days (clear flows). Initially, less frequent monitoring may be appropriate to determine the need for more extensive monitoring (Caux *et al.,* 1997).

TSS has been identified as a significant concern in the Little Qualicum River watershed, having a considerable impact on egg and juvenile salmonid survival in the spawning channels located in the lower watershed (Sweeten *et al*. 2003). As part of their 15-year study (1986-2001); Sweeten *et al*. (2003) identified numerous sources of TSS throughout the watershed, originating from a variety of land use activities as well as from natural landslides. Of particular concern were the turbidity events occurring in the upper watershed that contributed significant amounts of clay – these small particles pass through Cameron Lake and can result in prolonged turbidity events both in the lake and downstream from the lake. While these particles are too small to settle out of the water column in the lake, they are readily deposited in the spawning beds and lead to significantly decreased egg and juvenile salmonid survival rates, despite the construction of a settling basin at the inlet of the spawning channel (Sweeten *et al*. 2003).

Concentrations of TSS at all sites ranged from below detection limits (<1 mg/L to <4 mg/L) for most samples with number of samples below detection decreasing further downstream. Samples with TSS below detection limits ranged from 18 of 21 samples at the Upper Cameron River site to only seven of 22 samples at the intake site, with a maximum of 59 mg/L (at the intake site) (Table 12). TSS values were consistently low with elevated levels only occurring during or after rain storm events during the months of October and November. Of the four samples with TSS concentrations exceeding 25 mg/L at the intake site, rainfall over the preceding three days ranged from 27.5 mm to 74.7 mm (as measured at the nearby Qualicum Hatchery site, Environment Canada Climate ID 1024638).

Table 12. Summary of results of TSS analyses (mg/L) within the Little Qualicum River watershed.

		Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Std Dev	No. of samples	No of samples below detection limit (<1 mg/L)
E285669	Upper Cameron River	< 1	8.9	1.4	1.7	21	18
E220635	Cameron River U/S Cameron Lake	< 1	18.5	2.2	3.9	21	17
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	< 1	3	1.2	0.5	21	16
E256394	Little Qualicum at intake 2004-07	< 1	59	4.6	9.6	61	29
E256394	Little Qualicum at intake 2011-12	< 1	32	3.5	6.7	22	7

To determine average background values relative to impacted sites, a minimum of five weekly samples within 30 days were collected on two occasions (once for summer and once for fall) for all sites in 2011, and the intake site had an additional six average values (three for summer and three for fall) from the 2004-2007 sample periods (Table 13). Both summer and fall average background TSS levels (as measured in the Upper Cameron River) are similar at 1 mg/L and 1.1 mg/L, respectively. Using these values, BC Water Quality Guidelines for aquatic life in the watershed would specify a maximum of 26 mg/L (25 mg/L over background) at any one time in 24 hours, and of maximum of 6 mg/L (5 mg/L over background) at any one time for a duration 30 days.

Table 13. Summary of average TSS concentrations (mg/L) (based on five samples collected in 30 days) within the Little Qualicum River watershed.

	E285669 Upper Cameron R	E220635 Cameron R U/S Cameron Lk.	E268993 Little Qualicum River 1.2 km d/s Cameron Lake	E256394 Little Qualicum R at intake*
Summer	1	1.6	1.4	1.5
Fall	1.1	1	1	8.5

*Averages for Little Qualicum River at intake based on the average of four averages, for both summer and fall.

In general, TSS concentrations showed trends similar to those shown by turbidity, with increases occurring in a downstream direction, generally after a rainfall event. As with turbidity, concentrations of TSS tended to be lowest in the upper watershed, increased slightly upstream from Cameron Lake, decreased downstream from the lake (due to settling and residence time), and increased to their highest levels at the intake site, indicating that anthropogenic factors are influencing water quality in the lower watershed. Therefore, it is evident that occasional high concentrations of TSS can occur, and for this reason a water quality objective for TSS is proposed. The objective is meant to apply to situations that are not natural but may have been triggered by human activities (agriculture, timber harvesting or urban runoff). ***It is recommended that TSS measured in the Cameron and Little Qualicum Rivers should not exceed 26.0 mg/L (25 mg/L above clear flow background levels as measured in the Upper Cameron River) at any time and the mean of five samples in 30days should not exceed 6.0 mg/L (5 mg/L above clear flow background levels as measured in the Upper Cameron River) .*** Means of five weekly samples in 30 days were chosen (rather than maximum values of 30 samples in a 30 day period, as recommended in the guideline) considering the resources available for monitoring, as well as local hydrology and the fact that Vancouver Island streams have clear flows for most of the year.

6.6 COLOUR AND TOTAL ORGANIC CARBON

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour is a measure of the dissolved colour in water after the particulate matter has been removed, while apparent colour is a measure of the dissolved and particulate matter in water. Colour can affect the aesthetic acceptability of drinking water, and the aesthetic water quality guideline is a maximum of 15 true colour units (TCU) (Moore and Caux, 1997). Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it can produce disinfection by-products (DBPs) such as trihalomethanes, which may pose a risk to human health.

Colour was measured approximately 12 times at each site (one additional time at the intake site between 2004 and 2007). Colour ranged from below detection limits (< 5 TCU) at the three upper sites to a maximum of 40 TCU at the Intake site, with medians of 5TCU for all sites (Table 14). True colour increased in a downstream direction: on the two occasions when the 15 TCU guideline was exceeded at the intake site, true colour levels at the Little Qualicum River downstream from Cameron Lake site were only 5 TCU. Therefore, it appears that colour may be an occasional aesthetic concern. ***Thus, the following objective is proposed: true colour should not exceed 15 TCU at the Little Qualicum Waterworks District intake.***

Table 14. Summary of true colour within the Little Qualicum River watershed.

		Minimum (TCU)	Maximum (TCU)	Median	90th percentile	No. of samples
E285669	Upper Cameron River	< 5	10	5	5	12
E220635	Cameron River U/S Cameron Lake	< 5	20	5	5	12
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	< 5	10	5	5	12
E256394	Little Qualicum at intake 2004-07	5	5	5	5	1
E256394	Little Qualicum at intake 2011-12	5	40	5	19.5	12

Elevated total organic carbon (TOC) levels (above 4.0 mg/L) can result in higher levels of DBPs in finished drinking water if chlorination is used to disinfect the water (Moore, 1998). As the Little Qualicum Waterworks District uses chlorine to disinfect their drinking water, TOC concentrations should be monitored. Concentrations of TOC ranged from 0.9 mg/L to 6.65 mg/L for the 30 samples analyzed for TOC at the intake site between 2004 and 2012 (Table 15). The median value at the Upper Cameron River site was 0.9 mg/L, generally increasing in a downstream direction to 1.8 and 1.6 mg/L at the intake site in 2004-2007 and 2011-2012, were respectively. Only the maximum value (6.65 mg/L), measured at the intake on November 22, 2011, exceeded the guideline. Similar to turbidity and TSS, TOC increased considerably in a downstream direction during this event, from 2.74 mg/L downstream of Cameron Lake to 6.65 mg/L at the intake site, indicating that anthropogenic factors are likely influencing water quality in the lower watershed. As Little Qualicum River water is chlorinated prior to use as drinking water, a water quality objective for TOC is proposed. ***It is recommended that maximum TOC concentrations should not exceed 4.0 mg/L at any time in the Little Qualicum River at the intake site.***

Table 15. Summary of results of TOC analyses within the Little Qualicum River watershed.

		Minimum (mg/L)	Maximum (mg/L)	median	90th percentile	No. of samples
E285669	Upper Cameron River	< 0.5	3.05	0.9	1.9	21
E220635	Cameron River U/S Cameron Lake	< 0.5	3.29	0.8	2.1	21
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	0.8	2.74	1.3	1.8	21
E256394	Little Qualicum at intake 2004-07	0.9	3.2	1.8	3.2	8
E256394	Little Qualicum at intake 2011-12	0.89	6.65	1.6	2.9	22

6.7 NUTRIENTS (NITRATE, NITRITE, PHOSPHORUS, AND CHLOROPHYLL *A*)

The concentrations of nitrogen (including nitrate and nitrite) and phosphorus are important parameters, since they tend to be the limiting nutrients in biological systems. Productivity is therefore directly proportional to the availability of these parameters. Nitrogen is usually the limiting nutrient in terrestrial systems, while phosphorus tends to be the limiting factor in freshwater aquatic systems. In watersheds where drinking water is a priority, it is desirable that nutrient levels in surface water remain low to avoid algal blooms and foul tasting water. Similarly, to protect aquatic life, nutrient levels should not be too high or the resulting plant and algal growth can deplete oxygen levels when it dies and begins to decompose, as well as during periods of low productivity when plants consume oxygen (*i.e.*, at night and during the winter under ice cover).

The guideline for the maximum concentration for nitrate in drinking water is 10 mg/L as nitrogen and the guideline for nitrite is a maximum of 1 mg/L as nitrogen. When both nitrate and nitrite are present, their combined concentration must not exceed 10 mg/L as N. For the protection of freshwater aquatic life, the nitrate guidelines are a maximum concentration of 31.3 mg/L and an average concentration of 3 mg/L. Nitrite concentrations are dependent on chloride; in low chloride waters (*i.e.*, less than 2 mg/L) the maximum concentration of nitrite is 0.06 mg/L and the average concentration is 0.02 mg/L. Allowable concentrations of nitrite increase with ambient concentrations of chloride (Meays, 2009).

Dissolved nitrate (NO_3) and dissolved nitrite (NO_2) concentrations were measured at the intake site (E256394) between 2004 and 2007. Dissolved nitrate concentrations ranged from below detection limits (< 0.001 mg/L as N) to a maximum of 0.11 mg/L as N for 31 samples, while dissolved nitrite concentrations ranged from below detection limits (<0.002 mg/L as N) to a maximum of 0.006 mg/L as N (Appendix I). All values of both nitrate and nitrite species were well below the existing aquatic life guidelines, and therefore no objective is proposed for this parameter.

