Surface Water Quality Trend Analysis for Regional District of Nanaimo Community Watershed Monitoring Network Data (2011-2017)

Prepared For:

Regional District of Nanaimo

Prepared By:

Ecoscape Environmental Consultants Ltd.

July 2018

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Prepared For:
Regional District of Nanaimo
Regional and Community Utilities
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ACRONYMS AND ABBREVIATIONS

~	Approximately
BCCF	BC Conservation Foundation
B-IBI$_{10\text{-}50}$	Benthic Index of Biological Integrity
cm	centimeter
CABIN	Canadian Aquatic Biomonitoring Network
CWMN	Community Watershed Monitoring Network
CART	Classification and Regression Tree
D/S	downstream
D8	Deterministic-8
DEM	Digital Elevation Model
DO	dissolved oxygen
DRA	Digital Road Atlas
km	kilometer
L	litre
m	metre
m.a.s.l.	metres above sea level
mg	milligrams
µs	microsiemens
MoE	Ministry of Environment
MSE	Mean Squared Error
n	sample size
NTU	Nephelometric Turbidity Unit
QA/QC	Quality assurance, quality control
r	Spearman's rank correlation coefficient
R^2	Coefficient of Variation
RDN	Regional District of Nanaimo
SAGA	System for Automated Geoscientific Analyses
SD	Standard Deviation
tau	Kendall's tau coefficient
U/S	upstream

SUGGESTED CITATION

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EXECUTIVE SUMMARY

The Regional District of Nanaimo (RDN) and the British Columbia Ministry of Environment (MoE) started the Community Watershed Monitoring Network (CWMN) program in 2011 with the long-term goal of identifying trends in water quality to assist in regional land use planning and restoration decisions. The CWMN program consists of annual sampling in both the summer low flow period (August – September) and fall flush period (October – November) and has been conducted from 2011 to present, with some sites added or removed during that period. The program includes sampling of dissolved oxygen, temperature, turbidity and specific conductivity at 73 sites; as of 2018 there are 62 active sites. This sampling is done by trained volunteers from 13 stewardship groups in partnership with RDN, BC MoE, and Island Timberlands. These co-ordinated efforts have resulted in an excellent database that supported the statistical analysis presented in this report.

Ecoscape analyzed the 2011-2017 data using:

1. comparison to BC water quality Guidelines and Objectives to identify sites of concern,
2. trend analysis using seasonal Mann-Kendall to detect changes in water quality over time,
3. statistical modelling using Random Forest to determine if watershed characteristics and land uses affect water temperature, dissolved oxygen, conductivity and turbidity.

Forty-seven percent of the CWMN sampling sites had been sampled for at least six years in both summer and fall to allow a seasonal Mann-Kendall trend analysis to determine if a water quality parameter was stable, increasing, or decreasing in the fall and summer sample periods from 2011-2017. Twenty-seven of the 34 sites had stable water quality and changes over time were not observed. There were five sites that experienced increases in mean summer and fall turbidity from 2011-2017. The Cat Stream site in Water Region 5 experienced an increase in mean summer and fall conductivity from 2012-2017, whereas the Beach Creek site near Hemsworth had decreasing summer and fall conductivity from 2011-2017. Increasing water temperature at three sites and decreasing DO at two sites is probably associated with annual variations in air temperature.

All available CWMN data was examined to expose sites with water quality concerns. Sites with frequent exceedances of water quality guidelines or objectives, with depleted oxygen concentrations and/or with adverse trends in water quality over time were identified as sites of concern. Twelve sites of concern were identified of which seven sites have high agricultural use within the watershed, a land use frequently involving ditching and lack of riparian vegetation cover through disturbance. Two sites of concern have upstream stormwater outfalls, and three sites of concern should be closely monitored because the cause of poor water quality is not well understood and are likely related to annual differences in rainfall

and temperature that directly affect the monitored parameters. The sites of concern or interest are summarized in Table 1-1.

Statistical modelling of water quality in the summer and fall sampling periods indicated that land use types associated with human disturbance were important predictors of dissolved oxygen, water temperature, specific conductivity, and turbidity. Turbidity and conductivity models for both sampling periods indicated that when watersheds were <60% forested changes in turbidity and conductivity were apparent. Summer turbidity and dissolved oxygen models also indicated watersheds with >20% agricultural use generally have higher turbidity and lower dissolved oxygen. Increased turbidity levels and depleted dissolved oxygen are likely the result of increased sediment loads due to a lack of riparian vegetation, stream channelization, and nutrient enrichment. Adverse effects on water quality in watersheds with high agricultural land use are well documented in the literature.

Both the summer and fall conductivity models suggested that when paved road densities increase above 0.002m/m^2, impacts on water quality were evident in the CWMN data. The increased conductivity in urbanized watersheds is possibly the result of point source salinized discharges. The summer and fall temperature models indicate that watercourses with less shading due to increased imperviousness associated with urbanization have higher water temperatures than watersheds with less intensive urban land use. These results are also common in the literature and further support the importance of riparian vegetation for temperature moderation and bank stability in the Nanaimo region.

Based on the water quality analysis and modelling of the CWMN surface water quality 2011-2017 dataset, general recommendations include:

- Sample every 2-5 years during the summer and fall sampling periods for ultra-low detection (0.002 mg/L RDL) Total and Dissolved Phosphorous in watersheds that have >20% agricultural land use or show evidence of excessive algae growth
- Sample for chloride during the summer low flow period at sites that have road densities >0.002 m/m^2 or that have adjacent stormwater outfalls
- Conduct riparian plantings at the seven identified sites to help with bank stability and provide shading for water quality and habitat improvement
- Completion of benthic invertebrate sampling within watersheds using the CABIN methods would be useful to add another indicator of watershed health. These samples could be collected every 2 to 5 years depending upon budget, and are most useful if done as part of a long-term monitoring program.
- Trend analysis using Mann-Kendall test should be repeated after there is a suitable continuous dataset. At least seven years is needed to look for sampling period specific trends.

- Refine and improve the current land use layer by using remote sensing techniques. We recommend working with the Vancouver Island University to create a land use/cover layer that accurately maps the extent of impervious surface, tree cover and other relevant components of the landscape. This analysis could be done every 5-10 years as an effective way to keep track of land cover changes.

This research confirms the importance of intact riparian corridors and undisturbed forested lands to stream health in the Nanaimo region. It identified water quality exceedances and that adverse trends in the monitored parameters were rare at the sample sites. None the less, impacts from agriculture, roads, urban residential were identified using statistical modelling. This study concurs with the remedial prescriptions provided in earlier habitat assessment reports.

Table 1-1: CWMN Sites of Interest or Concern

Water Region	Site of Interest (EMS)	Sites of Concern			Watershed Impacts					
		WQ exceedances	Adverse trends	Low DO	Storm water	>20% agri	>30% resid.	<60% forest	>0.002 m/m² paved rd	Un known
Big Qualicum	Annie Creek (E290474)	✓		✓		✓		✓	✓	
Little Qualicum	Little Qualicum at intake (E256394)		✓							✓
French Ck	French Ck at Grafton Rd (E243024)	✓	✓	✓			✓			
French Ck	Grandon Ck at Laburnum Rd (E288091)	✓		✓		✓		✓	✓	
French Ck	Grandon Ck at W Crescent (E288090)					✓		✓	✓	
French Ck	Beach Ck Near Chester Rd at Hemsworth Rd (E288092)	✓	✓			✓			✓✓	
French Ck	Beach Ck Near Memorial Golf Pond (E288093)					✓			✓	
Englishman R	Shelly Ck at Hamilton Rd (E287131)	✓		✓				✓	✓	✓
Englishman R	Shelly Ck at end of Blower Rd (E290452)	✓		✓		✓		✓	✓	✓
Englishman R	Swane Ck (E308186)	✓		✓		✓				
S Wellington to Nanoose	Walley Ck D/S of Hammond Bay (E306256)	✓			✓		✓		✓✓	
S Wellington to Nanoose	Walley Ck @ Morningside Dr (E306257)						✓		✓✓	
S Wellington to Nanoose	Walley Ck 20 m u/s Beach (E306434)						✓		✓✓	
S Wellington to Nanoose	Cat Stream (E290486)	✓	✓		✓		✓	✓	✓✓	
S Wellington to Nanoose	Departure Ck @ Neyland Rd (E290469)						✓	✓	✓✓	
S Wellington to Nanoose	Departure Ck off Netwon St (E290470)						✓	✓	✓✓	
S Wellington to Nanoose	Departure Ck at Lower End of Woodstream Park (E290471)						✓	✓	✓✓	
S Wellington to Nanoose	Departure Creek at Outlet (E290472)						✓	✓	✓✓	
S Wellington to Nanoose	Cottle Creek at Landalt Rd (E290476)					✓	✓	✓	✓✓	
S Wellington to Nanoose	Bloods Ck u/s of Dickenson (E294010)					✓		✓	✓✓	
Nanaimo R	Lower Holden Creek (E309281)	✓		✓		✓		✓	✓	
Nanaimo R	Holden Creek (E310147)	✓				✓	✓	✓	✓	
Nanaimo R	Nanaimo R. u/s Haslam Ck (E287699)		✓							

✓exceeds threshold ✓✓ exceeds threshold by >3x

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1 INTRODUCTION

Ecoscape Environmental Consultants Ltd. (Ecoscape) was retained by the Regional District of Nanaimo (RDN) to conduct trend analyses on the Community Watershed Monitoring Network (CWMN) surface water quality dataset. The RDN and the British Columbia Ministry of Environment (MoE) started the CWMM program in 2011. The CWMN program trains volunteers from over 13 stewardships groups to conduct water quality sampling. The long-term goal of the program is to identify watershed trends to assist in land use planning and restoration decisions (Barlak et al. 2012).

The CWMN program consists of annual sampling in both the summer low flow period (August – September) and fall flush period (October – November). There are 73 sites that have been sampled for dissolved oxygen, temperature, turbidity and specific conductivity. However, as of 2018 there are 62 active sites. In 2015, 11 sites had additional water quality parameters sampled because they were previously identified as sites of concern due to high turbidity values (Barlak and Pisani 2017). The additional water quality sampling included: E. coli, Total Phosphorous, lab and in-situ turbidity, and total metals. The monitoring program is designed to calculate the BC 30-day average guidelines (five weekly grab samples taken within 30 days during each sampling period) (Barlak et al. 2015).

Ecoscape conducted a comprehensive trend and water quality model analysis of the CWWN water quality dataset using data from 2011-2017 sampling events. Trend analysis was used to determine whether watershed health (measured by dissolved oxygen, temperature, turbidity and specific conductivity) is stable or changing, either through improvement or decline in water quality parameters. Water quality models were used to identify potential effects of varying land use on water quality. Statistical models of dissolved oxygen, temperature, turbidity and specific conductivity provide a better understanding of the relationships between water quality and observed changes in the surrounding watershed. Recommendations for improvements to the water quality sampling and future management actions are provided for current monitoring program using the results of the trend and modelled water quality analysis.

1.1 Report Objectives and Study Questions

To provide a better understanding of the watershed health in the streams and rivers of the RDN, Ecoscape set out to perform:

Trend analysis for each site to help address the following questions:

- Are fall flush turbidity levels increasing, decreasing or stable?
- Are summer low flow water temperatures increasing, decreasing or stable?

- Are summer low flow levels of dissolved oxygen increasing, decreasing or stable?

Statistical models to help address the following questions:

- Does turbidity increase within a watershed from upstream to downstream sites?
- Is there a relationship between turbidity and land use changes, streamflow and/or climate?
- If there are any trends in water temperature, is there a correlation between lands use changes, climate, or stream flows?

General Questions

- Are observed dissolved oxygen levels consistent with saturation based on water temperature or are they depleted?

2 METHODS

RDN and Ecoscape worked together to gather climate, land use, geospatial data, and water quality data. Ecoscape conducted Quality Assurance/ Quality Control (QA/QC) on 2011-2017 datasets to identify data gaps and errors. The geospatial data included information about watercourses, waterbodies, and elevations were used to delineate watersheds for the CWMN sites. These watersheds and the zoning information were used to calculate the land use composition of each watershed. Statistical analysis was used to identify temporal trends in water quality parameters and to determine effects of land use on water quality.

2.1 CWMN Water Quality Sampling Program

The CWMN partnership collects water temperature, dissolved oxygen, conductivity and turbidity for streams throughout the RDN. The RDN and MoE train volunteers from various stewardship groups. The RDN provides the trained volunteers with equipment and overall program support, while Island Timberlands provides land access and safety gear to the volunteers (Barlak 2012). The trained volunteers conduct water quality sampling five times in summer low flows and 5 times in fall flush flows. The RDN and MoE work together to ensure accurate data is uploaded into the Environmental Monitoring System (EMS). Each water quality parameter sampled by the program is described below:

WATER TEMPERATURE: Water temperature can alter the physical and chemical properties of water, notably dissolved oxygen and carbon dioxide concentrations, pH, conductivity, and compound solubilities. Additionally, water temperature can directly affect the metabolic rates of aquatic organisms.

DISSOLVED OXYGEN: The solubility of oxygen and other gases will decrease as temperature increases. So, for example, if stream water is too warm, it will not hold enough oxygen for fish and other aquatic organisms to survive. Many other factors also affect the oxygen concentration in water, including photosynthesis, water turbulence and the oxygen demand within the water. Thus, oxygen within water can be either above or below saturation, or the maximum concentration at any given temperature Thus, oxygen within water can be either above or below saturation, or the maximum concentration at any given temperature. Oxygen super-saturation (rarely a problem for aquatic life) can occur during intense photosynthesis while dissolved oxygen below 5 mg/L can stress fish. Most pristine coastal streams would average >8 mg/L.

CONDUCTIVITY: Conductivity is a measure of the amount of dissolved material in water. It is affected by the concentration, charge and mobility of dissolved ions. Conductivity is affected by water temperature, so specific conductance was measured (conductivity corrected to 25°C). Warm water can dissolve several minerals and salts more easily than cold water, so conductivity usually increases with water temperature. Common causes of high conductivity in streams include: inflows of hard (high calcium carbonate) ground water and salinity from roads and fertilizers. Most pristine coastal stream with no groundwater influence average <80 µS/cm.

TURBIDITY: Turbidity is the amount of suspended solids in water. Increased turbidity will also increase water temperature because suspended particles absorb heat from the sun more efficiently than clear water. Turbidity is variable in pristine coastal streams, but is generally <2 NTU.

2.2 Database Management and Analytical Methods

Water quality data was retrieved from the Environmental Monitoring System (EMS) which included in situ data collected by trained volunteers during 2011-2017. EMS numbers for the 73 sites samples as part of the CWMN program are listed in Table 2-1. Gaps and data entry errors in the EMS dataset were identified and corrected by Ecoscape. Due to incomplete data, eight sites (Bloods Creek u/s of Aulds Rd, Slogar Brook, Heikkela Brook, and Knarston Creek at Hydro Bridge, the three Bonnell Creek sites, Nanoose Creek just u/s 142 main (km 4)) that are part of the CWMN program were not included in water quality and subsequent analysis. Data exploration techniques including descriptive statistics (mean, minimum, maximum, standard deviation, etc.) and simple graphs such as boxplots were used to compare sites. Box plots were prepared to visually display the results, and provide an understanding of the mean, median, and range in data or variability. Figure 2-1 shows how to interpret a boxplot.

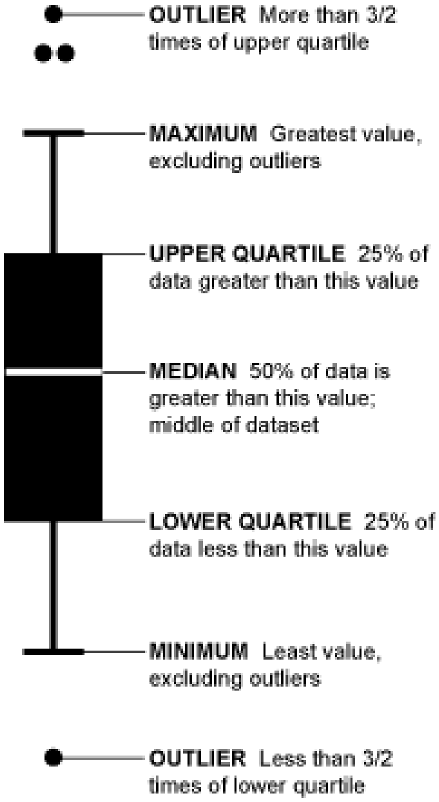

Figure 2-1: How to interpret a boxplot.

The water quality data was compared to applicable BC guidelines (BC MoE) or to specific water quality objectives for the Englishman River. The Englishman Water

Quality Objectives turbidity objective of 5 NTU was used for the fall flush period and 2 NTU was used for the summer low flow period. The Englishman River Objective was compared to each individual turbidity measurement. For temperature, the Englishman River has a short-term objective of 17°C and a long-term objective of 15°C. Thirty-day mean temperature averages over a sampling period were compared to the long-term objective, whereas single measurements were compared to the short-term. For dissolved oxygen, the BC Water Quality guidelines protective of aquatic life were used. The 30 day average is 8 mg/L and the instantaneous minimum is 5 mg/L. There is no guideline for specific conductivity but typically coastal streams have conductance less than 80 µS/cm. If a stream has higher conductivity, it is usually indicative of ground water or ocean influence.

Table 2-1: List of CWMN sites by Water Region with EMS numbers.

Water Region	Water Region Code	EMS.ID	Location Description
Big Qualicum	WR1	E240141	Annie Creek
Big Qualicum	WR1	E286549	Thames Creek 200m u/s Old Island Hwy
Big Qualicum	WR1	E286550	Thames Creek 100m u/s Inland Island Hwy
Big Qualicum	WR1	E286551	Upper Nile Creek at Cochrane Main
Big Qualicum	WR1	E286552	Nile Creek 25m u/s hatchery
Big Qualicum	WR1	E286553	Nile Creek 50m u/s Old Island Hwy
Big Qualicum	WR1	E298597	Big Qualicum u/s site
Big Qualicum	WR1	E298598	Big Qualicum River about 700m d/s hatchery
Big Qualicum	WR1	E306374	Rosewall Creek @ Rosewall Creek Park
Big Qualicum	WR1	E306375	Deep Bay Creek
Big Qualicum	WR1	E309086	Cook Creek at Old Island Hwy Connector
Little Qualicum	WR2	E220635	Cameron River (near the highway)
Little Qualicum	WR2	E256394	Little Qualicum River at Intake
Little Qualicum	WR2	E268993	Little Qualicum River 1.2 km d/s Cameron Lake
Little Qualicum	WR2	E285669	Upper Cameron River
Little Qualicum	WR2	E287697	Whiskey Creek on Hwy 4, TB Ave Save on Gas
Little Qualicum	WR2	E299853	Little Qualicum River 20m u/s hwy 19A
French Creek	WR3	E243021	French Creek at new highway
French Creek	WR3	E243022	French Creek at Barclay Bridge
French Creek	WR3	E243024	French Creek at Grafton Road
French Creek	WR3	E288090	Grandon Creek at West Crescent (Caissons)
French Creek	WR3	E288091	Grandon Creek at Laburnum Road
French Creek	WR3	E288092	Beach Creek near Chester Road at Hemsworth Road
French Creek	WR3	E288093	Beach Creek near Memorial Golf Course Pond
Englishman River	WR4	121580	Englishman River at Highway 19A

Water Region	Water Region Code	EMS.ID	Location Description
Englishman River	WR4	E248834	Englishman River U/S from Morison Creek
Englishman River	WR4	E248835	Morison Creek U/S from Englishman River
Englishman River	WR4	E248836	South Englishman River U/S from Englishman River
Englishman River	WR4	E252010	Englishman River U/S from Allsbrook Canyon
Englishman River	WR4	E282969	Upper Englishman River u/s Centre Fork Creek
Englishman River	WR4	E287131	Shelly Creek @ Hamilton Road
Englishman River	WR4	E290452	Shelly Creek @ end of Blower Rd
Englishman River	WR4	E299852	Centre Creek
Englishman River	WR4	E308186	Swane Creek d/s of Errington Road
South Wellington to Nanoose	WR5-1	E290473	Cottle Creek @ Nottingham
South Wellington to Nanoose	WR5-1	E290474	North Cottle Creek 100 m d/s from Burma Rd.
South Wellington to Nanoose	WR5-1	E290475	Cottle Creek @ Stephenson Pt Rd
South Wellington to Nanoose	WR5-1	E290476	Cottle Creek @ Landalt Rd
South Wellington to Nanoose	WR5-1	E294010	Bloods Creek just u/s Dickenson Rd
South Wellington to Nanoose	WR5-1	E294013	Knarston Ck just u/s Lantzville Rd
South Wellington to Nanoose	WR5-1	E294017	Craig Creek just u/s Northwest Bay Rd
South Wellington to Nanoose	WR5-1	E294019	Nanoose Creek @ Nanoose Campground
South Wellington to Nanoose	WR5-1	E294020	Nanoose Creek @ Matthew Crossing
South Wellington to Nanoose	WR5-1	E306255	Knarston Ck @ Superior Rd
South Wellington to Nanoose	WR5-1	E306256	Walley Ck d/s Hammond Bay
South Wellington to Nanoose	WR5-1	E306257	Walley Ck @ Morningside Dr
South Wellington to Nanoose	WR5-1	E306434	Walley Creek 20m u/s beach
South Wellington to Nanoose	WR5-1	E309186	Cottle Creek downstream of Hammond Bay Rd
South Wellington to Nanoose	WR5-2	E290469	Departure Ck @ Neyland Rd
South Wellington to Nanoose	WR5-2	E290470	Departure Ck off Newton St
South Wellington to Nanoose	WR5-2	E290471	Departure Ck at lower end of Woodstream Park
South Wellington to Nanoose	WR5-2	E290472	Departure Ck @ outlet
South Wellington to Nanoose	WR5-2	E290477	Benson Creek @ Biggs Road

Water Region	Water Region Code	EMS.ID	Location Description
South Wellington to Nanoose	WR5-2	E290478	Millstone River @ Biggs Road
South Wellington to Nanoose	WR5-2	E290479	McGarrigle Ck @ Jingle Pot Rd
South Wellington to Nanoose	WR5-2	E290480	Millstone River @ East Wellington
South Wellington to Nanoose	WR5-2	E290481	Millstone River in Barsby Park
South Wellington to Nanoose	WR5-2	E290482	Northfield Creek @ outlet
South Wellington to Nanoose	WR5-2	E290483	Chase River @ Aebig
South Wellington to Nanoose	WR5-2	E290484	Chase River @ Howard
South Wellington to Nanoose	WR5-2	E290485	Chase River @ Park Ave
South Wellington to Nanoose	WR5-2	E290486	Cat Stream
South Wellington to Nanoose	WR5-2	E306254	Upper McGarrigle Ck
South Wellington to Nanoose	WR5-2	E306294	Millstone River @ Jingle Pot Road
South Wellington to Nanoose	WR5-2	E309187	McClure Creek at Montessori School
South Wellington to Nanoose	WR5-2	E309280	Chase River at Estuary Park
Nanaimo River	WR6	E215789	Nanaimo River at Cedar Rd bridge
Nanaimo River	WR6	E287699	Nanaimo River u/s Haslam Ck
Nanaimo River	WR6	E287700	Haslam Ck u/s Nanaimo River
Nanaimo River	WR6	E290487	Beck Creek @ Cedar Rd
Nanaimo River	WR6	E309281	Lower Holden Creek at Maughan Rd
Nanaimo River	WR6	E310147	Upper Holden Creek at Lazo Lane
Gabriola Island	WR7	E304070	Mallett Creek.

