ENVIRONMENTAL PROTECTION DIVISION

ENVIRONMENTAL SUSTAINABILITY AND
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MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for the French Creek Community Watershed

TECHNICAL REPORT

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EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of French Creek, British Columbia, and proposes water quality objectives designed to protect existing and future water uses. The water quality assessment for the creek and an evaluation of the watershed, as well as a comparison with the neighboring Englishman River, form the basis for the objectives.

French Creek, with a length of 24 km, drains into Georgia Strait between Qualicum Beach and Parksville. The designated water uses in French Creek include drinking water, irrigation, livestock watering, primary contact recreation, wildlife and aquatic life. Epcor Water (West) Inc., a private utilities company supplying water to the community of French Creek, withdraws drinking water from French Creek as a backup to their well system. Logging roads provide recreational access to the upper watershed where hunting, ATV use and hiking occurs. These activities, as well as forestry, urban and residential development, light industrial development, agriculture, and wildlife, all potentially affect water quality in the creek.

Water quality monitoring was conducted between 2000 and 2011. The results of this monitoring indicated that the overall state of the water quality is moderate. Chemical, physical and biological parameters that exceeded provincial water quality guidelines on occasion for drinking water and/or aquatic life included temperature, turbidity, total suspended solids, true colour, total organic carbon, dissolved aluminum, chlorophyll *a*, fecal coliforms and *Escherichia coli*. To support the maintenance and protection of the water quality in French Creek, ambient water quality objectives were set for these parameters (with the exception of fecal coliforms) and for total phosphorous.

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 five monitoring sites throughout the watershed.

Water Quality Objectives for French Creek

(Objectives apply to all sites unless otherwise stated)

Variable	Objective Value
Temperature	Short term (< 5 years): ≤17°C maximum average weekly Long term (5 – 10 years): ≤15°C maximum average weekly
Turbidity	5 NTU maximum Oct – Dec 2 NTU maximum Jan – Sept 95% of samples ≤1 NTU at intake
Total Suspended Solids (TSS)/ Non-Filterable Residue	26 mg/L maximum 6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
True Colour	15 TCU maximum
Total Organic Carbon	4.0 mg/L maximum at intake
Total Phosphorus	10 µg/L max 5 µg/L avg (based on a minimum of monthly samples collected from May – Sept)
Chlorophyll *a*	0.1 g/m^2 average during summer (based on minimum of three samples)
Dissolved Aluminum	0.1 mg/L maximum 0.05 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Escherichia coli	≤ 41 CFU/100 mL (90^{th} percentile) (based on a minimum of five weekly samples collected over a 30-day period)
Benthic Invertebrates (provisional objective)	≥27.304 (or the 20^{th} percentile of the distribution of BCC scores for the West Coast Region)

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

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ACKNOWLEDGEMENTS

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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 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. Water quality 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. This report represents the first application of this methodology, with the neighboring Englishman River used as the representative watershed. Both watersheds are located in the Nanaimo Lowland Ecoregion of Vancouver Island, and a complete three-year monitoring program was conducted on the Englishman River between 2002 and 2005 with Water Quality Objectives approved for the watershed in 2010 (Barlak *et al*., 2010).

Figure 1. Map of Vancouver Island Ecoregions

Partnerships formed between the MOE, local municipalities 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.

French Creek community watershed provides a backup source of drinking water to the local community and has high fisheries values, with steelhead, rainbow trout, cutthroat trout, coho salmon, chinook salmon, pink salmon, and chum salmon present at some point during the year (FISS, 2013). Anthropogenic land uses within the watershed include timber harvesting, agriculture, commercial/light industrial development, urban and residential development, and recreation. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in French Creek.

This report examines the existing water quality of French Creek and recommends water quality objectives for this watershed based on potential impacts and water quality parameters of concern. French Creek 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) in 2004 and infers a level of protection. As the majority of the French Creek 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 within these watersheds is protected and managed in a consistent manner.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

French Creek is a fourth-order stream 24 km in length, draining into the Georgia Strait between the towns of Parksville to the east and Qualicum Beach to the west. The community watershed portion is 6,648 ha in area and ranges from near sea level at the Epcor Water (West) intake to about 1,080 m at the edge of the South Vancouver Island Ranges. The intake is located approximately 1.5 km upstream from the mouth of French Creek (Figure 2). It is bounded to the east by the Englishman River and to the west by the Little Qualicum River. There are a few marshes within the watershed. The largest of these is Hamilton Marsh at about 90 m elevation which drains into French Creek between the Alberni Highway and Inland Island Highway about 11 km from the mouth of the creek. A large tributary called South French Creek joins French Creek mainstem approximately 11 km from the mouth of the creek, just south of Coombs.

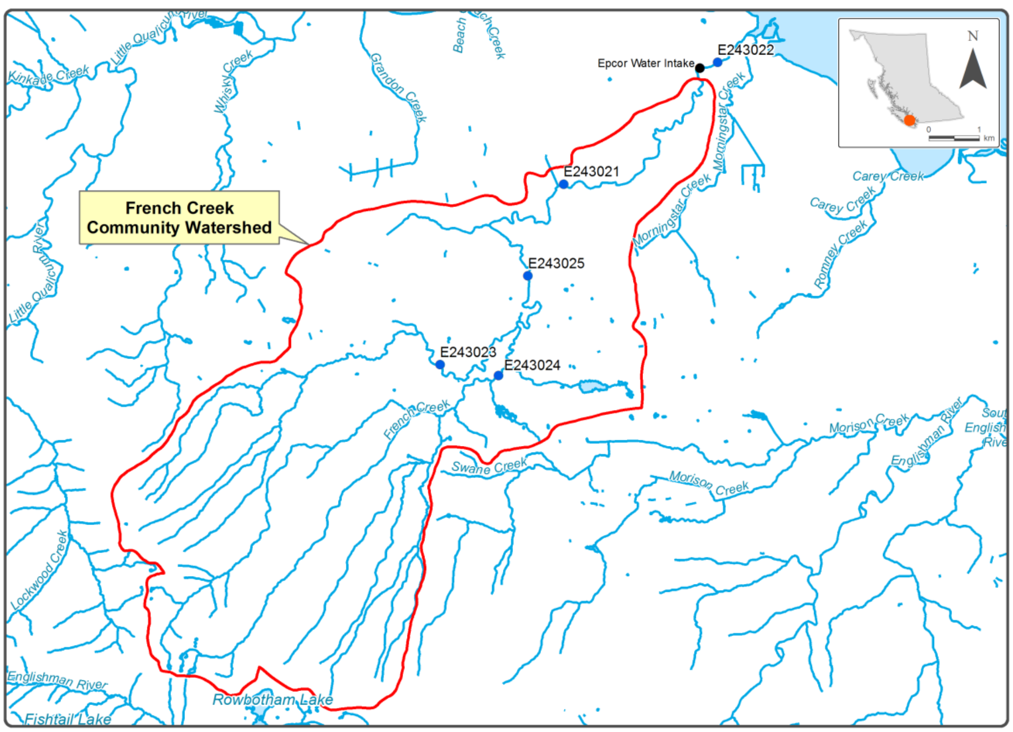

Figure 2. French Creek Community Watershed boundary and location of water quality monitoring sites.

The lower portion of the watershed lies within the Moist Maritime Coastal Douglas-fir (CDFmm) biogeoclimatic zone, giving way at about 140 m elevation to Very Dry Maritime Coastal Western Hemlock (CWHxm1). A very small portion of the watershed above about 980 m elevation lies within the Moist Maritime Mountain Hemlock (MHmm1) zone. The watershed lies within the rain-shadow of the island ranges, and typically exhibits warm dry summers and mild wet winters. Growing seasons within these forests are therefore relatively long, although moisture deficits can be a limiting factor to productivity, especially on drier sites. These zones represent the mildest climates in Canada and as a result, the French Creek basin provides prime habitat and growing conditions for many forest-based wildlife species and ecosystems (BC MOE, 2002). Most of the watershed lies within the Nanaimo Area Lowlands (NAL) ecoregion, with higher elevation tributaries within the Leeward Island Mountains (LIM) ecoregion (see Figure 1).

The French Creek watershed primarily overlies the Nanaimo Group rocks, a formation of Cretaceous sedimentary rocks including coal, sandstone, siltstone, shale and conglomerate that form the coastal plain from Campbell River to the Saanich Penninsula. The steeper headwaters represent a change in geology to Jurassic age Island Intrusives (granites and granodiorites) and Triassic Karmutsen Volcanics. Covering the bedrock geology is a combination of coarse glacio-marine sediments less than 2 m thick over glacial till. Fluvial and glacio-fluvial deposits are common along the lower half of French Creek including exposures of the Quadra Sands. The urban areas near the mouth sit primarily on a thin section of terraced deltaic deposits, underlain by silt and clay (BC MOE, 2002).

2.2 HYDROLOGY AND PRECIPITATION

The nearest climate station to the watershed for which normal climate data were available is the Qualicum River station (elevation 7.6 m) (Environment Canada Climate Station 1026565) (Environment Canada, 2013). Temperature and precipitation data (1971 to 2000) are summarized in Figure 3. Average daily temperatures ranged from 3.0°C in January to 16.8°C in July. Average total annual precipitation between 1971 and 2000 was 1,314 mm, with only 50 mm (water equivalent) (4%) of this falling as snow. A larger portion of the annual total precipitation occurred as snowfall in the higher-elevation terrain of the watershed (above about 800 m, which represents about 11% of the watershed (Cooper, 2002 *in* BC MOE, 2002). Most precipitation (1,031 mm, or 78%) fell between October and March.

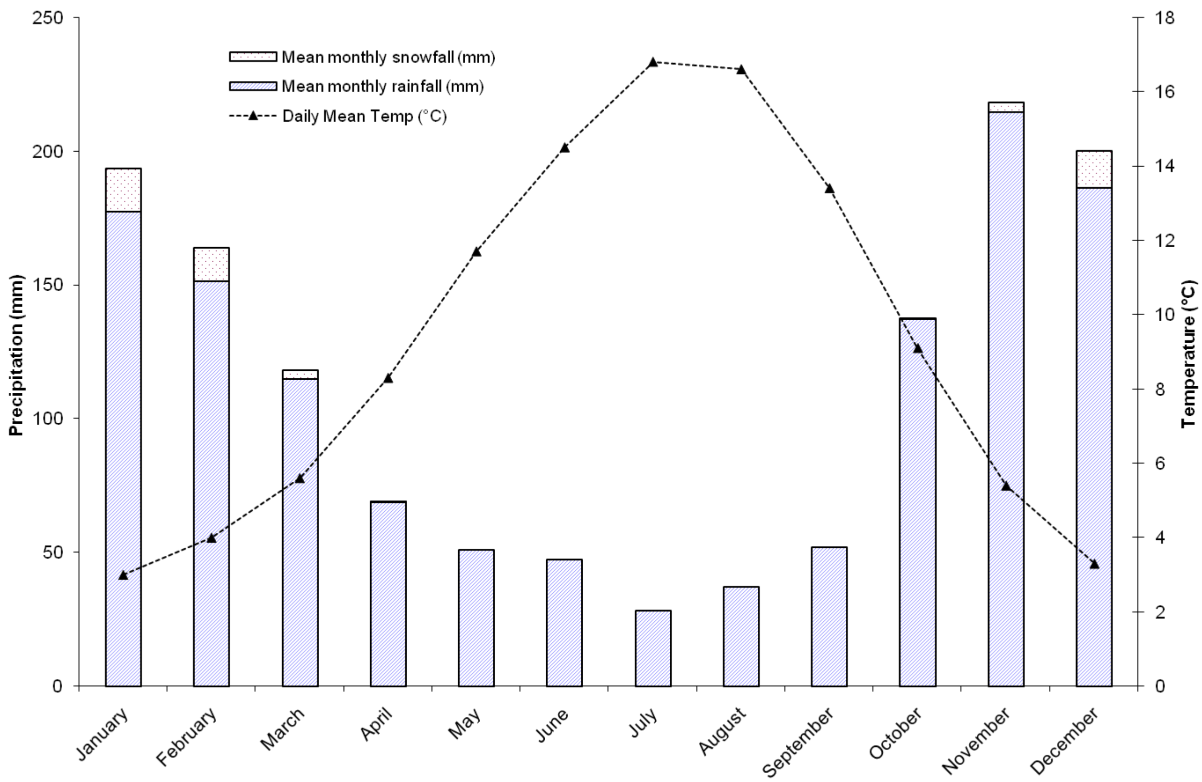

Figure 3. Climate data (1971-2000) for Qualicum River (Environment Canada Weather Station 1026565).

Water Survey Canada (WSC) operated a hydrometric station on French Creek at Coombs (WSC Station ID 08HB038) during the summer months between 1969 and 1971 and again between 1983 and 1989, and near the intake (WSC Station ID 08HB078) from the fall of 1989 through the spring of 1996 (WSC, 2013). Minimum, maximum and average daily flows for the period of record are shown in Figure 4 and Figure 5. Peak daily flows measured between 1989 and 1996 were approximately 36.6 m^3/s, and flows decreased to 0 m^3/s (essentially, the creek dried up) at Coombs on a number of occasions over the period of record. Minimum flows occurred during the summer, while winter rains result in the highest flows of the year. The spring freshet (a result of melting snow in the upper watershed between April and June) is relatively minor compared with winter high flows.

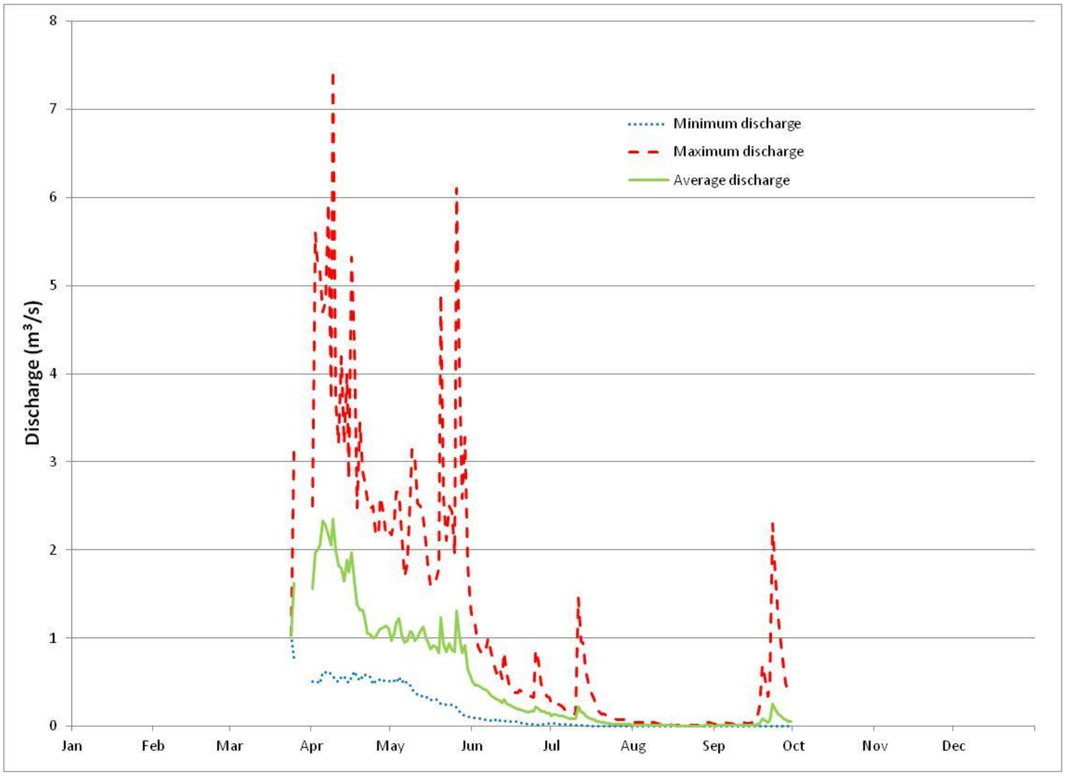

Figure 4. Minimum, maximum and average daily discharge data for French Creek at Coombs (Water Survey Canada Station 08HB038) between 1969 and 1989 (WSC, 2013).