The BC MOE has proposed a phosphorus objective for Vancouver Island. This objective takes into consideration the fact that elevated phosphorus is primarily a concern during the summer low flow period when elevated nutrient levels are most likely to lead to deterioration in aquatic life habitat and aesthetic problems. The proposed total phosphorus objective applies from May to September and is an average of 0.005 mg/L and a maximum of 0.010 mg/L, based on a minimum of five monthly samples (BCMOE, *in press*). As this objective is under development, the numbers and the way in which they are applied are subject to change.

Summary statistics for all total phosphorus data are in Appendix I. Total phosphorus concentrations ranged from below detection limits (< 0.002 mg/L) at all sites to a maximum of 0.088 mg/L at the intake site (Appendix I). All of the highest values (>0.02 mg/L) measured at the intake site occurred during the month of November (in both 2004 and 2011). This is likely due to the fact that, with reduced sunlight and water temperatures, algal growth is considerably reduced and therefore available phosphorus is not immediately taken up by algae. There could also be increased sediment bound total phosphorous associated with increased runoff. As well, dead and decomposing algae and other plant materials would be releasing phosphorus into the stream.

Considering just May through September data at the upstream sites, the average total phosphorous was 0.002 mg/L at all three upstream sites (Table 16). May through September averages at the intake in different years ranged from 0.003 mg/L (2006 and 2011) to 0.005 mg/L (2004 and 2005), while maximums ranged between 0.004 mg/L (2011) to 0.01 mg/L (2005). Total phosphorous at the intake occasionally reaches the average (0.005 mg/L) and maximum (0.010 mg/L) objectives and results suggest increasing anthropogenic inputs of phosphorous in the lower watershed. Though more than the existing one year of data in the upper watershed are needed to confirm this apparent trend, a water quality objective for phosphorous will help to prevent objective exceedences.

Table 16. Summary of results of total phosphorus analyses (mg/L) within the Little Qualicum River watershed.

		Min (May – Sept)	Max (May – Sept)	Average (May – Sept)	No. of samples
E285669	Upper Cameron River	0.002	0.003	0.002	8
E220635	Cameron River U/S Cameron Lake	0.002	0.003	0.002	8
E268993	Little Qualicum River 1.2 km d/s Cameron Lake	0.002	0.003	0.002	8
E256394	Little Qualicum at intake 2004	0.004	0.006	0.005	3*
E256394	Little Qualicum at intake 2005	0.002	0.010	0.005	7
E256394	Little Qualicum at intake 2006	0.002	0.005	0.003	6
E256394	Little Qualicum at intake 2011	0.002	0.004	0.003	8

*2004 did not have samples each month and thus cannot be directly compared to the objective.

For the reasons above, ***a water quality objective for phosphorous is proposed that the May through September (based on a minimum of five monthly samples) average total phosphorous at any location in Little Qualicum River should not exceed 0.005 mg/L and maximum values should not exceed 0.010 mg/L.***

Chlorophyll *a* concentrations were measured on one occasion at each of the sites, in mid-September 2011. In streams (as opposed to lakes), concentrations of chlorophyll a rather than total phosphorus are used as a provincial guideline, due to the fact that a number of factors (including suitable water velocity, substrate, light, temperature and grazing pressures) are necessary before phosphorus becomes a limiting factor (Nordin, 1985). The recreational guideline for chlorophyll *a* is 50 mg/m^2, and the guideline for aquatic life is 100 mg/m^2 (Nordin, 1985). Table 17 summarizes the concentration of total chlorophyll *a* measured at each of the sites. In all instances, chlorophyll *a* concentrations were below both the drinking water and aquatic life guidelines at all of the sites. Concentrations of chlorophyll *a* increased from the Upper Cameron River site to the Cameron River upstream from Cameron Lake site, then decreased considerably at the Little Qualicum River downstream from Cameron Lake, and increased to their highest values at the Little Qualicum River intake site. The cause for the decrease between the Cameron River site upstream from Cameron Lake and the Little Qualicum River site downstream from Cameron Lake is not clear, since phosphorus concentrations increased between these two sites. However, it is likely that one of the other conditions mentioned above for growth was not met. More sampling should be conducted before drawing conclusions from this limited amount of data. As chlorophyll *a* concentrations remained within guideline levels, and because the objective proposed for total phosphorus should protect from elevated chlorophyll *a* concentrations, no guideline is recommended for chlorophyll *a* at this time.

Table 17. Summary of results of total chlorophyll *a* (mg/m^2) analyses within the Little Qualicum River watershed.

	E285669 Upper Cameron R	E220635 Cameron R U/S Cameron Lk.	E268993 Little Qualicum River 1.2 km d/s Cameron Lake	E256394 Little Qualicum R at intake
Sample 1	1.4	14.3	1.8	28.3
Sample 2	1.5	28.9	4	30.4
Sample 3	2.1	10.5	5.7	49
Average	**1.7**	**17.9**	**3.8**	**35.9**

6.8 METALS

As increasing water hardness can decrease the toxicity of copper and some other metals to some organisms, hardness values are an important component of certain metals guidelines. Hardness in the Little Qualicum River was relatively consistent throughout the watershed. However, this observation was based on relatively few values: Upper Cameron River (average 36 mg/L (n=3)), Cameron River upstream of Cameron Lake (average 43mg/L (n=3)) , Little Qualicum River 1.2 km downstream Cameron Lake (average 35 mg/L (n=3)), Little Qualicum at Intake 2004-2007 (one value of 41 mg), Little Qualicum at Intake 2011-12 (average 38 mg/L (n=4)). Though it is important to understand site specific hardness, it may also be influenced by anthropogenic factors in the watershed. Thus average hardness (40mg/L (based on the six samples from the two Cameron River sites) at the representative background sites was used to ensure applicable water quality guidelines relative to background hardness were being met.

Total and dissolved metals concentrations were measured three to four times at each of the upper sites and at the intake site in 2011-12, and on 38 occasions (Appendix I) at the intake site between 2004 and 2007. The concentrations of most metals were below detection limits, and well below guidelines for drinking water and aquatic life.

One exception to this was the maximum concentration for total cadmium measured at the intake site between 2004 and 2007. The 2004-2007 detection limit for total cadmium was 0.01 µg/L, which is very close to the working guideline value (average of 0.015 µg/L at a hardness of 40 mg/L). A detection limit of no more than $1/10^{th}$ the guideline is recommended in order to properly assess compliance, thus the 2004-2007 cadmium data should not be used to determine if the guideline is met. Most of the 38 metals samples collected between 2004 and 2007 had total cadmium results near or below the detection limit, but nine of the 38 had values from 0.1 to 0. 8 µg/L. The more recent 2011-12 data with a lower detection limit (< 0.005 µg/L) were more reliable for determining true objective exceedences. For these samples the maximum concentration of total cadmium measured at that time was 0.009 µg/L, so it does not appear that cadmium is a concern at this time.

As well, two samples at the intake site had total copper concentrations approaching the maximum guideline of 5.8 µg/L (at a hardness of 40 mg/L) (5.1 µg/L on November 15, 2004 and 4.2 µg/L on November 15, 2006). More recent sampling in 2011 showed a maximum of only 0.5 µg/L for the four samples collected between August and October. Though not enough data were available to compare to the average total copper guideline (2 µg/Lat a hardness <50 mg/L), available data suggest that copper is not likely a concern at this time. However, increased metals from rainwater runoff from roadways and developed areas could occur in the lower watershed. Therefore, continued monitoring for metals is recommended, but no water quality objectives are proposed for metals in the Little Qualicum River.

Metal speciation determines the biologically available portion of the total metal concentration. Only a portion of the total metals level is in a form which can be toxic to aquatic life. Naturally occurring organics in the watershed can bind substantial proportions of the metals which are present, forming metal complexes that are not biologically available. The relationship will vary seasonally, depending upon the metal under consideration (*e.g.* copper has the highest affinity for binding sites in humic materials). Levels of organics as measured by dissolved organic carbon (DOC) vary from ecoregion to ecoregion. To aid in future development of metals objectives, DOC has been included in the Little Qualicum River monitoring program. For the reasons given at the beginning of this section, hardness has also been included in the Little Qualicum River monitoring program.

6.9 MICROBIOLOGICAL INDICATORS

Fecal contamination of surface waters used for drinking and recreating can result in high risks to human health from pathogenic microbiological organisms as well as significant economic losses due to closure of beaches (Scott *et al*., 2002). The direct measurement and monitoring of pathogens in water, however, is difficult due to their low numbers, intermittent and generally unpredictable occurrence, and specific growth requirements (Krewski *et al*., 2004; Ishii and Sadowsky, 2008). To assess risk of microbiological contamination from fecal matter, resource managers commonly measure fecal indicator bacteria levels (Field and Samadpour, 2007; Ishii and Sadowsky, 2008). The most commonly used indicator organisms for assessing the microbiological quality of water are the total coliforms, fecal coliforms (a subgroup of the total coliforms more appropriately termed thermotolerant coliforms as they can grow at elevated temperatures), and *E. coli* (a thermotolerant coliform considered to be specifically of fecal origin) (Yates, 2007).

There are a number of characteristics that suitable indicator organisms should possess. They should be present in the intestinal tracts of warm-blooded animals, not multiply outside the animal host, be nonpathogenic, and have similar survival characteristics to the pathogens of concern. They should also be strongly associated with the presence of pathogenic microorganisms, be present only in contaminated samples, and be detection and quantifiable by easy, rapid, and inexpensive methods (Scott *et al*., 2002; Field and Samadpour, 2007; Ishii and Sadowsky, 2008).