2.2.1 Rainfall and Discharge Data

Rainfall, temperature and flow data were aggregated from multiple sources to provide insights into the linkage between water quality and climate. Correlation tests determine the magnitude and direction of the trend between two variables. A Spearman rank correlation test was used to compare the total rainfall three days prior to the sampling date and including the sampling date with a single water quality measure in the fall flush period. Comparisons were done on a site-specific basis and only sites that had more than 25 fall samples were included in the analysis. The rainfall data for the rain gauge that was closest to the site of interest was used. There were fourteen rain gauge stations used for this analysis and they are shown in Figure 2-2. To identify peak flows and storm events, flow and rainfall graphs were generated for the summer and fall sampling periods for 2011-2017. There are active Water Survey of Canada hydrometric stations on Nile Creek, Little Qualicum River, Englishman River, Millstone River, and Nanaimo River (Figure 2-2). BC Conservation Foundation (BCCF) operates hydrometric stations on Grandon and Rosewall creeks.

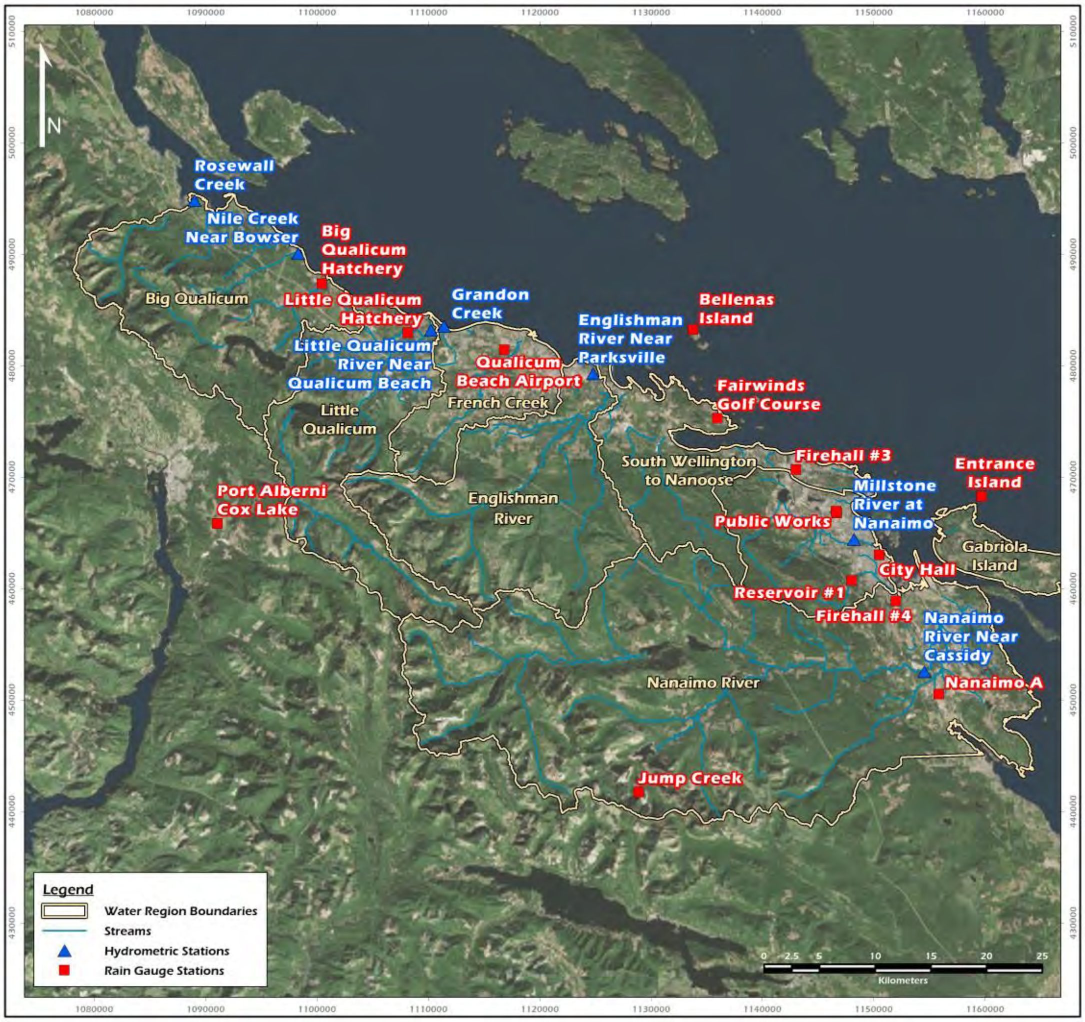

Figure 2-2: Map of hydrometric and rain gauge stations used for analysis.

2.2.2 Trend Analysis

Seasonal Mann-Kendall tests were used to identify and assess the direction and statistical significance of trends in water quality measurements over time (2011-2017). Mann-Kendall is a robust non-parametric regression analysis because it is easy to meet the assumptions needed for an accurate analysis and this test yields a result that is easy to interpret as either increasing, decreasing, or not changing. Further, seasonal Mann-Kendall tests account for seasonal variability by only comparing the same months from different years. Only sites that were sampled for at least six years in both summer and fall were included in trend analysis. Water quality measures that had significant trends over time were graphed with locally weighted scatterplot smoothing (LOWESS) trend lines, which help readers understand how the data is changing over time. Tests were performed using the "Kendall" package version 2.2 in R (McLeod, 2011).

2.3 GIS Methods

Available contour data and stream centerlines were used to determine watershed boundaries. Since the analyses required an understanding of the drainage area above each sampling point, the data were used to accurately determine the upstream drainage area for each sampling location. ArcHydro tools were used in ArcGIS Desktop version 10.6 (Environmental Systems Research Institute, 2018).

The following were the general tasks completed to achieve delineation of watershed boundaries. A Digital Elevation Model (DEM) with 2 m resolution was obtained from the RDN. Watercourse and waterbody data was also received from RDN. The DEM was resampled by bilinear interpolation to a resolution of 5 m. The watercourse data from the RDN was modified to remove rivers that had a right and left bank line and were replaced with a river centerline. The modified watercourse data was used as the stream network to burn into the DEM and then sinks were filled. To burn in the stream network ensures the flow direction is congruent with existing watercourses. This reconditioned DEM was used to determine flow direction by the Deterministic-8 (D8) flow algorithm and flow accumulation. Some of the CWMN sampling points were moved to be on the stream. Watersheds were then delineated for the adjusted CWMN sampling points. Some watersheds for sites in coastal areas were not delineated accurately. These watersheds were manually delineated using contours, watercourses, waterbodies, and other available watershed boundaries as accurately as possible. A list of watersheds that were manually delineated or adjusted is in Table 2-2.

Table 2-2: List of watersheds that were manually adjusted or delineated.

Water Region	LOCATION.NAME	EMS.ID
1 -Big Qualicum	ANNIE CREEK	E240141
1- Big Qualicum	DEEP BAY CREEK	E306375
4 -Englishman River	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	E248836
4 -Englishman River	SHELLY CREEK AT HAMILTON RD	E287131
4 -Englishman River	SHELLY CREEK @ END OF BLOWER RD	E290452
5 -South Wellington to Nanoose	MILLSTONE RIVER @ BIGGS ROAD	E290478
5 - South Wellington to Nanoose	MILLSTONE RIVER IN BARSBY PARK	E290481
5 -South Wellington to Nanoose	CHASE RIVER @ AEBIG RD	E290483
5- South Wellington to Nanoose	CHASE RIVER @ PARK AVE	E290485
5- South Wellington to Nanoose	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	E290486
5 - South Wellington to Nanoose	BLOODS CK JUST U/S DICKENSON RD	E294010
5 - South Wellington to Nanoose	MILLSTONE R @ JINGLE POT ROAD	E306294
5 - South Wellington to Nanoose	NANAIMO CHASE RIVER AT ESTUARY PARK (RDN CWMN)	E309280
6 - Nanaimo River	NANAIMO RIVER AT CEDAR RD BRIDGE	E215789
6 - Nanaimo River	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	E287699
6 - Nanaimo River	NANAIMO LOWER HOLDEN CREEK (RDN CWMN)	E309281
6- Nanaimo River	BECK CREEK @ CEDAR RD	E290487

Watershed land use is a very important parameter that can directly affect water quality. To assess the effects of different land use types, land use data for the all Water Regions was obtained from each local government and the total area of each land use within the watershed was determined. Zoning information was obtained from Town of Qualicum Beach, City of Nanaimo, Regional District of Nanaimo, Comox Valley Regional District, Cowichan Valley Regional District and City of Parksville. Spatial gaps and missing zoning codes were manually filled in by aerial image interpretation. Land uses were categorized into broad land use types that were similar in form and function. The land use classes provided generally included: Agricultural, Commercial, Comprehensive, Conservation, Forestry, Industrial, Institutional, Multi-Family Residential, Recreation, Rural Residential, Single Family Residential, Transportation, Water and Wetland. These generalized groups were further sub-categorized into more general, broad land use categories in six classes that were similar in form and function. Table 2-3 describes how land use classes were combined to yield the final broad land use classes used in the analysis. Once the land use classes were identified, they were converted to percentages for the water regions, noting that we did not attempt to rectify actual land use versus land use obtained from the data (e.g., an industrial land use type that is currently undeveloped and is closer to residential as an example).

The percentage of the watershed for any given broad land use type was determined at two different scales. The first scale was the watershed as a whole, while the second scale considered a region within 500 m of the sampling point. The 500 m upstream buffer was determined by buffering each CWMN site by 500 m and then clipping the resultant 500 m buffer polygon with the watershed of that site. The 500 m upstream buffer zones were only determined for areas upstream of the sampling site within 500 m because these are the only areas that can directly impact water quality at any given sampling location.

Table 2-3: Summary of land use classes combined from zoning information.

Class	Calculation
Agricultural	Rural Residential+Agricultural
Forested	Forestry+Conservation
Impervious	Commercial+Industrial+Transportation
Recreation	Institutional+Recreation
Residential	Comprehensive+Multi-Family Residential+Single Family Residential
Water	Water+Wetland

To better understand specific trends due to urbanization, the density of paved and unpaved roads was also determined. Road density is a common parameter used to assess potential effects in watersheds, and is determined by dividing the total road length (m) within the watershed by the watershed area (m^2), yielding a variable with units (m/m^2) which means the total length of road (m) within the area (m^2) of the watershed. Paved and unpaved road densities were determined for the entire watershed and for the 500 m upstream buffer. Data for roads was obtained from the Digital Road Atlas (DRA).

The maximum flow or water travel distance and percent slope for each watershed were also determined. The elevation of each monitoring site and percent slope was determined to understand if watershed position and morphometry (size and shape) had an effect on water quality. The maximum flow path length tool in System for Automated Geoscientific Analyses (SAGA) GIS version 2.1.4 was used to calculate the flow distance to the ocean (Conrad et al 2015). Percent slope was calculated in ArcGIS Desktop using the 5 m resampled DEM. The mean slope of each watershed was calculated using zonal statistics in RSAGA (Brenning 2008). The elevation of a sample site was determined from the 5 m resampled DEM.

2.4 Water Quality Models

Water quality in streams can be affected by multiple factors, which are both natural and anthropogenic. Any factor that affects water quality operates on a different spatial or temporal scale. These natural and human factors were grouped into three categories by Soranno et al. 2010, which were freshwater, terrestrial and human landscape (Figure 2-3). Statistical models that compared each water quality parameter (e.g., DO) were developed where the models defined a mathematical relationship between the water quality parameter and variables that were grouped into each of these categories. Thus, the goal of the water quality models was to take a holistic approach and consider as many potential factors as possible, whether factors were anthropogenic or natural, using available spatial data. The analysis allows us to better understand how water quality in each of the watersheds may respond to natural and/or anthropogenic factors, and help facilitate better management decisions (Figure 2-3). It must be recognized that these analyses are used to better understand how the stream water quality in the CWMN sites may be influenced by watershed characteristics by using spatial data that is readily available for the watershed, but is constrained by available data (i.e., models can always be improved if more data is added). The variables that were included attempt to quantify the catchment morphology such as watershed slope and flow distance and consider the position of the sample site in the drainage network. A primary focus of our analysis was to include land use variables, with available road infrastructure data (i.e., roads) to determine if a land use type or urban density may be influencing water quality. The suite of variables selected were chosen because they have been used to describe watershed effects in other studies, and because a complete data set was available (both spatially and temporally), meaning we could develop the watershed characteristics (land use, catchment morphology, land cover) at a spatial scale necessary to complete the analysis.

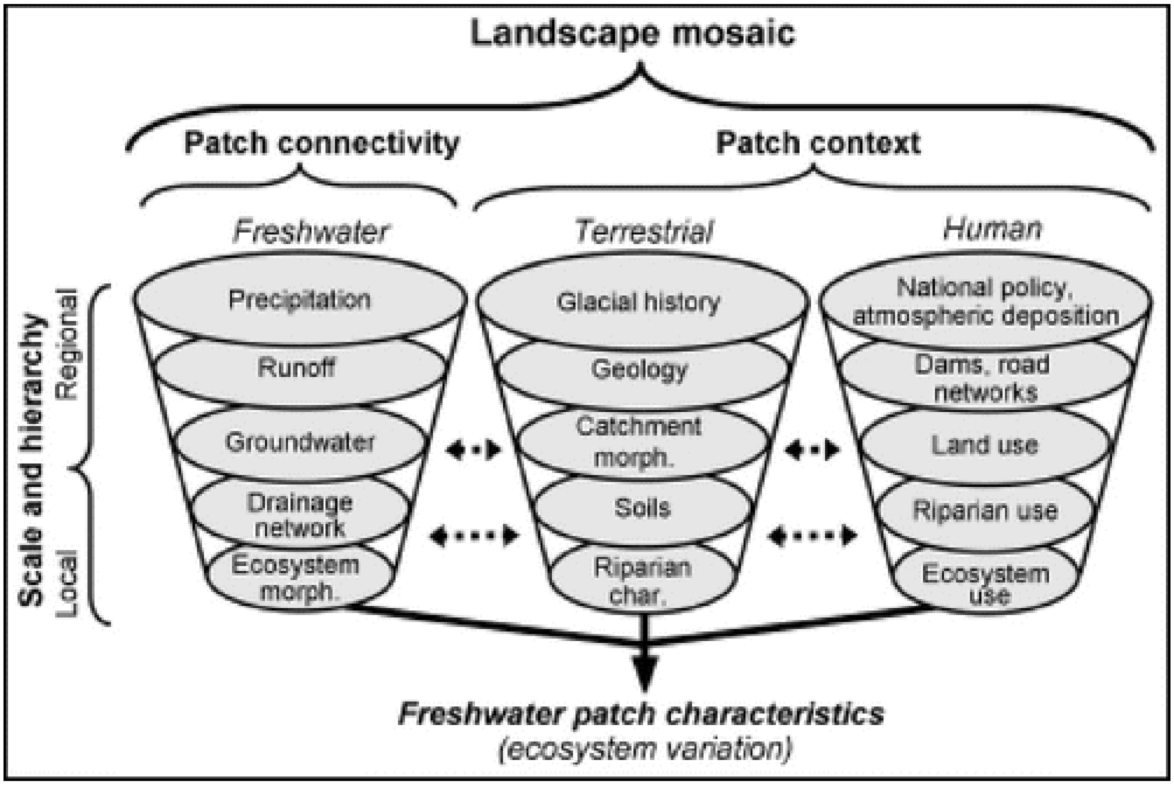

Figure 2-3: The different freshwater, terrestrial, and human characteristics that can affect stream water quality from Soranno et al. 2010.

We used the statistical models from Random Forest to model water quality in the RDN CWMN watersheds. These models were chosen because Random Forest successfully modelled water quality in streams and lakes in the US and Canada (Read et al. 2015; Jones et al. 2017). Random Forest can accommodate predictor variables that are correlated with one another and have non-normal distributions (Read et al. 2015). Non-normal distributions are common with land use variables.

A water quality model was defined in both seasons for dissolved oxygen, turbidity, water temperature and specific conductivity, for eight models in all. They were modelled using the 20 predictor variables listed in Table 2-4. The median of each water quality variable for all summer and fall available data was used as the response variable in each model. The median was used because it is not sensitive to outliers like the mean is. Some sites were excluded from models because they were determined as outliers. The list of sites excluded is in Table 2-5.

Table 2-4: Predictors used in random forest water quality models.

Predictor	Units
Watershed Paved Road Density	m/m2
Watershed Unpaved Road Density	m/m2
Watershed % Water	%
Flow Distance to Ocean (m)	m
Watershed Slope	% Slope
Elevation (m.a.s.l.)	m.a.s.l.
Watershed Area (m2)	m2
500m Upstream Buffer Paved Road Density	m/m2
500m Upstream Buffer Unpaved Road Density	m/m2
500m Upstream Buffer % Water	%
Watershed % Residential	%
500m Upstream Buffer % Residential	%
Watershed % Impervious	%
500m Upstream Buffer % Impervious	%
Watershed % Forested	%
500m Upstream Buffer % Forested	%
Watershed % Agricultural	%
500m Upstream Buffer % Agricultural	%
Watershed % Recreation	%
500m Upstream Buffer % Recreation	%

Table 2-5: Summary of sites removed from fall and summer water quality models.

Model	Sites Removed	EMS ID	Reason for Removal
Fall Temperature	North Cottle Creek @ Landalt Rd	E290474	Only sampled 2012-2014
Summer and Fall Temperature	Upper Cameron River	E285669	At high elevation relative to other sites
Summer and Fall Temperature	Thames Creek 100 u/s of Inland Island Highway	E286550	Low temperatures due to groundwater influence
Fall Temperature	Chase River at Estuary Park	E309280	Only sampled in 2017, had low temperature
Summer and Fall Turbidity	Mallett Creek	E304070	Outlier (very high turbidity)
Summer and Fall Turbidity	Lower Holden Creek	E309281	Outlier (very high turbidity)
Fall Turbidity	Annie Creek	E240141	Outlier (very high turbidity)
Fall Turbidity	Swane Creek	E308186	Outlier (very high turbidity)
Fall Conductivity	Lower Holden Creek	E309281	Suspected ocean influence
Summer and Fall Conductivity	Chase River at Aebig Rd	E290483	Suspected ocean influence
Summer and Fall Conductivity	Chase River at Estuary Park	E309280	Suspected ocean influence
Summer and Fall Conductivity	Lower Holden Creek	E309281	Suspected ocean influence

Random Forest determines the importance of each predictor variable and the relationships between each predictor variable and response variable (water quality). The variable importance measure for each predictor is calculated by calculating the mean decrease in prediction error (Mean Squared Error), if the predictor is dropped from the model (Liaw and Wiener, 2002). Predictor variables that have a strong relationship with the water quality response variable should have large variable importance. Dropping these predictors from the model causes a large increase in prediction error. Variable importance plots for the top 10 predictors of each model were generated to help identify potential land use types associated with the water quality variables. Partial dependence plots were generated to better understand the effect of the top five predictors on each water quality variable. These partial dependence plots provide the relationship between the selected predictor and the response variable while considering the effects of the other variables in the Random Forest model (Liaw and Wiener, 2002).

