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Summary of Baseline Water Quality Monitoring in Agricultural Areas of the Comox Valley

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EXECUTIVE SUMMARY

This report summarizes 2019 baseline water quality data for the lower Tsolum River and Portuguese Creek (a tributary to the Tsolum River) in the Comox Valley, B.C, collected by the Tsolum River Restoration Society in partnership with the B.C. Ministry of Environment and Climate Change Strategy (ENV). Data were analyzed to determine potential impacts associated with agricultural activity. These baseline data were important to have early in the phasing in of the 2018 *Agricultural Environmental Management Code of Practice* (*AEM Code*) under the *Environmental Management Act*, a process that will occur over ten years, such that future monitoring can use the 2019 baseline data to determine *AEM Code* effectiveness. The Comox Valley was chosen for this focussed study as it was an area ENV had minimal water quality data for agricultural areas. This study indicated that water quality is generally good in the lower Tsolum River and poor in Portuguese Creek, where almost 40% of the land use is for agricultural purposes. Elevated values in the Tsolum River above applicable Tsolum River Water Quality Objectives or BC Water Quality Guidelines were most often associated with rainfall events. Elevated values in Portuguese Creek were generally higher than those in the Tsolum River and were associated with the growing season. The results suggest that agriculture is a large contributor to negative impacts on water quality in Portuguese Creek and in Tsolum River. As more aspects of the new *AEM Code* are implemented and enforced, it is expected that water quality in the study area will improve.

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1. INTRODUCTION

On February 28, 2019, the B.C. Ministry of Environmental and Climate Change Strategy (ENV) released a new regulation under the *Environmental Management Act* called the *Code of Practice for Agricultural Environmental Management (AEM Code*), which replaced the *Agricultural Waste Control Regulation*. The new *AEM Code* applies to all agricultural operations in British Columbia, from small hobby farms to large commercial operations. Key requirements of the code include no direct discharges to watercourses or groundwater, prevention of contaminated water from entering watercourses or groundwater, minimum setbacks from drinking water sources, watercourses and property boundaries, and keeping records. Additional measures are required for operations in high-risk areas (in high rainfall areas, vulnerable aquifer areas and phosphorus-affected areas) and operating during high-risk conditions (e.g., during storms, flooding and strong winds) (B.C., 2020; BCAC, 2020).

All of Vancouver Island is a phosphorus-affected area (B.C., 2019a), meaning that watercourses may be adversely affected by high levels of phosphorus. Under the *AEM Code*, as of July 15, 2024, all agriculture operations larger than 5 hectares (ha) in phosphorus-affected areas will be required to have a Nutrient Management Plan to ensure that nutrients (e.g., commercial fertilizer, manure) applied to land match crop needs.

The Comox Valley on Vancouver Island is an area for which ENV has minimal data for watercourses in agricultural areas. It is important to understand the state of water quality in this area before the *AEM Code* fully comes into force to evaluate the effectiveness of the code in the future. This report presents baseline water quality data for agricultural areas in the Comox Valley relative to applicable current BC Water Quality Guidelines (WQGs), Water Quality Objectives (WQOs) and the guidance document *Phosphorus management in Vancouver Island Streams (MOE, 2014)*.

The study area lies within the unceded territory of the K'òmoks First Nation and has always been a vital part of the K'òmoks First Nation community. Agriculture has played an important role in the Comox Valley for thousands of years. K'òmoks First Nation has hunted, fished and farmed crops in the watershed since time immemorial (K'òmoks First Nation, 2013). Currently, agriculture is an important economic driver in the Comox Valley, and is growing (Comox Valley Economic Development, 2018).

ENV has a communications plan to help agricultural operators, stakeholders and First Nations become aware of the new *AEM Code* and its positive environmental benefits; this will help agricultural operators comply with current requirements and voluntarily adopt future requirements of the code. The plan includes outreach to large scale farmers and ranchers through presentations to different associations and groups, and at different events in 2019-20, with ad-hoc presentations when requested after 2020. Outreach to small scale or hobby farms includes holding information booths at farmer's markets and pamphlets left at supply stores. Outreach to key influencers (regional agrologists, representatives of agricultural industry groups, etc.) is also an important part of the communications plan.

The Tsolum River and Portuguese creek were chosen to represent potential agricultural impacts because they run through large areas with extensive agricultural use. Notably, in 1984, ENV became aware of water quality problems in the Tsolum River caused by acid rock drainage and copper leaching from an abandoned mine on Mount Washington. As a result, much of the previous research and effort in the Tsolum River were spent on understanding mine impacts on water quality and on mitigating those impacts. This is described in the Tsolum River Water Quality Assessment and Updated Objectives (Phippen, 2012) and is outside of the scope of this report. WQOs provide goals that need to be met to ensure protection of designated water uses in a specific watershed. The inclusion of WQOs 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.

1.1 Purpose of Report

The purpose of this report is to provide an analysis and summary of baseline water quality monitoring results collected by ENV and the Tsolum River Restoration Society from March 28 to November 6, 2019 in the Comox Valley. These summarized baseline data, combined with future monitoring of the area, will help to determine if requirements under the *AEM Code* are contributing to improved water quality.

2. WATERSHED PROFILE AND HYDROLOGY

The Tsolum River is approximately 39.8 km long, from its origin on Mt. Washington to the point where it joins the Puntledge River in Courtenay, just upstream from Comox Harbour (FISS, 2012). The drainage area of the Tsolum River near its mouth at Courtenay is 262 km^2. Portuguese Creek, an important tributary to the Tsolum River, drains approximately 37 km^2 of the eastern side of the Tsolum, running parallel to the coast for 11.6 km before joining the Tsolum River upstream of Courtenay. Portuguese Creek and the lower portion of the Tsolum River watershed fall within the Coastal Western Hemlock (Eastern very dry maritime, CWHxm1) biogeoclimatic zone.

Mean monthly air temperatures measured at the nearest Environment Canada weather station (Comox A, Station 1021830) ranged from 3.5°C in December to 17.6°C in July, with an average annual temperature of 9.7°C (Figure 1) based on 30-year climate normal data collected between 1981 and 2010. High rainfall between October and April may influence the classification of some agricultural areas within the region as high risk under the *AEM code*.

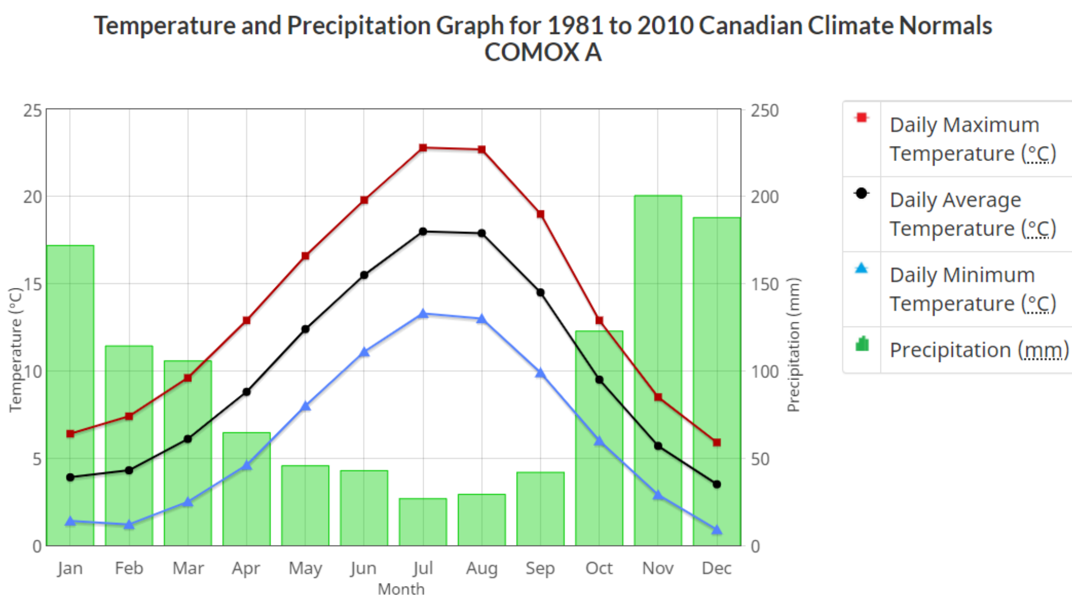

Figure 1: Climate normal from Environment Canada (Comox A, Station 1021830) (From CVRD, 2019).

A hydrology study conducted in 2011 by Northwest Hydraulic Consultants (NHC, 2011) provides a detailed examination of climate and hydrology within the Tsolum River watershed. Both extremely high and extremely low flows on the Tsolum River are of concern and are the focus of many previous studies. The NHC hydrology study found that both overall precipitation and the number of significant floods has increased in the Tsolum River over the period of record (NHC, 2011), and the highest flood on record occurred in 2010. It is thought that bedload movement during these higher floods is impacting salmonid eggs and fry survival, contributing to variability in the recovery of pink salmon populations. Low flows, especially in the lower mainstem of the Tsolum River, are a significant concern as they represent an obstacle to returning spawning salmon and the survival of their offspring. For this reason, water is stored in Wolf Lake from spring melt and rain events and is portioned out over the summer and fall to maintain a flow of at least 10% mean annual discharge (MAD). Even with this flow augmentation, summer flows below 10% MAD are not uncommon (Van Tongeren, *pers. comm.* 2021)

In 2019, Comox Valley Regional District (CVRD) updated the boundaries of aquifers in the region by creating a 3D hydrogeological model based on the most up-to-date well information from ENV (CVRD, 2019). The results of the model demonstrate that there are two distinct surficial sand and gravel aquifers in the Tsolum River watershed and Portuguese Creek sub-basin. One is a previously unmapped confined aquifer that extends from Black Creek to the lower Tsolum River between Portuguese Creek and the Tsolum River mainstem. The second aquifer is the Quadra Sand aquifer, a pre-Fraser glacial deposit, which is below the first aquifer and extends east to the Georgia Strait (CVRD, 2019).