Total and fecal coliforms have traditionally been used in the assessment of water for domestic and recreational uses. However, research in recent years has shown that there are many differences between the coliforms and the pathogenic microorganisms they are a surrogate for, which limits the use of coliforms as an indicator of fecal contamination (Scott *et al*., 2002). For example, many pathogens, such as enteric viruses and parasites, are not as easily inactivated by water and wastewater treatment processes as coliforms are. As a result, disease outbreaks do occur when indicator bacteria counts are at acceptable levels (Yates, 2007; Haack *et al*., 2009). Additionally, some members of the coliform group, such as *Klebsiella*, can originate from non-fecal sources (Ishii and Sadowsky, 2008) adding a level of uncertainty when analyzing data. Waters contaminated with human feces are generally regarded as a greater risk to human health, as they are more likely to contain human-specific enteric pathogens (Scott *et al*., 2002). Measurement of total and fecal coliforms does not indicate the source of contamination, which can make the actual risk to human health uncertain; thus, it is not always clear where to direct management efforts.

The BC-approved water quality guidelines for microbiological indicators were developed in 1988 (Warrington, 2001) and include *E. coli*, enterococci, *Pseudomonas aeruginosa*, and fecal coliforms. The monitoring programs of the BC MOE have traditionally measured total coliforms, fecal coliforms, *E. coli* and enterococci, either alone or in combination, depending on the specific program. As small pieces of fecal matter in a sample can skew the overall results for a particular site, the 90th percentiles (for drinking water) and geometric means (for recreation) are generally used to determine if the water quality guideline is exceeded, as extreme values would have less effect on the data. The BC MOE drinking water guideline for raw waters receiving disinfection only is that the 90th percentile of at least five weekly samples collected in a 30-day period should not exceed 10 CFU/100 mL for either fecal coliforms or *E. coli* (Warrington, 2001).

Fecal coliform concentrations were measured 26 times in the Little Qualicum River at the intake between 2004 and 2007, with values ranging from 9 CFU/100 mL to a maximum of 220 CFU/100 mL (Appendix I). Samples were collected with sufficient frequency (a minimum of five weekly samples within 30 days) on five occasions, and the 90th percentile for these groups of samples ranged from 65 CFU/100 mL to 171 CFU/100 mL. All 90th percentile values exceeded the drinking water guideline.

E. coli concentrations were measured weekly five times at each of the four sites (except Little Qualicum River at Intake in summer 2011, sampled only four times) during each of the 2011summer low-flow and fall high-flow periods, for a total of 10 samples each. As well, the intake site was sampled on 31 occasions between August 16, 2004 and November 20, 2006. Values ranged from <1 CFU/100 mL(at the two Cameron River sites and Little Qualicum River 1.2 km downstream Cameron Lake) to a maximum of 560 CFU/100 mL (at Little Qualicum at Intake in 2011) (Appendix I). *E. coli* concentrations were low at the three upper sites, and considerably higher at the intake site (Table 18). In those instances when at least five samples were collected within a 30-day period, a 90th percentile value was calculated. Although Little Qualicum River at intake did not have the requisite five samples for August/September 2011 to enable comparison to BC water quality guidelines, the 90th percentile was calculated for the four *E. coli* results available as the data were useful in understanding sample period trends.

Table 18. Summary of results of *E. coli* analyses (CFU/100 mL) within the Little Qualicum River watershed. *indicates value calculated from four samples in 30 days.

		Summer 2004 90th %ile	Winter 2004 90th %ile	Summer 2005 90th %ile	Winter 2005 90th %ile	Summer 2006 90th %ile	Winter 2006 90th %ile	Summer 2011 90th %iles	Winter 2011 90th %iles
E285669	Upper Cameron River							4.8	1.0
E220635	Cameron River U/S Cameron Lake							7.2	6.4
E268993	Little Qualicum River 1.2 km d/s Cameron Lake							7.6	1.0
E256394	Little Qualicum at intake	56.2	70.4	57.6	125.6	120	129.2	35.5*	362

Concentrations of *E. coli* measured in the upper portions of the watershed were consistently below the guideline levels for drinking water, and tended to be slightly higher in the summer than the fall. Concentrations increased considerably at the intake site, such that the drinking water guidelines were not met on any of the seven occasions when the requisite sampling frequency was met. At the intake site *E. coli* concentrations tended to be higher in the fall than in the summer.

The source of the microbiological inputs causing drinking water guideline exceedences is unknown, but since higher levels are not appearing at the site downstream from Cameron Lake, it would appear that the majority of the coliforms being measured at the intake site are originating in the lower watershed (between the site located 1.2 km downstream from Cameron Lake and the intake site). The source of these coliforms is likely anthropogenic (possibly associated with faulty septic fields or domestic animals), although wildlife undoubtedly contributes somewhat as well. These coliforms are of significant concern, as values were consistently high regardless of time of year or water level.

In the Little Qualicum River, results for fecal coliforms and *E. coli* were not consistently similar. Studies have shown that *E. coli*, a component of the fecal coliforms group, is the main thermo-tolerant coliform species present in human and animal fecal samples (94%)

(Tallon *et al*., 2005) and at contaminated bathing beaches (80%) (*Davis et al.*, 2005). In those instances where fecal coliform concentrations were higher than those of *E. coli*, we can assume a high likelihood of contributions from non-fecal sources. Thus, the benefit of measuring both groups is limited. Given the uncertainty in linking thermotolerant (*i.e.* fecal) coliforms to human sources of sewage, we recommend using *E. coli* as the microbiological indicator for the Little Qualicum River.

For the reasons given above, ***a water quality objective is recommended for* E. coli *in the Little Qualicum River. It is recommended that, at the water intake* (*E256394), the 90th percentile of a minimum of 5 weekly samples collected within a 30-day period must not exceed 10 CFU/100 mL for* E. coli.** Meeting these objectives will provide protection from most pathogens but not from parasites such as *Cryptosporidium* or *Giardia*. Sampling for these pathogens falls under the auspices of the water purveyor, in this case the Little Qualicum Waterworks District.

6.10 BIOLOGICAL MONITORING

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. However, as aquatic life is typically the most sensitive use of water bodies, the inclusion of biological data into the overall objective development program is crucial. In partnership with Canada's national biomonitoring program (Canadian Aquatic Biomonitoring Network (CABIN)), benthic macroinvertebrates have been collected from British Columbia streams for bioassessment purposes for many years. Using this information, biological objectives have been developed for Vancouver Island as outlined in Gaber (2013). The biological objective development process is summarized in the following paragraph:

Using a network of 102 minimally impacted (reference) streams on Vancouver Island and Gwaii Haanas National Park, ecologically-based numerical benchmarks were created by calculating the similarity of the benthic macroinvertebrate community of these sites to each other using the Bray-Curtis Coefficient (BCC). BCC is an ecological distance metric with values of 0 representing complete difference from the reference community and values of 100 representing a community identical to the reference community. By measuring the similarity of a test site to the 102 reference sites, its BCC score can be calculated, indicating its position relative to the ecological benchmarks. These ecological benchmarks were set as the 1st, 10th, and 20th percentiles (a score of 15.2, 23.8, and 27.3, respectively) of the distribution of BCC scores for the 102 reference streams. The 20th percentile score is recommended as the biological objective for Vancouver Island (*i.e.* a stream must have a score of 27.3or greater to meet the objective), with values between the 20th and the 10th percentile score indicating further investigation required, and values between the 10th and the 1st percentile score indicating that activities adversely affecting stream conditions should cease. It is also recommended that, when a test sites BCC score does not meet the Vancouver Island biological objective, year over year scores should be increasing, indicating an improvement in the condition of that stream (Gaber, 2013).

In the Little Qualicum River, benthic invertebrate samples were collected in the Little Qualicum River at the intake site in 2006 and downstream of Cameron Lake in 2007. The the BCC score for each with its interpretation regarding invertebrate community health is summarized in Table 19 and Figure 11. As scores for both sites fall above the 20th percentile (meets Vancouver Island objective), no biological objective is proposed for the Little Qualicum River.

Table 19. Summary of Bray-Curtis Coefficient calculated for two Little Qualicum River monitoring sites for benthic invertebrate samples collected in 2006 and 2007.

Site	Bray-Curtis Coefficient	Conclusion
E256394 Little Qualicum at Intake	31.1	Meets objective
E268993 Little Qualicum 1.2 km d/s Cameron Lake	34.7	Meets objective

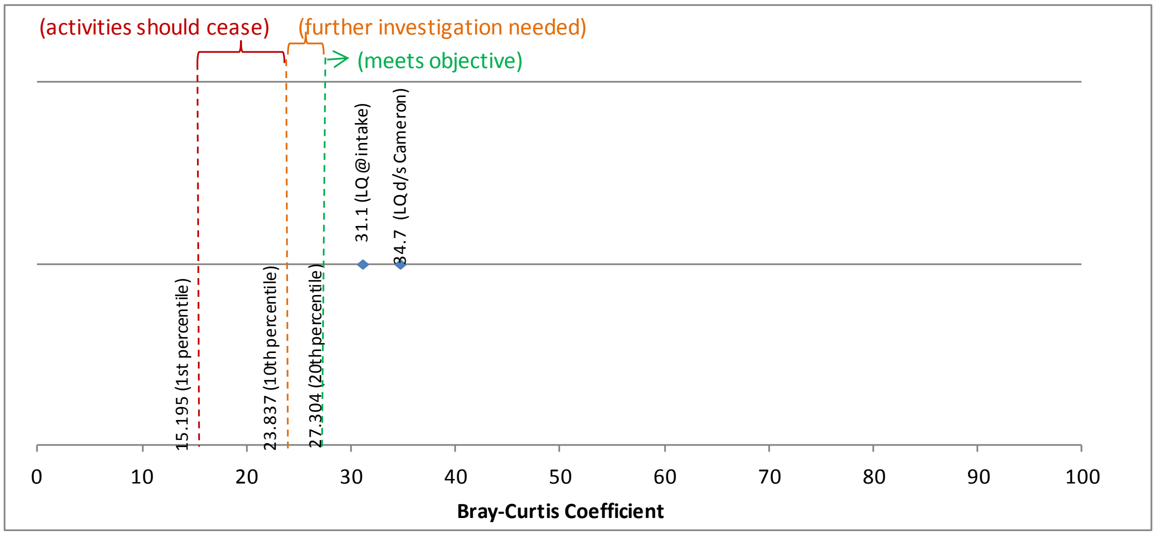

Figure 11. Summary of Bray-Curtis Coefficient calculated for two Little Qualicum River monitoring sites for benthic invertebrate samples collected in 2006 and 2007.