Random Forest is a complex machine-learning algorithm that uses Classification and Regression Tree (CART) models as the base model. CART is a non-parametric tree-based method that splits data into separate groups based on the response variable (De'ath and Fabricus 2000; Jun 2013). CART initially partitions the data into two groups based on a split point and splitting variable that minimizes the sum of squares of the response variable of each group (De'ath and Fabricus 2000; Hastie et al. 2001). A recursive algorithm is used to search through every possible combination of explanatory variables and values to determine the best splitting variable and split point (Hastie et al. 2001). The CART algorithm continues to make binary splits at each tree node until a stopping criterion is reached (Jun, 2013).

Random Forest builds different CART models by bagging (using a subset) the data and the explanatory variables tried at each split. Each CART model only uses a random subset of the dataset in the model and at each split in the tree only a random subset of predictor variables is tried as a potential splitting variable (Jones and Linder, 2015). The default setting used in the R package Random Forest were used for the water quality models. The Random Forest models contain 500 trees (CART models) and in our case, six of the predictor variables were tried at each split (Liaw and Wiener, 2002).

3 RESULTS

Detailed results for each Water Region are presented in Appendix D. Results include all water quality data collected as part of the valuable CWMN program. These data are displayed as boxplots compared to relevant water quality guidelines or objectives. The sections below include an overview of the study's findings and relevant discussion.

The sections below include a description of the percent land use in each watershed. The land use categories are described in 2.3. Please note, the term forested refers to land that is zoned for forestry or conservation use. This can include mature forest or forest that has been recently harvested.

3.1 Water Region 1- Big Qualicum

Water Region 1 is the most northerly Water Region and has an area of approximately 292 km^2. Most of this Water Region resides in RDN Electoral Area H. A small portion of this Water Region includes Comox Valley Electoral Area A. The two hydrometric stations in this Water Region are Nile Creek near Bowser and Rosewall Creek near Hwy 19a bridge. The Rosewall Creek hydrometric station is operated by BCCF and started collecting data in October 2012. Mean daily temperatures from 1981 to 2010 were 16.7°C for August and 13.6°C for September within the water region. For the fall sampling period, mean daily temperatures from 1981 to 2010 were 9.1°C for October and 5.6°C for November. Water Region 1 receives the most rainfall according to the rainfall data from Big Qualicum Hatchery. The mean total rainfall from 1981 to 2010 was 34.6 mm, 46.3 mm, 146.8 mm and 214.0 mm for August- November, respectively.

3.1.1 Overview of Watersheds

Water Region 1 contains the Big Qualicum River watershed and seven smaller watersheds. The creeks that are sampled by the CWMN program include Rosewall Creek, Cook Creek, Nile Creek, Thames Creek, and Annie Creek. Big Qualicum River has two sites that are sampled as part of CWMN program. The Fanny Bay Salmonid Enhancement Society started sampling Rosewall, Cook and Deep Bay creek in 2016. The Nile Creek Enhancement Society samples the remainder of the CWMN sites in Water Region 1 and started some sites in 2011.

Both Big Qualicum sites (u/s of Hwy 19 Bridge- E298597 and 700m d/s Hatchery-E298598) have watersheds that are primarily forested and include Horne Lake in the headwaters (Appendix A).

Nile Creek has three sites that are sampled as part of CWMN program. The Upper Nile site (E286551), which is the furthest upstream, has a watershed that is entirely forested (99.9%). The two downstream sites, u/s of hatchery (E286552) and Old Island Hwy (E286553), are primarily forested with some land that is zoned recreational but appears vacant (Figure 3-1). The furthest downstream site near Old Island Hwy has a watershed with approximately one percent residential development.

The Thames Creek watershed is south of the Nile Creek watershed. Thames Creek has two sites that are sampled as part of the CWMN program. The furthest upstream site near Inland Island Highway (E286550) is primarily forested with some vacant land that is zoned for recreational/institutional use. The watershed of the Thames Creek u/s of Old Highway site (E286549) is primarily forested (forest and vacant land) and has small wetlands. Two-percent of this watershed has land use associated with commercial development (Figure 3-1).

Cook Creek, Rosewall Creek, Deep Bay Creek and Annie Creek each have one site included as part of the CWMN program. Rosewall Creek (E306374) is the furthest north watershed in Water Region 1, whereas Annie Creek (E240141) is the furthest south (Appendix A). The watersheds of Cook (E309086) and Rosewall Creek are primarily forested. The Deep Bay Creek watershed (E306375) is small and flat with approximately 60% rural residential and 36% commercial and other residential development (Figure 3-1). The Annie Creek watershed is primarily rural residential and agricultural with 8% of associated with commercial development (a Bed and Breakfast) and roads. Annie Creek originates from groundwater and shallow wetlands and is ditched in its headwaters (Clough 2017a).

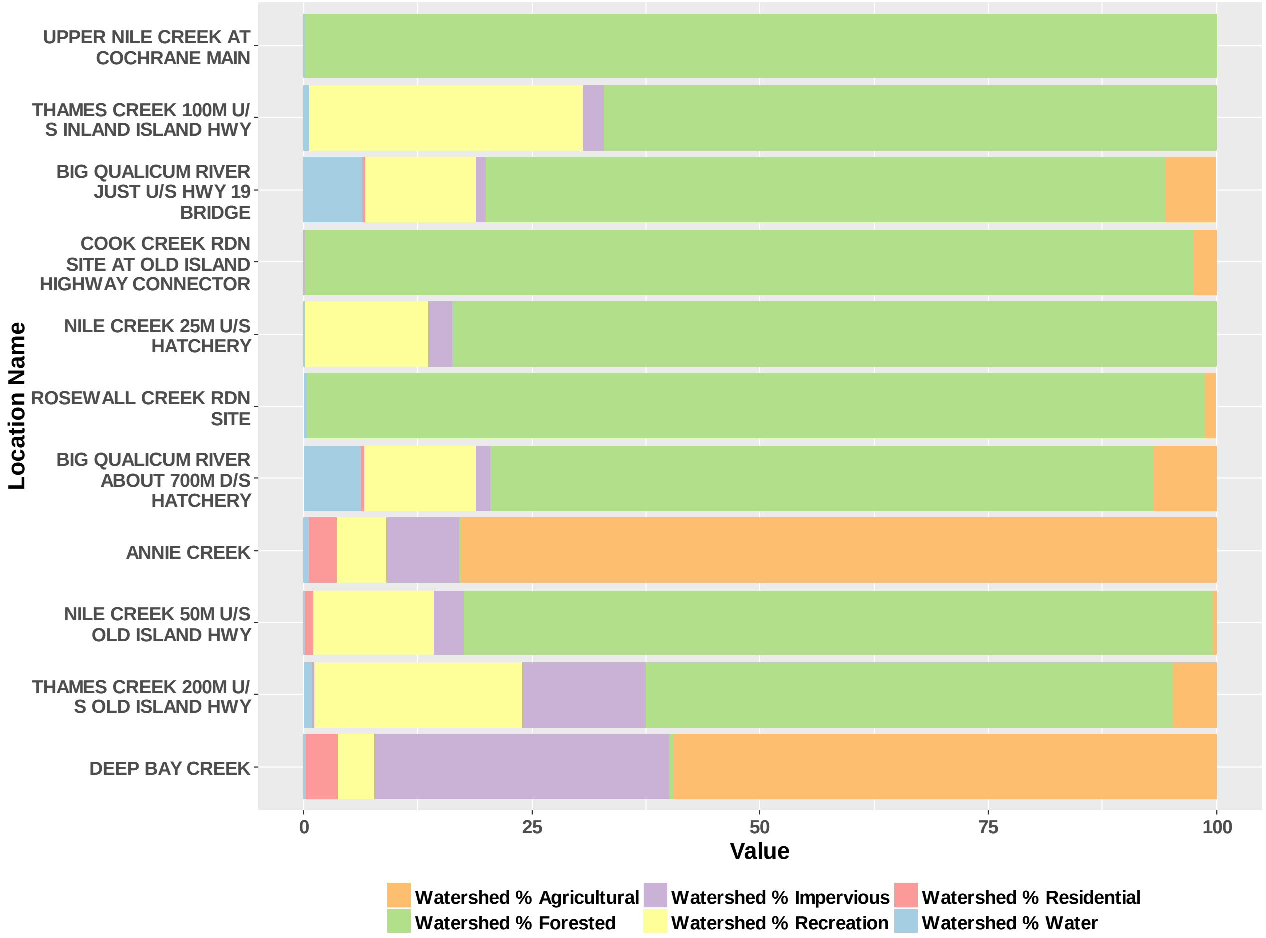

Figure 3-1: Percent land use composition for CWMN site watersheds of Water Region 1 (Big Qualicum River).

3.1.2 Water Quality Summary and Trends

Please refer to section 2.1 for a description of the parameters that were sampled and their value.

3.1.2.1 Temperature

All samples sites in the Big Qualicum water region had suitable water temperatures for aquatic life during the fall flow period (Figure A13). However, during summer low flows, water temperatures were consistently above the 15°C target at Rosewall and Cook Creek despite the relatively undeveloped nature of these watersheds (Figure A9). Thames Creek, approximately 200m u/s Old Island Highway, and the Annie Creek sample stations occasionally exceeded these guidelines during the summer period.

3.1.2.2 Dissolved Oxygen

The dissolved oxygen concentration in water is directly related to the water temperature, where cooler waters have greater concentrations of oxygen than warmer waters. In Figure A129, the concentration of oxygen is shown for each site, where points above the grey shaded area represent super-saturation (rarely a problem for aquatic life) and those points falling below the shaded area are below 5 mg/L and stress to fish or other aquatic species is probable.

The Annie Creek site usually had depleted dissolved oxygen in the summer months (Figure A10). The Cook Creek site had low DO but had DO concentrations close to saturation. All measured dissolved oxygen concentrations in the Big Qualicum region were suitable for aquatic life in the fall (Figure A14).

3.1.2.3 Conductivity

Within the Big Qualicum water region, Annie Creek had the highest specific conductance, averaging >100 µS/cm in fall and >150 µS/cm in summer, suggesting groundwater influence (Figure A11). Upper watershed sites had lower conductivity, generally below 50 µS/cm in fall and below 70 µS/cm during summer low flows (Figure A15).

3.1.2.4 Turbidity

In the Big Qualicum water region, turbidity spikes were most common at Deep Bay and Annie Creek sampling stations. At Thames Creek approximately 200m u/s of the Old Island Highway, and at Rosewall Creek, occasional turbidity spikes were observed. The Englishman River water quality Objective for turbidity is 2 NTU for low flow periods such as the summer and 5 NTU for higher flow periods. Individual measurements >5 NTU were recorded at Annie and Rosewall creeks in the fall and >2 NTU at Annie and Deep Bay creeks in the summer (Figure A12 and Figure A16). Elevated turbidity during summer low flows can be indicative of watershed disturbances such as the rural residential or agricultural development. Land used for agriculture frequently has less riparian vegetation and has altered drainage patterns. As a result soils and sediments can be easily mobilized from the riparian area into the stream. The primary cause of sediment mobilization is erosion which can be caused by livestock grazing and unstable stream banks due to lack of vegetation. Watersheds with a high agricultural land use often have altered drainage systems because of drain tile and ditching (Choquette 2014). These altered drainage patterns result in more runoff that causes an increase in sediment loads to streams. The Annie Creek watershed has high agricultural land use and known bank stability issues (Clough 2017a). Similarly, there is 91% rural residential/agricultural and commercial land use in the Deep Bay Creek watershed that could be contributing to its elevated turbidity.

3.1.3 Rainfall, Flows, and Water Quality

Thames Creek upstream of Inland Island Hwy and Nile Creek upstream of Old Island Road were the only sites in this Water Region that had enough fall data to test correlations between fall rainfall and water quality. Both of these sites had a positive association between temperature and rainfall in fall. This correlation may be a result of annual variations in air temperature. For example, the fall of 2014 was warm and also had some high intensity rainfall events (Figure A96 and Figure A111).

Rainfall and turbidity were positively associated, whereas conductivity was negatively associated with rainfall at Thames Creek upstream of Inland Island Hwy (Table A1). Thames Creek upstream of Inland Island Hwy experienced a spike in turbidity on October 23, 2014 which was associated with a rainfall event. The increases in turbidity during rainfall events is expected and is a result of increased mobilization of sediment in the watershed due to more runoff and increases in discharge which causes more bank erosion. The decrease in conductivity during rainfall events is a result of dilution of stream flows (Girardi et al. 2016).

During the low flow summer period, Nile Creek near Bowser had high flows in September of 2015-2016 (Figure A124). On September 1, 2015 high flows of 0.35 m^3/s were likely associated with a rainfall event on August 29th, 2015 (Figure A74). There were five sites in Water Region 1 sampled on September 1, 2015. However, Big Qualicum d/s of hatchery was the only site that experienced a spike in turbidity on this day.

3.1.4 Trend Analysis

Nile Creek upstream of Old Island Highway was the only site in Water Region 1 that had a suitable continuous dataset for trend analysis. Trend analysis indicated that conductivity, DO, temperature and turbidity were relatively stable from 2011-2017 for both the summer and the fall sampling periods at the Nile Creek site (Table A2).

3.1.5 Sites of Concern in Water Region 1

Annie Creek was added to the CWMN monitoring program in 2014. This is a site that was previously identified as needing restoration works. Our analysis supports the need for restoration, given its depleted dissolved oxygen levels, high summer temperatures and high summer turbidity. In addition, Annie Creek has high fisheries values and the lower portions of Annie Creek are known to support Coho Fry and Cutthroat Trout (Clough 2017a). Annie Creek's turbid waters are linked to eroding muddy stream banks (Clough 2017a). There were several remedial actions recommended in Clough (2017a). We agree with these recommendations and emphasize the need to plant native riparian vegetation to stabilize banks and provide more shade.

3.2 Water Region 2- Little Qualicum

Water Region 2 has an area of approximately 259 km^2, and includes parts of RDN Electoral Areas F, G and H. There is a Water Survey of Canada hydrometric station on Little Qualicum River near Qualicum Beach. There is a climate station at the Little Qualicum Hatchery and mean daily temperatures from 1981 to 2010 were 16.4°C for August and 13.3°C for September. For the fall sampling period, mean daily temperatures from 1981 to 2010 were 8.8°C for October and 5.2°C for November. The mean total rainfalls at the Little Qualicum Hatchery from 1981 to 2010 were 31.8 mm, 40.7 mm, 112.9 mm and 177.0 mm for August to November, respectively.

3.2.1 Overview of Watersheds

The Little Qualicum watershed includes Cameron and Little Qualicum rivers. Whiskey Creek is a major tributary of the Little Qualicum River. Cameron River has two sites and Little Qualicum River has three sites sampled by the CWMN. The Qualicum Beach Streamkeepers sample all the CWMN sites in Water Region 2. The headwaters of Cameron River start in the Beaufort Mountain Range. The Upper Cameron River site (E285669) has the highest elevation of any site sampled in the CWMN program. This site is at ~463 m.a.s.l. and has a watershed that is 96% forested and includes Labour Day Lake (Figure 3-2). The watershed of the Cameron River site (E220635) is also primarily forested. The most upstream Little Qualicum River site is 1.2 km downstream of Cameron Lake (E268993) and has a watershed that is 84% forested. The Little Qualicum site at intake (E256394) and u/s of Hwy 19A (E299853) have watersheds that are 65% forested but have 7-9% agricultural and rural land with 1% residential land use. The Whiskey Creek sample site (E287697) is located near Hwy 4 and has a mix of forested land, rural and agricultural land with 9% of the watershed associated with industrial land use and roads.

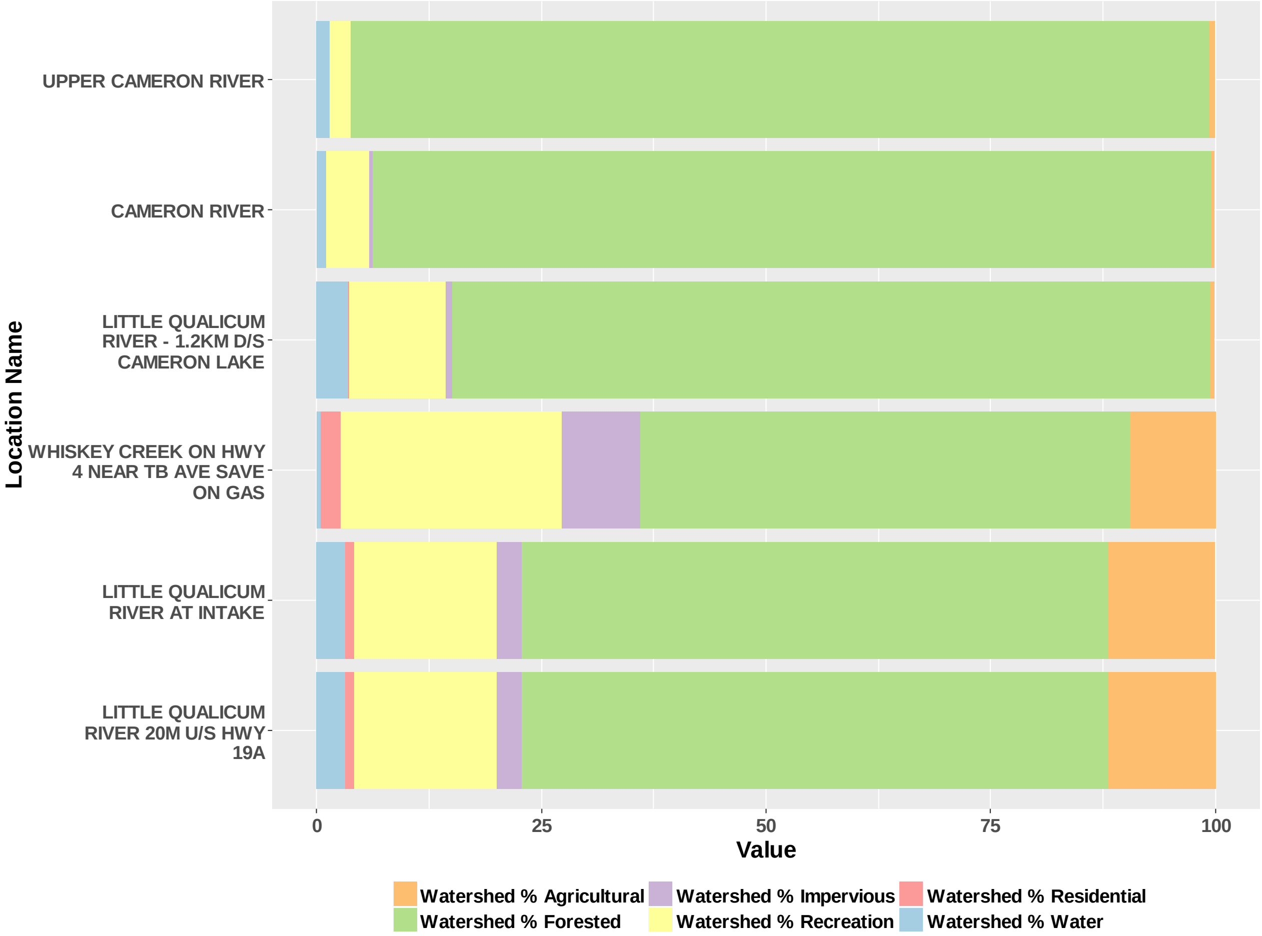

Figure 3-2: Percent land use composition for CWMN site watersheds of Water Region 2 (Little Qualicum River).

3.2.2 Water Quality Summary and Trends

3.2.2.1 Temperature

All samples sites in the Little Qualicum water region had suitable water temperatures for aquatic animals in the fall (Figure A21). However, during summer low flows, water temperatures consistently exceeded the 15°C drinking water aesthetic target and the 17°C coho rearing target in all Little Qualicum River sampling stations (Figure A17). Little Qualicum River is fed by warm surface discharges from Cameron Lake in summer; that can contribute to this observed exceedance. Additionally, these sampling sites had open canopies and low flows in summer, both of which contributed to the sun penetrating to the stream bed substrate and increasing the water temperature.

3.2.2.2 Dissolved Oxygen

All sites in the Little Qualicum watershed had DO concentrations suitable for aquatic life in both fall and spring sample seasons (Figure A18 and Figure A22).