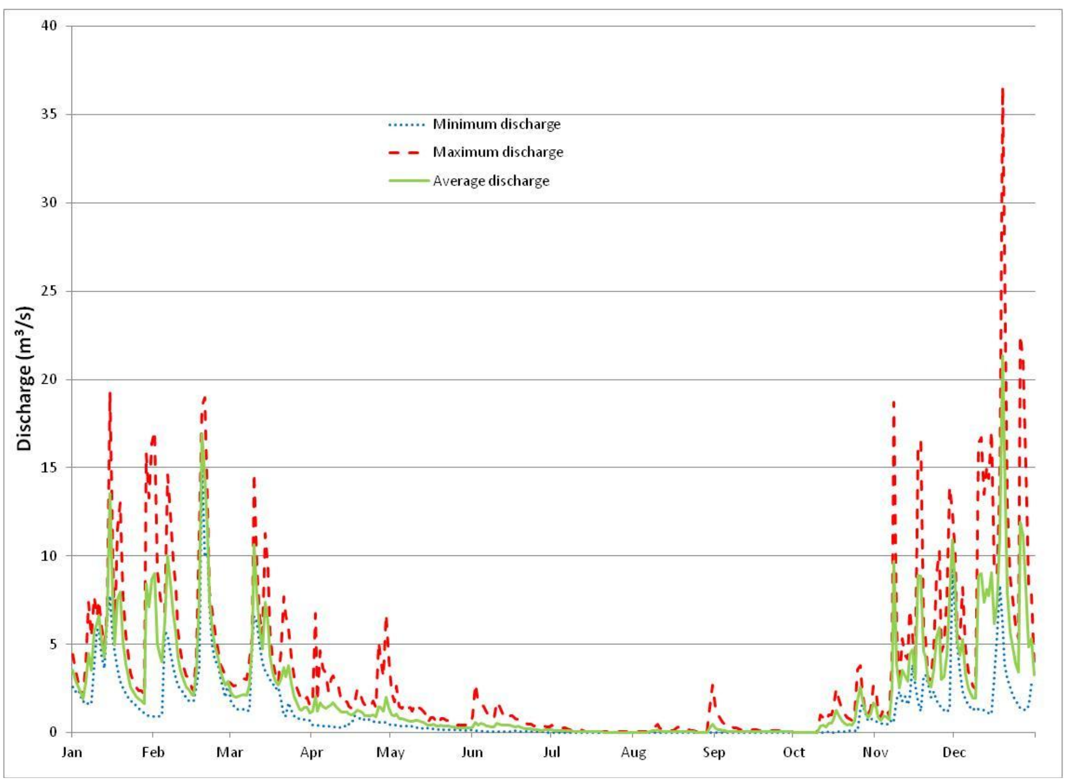

Figure 5. Minimum, maximum and average daily discharge data for French Creek at the Pump House (intake) (WSC Station 08HB078) between 1989 and 1996 (WSC, 2013).

3.0 WATER USES

3.1 WATER LICENSES

Sixteen water licenses have been issued for the French Creek main stem, with a further 12 water licences issued for South French Creek and one for Hamilton Marsh (Table 1). Epcor Water (West) Inc. has a license to remove 207.4 dam^3/year (cubic decametres/year, where 1 $dam^3 = 1{,}000\ m^3$) of water for domestic use under a "Waterworks – Local Authority" license, which they use to supplement water from underground wells. Since purchasing the water utility, Epcor has utilized the intake on French Creek only during the summer months, to supplement their groundwater supply, and shut down their use during the winter months due to poor water quality (Thorburn, pers. comm., 2013). The volume of water, as well as the fraction of their overall usage, supplied by the surface water intake decreased annually between 2008 and 2012 (Table 2). In 2013 new groundwater wells were approved, removing the need to use the intake on French Creek except for emergency situations; the French Creek surface water intake was not used in 2013 and there are no plans to utilize it regularly in the future (Thorburn, pers. comm., 2013). There are a number of other small domestic licenses for individual residences, as well as irrigation licenses for both French Creek and Little Hamilton Swamp (Hamilton Marsh). There is also one license issued to the Parksville/Qualicum Fish and Game Club totaling 441.5 dam^3/year that they divert to their fish hatchery, with peak demand occurring between October 1 and June 30 each year. This water is then returned to the creek downstream from the hatchery, and is therefore non-consumptive.

Table 1. Summary of consumptive water licences for French Creek and its tributaries.

Stream Name	Use	Number of licenses	Total volume of licenses (dam^3/year)	Principle Licensee
French Creek	Domestic	9	9.13	Various
South French Creek	Domestic	7	8.30	Various
French Creek	Irrigation	3	43.58	Various
South French Creek	Irrigation	5	5.24	Various
Little Hamilton Swamp	Irrigation	1	74.01	Andrew De Groot
French Creek	Stockwatering	1	0.83	Ashworth's
French Creek	Waterworks - local authority	1	207.42	Epcor Water (West) Inc.
Total			**348.5**	

Table 2. Summary of water withdrawals from French Creek surface water relative to overall consumption by Epcor Water (West) Inc. (from Thorburn, 2013).

Year	Total volume (dam^3)	Volume from French Creek (dam^3)	% volume from French Creek
2008	684	57.4	8.4%
2009	682	49.9	7.3%
2010	509	38	7.5%
2011	587	48.6	8.3%
2012	609	36.9	6.1%

3.2 FISHERIES

French Creek has high fisheries values, and species present include chinook (*Oncorhynchus tshawytscha*), pink (*O. gorbuscha*), coho (*O. kisutch*) and chum (*O. keta*) salmon, as well as cutthroat trout (*O. clarkii*), rainbow trout (*O. mykiss*), and steelhead (*O. mykiss*) (FISS, 2013). Fish access to the upper watershed is restricted by Schaedler's Falls, located about 3.5 km upstream from Coombs.

No recent stocking by the Provincial fisheries department has taken place in French Creek (McCulloch pers.com., 2013); however, the creek has been stocked historically with species including Atlantic salmon (1905), rainbow trout (1945 and 1946) and steelhead (1955) (FISS, 2013). As well, volunteers have operated the Marion Baker Fish Hatchery (located off Miller Road in Parksville, approximately 800 m upstream from the Barklay Bridge site) since 1982 and release coho and chum salmon fry into the creek each year. Their goal was to release about 75,000 coho fry annually, but by 2001 these numbers had decreased considerably due to declining adult returns to the hatchery, with as few as 13,000 fry released in 1999 (BC MOE, 2002). By 2012, approximately 30,000 and 100,000 chum were being released annually (Fong, pers.comm., 2013). Populations of adult coho, steelhead and cutthroat decreased considerably between the 1980's and 2002, to the point where steelhead and anadromous cutthroat populations may have been eliminated (Axford, 2001 *in* BC MOE, 2002). Current stock status of steelhead and anadromous cutthroat trout are unknown. The historically small population of steelhead may be locally extirpated based on a combination of low productive capacity and recent low marine survival (McCulloch, pers. comm., 2013).

3.3 RECREATION

No specific studies have been conducted to determine the recreational use of the French Creek watershed, but the presence of roads throughout the watershed allows recreational access. Swimming is not popular due to low summer flows but children have been observed playing in the creek in the summer. Recreational fishing also occurs near the mouth of the creek.

3.4 FLORA AND FAUNA

While degradation of habitat within the watershed over the past century has resulted in the loss of some species that historically occurred here (including marbled murrelets (*Brachyramphus marmoratus*), water shrew (*Sorex palustris brooksi*), Keen's Long-eared bat (*Myotis keenii*), ermine (anguinae subspecies, *Mustela erminea anguinae*), and steelhead trout (*O. mykiss*)), the French Creek watershed continues to provide valuable habitat to a wide variety of species including blacktail deer (*Odocoileus hemionus columbianus*), Roosevelt Elk (*Cervus elaphus roosevelti*), black bear (*Ursus americanus*), river otter (*Lontra canadensis*), mink (*M. vison*), beaver (*Castor canadensis*), at least two species of bat (*Myotis* spp.), and numerous other small mammals and birds (BC MOE, 2002). The watershed also has occurrences of the red-listed Coastal Douglas Fir ecosystem, as well as historical records of the blue-listed Howell's violet (*Viola howellii*) and umbilicate sprite (*Promenetus umbilicatellus*) (a snail found at Hamilton Marsh) (BCCDC, 2013). There is also a great blue heron (*Ardea herodius fannini)* rookery near the coast north of Parksville. This colony was abandoned in 2012 due to Bald Eagles but may re-establish in the area. A bird checklist compiled for the Parksville – Qualicum Beach area by Dawe and Ostling in 1993 (BC MOE, 2002) lists over 250 bird species, of which 33 are year-round residents. The year-round resident list includes 11 waterfowl, one upland game, three raptors, and 18 passerine species (BC MOE, 2002).

The invasive species giant hogweed (*Heracleum mantegazzianum)* is very abundant in the French Creek watershed and is considered to pose a human health and environmental hazard (Page *et al*., 2009).

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 attainment of the objectives will protect the most sensitive designated uses. The preceding discussion suggests that water uses to be protected should include drinking water, irrigation, livestock watering, primary-contact recreation, wildlife and aquatic life.

4.0 INFLUENCES ON WATER QUALITY

4.1 LAND OWNERSHIP

Much of the information included in this section is taken from BC MOE (2002). Almost all of the land within the French Creek watershed is privately owned. There are approximately 232 ha areas of Crown forest land remaining within the upper watershed (generally smaller-order streams draining the steep uplands) which is comprised primarily of privately owned forest land (89% of the land base), with the majority of the remaining 11% comprised of lands in the Agricultural Land Reserve. About 56% of the lower watershed (which encompasses the lower main stem of French Creek and most of the coastal plain area) is comprised of second growth forest, the majority of which is highly fragmented by development, and only 21% of vegetated land cover is comprised of dense coniferous forest. About 15% of the total watershed is comprised of agricultural lands and rural residential developments (these are distributed fairly evenly through the middle of the watershed), and only about 3% of the watershed is urban residential (near the mouth of the creek along Highway 19A and near Highway 4 in concentrated areas around Hilliers and Coombs). Commercial and industrial developments, as well as roads, comprise about 5% of the land base, and are also concentrated along Highway 19A and the mouth of the creek.

Runoff from developed areas can introduce sediments and contaminants into waterbodies, including elevated nutrients (nitrogen and phosphorus) from fertilizers used on farms and residential properties, fecal matter from livestock and domestic animals, pesticides used on crops or lawns, contaminants from roads (including petroleum products, antifreeze, contaminants from brake, clutch and tire wear, exhaust emissions, etc.), litter, and various other contaminants. As well, residences in portions of the watershed (specifically in the area around Coombs and in the Barclay Crescent area) rely on septic systems to dispose of sewage, many of which have reached the end of their lifespan (BC MOE, 2002). This, coupled with high groundwater levels in the lower watershed (BC MOE, 2002), is likely resulting in significant contributions of nutrients and pathogens as well as other contaminants associated with household sewage (solvents, detergents, etc.), to the creek.

Impervious surfaces are those which prevent or resist the absorption of water into the ground, and the relative percentage of these as overall land cover in a watershed gives a good indication of potential impacts from land use. Watersheds with over 10% impervious surfaces are considered impacted, and degraded when impervious cover exceeds 25% (BC MOE, 2002). Estimates for impervious cover in the French Creek watershed as a whole are in the range of 4.6%, although portions of the watershed (primarily near the mouth) approach 90% imperviousness. In 2001, the majority (about 92%) of the riparian corridor was intact within 30m of the bank along fish-bearing portions of the creek and its tributaries, thus mitigating some of these impacts (BC MOE, 2002). No current data on riparian cover are available, but major changes have not occurred in the watershed to considerably change the 2001 estimates.

Other potential impacts on water quality associated with land use are impacts to stream banks by land owners, who may shore up banks, install gabion rip-rap and cement walls to prevent erosion, alter bank levels to provide stream access, and take other measures that affect the natural channel of the creek and therefore directly impact its behavior. Erosion and sedimentation associated with these changes can have significant impacts on channel morphology downstream, as well as result in siltation and scouring of salmonid spawning grounds and habitat. Movement of soil can also assist in the spread of invasive species such as giant hogweed (Page *et al*., 2009), which can outcompete native vegetation.

Finally, there is one highway crossing (Highway 4) near Coombs, and two highway crossings in the lower French Creek watershed: the Inland Island Highway (Highway 19) crosses the creek about 9 km from the mouth of the creek; and the Old Island Highway (Highway 19A), a major highway and local thoroughfare with high traffic volume, crosses French Creek a few hundred meters from its mouth. Runoff from highways can also impact the lower portion of French Creek with increased sediment loads and contaminants such as polycyclic aromatic hydrocarbons from vehicles.

4.2 LICENSED WATER WITHDRAWALS

There is a maximum licensed water withdrawal from the French Creek community watershed of 348.5 dam^3/year. The irrigation licenses, which are utilized during the summer months when flows are at their lowest, as well as the Epcor Water (West) Inc. licence, have the potential to negatively impact flows in the lower reaches of French Creek during the summer months. However, Epcor Water (West) Inc. utilizes only a small portion of its overall licence (36.9 dam^3 in 2012, compared with their overall licenced volume of 207 dam^3/year), and discontinued regular use of the surface water intake in 2013. The Mean Annual Discharge (MAD) for French Creek is approximately 2.1 m^3/s (BC MOE, 2002), and flows are below 10% MAD (the level below which fisheries values, including spawning and rearing, are seriously impacted) between the months of July and September. According to the French Creek Water Allocation Plan, extractive uses (including for irrigation and domestic use) are only permitted when flows exceed 60% of MAD, which occurs between the months of November and April (Bryden *et al.* 1994). The Plan recommends that storage development be required to support any further extractive water demand in the period from May through October.

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.

Privately owned Managed Forest (MF) in the upper French Creek watershed represents about 80% of the total MF in the French Creek watershed. TimberWest and Island

Timberlands are the two companies that own and manage these MF lands. The most recent harvesting information available for the watershed is included in BC MOE (2002). At that time, it was estimated that approximately one third of the upper watershed had been harvested between 1982 and 2002, and about 75% of that harvest had occurred between 1992 and 2002.