3. WATER USES

3.1 Water Licenses

Fifty-four water licenses (14 domestic use and 40 private irrigation) have been issued for the Tsolum River mainstem, as well as two licenses (domestic use) on Portuguese Creek (B.C., 2019b). Several springs in the Portuguese Creek watershed also have water licenses (B.C., 2019b) and it is anticipated there is significant unlicensed demand from groundwater sources.

3.2 Fisheries

The Tsolum River historically has supported an extremely diverse and important fish population. Prior to the operation of the copper mine on Mt. Washington between 1964 and 1967, and extensive logging and development conducted in the watershed in the 1960’s, the Tsolum produced large escapements of pink (*Oncorhynchus gorbuscha*), coho (*O. kisutch*) and chum (*O. keta*) salmon as well as a few sockeye (*O. nerka*) and chinook (*O. tshawytscha*) (Phippen, 2012). There have also been populations of resident and anadromous rainbow (*Oncorhynchus mykiss*) and cutthroat trout (*O. clarki*), Dolly Varden (*Salvelinus malma*), and three-spine stickleback *Gasterosteus aculeatus*). Chinook and coho salmon, anadromous cutthroat trout, steelhead (*O. mykiss irideus*), and threespine stickleback have all been observed in Portuguese Creek (most recent fish observations available were from 1999) (B.C., 2019c). Maximum and minimum historical escapements are summarized in Table 1. Since the restoration of the mine site on Mt. Washington, beginning in 2009, pink salmon runs have begun to improve in the Tsolum River (TRRS, 2019). In 2017, the most recent year with available data, a total of 84,257 pink salmon returned to spawn in the Tsolum River, although even year runs have yet to recover (TRRS, 2019).

Table 1: Summary of maximum and minimum escapements for salmonids in the Tsolum River Watershed (TRRS, 2019).

Species	Maximum		Minimum	
	Number	Year	Number	Year
Pink	100,000	1935, 1936, 1951	10	1984
Coho	15,000	1952, 1954, 1964, 1966	1	1997
Chum	18,000	2004	25	1958
Sockeye	25	1958, 1965-1968	0	most years
Chinook	10	1980	0	most years
Steelhead	3,500	unknown	0	Since 1986

The Tsolum River Restoriation Society (TRRS) highlights that there is excellent Coho spawning habitat throughout the lowest reaches of Portuguese Creek (Remillard and Clough, 2015). However, they note that possible limiting factors to salmon recovery include waste water, riparian areas, low flow and water quality (Remillard and Clough, 2015).

3.3 Recreation

Historically, there has been a strong recreational fishery within the Tsolum River watershed. Angler effort in the late 1960's was over 2,100 angler days/year for steelhead alone (BC Steelhead Harvest Analysis, from Campbell, 1999). Angling effort dropped off rapidly to less than 100 angler days/year in the 1980's. Currently, all fishing is prohibited in the Tsolum River until the health of the river increases (TRRS, 2019). Recent operation of a rotary screw trap by the TRRS has shown healthy populations of both rainbow and cutthroat trout, thought to be indicative of a remnant of the original steelhead population (Clough, 2014). With water quality in the Tsolum River improving due to the mine site remediation, and salmonid escapements in the river increasing, steelhead observations been again been reported in the Tsolum River (White, *pers.comm.,* 2021). Some reaches of the lower Tsolum River are popular for primary contact recreation (e.g. swimming). As water quality continues to improve and population density in the area increases, it is likely that swimming activities in the Tsolum River will increase in future years.

3.4 Flora and Fauna

The Tsolum River watershed, including Portuguese Creek, provides habitat to a wide variety of animal and plant species (Phippen, 2012). In addition to flora and fauna typical of Vancouver Island, there are also many threatened or endangered species that have been observed including Western Screech-Owl (*Megascops kennicottii kennicottii*), Northern Red-legged Frog (*Rana aurora*), Vancouver Island Marmot (*Marmota vancouverensis*) and Western Wahoo (*Euonymus occidentalis var. occidentalis*) (B.C., 2019d).

3.5 Designated Water Uses

Designated water uses are those water uses that are designated for protection in a watershed or waterbody. As outlined in the Water Quality and Objectives Report, the dedicated water uses for the Tsolum River watershed are aquatic life, wildlife, drinking water, irrigation and recreation (Phippen, 2012).

4. INFLUENCES ON WATER QUALITY

Most of the Tsolum River watershed and Portuguese Creek sub-basin are privately owned. Large portions of the upper Tsolum watershed are owned by the forestry company TimberWest (managed by Mosaic Forest Management), while the Portuguese and lower Tsolum watersheds contain significant agricultural activity, in addition to rural and urban residential development in the Courtenay area. Increased road density, impermeable surfaces and stormwater also contribute to water quality impacts in rural and urban developed areas but are not the focus of this report.

Historically, the most significant anthropogenic impact on water quality within the watershed was the acid rock drainage from the abandoned copper mine on Mt. Washington. Reclamation of the open pit site occurred between 2009 and 2011 when a thick geomembrane was installed, then further covered in glacial till and organic material (Phippen, 2012). The impacts of the acid rock drainage from the abandoned copper mine decreased considerably since the site was restored; acid rock drainage impacts are outside of the scope of this report and but are described in detail in other reports (Phippen, 2012).

Lands within the Agricultural Land Reserve (ALR) are found in the lower portion of the watershed, often directly adjacent to the mainstem of the Tsolum River. Agricultural land use makes up 38.6% of the Portuguese Creek and 8.8% of the Tsolum River watershed (Table 2, Figures 2 and 3*)* (BC Ministry of Agriculture, 2013). These values are based on agricultural land use inventory (ALUI) data; note these data were mostly collected for parceled land within the Agricultural Land Reserve (ALR) (except for 9628 ha outside the ALR), and it does not fully cover the watershed (BC Ministry of Agriculture, 2013). ALUI data cannot be viewed in detail due to an ongoing Privacy Impact Assessment.

Agricultural activities within the watershed include raising livestock (beef cattle, dairy cattle, and chickens), providing forage and pasture, and growing tree fruit, small fruit and vegetables. Agricultural activity also occurs outside of the ALR. Sediments, nutrients, pesticides, and animal waste from agricultural land use can all be transported from farmland into the river. In addition, many farm properties have limited riparian areas along the river and its tributaries. Portuguese Creek was historically ditched and relocated from its natural stream channel during agricultural development activities prior to 1937 (Campbell, 2010). In addition, wetlands were drained, and artificial ponds created in the Portuguese Creek sub-basin (Campbell, 2010).

Table 2: Total Area and % of watershed in the Portuguese and Tsolum watersheds (BC Ministry of Agriculture, 2013).

	Tsolum River		Portuguese Creek	
Category	**Total Area (ha)**	**% of Watershed**	**Total Area (ha)**	**% of Watershed**
Agriculture	2348.2	8.8	1426.6	38.6
Forested	6699.9	25.1	2147.9	58.1
Impervious	0.3	0.0	0.3	0.0
Recreation	12.3	0.0	6.4	0.2
Residential	4.0	0.0	3.5	0.1
Water	17.3	0.1	2.9	0.1
Total Area of Watershed (ha)	26642.7		3697.0	

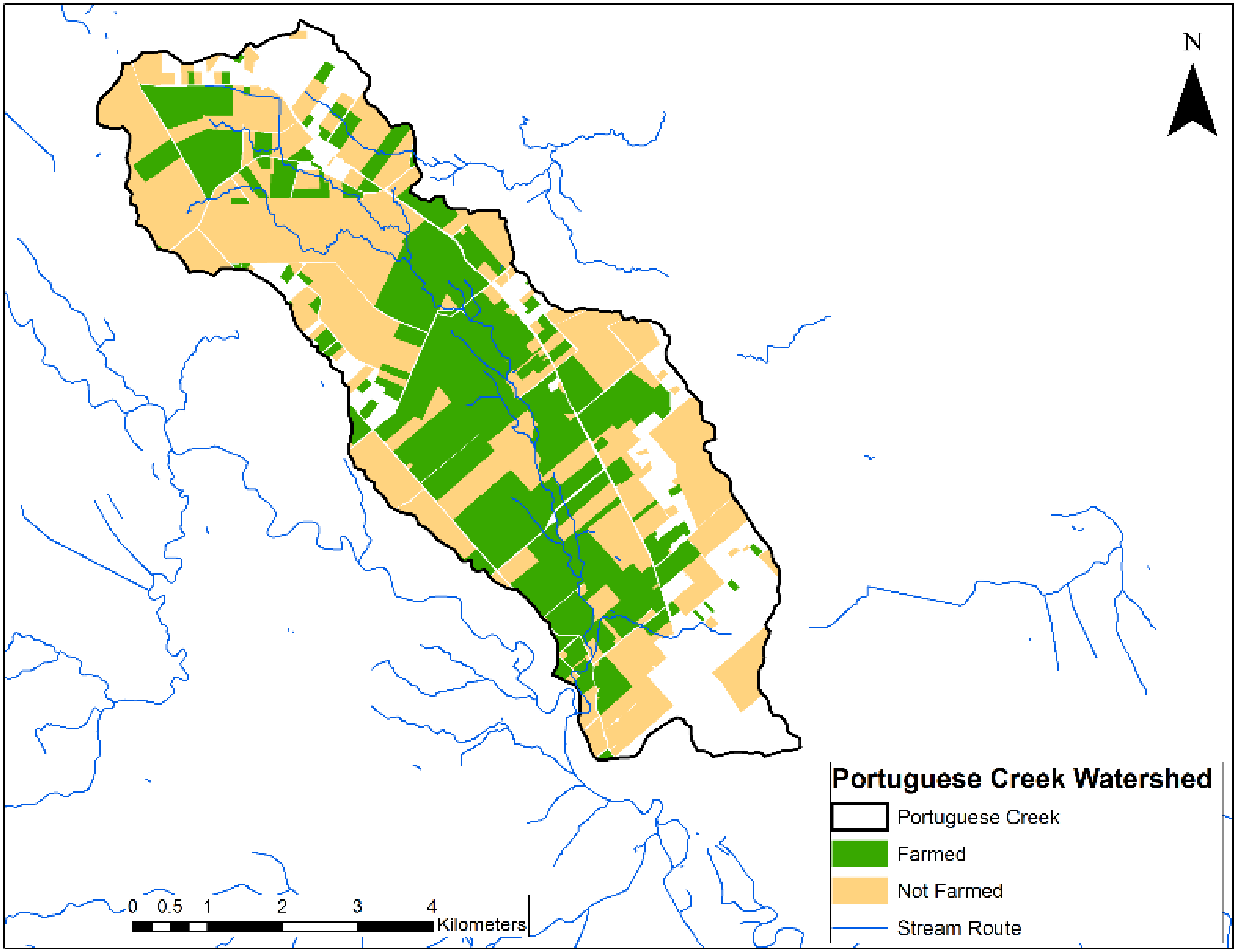

Figure 2: Map of Portuguese watersheds showing agricultural land use (BC Ministry of Agriculture, 2013).