3.2.2.3 Conductivity

Within the Little Qualicum water region, all sites ranged between 60 µS/cm and 160 µS/cm in fall, and 80 µS/cm to 160 µS/cm in summer low flows, both typical ranges for this ecoregion (Figure A19 and Figure A23). Conductivity generally increased as water travelled through the watershed, again a typical finding.

3.2.2.4 Turbidity

Turbidity exceedances were rare in the Little Qualicum watershed. Turbidity spikes >5 NTU were recorded on Whiskey Creek and at Little Qualicum River at intake in the fall on <10% of sample dates (Figure A24). Turbidity exceedances also occurred at Little Qualicum River 20m u/s HWY 19A during summer low flows, but were rare (<10% of sample dates). In all cases, average turbidity levels were far below the 2 NTU guideline (Figure A20).

3.2.3 Rainfall, Flows, and Water Quality

Fall conductivity, turbidity and temperature all had significant relationships with rainfall in Water Region 2. Fall conductivity was negatively correlated with rainfall at the Upper Cameron River site and the Little Qualicum site downstream of Cameron Lake. This means that as rainfall increases, the conductivity of the water decreases through rainwater dilution of stream flows. The Cameron River sites had a positive association between fall water temperatures and rainfall (Table A1). However, this association had moderate strength and it thought to be a result of annual variability in fall air temperatures.

Fall turbidity was positively correlated to rainfall at the Upper Cameron River site and Little Qualicum River at intake. A Turbidity spike on November 8, 2016 at Upper Cameron River was associated with heavy rainfall from November 5- 8, 2016 (Figure A102). The Little Qualicum River site at intake also experienced a turbidity spike on November 21, 2017 which was associated with heavy rainfall from November 18-21, 2017 (Figure A99). The turbidity spike on November 8, 2016 was probably associated with high flows >50 m^3/s on Little Qualicum River (Figure A122). High flows have more energy and as a result can erode river banks and mobilize sediments. During the low flow summer period, Little Qualicum River near Qualicum Beach had high flows from September 1-9, 2015 (Figure A122), these high flows were associated with a rainfall event. On September 1, 2015 both Little Qualicum River sites had turbidity >1 NTU, which is the highest turbidity recorded for these sites during the summer (Figure A20).

3.2.4 Trend Analysis

Five of the six sites sampled in Water Region 2 had suitable continuous datasets for trend analysis. Trend analysis indicated that conductivity, DO, temperature and turbidity were stable from 2011-2017 for both the summer and fall sampling periods at the Upper Cameron and Cameron River, Little Qualicum River1.2 km d/s of Cameron Lake, and Whiskey Creek. However, fall and summer turbidity at Little Qualicum River at Intake have increased in recent years (Figure A137).

3.2.5 Sites of Concern in Water Region 2

Because turbidity has been increasing at Little Qualicum River, we recommend that the reach directly upstream of the Little Qualicum River at Intake site (E256394) be inspected for potential bank stability issues.

3.3 Water Region 3- French Creek

Water Region 3 has an area of approximately 121 km^2 and includes the Town of Qualicum Beach, part of RDN Electoral Areas F and G, and part of the City of Parksville. There are no active hydrometric stations with a long-term dataset in Water Region 3, However, there is a hydrometric station run by BC Conversation Foundation (BCCF) established in August of 2012 on Grandon Creek 35 m upstream of Old Island Highway 19a. Also a hydrometric station was added on French Creek in July 2018. In Water Region 3here are climate stations at the Qualicum Beach Airport and at Coombs. Mean total rainfalls and daily temperatures from 1981-2010 are not available for Qualicum Beach Airport because monitoring started in 2006. Coombs mean daily temperatures from 1981 to 2010 were 17.1°C for August and 13.8°C for September. For the fall sampling period, mean daily temperatures from 1981 to 2010 were 8.9°C for October and 4.7°C for November. The mean total rainfall at Coombs from 1981 to 2010 was 34.5 mm, 39.3 mm, 113.2 mm and 180.7 mm for August-November, respectively.

3.3.1 Overview of Watersheds

Water Region 3 has three creeks that are sampled by the CWMN program. French Creek is the largest creek in Water Region 3. French Creek has been sampled by the Friends of French Creek since 2011. Grandon and Beach are small creeks that drain into the Strait of Georgia and are sampled by the Qualicum Beach Streamkeepers.

French Creek has three sites sampled by the CWMN. The furthest upstream site at Grafton Rd (E243024) has a watershed that is primarily forested with 15% rural and agricultural land (Figure 3-3). The French Creek site at New Highway (E243021) is downstream of Hamilton Marsh and has a watershed with 30% rural/agricultural and 58% forested. The watershed of the Barclay bridge site (E243022) is similar to the New Highway site with a mix of forested and rural/agricultural land use. However, the

Barclay site watershed has 13% of its watershed associated with residential land, the Qualicum Beach Airport and roads.

Beach and Grandon creeks have watersheds with high agricultural use and have two sites each sampled by the CWMN. Both Grandon Creek sites have >50% agricultural upstream land use. The watershed of the furthest downstream site at West Crescent (E288090) is more developed with 5% residential land, compared to 1% at the Laburnum Rd site (E288091). Similar to Grandon Creek, the two Beach Creek sites have highly disturbed watershed with only 6% forested (Figure 3-3). The Beach Creek site at Hemsworth Rd (E288092) has a watershed that includes large wetlands, a golf course, 50% agricultural and rural land and 6% residential land. The watershed of Beach Creek near memorial golf pond (E288093) has more residential development (18%) than the Hemsworth site (6%).

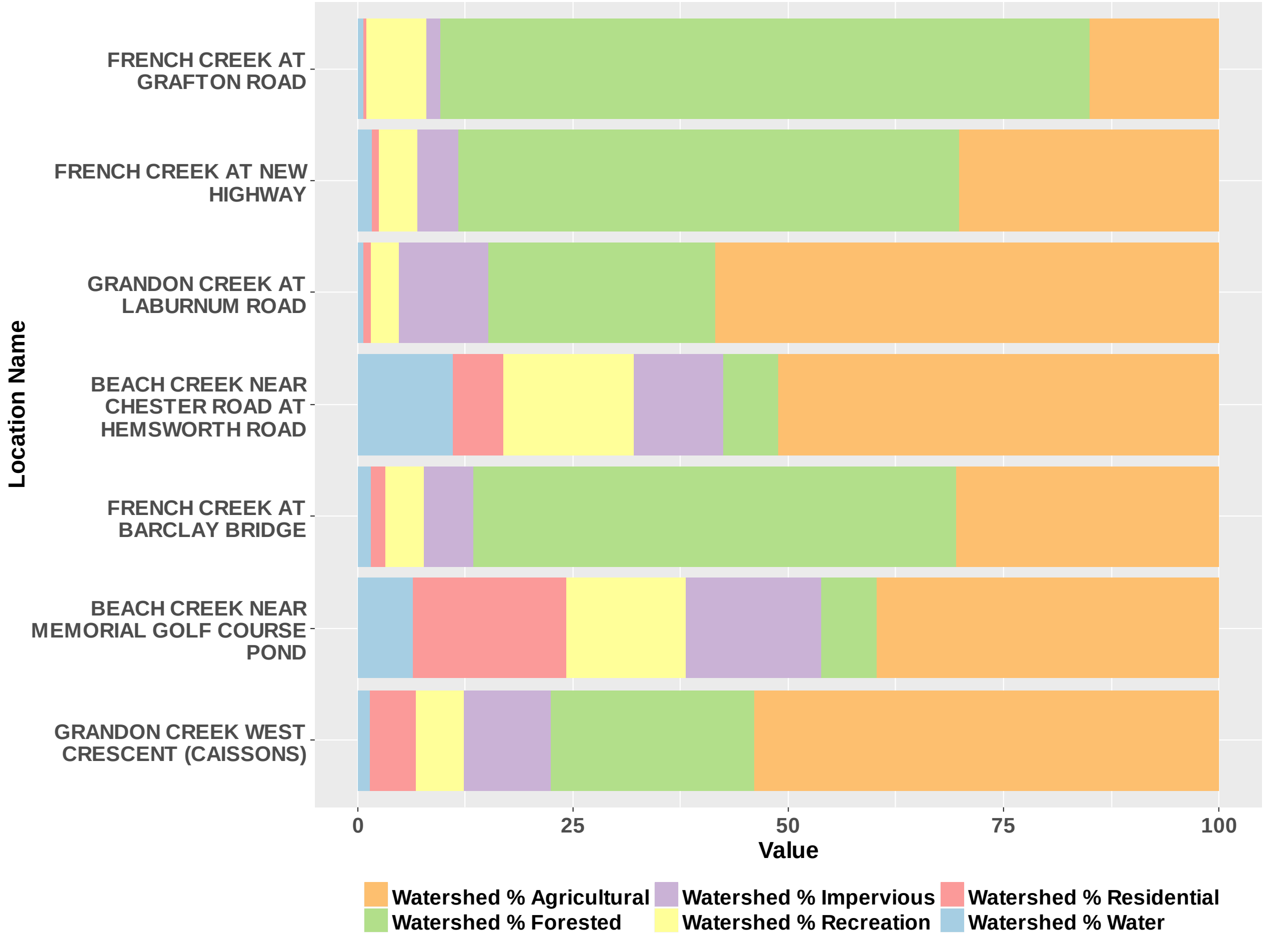

Figure 3-3: Percent land use composition for CWMN site watersheds of Water Region 3 (French Creek).

3.3.2 Water Quality Summary and Trends

3.3.2.1 Temperature

All samples sites in the French Creek water region had suitable water temperatures for aquatic animals in the fall flush period (Figure A21). However, in the summer months, water temperatures consistently exceeded the 15°C target at Grandon Creek at West Crescent, Grandon Creek at Laburnum Rd., French Creek Barclay Bridge and French Creek Grafton Rd sample stations (Figure A25).

3.3.2.2 Dissolved Oxygen

All sites in the French Creek watershed region had DO concentrations suitable for aquatic life in the fall except Grandon Creek at Laburnum Rd (Figure A30). Two stations with warm summer water temperatures also had low DO - Grandon Creek at Laburnum Rd, and French Creek Grafton Rd. Both these sites had summer DO concentrations well below saturation limits (Figure A131). All mean summer DO measurements at. Grandon Creek at Laburnum Rd were below 5.0 mg/L, whereas French Creek at Grafton Rd mean summer DO were below 8 mg/L (Figure A26). The Grandon Creek site at Laburnum Rd has very slow flow which limits the mixing of DO. This site also has mixed land uses including 58% rural/agriculture in watershed and 79% within the 500m upstream buffer (Figure A3).

3.3.2.3 Conductivity

French Creek has the lowest specific conductance observed in this Water Region, averaging >75 µS/cm in fall; in the summer only the French Creek at Grafton Rd remained that low (Figure A27 and Figure A31). The remaining sites averaged conductivities exceeding 160 µS/cm during summer low flows, suggesting groundwater influence or salinized inflow from adjacent lands.

3.3.2.4 Turbidity

Infrequent turbidity objective exceedances occurred throughout this water region. These spikes may relate to agriculture or road corridor stormwater. In the fall, turbidity >5 NTU was periodically measured (<10% of sample dates) at all sites except French Creek at Grafton Rd (Appendix D). In the summer months, turbidity spikes were recorded at Grandon Creek Laburnum Rd that averaged >2 NTU, while the two Beach Creek sites, Grandon Creek at West Crescent and French Creek at Barclay Bridge averaged just under 2 NTU. Seventy-five percent of the exceedances at Grandon Creek at West Crescent were likely associated with rainfall events.

3.3.3 Rainfall, Flows, and Water Quality

Rainfalls in fall were correlated to conductivity and turbidity in Water Region 3. Fall conductivity had a negative correlation with rainfall at all Grandon Creek sites, Beach Creek Near Memorial Golf Course Pond, and two French Creek sites (Grafton Rd and Barclay Bridge). All sites that are sampled in Water Region 3 had a positive correlation between rainfall and fall turbidity. Peaks in turbidity at Grandon, Beach and French creeks were observed on November 14 and 21, 2017. Both these sampling events coincided with heavy rainfall. The increases in turbidity during rainfall events is expected and is a result of increased mobilization of sediment in the watershed due to more runoff and increases in discharge which causes more bank erosion.

Fall temperature and DO also had some correlations in Water Region 3. Fall water temperatures were positively correlated with rainfall at both Grandon Creek sites, two French Creek sites (Grafton Rd and Barclay Bridge), and Beach Creek near Chester Rd at Hemsworth Rd. However, these correlations had moderate strength and it thought to be a result of annual variability in fall air temperatures. DO at French Creek at New Highway and Barclay Bridge was negatively correlated with rainfall (Table A1). A rainfall event adds water to the stream that is under saturated in DO, rainwater typically has depleted oxygen levels (Komabayasi 1959).

During the low flow summer period, Grandon Creek 35 m upstream of Old Island Highway 19a had high flows at the end of August in 2013-2015 (Figure A123). On September 2, 2014 the Grandon Creek site at West Crescent had a turbidity of 4.02 NTU. This spike in turbidity was associated with a rainfall event (Figure A78).

3.3.4 Trend Analysis

All seven sites in Water Region 3 had suitable continuous datasets for trend analysis. Trend analysis identified that summer and fall turbidity are increasing at Beach Creek near Hemsworth and French Creek at Grafton Rd (Table A2). Mean summer and fall turbidity at French Creek at Grafton Rd are well below the Objectives. However, in 2017 mean summer turbidity at Beach Creek near Hemsworth exceeded the >2 NTU objective (Figure A140). In 2017, the mean fall turbidity was approaching the fall objective of 5 NTU at Beach Creek near Hemsworth.

Beach Creek at Hemsworth Road was the only site in Water Region 3 that had trends in conductivity and temperature. The mean summer and fall specific conductivity at Beach Creek at Hemsworth Rd decreases from 2011-2017 while the mean water temperature in fall and summer have been increasing. The trend observed with water temperature is explained by annual differences in air temperature. The fall sampling period of 2014-2016 had warmer temperatures at Qualicum Beach Airport compared to the fall of 2011-2013 (Appendix E).

3.3.5 Sites of Concern in Water Region 3

The three sites of concern in Water Region 3 have >78% agricultural land use within the 500 m upstream buffer. French Creek at Grafton Road has low DO, high water temperatures and an increasing turbidity trend. Remedial planting was conducted at this site because it has compromised bank stability due to lack of riparian vegetation (Clough 2015a). Grandon Creek at Laburnum Rd has depleted DO, high summer water temperatures and high summer turbidity. A large portion of Grandon Creek upstream of the Laburnum Rd site is ditched and has very little riparian vegetation. Hilliers Estate farm planted trees as part of restoration efforts, and more tree planting is recommended along the agricultural portion of Grandon Creek (Clough 2015b). Beach Creek at Hemsworth is a site of concern because turbidity has increased and conductivity has decreased from 2011-2017. The reasons for these changes should be investigated because the Beach Creek watershed has both a golf course and agricultural land use.

3.4 Water Region 4- Englishman River

Water Region 4 covers approximately 322 km^2 and includes the City of Parksville and parts of RDN Electoral Areas F and G. The upper part of Englishman River Water Region was historically logged (Barlak et al. 2010). There is a hydrometric station on Englishman River near Parksville. The closest climate station to Water Region 4 is the Nanaimo Airport. Mean daily temperatures from 1981 to 2010 were 18.2°C for August and 14.9°C for September. For the fall sampling period, mean daily temperatures from 1981 to 2010 were 9.9°C for October and 5.6°C for November. The mean total rainfall at the Nanaimo Airport from 1981 to 2010 was 28.4 mm, 35.8 mm, 101.2 mm and 186.5 mm for August- November, respectively.

3.4.1 Overview of Watersheds

The major tributaries of the Englishman River that are sampled as part of the CWMN program include the Upper Englishman River, Morison Creek, Centre Creek, South Englishman River and Shelly Creek. Swane Creek is also sampled and is a tributary of Morison Creek. The Mid Vancouver Island Habitat Enhancement Society have sampled ten sites in Water Region 4 from 2011-2017.

The Upper Englishman River site (E282969) and Englishman River site upstream of Morison Creek (E248834) are the furthest upstream. The watersheds of the Upper Englishman River and Englishman River site upstream of Morison Creek are primarily forested with some recreational land use. The watershed of Morison Creek site (E248835) includes the Swane Creek watershed. The Swane Creek (E308186) and Morison Creek sites have unnamed lakes in their headwaters (Appendix A). The Swane Creek watershed has 19% agricultural/rural land, whereas the Morison Creek

Watershed has 30% agricultural/rural land (Figure 3-4). The purpose of the Morison Creek sample site was to monitor the effects of timber harvesting and agriculture on water quality (Barlak et al 2010).

Centre Creek and the South Englishman River are both tributaries of the Englishman River and each have one site sampled as part of the CWMN program. The South Englishman River site (E248836) has an upstream watershed that is primarily forested with some wetlands and small lakes. The Centre Creek site (E299852) has a watershed is 100% forested. The downstream Englishman River sites near Allsbrook Canyon (E252010) and Highway 19A (0121580) are downstream of an unnamed lake and are primarily forested with 4% rural/agricultural and recreational land use (Figure 3-4).

Shelly Creek is the furthest downstream tributary to the Englishman River and has two sample sites that are sampled as part of the CWMN program. The two sites are in close proximity and therefore have watersheds with similar land use compositions. The Shelly Creek site at Blower Rd (E290452) is approximately 350 m downstream from the site at Hamilton Rd (E287131). The watershed of the Shelly Creek site at Hamilton Rd has 18% forested and large wetlands. The lower portion of the Shelly Creek watershed is 35% rural residential with 10% single family development and recreational land use (Figure 3-4).

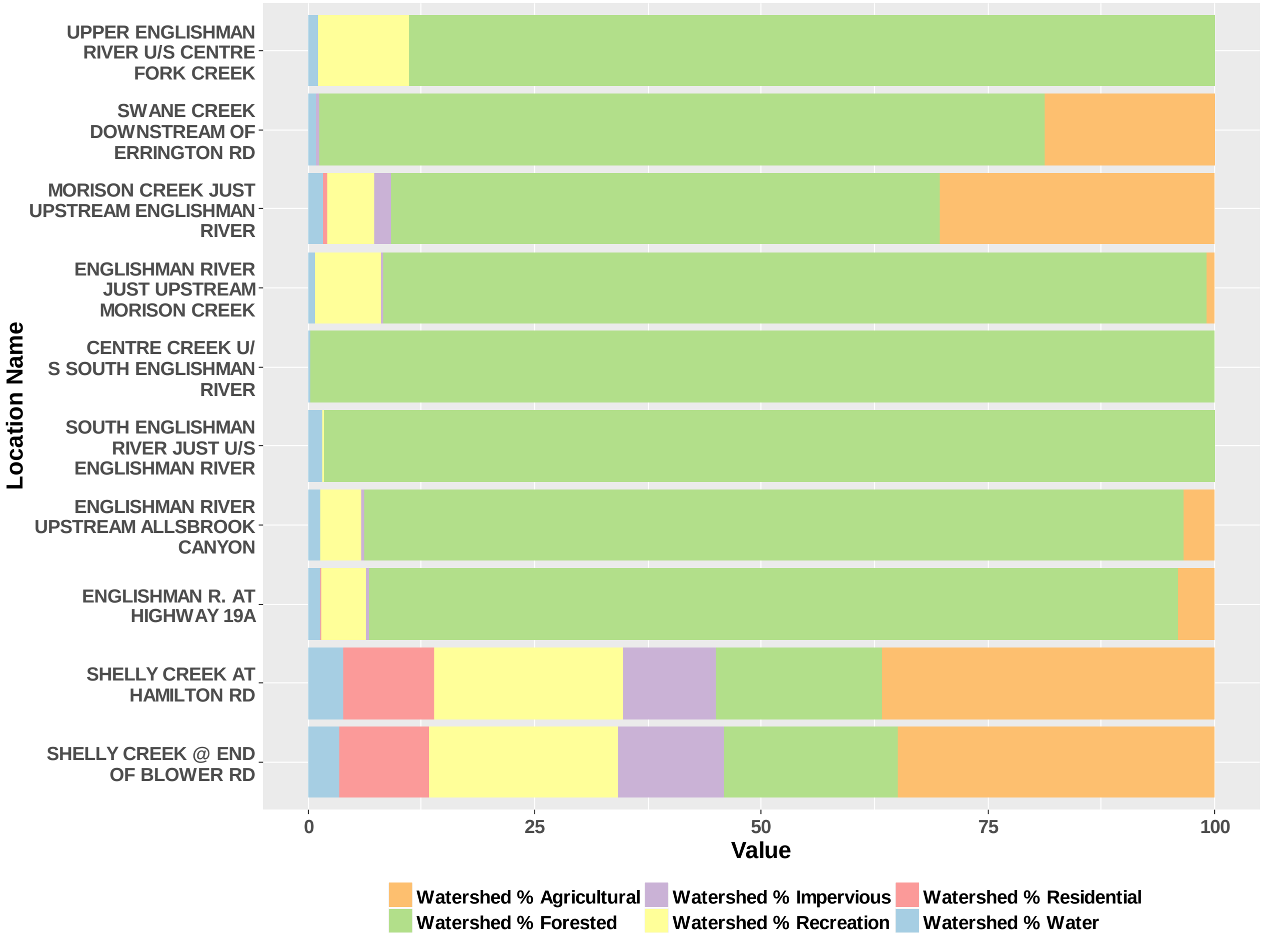

Figure 3-4: Percent land use composition for CWMN site watersheds of Water Region 4 (Englishman River).