The steeper uplands portion of the watershed, managed by TimberWest, is expected to contribute more runoff per unit area than the lower watershed. This is due to higher precipitation at higher elevations, steeper topography (allowing less time for precipitation to be absorbed into soils), higher drainage density (2.4 km of stream / km^2 versus 1.1 km of stream/km^2 in the lower watershed), and shallower soils. While the upper watershed has high road density and high frequency of stream crossings, there is no reported evidence of slope stability problems from past timber harvesting activities. Road maintenance and the protection of streams from sediment and debris have been identified as the highest priorities for protecting water quality (BC MOE, 2002).

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 4-wheel drive and ATV 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 French Creek watershed, the relative impacts of recreational activities cannot be discussed.

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.

French Creek 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 impact water quality by introducing high concentrations of metals and other contaminants (*e.g.*, sulphate) to waterbodies. The leaching of waste rock or adit discharges can also contribute to acidification of the water. Mining activities generally include road construction and land-clearing, which can change water movement patterns and result in increased turbidity levels.

Provincial records show prospects of copper, gold and/or silver at three sites in the extreme upper portions of the watershed, but no mines have been established within the watershed (MINFILE, 2013). If mineral exploration was to occur at one of these sites, or elsewhere in the watershed, impact assessments would have to be conducted to ensure that impacts to water quality did not occur.

5.0 STUDY DETAILS

Five water quality monitoring sites were established within the French Creek watershed: two sites were located in the upper watershed (BC Ministry of Environment Environmental Monitoring System (EMS) Site E243024, French Creek at Grafton Rd; and E243023, French Creek at Winchester Road); a third site was located at Coombs (E243025), downstream of the confluence of the north and south forks of upper French Creek; the fourth site (E243021) was located just upstream from the Highway 19 bridge crossing; and the fifth site (E243022) was located downstream from the Epcor Water

(West) intake, at the Barclay Crescent footbridge (Figure 2). The project 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 2000-02, and in 2010-11. Drinking water is one of the designated water uses in French Creek 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 the sub-watersheds (generally associated with forestry, residential and urban development, commercial and light industrial development, agriculture, and recreation), natural features (wildlife), and the lack of authorized waste discharges directly to the creek, the following water quality variables were included:

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

To represent the worst case scenario, water samples were collected at the sites on a weekly basis for five consecutive weeks during the fall high flow (November - December) period in 2000 and during the summer low flow period (July - August) in 2001. Two samples were collected during the summer of 2002 at the various sites, and sampling did not occur again until early 2010. Then, samples were collected on approximately a monthly basis (except for weekly sampling for five consecutive weeks during the summer low-flow and fall high-flow periods) until March 2011. As well, three of the above-mentioned sites (Grafton Road (E243024), Highway 19 (E243021) and at the Barclay bridge (E243022)) were sampled on a weekly basis during summer low-flow and fall high-flow periods in both 2011 and 2012 by a local stewardship group (Friends of French Creek) using a YSI ProPlus handheld meter and LaMott turbidity meter. They measured water temperature, dissolved oxygen, specific conductivity and turbidity (Barlak, 2012; Barlak, 2013).

Grab samples were collected at the water surface in strict accordance with Resource Inventory Standards Committee (RISC) standards (BC MOE, 2003) by trained personnel. Water chemistry analyses were conducted by Maxxam Analytics Inc. in Burnaby, BC. Bacteriological analyses were conducted by Cantest Laboratories in Burnaby, BC until the labs merged and all analysis were all done under the name of Maxxam Analytics. Taxonomic identification of benthic invertebrates was conducted by Fraser Environmental Services of Surrey, B.C. 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. The data are summarized in Appendix I.

As well, the data are compared with the nearby Englishman River as part of the ecoregion approach to water quality objective development. The proximity of the two watersheds, the fact that they are in the same ecoregion (and therefore having similar climate, geology, soils and hydrology), and the similarity of land use (forestry in the upper watershed, agricultural use through portions of the watershed, and residential/urban/ industrial uses primarily in the lower watershed) makes the comparison of water quality in the two watersheds useful, especially considering the longer period of record for water quality data in the Englishman River watershed. In particular, Morison Creek, a tributary to the Englishman River, drains opposite sides of the same rural residential and agricultural area (Errington and Coombs) as French Creek.

5.1 QUALITY ASSURANCE / QUALITY CONTROL

For the 2012 field data collected by the local stewardship group, duplicate turbidity readings for quality assurance purposes were taken, re-zeroing the meter before each new reading. Four of the 30 duplicate samples taken had duplicate readings that were both within the accuracy of the meter (*i.e.* higher than 0.04 NTU) and more than 25% different from the first readings. These four sets of values were on the low range of the meter (*i.e.* less than 1 NTU) and most were less than 0.40 NTU, thus none would have the potential to artificially show a turbidity objective exceedence. In addition, three more readings were taken at each site, not zeroing the meter after each reading. With the exception of results from the Highway 19 site (E243021) on Sept 11, 2012, where the triplicate values were within 25% of the first reading but not the duplicate reading, all were within 25% of the duplicate reading.

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 source and end of tap water quality. As such, VIHA requires all surface water supply systems to provide two types of treatment processes. Currently Epcor Water (West) Inc. only treats through chlorine disinfection prior to distribution (Epcor, 2011). To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, Epcor Water (West) Inc. may be required to provide additional disinfection, such as UV or ozone, and/or treatment, such as filtration. The following sections describe the characteristics considered in assessing the water quality of French Creek.

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 guideline 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 the five sites was slightly alkaline, with average values ranging from 7.19 pH units to 7.51 pH units, increasing in a downstream direction (Table 3). All pH values fell within the drinking water guideline.

Table 3. Summary of pH values (in pH units) measured at the five French Creek monitoring sites between 2000 and 2011. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	Std Dev	No. of samples
E243023	At Winchester Rd.	6.05	8.45	7.2	0.5	34
E243024	At Grafton Rd.	6.61	8.48	7.2	0.5	34
E243025	At Coombs	6.87	8.42	7.4	0.4	34
E243021	At Highway 19	6.47	8.21	7.4	0.4	37
E243022	At Barclay Bridge	6.94	8.2	7.5	0.3	35

In the adjacent Englishman River watershed, maximum pH values measured throughout the watershed ranged from 7.7 to 8.0 pH units, and mean pH ranged from 7.3 to 7.5 pH units. No objective was proposed for that watershed, and no objective is proposed for pH in French Creek.

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 are based on species-specific life history stages such as incubation, rearing, migration, and spawning. For steelhead, which have historically been present in French Creek, 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). The current status of the steelhead population is not well understood, but it is important that conditions for their survival be maintained in order to reestablish a healthy population of this species. Each salmon species also has its own optimum temperature range. Chum salmon, which are present in French Creek, 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 in the watershed for the longest periods of time, including the summer. In the nearby Little Qualicum River, coho typically spawn between mid-November and mid-January, while steelhead spawn from early March to early May (McCulloch, pers. comm., 2013). Maturation of the embryos is temperature-dependent, but coho typically emerge by mid-May and steelhead typically emerge by late June. As fish remain in the alevin stage for a few weeks, the incubation period for coho would be from mid-November through late April, while the incubation period for steelhead would be from early March to the end of May.

Water temperatures in French Creek varied seasonally, with maximum temperatures occurring in late July through the end of August (Figure 6), and higher temperatures generally occurring lower in the watershed (Table 4).

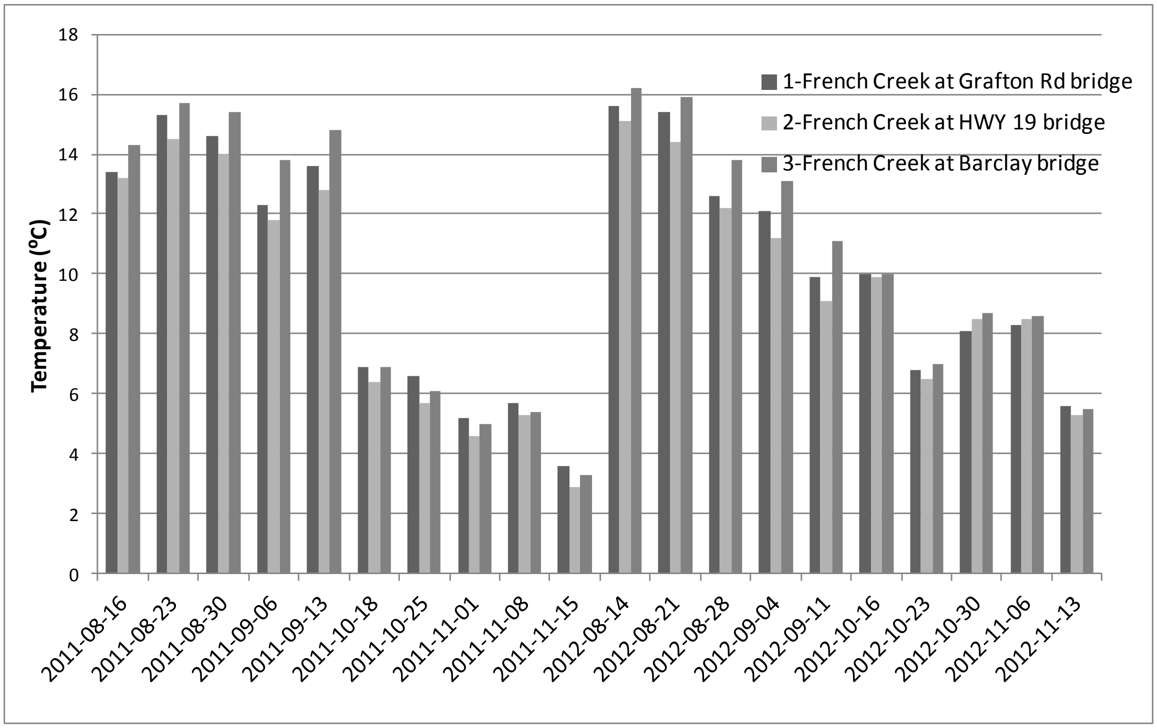

Figure 6. Maximum water temperature data measured in 2011-12 at three French Creek monitoring sites by stewardship groups.

Table 4. Summary of water temperatures (°C) measured at the five French Creek monitoring sites between 2010 and 2012. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	Std Dev	No. of samples
E243023	At Winchester Rd.	2.1	17	9.0	4.3	14
E243024	At Grafton Rd.	2.2	17	9.6	4.0	34
E243025	At Coombs	1.7	18.5	9.2	4.8	14
E243021	At Highway 19	2	15.7	9.1	3.8	33
E243022	At Barclay Bridge	1.9	18.5	10.0	4.5	33

Water temperatures remained below the aquatic life guidelines for the spawning, incubation and rearing periods for salmonids over the course of the monitoring program, with the exception of maximum summer water temperatures that exceeded the guideline for coho rearing (17°C) both at Coombs and at the Barclay Bridge sites. As water temperatures were only measured during site visits, and the program was not specifically designed to measure peak maximum temperatures, it is possible that higher maximum temperatures occurred at all of the sites, and exceedances were likely more common and more severe than those reported here. This could be determined by the use of automated temperature probes, which log data on a continual basis (usually every 15 minutes). The BC Conservation Foundation (BCCF) operated an automated station near the fish hatchery on French Creek which measured water level and temperature at one-hour intervals from early August until mid-November, 2012 (Figure 7) (Stenhouse, 2012, unpublished data). Maximum temperatures during this time reached 18.9°C, similar to the 18.5°C reported for the Barclay Road site. These temperatures can be characteristic of streams downstream of wetlands (such as Hamilton Marsh) with longer residence times; however, anthropogenic influences such as reduced riparian cover and land clearing could exacerbate these higher temperatures. At the adjacent Englishman River watershed, automated monitors were used to measure water temperature near the mouth of the river between May 2003 and March 2005 (Barlak *et al*., 2010), and waters reached a maximum temperature of 21.5°C. It is not unreasonable to assume that similar temperatures may be reached on occasion in French Creek, especially in the lower reaches. Though the Englishman River water quality objectives report does not include temperature data for the background site, more recent temperature data are available for the Englishman River upstream of Morison Creek (background) (Barlak, 2012, Barlak, 2013); these 2011 and 2012 data show background temperatures generally stay below 15°C throughout the summer, though there was one 2012 observation where temperature reached 15°C.

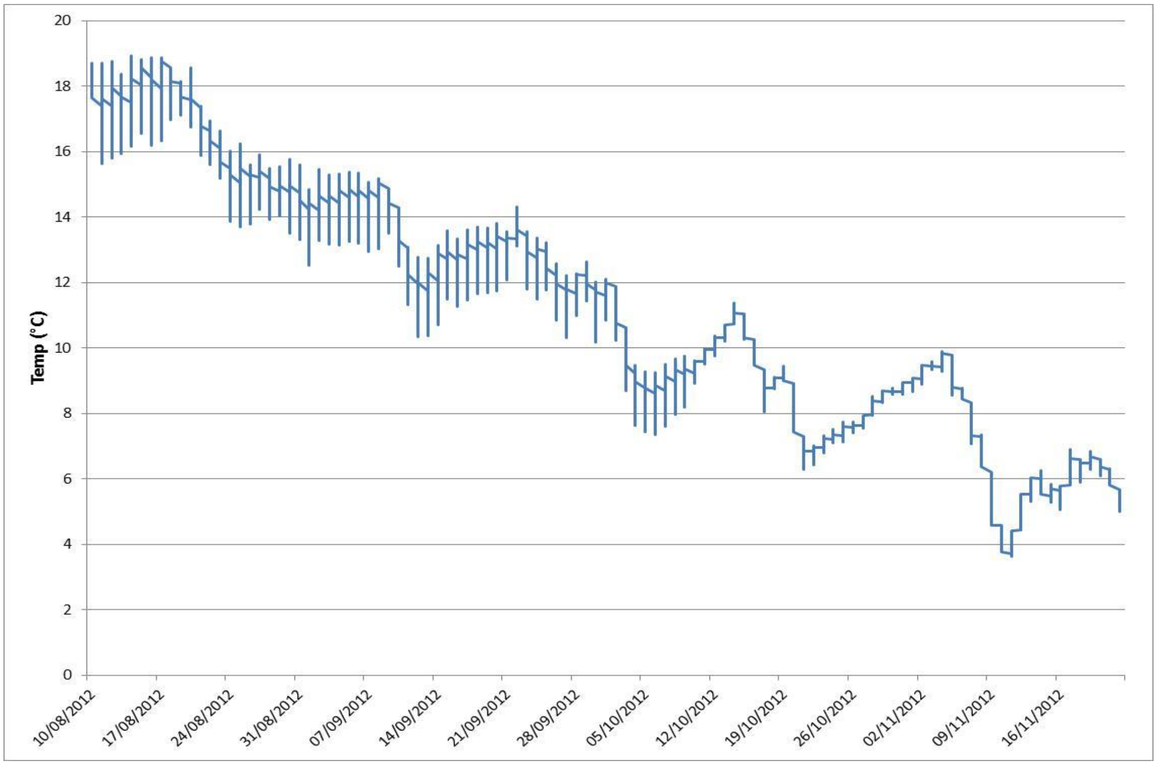

Figure 7. Water temperature data measured near the fish hatchery on French Creek at one-hour intervals between August and November, 2012 (from Stenhouse, unpublished data).