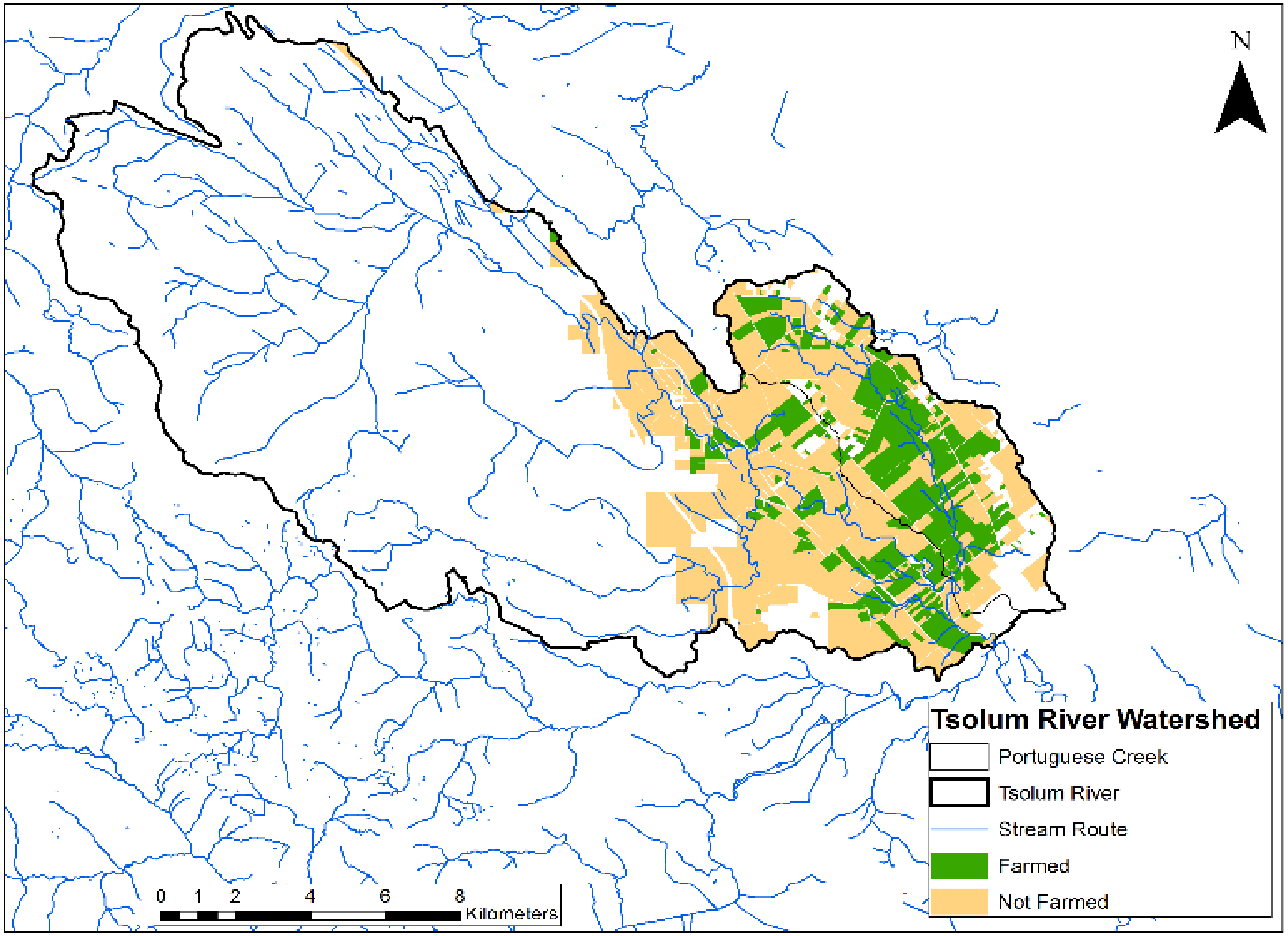

Figure 3: Map of Tsolum watershed (including Portuguese Creek watershed) showing agricultural land use (BC Ministry of Agriculture, 2013). Note unshaded areas do not have ALUI data.

5. STUDY DETAILS

Four water quality monitoring sites were selected in the lower Tsolum River and three sites were selected in Portuguese Creek, a tributary to the Tsolum River (Table 3, Figure 4). In the Tsolum River, one site was selected to provide information on water quality upstream of most agricultural operations (E277272). Two sites in the Tsolum River, approximately 680m above and 1500m below the confluence of Portuguese Creek (E315790 and E280016), were selected to determine impacts from Portuguese Creek. The fourth site in the Tsolum River above the confluence with the Courtenay River (E315791) was intended to capture the state of water quality from the entire study area (Figure 4). Upper, middle and lower creek sites were chosen in Portuguese Creek (E315792, E315793, and E315794). The sites in Portuguese Creek serve to reflect potential impacts from the agriculture that occurs throughout most of the watershed.

Discrete (or grab) water samples were collected by ENV and the Tsolum River Restoration Society in accordance with the *B.C. Field Sampling Manual* (MOE, 2013) and the B.C. Ministry of Environment, Lands and Parks *Freshwater Biological Sampling Manual* (Cavanagh, Nordin, & Warrington, 1996). Water samples were collected in laboratory-supplied sample bottles, packed on ice and shipped within appropriate hold times to ALS Laboratories in Vancouver. Water samples analyzed in a laboratory were turbidity, phosphorus, nitrate and *Escherichia coli.* Parameters collected *in situ* using a hand-held YSI metre included pH, temperature, specific conductivity and dissolved oxygen (DO).

Samples were collected at a frequency of five weekly samples in 30 days (5-in-30s) for the periods between March 28th and April 29th, 2019 and between October 9th and November 6th, 2019. The period between March and April covered the time when most farmers spread manure on their land, while the period between October and November was intended to cover fall flush events. 5-in-30 sampling allows for comparison of turbidity and *E. coli* results to the applicable Tsolum River WQOs (Phippen, 2012) (Table 4). For parameters not included in the WQOs (nitrate and DO), data were compared to BC WQGs. Monthly samples for total phosphorus were collected between May 21st and September 24th to enable comparison to the phosphorus guidance for Vancouver Island streams (MOE, 2014).

Table 3: Tsolum River and Portuguese Creek 2019 sample site coordinates.

EMS ID	Description	Latitude/Longitude
E277272	Tsolum River D/S McEachren Bridge	49.7556 N, 125.1044W
E315790	Tsolum River U/S Portuguese Creek	49°42'53.10"N, 125° 1'6.82"W
E280016	Tsolum Near Courtenay	49.707220 N, 125.011390 W
E315791	Tsolum River U/S of Puntledge River Connection	49°42'0.65"N, 124°59'51.17"W
E315792	Portuguese Creek at Smith Road Bridge	49°45'51.12"N, 125° 1'58.44"W
E315793	Portuguese Creek at Bridges Road Bridge	49°44'21.52"N, 125° 0'57.24"W
E315794	Portuguese Creek U/S of Tsolum River	49°43'15.96"N, 125° 0'33.16"W