3.4.2 Water Quality Summary and Trends

3.4.2.1 Temperature

All samples sites in the Englishman River water region had suitable water temperatures for aquatic animals in the fall (Figure A37). However, during summer low flows, water temperatures consistently exceeded the 15°C target and occasionally the 17°C target at all sites except the Upper Englishman River site (Figure A33). This higher water temperatures are likely a result of wide and shallow nature of the river in the lower reaches (Barlak et al. 2010).

3.4.2.2 Dissolved Oxygen

All sites in the Englishman watershed had DO concentrations suitable for aquatic life in the fall except Swane Creek and both Shelly Creek sites (Figure A38). These three sites also had water temperatures exceeding 17°C in summer low flows, when they also averaged DO below the 8 mg/L 30-day guideline (Figure A34). Average summer DO at Swane Creek was below 2.5 mg/L – a lethal threshold for most fish and many benthic invertebrates. A large portion of Swane Creek is ditched resulting in high oxygen consumption and very little turbulent mixing in this creek, both of which contribute to very low DO concentrations.

3.4.2.3 Conductivity

In the Englishman River water region results, Shelly Creek and Center Creek had the highest specific conductance, averaging >150 µS/cm in fall and >200 µS/cm in summer, suggesting groundwater influence (Figure A35). Additionally, Swane Creek has a large groundwater component with subsurface flows. Upper Englishman River had lower conductivity, generally below 70 µS/cm in both fall and summer flows, indicating a comparatively small groundwater contribution Figure A35 and Figure A39).

3.4.2.4 Turbidity

Turbidity exceedances occurred throughout this water region. In the fall, high turbidity was measured at all sites except those in the Upper Englishman River, and was >5 NTU at Swane and Shelly creeks (Figure A40). During summer low flows, turbidity exceedances >2 NTU were particularly evident at Swane and Shelly Creek sites, the same ones with frequent temperature and DO exceedances (Figure A36). Infrequent turbidity spikes were recorded at the Morison Creek and Englishman River sites. No turbidity spikes were detected at the upper watershed Englishman River sample sites.

3.4.3 Rainfall, Flows, and Water Quality

Fall conductivity, water temperature and turbidity were the only water quality variables that had significant relationships with rainfall in Water Region 4. Fall conductivity was negatively correlated to rainfall at the Upper Englishman River site, Englishman River upstream of Morison Creek, and Englishman River at Hwy 19A. When streams receive rainwater from runoff or rainfall the concentration of ions (conductance) get diluted. Fall turbidity was positively correlated to rainfall at the Upper Englishman River site, Morison Creek site, Englishman River upstream of Morison Creek, South Englishman River site, and Englishman River at Hwy 19A (Table A1). These five sites experienced spikes in turbidity on November 14, 2017 which was associated with heavy rainfall from November 11-14, 2017 (Figure A103). The increases in turbidity during periods of heavy rainfall is expected and is a result of increased mobilization of sediment in the watershed due to more runoff and increases in discharge which causes more bank erosion. Fall water temperature was positively correlated to rainfall at the Upper Englishman River site, Morison Creek site, South Englishman River site, and Englishman River upstream of Morison Creek (Table A1). However, these correlations had moderate strength and it thought to be a result of annual variability in fall air temperatures.

Englishman River at Parksville experienced a peak flow of 8.7 m^3/s on September 1 2015 this high flow event was associated with a rainfall event (Figure A118). There were six sites in the Englishman River Water Region sampled on this day. The turbidity of these sites on September 1 2015 was not elevated compared to other summer samples.

3.4.4 Trend Analysis

Five of seven sites in Water Region 4 had had suitable continuous datasets for trend analysis. These five sites are Englishman River at Highway 19A, Englishman River upstream of Morison Creek, Morison Creek, South Englishman River and Upper Englishman River. Trends were identified for turbidity at the Englishman River at Hwy 19A and DO for Englishman River Upstream of Morison from 2011-2017 (Table A2). Data from 2007-2017 was available for Englishman River at Hwy 19A and Englishman River upstream of Morison sites from another monitoring program. DO was stable at Englishman River upstream of Morison from 2007-2017. At Englishman River at Hwy 19A turbidity was also stable from 2007-2017.

3.4.5 Sites of Concern in Water Region 4

Three sites of concern identified for Water Region 4 were added to the CWMN program in 2014. Both Shelly Creek sites and the Swane Creek site are a concern because they have low and depleted DO, high summer temperatures and high turbidity. The reach upstream of the two Shelly Creek samples sites has a high percentage of fines and the channel banks are eroding (Law et al. 2016). Swane Creek is ditched and has limited riparian shading. However, restoration works were conducted from 2000-2007 along Swane Creek and were successful at reducing sediment sources from agricultural activities (Barlak et al. 2010).

3.5 Water Region 5 South Wellington to Nanoose

Water Region 5 covers approximately 322 km^2 and includes the City of Nanaimo and the District of Lantzville and parts of RDN Electoral Areas C, E and G. There is a hydrometric station on Millstone River south of Bowen Road in Nanaimo. There are rain gauges at Fairwinds Golf Course, City Hall, Nanaimo City Yard, Firehall #3 and Reservoir. The mean total rainfall at the Nanaimo City Yard from 1981 to 2010 was 28.8 mm, 37.0 mm, 99.2 mm and 179.1 mm for August- November, respectively.

3.5.1 Overview of Watersheds

Water Region 5 includes Millstone River, Chase River, Bonnell Creek, Craig Creek, Nanoose Creek and many smaller creeks. Nanoose Creek, Bonnell Creek, and Craig Creek are in the northern part of Water Region 5 and these creeks all drain into the ocean (Appendix B). The Lantzville Nanoose Streamkeepers, Island Water Fly Fishers, Departure Creek Streamkeepers, Walley Creek Streamkeepers, Vancouver Island Research Lab sample sites throughout Water Region 5. The Millstone River Watershed is north of the Chase River watershed. Catstream is a tributary of the Chase River while McGarrigle Creek and McClure Creek are both tributaries of the Millstone River. Walley Creek, Cottle Creek, Departure Creek, and Northfield Creek have small watersheds within the City of Nanaimo boundary. Knarston Creek and Bloods Creek also have small watersheds and are west of the City of Nanaimo boundary.

The Northern part of Water Region 5 is less developed than the Southern part of Water Region 5 and includes Craig Creek, and Nanoose Creek (Appendix B). The Craig Creek watershed borders the Englishman River watershed. Craig Creek has one site (E294017) that was sampled as part of the CWMN program. This site is upstream of Northwest Bay Rd and has a watershed with 49% forest and 37% rural agricultural (Figure 3-6). The Nanoose Creek watershed is south of Craig Creek. Nanoose Creek has two sites that are sampled as part of the CWMN monitoring program. The Matthew Crossing site (E294020) is also primarily forested with 1% rural/agricultural land. The furthest downstream site at Nanoose Campground (E294019) has a watershed that is also primarily forested with 16% rural/agricultural land.

Millstone River is in the middle of Water Region 5 and has four sample sites in the CWMN monitoring program. Brannen Lake is within the watershed of the four sites. Benson Creek flows into Brannen Lake and has one site at Biggs Road (E290477) that was sampled as part of the CWMN. The watershed is 84% forested and 13% agricultural/rural land and vacant industrial land (Figure 3-5). The nearby Biggs Road site on Millstone River (E290478) is 53% forested with 25% rural/agricultural land use. The Jingle Pot Rd (E306294) and East Wellington Road (E290480) sites have watersheds with 34% and 45% rural/agricultural and residential land. The furthest downstream site in Barsby Park (E290481) is similar to the East Wellington site; its watershed is composed of 36% forest, 35% rural/agricultural land and 11% impervious (Figure 3-5). The Barsby site has 2% more residential cover compared to the East Wellington Site.

McGarrrigle Creek has two sites and McClure Creek has one site that are sampled as part of the CWMN program. These creeks drain into Millstone River between the Jingle Pot Rd and East Wellington Road sites (Appendix A). The Upper McGarrigle site (E306254) is approximately 770 m upstream of the McGarrigle site at Jingle Pot Rd (E290479). The two McGarrigle sites have watersheds with a 62-63% rural/agricultural land and have some forested land with a portion that is zoned for recreation (Figure 3-5). Similarly, the McClure Creek watershed (E309187) is 63% agricultural and 34% forested.

Chase River is south of Millstone River and has four sites that are sampled as part of the CWMN monitoring program. The furthest upstream site is below the Colliery Dam (E290484). The watershed of the Colliery Dam site is 69% forested with 23% rural/agricultural land use and the remaining land use is a mix of residential, recreation, roads and water (Figure 3-5). Cat Stream flows into Chase River between the Chase River sites at Colliery Dam and Park Ave. Cat Stream has one site (E290486) that is sampled as part of the CWMN monitoring program. The Cat Stream watershed is primarily residential with some parkland. The three Chase River sites at Park Ave (E290485), Aebig Rd (E290483), and Estuary Park (E309280) are close together and hence have a similar land use percentages at the watershed level. These three sites have watersheds with approximately 14% residential, 55% forested, 18% Agricultural/Rural, and 8% impervious (roads, commercial, and industrial).

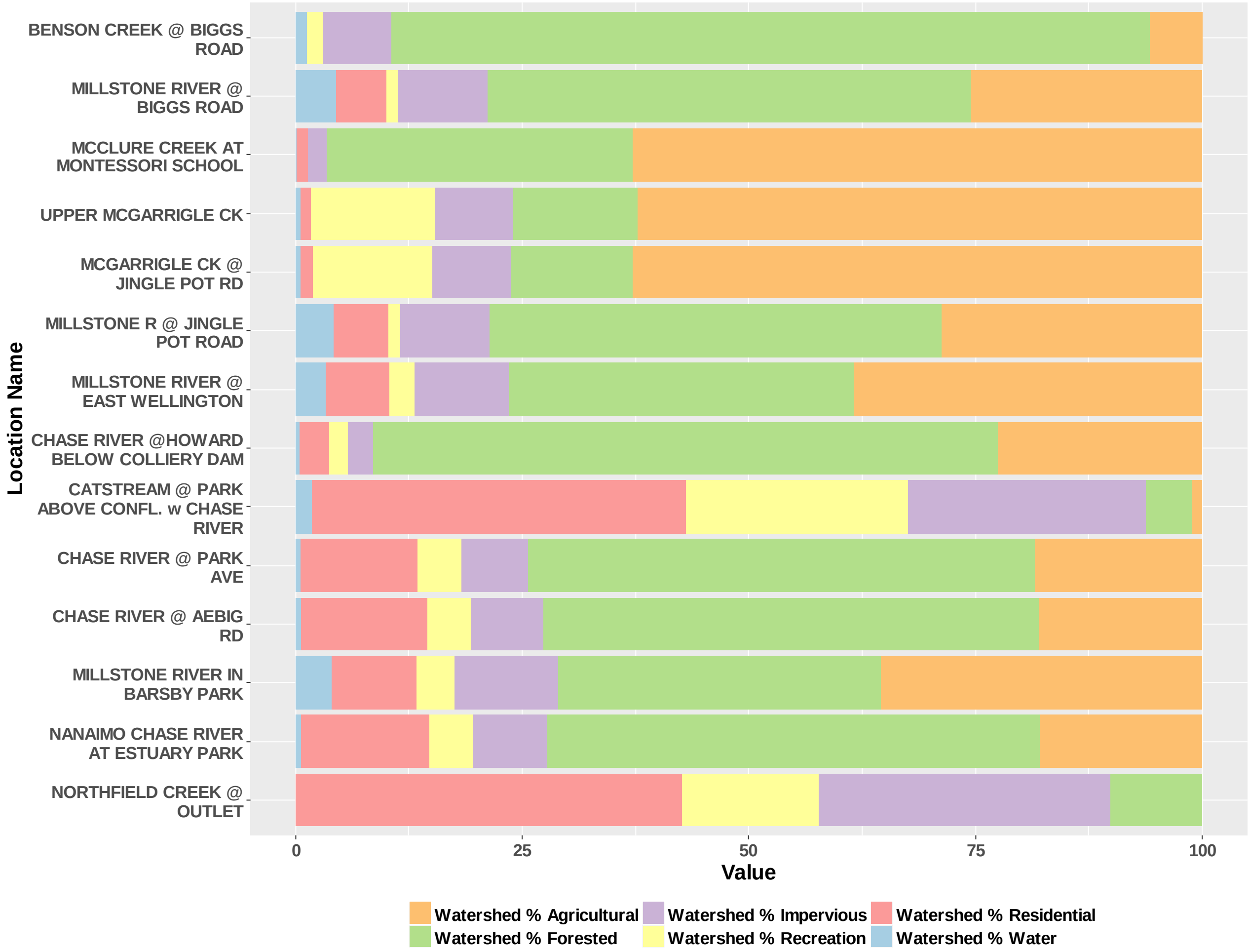

Figure 3-5: Percent land use composition for CWMN site watersheds of Water Region 5-2 (South Wellington to Nanoose).

Walley Creek, Departure Creek and Northfield Creek have the most developed watersheds. Walley Creek watershed includes three sites and Departure Creek includes four sites that are sampled as part of the CWMN monitoring program. All of the Walley Creek sites and the Departure Creek site at Neyland Rd (E290469) have watersheds that are characteristic of single family subdivisions. These watersheds are primarily residential land use (65-73%), with some park land and schools (recreation) and have a high density of paved roads (Figure 3-6). The Departure Creek site off Newton St (E290470) is on Joseph's Creek and has a watershed that is 78% residential. The lower two Departure Creek sites, at Woodstream Park (E290471) and Outlet (E290472, have less residential land use (48-59%) and more commercial and industrial land use. The Nanaimo Golf Club is within the watershed of Departure Creek. The watershed of Northfield Creek at Outlet (E290482) is primarily residential and impervious (roads, commercial and industrial). There are also some schools and park land within the Northfield Creek watershed.

The Cottle Creek watershed is most developed in the upper and lower reaches and has four sites that are sampled as part of the CWMN monitoring program. The furthest upstream site at Landalt Road (E290476) has a watershed that is primarily residential at 69%, with 2% parkland and a wetland (Figure 3-6). The North Cottle Creek site (E290474) is downstream from Lost Lake and has a watershed that is 72% rural residential. The three Cottle Creek sites at Nottingham (E290473), Hammond Bay Rd (E309186) and Stephenson Pt Rd (E290475) are a mix of single family and rural residential with some forested conservation land. The conservation land is between the Landalt Rd site and the Nottingham Rd site. The watershed of the Cottle Creek site at Nottingham has 28% single family residential compared to 31-32% at the two downstream sites at Hammond Bay Road and Stephenson Pt Rd.

The watersheds of Knarston Creek and Bloods Creek have moderate levels of development. Knarston Creek has two sites sampled by the CWMN program. The watershed of the Knarston Creek at Superior Rd (E306255) site is primarily forest with 17% rural and agricultural land (Figure 3-6). There is a large wetland and a golf course within the Superior Rd site watershed. The further downstream site near Lantzville Road (E294013) has the same dominant land uses. However, the Lantzville Road watershed has 22% rural and agricultural land and 2% residential land. Bloods Creek-has one sample site that is regularly sampled as part of the CWMN program. The Dickenson Rd site (E294010) has a watershed that is a mixture of rural residential, single family residential and commercial land use.

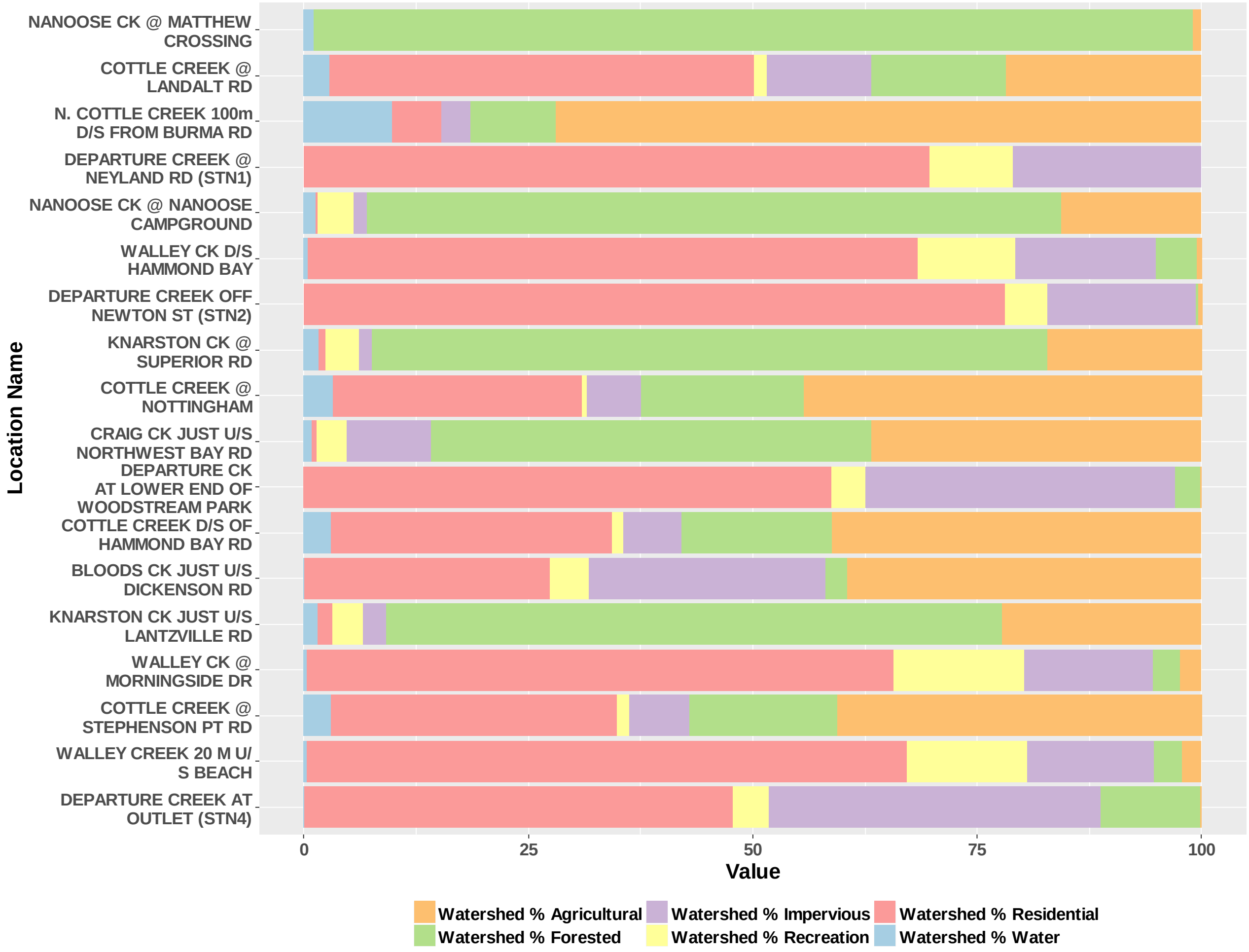

Figure 3-6: Percent land use composition for CWMN site watersheds of Water Region 5-1 (South Wellington to Nanoose).

3.5.2 Water Quality Summary and Trends

3.5.2.1 Temperature

All samples sites in Water Region 5 had suitable water temperatures for aquatic animals in the fall (Figure A49 and Figure A50). However, during summer low flows, water temperatures regularly exceeded the 15°C target at all but 6 sites; these were Benson Creek, Nanoose Creek at Matthews Crossing, Craig Creek, Knarston Creek at Superior, and Departure at Neyland Rd. (Figure A41 and Figure A42). The watersheds of Benson Creek, Nanoose Creek at Matthew Crossing and Knarston Creek at Superior are >75% forested with <20% agricultural and rural land use. However, the watersheds at Departure Creek at Neyland Rd and Craig Creek are more developed. Therefore, lower summer water temperatures cannot be linked to development.

The sites with the warmest average summer water temperatures that exceeded the 17ºC coho rearing guideline included: Millstone River at Biggs Rd., Millstone River at East Wellington –(both of which receive warm lake water) Chase River below Colliery Dam, Chase River at Park Ave, Chase River at Estuary Park, and Cat Stream (Figure A42). The Millstone River site at Biggs Road is fed by the warm surface water of Brannen Lake. Both the Millstone River sites at Biggs Rd and East Wellington Rd lack riparian tree and shrub cover (Clough 2016a). The Chase River sites are all below the Colliery Dam. Surface releases from this dam elevate water temperatures during low flow periods. Cat Stream had an upstream wetland in Robins Park with minimal tree canopy, resulting in elevated water temperatures. The hottest summer water temperatures averaged 21°C at Chase River at Estuary Park. To attain those temperatures, this site was likely unshaded, shallow and slow flowing.