7.0 MONITORING RECOMMENDATIONS

Although most recommended objectives apply specifically to the Little Qualicum River at the intake, attainment monitoring should occur at all four water quality monitoring sites. This information can be used to inform resource management decisions to ensure water quality is protected throughout the watershed and help determine the source of exceedances, should they occur.

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, freshet and summer low-flow) we recommend that a minimum of five weekly samples be collected within a 30-day period between August and September, as well as between October and February. Samples collected during the winter months should coincide with rain events whenever possible. In this way, the two critical periods (minimum dilution and maximum turbidity), will be monitored. Samples should be analyzed for general water chemistry (including pH, specific conductivity, TSS, turbidity, colour, DOC, TOC, nitrate and nitrite, total phosphorous), chlorophyll *a*), as well as bacteriology (*E. coli*); water temperature should also be measured in the field. At least one of the samples collected during the both the high-flow and low-flow period should also be analyzed for total and dissolved metals concentrations (low level analysis) and hardness. For determination of growing season total phosphorous levels, monthly samples between May and September are recommended. Benthic invertebrate monitoring should also occur according to CABIN protocols.

8.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES AND MONITORING SCHEDULE

In BC, water quality objectives are based mainly on approved or working water quality guidelines. These guidelines are established to prevent specified detrimental effects from occurring with respect to a designated water use. Designated water uses for the Little Qualicum River that are sensitive and should be protected are drinking water, irrigation, primary and secondary contact recreation, aquatic life and wildlife. The water quality objectives recommended here (Table 20) take into account background conditions, impacts from current land use and any known potential future impacts that may arise within the watershed. These objectives should be periodically reviewed and revised to reflect any future improvements or technological advancements in water quality assessment and analysis.

The recommended water quality monitoring program for the Little Qualicum River is summarized in Table 21. It is recommended that future attainment monitoring occur once every 3-5 years based on staff and funding availability, and whether activities, such as forestry or development, are underway within the watershed.

Table 20. Summary of proposed water quality objectives for the Little Qualicum River Community Watershed. All objectives apply to the Little Qualicum River at intake site unless stated otherwise.

Variable	Objective Value
Turbidity	2 NTU max March - September 5 NTU max October – February ≤1 NTU at intake 95% of time
Temperature (throughout watershed)	Short term (< 5 years): ≤17°C maximum average weekly
Total Suspended Solids (TSS)/ Non Filterable Residue (throughout watershed)	26 mg/L max 6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Total Organic Carbon	≤4.0 mg/L maximum
True colour	15 TCU maximum
Total Phosphorus (throughout watershed)	0.010 mg/L maximum 0.005 mg/L average (based on a minimum of monthly samples collected from May – Sept)
Escherichia coli	≤10 CFU/100 mL (90th percentile) (based on a minimum 5 weekly samples collected over a 30-day period)

Designated water uses: drinking water, irrigation, primary and secondary contact recreation, aquatic life, and wildlife.

Table 21. Proposed schedule for future water quality monitoring at all sites in the Little Qualicum River.

Frequency and timing	Parameters to be measured
August – September (low-flow season): five weekly samples in a 30-day period	Temperature, TSS, turbidity, DOC, TOC, colour, nutrients (nitrate, nitrite, total phosphorous, chlorophyll *a*) and *E. coli*
October – February (high-flow season): five weekly samples in a 30-day period	Temperature, TSS, turbidity, DOC,TOC, colour, nutrients (nitrate, nitrite, total phosphorous, chlorophyll *a*) and *E. coli*
Monthly from May-September	Total phosphorous
At least once each during each summer and fall 5 weekly samples in 30 day sample period	Total and dissolved metals, hardness
Once every five years in September	Benthic invertebrate sampling

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APPENDIX I. SUMMARY OF WATER QUALITY DATA

Table 22. Summary of general water chemistry for discrete water quality samples collected at Site E285669, Upper Cameron River, 2011-12.

	Minimum	Maximum	Average	Std Dev	Number of samples
E. coli **(CFU/100mL)**	< 1	6	1.7	1.6	10
Carbon Total Organic (mg/L)	< 0.5	3.05	1.2	0.7	21
Ca-D (mg/L)	11	13.1	12.1	1.5	2
Ca-T (mg/L)	10.7	14	12.5	1.7	3
Chlorophyll A (g/m2)	1.5	1.5	1.5	0.0	1
Color True (Col unit)	< 5	10	5.4	1.4	12
Hardness (Dissolved) (mg/L)	32.1	38	35.1	4.2	2
Hardness Total (T) (mg/L)	31.8	41.2	36.8	4.7	3
Mg-D (mg/L)	1.1	1.31	1.21	0.15	2
Mg-T (mg/L)	1.24	1.53	1.35	0.16	3
Nitrogen Total (mg/L)	0.07	0.07	0.07	0.00	1
pH (pH units)	7.23	7.84	7.56	0.19	12
P--T (mg/L)	< 0.002	0.016	0.004	0.004	21
Residue total (mg/L)	< 55	< 55	< 55	0	1
Residue Filterable 1.0u (mg/L)	54	54	54	0	1
Residue Non-filterable (mg/L)	< 1	8.9	1.4	1.7	21
Turbidity (NTU)	0.08	4.96	0.45	1.08	30
Ag-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Ag-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Al-D (mg/L)	0.0107	0.0196	0.0152	0.0063	2
Al-T (mg/L)	0.0078	0.0189	0.0127	0.0057	3
As-D (mg/L)	0.00005	0.00007	0.00006	0.00001	2
As-T (mg/L)	0.00005	0.00007	0.00006	0.00001	3
Ba-D (mg/L)	0.00392	0.00444	0.00418	0.00037	2
Ba-T (mg/L)	0.004	0.00483	0.00443	0.00042	3
B--D (mg/L)	< 0.05	< 0.05	< 0.05	0	2
Be-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Be-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Bi-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Bi-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
B--T (mg/L)	< 0.05	< 0.05	< 0.05	0	3
Cd-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Cd-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Co-D (mg/L)	0.000008	0.000017	0.000013	0.000006	2
Co-T (mg/L)	0.000007	0.000012	0.000009	0.000003	3

	Minimum	Maximum	Average	Std Dev	Number of samples
Cr-D (mg/L)	0.0002	0.0003	0.0003	0.0001	2
Cr-T (mg/L)	0.0002	0.0003	0.0002	0.0001	3
Cu-D (mg/L)	0.00012	0.00028	0.00020	0.00011	2
Cu-T (mg/L)	0.00012	0.00033	0.00020	0.00011	3
Li-D (mg/L)	< 0.0005	0.0005	0.0005	0	2
Li-T (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	3
Mn-D (mg/L)	0.00059	0.00078	0.00069	0.00013	2
Mn-T (mg/L)	0.00073	0.00111	0.00092	0.00019	3
Mo-D (mg/L)	< 0.00005	< 0.00005	< 0.00005	0	2
Mo-T (mg/L)	< 0.00005	< 0.00005	< 0.00005	0	3
Ni-D (mg/L)	0.00002	0.00008	0.00005	0.00004	2
Ni-T (mg/L)	< 0.00002	0.00006	0.00003	0.00002	3
Pb-D (mg/L)	< 0.000005	0.000017	0.00001	0.00001	2
Pb-T (mg/L)	< 0.000005	0.000012	0.00001	0.000004	3
Sb-D (mg/L)	< 0.00002	< 0.00002	< 0.00002	0	2
Sb-T (mg/L)	< 0.00002	< 0.00002	< 0.00002	0	3
Se-D (mg/L)	< 0.00004	< 0.00004	< 0.00004	0	2
Se-T (mg/L)	< 0.00004	< 0.00004	< 0.00004	0	3
Sn-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Sn-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Sr-D (mg/L)	0.0268	0.0289	0.0279	0.0015	2
Sr-T (mg/L)	0.0263	0.0325	0.0292	0.0031	3
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	2
Tl-T (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	3
U--D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	2
U--T (mg/L)	< 0.000002	0.000007	0.000004	0.000003	3
V--D (mg/L)	0.0004	0.0007	0.0006	0.0002	2
V--T (mg/L)	0.0004	0.0005	0.0005	0.0001	3
Zn-D (mg/L)	0.0001	0.0003	0.0002	0.0001	2
Zn-T (mg/L)	< 0.0001	0.0001	0.0001	0	3

Table 23. Summary of general water chemistry for discrete water quality samples collected at Site E220635, Cameron River upstream from Cameron Lake, 2011-12.