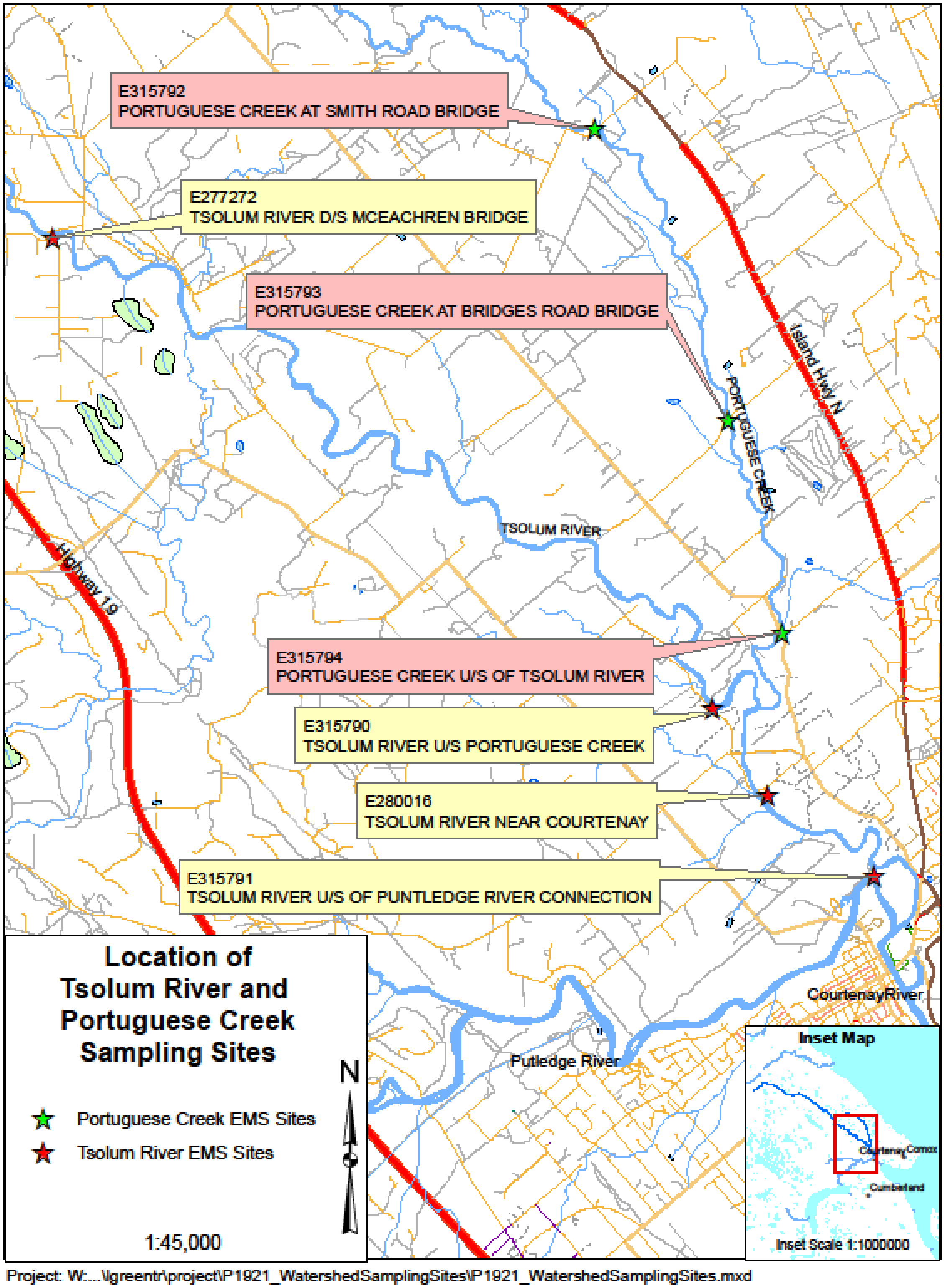

Figure 4: Location of 2019 water quality sampling sites within the lower Tsolum River and Portuguese Creek watersheds.

Table 4: Applicable Water Quality Objectives for the Tsolum River watershed (Phippen, 2012).

Variable	Objective Value
Turbidity	October to December: 5 NTU maximum January to September: 2 NTU maximum
Temperature	≤16°C weekly average
Escherichia coli	October to November: ≤ 10 CFU/100mL 90th percentile December to September: ≤ 22 CFU/100mL 90th percentile

5.1 Quality Assurance / Quality Control

Quality assurance and quality control was verified by collecting duplicate samples. Duplicate (or triplicate) co-located samples are collected by filling two (or three) sample bottles in as close to the same time period as possible (one right after the other) at a monitoring location, and then calculating the percent difference between the laboratory results reported for the various samples. The maximum acceptable percentage differences between duplicate samples is 25%. However, this interpretation only holds true if the results are at least ten times the detectable limits for a given parameter, as the accuracy of a result close to the detectable limit shows more variability than results well above detectable limits. As well, some parameters (notably bacteriological indicators) are not homogeneous throughout the water column and therefore it is expected to see a higher degree of variability between replicate samples.

Twenty-eight sets of replicate samples were collected during the sampling program (four at E277272, four at E315790, three at E280016, four at E315791, six at E315792, five at E315793, and two at E315794). In 96% (27 of 28) of replicate samples, percent mean differences were found to be within acceptable limits as discussed above. Based on these samples, the data can be considered within acceptable limits for data quality.

6. <u>RESULTS</u>

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 less than 7 is acidic (the lower the number, the more acidic the water) and a pH greater than 7 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). The effectiveness of chlorine as a disinfectant is reduced outside of this range. The water quality guideline for pH for the protection of aquatic life is no statistically significant change in pH when ambient pH is outside of the range of 6.5 to 9.0 pH units (McKean and Nagpal, 1991). Inside of this range, there is no restriction on change.

Lab and field pH collected on the same day varied considerably for some dates and sites, with field data often outside the expected range based on historical data. This indicated an issue with the field pH instrument, likely due to incorrect storage/operation. This issue was particularly prominent in data from E277272 and E315792, the first sites sampled by each sampling group in each round of sampling. There were both lab and field pH data for 76 of 111 samples (68%). Percentage differences in 18.4% of these duplicates were greater than the acceptable limit of 25% (Appendix A, Table 9Table 9). As a result, no field data were further considered for comparison to the water quality guideline.

Based on laboratory data only, pH in the Tsolum River Ranged from 7.08 to 7.68, and in Portuguese Creek from 7.24 to 8.11 (Table 5). Generally, pH was highest in the summer months. All laboratory pH values were inside the WQG range.

Table 5: Lab analysis pH sampling results in the Tsolum River (E277272, E280016, E315790, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) during the period March 28th to November 6th, 2019. Sites are arranged upstream to downstream.

EMS ID	Average of lab pH	Number of samples
Tsolum River		
E277272	7.26	17
E315790	7.35	16
E280016	7.36	16
E315791	7.37	19
Portuguese Creek		
E315792	7.62	16
E315793	7.77	18
E315794	7.81	18
Grand Total	**7.51**	**120**

6.2 Temperature

Water temperature alters the solubility of water for oxygen and other gasses, pH, and conductivity; and the metabolic rates of aquatic organisms. Lower water temperatures allow for higher DO concentrations (Oliver and Fidler, 2001). The WQO for temperature in the Tsolum River and surrounding area is a weekly average of ≤16°C to protect fish species that are present (Phippin, 2012). As samples in this report were only taken weekly and monthly, the weekly averages could not be calculated. However, any recorded temperatures that are higher than the WQO demonstrate that there may be potential for an exceedance of the WQO.

Temperatures recorded had the potential to exceed the WQO in the period between May and August at all sites except E315793 and E315794, the two lower sites on Portuguese Creek (Figure 5), which likely have groundwater contributions (see section 6.3 Conductivity) lowering surface water temperatures. Temperatures ranged from 2.43°C at E315794 in October to 20.9°C at E315791 in June. There were low discharge rates in the Tsolum River during the summer for the study period which is common for this system. The Tsolum River is wide and during low summer flows the water depth is typically low leading to increased temperature. The one site that had the potential to exceed WQOs for Portuguese Creek was E315792, which had little riparian cover within 200m upstream of the site. The WQO report for the Tsolum River states that maximum temperatures in the lower portion of the river may exceed the WQO, and that as long as refuges remain with average temperatures below the guideline, juvenile fish should be able to retreat to these areas during periods of elevated temperatures (Phippen, 2012).

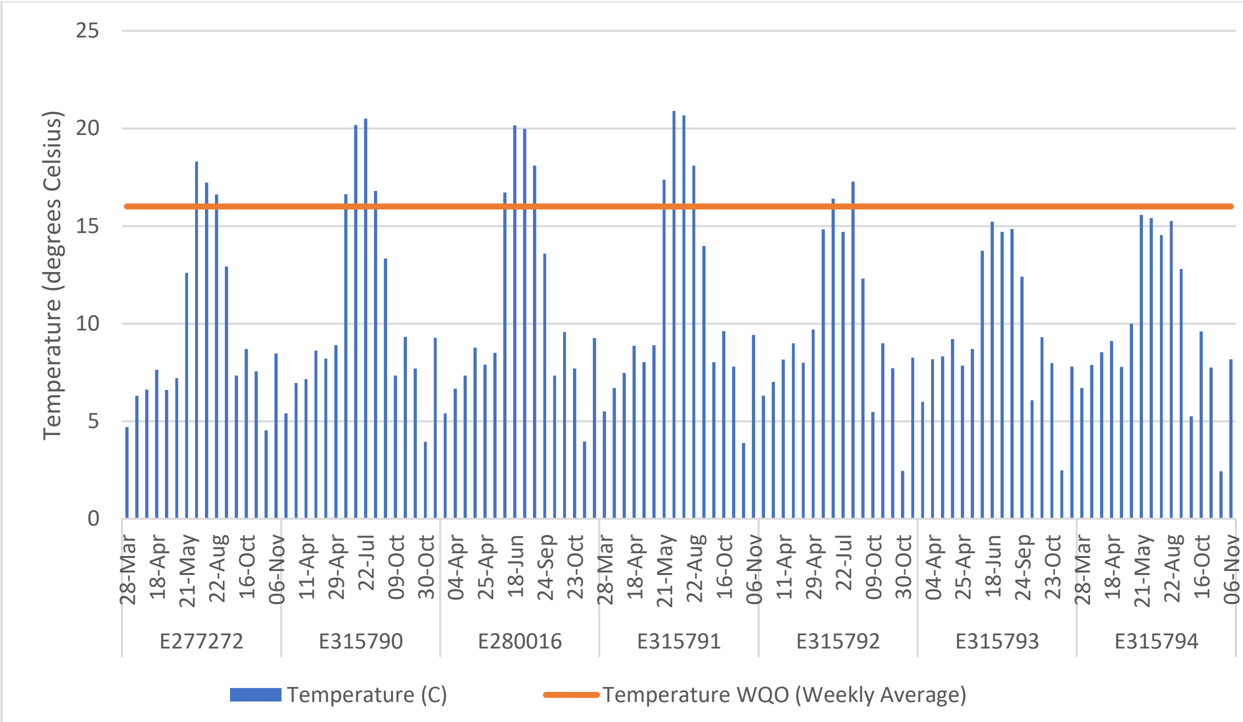

Figure 5: Summary of individual temperature measurements at sites in the lower Tsolum River (E277272, E315790, E280016 and E315791) and in Portuguese Creek (E315792, E315793, and E315794) during the period March 28th to November 6th, 2019. The temperature WQO is included for reference.