As French Creek results are not reflective of background, Englishman River background data are considered and the Englishman River temperature objective is proposed for French Creek. Due to the high summer temperatures and the high values of French Creek as fisheries habitat, in particular coho (the most sensitive species at this time), ***a short term (within five years) water quality objective is proposed to protect juvenile salmonids. The average weekly temperature at any location in the river 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 at all of the sites each year. Many watersheds on the west coast of Vancouver Island, as well as throughout the Southern Interior, typically have elevated summer water temperatures. It is therefore likely that higher summer temperatures are, for the most part, a natural occurrence. However, it is possible that activities such as forest harvesting, agriculture or rural and industrial developments, activities that have the potential to decrease stream shading if removal of vegetation occurs in riparian areas, and climate change, could exacerbate these peak summer temperatures. ***Therefore, a long-term (within five to ten years) objective is also proposed for drinking water purposes whereby by the average weekly temperature should not exceed 15°C at any location in French Creek.***

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 tend 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 French Creek, specific conductivity values ranged from a minimum of 6.2 µS/cm at Winchester Road on October 26, 2010 to a maximum of 210 µS/cm at the Highway 19 site on September 15, 2010. Average specific conductivity at the five sites increased in a downstream direction, from 41 µS/cm at Grafton Road to 98 µS/cm at Highway 19 and 95 µS/cm at the Barclay Bridge (Table 5). Values were correlated with flows, with the highest conductivity levels occurring during low summer flows (when dilution was lowest) and decreasing conductivity during the winter (when dilution from rainfall was highest) (Table 5). The seasonal variability was greatest at the downstream sites, likely showing the effects of groundwater infiltration into the creek. Groundwater typically has a higher specific conductivity than surface water, especially in coastal systems where annual rainfall is high, and dilution of the groundwater would be lower during the summer months. Average specific conductivity in the neighboring Englishman River was about 60 µS/cm, except for the South Englishman River, where the average was 112 µS/cm. As there is no BC Water Quality Guideline for specific conductivity, and the average specific conductivity observed was typical of coastal systems, and similar to that found in the Englishman River, no objective is proposed for specific conductivity in French Creek.

Table 5. Summary of specific conductivity (in µS/cm) measured at the five French Creek monitoring sites between 2000 and 2012. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	No. of samples	Jul - Sept Average	Oct - Jun Average
E243023	At Winchester Rd.	6	83	48	27	62	41
E243024	At Grafton Rd.	14	67	41	47	50	35
E243025	At Coombs	18	195	63	27	97	42
E243021	At Highway 19	24	210	98	48	170	54
E243022	At Barclay Bridge	7	170	95	47	138	65

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 less than 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, which includes French Creek, is that it demonstrate 1 NTU turbidity or less on

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

Turbidity values measured at the five sites ranged from 0 NTU (at the Grafton Road site) to 7.4 NTU (at the Barclay Bridge site), with average turbidity ranging from 0.6 NTU at the Grafton Road site to a maximum of 1.7 NTU at the Barclay Bridge site (Table 6). Both maximum and average turbidity values increased in a downstream direction, reflecting increasing contributions of suspended sediments as development in the watershed increases. Turbidity also tended to increase outside of the low-flow season (July through September), and this seasonal variability increased in a downstream direction (Table 6).

Table 6. Summary of turbidity (in NTU) measured at the five French Creek monitoring sites between 2000 and 2012. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	No. of samples	Jul - Sept Average	Oct - Jun Average
E243023	At Winchester Rd.	0.15	3.1	1.1	25	1.3	1.0
E243024	At Grafton Rd.	0	4.3	0.6	44	0.3	0.7
E243025	At Coombs	0.2	4	1.1	24	0.3	1.4
E243021	At Highway 19	0.08	6.2	1.3	45	0.4	1.7
E243022	At Barclay Bridge	0.19	7.4	1.7	44	1.0	2.0

In the neighboring Englishman River, the range of turbidity values measured at the intake site was similar to that measured at the Barclay Bridge site (0.3 NTU to 10.5 NTU), although the average of 1.0 NTU was lower than the 1.7 NTU average seen at Barclay Bridge. In that watershed, Morison Creek (a large tributary to the Englishman River, and draining the opposite side of the same rural agricultural area as French Creek) contributed significant amounts of turbidity to the system and had the highest average value at 1.84 NTU. As the turbidity values measured at the five sites in the French Creek watershed, where no background data are available, were similar to turbidity values measured in the nearby Englishman River watershed (site averages ranging from 0.5 to 1.84 NTU for discrete samples collected, (Barlak *et al*. 2010)) (where considerably more data was collected, and an automated turbidity probe was used to continuously measure turbidity for a two-year period), we recommend that the Englishman River water quality objective for turbidity be proposed for French Creek. This objective was based on data from the Englishman River site upstream of Morison Creek (representative of natural conditions) where turbidity was maintained at a constant level (< 1 NTU for 90% of the grab sample data) with only minor fluctuations during rain storm events (to a maximum value of < 5 NTU). ***Thus, to protect drinking water in French Creek, it is recommended that from October to December (when turbid flows can occur), turbidity at any of the monitoring sites should not exceed 5 NTU; during the remainder of the year (clear flow periods), turbidity measured at the monitoring sites should not exceed 2.0 NTU (1 NTU above ambient levels, as measured in the Englishman River upstream from Morison Creek). To align with VIHA criteria, turbidity at any intake in the watershed should be <1 NTU 95% of the time.*** An alternative to the objective of 2 NTU would be to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency.

6.5 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS), or non-filterable residue (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).

Concentrations of TSS ranged from below detection limits (<1 mg/L) to a maximum of 8 mg/L at Barclay Bridge on November 2, 2011 (the date upon which the maximum concentration of TSS occurred for both the Coombs and Highway 19 sites (Table 7)). TSS was measured between 2000 and 2002 at each of the five sites, but those data are omitted from this analysis because the detection limit used was much higher than that used in 2010-11 (< 5 mg/L, versus the later < 1 mg/L) and all samples at all sites were below the detection limits during that time (with the exception of one sample, collected on December 12, 2000 at Grafton Road, which was equal to the detection limit). Inclusion of those data would skew the average TSS concentrations to an artificially high level.

TSS values were consistently low with elevated fluctuations only occurring during rain storm events. To determine average concentrations, a minimum of five weekly samples within 30 days were collected on two occasions at each of the five sites: summer 2010 (mid-August through mid-September) and fall 2010 (mid-October through mid-November) (Table 7). Average concentrations were similar between summer and fall periods at the upper sites, but increased between summer and fall at the lower sites. Average concentrations in the fall at the lower sites also increased in a downstream direction.

Table 7. Summary of total suspended solids concentrations (mg/L) measured at the five French Creek monitoring sites between 2010 and 2011. Sites are listed upstream to downstream.

		Minimum (n=18)	Maximum (n=18)	Average (n=18)	Std Dev (n=18)	5 in 30 Avg Aug 16-Sept 15, 2010	5 in 30 Avg Oct 20 – Nov 16, 2010
E243023	At Winchester Rd.	< 1	4	1.4	0.8	2	1.6
E243024	At Grafton Rd.	< 1	3	1.4	0.7	1.6	1.8
E243025	At Coombs	< 1	6	1.4	1.2	< 1	2.2
E243021	At Highway 19	< 1	7	2.0	1.6	< 1	3.4
E243022	At Barclay Bridge	< 1	8	2.6	2.3	1	3.8

Total suspended solids concentrations in the neighboring Englishman River watershed were considerably higher than those seen in French Creek, with maximum concentrations as high as 57 mg/L at the City of Parksville drinking water intake. The Englishman background site had a fall mean 8.4 mg/L, higher than any value observed in French Creek. Lack of higher TSS observations in the French Creek watershed might be a result of the shorter period of monitoring. For that reason, a water quality objective is proposed for TSS in French Creek. The objective is meant to apply to situations which both identify natural conditions and those that are not natural but may have been triggered by human activities. ***It is recommended that TSS measured at any of the monitoring locations should not exceed 26 mg/L at any time (25 mg/L above clear flow background levels as measured in the Englishman River upstream from Morison Creek) and the mean of five weekly samples in 30-days should not exceed 6 mg/L (5 mg/L above clear flow background levels as measured in the Englishman River upstream from Morison Creek).*** 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 only measured once at four of the five sites on French Creek, and seven times at the Barclay Bridge site. Colour ranged from 5 TCU at the Grafton Road, Coombs and Barclay Bridge site to a maximum of 40 TCU at the Barclay Bridge, with an median of 20 TCU and 90th percentile of 34 TCU for the seven samples collected there (Table 8). Only two of these seven samples were less than 15 TCU, both of which were the only samples collected during summer low flow (August and September). As colour has not been measured regularly in the watershed, nor was it collected at the Englishman River upstream of Morison Creek (used as background for French Creek), the origin of the occasional elevated colour values is not known. However, it appears that colour may be an occasional aesthetic concern. Thus the following objective is proposed: ***maximum true colour should not exceed 15 TCU at any point in the watershed.*** Colour should be monitored at all sites in the watershed to determine the source of the occasional higher levels; the recommended objective should be re-evaluated when additional data are available.

Table 8. Summary of colour (in TCU) measured at the five French Creek monitoring sites in 2010-11. Sites are listed upstream to downstream.

		Minimum	Maximum	Median	90th percentile	No. of samples
E243023	At Winchester Rd.	20	20			1
E243024	At Grafton Rd.	5	5			1
E243025	At Coombs	5	5			1
E243021	At Highway 19	15	15			1
E243022	At Barclay Bridge	5	40	20	34	7

The total organic carbon (TOC) guideline to protect drinking water is 4.0 mg/L; elevated TOC can result in higher levels of DBPs in finished drinking water if chlorination is used to disinfect the water (Moore, 1998). As Epcor Water (West) Inc. uses chlorine to disinfect their drinking water (Epcor, 2011), TOC concentrations should be monitored. During the study period, TOC was sampled 11 times at each site, and concentrations in these samples ranged from 1.6 mg/L to 11.5 mg/L (both measured at the Grafton Road site) (Table 9). The maximum concentration of TOC measured at the Barclay Bridge site (located near the Epcor Water (West) Inc. intake) was 7.3 mg/L and the 90th percentile was 7.1 mg/L, exceeding the drinking water guideline; while the median at this site was 3.7 mg/L. Median TOC concentrations of all sample dates exceeded 4.0mg/L at the two upper sites only. When considering the median data seasonally (Table 9), only the summer median at Grafton Road (6.5 mg/L) exceeded the guideline while the fall median exceeded the guideline at every site. Elevated summer values in the upper watershed, particularly at Grafton Road, are likely due to land uses in the rural agricultural area in which these sites (Winchester, Grafton and Coombs) are located. The maximum value at Coombs (10.5 mg/L on August 24, 2010) was much higher than any other summer values at that site (next highest 3.1 mg/L) and higher than any other value observed at all other sites that day (next highest 3.1 mg/L). This data point should be considered with caution, as though it does not appear to be an error, it is unknown why it is irregular relative to the other data points. Flows at Coombs were very low through the summer and the site gets some algal growth which may have influenced colour values.

Table 9. Summary of total organic carbon (in mg/L) measured at the five French Creek monitoring sites in 2000 and 2010. Sites are listed upstream to downstream.

		Minimum (n=11)	Maximum (n=11)	Median (n=11)	90th percentile (n=11)	Summer median (n=5)	Fall median (n=6)
E243023	At Winchester Rd.	2.2	6.4	4.3	6.3	3.4	4.4
E243024	At Grafton Rd.	1.6	11.5	5.0	9.1	6.5	4.65
E243025	At Coombs	2.1	10.5	3.3	6.8	2.7	4.35
E243021	At Highway 19	1.7	6.7	3.7	5.9	2.8	5.35
E243022	At Barclay Bridge	2.7	7.3	3.7	7.1	3.1	5.95

TOC was not was not sampled at the Englishman River upstream of Morison Creek; however, at Englishman River at Highway 19A, concentrations of TOC ranged from 2.1 mg/L to 3.7 mg/L (Barlak *et al*., 2010), and therefore may not be a concern in that watershed. As maximum and 90^{th} percentnile TOC concentrations at all sites in French Creek, as well as the fall median concentrations exceeded 4.0 mg/L, it appears that TOC may be a concern in the French Creek watershed. ***For this reason, a water quality objective for total organic carbon is proposed. It is recommended that maximum TOC values should not exceed 4.0 mg/L at the Epcor Water (West) Inc. intake.*** The recommended objective should be re-evaluated when additional data are available. It is also recommend that DBPs be measured in the finished drinking water (post-chlorination) to determine if these by-products are present in unsafe concentrations. It may be that the elevated TOC levels in French Creek are due to natural phenomena (marshes, such as Hamilton marsh, often produce high levels of organic carbon), in which case, additional water treatment may be necessary to prevent the formation of DBPs in the finished water.

6.7 NUTRIENTS (NITRATE, NITRITE AND PHOSPHORUS)

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).

Nitrogen concentrations were measured in terms of dissolved nitrite (NO_2) and dissolved nitrate + nitrite ($NO_2 + NO_3$). Dissolved nitrate was measured on a few occasions by itself, but the majority of samples measured the combined nitrate + nitrite concentrations. Dissolved nitrite concentrations were consistently below detection limits (< 0.002 mg/L or < 0.005 mg/L as N) for the seven or eight samples measured at each site. Mean dissolved nitrate + nitrite concentrations ranged from 0.073 mg/L at Winchester Road to 0.174 mg/L at Grafton Road (Table 10). As nitrite concentrations were consistently below detection limits, it can be assumed that the majority of the combined nitrate + nitrite in these samples consisted of nitrate. All values of both nitrate and nitrite species were well below the existing aquatic life guidelines (Appendix I), and comparable to those found in the neighboring Englishman River. As concentrations of nitrogen are generally low in French Creek, no objective is proposed for this parameter.

Table 10. Summary of dissolved nitrate + nitrite (in mg/L) measured at the five French Creek monitoring sites between 2000 and 2011. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	Std Dev	No. of samples
E243023	At Winchester Rd.	0.028	0.161	0.073	0.041	14
E243024	At Grafton Rd.	0.024	0.593	0.174	0.137	15
E243025	At Coombs	0.035	0.321	0.131	0.072	15
E243021	At Highway 19	< 0.002	0.151	0.086	0.039	16
E243022	At Barclay Bridge	0.024	0.415	0.128	0.111	16

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. Considering just May to September data, samples were not collected each month from May to September in 2001 and 2002 (Table 11) to enable direct comparison to the average objective but are presented to show watershed trends; 2010 May to September averages ranged from 0.007 mg/L (at Coombs) to 0.017 mg/L at Winchester Rd (Table 11), exceeding the average objective of 0.005 mg/L at every site. In 2010 average total phosphorous tended to be highest at Winchester and Grafton, decreasing to the lowest average value at Coombs, and increasing slightly again at the two downstream sites. Average total phosphorous in 2010 was higher at all French Creek sites than the average May through September total phosphorous at the Englishman River upstream of Morison Creek (background) site (0.002 mg/L) (Barlak *et al*., 2010). All sites exceeded the maximum May to September objective of 0.010 mg/L in at least one sample between 2001 and 2010 (Table 11), with the most maximum objective exceedences (11) at the Highway 19 and Barclay Bridge sites. The maximum value observed was 0.054 mg/L (September 7, 2010) at the Winchester Road site. All French Creek sites also had higher maximum values than Englishman River upstream of Morison Creek, reflecting possible nutrient contributions from sources such as faulty septic systems or the use of fertilizers on residential and agricultural properties. Such sources could be addressed to reduce nutrient inputs. As phosphorus concentrations in French Creek are elevated relative to background (the Englishman River upstream from Morison Creek) a total phosphorous objective is proposed. ***The objective is that the May through September (based on a minimum of five monthly samples) average total phosphorous at any location in French Creek***

should not exceed 0.005 mg/L (5 µg/L) and maximum values should not exceed 0.010 mg/L (10 µg/L).