	Minimum	Maximum	Average	Std Dev	Number of samples
E. coli **(CFU/100mL)**	< 1	10	3	3.7	10
Ca-D (mg/L)	13.3	14.7	14	1.0	2
Carbon Total Organic (mg/L)	< 0.5	3.29	1.26	0.75	21
Ca-T (mg/L)	13.7	16.5	14.8	1.5	3
Chlorophyll *a* (g/m2)	14.3	14.3	14.3	0	1
Color True (Col unit)	< 5	20	6.3	4.3	12
Hardness (Dissolved) (mg/L)	38.5	42.8	40.65	3.04	2
Hardness Total (T) (mg/L)	40	48.6	43.4	4.6	3
Mg-D (mg/L)	1.29	1.47	1.38	0.13	2
Mg-T (mg/L)	1.38	1.81	1.56	0.22	3
Nitrogen Total (mg/L)	0.09	0.09	0.09	0	1
pH (pH units)	7.46	7.98	7.78	0.18	12
P--T (mg/L)	< 0.002	0.019	0.004	0.005	21
Residue total (mg/L)	< 51	< 51	< 51	0	1
Residue Filterable 1.0u (mg/L)	50	50	50	0	1
Residue Non-filterable (mg/L)	< 1	18.5	2.2	3.9	21
Turbidity (NTU)	0.02	11.3	0.7	2.1	31
Ag-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Ag-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Al-D (mg/L)	0.0132	0.0206	0.0169	0.0052	2
Al-T (mg/L)	0.018	0.0385	0.0249	0.0118	3
As-D (mg/L)	0.00007	0.00007	0.00007	0	2
As-T (mg/L)	0.00006	0.00014	0.00010	0.00004	3
Ba-D (mg/L)	0.00626	0.00673	0.00650	0.00033	2
Ba-T (mg/L)	0.00621	0.00758	0.00692	0.00069	3
B--D (mg/L)	< 0.05	< 0.05	< 0.05	0	2
Be-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Be-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Bi-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Bi-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
B--T (mg/L)	< 0.05	< 0.05	< 0.05	0	3
Cd-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Cd-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Co-D (mg/L)	0.000005	0.000007	0.000006	0.000001	2

	Minimum	Maximum	Average	Std Dev	Number of samples
Co-T (mg/L)	0.000011	0.000036	0.000021	0.000013	3
Cr-D (mg/L)	0.0002	0.0003	0.0003	0.0001	2
Cr-T (mg/L)	0.0002	0.0003	0.0003	0.0001	3
Cu-D (mg/L)	0.00017	0.00024	0.00021	0.00005	2
Cu-T (mg/L)	0.00017	0.00034	0.00023	0.00009	3
Li-D (mg/L)	< 0.0005	0.0005	0.0005	0	2
Li-T (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	3
Mn-D (mg/L)	< 0.00005	0.0003	0.0002	0.0002	2
Mn-T (mg/L)	0.00063	0.00157	0.0010	0.0005	3
Mo-D (mg/L)	< 0.00005	0.00006	0.0001	0.0000	2
Mo-T (mg/L)	< 0.00005	< 0.00005	< 0.00005	0	3
Ni-D (mg/L)	0.00003	0.00004	0.00004	0.00001	2
Ni-T (mg/L)	0.00002	0.00008	0.00005	0.00003	3
Pb-D (mg/L)	< 0.000005	0.000005	0.000005	0	2
Pb-T (mg/L)	< 0.000005	0.000033	0.000017	0.000014	3
Sb-D (mg/L)	< 0.00002	0.00003	0.000025	0.000007	2
Sb-T (mg/L)	< 0.00002	0.00002	0.00002	0	3
Se-D (mg/L)	< 0.00004	0.00004	0.00004	0	2
Se-T (mg/L)	< 0.00004	< 0.00004	< 0.00004	0	3
Sn-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Sn-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Sr-D (mg/L)	0.03	0.0316	0.0308	0.0011	2
Sr-T (mg/L)	0.0302	0.0378	0.0333	0.0040	3
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	2
Tl-T (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	3
U--D (mg/L)	0.000002	0.000005	0.000004	0.000002	2
U--T (mg/L)	0.000002	0.000003	0.000002	0.000001	3
V--D (mg/L)	0.0002	0.0006	0.0004	0.0003	2
V--T (mg/L)	0.0004	0.0005	0.00047	0.00006	3
Zn-D (mg/L)	< 0.0001	0.0004	0.0003	0.0002	2
Zn-T (mg/L)	< 0.0001	0.0002	0.0002	0.0001	3

Table 24. Summary of general water chemistry for discrete water quality samples collected at Site E268993, Little Qualicum River 1.2 km downstream from Cameron Lake, 2011-12.

	Minimum	Maximum	Average	Std Dev	Number of samples
E. coli **(CFU/100mL)**	< 1	8	2.5	2.7	10
Carbon Total Organic (mg/L)	0.8	2.74	1.4	0.5	21
Ca-D (mg/L)	11.4	11.4	11.4	0	2
Ca-T (mg/L)	11.6	12.3	12.0	0.4	3
Chlorophyll *a* (g/m2)	4	4	4	0	1
Color True (Col.unit)	< 5	10	5.4	1.4	12
Hardness (Dissolved) (mg/L)	33.6	34.1	33.9	0.4	2
Hardness Total (T) (mg/L)	34.5	36.5	35.4	1.0	3
Mg-D (mg/L)	1.25	1.35	1.30	0.07	2
Mg-T (mg/L)	1.3	1.43	1.37	0.07	3
Nitrogen Total (mg/L)	0.07	0.07	0.07	0	1
pH (pH units)	7.35	7.88	7.70	0.17	12
P--T (mg/L)	< 0.002	0.028	0.004	0.006	21
Residue total (mg/L)	< 49	< 49	< 49	0	1
Residue Filterable 1.0u (mg/L)	48	48	48	0	1
Residue Non-filterable (mg/L)	< 1	3	1.2	0.5	21
Turbidity (NTU)	0.16	2.5	0.49	0.56	21
Ag-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Ag-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Al-D (mg/L)	0.0105	0.0158	0.0132	0.0037	2
Al-T (mg/L)	0.0148	0.0206	0.0169	0.0032	3
As-D (mg/L)	0.00009	0.00011	0.0001	0.00001	2
As-T (mg/L)	0.00009	0.00011	0.0001	0.00001	3
Ba-D (mg/L)	0.00474	0.00504	0.00489	0.00021	2
Ba-T (mg/L)	0.00483	0.00534	0.00509	0.00026	3
B--D (mg/L)	< 0.05	< 0.05	< 0.05	0	2
Be-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Be-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Bi-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Bi-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
B--T (mg/L)	< 0.05	< 0.05	< 0.05	0	3
Cd-D (mg/L)	< 0.000005	0.000005	0.000005	0	2
Cd-T (mg/L)	< 0.000005	0.000006	0.000005	0.000001	3
Co-D (mg/L)	< 0.000005	0.000018	0.000012	0.000009	2
Co-T (mg/L)	0.00001	0.000016	0.000012	0.000003	3

	Minimum	Maximum	Average	Std Dev	Number of samples
Cr-D (mg/L)	0.0002	0.0002	0.0002	0	2
Cr-T (mg/L)	0.0002	0.0002	0.0002	0	3
Cu-D (mg/L)	0.00024	0.00041	0.00033	0.00012	2
Cu-T (mg/L)	0.00024	0.00034	0.00028	0.00005	3
Li-D (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	2
Li-T (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	3
Mn-D (mg/L)	0.00024	0.00044	0.00034	0.00014	2
Mn-T (mg/L)	0.00149	0.00181	0.00168	0.00017	3
Mo-D (mg/L)	< 0.00005	0.00007	0.00006	0.00001	2
Mo-T (mg/L)	< 0.00005	0.00008	0.00006	0.00002	3
Ni-D (mg/L)	0.00002	0.00004	0.00003	0.00001	2
Ni-T (mg/L)	< 0.00002	0.00007	0.00005	0.00003	3
Pb-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	2
Pb-T (mg/L)	0.000011	0.000026	0.000020	0.000008	3
Sb-D (mg/L)	< 0.00002	0.00002	0.00002	0	2
Sb-T (mg/L)	0.00002	0.00003	0.00003	0.00001	3
Se-D (mg/L)	0.00004	0.00004	0.00004	0	2
Se-T (mg/L)	< 0.00004	< 0.00004	< 0.00004	0	3
Sn-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	2
Sn-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Sr-D (mg/L)	0.0255	0.026	0.0258	0.0004	2
Sr-T (mg/L)	0.026	0.0268	0.0265	0.0004	3
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	2
Tl-T (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	3
U--D (mg/L)	< 0.000002	0.000003	0.000003	0.000001	2
U--T (mg/L)	0.000003	0.000004	0.000004	0.000001	3
V--D (mg/L)	0.0005	0.0006	0.0006	0.0001	2
V--T (mg/L)	0.0004	0.0005	0.0004	0.0001	3
Zn-D (mg/L)	< 0.0001	0.0006	0.0004	0.0004	2
Zn-T (mg/L)	0.0001	0.0008	0.0004	0.0004	3