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 1^{o}C increase in temperature results in approximately a 2% increase in conductivity), specific conductance is used (rather than simply conductivity) as it is corrected to 25^{o}C (Phippen, 2012). Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 µS/cm), while interior watersheds generally have higher values (Phippen, 2012). Increased flows resulting from precipitation events or snowmelt tends to dilute the ions, resulting in decreased specific conductivity levels with increased flow levels.

The Tsolum River had low specific conductance, averaging between 35.79 µS/cm and 45.76 µS/cm across all sites, while the maximum value was 58 µS/cm (Table 6). Portuguese Creek had higher specific conductance with values averaging between 125.93 µS/cm and 145.23 µS/cm, and maximum values in the summer of 193 µS/cm to 244 µS/cm (Table 6). Portuguese Creek is the low point above the Quadra Sand Aquifer (Aquifer #408), and there are flowing wells/springs above the creek (CVRD, 2019); thus, there is likely groundwater influence in the creek, which would be more prominent during lower summer flows. Turbidity (see Turbidity section below) results support that higher conductivity levels in Portuguese creek are also influenced by particulates in the water. Across all sites, specific conductance decreased with increased discharge rate in the Tsolum River.

Table 6: Summary of specific conductance sampling results in the lower Tsolum River (E277272, E280016, E315790, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) during the period March 28th to November 6th, 2019.

EMS Site	Average of Specific Conductance (uS/cm)	Max of Specific Conductance (uS/cm)	Min of Specific Conductance (uS/cm)	Number of samples
Tsolum River				
E277272	35.79	45	28	17
E315790	40.68	52	30.4	18
E280016	43.67	58	33.8	19
E315791	45.76	58	34.6	19
Portuguese Creek				
E315792	125.93	193	96	22
E315793	145.23	244	28.3	22
E315794	142.40	229	11.7	22

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 (Caux *et al*., 1997). To protect drinking water quality in the Tsolum River, the WQOs are: between October to December (when turbid flows can occur), turbidity should not exceed 5 NTU; and, during the remainder of the year (clear flow periods), turbidity should not exceed 2 NTU (1 NTU above ambient levels) (Phippen, 2012).

Turbidity values ranged from a low of 0.32 to 0.93 NTU at all seven sites to a high of between 6.08 NTU at E315793 to 15.1 NTU at E315792 (Figure 6). Maximum values for sites in the Tsolum River, including those from April 4th when the 2 NTU WQO was exceeded and from Oct 16th where the 5 NTU WQO was exceeded, were associated with high discharge (rainfall) events (Figure 7A). Values were generally lowest at site E277272, where less agriculture and development occur. Contrastingly, most maximum turbidity values in Portuguese Creek were not associated with high flows (Fig 7B), and instead occurred in the summer during low flows. Of the 16 samples collected at the Portuguese Creek sites, exceedances of the 2 NTU WQO occurred in eight to ten samples, depending on the site, while the 5 NTU WQO was exceeded only once on Oct 16th at E315794 (associated with a rainfall event).

Residential and rural development is associated with many potential sources of increased turbidity in watersheds including land disturbance, rainwater runoff, and, during low summer flows, nutrient-induced algal growth. While nutrients in residential areas are usually associated with lawn/garden fertilization, rural areas used for agriculture have several additional potential sources including animal wastes, crop fertilization and septic fields. In addition, land used for agriculture typically has reduced riparian vegetation and altered drainage patterns. The top site on Portuguese Creek has very little riparian vegetation in an area approximately 200m upstream of the sampling site. As turbidity is highest at the top site in Portuguese Creek and lower at downstream sites, higher nutrients are the most likely cause of the high turbidity. This is supported by high phosphorus concentrations in Portuguese Creek (see section 6.5 below).

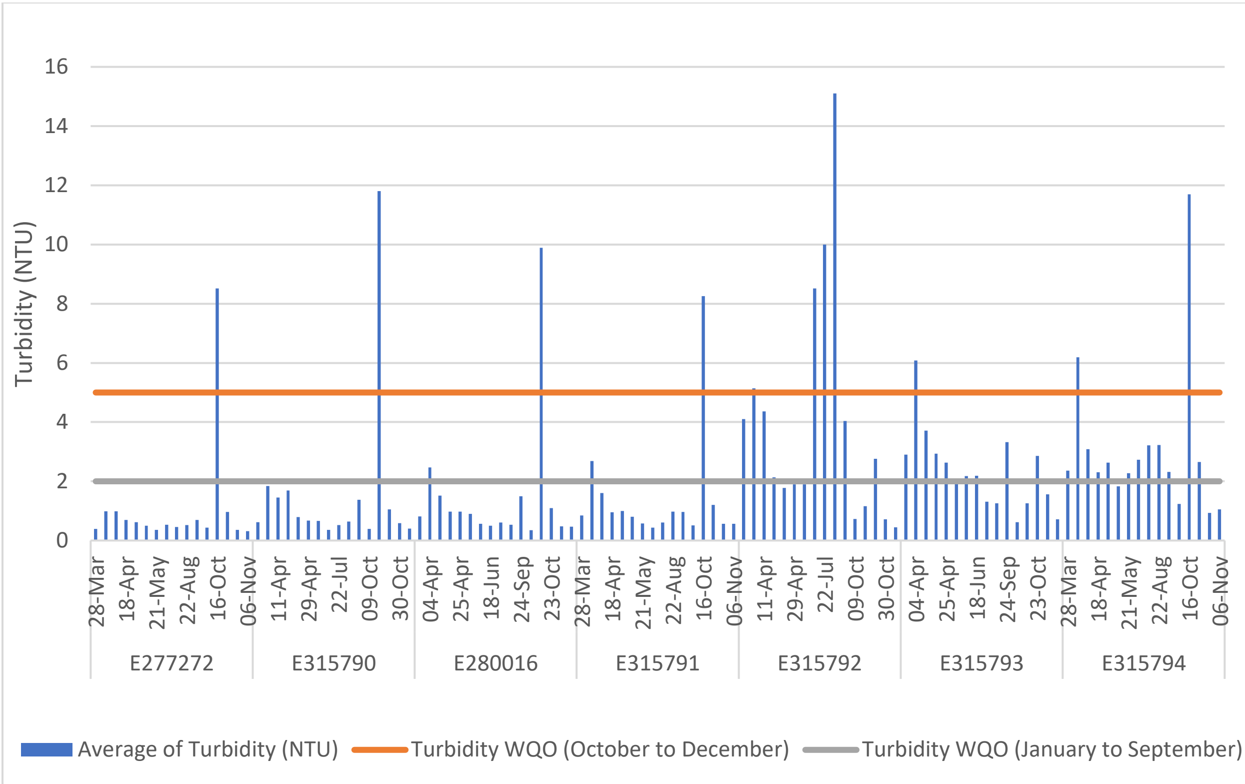

Figure 6: Summary of turbidity at sites in the lower Tsolum River (E277272, E315790, E280016, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) during the period March 28th to November 6th, 2019. WQO are included for the period October to December and the period January to September.

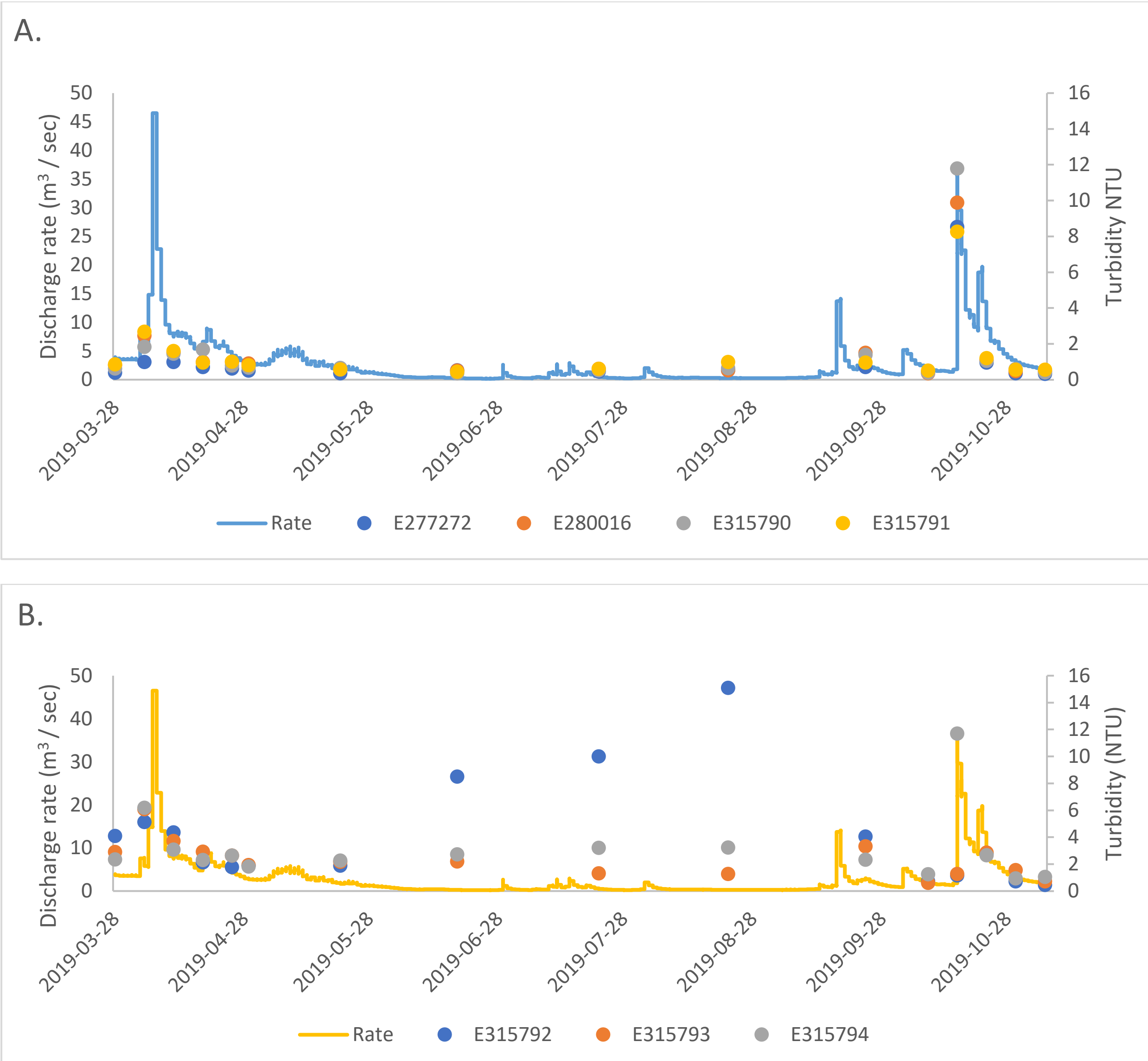

Figure 7: Summary of turbidity compared to discharge rate in the Tsolum River at sites in the lower Tsolum River (A) and in Portuguese Creek (B) during the period March 28th to November 6th, 2019.