Table 11. Summary of average May to September total phosphorus (in mg/L) measured at the five French Creek monitoring sites between 2000 and 2010. Sites are listed upstream to downstream. Boldfaced values exceed the objective.

		Average 2001-2010 May – Sept*	Average 2001 May – Sept)*	Average 2002 May – Sept)*	Average 2010 May – Sept)	# of 2001-2010 May-Sept max values higher than 0.010 mg/L
E243023	At Winchester Rd.	0.013 (n=14)	0.009 (n=6)	Not available	**0.017 (n=8)**	**3 (n=14)**
E243024	At Grafton Rd.	0.010 (n=16)	0.005 (n=6)	0.008 (n=2)	**0.014 (n=8)**	**5 (n=16)**
E243025	At Coombs	0.007 (n=16)	0.008 (n=6)	0.006 (n=2)	**0.007 (n=8)**	**1 (n=16)**
E243021	At Highway 19	0.017 (n=16)	0.023 (n=6)	0.018 (n=2)	**0.012 (n=8)**	**11 (n=16)**
E243022	At Barclay Bridge	0.013 (n=17)	0.018 (n=7)	0.011 (n=2)	**0.010 (n=8)**	**11 (n=17)**

*2001 and 2002 did not have samples each month and thus cannot be directly compared to the objective.

Chlorophyll *a* concentrations were measured once at the Grafton Road site, and twice at each of the three lower sites (no samples were collected from the Winchester Road site). In streams (as opposed to lakes), concentrations of chlorophyll *a* rather than total phosphorus are used as a 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 0.05 g/m^2, and the aquatic life guideline is 0.1 g/m^2. Table 12 summarizes the concentration of total chlorophyll *a* measured at each of the sites. In all instances, aquatic life guidelines were met for the samples collected in 2001 and 2010, though this guideline was approached at the Barclay site in 2001. The recreational guideline was exceeded at Barclay in 2001 and approached in 2010. Concentrations of chlorophyll *a* measured in both 2001 and 2010 decreased from the Coombs site (below agricultural activity) to the Highway 19 site, and then increased again at the Barclay Bridge site (known area of failing septic fields). The cause for the decrease between the Coombs site and the Highway 19 site is not clear, but it is likely that one of the other conditions mentioned above for growth was not met. Only one sample was collected at each of the three sites in 2001, which could lead to a skewing of the results. In general it appears that chlorophyll *a* values can occasionally be elevated. For this reason, and because total phosphorous levels in French Creek are elevated relative to background, an objective for chlorophyll *a* is recommended for the French Creek watershed. ***The objective is that the average concentration of chlorophyll*** **a** ***in at least three samples collected during the summer should not exceed 0.1 g/m^2.*** Management plans for nutrients in the watershed will hopefully result in this objective being met in the future.

Table 12. Summary of results of total chlorophyll *a* (g/m^2) analyses within the French Creek watershed. Note * indicates the value listed is an average of three samples. Sites are listed upstream to downstream.

	Site	28-Aug-01	15-Sep-10
E243024	At Grafton Rd.	0.0105	
E243025	At Coombs	0.0051	*0.0255
E243021	At Highway 19	0.0014	*0.0092
E243022	At Barclay Bridge	0.1	*0.0485

6.8 METALS

Total and dissolved metals concentrations were measured between six and 13 times (depending on the metal) at the five French Creek sites (Appendix I). The concentrations of most metals were below detection limits, and well below guidelines for drinking water and aquatic life. However, concentrations of three metals (dissolved aluminum, total chromium and total copper) either exceeded their respective guidelines, or were found at high enough concentrations that they require further discussion.

Mean concentrations of dissolved aluminum ranged from 0.059 mg/L at the Winchester Road site to 0.097 mg/L at Highway 19 (Table 13). In general, dissolved aluminum concentrations increased in a downstream direction. Eight of the 42 samples analyzed had dissolved aluminum concentrations exceeding the maximum guideline of 0.1 mg/L (one sample at Coombs, four samples at Highway 19 and three samples at Barclay Bridge). As well, the requisite sampling frequency (a minimum of five samples in a 30-day period) was met on one occasion at each site, and in all instances, the average aquatic life guideline for dissolved aluminum of 0.05 mg/L was exceeded (Table 13). Average dissolved aluminum concentrations also increased in a downstream direction. There are insufficient data to calculate seasonal means (only one sample was collected in September at each site, the remaining samples were collected between the months of

October and January), but the lowest concentrations measured at each site occurred in September, suggesting that exceedences occur primarily during the high-flow period.

Table 13. Summary of dissolved aluminum (in mg/L) measured at the five French Creek monitoring sites between 2000 and 2011. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	Std Dev	5 in 30 Average (Nov 28-Dec 18, 2000)	No. of samples
E243023	At Winchester Rd.	0.0227	0.0856	0.059	0.019	0.063	9
E243024	At Grafton Rd.	0.0201	0.0942	0.071	0.025	0.075	8
E243025	At Coombs	0.0104	0.104	0.070	0.030	0.077	8
E243021	At Highway 19	0.0096	0.155	0.097	0.044	0.106	9
E243022	At Barclay Bridge	0.0077	0.158	0.089	0.050	0.098	8

At the ambient site on Englishman River (upstream from Morison Creek), both the maximum and average guidelines for dissolved aluminum were exceeded on one occasion (Barlak *et al*. 2010). This suggests that the source of the dissolved aluminum in French Creek is likely, to a large extent, a result of the natural geology of the area. However, the trend towards increasing concentrations in the lower watershed suggests that anthropogenic sources (e.g. land disturbance, roadways, and developed areas) may be contributing to these levels and resulting in occasional exceedences of the aquatic life guideline. For this reason, water quality objective for dissolved aluminum is proposed. The objective is that, at any location in the creek, ***dissolved aluminum should not exceed a maximum of 0.1 mg/L at any one time and the mean of 5 weekly samples in 30 days should not exceed 0.05 mg/L***.

Maximum total copper concentrations increased in a downstream direction (0.99 µg/L at Grafton Road to 2.44 µg/L at Barclay Bridge), while mean concentrations of total copper also showed this trend (0.58 µg/L at Grafton Road to 1.22 µg/L at the Barclay Bridge) (Table 14). These concentrations were below the maximum aquatic life guideline (ranging from 2.83 to 9.71 µg/L depending on the sample) calculated for sample specific hardness; and were below the averages guidelines (2.00 µg/L for site specific hardness ≤50 mg/L or =0.04(hardness) for site specific hardness >50 mg/L) at all sites where the requisite average total copper guideline frequency of five weekly samples in 30 days was met.

Hardness in French Creek tended to increase in a downstream direction: (winter 2000: 11.2-12.8 mg/L at Winchester Road, with a slight decrease at Grafton Rd (8.8-10.1mg/L), to a maximum at Barclay Bridge (16.5-20.1 mg/L)), (summer 2001: 15.5-24.5 mg/Lat Winchester Road, with a slight decrease at Grafton Rd (14.8-17.9 mg/L), to a maximum at Highway 19 (43.4-82.0 mg/L) and slight decrease at Barclay Bridge (46.1-75.3 mg/L)). This trend was more defined in winter with more variability between summer dates, and was likely due to a combination of increased surface water/groundwater interaction in summer and in a downstream direction, as well as to anthropogenic influences. Two apparent errors in the hardness data for sites E243023 and E243024 on July 31, 2001 (115.5 and 117.9 mg/L, respectively) were corrected to 15.5 and 17.9 mg/L, respectively, based on other results for the site and others sites sampled on that date.

Though it is important to understand site specific hardness, none of the French Creek sites are considered background and showed exceedences of several parameters in the study period, suggesting hardness may also be influenced by anthropogenic factors in the watershed. Thus average hardness (22 mg/L (MOE, *unpublished data*) at the representative background site (Englishman River upstream from Morison Creek) is used to ensure water quality guidelines (4.1 µg/L maximum and 2.0 µg/L average) relative to background hardness are being met.

Table 14. Summary of total copper (in µg/L) measured at the five French Creek monitoring sites between 2000 and 2011. Sites are listed upstream to downstream.

		Minimum	Maximum	Average	Std Dev	No. of samples	5 in 30 Average (Nov 28 – Dec 18, 2000)	5 in 30 Average (Jul 17 – Aug 15, 2001)
E243023	At Winchester Rd.	0.46	1.34	0.72	0.24	14	0.58	0.72
E243024	At Grafton Rd.	0.35	0.99	0.58	0.17	13	0.46	0.57
E243025	At Coombs	0.54	1.33	0.92	0.26	13	0.71	1.08
E243021	At Highway 19	0.65	1.51	1.02	0.25	14	1.11	0.85
E243022	At Barclay Bridge	0.79	2.44	1.22	0.42	13	1.36	1.07

Concentrations of total chromium (which includes chromium I-VI) were also high on occasion; nine samples (one sample, 0.0011 mg/L at Coombs, four samples ranging from 0.0011 mg/L to 0.002 mg/L at Highway 4, and four samples ranging from 0.0011 mg/L to 0.0018 mg/L at the Barclay bridge) had total chromium concentrations higher than the aquatic life working guideline (a maximum of 0.001 mg/L chromium VI). These exceedances all occurred during the summer months, when low water levels result in minimal dilution of metals concentrations. Chromium concentrations followed a trend similar to that of dissolved aluminum and total copper, increasing in a downstream direction; this pattern likely reflects contributions from anthropogenic sources. Sampling specific to chromium VI is necessary to determine if the chromium VI working guideline is actually exceeded. As there are two primary valence states (chromium III and chromium VI, of which chromium III is an essential dietary element for humans and other animals and chromium VI has some toxicity), the likelihood of individual samples containing sufficient chromium VI to exceed the guidelines is unlikely.

No objective is proposed for either total copper or total chromium in French Creek at this time, but it should be recognized that the observed increases in the concentrations of these and other metals in the French Creek watershed in a downstream direction likely reflects contributions from anthropogenic sources. Various land uses could increase inputs from areas with possibly naturally elevated levels of these parameters. To better understand this downstream trend, more investigation into potential natural sources in the surrounding bedrock and soils should be conducted in future studies. As population growth, urbanization and development continue, concentrations of these metals could begin to approach guideline levels, and for that reason should continue to be closely monitored.

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 on 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 French Creek monitoring program. As increasing water hardness can decrease the toxicity of copper and some other metals to some organisms, hardness has also been included in the French Creek 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 detectable 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).

To represent the worst case scenario, bacteriological samples were only collected during summer low flow and fall flush periods. Fecal coliform concentrations were measured 22 to 24 times (depending on the site) in French Creek, with values ranging from below detection limits (<1 CFU/100 mL) for one sample at Winchester Road to a maximum of 16,000 CFU/100 mL for one sample collected at the Barclay Bridge site (Appendix I). In those instances when at least five samples were collected within a 30-day period, a 90th percentile value was calculated, and these are summarized in Table 15. In all instances when 90th percentile values could be calculated, the drinking water guideline was exceeded. At each of the sites, fecal coliform concentrations were consistently higher in the summer than in the fall, and were higher (usually much higher) in 2010 than in 2000 and 2001, suggesting that the problem is getting worse. Concentrations tended to be highest at the two upper sites (upstream from which significant amounts of agricultural activities occur), as well as at the Barclay Bridge site.

Table 15. Summary of 90th percentile fecal coliform concentrations (CFU/100 mL) calculated for each of the five French Creek sites. Sites are listed upstream to downstream.

		Nov 28 - Dec 18, 2000	Jul 17 - Aug 15, 2001	Aug 16 - Sep 15, 2010	Oct 20 - Nov 16, 2010
E243023	At Winchester Rd.	12.4	111.2	5300	31.6
E243024	At Grafton Rd.	14.4	113.6	3444	31.8
E243025	At Coombs	16.6	111.2	214	55.6
E243021	At Highway 19	48.8	122.4	244	48.4
E243022	At Barclay Bridge	28.8	232	12360	85.6

E. coli was collected 10 or 11 times depending on the site, and concentrations ranged from a minimum of 1 CFU/100 mL for one sample collected at each of the Winchester Road and Highway 19 sites to a maximum of 16,000 CFU/100 mL at the Barclay Bridge site (Appendix I). As with fecal coliforms, in all instances when a 90^{th} percentile could be calculated (twice at each site), the drinking water guideline was exceeded, concentrations were much higher in the summer than in the fall, and the Winchester Road and Barclay bridge sites tended to have the highest concentrations of *E. coli* (Table 16). The sources of some of the coliforms within the watershed are undoubtedly anthropogenic (such as domestic animals including livestock, or seepage from faulty septic fields). Wildlife may also provide a significant source of fecal contamination in the water supply, particularly further up in the watershed. This is fairly common in watersheds on Vancouver Island and elsewhere in BC: for example, in the untouched watershed of McKelvie Creek, an objective of 60 CFU/100 ml (90^{th} percentile for 5 samples in 30 days) was recommended to reflect natural variability within the watershed (Epps and Phippen, 2007). Bacterial source tracking (whereby genetic material extracted from coliforms found in the water supply is used to determine the species of animal from which it originated) is recommended to determine the primary source(s) of the fecal contamination.

Table 16. Summary of 90th percentile *E. coli* concentrations (CFU/100 mL) calculated for each of the five French Creek sites.

		Aug 16 - Sep 15, 2010	Oct 20 - Nov 16, 2010
E243023	At Winchester Rd.	5004	27.4
E243024	At Grafton Rd.	70.4	26.6
E243025	At Coombs	147.2	55.6
E243021	At Highway 19	132	39.2
E243022	At Barclay Bridge	12360	70.8

As there are no monitoring sites within the French Creek watershed that can be considered ambient (*i.e.* unimpacted by human activities) with respect to fecal coliforms or *E. coli*, a comparison with the nearby Englishman River watershed was used to establish a drinking water objective. In that watershed, the mean of 90th percentiles collected at two sites (the Englishman River upstream from Morison Creek and the South Englishman River) was used to establish an objective of 41 CFU/100 mL for the months of October and November (when the first fall flush occurred, resulting in the highest concentrations of bacteriological indicators), and the drinking water guideline of 10 CFU/100 mL was proposed as an objective for the remainder of the year. In French Creek, fall concentrations of *E. coli* were not higher than summer concentrations, and overall concentrations of *E. coli* were consistently higher during both the summer and fall. Therefore, ***a long-term objective of a maximum 90th percentile of 41 CFU/100 mL for*** **E. coli** ***at any of the five monitoring site in the watershed (based on a minimum of five samples collected within a 30-day period) is proposed for French Creek***. It is not likely that this objective will be met in the short-term, based on the high concentrations of *E. coli* consistently observed at each of the sites, but hopefully as efforts to reduce contamination from septic fields continues, and if sources of contamination are identified by methods such as bacterial source tracking (see above), this objective will be met in the longer term. As mentioned above, *E. coli* is the best indicator of fecal contamination, and fecal coliforms do not indicate the source of contamination, and therefore no objective is proposed for fecal coliforms in French Creek.