3.5.2.2 Dissolved Oxygen

All sites in the Water Region 5 had DO measurements suitable for aquatic life in the fall except Walley Creek downstream of Hammond Bay (E306256), however it averaged >8 mg/L DO overall (Figure A51). This site was added to the monitoring program in 2016 and has a stormwater outfall directly upstream. During summer low flows, sites with average DO below 5.0 mg/L include Benson Creek, Nanoose Creek at Matthew Crossing, and Cottle Creek at Nottingham (Figure A43 and Figure A44). These three sites all had DO values that were well below saturation for their respective water temperatures (Figure A133 and Figure A134). The causes of depleted DO at Nanoose Creek at Mathew Crossing are unknown. However, depleted oxygen levels at the Benson Creek site may be a result of sedimentation from nearby sand and gravel industry. It is suspected the DO at Cottle Creek at Nottingham site is being impacted by the nearby residential home construction that has been ongoing in recent years. Increased sediment loads from construction or other industrial activities can reduce the available light in the water column and increase the water temperature. Less available light results in a reduction of photosynthesis from aquatic plants and algae and hence less DO. DO levels become further depleted because warm water holds less DO.

A large number of sites had mean summer DO below 8.0 mg/L and had DO >20% below saturation (Figure A133 and Figure A134). The sites with low mean summer DO are influenced by groundwater, which has low concentrations of DO. However, sites that were the closest to the ocean (i.e. furthest downstream) are less influenced by groundwater and had higher mean summer DO and had DO close to saturation. These sites included Chase River at Aebig and Estuary Park, Millstone at Barsby, Walley Creek at Morningside and upstream of Beach, Knarston Creek near Lantzville, Bloods Creek, and all the Departure Creek sites.

3.5.2.3 Conductivity

Average specific conductance in Water Region 5 varied widely between 35 to 400 µS/cm in the fall and between 75 to 500 µS/cm during summer low flows (Figure A53 and Figure A54). The outlier occurred at the Nanaimo Chase R site where average summer conductivity exceeded 1000 µS/cm, suggesting saline influence (Figure A46). Conductivity in Nanoose, Departure, Cottle and Walley creeks indicates a significant groundwater component to their low summer flows (Figure A45). High conductance in Departure, Cottle and Walley creeks could also be associated with stormwater as these creeks are in developed areas. The high conductance at the three Chase River sites (Park Avenue, Aebig Rd and Estuary Park) are probably associated with ocean spray.

3.5.2.4 Turbidity

Turbidity exceedances occurred throughout Water Region 5 in both seasons. In the fall flush, turbidity >5 NTU was measured infrequently at most sites (Figure A55 and Figure A56). Northfield Creek frequently exceeded the 2 NTU guideline during the summer sampling period (Figure A48). During summer low flows, turbidity exceedances were particularly evident at Northfield Creek, Walley Creek d/s Hammond Bay, at McClure Creek, and Millstone River at Jingle Pot Rd, and Cat Stream (Figure A47 and Figure A48). The Northfield Creek site was dropped from the monitoring program in 2015, whereas Walley Creek d/s Hammond Bay was added in 2016 and McClure Creek was added in 2017. The Northfield site is known to receive stormwater runoff from an industrial area and is now understood to be monitored by a separate City of Nanaimo program. High summer turbidity at the Millstone River site at Jingle Pot Rd is likely a result of bank erosion occurring near Biggs Rd and lack of riparian cover (Clough, 2016a). On September 2, 2014, Northfield Creek and Walley Creek d/s Hammond Bay very high turbidity values (>20 NTU) were associated with a rainfall event. Another rainfall event, on September 2, 2016 resulted in turbidity >20 NTU at Walley Ck d/s Hammond Bay and Departure Creek at Woodstream Park.

3.5.3 Rainfall, Flows, and Water Quality

Fall turbidity and conductivity had the strongest relationships with rainfall in Water Region 5. Fall conductivity had a negative correlation with rainfall at the Chase River at Aebig Rd, Craig Creek, Nanoose Creek at Matthew Crossing, Departure Creek at Neyland Road and McGarrigle Creek sites. The negative correlation is the result of a dilution effect because rainfall has lower conductance. The three upper Chase River sites, the two lower Cottle Creek sites, the three lower Departure Creek sites, the two lower Millstone River site, the two Nanoose Creek sites, the Craig Creek site, the McGarrrigle Creek site, and Cat Stream site had a positive correlation with rainfall and fall turbidity. The two lower Cottle Creek sites experienced turbidity spikes on November 3, 2015 and November 17, 2017. Both these turbidity spikes were associated with heavy rainfall. On November 14, 2017 three lower Departure Creek sites, two Chase River sites, two Millstone River sites and the McGarrrigle Creek site also had spikes in turbidity associated with heavy rainfall. From November 11-14, 2017 there was ~120 mm of rainfall (Figure A101). These turbidity spikes support that heavy rainfall increases the mobilization of sediment in the watershed. During intense rainfall events the ground becomes saturated in places and the amount of runoff increases. Fall temperature was negatively correlated with rainfall at Departure Creek off Newton St (Table A1). However, this correlation had moderate strength and it thought to be a result of annual variability in fall air temperatures.

At the Millstone River hydrometric station (south of Bowen Road) there were flows greater than 0.1 m^3/s in the summer low flow sampling periods of 2014 and 2016 (Figure A119). The 0.17 m^3/s flow on August 2, 2016 and 0.13 m^3/s flow on August 2, 2014 were associated with a rainfall event (Figure A80). There were 23 sites in Water Region 5 sampled on August 2, 2016. Some of these sites had very turbidity levels on this date.

3.5.4 Trend Analysis

Fourteen of 37 sites in Water Region 5 had suitable continuous datasets for trend analysis. These sites included the four Departure Creek sites, the Cottle Creek sites at Nottingham and Stephenson Pt Rd, the four Millstone River sites, the three upper Chase River sites, and Cat Stream. Conductivity data showed an increasing trend over the sample years at Cat Stream (Figure A144), possibly due to a combination of stormwater runoff and garden waste dumped in a nearby wetland (Clough 2017b). This site was also identified as a concern for high total phosphorus on August 25, 2015, and that TP may have resulted from an isolated runoff event (Barlak and Pisani, 2017).

3.5.5 Sites of Concern in Water Region 5

The two sites of concern in Water Region 5 are Cat Stream and Walley Creek at Hammond Bay and both are adjacent to stormwater outlets. Walley Creek at Hammond Bay was added to the CWMN program in 2016. In 2016 and 2017, this site had low DO and high turbidity. However, the two downstream Walley Creek sites had lower turbidity and high DO. This suggests the stormwater outlet is a source of suspended sediment and possibly nutrients. The other site of concern, Cat Stream, has high turbidity, warm summer water temperatures and conductivity has been increasing from 2012-2017. Robbins Park is upstream of the Cat Stream site and is thought to be a heat source because the stream flows through a ball field wetland (Clough 2017b). We agree that riparian planting should occur around the ball field as prescribed by Clough (2017b).

3.6 Water Region 6 Nanaimo River

Water Region 6 is the largest water region and covers approximately 939 km^2. The Nanaimo River water region includes a portion of the City of Nanaimo and RDN Electoral Areas A and C. There is a hydrometric station on Nanaimo River near Cassidy downstream of the climate station at the Nanaimo Airport. The South Nanaimo River also has hydrometric station. There are additional rain gauges at Firehall #4 and Jump Creek. The Jump Creek and South Nanaimo River results have not been presented because these sites were far from any CWMN site. Mean daily temperatures from 1981 to 2010 were 18.2°C for August and 14.9°C for September. For the fall sampling period, mean daily temperatures from 1981 to 2010 were 9.9°C for October and 5.6°C for November. The mean total rainfall at the Nanaimo Airport from 1981 to 2010 was 28.4 mm, 35.8 mm, 101.2 mm and 186.5 mm for August-November, respectively.

3.6.1 Overview of Watersheds

The Nanaimo River is the largest river within the studied Water Regions. The five sites that are sampled as part of the CWMN program are concentrated in the lower portion of the Nanaimo River Water Region and have an elevation <30 m (Appendix D). The Nanaimo and Area Land Trust samples all sites except for Beck Creek. The Vancouver Island University Research Lab samples Beck Creek. The regulation of flows from distant upstream dams have a limited influence on these sites (Butler et al. 2014). Haslam Creek is the major tributary to the Nanaimo River in the sampling area and it flows into the Nanaimo River north of Nanaimo Airport. Both Beck and Holden Creek flow into the Nanaimo River Estuary.

The upper part of the Nanaimo River watershed includes the four Nanaimo lakes and is primarily forested. The Nanaimo River site downstream of Haslam Creek (E287699) has a watershed that is 83% forested with 7% agricultural/rural land (Figure 3-7). There is industrial land use associated with an asphalt plant, and sand and gravel in the lower portion of this site’s watershed. The further downstream, the Nanaimo River site at Cedar Rd Bridge (E215789) is 80% forested but has more rural and residential development in its lower watershed (10%).

Haslam and Beck creeks each have one site that is sampled as part of the CWMN program. The Beck Creek watershed includes a few large wetlands along with Beck Lake. The Beck Creek site (E290487) has a watershed that is a mixture of 47% single family and rural residential development, 41% agricultural land and 32% land zoned for industrial use (Figure 3-7). A large portion of the land zoned for industrial use in this watershed is in the process of being rezoned as part of the Sandstone Development (Northwest Properties 2009). The Haslam Creek watershed (E287700) includes Michael Lake and a large portion of Nanaimo Airport. The watershed is 74% forested with 19% agricultural land use.

There are two sites on Holden Creek that are sampled by the CWMN program. The Holden Creek watershed contains Holden Lake and Quennell Lake and has over 50% rural and agricultural land use (Appendix A). The watershed of the Lower Holden Creek is more developed then the Holden Creek watershed (E310147). The Lower Holden Creek watershed (E309281) has development associated with land that is zoned for industrial use (currently vacant).

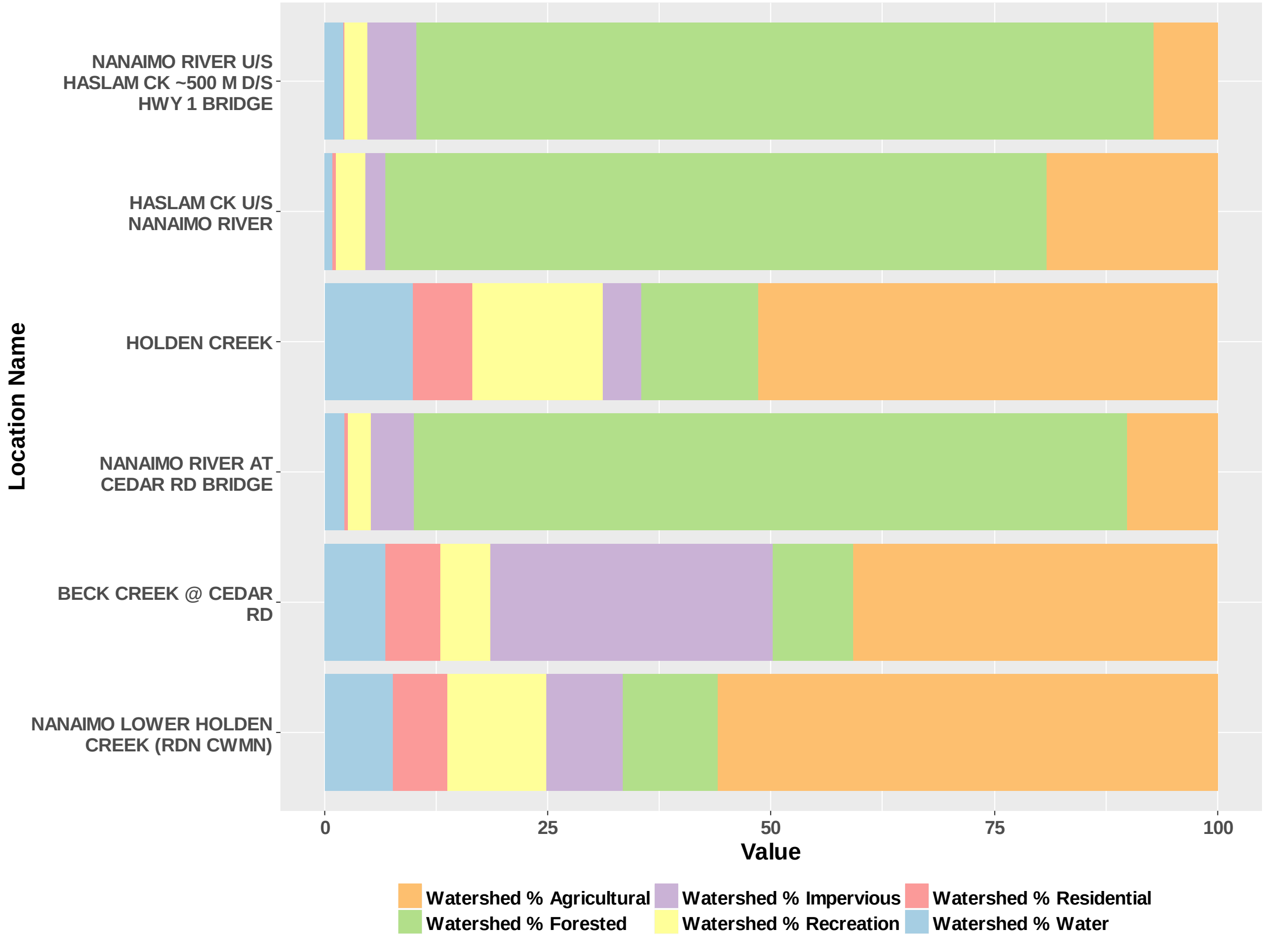

Figure 3-7: Percent land use composition for CWMN site watersheds of Water Region 6 (Nanaimo River).

3.6.2 Water Quality Summary and Trends

3.6.2.1 Temperature

All samples sites in the Nanaimo River Water Region 6 had suitable water temperatures for aquatic animals in the fall (Figure A61). However, during summer low flows, water temperatures consistently exceeded the 15°C target and 17°C coho rearing guideline at all Nanaimo River sites and the Lower Holden Creek site (Figure A57). The Lower Holden Creek site receives warm surface flows from Holden Lake. The higher water temperatures at the Nanaimo River sites are likely a result of wide and shallow nature of the river.

3.6.2.2 Dissolved Oxygen

All sites in Water Region 6 had DO concentrations suitable for aquatic life in the fall except for the Lower Holden site that averaged 7.9 mg/L (Figure A62). The Lower Holden Creek site was added in 2017 to the CWMN program and is ditched. During summer low flows, Nanaimo River sample stations with consistent high water temperature also had DO below 8 mg/L, while Haslam Creek and Holden Creek had the lowest DO, averaging 7.2 and 4.6 mg/L DO, respectively (Figure A58). Holden Creek drains warm surface water from Holden Lake and the Holden Creek site was added in fall 2017. It was rated as having poor bank stability due to historic forestry, farming and residential practises, however, recovery is underway (Clough 2016b).

3.6.2.3 Conductivity

Specific conductance readings in the Nanaimo River water region were higher than in the other water regions at several sites in both seasons. For example, during summer low flows, Beck Creek averaged 500 µS/cm, possibly due to historical coal mining in this watershed, and Lower Holden Creek averaged 20,000 µS/cm, the later indicating its intertidal habitat (estuary) influence (Figure A59 and Figure A63).

3.6.2.4 Turbidity

Turbidity exceedances occurred consistently at the Lower Holden Creek site and periodically at Beck Creek during both seasons. Otherwise turbidity spikes were rare in Water Region 6, resulting in average values of <2 NTU throughout (Figure A60 and Figure A64).

3.6.3 Rainfall, Flows, and Water Quality

The Nanaimo River upstream of Haslam Creek and the Beck Creek site had some significant correlations between fall rainfall and water quality (Table A1). Fall turbidity was positively associated with rainfall at the Nanaimo River and Beck Creek sites. High turbidity values at the Nanaimo River site upstream of Haslam Creek and Beck Creek on November 14 and 21, 2017 were associated with heavy rainfall (Figure A100). Fall conductivity was negatively associated with rainfall at Beck Creek. Rainfall causes mobilization of sediments which increases turbidity, whereas decreases in conductivity are a result of stream flow dilution.

The Nanaimo River hydrometric station at Cassidy experienced a peak flow of 27.9 m^3/s on September 2 2015 (Figure A120). No sites in Water Region 6 were sampled on this day or the two days following the high flow event.

3.6.4 Trend Analysis

The Nanaimo River upstream of Haslam and Beck Creek were the only sites in Water Region 6 that had suitable continuous datasets for trend analysis. Trend analysis identified that Nanaimo River has increasing turbidity and water temperature trends and decreasing DO trends over the 2011-2017 dataset. These trends may be amplified by high values associated with rainfall events and should be further investigated. For example, two very high turbidity values of ~3.5 NTU were recorded on November 11 and 21, 2017. These dates were associated with high flows and rainfall events. The increasing water temperature trend is likely related to annual differences in air temperature. The average summer temperature of the Nanaimo River was below 20°C from 2011-2013 but was above 20°C from 2016-2017. Summer dissolved oxygen concentrations show the effect of water temperature, with average summer DO at this site above 8 mg/L from 2011-2013 and below 8 mg/L from 2016-2017(Figure A148).

3.6.5 Sites of Concern in Water Region 6

The three sites of concern in Water Region 6 are Nanaimo River upstream of Haslam Creek, Lower Holden Creek, and Holden Creek. Lower Holden and Holden Creek were added to CWMN program in 2017. The 2017 data for these sites suggest depleted DO in the summer. Lower Holden Creek was previously identified as having nutrient loading from adjacent agriculture and from limited riparian vegetation (Clough 2016b). Recommended restoration actions for Lower Holden Creek included tree planting along riparian area and culvert repairs (Clough 2016b). However, some of water quality trends at Nanaimo River upstream of Haslam Creek can be explained by annual variation. We recommend that this site be closely monitored because of its proximity to the Nanaimo Airport and to agriculture, both of which are known contributors of water with periodic excessive oxygen demand (Canadian Council of Ministers of the Environment 1999).

3.7 Water Region 7 Gabriola Island

Water Region 7 includes all of Gabriola Island and has an area of 52.6 km^2. Only one creek with one site was sampled on Gabriola Island – Mallett Creek (E304070). The Gabriola Streamkeepers started sampling this site in 2015. The Mallett Creek watershed is primarily rural residential and agricultural and includes a wetland (Figure 3-8). The CWMN sample site on Mallett Creek is approximately 50 m east of Taylor Bay Rd and at only 2 m.a.s.l. The closest climate station to Gabriola Island is Entrance Island. Mean total rainfalls and daily temperatures from 1981-2010 are not available for

Entrance Island because monitoring started in 2006. However, Water Region 7 has a similar climate to Water Region 5.