6.5 Phosphorus

Phosphorus is usually the limiting factor in freshwater aquatic systems. Phosphorus is essential to primary productivity in streams, but levels even slightly higher than background can cause excessive algal growth and many associated impacts to the health of streams and their resources. In watersheds where drinking water is a priority, it is desirable that nutrient levels 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 (MOE, 2014).

Rainwater runoff and groundwater inflow from land development, agriculture (fertilizer and/or animal wastes), failing septic fields and treated sewage effluent discharges are leading sources of phosphorus in urban and rural residentially developed areas. The high rate of population growth on Vancouver Island and very low summer stream flows make streams extremely sensitive to phosphorus pollution, thus it is vital to manage phosphorus inputs into streams (MOE, 2014). To address this challenge, a Vancouver Island phosphorus guidance document was developed to protect Vancouver Island streams using area specific data, with the intent of limiting and preventing excessive nutrient input and subsequent environmental impact (MOE, 2014). This document specifies that the May to September total phosphorus average, with samples collected monthly, should not exceed 5 µg/L, and maximum total phosphorus should not exceed 10 µg/L in any one sample.

In the Tsolum River, total phosphorus (TP) concentrations ranged from 2.9 µg/L to 89.3 µg/L (Figure 8). Monthly May – September average TP values in the Tsolum River just exceeded the recommended value of 5 µg/L (Figure 9) (5.14 µg/L for E277272, 5.08 µg/L for E315790 (upstream of Portuguese Creek), and 5.14 for E280016 (downstream of Portuguese Creek)) except for site E315791 that had an average of 4.76 µg/L. All individual higher values were associated with rainfall events during the fall flush period from October to November (maximum TP value of 10 µg/L not applicable at this time) (Figure 10A), and therefore are not a concern.

In Portuguese Creek, TP values ranged from 15.1 µg/L to 381 µg/L, all higher than the recommended maximum of 10 µg/L (applicable only May-September) (Figure 10). The highest concentrations were found at E315792 in July and August and were not associated with any rainfall events. The only peak TP sample associated with a rainfall event for Portuguese Creek was for E315793 on October 30th, 2019, and all other peaks were during dry periods (Figure 10B). Peaks during low flows may be because water is evaporated, creating higher concentrations, or due to irrigation flushing excess fertilizer and nutrients into the creek, or both. Monthly May-September average values for sites on Portuguese Creek were 211.68 µg/L for E315792, 62.22 µg/L for E315793, and 37.76 µg/L for E315794 (Figure 9). These exceedances are substantial and can contribute to excessive algal growth that can lead to significant negative impacts on the water quality of the creek, as well as being a source of phosphorus loading to the Tsolum River.

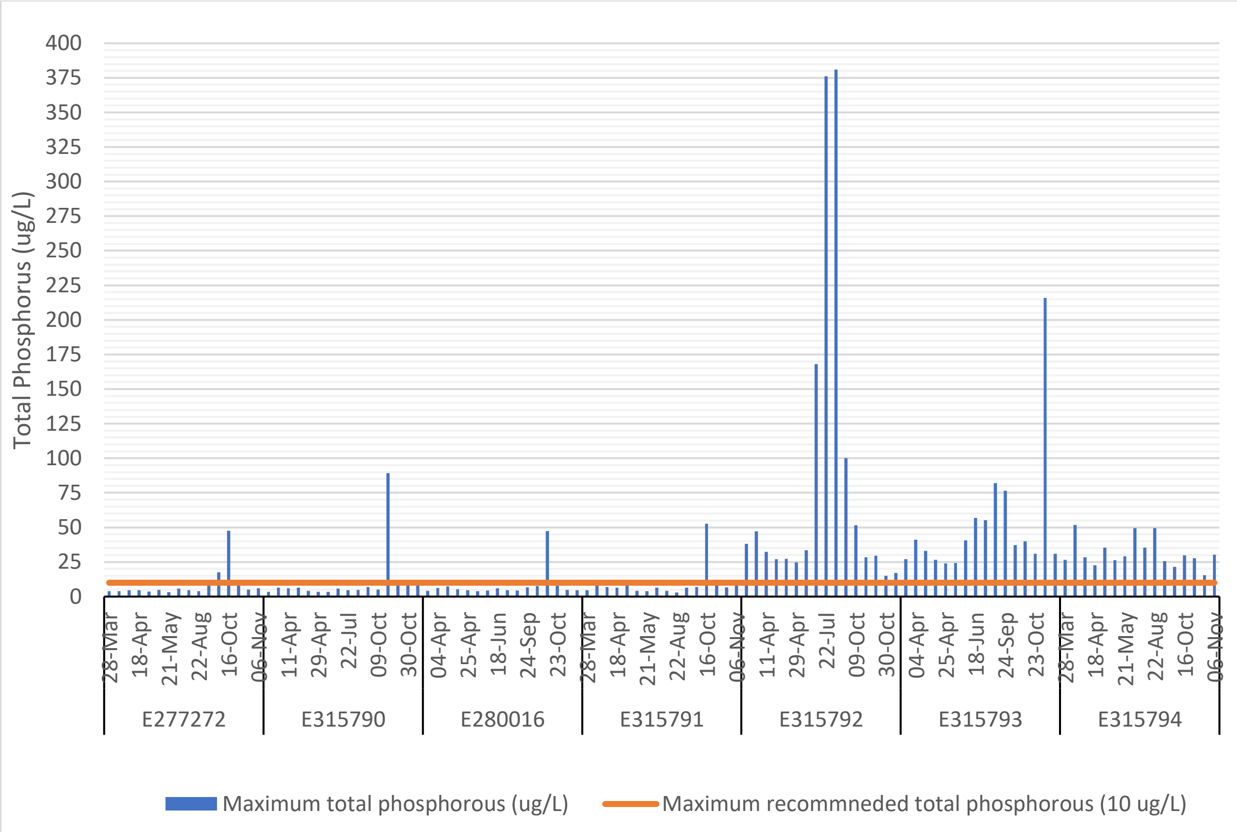

Figure 8: Summary of individual phosphorus (P) samples in the lower Tsolum River (E277272, E315790, E280016, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) during the period March 28th to November 6th, 2019. The Maximum recommended value of 10 µg/L (applicable May through September only) is included.

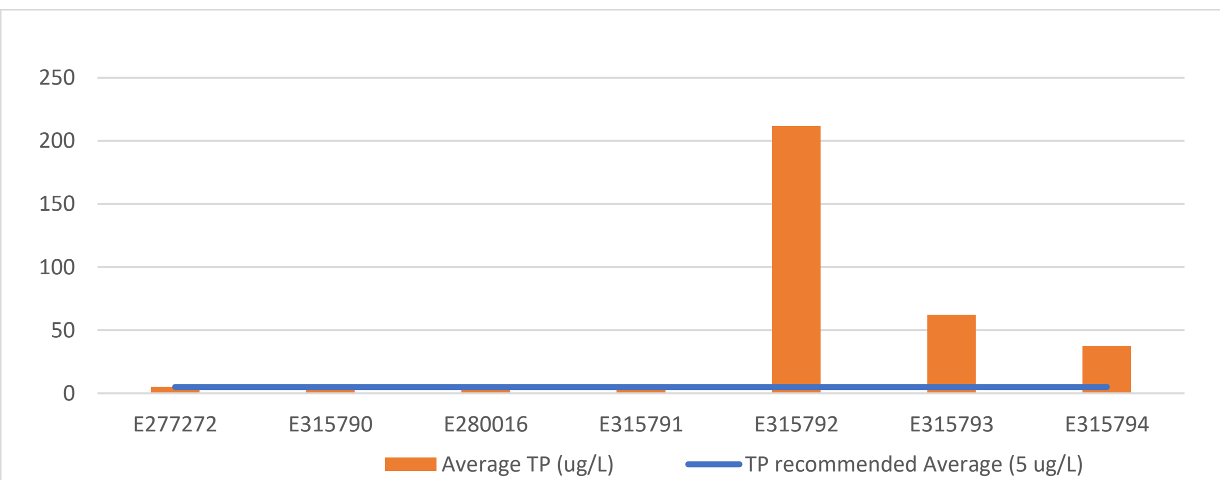

Figure 9: Average total phosphorus from May to September with samples collected monthly in the lower Tsolum River (E277272, E280016, E315790, and E315791) and in Portuguese Creek (E315792, E315793, and E315794). The average recommended value of 5 µg/L for monthly samples between May and September is included.