The fact that 90th percentile values for both fecal coliforms and *E. coli* measured at Barclay Bridge (near the drinking water intake) were considerably higher than the drinking water guideline in all instances highlights the need for water purveyors to provide adequate treatment prior to consumption. 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 purveyors, in this case Epcor Water (West) Inc.

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 French Creek benthic invertebrate samples were collected at the three lower sites in 2010 (due to very low flows). The BCC score for each with its interpretation regarding invertebrate community health is summarized in Table 17 and Figure 8. Despite other water quality pararmeter exceedences at the Highway 19 site, the BCC score met the biological objective. This is likely due to the Highway 19 site having relatively good physical habitat for benthic invertebrates (substrate type, riparian cover…etc), with little apparent disturbance at the site. At the time of sampling flows were extremely low at the Coombs site and sampling restricted to an area where it was difficult to collect benthic invertebrates using CABIN methods; this may have negatively influenced the BCC score for this site. However, the BCC for the Barclay Bridge site (where flows were appropriate for sampling) indicated further investigation was required. Future sampling, combined with consideration of background Englishman River benthic invertebrate data, is required to determine how results can be applied in very low flow situations. ***For all of these reasons a provisional biological objective is proposed for French Creek that the BCC score at any location in the river should be greater than or equal to the 20th percentile of the distribution of BCC scores for the West Coast Regions reference streams (as per the current model this value is 27. 304).***

Table 17. Summary of Bray-Curtis Coefficient calculated for three French Creek monitoring sites for benthic invertebrate samples collected in 2010.

Site	Bray-Curtis Coefficient	Conclusion
E243025 French Creek at Coombs	24.3	Further investigation required
E243021 French Creek at Highway 19	34.7	Meets objective
E243022 French Creek at Barclay Bridge	26.9	Further investigation required

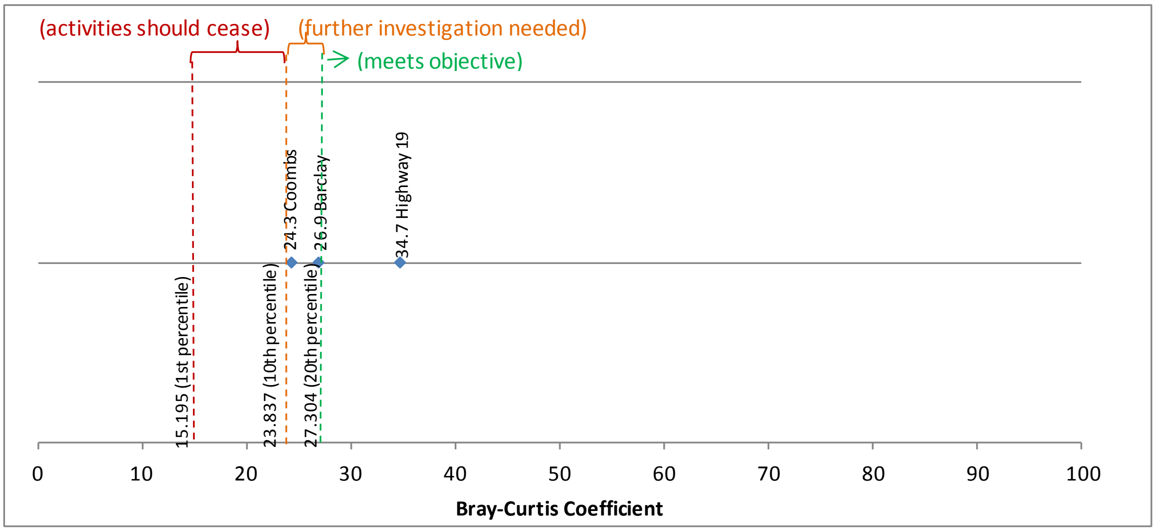

Figure 8. Plotted Bray-Curtis Coefficients for the three French Creek monitoring sites for benthic invertebrate samples collected in 2010, relative to defined ecological benchmarks.

7.0 MONITORING RECOMMENDATIONS

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, fall flush 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 November. 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, total phosphorous and chlorophyll *a*), as well as bacteriology (*E. coli*), and field measurements of temperature should be taken. 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 French Creek that are sensitive and should be protected are drinking water, irrigation, livestock watering, primary contact recreation, aquatic life and wildlife. The water quality objectives recommended here (Table 18) 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 French Creek is summarized in Table 19. 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 18. Summary of proposed water quality objectives for French Creek Community Watershed. Objectives apply to all sites unless otherwise specified.

Variable	Objective Value
Temperature	Short term (< 5 years): ≤17°C maximum average weekly Long term (5 – 10 years): ≤15°C maximum average weekly
Turbidity	5 NTU maximum Oct – Dec 2 NTU maximum Jan – Sept 95% of samples ≤1 NTU at intake
Total Suspended Solids (TSS)/ Non-Filterable Residue	26 mg/L maximum 6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
True Colour	15 TCU maximum
Total Organic Carbon	4.0 mg/L maximum at intake
Total Phosphorus	10 µg/L max 5 µg/L avg (based on a minimum of monthly samples collected from May – Sept)
Chlorophyll *a*	0.1 g/m^2 average during summer (based on minimum of three samples)
Dissolved Aluminum	0.1 mg/L maximum 0.05 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Escherichia coli	≤ 41 CFU/100 mL (90^{th} percentile) (based on a minimum of five weekly samples collected over a 30-day period)
Benthic Invertebrates (provisional objective)	≥27.304 (or the 20^{th} percentile of the distribution of BCC scores for the West Coast Region)

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

Table 19. Proposed schedule for future water quality and benthic invertebrate monitoring applicable to all sites in French Creek.

Frequency and timing	Characteristic to be measured
August – September (low-flow season): once per week for five consecutive weeks	Temperature, pH, specific conductivity, TSS, turbidity, colour, total phosphorous, DOC, TOC, and *E. coli*
October – November (high-flow season): once per week for five consecutive weeks	Temperature, pH, specific conductivity, TSS, turbidity, colour, total phosphorous, DOC, TOC, and *E. coli*, total and dissolved metals, hardness
Once during summer	Chlorophyll *a* (at least three samples)
Monthly from May-September	Total phosphorous
Once during low-flow season	Total and dissolved metals, hardness
Once every five years	Benthic invertebrate sampling

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APPENDIX I. SUMMARY OF WATER QUALITY DATA

Table 20. Summary of general water chemistry at Site E243023, French Creek at Winchester Road.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Alkalinity pH 4.5/4.2 (mg/L)	9.7	21	13.8	4.8	10
Alkalinity Total 4.5 (mg/L)	21.2	23.9	22.6	1.9	2
Ammonia Dissolved (mg/L)	0.005	0.014	0.007	0.003	13
Bromide Dissolved (mg/L)	< 0.05	< 0.05	< 0.05	0.00	7
Carbon Dissolved Organic (mg/L)	2.1	7.2	3.7	1.3	18
Carbon Total Inorganic (mg/L)	2.5	2.5	2.50		1
Carbon Total Organic (mg/L)	2.2	6.4	4.2	1.4	11
Chlrid:D (mg/L)	2.1	7.15	2.99	1.84	7
Coliforms fecal (CFU/100mL)	< 1	8200	496	1738	22
Color True (Col.unit)	20	20	20		1
Diss Oxy (mg/L)	4.93	43.8	12.8	9.9	13
E Coli (CFU/100mL)	1	8200	860	2580	10
Fluoride D (mg/L)	0.02	0.04	0.03	0.01	7
Hardness (Dissolved) (mg/L)	11.4	26	13.2	3.5	16
Hardness Total (T) (mg/L)	11.2	115.5	23.6	29.3	12
Nitrogen Kjeldahl (mg/L)	0.25	0.25	0.25		1
Nitrate (NO3) Dissolved (mg/L)	0.023	0.082	0.044	0.023	8
Nitrate + Nitrite Diss. (mg/L)	0.028	0.161	0.073	0.041	14
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	< 0.005	< 0.005		8
Nitrogen Total (mg/L)	0.1	0.32	0.19	0.06	14
NO2+NO3 (mg/L)	0.07	0.07	0.07		1
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.002	0.002	0.001	7
pH (pH units)	6.05	8.45	7.19	0.52	34
Phosphorus Tot. Dissolved (mg/L)	0.009	0.015	0.01	0.00	7
P--T (mg/L)	0.005	0.054	0.012	0.009	27
Residue Total (mg/L)	62	62	62		1
Residue Filterable 1.0u (mg/L)	60	60	60		1
Residue Non-filterable (mg/L)	< 1	4	1.4	0.8	18
Specific Conductance (µS/cm)	6.24	83.2	48.0	16.5	27
Sulfate D (mg/L)	1.6	2.27	1.73	0.24	7
Sulfur Dissolved (mg/L)	0.55	0.64	0.60	0.03	7
Sulfur Total (mg/L)	0.44	13.41	1.60	3.72	12
Temp (°C)	2.1	17	9.0	4.3	14
Turbidity (NTU)	0.15	3.1	1.10	0.69	25
Ag-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		9
Ag-T (mg/L)	0.000005	0.00002	< 0.00002	0.00001	14

	Minimum	Maximum	Average	Std Dev	No. of Samples
Al-D (mg/L)	0.0227	0.0856	0.06	0.02	9
Al-T (mg/L)	0.016	0.117	0.06	0.03	14
As-D (mg/L)	< 0.0001	0.00049	0.0002	0.0002	9
As-T (mg/L)	< 0.0001	0.0007	0.0004	0.0002	14
Ba-D (mg/L)	0.005	0.00863	0.0055	0.0009	16
Ba-T (mg/L)	0.00521	0.0099	0.0063	0.0013	14
B--D (mg/L)	0.007	0.012	0.010	0.002	7
Be-D (mg/L)	< 0.000002	0.000013	0.000007	0.000004	9
Be-T (mg/L)	< 0.000002	0.000029	0.000009	0.000007	14
Bi-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		9
Bi-T (mg/L)	< 0.000005	0.00008	0.00002	0.00002	14
B--T (mg/L)	0.007	0.023	0.013	0.005	12
Ca-D (mg/L)	3.2	7.33	3.9	1.3	9
Ca-T (mg/L)	3.1	43.9	7.7	11.5	12
Cd-D (mg/L)	< 0.000005	0.00007	0.00002	0.00002	9
Cd-T (mg/L)	< 0.000005	0.00003	0.00001	0.00001	14
Co-D (mg/L)	0.000025	0.000057	0.000037	0.000012	9
Co-T (mg/L)	0.00003	0.000133	0.000054	0.000027	14
Cr-D (mg/L)	< 0.0001	0.0004	0.0002	0.0001	9
Cr-T (mg/L)	< 0.0001	0.0008	0.0003	0.0002	14
C--T (mg/L)	7.3	7.3	7.30		1
Cu-D (mg/L)	0.00048	0.00085	0.00069	0.00013	9
Cu-T (mg/L)	0.00046	0.00134	0.00072	0.00024	14
Fe-D (mg/L)	0.093	0.157	0.119	0.028	7
Fe-T (mg/L)	0.09	0.247	0.162	0.049	12
K--D (mg/L)	0.2	0.3	0.2	0.04	7
K--T (mg/L)	0.1	0.7	0.3	0.2	12
Li-D (mg/L)	< 0.00005	0.00019	0.00010	0.00006	7
Li-T (mg/L)	< 0.00005	0.00022	0.00012	0.00006	12
Mg-D (mg/L)	0.68	1.86	0.92	0.36	9
Mg-T (mg/L)	0.63	1.98	1.12	0.42	14
Mn-D (mg/L)	0.00048	0.00527	0.00277	0.00160	9
Mn-T (mg/L)	0.0032	0.025	0.0071	0.0059	14
Mo-D (mg/L)	< 0.00005	0.0002	0.0001	0.0001	9
Mo-T (mg/L)	< 0.00005	0.00073	0.0002	0.0002	14
Na-D (mg/L)	1.7	2	1.8	0.1	7
Na-T (mg/L)	1.4	3.4	2.2	0.7	12
Ni-D (mg/L)	0.00013	0.00044	0.00025	0.00009	9
Ni-T (mg/L)	0.00016	0.00042	0.00028	0.00007	14
Pb-D (mg/L)	< 0.00001	0.00004	0.00002	0.00001	9
Pb-T (mg/L)	< 0.00001	0.00011	0.00003	0.00003	14

	Minimum	Maximum	Average	Std Dev	No. of Samples
Sb-D (mg/L)	< 0.000005	0.00004	0.000016	0.000014	9
Sb-T (mg/L)	< 0.000005	0.000081	0.000027	0.000027	14
Se-D (mg/L)	< 0.00004	< 0.00004	< 0.00004		5
Se-T (mg/L)	< 0.00004	< 0.00004	< 0.00004		5
Si-D (mg/L)	3.37	3.86	3.63	0.18	7
Si-T (mg/L)	3.37	4.51	3.82	0.44	12
Sn-D (mg/L)	< 0.00001	0.00004	0.00	0.00	9
Sn-T (mg/L)	< 0.00001	0.0001	0.00	0.00	14
Sr-D (mg/L)	0.016	0.0344	0.020	0.004	16
Sr-T (mg/L)	0.0161	0.0333	0.023	0.004	14
Ti-D (mg/L)	< 0.002	0.004	0.003	0.001	7
Ti-T (mg/L)	< 0.002	0.008	0.003	0.002	12
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002		9
Tl-T (mg/L)	< 0.000002	0.000006	0.000002	0.000001	14
U--D (mg/L)	< 0.000002	0.000018	0.000008	0.000006	9
U--T (mg/L)	< 0.000002	0.00002	0.000006	0.000006	14
V--D (mg/L)	0.0004	0.0008	0.0005	0.0001	9
V--T (mg/L)	0.00048	0.0012	0.0006	0.0002	14
Zn-D (mg/L)	0.0003	0.001	0.0007	0.0003	9
Zn-T (mg/L)	0.0001	0.0015	0.0006	0.0004	14

Table 21. Summary of general water chemistry at Site E243024, French Creek at Grafton Road.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Alkalinity pH 4.5/4.2 (mg/L)	8.3	15.3	11.6	2.8	11
Alkalinity Total 4.5 (mg/L)	13	21	17	6	2
Ammonia Dissolved (mg/L)	< 0.005	0.012	0.006	0.002	14
Bromide Dissolved (mg/L)	< 0.05	< 0.1	< 0.06		8
Carbon Dissolved Organic (mg/L)	1.4	12	4.3	2.7	18
Carbon Total Inorganic (mg/L)	2.2	2.2	2.2		1
Carbon Total Organic (mg/L)	1.6	11.5	5.4	3.0	11
Chlorophyll A (g/m2)	0.0105	0.0105	0.0105		1
Chloride D (mg/L)	1.89	3.56	2.51	0.57	8
Coliforms fecal (CFU/100mL)	1	5500	305	1165	22
Color True (Col.unit)	5	5	5		1
Diss Oxy (mg/L)	5.17	14.63	9.59	3.09	33
E coli (CFU/100mL)	3	76	34	26	10
Fluoride D (mg/L)	0.02	0.03	0.03	0.004	6
Hardness (Dissolved) (mg/L)	8.4	19.5	10.6	2.6	14
Hardness Total (T) (mg/L)	8.8	179.2	27.1	50.5	11