Table 25. Summary of general water chemistry for discrete water quality samples collected at Site E256394, Little Qualicum River at Intake, 2004-2007.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Fecal coliforms (CFU/100mL)	9	220	59.9	51.8	29
E. coli **(CFU/100mL)**	7	190	48.2	44.3	34
Streptococci (CFU/100mL)	24	270	93.4	101.5	5
Alkalinity Total 4.5 (mg/L)	48.8	48.8	48.8		1
Ammonia Dissolved (mg/L)	< 0.005	0.01	0.008	0.004	2
Carbon Dissolved Organic (mg/L)	< 0.5	6	2.0	1.4	31
Carbon Total Organic (mg/L)	0.9	3.2	1.9	0.9	8
Chloride -D (mg/L)	1.4	4.9	2.3	0.7	27
Color True (TCU)	5	5	5		1
Hardness Total (D) (mg/L)	39	39	39		1
Hardness Total (T) (mg/L)	41	41	41		1
Nitrate (NO3) Dissolved (mg/L)	< 0.001	0.11	0.038	0.030	31
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.114	0.036	0.031	33
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	0.006	0.003	0.001	31
Nitrogen (Kjel.) Tot Diss (mg/L)	0.06	0.14	0.087	0.046	3
Nitrogen Organic-Total (mg/L)	0.05	0.11	0.073	0.032	3
Nitrogen Total (mg/L)	0.08	0.2	0.123	0.067	3
Nitrogen Total Dissolved (mg/L)	0.075	0.207	0.122	0.074	3
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.011	0.004	0.003	26
pH (pH units)	6.7	8	7.6	0.3	33
Phosphorus Tot. Dissolved (mg/L)	< 0.002	0.015	0.008	0.019	27
P--T (mg/L)	< 0.002	0.066	0.011	0.021	29
Residue Non-filterable (mg/L)	< 1	59	4.6	9.6	61
Silica - D (mg/L)	9.7	9.7	9.7		1
Specific Conductance (µS/cm)	59	105	85.5	11.1	32
Turbidity (NTU)	0.1	7.36	1.23	1.54	32
UV Absorbance 250nm (AU/cm)	0.02	0.22	0.07	0.05	12
UV Absorbance 254nm (AU/cm)	0.02	0.21	0.07	0.05	12
UV Absorbance 310nm (AU/cm)	< 0.01	0.1	0.03	0.02	12
UV Absorbance 340nm (AU/cm)	< 0.01	0.06	0.02	0.01	12
UV Absorbance 360nm (AU/cm)	< 0.01	0.04	0.01	0.01	12
UV Absorbance 365nm (AU/cm)	< 0.01	0.04	0.01	0.01	12
Ag-D (mg/L)	< 0.00002	< 0.00002	< 0.00002	0	36
Ag-T (mg/L)	< 0.00002	< 0.00002	< 0.00002	0	38
Al-D (mg/L)	0.0016	0.06	0.0141	0.0165	36
Al-T (mg/L)	0.0043	0.687	0.069	0.134	38

	Minimum	Maximum	Average	Std Dev	No. of Samples
As-D (mg/L)	< 0.0001	0.0003	0.0002	0.0001	36
As-T (mg/L)	< 0.0001	0.0004	0.0002	0.0001	38
Ba-D (mg/L)	0.0029	0.0062	0.0047	0.0009	36
Ba-T (mg/L)	0.0037	0.0092	0.0054	0.0010	38
B--D (mg/L)	0.01	0.01	0.01		1
B--T (mg/L)	0.012	0.012	0.012		1
Be-D (mg/L)	< 0.00002	0.00002	< 0.00002	0	36
Be-T (mg/L)	< 0.00002	0.0001	< 0.00002	0.00002	38
Bi-D (mg/L)	< 0.00002	< 0.00002	< 0.00002	0	36
Bi-T (mg/L)	< 0.00002	0.00002	< 0.00002	0	38
Ca-D (mg/L)	13.1	13.1	13.1		1
Ca-T (mg/L)	13.7	13.7	13.7		1
Cd-D (mg/L)	< 0.00001	0.0002	0.00002	0.0001	36
Cd-T (mg/L)	< 0.00001	0.0008	0.00005	0.0001	38
Co-D (mg/L)	< 0.000005	0.000005	0.000005	0	36
Co-T (mg/L)	< 0.000005	0.0005	0.00004	0.00010	38
Cr-D (mg/L)	< 0.0002	0.0003	0.0002	0.0000	36
Cr-T (mg/L)	< 0.0002	0.0011	0.0002	0.0002	38
Cu-D (mg/L)	0.0003	0.0044	0.0007	0.0007	36
Cu-T (mg/L)	0.0003	0.0051	0.0009	0.0010	38
Fe-D (mg/L)	0.018	0.018	0.018		1
Fe-T (mg/L)	0.088	0.088	0.088		1
K--D (mg/L)	< 1	< 1	< 1		1
K--T (mg/L)	< 1	< 1	< 1		1
Li-D (mg/L)	< 0.0001	0.0003	0.0002	0.0001	36
Li-T (mg/L)	< 0.0001	0.0005	0.0002	0.0001	38
Mg-D (mg/L)	1.52	1.52	1.52		1
Mg-T (mg/L)	1.63	1.63	1.63		1
Mn-D (mg/L)	0.0001	0.0033	0.0011	0.0007	36
Mn-T (mg/L)	0.0007	0.0388	0.0054	0.0073	38
Mo-D (mg/L)	< 0.0001	0.0001	0.0001	0.0000	36
Mo-T (mg/L)	< 0.0001	0.0001	0.0001	0.0000	38
Na-D (mg/L)	1.66	1.66	1.66		1
Na-T (mg/L)	1.7	1.7	1.7		1
Ni-D (mg/L)	< 0.0001	0.0003	0.0001	0.0001	36
Ni-T (mg/L)	< 0.0001	0.0011	0.0002	0.0002	38
Pb-D (mg/L)	< 0.00001	0.0001	0.00001	0.00002	36
Pb-T (mg/L)	< 0.00001	0.0007	0.00006	0.00013	38
Sb-D (mg/L)	< 0.000005	0.000005	0.000005	0	36
Sb-T (mg/L)	< 0.000005	0.000005	0.000005	0	38

	Minimum	Maximum	Average	Std Dev	No. of Samples
S--D (mg/L)	0.5	0.5	0.5		1
S--T (mg/L)	0.5	0.5	0.5		1
Se-D (mg/L)	< 0.0002	0.0003	0.0002	0	36
Se-T (mg/L)	< 0.0002	0.0006	0.0002	0.0001	38
Sn-D (mg/L)	< 0.00001	0.0001	0.000003	0.000017	35
Sn-T (mg/L)	< 0.00001	0.0001	0.000008	0.000027	38
Sr-D (mg/L)	0.0164	0.036	0.0278	0.0059	36
Sr-T (mg/L)	0.0175	0.0364	0.0284	0.0054	38
Ti-D (mg/L)	< 0.003	< 0.003	< 0.003		1
Ti-T (mg/L)	< 0.003	< 0.003	< 0.003		1
Tl-D (mg/L)	< 0.00002	0.000005	0.000002		36
Tl-T (mg/L)	< 0.00002	0.000006	0.000002		38
U--D (mg/L)	< 0.000002	0.000004	0.000003		36
U--T (mg/L)	< 0.000002	0.000004	0.000003		38
V--D (mg/L)	0.0004	0.0014	0.0006	0.0002	36
V--T (mg/L)	0.0005	0.0028	0.0009	0.0004	38
Zn-D (mg/L)	< 0.0001	0.0023	0.0005	0.0006	36
Zn-T (mg/L)	< 0.0001	0.0096	0.0011	0.0017	38
Zr-D (mg/L)	< 0.005	< 0.005	< 0.005		1
Zr-T (mg/L)	< 0.005	< 0.005	< 0.005		1

Table 26. Summary of general water chemistry for discrete water quality samples collected at Site E256394, Little Qualicum River at Intake, 2011-12.

	Minimum	Maximum	Average	Std Dev	Number of samples
E. coli **(CFU/100mL)**	4	560	84.7	179.3	9
Ca-D (mg/L)	11.2	12.7	11.9	0.8	3
Ca-T (mg/L)	11.7	13.8	12.5	1.0	4
Carbon Total Organic (mg/L)	0.89	6.65	1.91	1.23	22
Chlorophyll A (g/m2)	28.3	28.3	28.3	0.0	1
Color True (Col.unit)	5	40	11.3	10.5	12
Hardness (Dissolved) (mg/L)	33.9	38.9	36.0	2.6	3
Hardness Total (T) (mg/L)	35.8	42.6	38.2	3.2	4
Mg-D (mg/L)	1.44	1.74	1.54	0.17	3
Mg-T (mg/L)	1.62	1.96	1.73	0.16	4
Nitrogen Total (mg/L)	0.11	0.11	0.11	0.00	1
pH (pH units)	7.36	7.89	7.72	0.17	12
P--T (mg/L)	< 0.002	0.088	0.018	0.026	22
Residue total (mg/L)	< 49	< 49	< 49	0	1
Residue Filterable 1.0u (mg/L)	48	48	48.0	0.0	1
Residue Non-filterable (mg/L)	< 1	32	3.5	6.7	22
Turbidity (NTU)	0.17	12.3	1.10	2.24	32
Ag-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Ag-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	4
Al-D (mg/L)	0.0083	0.0155	0.0130	0.0041	3
Al-T (mg/L)	0.0146	0.083	0.0468	0.0360	4
As-D (mg/L)	0.00009	0.00015	0.00011	0.00003	3
As-T (mg/L)	0.00012	0.00017	0.00014	0.00002	4
Ba-D (mg/L)	0.00441	0.00481	0.00458	0.00021	3
Ba-T (mg/L)	0.00499	0.00559	0.00540	0.00028	4
B--D (mg/L)	< 0.05	< 0.05	< 0.05	0	3
Be-D (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	3
Be-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	4
Bi-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Bi-T (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	4
B--T (mg/L)	< 0.05	< 0.05	< 0.05	0	4
Cd-D (mg/L)	< 0.000005	< 0.000005	< 0.000005	0	3
Cd-T (mg/L)	< 0.000005	0.000009	0.000006	0.000002	4
Co-D (mg/L)	0.000006	0.000013	0.000010	0.000004	3
Co-T (mg/L)	0.000014	0.000053	0.000034	0.000021	4
Cr-D (mg/L)	0.0001	0.0002	0.0002	0.0001	3