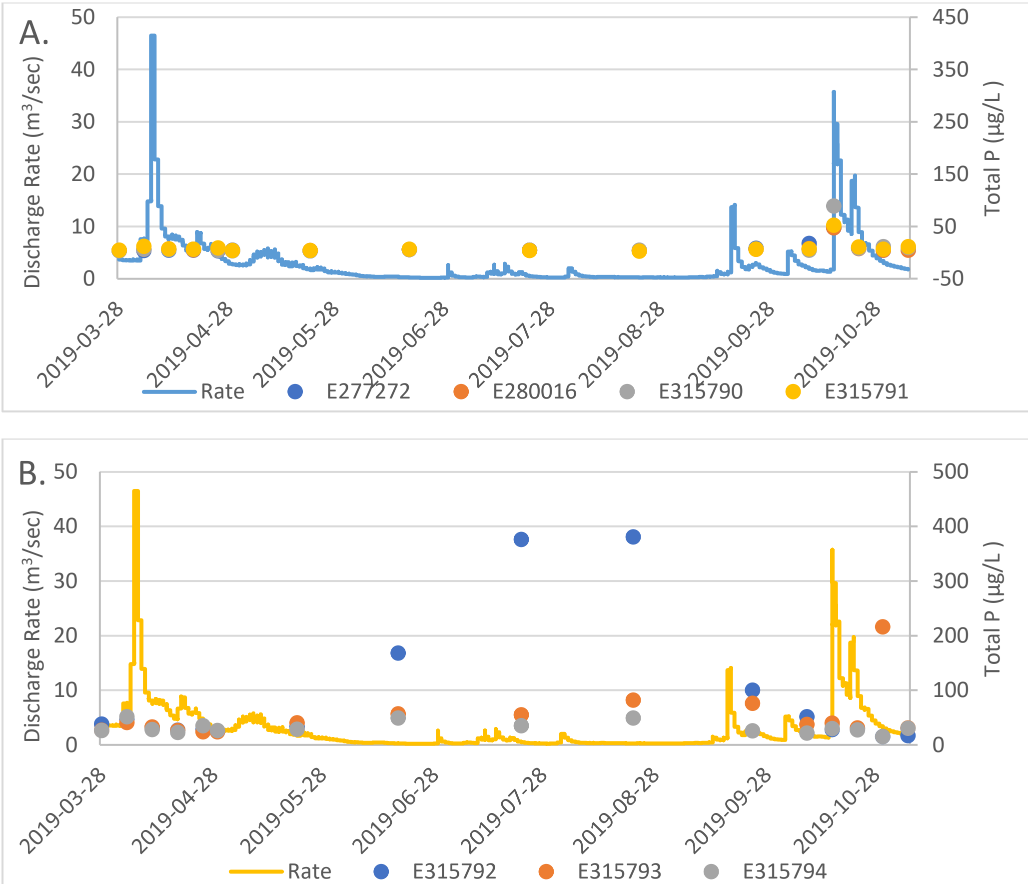

Figure 10: Individual total phosphorus (P) samples in the lower Tsolum River (E277272, E315790, E280016, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) compared to discharge rates in the Tsolum River (Hydrometric Station o8HB011) during the period March 28th to November 6th, 2019.

6.6 Nitrate

Nitrogen levels were measured as dissolved nitrate (NO_3). For the protection of aquatic life, the BC WQG for dissolved nitrate is a maximum concentration of 32.8 mg/L and an average concentration of 3.0 mg/L (Meays, 2009).

Nitrate concentrations were low relative to WQGs at all sites but were relatively higher in Portuguese Creek than in the Tsolum River (Table 7). Fall averages for 5-in-30 sampling were higher than spring averages in the Tsolum River, while spring averages were higher than fall averages in Portuguese Creek.

Nitrate levels in the Tsolum River were elevated downstream of Portuguese Creek (E280016) compared to upstream (E315790) (Table 7). This difference between upper and lower sites was greater in the spring sampling period than the fall period. Relatively increased levels in Portuguese Creek likely demonstrate agricultural impact and will be important to monitor as the *AEM Code* comes into force.

Table 7: Summary of dissolved nitrate concentrations measured in the lower Tsolum River (E277272, E280016, E315790, and E315791) and in Portuguese Creek (E315792, E315793, and E315794). Maximum and minimum values were from the period March 28 to November 6, 2019 and contained 16 samples. Spring 5-in-30 sampling was from the period March 28 to April 29, 2019 and fall 5-in-30 sampling was from the period October 9, to November 6, 2019.

EMS Site:	Max of Dissolved NO_3 (mg/L)	Min of Dissolved NO_3 (mg/L)	Spring NO_3 5-in-30 Average	Fall NO_3 5-in-30 Average
	WQG: < 32.8 mg/L		**WQG: < 3.0 mg/L**	
Tsolum River:				
E277272	0.10	0.007	0.031	0.064
E315790	0.11	< 0.003	0.032	0.072
E280016	0.12	0.007	0.054	0.080
E315791	0.12	0.008	0.058	0.069
Portuguese Creek:				
E315792	0.68	< 0.003	0.099	0.161
E315793	1.00	< 0.003	0.470	0.344
E315794	0.97	< 0.003	0.424	0.241

6.7 Dissolved Oxygen

Oxygen is the single most important component of surface water for self-purification processes and the maintenance of aquatic organisms which utilize aerobic respiration (MOE, 1997). The WQG for dissolved oxygen (DO) is expressed as an instantaneous minimum value of 5 mg/L O_2, and a 5-in-30 mean of 8 mg/L O_2. The dissolved oxygen concentration in water is directly related to water temperature, where cooler waters have higher concentrations of oxygen than warmer waters.

DO concentrations ranged from 7.8 mg/L to 16.2mg/L in the Tsolum River, and from 2.72 mg/L to 13.82 mg/L in Portuguese Creek (Figure 11). Only the uppermost site on Portuguese Creek (E315792) had recorded values that were below the WQG, and at this site DO concentrations were below the WQG for all July to September data points.

The low DO at E315792 does not appear to be due to high temperatures, because temperatures were higher at all Tsolum River sites. However, turbidity and P were both highest at this site and suggest excessive algal growth may be responsible. The timing of the algal growth correlates with the low DO and, therefore, is the likely cause of the low levels. All the above parameters were likely exacerbated by low summer flows.

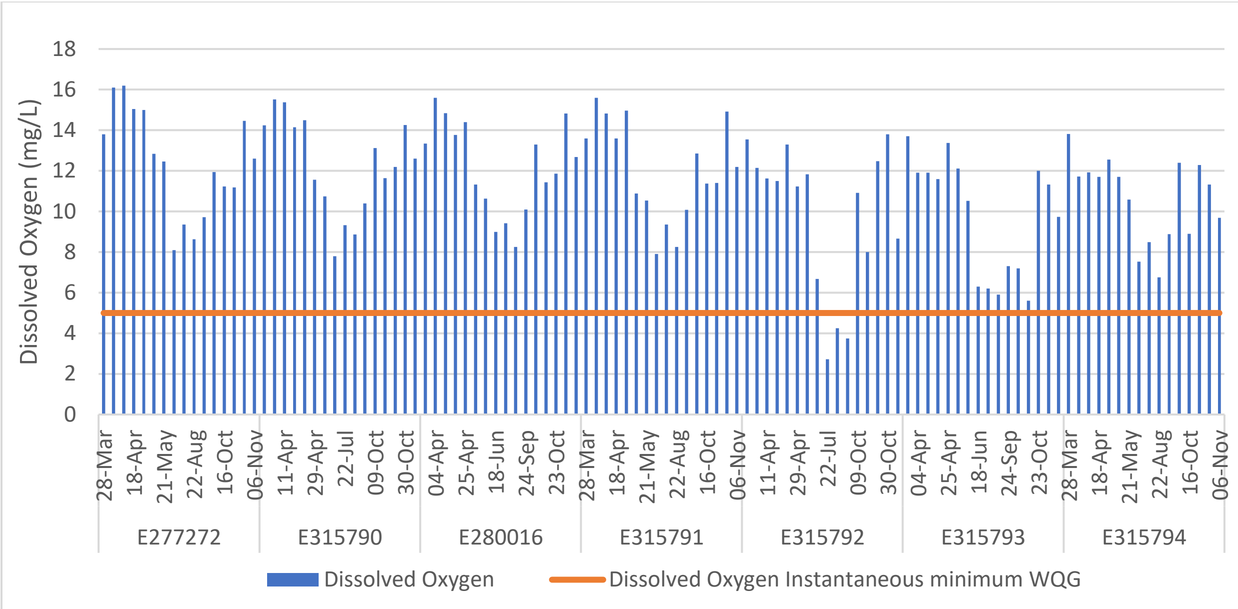

Figure 11: Summary of individual dissolved oxygen samples measured in the lower Tsolum River (E277272, E315790, E280016, and E315791) and in Portuguese Creek (E315792, E315793, and E315794) between March 28 and Nov 6, 2019.

6.8 Microbiological Indicators – *E. coli*

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). Studies have shown that *Escherichia coli* is the main thermo-tolerant coliform species present in fecal samples (94%) of humans and other endotherms such as birds and mammals, (Tallon *et al*., 2005), and at contaminated bathing beaches (80%) (Davis *et al.*, 2005). The BC-approved water quality guidelines for microbiological indicators were developed in 1988 (Warrington, 1988) and include *E. coli*, enterococci; portions of these guidelines have been rescinded (ENV, 2020a) and replaced with summary documents for recreational and drinking water guidelines (ENV, 2019; ENV, 2020b). 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 seasonally adjusted Tsolum River WQO, to protect drinking water and irrigation sources, is that the 90th percentile of a minimum of 5-in-30 sampling from October to November (to capture the first fall flush) must not exceed 10 CFU/100 mL for *E. coli*. For the remainder of the year, the 90th percentile of a minimum of five weekly samples collected within a 30-day period (sampling should occur during July-September to capture low flow conditions) must not exceed 22 CFU/100mL.

Lab hold times were exceeded for samples collected on April 18th, 2019 and therefore samples were not analyzed. To allow for results to still be comparable to the WQOs, which require 5-in-30 sampling, another round of sampling was conducted on April 29th, 2019.