	Minimum	Maximum	Average	Std Dev	No. of Samples
Nitrogen Kjeldahl (mg/L)	0.02	0.02	0.02		1
Nitrate (NO3) Dissolved (mg/L)	0.094	0.593	0.182	0.182	7
Nitrate + Nitrite Diss. (mg/L)	0.024	0.593	0.174	0.137	15
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	< 0.005	< 0.005		7
Nitrogen Total (mg/L)	0.14	0.6	0.26	0.11	15
NO2+NO3 (mg/L)	0.58	0.58	0.58		1
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.003	0.002	0.001	9
pH (pH units)	6.61	9.05	7.21	0.56	35
Phosphorus Tot. Dissolved (mg/L)	0.003	0.015	0.009	0.004	8
P--T (mg/L)	0.003	0.036	0.009	0.007	28
Residue Filterable 1.0u (mg/L)	40	40	40		1
Residue Non-filterable (mg/L)	< 1	3	1.4	0.7	18
Specific Conductance (µS/cm)	14	67.1	42	10	47
Sulfate D (mg/L)	0.7	1.3	0.9	0.2	8
Sulfur Dissolved (mg/L)	0.27	0.33	0.30	0.03	6
Sulfur Total (mg/L)	0.24	62.2	5.91	18.67	11
Temp (°C)	2.2	17	9.6	4.0	34
Turbidity (NTU)	0	4.3	0.6	0.8	44
Ag-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		8
Ag-T (mg/L)	< 0.000005	0.00003	0.000018	0.000007	13
Al-D (mg/L)	0.0201	0.0942	0.0711	0.0251	8
Al-T (mg/L)	0.0144	0.131	0.0592	0.0438	13
As-D (mg/L)	0.00009	0.0004	0.0001	0.0001	8
As-T (mg/L)	< 0.0001	0.0005	0.0002	0.0001	13
Ba-D (mg/L)	0.00514	0.011	0.0064	0.0019	8
Ba-T (mg/L)	0.00543	0.0113	0.0069	0.0016	13
B--D (mg/L)	< 0.002	0.005	0.003167	0.001169	6
Be-D (mg/L)	< 0.000002	0.000017	0.000007	0.000006	8
Be-T (mg/L)	< 0.000002	0.000029	0.000008	0.000008	13
Bi-D (mg/L)	< 0.000005	0.00003	0.000019	0.000010	8
Bi-T (mg/L)	< 0.000005	< 0.00002	< 0.00002		13
B--T (mg/L)	< 0.002	0.019	0.006636	0.005065	11
Ca-D (mg/L)	2.51	5.67	3.16	1.03	8
Ca-T (mg/L)	2.4	69.9	9.4	20.1	11
Cd-D (mg/L)	< 0.000005	0.00001	0.000009	0.000002	8
Cd-T (mg/L)	< 0.000005	0.00003	0.000012	0.000007	13
Co-D (mg/L)	0.00002	0.000048	0.00003	0.00001	8
Co-T (mg/L)	0.000022	0.000086	0.00004	0.00002	13
Cr-D (mg/L)	< 0.0001	0.0004	0.0002	0.0001	8
Cr-T (mg/L)	< 0.0001	0.0008	0.0003	0.0002	13

	Minimum	Maximum	Average	Std Dev	No. of Samples
C--T (mg/L)	7.2	7.2	7.2		1
Cu-D (mg/L)	0.00038	0.00096	0.0006	0.0002	8
Cu-T (mg/L)	0.00035	0.00099	0.0006	0.0002	13
Fe-D (mg/L)	0.048	0.063	0.056	0.007	6
Fe-T (mg/L)	0.029	0.443	0.098	0.118	11
K--D (mg/L)	0.1	0.6	0.3	0.2	6
K--T (mg/L)	0.1	0.4	0.3	0.1	11
Li-D (mg/L)	< 0.00005	0.0003	0.00018	0.00011	6
Li-T (mg/L)	< 0.00005	0.00029	0.00018	0.00007	11
Mg-D (mg/L)	0.51	1.3	0.74	0.24	8
Mg-T (mg/L)	0.624	1.36	0.904	0.264	13
Mn-D (mg/L)	0.00033	0.00264	0.0014	0.0007	8
Mn-T (mg/L)	0.001285	0.0145	0.0031	0.0035	13
Mo-D (mg/L)	< 0.00005	0.0003	0.00013	0.00009	8
Mo-T (mg/L)	< 0.00005	0.00025	0.00014	0.00006	13
Na-D (mg/L)	1.6	4	2.1	1.0	6
Na-T (mg/L)	1.4	3.5	2.3	0.8	11
Ni-D (mg/L)	0.00022	0.00035	0.00027	0.00005	8
Ni-T (mg/L)	0.00021	0.0004	0.00028	0.00005	13
Pb-D (mg/L)	0.000007	0.00008	0.00003	0.00002	8
Pb-T (mg/L)	0.000008	0.000048	0.00002	0.00001	13
Sb-D (mg/L)	< 0.000005	0.000046	0.000021	0.000017	8
Sb-T (mg/L)	< 0.000005	0.000032	0.000019	0.000010	13
Se-D (mg/L)	< 0.00004	< 0.0002	< 0.0002		8
Se-T (mg/L)	< 0.00004	< 0.0002	< 0.0002		13
Si-D (mg/L)	3.14	3.46	3.33	0.13	6
Si-T (mg/L)	3	3.96	3.54	0.36	11
Sn-D (mg/L)	< 0.00001	0.00005	0.00002	0.00002	8
Sn-T (mg/L)	< 0.00001	0.00003	0.00001	0.00001	13
Sr-D (mg/L)	0.0167	0.0338	0.0215	0.0052	8
Sr-T (mg/L)	0.0169	0.0335	0.0224	0.0041	13
Ti-D (mg/L)	< 0.002	0.005	0.003	0.001	6
Ti-T (mg/L)	< 0.002	0.005	0.003	0.001	11
Tl-D (mg/L)	< 0.000002	0.000003	0.000002	0.000000	8
Tl-T (mg/L)	< 0.000002	0.000009	0.000003	0.000002	13
U--D (mg/L)	< 0.000002	0.000029	0.000012	0.000010	8
U--T (mg/L)	< 0.000002	0.000039	0.000009	0.000011	13
V--D (mg/L)	0.00031	0.00057	0.00041	0.00008	8
V--T (mg/L)	0.0003	0.00064	0.0004	0.0001	13
Zn-D (mg/L)	0.0002	0.0014	0.0007	0.0004	8
Zn-T (mg/L)	< 0.0001	0.0118	0.0013	0.0032	13

Table 22. Summary of general water chemistry at Site E243025, French Creek at Coombs.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Alkalinity pH 4.5/4.2 (mg/L)	10.2	12.6	11.5	1.1	6
Alkalinity Total 4.5 (mg/L)	23	37.3	28.6	5.5	6
Ammonia Dissolved (mg/L)	< 0.005	0.018	0.008	0.004	14
Bromide Dissolved (mg/L)	< 0.05	< 0.05	< 0.05		6
Carbon Dissolved Organic (mg/L)	1.9	5.6	3.3	1.0	18
Carbon Total Inorganic (mg/L)	2.4	2.4	2.4		1
Carbon Total Organic (mg/L)	2.1	10.5	4.3	2.5	11
Chlorophyll A (g/m2)	0.0051	30.4	15.2	21.5	2
Chloride D (mg/L)	2.29	20.7	5.21	6.37	8
Coliforms fecal (CFU/100mL)	2	230	66.1	65.5	22
Color True (Col.unit)	5	5	5		1
Diss Oxy (mg/L)	5.26	14.98	10.42	3.92	13
E coli (CFU/100mL)	2	230	39	66	11
Fluoride D (mg/L)	0.02	0.04	0.03	0.01	6
Hardness (Dissolved) (mg/L)	10.1	48.3	14.8	9.7	14
Hardness Total (T) (mg/L)	11.0	33.1	18.1	7.9	11
Nitrogen Kjeldahl (mg/L)	0.1	0.1	0.1		1
Nitrate (NO3) Dissolved (mg/L)	0.073	0.321	0.123	0.089	7
Nitrate + Nitrite Diss. (mg/L)	0.035	0.321	0.131	0.072	15
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	< 0.005	< 0.005		7
Nitrogen Total (mg/L)	0.14	0.43	0.25	0.08	15
NO2+NO3 (mg/L)	0.33	0.33	0.33		1
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.004	0.002	0.001	9
pH (pH units)	6.87	8.89	7.41	0.48	35
Phosphorus Tot. Dissolved (mg/L)	0.002	0.1	0.047	0.048	14
P--T (mg/L)	0.003	0.015	0.009	0.003	28
Residue Total (mg/L)	89	89	89		1
Residue Filterable 1.0u (mg/L)	88	88	88		1
Residue Non-filterable (mg/L)	< 1	6	1.4	1.2	18
Specific Conductance (µS/cm)	18	195.4	62.6	40.4	27
Sulfate D (mg/L)	1.2	8.6	2.2	2.6	8
Sulfur Dissolved (mg/L)	0.44	0.52	0.48	0.03	6
Sulfur Total (mg/L)	0.41	0.75	0.51	0.10	11
Temp (°C)	1.7	18.5	9.2	4.8	14
Turbidity (NTU)	0.2	4	1.1	1.1	24
Ag-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		8
Ag-T (mg/L)	< 0.000005	0.00005	0.00002	0.000011	13
Al-D (mg/L)	0.0104	0.104	0.070	0.030	8

	Minimum	Maximum	Average	Std Dev	No. of Samples
Al-T (mg/L)	0.0106	0.152	0.064	0.052	13
As-D (mg/L)	< 0.0001	0.0005	0.0002	0.0001	8
As-T (mg/L)	< 0.0001	0.0007	0.0003	0.0002	13
Ba-D (mg/L)	0.00569	0.0305	0.0091	0.0087	8
Ba-T (mg/L)	0.00597	0.0327	0.0110	0.0076	13
B--D (mg/L)	0.003	0.008	0.006	0.002	6
Be-D (mg/L)	< 0.000002	0.000018	0.000006	0.000006	8
Be-T (mg/L)	< 0.000002	0.000012	0.000006	0.000004	13
Bi-D (mg/L)	< 0.000005	< 0.00002	< 0.00002	0.000007	8
Bi-T (mg/L)	< 0.000005	0.00006	0.00002	0.00001	13
B--T (mg/L)	0.003	0.021	0.011	0.006	11
C--T (mg/L)	7.7	7.7	7.7		1
Ca-D (mg/L)	3.09	14.1	4.7	3.8	8
Ca-T (mg/L)	3	9.2	5.1	2.2	11
Cd-D (mg/L)	< 0.000005	0.00013	0.00002	0.00004	8
Cd-T (mg/L)	< 0.000005	0.00004	0.00001	0.00001	13
Co-D (mg/L)	0.000024	0.000059	0.000037	0.000013	8
Co-T (mg/L)	0.000028	0.000092	0.000050	0.000018	13
Cr-D (mg/L)	< 0.0001	0.0004	0.0002	0.0001	8
Cr-T (mg/L)	< 0.0001	0.0011	0.0004	0.0003	13
Cu-D (mg/L)	0.00054	0.00157	0.00088	0.00040	8
Cu-T (mg/L)	0.00054	0.00133	0.00092	0.00026	13
Fe-D (mg/L)	0.085	0.121	0.105	0.014	6
Fe-T (mg/L)	0.016	0.238	0.108	0.067	11
K--D (mg/L)	0.2	0.6	0.3	0.2	6
K--T (mg/L)	0.2	0.8	0.4	0.2	11
Li-D (mg/L)	< 0.00005	0.00023	0.00014	0.00008	6
Li-T (mg/L)	< 0.00005	0.00042	0.00022	0.00011	11
Mg-D (mg/L)	0.59	3.2	1.11	0.85	8
Mg-T (mg/L)	0.73	3.17	1.43	0.76	13
Mn-D (mg/L)	0.00019	0.00404	0.0020	0.0013	8
Mn-T (mg/L)	0.00116	0.00631	0.0031	0.0013	13
Mo-D (mg/L)	< 0.00005	0.0008	0.0002	0.0002	8
Mo-T (mg/L)	< 0.00005	0.00095	0.0003	0.0003	13
Na-D (mg/L)	1.8	4	2.3	0.9	6
Na-T (mg/L)	1.5	6.8	3.8	2.1	11
Ni-D (mg/L)	0.00017	0.00053	0.00031	0.00010	8
Ni-T (mg/L)	0.00027	0.00076	0.00048	0.00020	13
Pb-D (mg/L)	< 0.00001	0.00009	0.00002	0.00003	8
Pb-T (mg/L)	0.00001	0.00006	0.00003	0.00002	13
Sb-D (mg/L)	< 0.000005	0.00013	0.000028	0.000042	8

	Minimum	Maximum	Average	Std Dev	No. of Samples
Sb-T (mg/L)	< 0.000005	0.000166	0.000050	0.000054	13
Se-D (mg/L)	< 0.00004	0.0002	0.00018	0.00006	8
Se-T (mg/L)	< 0.00004	0.00021	0.00019	0.00004	13
Si-D (mg/L)	3.33	3.68	3.55	0.16	6
Si-T (mg/L)	3.17	4.02	3.53	0.24	11
Sn-D (mg/L)	< 0.00001	0.00002	0.000011	0.000004	8
Sn-T (mg/L)	< 0.00001	0.00008	0.000022	0.000024	13
Sr-D (mg/L)	0.0175	0.0984	0.0264	0.0208	14
Sr-T (mg/L)	0.0177	0.104	0.0355	0.0232	13
Ti-D (mg/L)	< 0.002	0.007	0.004	0.002	6
Ti-T (mg/L)	< 0.002	0.009	0.004	0.002	11
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	8
Tl-T (mg/L)	< 0.000002	0.000005	0.000002	0.000001	13
U--D (mg/L)	< 0.000002	0.000024	0.000011	0.000008	8
U--T (mg/L)	< 0.000002	0.000032	0.000008	0.000009	13
V--D (mg/L)	0.0004	0.00068	0.000498	0.000088	8
V--T (mg/L)	< 0.0002	0.00074	0.00056	0.00015	13
Zn-D (mg/L)	0.0004	0.0012	0.00064	0.00030	8
Zn-T (mg/L)	0.0002	0.0016	0.00071	0.00046	13

Table 23. Summary of general water chemistry at Site E243021, French Creek Highway 19.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Alkalinity pH 4.5/4.2 (mg/L)	11.5	14.7	12.9	1.3	7
Alkalinity Total 4.5 (mg/L)	47.3	87.7	69.6	17.2	6
Ammonia Dissolved (mg/L)	0.005	0.015	0.009	0.004	15
Bromide Dissolved (mg/L)	0.05	0.2	0.07	0.05	9
Carbon Dissolved Organic (mg/L)	1.6	6.9	4.0	1.6	18
Carbon Total Inorganic (mg/L)	2.6	2.6	2.6		1
Carbon Total Organic (mg/L)	1.7	6.7	4.1	1.7	11
Chlorophyll A (g/m2)	0.0014	6.7	3.4	4.7	2
Chloride D (mg/L)	2.1	3.95	3.4	0.6	9
Coliforms fecal (CFU/100mL)	1	280	54.7	69.4	23
Color True (Col.unit)	15	15	15		1
Diss Oxy (mg/L)	5.6	15.77	11.0	2.7	33
E Coli (CFU/100mL)	1	140	45.5	50.4	11
Fluoride D (mg/L)	0.02	0.04	0.03	0.01	7
Hardness (Dissolved) (mg/L)	12.8	86.6	19.9	17.8	16
Hardness Total (T) (mg/L)	14.0	82.0	34.3	25.7	12
Nitrogen Kjeldahl (mg/L)	0.19	0.19	0.19		1