	Minimum	Maximum	Average	Std Dev	Number of samples
Cr-T (mg/L)	0.0002	0.0003	0.0003	0.0001	4
Cu-D (mg/L)	0.00033	0.00052	0.00039	0.00011	3
Cu-T (mg/L)	0.00029	0.0005	0.00040	0.00010	4
Li-D (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	3
Li-T (mg/L)	< 0.0005	< 0.0005	< 0.0005	0	4
Mn-D (mg/L)	0.00031	0.0019	0.00106	0.00080	3
Mn-T (mg/L)	0.00316	0.00657	0.00488	0.00179	4
Mo-D (mg/L)	< 0.00005	0.00006	0.00005	0.00001	3
Mo-T (mg/L)	< 0.00005	0.00007	0.00006	0.00001	4
Ni-D (mg/L)	0.00004	0.00007	0.00005	0.00002	3
Ni-T (mg/L)	0.00007	0.00013	0.00010	0.00003	4
Pb-D (mg/L)	0.000007	0.000032	0.000016	0.000014	3
Pb-T (mg/L)	0.000006	0.000021	0.000014	0.000008	4
Sb-D (mg/L)	< 0.00002	0.00002	0.00002	0	3
Sb-T (mg/L)	< 0.00002	0.00002	0.00002	0	4
Se-D (mg/L)	< 0.00004	< 0.00004	< 0.00004	0	3
Se-T (mg/L)	< 0.00004	0.00005	0.00004	0.00001	4
Sn-D (mg/L)	< 0.00001	0.00003	0.00002	0.00001	3
Sn-T (mg/L)	< 0.00001	< 0.00001	< 0.00001	0	4
Sr-D (mg/L)	0.0251	0.0281	0.0263	0.0016	3
Sr-T (mg/L)	0.0254	0.0297	0.0275	0.0019	4
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	3
Tl-T (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	4
U--D (mg/L)	0.000003	0.000004	0.000004	0.000001	3
U--T (mg/L)	0.000003	0.000006	0.000005	0.000001	4
V--D (mg/L)	0.0005	0.0007	0.0006	0.0001	3
V--T (mg/L)	0.0006	0.0007	0.0007	0.0001	4
Zn-D (mg/L)	< 0.0001	0.0002	0.0002	0.0001	3
Zn-T (mg/L)	0.0002	0.0004	0.0003	0.0001	4

Table 27. Summary of specific conductivity data (in µS/cm) collected by volunteer groups in 2011-12 at the four water quality monitoring sites and on Whiskey Creek.

	Minimum	Maximum	Average	Std Dev	No. of samples
Upper Cameron River	65.2	152.0	99.5	23.6	20
Cameron River U/S Cameron Lake	70.8	180.4	118.4	29.2	20
Little Qualicum River 1.2 km d/s Cameron Lake	78.9	133.1	102.7	20.1	10
Little Qualicum River at Intake	77.6	169.9	113.9	31.0	20
Whiskey Creek	109.4	199.6	136.1	31.8	9

Table 28. Summary of temperature data (in °C) collected by volunteer groups in 2011-12 at the four water quality monitoring sites and on Whiskey Creek.

	Minimum	Maximum	Average	Std Dev	No. of samples
Upper Cameron River	3.4	13.1	7.9	2.7	20
Cameron River U/S Cameron Lake	3.5	13.1	8.5	3.0	20
Little Qualicum River 1.2 km d/s Cameron Lake	8.8	18.7	13.7	3.7	10
Little Qualicum River at Intake	6.6	18.4	12.9	3.9	20
Whiskey Creek	6.9	12.7	10.0	2.2	9

Table 29. Summary of dissolved oxygen data (in mg/L) collected by volunteer groups in 2011-12 at the four water quality monitoring sites and on Whiskey Creek.

	Minimum	Maximum	Average	Std Dev	No. of samples
Upper Cameron River	7.5	14.0	11.8	0.9	20
Cameron River U/S Cameron Lake	10.8	14.0	11.9	0.8	20
Little Qualicum River 1.2 km d/s Cameron Lake	8.5	11.7	10.1	1.2	10
Little Qualicum River at Intake	9.5	12.3	10.5	0.8	20
Whiskey Creek	9.9	12.7	10.9	0.9	9

Table 30. Summary of turbidity data (in NTU) collected by volunteer groups in 2011-12 at the four water quality monitoring sites and on Whiskey Creek.

	Minimum	Maximum	Average	Std Dev	No. of samples
Upper Cameron River	0.0	2.1	0.3	0.4	20
Cameron River U/S Cameron Lake	0.0	1.2	0.2	0.3	20
Little Qualicum River 1.2 km d/s Cameron Lake	0.1	2.1	0.5	0.7	10
Little Qualicum River at Intake	0.2	1.6	0.5	0.4	20
Whiskey Creek	0.1	0.5	0.2	0.1	9

APPENDIX II. SUMMARY OF QA/QC DATA

Table 31. Summary of triplicate samples collected in mid-September, 2011 from the four sampling sites and analyzed for chlorophyll *a* (mg/L)

	Cameron River Upstream	Cameron River U/S Cameron Lake	Little Qualicum D/S Cameron Lake	Little Qualicum at intake
Sample 1	1.4	14.3	1.8	28.3
Sample 2	1.5	28.9	4	30.4
Sample 3	2.1	10.5	5.7	49
Average	1.7	17.9	3.8	35.9
Std Dev	0.4	9.7	2.0	11.4
Relative % Std Dev	**23%**	**54%**	**51%**	**32%**

Table 32. Summary of duplicate samples collected on Oct. 18, 2011 at the intake site and analyzed for ***E. coli***.

	E coli (CFU/100mL)
Sample 1	4
Sample 2	7
Average	5.5
Difference	3
Relative % difference	**55%**

Table 33. Summary of duplicate samples collected at intake site on Nov. 1, 2004 and analyzed for metals and TSS concentrations.

Parameter	Sample 1	Sample 2	Average	Difference	Relative % difference
Al-D (mg/L)	0.0101	0.0102	0.01015	0.0001	1%
Al-T (mg/L)	0.0197	0.0204	0.02005	0.0007	3%
As-D (mg/L)	0.0001	0.0001	0.0001	0	0%
As-T (mg/L)	0.0002	0.0001	0.00015	0.0001	67%
Ba-D (mg/L)	0.0045	0.0046	0.00455	0.0001	2%
Ba-T (mg/L)	0.0048	0.0046	0.0047	0.0002	4%
Cr-D (mg/L)	< 0.0002	< 0.0002	0.0002	0	0%
Cr-T (mg/L)	< 0.0002	< 0.0002	0.0002	0	0%
Cu-D (mg/L)	0.0003	0.0005	0.0004	0.0002	50%
Cu-T (mg/L)	0.0004	0.0005	0.00045	0.0001	22%
Li-D (mg/L)	0.0002	0.0002	0.0002	0	0%
Li-T (mg/L)	0.0002	0.0002	0.0002	0	0%
Mn-D (mg/L)	0.0011	0.0011	0.0011	0	0%
Mn-T (mg/L)	0.0021	0.0018	0.00195	0.0003	15%
Mo-D (mg/L)	0.0001	0.0001	0.0001	0	0%
Mo-T (mg/L)	0.0001	0.0001	0.0001	0	0%
Ni-D (mg/L)	< 0.0001	0.0001	0.0001	0	0%
Ni-T (mg/L)	0.0001	0.0002	0.00015	0.0001	67%
Residue Non-filterable (mg/L)	5	3	4	2	50%
Se-D (mg/L)	< 0.0002	< 0.0002	0.0002	0	0%
Se-T (mg/L)	< 0.0002	< 0.0002	0.0002	0	0%
Sr-D (mg/L)	0.0253	0.0255	0.0254	0.0002	1%
Sr-T (mg/L)	0.0255	0.0255	0.0255	0	0%
V--D (mg/L)	0.0005	0.0005	0.0005	0	0%
V--T (mg/L)	0.0005	0.0005	0.0005	0	0%
Zn-D (mg/L)	0.0001	0.0004	0.00025	0.0003	120%
Zn-T (mg/L)	0.0002	0.0004	0.0003	0.0002	67%

APPENDIX III. SUMMARY OF ALL TURBIDITY EVENTS (>5 NTU) MEASURED AT LITTLE QUALICUM RIVER INTAKE (FROM OBEE, 2012).

Event Start Date and Time	Duration (hrs)	Recovery Time (hrs)	n	Min (NTU)	Max (NTU)	Mean (NTU)	StDev
2011-05-15 19:45:50	0.25	>920.75	1	6.7	6.7	6.7	-
2011-06-05 05:15:50	0.25	489.25	1	5.3	5.3	5.3	-
2011-06-13 21:15:49	0.25	207.75	1	5.5	5.5	5.5	-
2011-06-13 21:45:50	0.25	0.25	1	5.9	5.9	5.9	-
2011-06-13 22:30:50	1.00	0.50	3	5.4	6.0	5.7	0.3
2011-06-13 23:45:50	0.25	0.25	1	5.7	5.7	5.7	-
2011-06-14 00:15:50	1.75	0.25	5	5.0	5.9	5.3	0.4
2011-06-14 03:15:50	0.25	1.25	1	5.1	5.1	5.1	-
2011-06-27 08:15:21	1.00	316.74	4	6.1	8.3	7.5	1.0
2011-07-10 09:30:50	0.25	312.26	1	5.6	5.6	5.6	-
2011-08-20 15:00:49	0.25	989.25	1	5.4	5.4	5.4	-
2011-08-23 16:00:49	0.50	72.75	2	10.2	18.7	14.5	6.0
2011-08-23 19:15:49	0.25	2.75	1	9.2	9.2	9.2	-
2011-09-07 08:30:50	0.25	349.00	1	5.8	5.8	5.8	-
2011-09-23 18:30:49	0.25	393.75	1	9.4	9.4	9.4	-
2011-09-24 18:30:50	0.25	23.75	1	20.7	20.7	20.7	-
2011-09-25 04:00:50	0.25	9.25	1	8.5	8.5	8.5	-
2011-09-25 05:00:50	0.25	0.75	1	6.0	6.0	6.0	-
2011-09-26 13:30:50	13.25	32.25	53	5.0	12.6	7.0	1.2
2011-09-27 03:00:50	4.00	0.25	16	5.0	10.8	5.8	1.4
2011-09-27 07:15:50	0.25	0.25	1	5.8	5.8	5.8	-
2011-09-27 07:45:50	0.50	0.25	2	5.0	5.2	5.1	0.1
2011-09-27 08:45:50	0.25	0.50	1	5.0	5.0	5.0	-
2011-09-27 09:45:50	0.25	0.75	1	5.4	5.4	5.4	-
2011-09-27 11:00:50	0.50	1.00	2	5.6	5.7	5.6	0.1
2011-10-12 07:00:50	0.25	355.50	1	5.7	5.7	5.7	-
2011-10-12 07:45:50	2.75	0.50	8	5.0	6.3	5.5	0.4
2011-10-12 10:45:50	0.25	0.25	1	5.1	5.1	5.1	-
2011-10-12 12:00:50	0.25	1.00	1	5.4	5.4	5.4	-
2011-10-12 13:15:50	0.25	1.00	1	5.8	5.8	5.8	-
2011-10-12 13:45:50	0.25	0.25	1	5.2	5.2	5.2	-
2011-10-13 03:30:50	0.25	13.50	1	6.5	6.5	6.5	-
2011-10-14 00:00:50	0.25	20.25	1	5.2	5.2	5.2	-
2011-10-18 12:00:50	0.25	107.75	1	17.9	17.9	17.9	-
2011-10-28 22:15:50	0.50	250.00	2	5.5	9.5	7.5	2.8
2011-10-30 20:00:51	0.25	45.25	1	11.8	11.8	11.8	-