In the Tsolum River, individual *E. coli* concentrations ranged from lower than detection limits (1 CFU/100mL) to 1400 CFU/100mL at E277272, the reference site (Table 8). The maximum values all occurred during the fall flush period in October. *E. coli* spring sampling 90th percentiles (based on 5-in-30 sampling) ranged from 8.00 CFU/100mL at E277272 to 90.60 CFU/100mL at E315791. This pattern was reversed in the fall samples, where the lowest 90th percentile was at E315791 and the highest was at E277272. All sites were above the WQO for fall, and E280016 and E315791 were above the WQO for spring. None of the sites exceeded the B.C. WQG for recreation (200 CFU/100mL, based on geometric mean of 5-in-30 sampling, ENV (2019)).

Individual samples collected from Portuguese Creek ranged from 3 CFU/100mL to 2200 CFU/100mL and tended to be highest in the summer (Table 8). In the spring period, 90th percentiles were highest at E315792, with 134.50 CFU/100mL, and were 88.80 CFU/100mL at both downstream sites. In the fall period, site E315794 had the highest 90th percentile at 655.60 CFU/100mL and E315793 had the lowest at 120.80 CFU/100mL. All sites exceeded the WQO for both spring and fall sampling. None of the sites exceeded the B.C. water quality guideline for recreation (200 CFU/200mL, based on geometric mean of 5-in-30 sampling, ENV (2019)).

Spring and summer *E.coli* levels appear to be driven by anthropogenic sources, as concentrations increased further downstream in the mainstem Tsolum River. During spring 5-in-30 sampling, *E. coli* levels in the Tsolum river above and below the confluence of Portuguese Creek (9.80 CFU/100mL at E280016 and 31.00 CFU/100mL at E280016) suggest that inputs from Portuguese Creek are having an impact on water quality in the Tsolum River, with agricultural operations as the likely source of *E. coli*. Agricultural operations in this portion of the watershed include beef and dairy farming. Other potential anthropogenic sources of *E. coli* in the study area include failing septic fields. Waterfowl present in the Tsolum River and in Portuguese Creek, and wildlife, especially in the upper watershed, could contribute to levels of *E. coli* observed in the fall in this study. Wildlife inputs can be higher in the fall when accumulated feces from dry periods are washed into watersheds.

E. coli levels observed in this report are of concern, as values were consistently over the WQO regardless of time of year. This highlights the need for water users to appropriately treat their water for domestic use. Microbial source tracking could be done in the future to help determine the sources of *E. coli* in the study area.

Table 8: Summary of E. coli concentrations (CFU/100mL) measured in the lower Tsolum River (E277272, E280016, E315790, and E315791) and in Portuguese Creek (E315792, E315793, and E315794). Maximum and minimum values were from the period March 28 to November 6, 2019 and contained 16 samples. Spring 5-in-30 sampling was from the period March 28 to April 29, 2019 and fall 5-in-30 sampling was from the period October 9, to November 6, 2019. Highlighted values exceed the WQO for the Tsolum River.

			90th Percentile		Geometric Mean	
EMS Site	**Min.**	**Max.**	**Spring**	**Fall**	**Spring**	**Fall**
Tsolum River						
E277272	<1	1400	8.00	864.40	2.19	35.17
E315790	3	910	9.80	555.60	10.58	29.97
E280016	<1	800	31.00	494.40	5.55	31.54
E315791	<1	360	90.60	242.80	14.82	46.88
Portuguese Creek						
E315792	4	1500	134.20	155.60	21.13	46.64
E315793	3	2200	88.80	120.80	36.61	28.93
E315794	10	1080	88.80	655.60	33.46	66.48

7. SUMMARY

Overall, the state of water quality is generally good in the lower Tsolum River and poor in Portuguese Creek. Water quality monitoring conducted between March and November 2019 in the Tsolum River demonstrated elevated turbidity levels for the fall flush period that exceeded WQOs and average total phosphorus for the May-September period that just exceeded guidance levels for three of four sites. In Portuguese Creek, turbidity showed elevated levels above WQO and total phosphorus showed levels above guidance level during the summer. Elevated turbidity and phosphorus levels suggest increased algal production and potential stress to aquatic organisms. Elevated *E. coli*, particularly in Portuguese Creek, were likely due to a combination of wildlife, agricultural and anthropogenic impacts and were above WQOs for six out of eight sampling events. In addition, slight seasonal increases were observed in total phosphorus, dissolved nitrate and *E. coli* in the Tsolum River downstream of Portuguese Creek, compared to upstream. The results suggest that agricultural activity is a large contributor to negative impacts in the study area, and that poor water quality in Portuguese Creek contributes to potential impacts in the lower Tsolum River.

The new *AEM Code* is anticipated to reduce contaminants from agricultural activities which should improve water quality across the province. As agriculture comprises a large proportion of the land use in the Tsolum River and Portuguese Creek watersheds, it is expected that, as the new code is applied and enforced, water quality will improve within the study area.

Sampling should be completed in the future, after all parts of the *AEM Code* come into force and have had enough time to improve conditions. This sampling will allow for an effectiveness review of the *AEM Code*. To determine the source of *E. coli* contamination, microbial source tracking should be conducted in the future. Future sampling could also include pesticides and herbicides to determine if these are having impacts in the watershed.

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APPENDIX A

Table 9: Comparison of ALS lab and field pH data including percent difference. Highlighted values show exceedances of the acceptable percentage difference (25%).

EMS ID	Row Labels	ALS pH	Field pH	Percent Difference (%)
E277272	28-Mar	7.05		
	04-Apr	7.09		
	11-Apr	7.2		
	18-Apr	7.17		
	25-Apr	7.54		
	29-Apr	7.16	6.35	11.99
	21-May	7.19	2.82	87.31
	18-Jun	7.52		0.00
	22-Jul	7.36	3.93	60.76
	22-Aug	7.47	5.98	22.16
	24-Sep	7.34	6.82	7.34
	09-Oct	7.3	6.32	14.39
	16-Oct	7.26	4.31	50.99
	23-Oct	7.12	5.69	22.33
	30-Oct	7.17	5	35.66
	06-Nov	7.32	5.28	32.38
E280016	28-Mar	7.28		
	04-Apr	7.2		
	11-Apr	7.49		
	18-Apr	7.27		
	25-Apr	7.58		
	29-Apr	7.34	7.06	3.89
	21-May	7.32	6.82	7.07
	18-Jun	7.37	6.51	12.39
	22-Jul	7.38	6.55	11.92
	22-Aug	7.56	6.25	18.97
	24-Sep	7.42	6.88	7.55
	09-Oct	7.39	6.23	17.03
	16-Oct	7.4	6.24	17.01
	23-Oct	7.19	6.7	7.06
	30-Oct	7.2	6.35	12.55
	06-Nov	7.3	6.07	18.40
E315790	28-Mar	7.47		
	04-Apr	7.08		
	11-Apr	7.3		
	18-Apr	7.22		
	25-Apr	7.58		
	29-Apr	7.29	7.14	2.08
	21-May	7.29	6.55	10.69
	18-Jun	7.39	6.82	8.02
	22-Jul	7.44	6.67	10.91
	22-Aug	7.59	6.28	18.89
	24-Sep	7.36	6.94	5.87
	09-Oct	7.29	6.37	13.47
	16-Oct	7.35	5.8	23.57
	23-Oct	7.22	6.65	8.22
	30-Oct	7.28	6.14	16.99
	06-Nov	7.4	5.88	22.89

EMS ID	Row Labels	ALS pH	Field pH	Percent Difference (%)
E315791	28-Mar	7.18		
	04-Apr	7.14		
	11-Apr	7.47		
	18-Apr	7.25		
	25-Apr	7.61		
	29-Apr	7.36	6.98	5.30
	21-May	7.35	6.78	8.07
	18-Jun	7.4	6.56	12.03
	22-Jul	7.41	6.21	17.62
	22-Aug	7.68	6.25	20.53
	24-Sep	7.36	6.71	9.24
	09-Oct	7.31	6.18	16.75
	16-Oct	7.39	6.16	18.15
	23-Oct	7.16	6.47	10.12
	30-Oct	7.2	6.25	14.13
	06-Nov	7.31	6.08	18.37
E315792	28-Mar	7.7		
	04-Apr	7.61		
	11-Apr	7.74		
	18-Apr	7.57		
	25-Apr	7.7		
	29-Apr	7.77	7.31	6.10
	21-May	7.84	7.12	9.63
	18-Jun	7.9	5.77	31.16
	22-Jul	7.45	4.09	58.23
	22-Aug	7.35	6.18	17.29
	24-Sep	7.49	5.2	36.09
	09-Oct		6.54	
	16-Oct	7.83	6.44	19.48
	23-Oct	7.24	3.74	63.75
	30-Oct	7.27	6.25	15.09
	06-Nov	7.5	6.5	14.29
E315793	28-Mar	7.73		
	04-Apr	7.69		
	11-Apr	7.84		
	18-Apr	7.84		
	25-Apr	7.8		
	29-Apr	7.83	7.45	4.97
	21-May	7.88	7.27	8.05
	18-Jun	8.07	5.95	30.24
	22-Jul	7.81	6.04	25.56
	22-Aug	7.88	6.58	17.98
	24-Sep	7.98	6.05	27.51
	09-Oct	7.94	6.82	15.18
	16-Oct	8.01	7.02	13.17
	23-Oct	7.37	5.29	32.86
	30-Oct	7.48	7.06	5.78
	06-Nov	7.57	6.69	12.34

EMS ID	Row Labels	ALS pH	Field pH	Percent Difference (%)
E315794	28-Mar	7.75		
	04-Apr	7.66		
	11-Apr	7.95		
	18-Apr	7.75		
	25-Apr	7.97		
	29-Apr	7.88	7.65	2.96
	21-May	7.98	7.37	7.95
	18-Jun	8.11	6.8	17.57
	22-Jul	7.92	6.24	23.73
	22-Aug	8.06	6.9	15.51
	24-Sep	7.87	6.3	22.16
	09-Oct	7.88	6.65	16.93
	16-Oct	7.86	7.04	11.01
	23-Oct	7.4	5.35	32.16
	30-Oct	7.36	7.03	4.59
	06-Nov	7.61	6.98	8.64
Count:		111	76	14.00