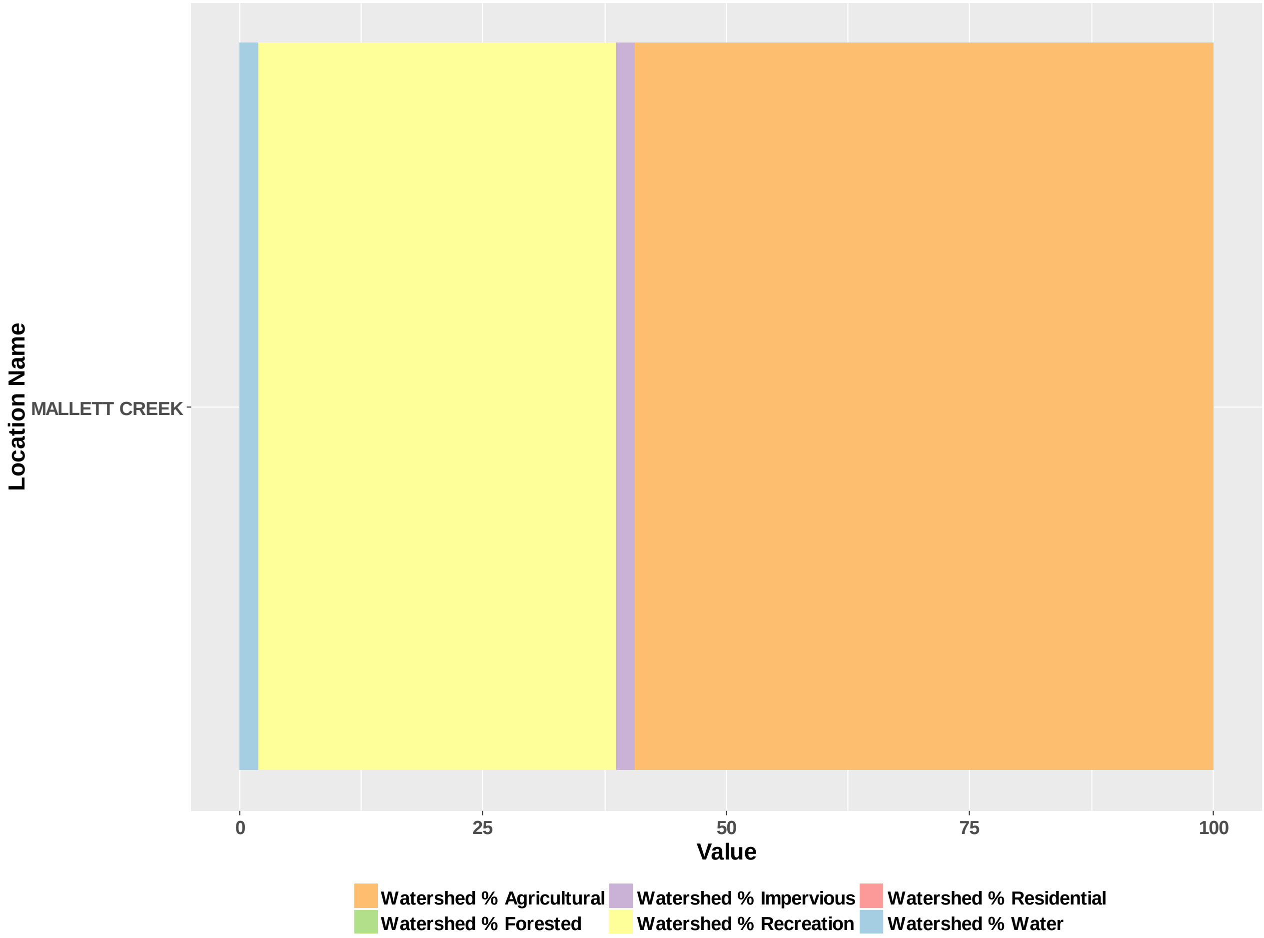

Figure 3-8: Percent land use composition for Mallett Creek watershed in Water Region 7 (Gabriola Island).

3.7.1 Water Quality Summary and Trends

3.7.1.1 Temperature

The Mallett Creek sample site had suitable water temperatures for aquatic animals in the fall (Figure A69). However, during summer low flows, water temperatures consistently exceeded the 15˚C target but rarely exceeded the 17˚C target, averaging 15.5˚C (Figure A65).

3.7.1.2 Dissolved Oxygen

Mallett Creek had DO concentrations suitable for aquatic life in the fall, while summer low flows had low DO in 60% of samples, and averaged 7.8 mg/L over the 2015 -2017 dataset (Figure A70 and Figure A66).

3.7.1.3 Conductivity

Mallett Creek averaged 110 µS/cm specific conductance in the fall and 142 µS/cm during summer low flows, suggesting groundwater influence (Figure A71 and Figure A67).

3.7.1.4 Turbidity

Turbidity values in Mallett Creek exceeding 5 NTU were common, with average values >6 NTU over the dataset in both seasons, suggesting impaired watershed functions (Figure A68 and Figure A72).

3.7.2 Sites of Concern in Water Region 7

The Mallett Creek site is a site of concern because of its high turbidity levels.

3.8 Water Quality Statistical Models

Random Forest statistical models were used to identify if watershed position or land use has an effect on temperature, dissolved oxygen, conductivity and turbidity. Random Forest models are an ensemble learning method, meaning they use multiple learning algorithms to improve predictive performance and are a useful tool to consider multiple criteria that may affect water quality simultaneously. Turbidity, dissolved oxygen, conductivity and temperature are water quality parameters referred to as responses in a statistical model. To build the models, key factors that could affect water quality, referred to as predictors, were generated. Predictors are things such as the percent coverage of land use, either within the 500 upstream buffer, or within the watershed as a whole, that could have an effect on water quality. For the models, both natural and urban variables were considered as potential predictors. Thus, for each modelled response (e.g., Turbidity or Oxygen), numerous different human-caused and natural (e.g., elevation) predictors were considered. Figure 3-9 and Figure 3-10 identify the top ten predictors or factors that affect each water quality parameter, meaning that these variables were the most important criteria in predicting water quality. The larger the variable importance the better the predictor is to explain water quality. Typically, the top two or three parameters are the most reliable predictors or factors.

The modelled effects of each predictor (land use variable) and the predictive accuracy of each model are presented in Appendix H. Most predictors did not affect water quality in a linear fashion because the water quality parameters modelled were curves, meaning that effects were more apparent as certain thresholds were reached. This type of response is well documented in the literature, where specific effects are not readily apparent until a threshold is met, at which point, change is observable. Specific details for each different response are found below.

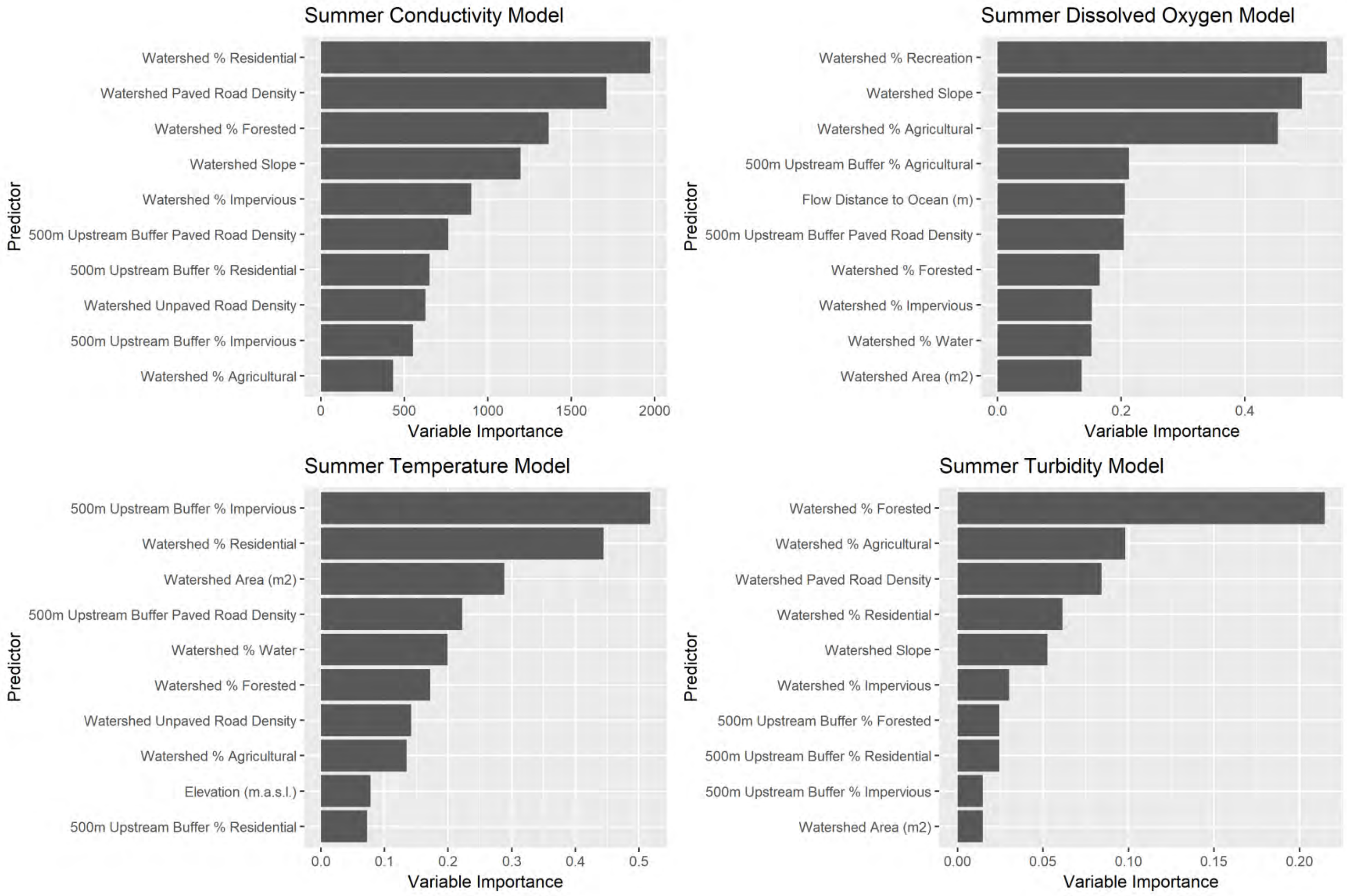

Figure 3-9: Variable importance plots for summer water quality models.

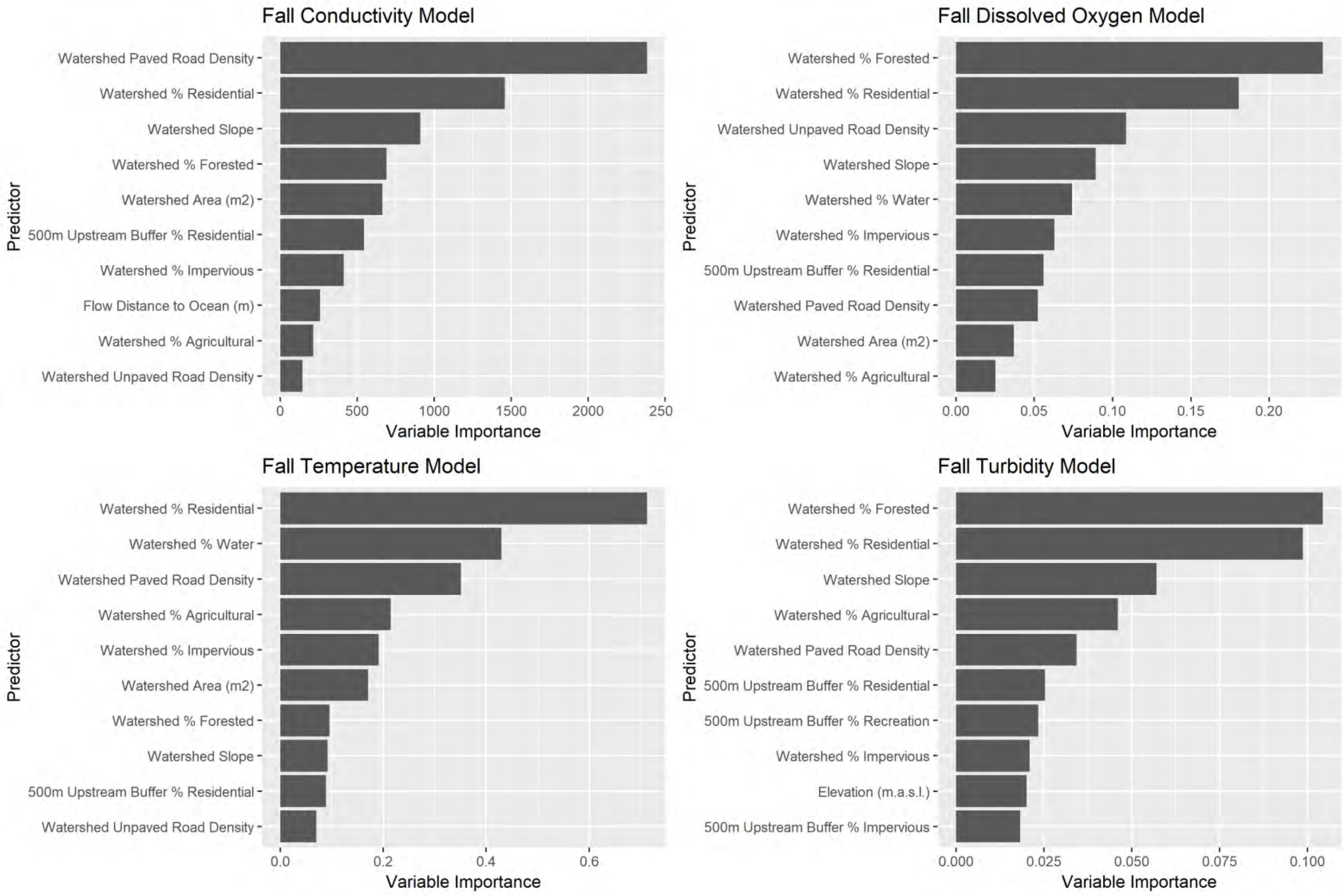

Figure 3-10: Variable importance plots for fall water quality models.

3.8.1 Temperature Models

The summer water temperature model suggests that a more developed watershed with more residential, industrial, and commercial land use has watercourses with warmer summer water temperatures (Figure 3-9 and Figure A149). In addition, rivers with large watershed areas such as the Nanaimo River, Englishman River, and Little Qualicum River have warmer summer water temperatures. These sites with bigger watershed areas are found at lower elevations and have less shading because they are wider watercourses. Warmer water temperatures in the fall are associated with watersheds with higher residential and paved road densities, and with upstream lakes (Figure 3-10 and Figure A150). In the fall, streams cool down faster than lakes, indicating that the larger upland lakes supply warmer water to downstream watercourses. Thus, the models suggest that both natural and anthropogenic factors affect water temperatures within the watershed.

3.8.2 Dissolved Oxygen Models and Turbidity Models

The summer Dissolved Oxygen model suggests that watershed with steeper slopes and those with lower densities of agricultural land and more green space have streams with higher dissolved oxygen concentrations (Figure 3-9 and Figure A151). Most of the streams in watersheds with high agricultural use in the RDN are ditched and lack riparian vegetation. These ditches are prone to slow-moving waters that are highly productive and warm, resulting in DO depletion. For the fall DO model, higher dissolved oxygen concentrations are associated with streams that have forested watersheds with steep slopes and unpaved roads, and a low density of residential development (Figure 3-10 and Figure A152). Watersheds with steeper gradients have greater DO because the turbulence within a stream increases with increasing grades and this turbulence acts to introduce more oxygen into the stream. Additionally, the steeper watersheds tended to occur at higher elevations, where cooler water temperatures maintain higher DO.

Both the fall and summer turbidity models indicate that streams in watersheds that have a higher density of paved roads and residential development, and those that have more agricultural land uses, tend to have higher turbidity (Figure 3-9 and Figure 3-10) than watersheds dominated by forest cover. Additionally, agricultural land use in the watershed was more important in the summer turbidity model compared to the fall turbidity model, likely because the effects of agriculture were more apparent during the low flow period. Streams that are in agricultural or urban areas often have less riparian vegetation, and are frequently channelized or straightened. Less riparian vegetation results in increased bank erosion, releasing more suspended sediment (Quinn et al. 2010). Watersheds that have more agricultural or urban land use also contribute higher suspended sediment loads to streams (Lenat and Crawford 1994). In contrast to these impacted watersheds, forested watersheds commonly have low water turbidity because the stream banks of these watersheds are stable and release less sediment to the system than developed streamside areas.

Like turbidity, the effect of agricultural land use on DO was stronger in the summer models. In the warmer low flow periods the effects of sedimentation, lack of riparian shading and enrichment are greater in watersheds with high agricultural land use. For example, during low- moderate flow periods, agriculture has been found to contribute large sediment loads to streams (Lenat and Crawford 1994). The lack of riparian shading in warmer summer month's results in increased stream water temperatures that hold less dissolved oxygen (Quinn et al. 2010). The warmer water temperatures also facilitate higher rates of decomposition that lead to further dissolved oxygen depletion. Additionally, watersheds with high agricultural land use contribute more nutrients to streams that induce higher primary production (Henderson et al. 2014), with greater day-to-night DO oscillations.

3.8.3 Conductivity Models

Both the fall and summer conductivity models suggest that streams with watersheds that are developed with high densities of paved roads and residential development have higher conductivities (Figure 3-9 and Figure 3-10). The direct relationship between development and conductivity is complex. Figure A155 shows conductivity increases substantially when residential development is greater than 0%. Residential development is likely accounting for conductivity differences in Water Regions. For example, Water Region 1 is the least developed Water Region and also has sites with the lowest conductivity relative to other Water Regions. Some sites in Water Region 1 have moderately developed watersheds but have low conductances. For example, Deep Bay Creek has a median summer conductivity of 68 µs/cm and has 32% of land use associated with impervious surfaces. This suggests Water Region 1 may have lower conductances naturally that are probably associated with soil type and surficial material, and more rainfall is this water region. However, we suspect that agricultural, residential, industrial and commercial land uses are sources of fertilizers and other pollutants which increase the conductance of streams. The positive relationship between urban land use (impervious surfaces) and stream conductivity has been reported in many regions (Kaushal et al. 2005; Morgan et al. 2012; Wang and Yin, 1997; Jones et al. 2017). The effect of impervious surfaces on stream conductivity is thought to be a threshold effect (Morgan et al. 2012) meaning once a certain level of urbanization or road density has been reached, there is little change in conductivity. However, before the threshold is reached, large changes in stream conductivity can occur. Figure 3-11 indicates that the threshold for paved road density is ~0.002 m/m2.

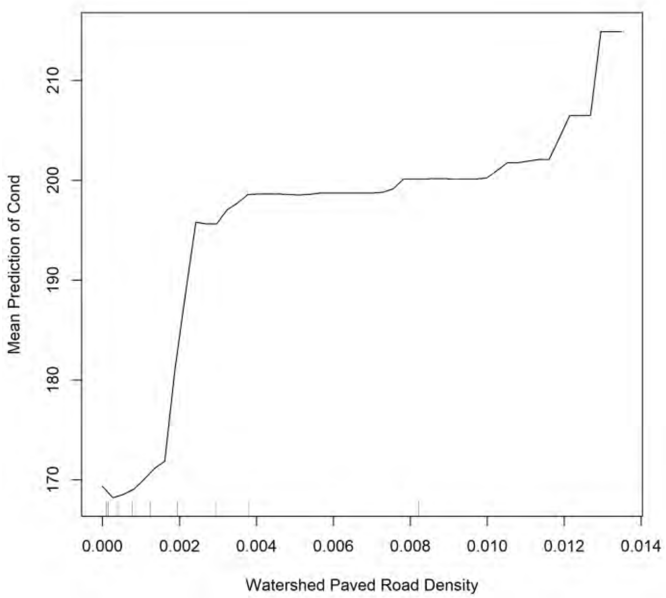

Figure 3-11: Partial Dependence plot for summer conductivity model shows paved road density has a threshold effect on conductivity.

3.8.4 Land Use Thresholds

The water quality models support that there are threshold effects of percent forested, percent agricultural, and paved watershed densities at the watershed level. The fall DO model, and all turbidity and conductivity models indicate that when forest cover is reduced to less than 60%, changes in turbidity, conductivity and DO become apparent (Figure 3-12). All turbidity and conductivity models indicate when watershed paved road densities are greater than 0.002 m/m^2 there are large changes in turbidity and conductivity (Figure 3-11). There are large changes in summer turbidity when the percent agricultural/rural land use in the watershed are greater than 20% (Figure 3-13).

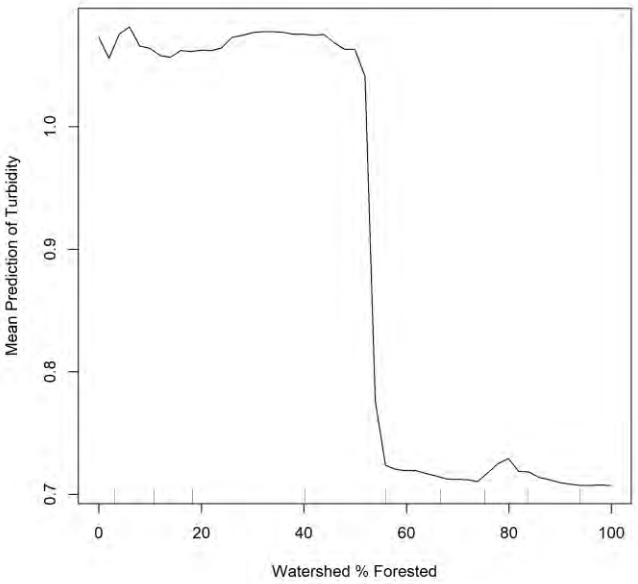

Figure 3-12: Partial Dependence plot for summer turbidity model shows percent forested has a threshold effect on turbidity.

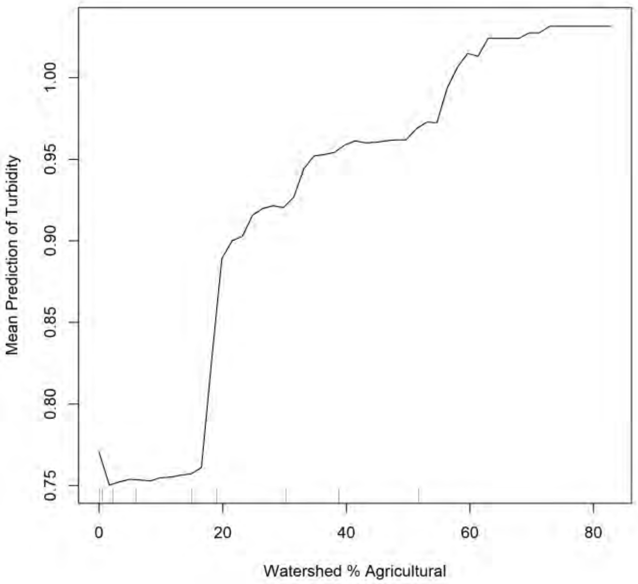

Figure 3-13: Partial Dependence plot for summer turbidity model shows percent agricultural/rural has a threshold effect on turbidity.