Event Start Date and Time	Duration (hrs)	Recovery Time (hrs)	n	Min (NTU)	Max (NTU)	Mean (NTU)	StDev
2011-11-01 00:15:50	0.25	28.00	1	5.2	5.2	5.2	-
2011-11-01 08:45:51	0.25	8.25	1	5.0	5.0	5.0	-
2011-11-02 11:15:51	0.25	26.25	1	5.0	5.0	5.0	-
2011-11-02 14:00:51	0.25	2.50	1	5.3	5.3	5.3	-
2011-11-02 17:45:51	0.25	3.50	1	5.0	5.0	5.0	-
2011-11-02 18:15:51	0.50	0.25	2	5.1	5.4	5.3	0.2
2011-11-02 19:00:51	0.25	0.25	1	5.2	5.2	5.2	-
2011-11-02 19:30:51	1.00	0.25	4	5.0	5.8	5.3	0.4
2011-11-02 20:45:50	0.25	0.25	1	5.2	5.2	5.2	-
2011-11-02 21:15:50	1.50	0.25	6	5.1	5.8	5.5	0.3
2011-11-02 23:00:51	1.00	0.25	4	5.1	5.7	5.3	0.3
2011-11-03 00:15:51	9.25	0.25	37	5.0	7.5	5.5	0.4
2011-11-03 09:45:50	0.25	0.25	1	5.2	5.2	5.2	-
2011-11-03 10:15:51	0.75	0.25	3	5.0	5.3	5.1	0.1
2011-11-03 11:30:51	0.25	0.50	1	5.0	5.0	5.0	-
2011-11-03 13:30:50	0.50	1.75	2	5.1	5.3	5.2	0.2
2011-11-03 14:45:50	0.50	0.75	2	5.0	5.0	5.0	0.0
2011-11-03 15:45:50	0.50	0.50	2	5.0	5.8	5.4	0.6
2011-11-03 16:30:50	0.25	0.25	1	5.3	5.3	5.3	-
2011-11-03 17:00:50	0.50	0.25	2	5.3	5.7	5.5	0.3
2011-11-03 17:45:51	8.75	0.25	35	5.0	6.1	5.5	0.3
2011-11-04 02:45:51	7.00	0.25	28	5.2	7.3	5.6	0.5
2011-11-04 10:15:50	0.50	0.50	2	5.1	5.1	5.1	0.0
2011-11-04 11:30:50	1.25	0.75	5	5.0	5.3	5.2	0.1
2011-11-04 13:30:50	0.25	0.75	1	5.2	5.2	5.2	-
2011-11-04 15:00:51	0.25	1.25	1	5.0	5.0	5.0	-
2011-11-04 15:45:51	0.25	0.50	1	5.3	5.3	5.3	-
2011-11-04 16:15:51	0.75	0.25	3	5.1	5.5	5.3	0.2
2011-11-04 17:15:51	449.75	0.25	1561	5.2	69.9	13.9	7.1
2011-11-26 22:00:50	0.25	83.00	1	5.9	5.9	5.9	-
2011-11-26 22:30:51	59.00	0.25	236	5.2	98.2	22.2	22.4
2011-11-29 09:45:51	0.75	0.25	3	5.2	5.6	5.3	0.3
2011-11-29 13:00:51	0.25	2.50	1	5.2	5.2	5.2	-
2011-11-29 15:00:50	0.25	1.75	1	5.3	5.3	5.3	-
2011-12-04 00:00:51	0.25	104.75	1	5.7	5.7	5.7	-
2011-12-26 22:00:51	0.25	549.75	1	5.3	5.3	5.3	-
2011-12-27 12:00:51	0.25	13.75	1	6.3	6.3	6.3	-
2011-12-27 20:00:51	0.25	7.75	1	5.7	5.7	5.7	-
2011-12-27 20:30:51	16.75	0.25	67	5.1	22.0	10.5	4.7
2011-12-28 13:30:51	0.75	0.25	3	5.0	5.3	5.1	0.1

Event Start Date and Time	Duration (hrs)	Recovery Time (hrs)	n	Min (NTU)	Max (NTU)	Mean (NTU)	StDev
2011-12-28 15:15:51	0.25	1.00	1	5.4	5.4	5.4	-
2011-12-28 16:00:51	0.25	0.50	1	5.1	5.1	5.1	-
2011-12-28 16:30:51	0.25	0.25	1	8.5	8.5	8.5	-
2011-12-28 17:30:51	16.00	0.75	64	5.1	19.9	10.6	4.1
2012-01-03 12:15:51	0.25	122.75	1	6.4	6.4	6.4	-
2012-01-03 15:30:51	115.25	3.00	461	5.0	75.0	24.4	19.0
2012-01-08 11:00:51	1.00	0.25	4	5.1	5.5	5.2	0.1
2012-01-08 12:15:51	0.50	0.25	2	5.3	5.6	5.5	0.2
2012-01-08 13:00:50	0.25	0.25	1	5.2	5.2	5.2	-
2012-01-08 13:30:50	1.00	0.25	4	5.1	7.2	6.1	0.8
2012-01-08 15:00:51	0.25	0.50	1	5.2	5.2	5.2	-
2012-01-08 15:45:51	0.25	0.50	1	5.4	5.4	5.4	-
2012-01-08 16:30:51	0.75	0.50	3	5.2	5.9	5.6	0.4
2012-01-10 09:00:51	0.25	39.75	1	5.0	5.0	5.0	-
2012-01-21 14:30:49	0.75	269.25	3	5.1	12.0	8.4	3.5
2012-01-21 17:30:50	0.50	2.25	2	5.9	6.0	5.9	0.1
2012-01-22 14:45:50	0.25	20.75	1	5.3	5.3	5.3	-
2012-01-22 20:30:50	0.75	5.50	3	5.3	6.4	5.7	0.6
2012-01-22 22:00:50	1.00	0.75	4	5.1	7.9	6.0	1.3
2012-01-22 23:15:50	0.25	0.25	1	5.2	5.2	5.2	-
2012-01-22 23:45:49	0.25	0.25	1	5.0	5.0	5.0	-
2012-01-23 00:15:50	0.50	0.25	2	5.1	5.2	5.2	0.0
2012-01-23 01:00:50	6.00	0.25	24	5.1	11.1	7.7	1.8
2012-01-23 07:30:50	1.00	0.50	4	5.2	6.2	5.8	0.5
2012-01-24 09:00:50	0.25	24.50	1	5.1	5.1	5.1	-
2012-01-24 12:15:50	28.50	3.00	114	5.2	22.7	13.2	5.2
2012-01-25 17:00:50	0.25	0.25	1	5.0	5.0	5.0	-
2012-01-29 04:00:50	0.25	82.75	1	5.1	5.1	5.1	-
2012-01-29 04:30:50	0.50	0.25	2	5.1	5.3	5.2	0.2
2012-01-29 05:15:50	3.00	0.25	12	5.0	6.6	5.5	0.4
2012-01-29 10:45:50	0.75	2.50	3	5.1	6.9	6.2	0.9
2012-01-29 14:15:50	0.25	2.75	1	5.3	5.3	5.3	-
2012-02-10 01:30:50	1.00	275.00	4	7.2	24.0	16.4	6.9
2012-02-10 07:45:50	1.00	5.25	4	5.3	6.1	5.7	0.4
2012-02-10 09:15:50	0.25	0.50	1	5.1	5.1	5.1	-
2012-02-10 10:15:51	0.75	0.75	3	6.2	8.2	7.3	1.0
2012-02-10 19:45:51	0.75	8.75	3	6.1	9.4	8.2	1.9
2012-02-10 21:00:51	0.75	0.50	3	5.0	5.1	5.1	0.1
2012-02-10 22:00:51	7.00	0.25	28	5.1	10.6	6.1	1.1
2012-02-12 19:30:51	2.00	38.50	8	5.8	26.9	11.5	7.4

Event Start Date and Time	Duration (hrs)	Recovery Time (hrs)	n	Min (NTU)	Max (NTU)	Mean (NTU)	StDev
2012-02-12 21:45:51	0.25	0.25	1	5.1	5.1	5.1	-
2012-02-15 19:00:51	0.50	69.00	2	6.2	7.2	6.7	0.7
2012-02-18 02:15:51	1.00	54.75	4	6.1	8.7	7.3	1.1
2012-02-18 04:45:51	0.75	1.50	3	5.1	6.5	5.8	0.7
2012-02-18 11:15:50	0.50	5.75	2	5.4	7.0	6.2	1.1
2012-02-23 21:00:50	0.25	129.25	1	6.7	6.7	6.7	-