	Minimum	Maximum	Average	Std Dev	No. of Samples
Nitrate (NO3) Dissolved (mg/L)	0.045	0.146	0.103	0.033	8
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.151	0.086	0.039	16
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	< 0.005	< 0.005		8
Nitrogen Total (mg/L)	0.16	0.38	0.24	0.07	16
NO2+NO3 (mg/L)	0.04	0.04	0.04		1
Ortho-Phosphate Dissolved (mg/L)	0.001	0.023	0.010	0.007	9
pH (pH units)	6.47	8.21	7.41	0.42	37
Phosphorus Tot. Dissolved (mg/L)	0.01	0.02	0.014	0.003	8
P--T (mg/L)	0.005	0.036	0.015	0.007	29
Residue total (mg/L)	111	111	111		1
Residue Filterable 1.0u (mg/L)	110	110	110		1
Residue Non-filterable (mg/L)	< 1	7	2.0	1.6	18
Specific Conductance (µS/cm)	24	210	97.7	59.9	48
Sulfate D (mg/L)	1.41	7.3	2.68	2.23	9
Sulfur Dissolved (mg/L)	0.55	1.03	0.65	0.17	7
Sulfur Total (mg/L)	0.44	1.22	0.79	0.29	12
Temp (°C)	2	15.7	9.1	3.8	33
Turbidity (NTU)	0.08	6.2	1.31	1.33	45
Ag-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		9
Ag-T (mg/L)	< 0.000005	< 0.00002	< 0.00002	0.000005	14
Al-D (mg/L)	0.0096	0.155	0.097	0.044	9
Al-T (mg/L)	0.0117	0.227	0.114	0.084	14
As-D (mg/L)	< 0.0001	0.00069	0.00021	0.00019	9
As-T (mg/L)	< 0.0001	0.0013	0.00046	0.00045	14
Ba-D (mg/L)	0.00533	0.0187	0.0072	0.0031	16
Ba-T (mg/L)	0.00658	0.019	0.0095	0.0037	14
B--D (mg/L)	0.005	< 0.05	0.007	0.001	9
Be-D (mg/L)	0.000002	0.00002	0.000008	0.000006	9
Be-T (mg/L)	0.000002	0.000029	0.000009	0.000008	14
Bi-D (mg/L)	< 0.000005	0.00003	< 0.000018	0.000008	9
Bi-T (mg/L)	< 0.000005	< 0.00002	0.000018	0.000005	14
B--T (mg/L)	0.004	< 0.05	0.010	0.005	14
Ca-D (mg/L)	3.68	23.5	6.2	6.5	9
Ca-T (mg/L)	3.7	18.7	8.5	6.0	12
Cd-D (mg/L)	< 0.000005	< 0.00001	< 0.000009		9
Cd-T (mg/L)	< 0.000005	< 0.00002	< 0.00001		14
Co-D (mg/L)	0.000024	0.000089	0.000055	0.000025	9
Co-T (mg/L)	0.000039	0.000297	0.000116	0.000066	14
Cr-D (mg/L)	0.0002	0.0006	0.0003	0.0001	9
Cr-T (mg/L)	0.0002	0.002	0.0007	0.0005	14

	Minimum	Maximum	Average	Std Dev	No. of Samples
C--T (mg/L)	9.3	9.3	9.3		1
Cu-D (mg/L)	0.0008	0.00141	0.0010	0.0002	9
Cu-T (mg/L)	0.00065	0.00151	0.00102	0.00025	14
Fe-D (mg/L)	0.115	0.175	0.142	0.023	7
Fe-T (mg/L)	0.159	0.467	0.261	0.101	12
K--D (mg/L)	0.2	0.3	0.2	0.05	7
K--T (mg/L)	< 0.1	0.6	0.3	0.2	12
Li-D (mg/L)	0.00005	0.00024	0.00016	0.00008	7
Li-T (mg/L)	0.00005	0.00044	0.00026	0.00011	12
Mg-D (mg/L)	0.88	6.78	1.56	1.40	16
Mg-T (mg/L)	1.02	8.57	3.27	2.70	14
Mn-D (mg/L)	0.00054	0.006	0.0028	0.0014	16
Mn-T (mg/L)	0.00258	0.053743	0.0158	0.0150	14
Mo-D (mg/L)	< 0.00005	0.00047	0.00019	0.00013	9
Mo-T (mg/L)	< 0.00005	0.00033	0.00018	0.00009	14
Na-D (mg/L)	2.2	2.5	2.4	0.1	7
Na-T (mg/L)	2	6.2	3.8	1.9	12
Ni-D (mg/L)	0.00028	0.00053	0.00045	0.00008	9
Ni-T (mg/L)	0.00042	0.00156	0.00077	0.00035	14
Pb-D (mg/L)	0.00001	0.00008	0.00004	0.00003	9
Pb-T (mg/L)	0.000007	0.00009	0.00004	0.00003	14
Sb-D (mg/L)	< 0.000005	0.00018	0.000044	0.000056	9
Sb-T (mg/L)	< 0.000005	0.000081	0.000039	0.000026	14
Se-D (mg/L)	0.00004	< 0.0002	< 0.00017	0.00006	9
Se-T (mg/L)	0.00004	< 0.0002	< 0.00018	0.00005	14
Si-D (mg/L)	3.58	3.9	3.75	0.15	7
Si-T (mg/L)	3.42	6.42	4.46	0.96	12
Sn-D (mg/L)	< 0.00001	0.00029	0.00004	0.00009	9
Sn-T (mg/L)	< 0.00001	0.00007	0.00002	0.00002	14
Sr-D (mg/L)	0.0195	0.0845	0.0277	0.0153	16
Sr-T (mg/L)	0.0201	0.084	0.04	0.02	14
Ti-D (mg/L)	0.002	0.006	0.004	0.001	7
Ti-T (mg/L)	0.002	0.018	0.007	0.006	12
Tl-D (mg/L)	< 0.000002	0.000002	< 0.000002	0	9
Tl-T (mg/L)	< 0.000002	0.000002	< 0.000002	0	14
U--D (mg/L)	< 0.000002	0.000029	0.00001	0.00001	9
U--T (mg/L)	< 0.000002	0.000032	0.00002	0.00001	14
V--D (mg/L)	0.00055	0.0015	0.00078	0.00033	9
V--T (mg/L)	0.00059	0.00282	0.00133	0.00075	14
Zn-D (mg/L)	0.0004	0.0018	0.0009	0.0005	9
Zn-T (mg/L)	0.0001	0.0016	0.0007	0.0004	14

Table 24. Summary of general water chemistry at Site E243022, French Creek Barclay Road Bridge.

	Minimum	Maximum	Average	Std Dev	No. of Samples
Alkalinity pH 4.5/4.2 (mg/L)	9.4	17.5	14.4	3.8	4
Alkalinity Total 4.5 (mg/L)	20.9	73.8	47.6	18.4	8
Ammonia Dissolved (mg/L)	< 0.005	0.029	0.009	0.006	15
Bromide Dissolved (mg/L)	< 0.05	< 0.1	< 0.06	0.02	9
Carbon Dissolved Organic (mg/L)	1.9	7.1	3.9	1.4	17
Carbon Total Inorganic (mg/L)	3.3	3.3	3.3		1
Carbon Total Organic (mg/L)	2.7	7.3	4.5	1.8	11
Chlorophyll A (g/m2)	0.1	48	24.1	33.9	2
Chloride D (mg/L)	4.26	8.9	5.63	1.72	9
Coliforms fecal (CFU/100mL)	3	16000	1382	3563	24
Color True (Col.unit)	5	40	22	12	7
Cyanide (WAD) (mg/L)	0.03	0.03	0.03		1
Diss Oxy (mg/L)	6.24	50.4	12.1	7.3	32
E Coli (CFU/100mL)	7	16000	2575.7	4906.8	11
Fluoride D (mg/L)	0.03	0.04	0.04	0.01	7
Hardness (Dissolved) (mg/L)	11.7	61.4	21.8	11.7	14
Hardness Total (T) (mg/L)	16.5	75.3	35.0	20.7	11
Nitrogen Kjeldahl (mg/L)	0.11	0.11	0.11		1
Nitrate (NO3) Dissolved (mg/L)	0.028	0.208	0.136	0.068	8
Nitrate + Nitrite Diss. (mg/L)	0.024	0.415	0.128	0.111	16
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	< 0.005	< 0.005		8
Nitrogen Total (mg/L)	0.14	0.62	0.30	0.14	16
NO2+NO3 (mg/L)	0.03	0.03	0.03		1
Ortho-Phosphate Dissolved (mg/L)	0.001	0.05	0.023	0.024	17
pH (pH units)	6.94	9.22	7.51	0.45	36
Phosphorus Tot. Dissolved (mg/L)	0.006	0.016	0.011	0.004	9
P--T (mg/L)	0.004	0.031	0.013	0.007	29
Residue total (mg/L)	87	87	87		1
Residue Filterable 1.0u (mg/L)	86	86	86		1
Residue Non-filterable (mg/L)	< 1	8	2.6	2.3	18
Specific Conductance (µS/cm)	7.1	169.9	95.1	41.8	47
Sulfate D (mg/L)	1.65	5	2.36	1.02	9
Sulfur Dissolved (mg/L)	0.68	0.8	0.74	0.05	6
Sulfur Total (mg/L)	0.58	1.02	0.72	0.12	11
Temp (°C)	1.9	18.5	10.0	4.5	33
Turbidity (NTU)	0.19	7.4	1.67	1.56	44
Ag-D (mg/L)	< 0.000005	< 0.00002	< 0.00002		8
Ag-T (mg/L)	< 0.000005	0.00006	0.00002	0.00001	13

	Minimum	Maximum	Average	Std Dev	No. of Samples
Al-D (mg/L)	0.0077	0.158	0.089	0.050	8
Al-T (mg/L)	0.0134	0.209	0.098	0.072	13
As-D (mg/L)	< 0.0001	0.0004	0.0002	0.0001	8
As-T (mg/L)	< 0.0001	0.0007	0.0003	0.0002	13
Ba-D (mg/L)	0.0052	0.0125	0.0070	0.0017	14
Ba-T (mg/L)	0.00676	0.0127	0.0089	0.0021	13
B--D (mg/L)	0.005	0.009	0.007	0.001	6
Be-D (mg/L)	0.000002	0.000021	0.000008	0.000006	8
Be-T (mg/L)	0.000002	0.000013	0.000006	0.000004	13
Bi-D (mg/L)	0.000005	0.00002	0.000016	0.000007	8
Bi-T (mg/L)	0.000005	0.00008	0.000022	0.000018	13
B--T (mg/L)	0.005	0.019	0.011	0.005	11
Ca-D (mg/L)	3.24	16.1	6.18	4.08	8
Ca-T (mg/L)	4.2	17.9	8.9	5.0	11
Cd-D (mg/L)	< 0.000005	< 0.00001	< 0.00001		8
Cd-T (mg/L)	< 0.000005	0.00003	0.00001	0.00001	13
Co-D (mg/L)	0.000028	0.000087	0.00005	0.00002	8
Co-T (mg/L)	0.000035	0.000131	0.00009	0.00003	13
Cr-D (mg/L)	< 0.0001	0.0007	0.0003	0.0002	8
Cr-T (mg/L)	< 0.0001	0.0018	0.0007	0.0005	13
C--T (mg/L)	10.6	10.6	10.6		1
Cu-D (mg/L)	0.00076	0.00127	0.00099	0.00018	8
Cu-T (mg/L)	0.00079	0.00244	0.00122	0.00042	13
Fe-D (mg/L)	0.123	0.184	0.146	0.028	6
Fe-T (mg/L)	0.088	0.394	0.204	0.085	11
K--D (mg/L)	0.3	0.8	0.4	0.2	6
K--T (mg/L)	0.1	1.2	0.6	0.3	11
Li-D (mg/L)	0.00005	0.0005	0.0002	0.0002	8
Li-T (mg/L)	0.00005	0.0005	0.0002	0.0001	13
Mg-D (mg/L)	0.87	5.14	1.90	1.33	14
Mg-T (mg/L)	1.05	7.44	3.09	2.00	13
Mn-D (mg/L)	0.00049	0.007	0.0039	0.0021	14
Mn-T (mg/L)	0.00432	0.027128	0.0093	0.0063	13
Mo-D (mg/L)	< 0.00005	0.00025	0.0002	0.0001	8
Mo-T (mg/L)	< 0.00005	0.00041	0.0002	0.0001	13
Na-D (mg/L)	2.6	5.4	3.4	1.0	6
Na-T (mg/L)	2.5	7.9	4.8	2.2	11
Ni-D (mg/L)	0.00025	0.00059	0.00047	0.00012	8
Ni-T (mg/L)	0.00033	0.00144	0.00075	0.00029	13
Pb-D (mg/L)	0.000006	0.00005	0.00002	0.00002	8
Pb-T (mg/L)	0.000009	0.00009	0.00004	0.00003	13

	Minimum	Maximum	Average	Std Dev	No. of Samples
Sb-D (mg/L)	< 0.000005	0.000052	0.00002	0.00002	8
Sb-T (mg/L)	< 0.000005	0.000082	0.00003	0.00002	13
Se-D (mg/L)	< 0.00004	< 0.0002	< 0.0002		8
Se-T (mg/L)	< 0.00004	< 0.0002	< 0.0002		13
Si-D (mg/L)	3.71	4.15	3.97	0.19	6
Si-T (mg/L)	3.7	6.27	4.50	0.75	11
Sn-D (mg/L)	< 0.00001	0.00009	0.00002	0.00003	8
Sn-T (mg/L)	< 0.00001	0.00019	0.00003	0.00005	13
Sr-D (mg/L)	0.0216	0.0691	0.0324	0.0153	14
Sr-T (mg/L)	0.0215	0.0692	0.0398	0.0156	13
Ti-D (mg/L)	< 0.002	0.006	0.004	0.002	6
Ti-T (mg/L)	< 0.002	0.02	0.006	0.005	11
Tl-D (mg/L)	< 0.000002	< 0.000002	< 0.000002	0	8
Tl-T (mg/L)	< 0.000002	0.000004	0.000002	0.000001	13
U--D (mg/L)	< 0.000002	0.000023	0.000011	0.000007	8
U--T (mg/L)	< 0.000002	0.000039	0.000013	0.000011	13
V--D (mg/L)	0.0004	0.00111	0.00067	0.00021	8
V--T (mg/L)	0.00065	0.00141	0.00096	0.00023	13
Zn-D (mg/L)	0.0003	0.0013	0.0006	0.0003	8
Zn-T (mg/L)	0.0003	0.0013	0.0008	0.0003	13