4 SUMMARY

Long term monitoring programs are integral to an adaptive management strategy, and are particularly important when conditions are ever changing. Data collection and analysis is the only method to ensure that appropriate information is available to make informed land use decisions. Continuing the CWMN monitoring program is important to meet these objectives and will help with identifying long-term trends in water quality of the watercourses of RDN, particularly those associated with land use change. Trend analysis was conducted for 35 of the 62 active sites. We suspect some of the trends identified were a result of annual variations in air temperature and rainfall because conductivity and turbidity are sensitive to changes in flow associated with rainfall in the fall flush period. Ongoing data collection ensures that the observed trends and interpretation are not erroneous or the result of extreme years (i.e. record rainfall such as November 2017).

Our analytical approach was to consider the entire watershed to facilitate a better understanding of both natural and anthropogenic factors that may affect water quality in the RDN. It is critically important to understand factors that affect the natural variability of stream water because this provides a baseline understanding of natural patterns in water quality. Once the natural patterns are known, the influence of anthropogenic effects can then be determined. Our results suggest some differences in water quality are a result of upstream lakes, watershed slope, channel width, ocean influence and climate (rainfall), which are all natural factors that vary and that variability is largely beyond the control of the RDN or member municipalities. However, the statistical models implemented in this report show that the extent of development or urbanization in a watershed are the most important factor in explaining differences in water quality among watercourses in the RDN. Thus, it is clear that the RDN or member municipalities play an integral role in water quality in the watershed, and the land use decisions should be carefully considered. For instance, the removal of riparian vegetation results generally results in streams that have lower DO and warmer water temperature as an example. Other changes such as stream channelization and agricultural activities can also cause depletion of DO. Land use ultimately influences all aspects of the watershed, and watershed disturbances such as agricultural activities or changes from rural / natural areas to urban space has the potential to mobilize sediments and further affect water quality. Once portions of a watershed become urban in nature, it is nearly impossible, or at the very minimum, extremely expensive to return to a natural state. Thus, urban changes such as storm water discharges, which have the potential to increase the conductivity of streams by the contribution of pollutants, must be carefully considered.

While our analyses do not answer all questions, they do suggest that certain thresholds may be present and that water quality impacts increase once the threshold is reached. This result is common in the literature, and is not overly surprising. The importance of this result supports the need for an adaptive management framework that includes ongoing data collection occur, and adjustments to answer key questions regarding how changes in land use may affect water quality. Further collection of data and subsequent analysis will allow the RDN or member municipalities to make more informed land use decisions, and help avoid future degradation of water quality. If ongoing data collection does not occur, key thresholds or risks may become apparent, but at a point that is too late or extremely costly to reverse.

5 RECOMMMEDATIONS

The CWMN monitoring program provides useful water quality data for key watercourses in the RDN. The program has been well designed to help understand factors that affect water quality during different flow periods. Maintaining this valuable program allows the detection of water quality trends. Our recommendations focus on identifying factors that can negatively impact watershed health and on identifying opportunities for stream restoration.

The water quality parameters of DO, specific conductivity, turbidity and water temperature are sensitive to changes in weather, agricultural activities and urban land use. These can be augmented by other water quality indicators and biological metrics to better understand watershed health and aid in making better land management/restoration decisions. However, the sustainable financing of the cost of these additional parameters should be evaluated. Some parameters such as chloride are relatively inexpensive while biological metrics are labor-intensive and more expensive.

The following is a summary of recommendations for the Regional District of Nanaimo Community Watershed Monitoring Network Program as a whole:

- Do not sample sites in the summer within 3 days of a rainfall event or until flows have returned to a near base flow condition. RATONALE: The existing data show outliers attributable to storm events, and these can complicate statistical analyses.

- Sample during the summer and fall sampling periods for ultra-low detection (0.002 mg/L RDL) Total and Dissolved Phosphorous for watersheds that have high agricultural land use or show evidence of excessive algae growth. These samples could be collected every 2 to 5 years depending upon budget. Nine sites were selected for Phosphorous sampling and these sites are listed in Table 5-1. RATIONALE The high agricultural use and depleted DO in some watersheds suggest high phosphorous concentrations. Sampling for total phosphorous in these streams will help to confirm potential causes of low DO.

- Sample for Chloride (Cl) during the summer low flow period for sites that are suspected to have high Cl based on elevated conductivity and on road densities. Ten sites were selected for Cl sampling because they have high paved road densities, >30% of impervious surface and/or high conductivity (Table 5-1). RATIONALE CConductivity values greater than 230 µS/cm have been shown to alter fish communities (Morgan et al. 2012). There are 22 sites in the CWMN monitoring program that have median summer conductance higher than 230 µS/cm. Some of these sites may be naturally high due to estuary or groundwater influence. However, it is important to identify if urban activities are causing high levels of conductivity and potential impairment of the stream ecosystem.

- Soil survey data from the Ministry of Environment online Soil Information Finder Tool should be utilized to better understand the natural variance in conductivity. It is expected that sites with watersheds that have more gleysols will have higher conductances, naturally. Gleysols typically have higher groundwater tables. RATIONALE: This analysis will help better understand natural differences between water regions.

- There are seven sites that need riparian plantings (Table 5-1). We recommend using red osier dogwood and willow live stakes or other available native riparian vegetation. Many of these sites already have restoration prescriptions provided by their habitat overview reports. RATIONALE: We concur with the authors of the habitat overview reports – riparian integrity is key to improved habitat values.

- Conduct benthic invertebrate sampling (B-IBI) before and after restoration works. The Benthic Index of Biological Integrity B-IBI is a measure of biological condition and is calibrated for coastal areas such as Seattle and Vancouver. We suggest evaluating the biological condition of streams before and after restoration works to assess the effectiveness of restoration actions (Table 5-1). We recommend using a similar methodology to Greater Vancouver's research where 3 replicate samples are collected at each site during a low flow period. RATIONALE: While many water quality indicators are sensitive to annual variation in flows, rainfall and temperature, B-IBI is sensitive to changes in human disturbances and has limited inter-annual variability (Page et al. 2008).

- Completion of benthic invertebrate sampling using the CABIN methods would be useful to add another watershed-level indicator of overall watershed health. These samples could be collected every 2 to 5 years depending upon budget, and are most useful if done as part of a long-term monitoring program. RATIONALE: The addition of this sampling would provide additional markers of change, either positive or negative, and allow trend analysis over time

- Trend analysis using the seasonal Mann-Kendall test should be repeated once there is a suitable, continuous dataset for the recently added sites. At least seven years is needed to look for sampling period specific trends. RATIONALE: As the years of data increase at all sites, the accuracy of the trend analyses improves.

- Targeted public education could be offered for areas where stormwater impacts are indicated. This could involve an info mailer, adding a stencilled fish symbol to stormwater grates that report to fish-bearing streams, incentives for rain-gardens, etc. Many programs are outlined on the internet RATIONALE: The public may not realize that washing paint cleaners down the storm drains, and over-watering/overfertilizing their landscapes can damage the receiving stream habitats. They can be encouraged to make simple changes that benefit their region's stream health

- Consider the construction of rain gardens to reduce the amount of stormwater reporting from impervious surfaces such as roofs and parking lots. Residential rain gardens can be easily constructed and maintained by the homeowners on their properties. There are many guidance documents publicly available including: http://www.saanich.ca/assets/Community/Documents/Rain%20Garden.pdf RATIONALE: Rain gardens are an easy way to reduce the stormwater inputs to surrounding waterbodies and provide an aesthetically appealing garden that helps conserve water (Figure A157). Rain gardens at the municipal scale can include swales. Swales can gather and slow the infiltration of stormwater to the surrounding area. Additionally, swales can be used to direct water to rain gardens or other gardens. Rain gardens at commercial and industrial properties are also viable. Swales can be used to adsorb or redirect runoff from large parking lots (Figure A158). Rain gardens can be constructed close to parking lots or roofs in industrial and commercial areas.

- Refine and improve the current land use layer by using remote sensing techniques. We recommend working with the Vancouver Island University to create a land use/cover layer that accurately maps the extent of impervious surface, tree cover and other relevant components of the landscape. RATIONALE: This analysis could be done every 5-10 years as an effective way to keep track of land cover changes.

Table 5-1: Summary of recommendations for CWMN sites. Sites that are in bold were identified as sites of concern.

Water Region	Site (EMS)	TP	Cl	B-IBI	Riparian Planting	Prescription Available	Previous Restoration	Targeted Public Education
Big Qualicum	**Annie Creek (E290474)**	✓		✓	✓	✓		
French Creek	**French Creek at Grafton Road (E243024)**	✓		✓	✓	✓	✓	✓
French Creek	**Grandon Creek at Laburnum Rd (E288091)**	✓		✓	✓	✓		✓
French Creek	Grandon Creek at West Crescent (E288090)	✓						✓
French Creek	**Beach Creek Near Chester Rd at Hemsworth Rd (E288092)**	✓						✓
French Creek	Beach Creek Near Memorial Golf Pond (E288093)	✓						✓
Englishman River	**Shelly Creek at Hamilton Rd (E287131)**			✓	✓			
Englishman River	**Shelly Creek at End of Blower Rd (E290452)**			✓	✓			
Englishman River	**Swane Creek (E308186)**	✓					✓	
South Wellington to Nanoose	**Walley Creek D/S of Hammond Bay (E306256)**		✓					✓
South Wellington to Nanoose	Walley Creek @ Morningside Dr (E306257)		✓					
South Wellington to Nanoose	Walley Creek 20 m u/s Beach (E306434)		✓					
South Wellington to Nanoose	**Cat Stream (E290486)**		✓	✓	✓	✓		✓
South Wellington to Nanoose	Departure Creek @ Neyland Rd (E290469)		✓					
South Wellington to Nanoose	Departure Creek off Newton St (E290470)		✓					

Water Region	Site (EMS)	TP	Cl	B-IBI	Riparian Planting	Prescription Available	Previous Restoration	Targeted Public Education
South Wellington to Nanoose	Departure Creek at Lower End of Woodstream Park (E290471)		✓					
South Wellington to Nanoose	Departure Creek at Outlet (E290472)		✓					
South Wellington to Nanoose	Cottle Creek at Landalt Rd (E290476)		✓					
South Wellington to Nanoose	Bloods Creek just u/s of Dickenson (E294010)		✓					
Nanaimo River	**Lower Holden Creek (E309281)**	✓		✓	✓	✓		
Nanaimo River	**Holden Creek (E310147)**	✓						

5.1 Water Region and Site Specific Recommendations

5.1.1 Big Qualicum

- Given the high fisheries value of Annie Creek it is recommended another CWMN site be added. The recommended location of the site is at Van Isle Road. This site should be sampled for summer and fall of 2019 and the data should be reviewed to determine if this site should be a long-term CWMN site.

5.1.2 Little Qualicum

- The reach immediately upstream of Little Qualicum River at Intake should be inspected for potential erosion issues

5.1.3 French Creek

- Given the high agricultural use in the French Creek watershed, we recommend that resources be provided to farmers to encourage sustainable practices and restoration efforts. Examples include ensuring that all farmers are aware of the Provincial Environmental Farms Program, where farmers can gain access to funding for fencing riparian areas, seeding, and planting programs, etc.
- At minimum, policies for land use should consider ensuring effective implementation of agricultural buffers to separate farms from streams, where the buffers are based upon the risks associated with the farm type. For example, a minimum 5 m buffer is often recommended between streams and cropland and a 15 m buffer for grazing.
- Closely monitor changes in turbidity and conductivity at the Beach Creek site near Hemsworth. We recommend that the trend analysis be re-run after the 2018 data is available.
- Conduct a stream mapping exercise, such as Fisheries and Oceans Canada Sensitive Habitat Inventory and Mapping (SHIM) to determine and document all extreme erosion cases. This mapping is also useful for determining the quantity and quality of fish habitat and it provides a useful tool for effective long term adaptive management.

5.1.4 Englishman River

- Continue to monitor Swane Creek and the effectiveness of restoration works established there in 2007.
- Identify any stormwater outlets near the Shelly Creek sample site to see if stormwater is contributing to poor water quality.

5.1.5 South Wellington to Nanoose

- Educate the residents of the Cat Stream and Walley Creek watersheds storm water contaminants and how it can impact aquatic ecosystems.

5.1.6 Nanaimo River

- Closely monitor changes in turbidity and DO at the Nanaimo River site upstream of Haslam Creek. It is recommended to re-run trend analysis once 2018 data is available.
- Continue to monitor Lower Holden and Holden Creek sites to better understand baseline conditions.

5.1.7 Gabriola Island

- Continue to monitor the Mallett Creek site and investigate potential sources of suspended sediment.

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Appendix A Land Use Maps by Watershed

Appendix B Water Region Maps

Appendix C Land Use Summaries for 500m Upstream Buffer

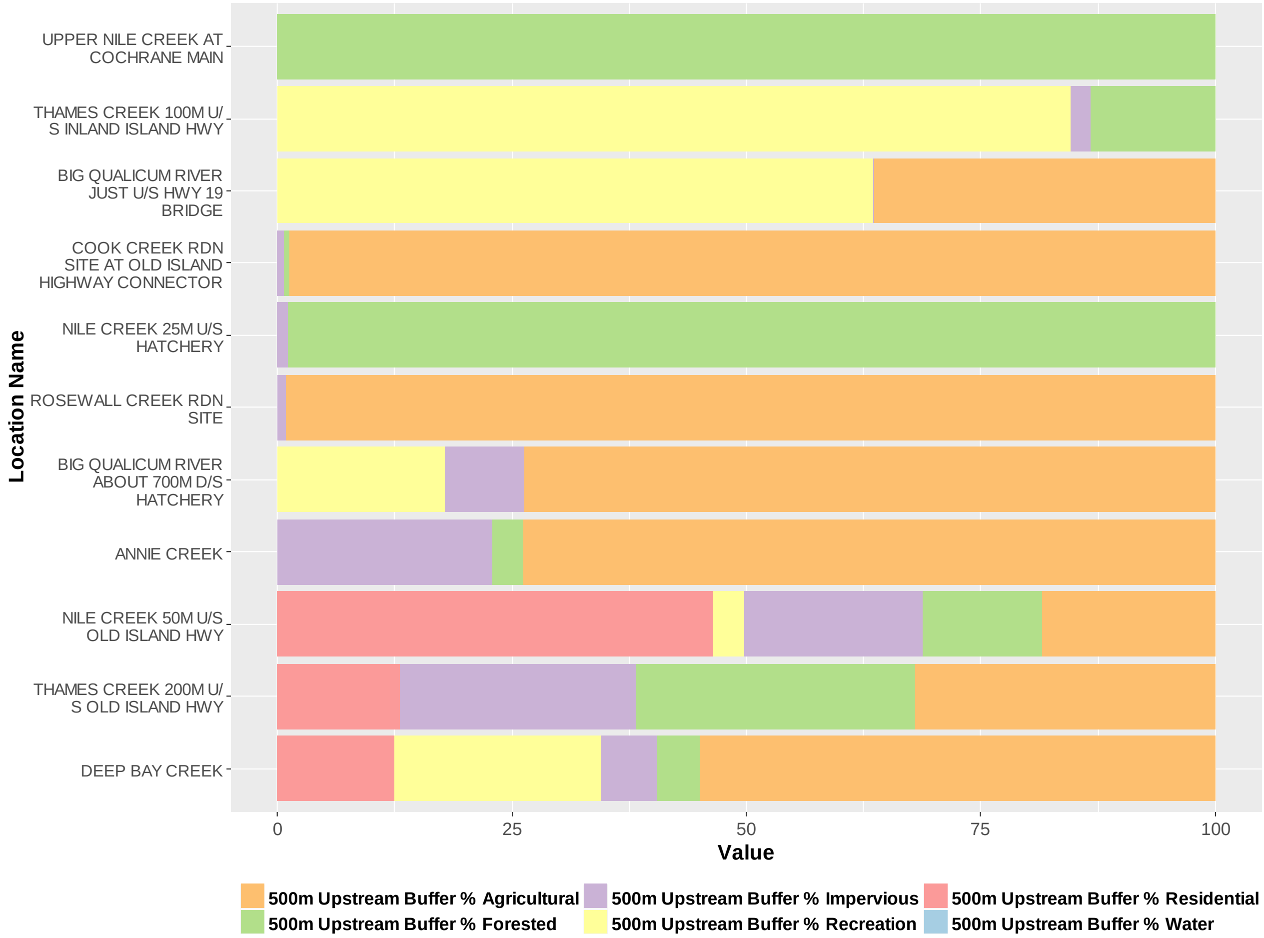


Figure A1. Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 1 (Big Qualicum River).

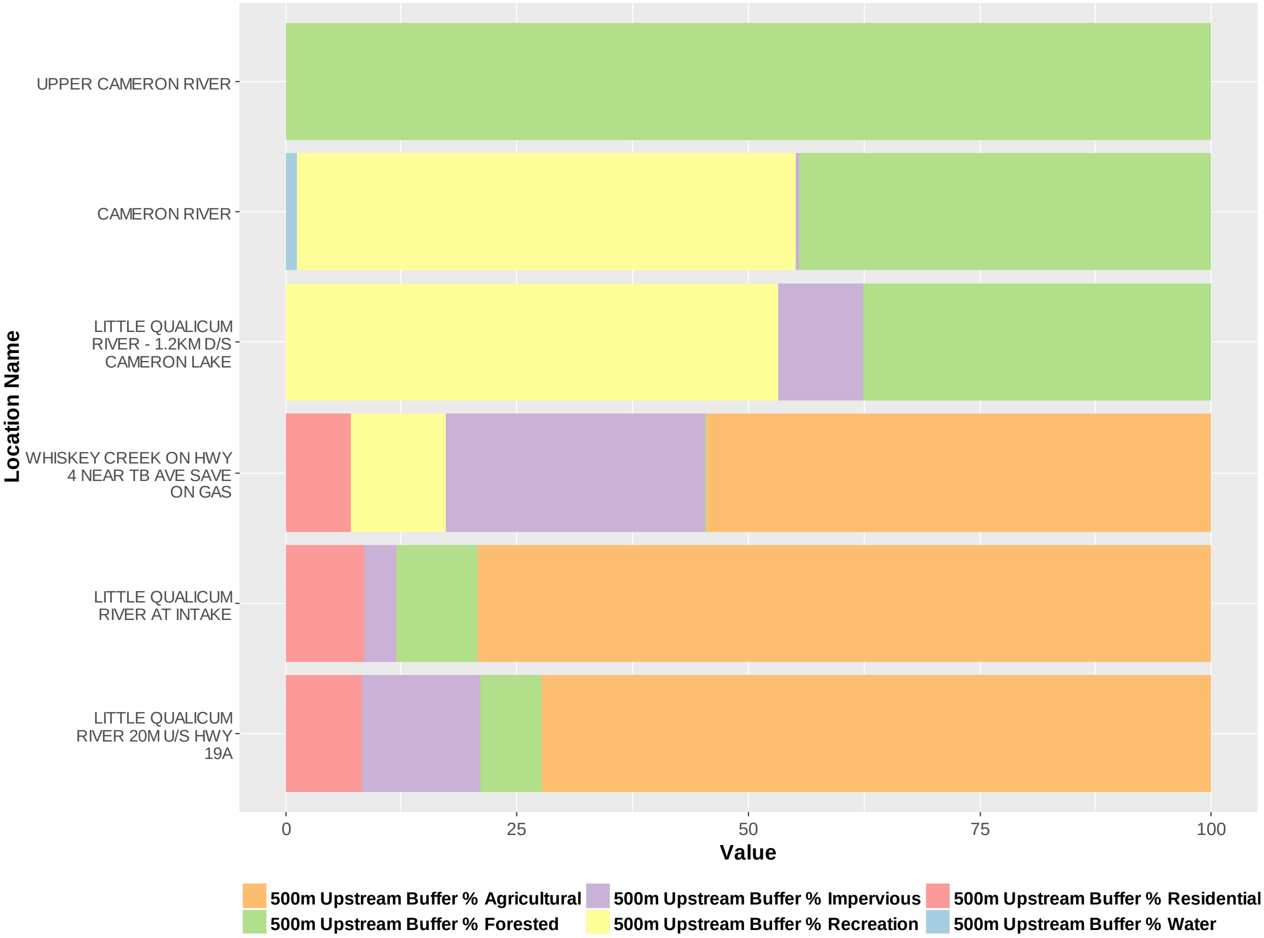


Figure A2. **Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 2 (Little Qualicum River).**

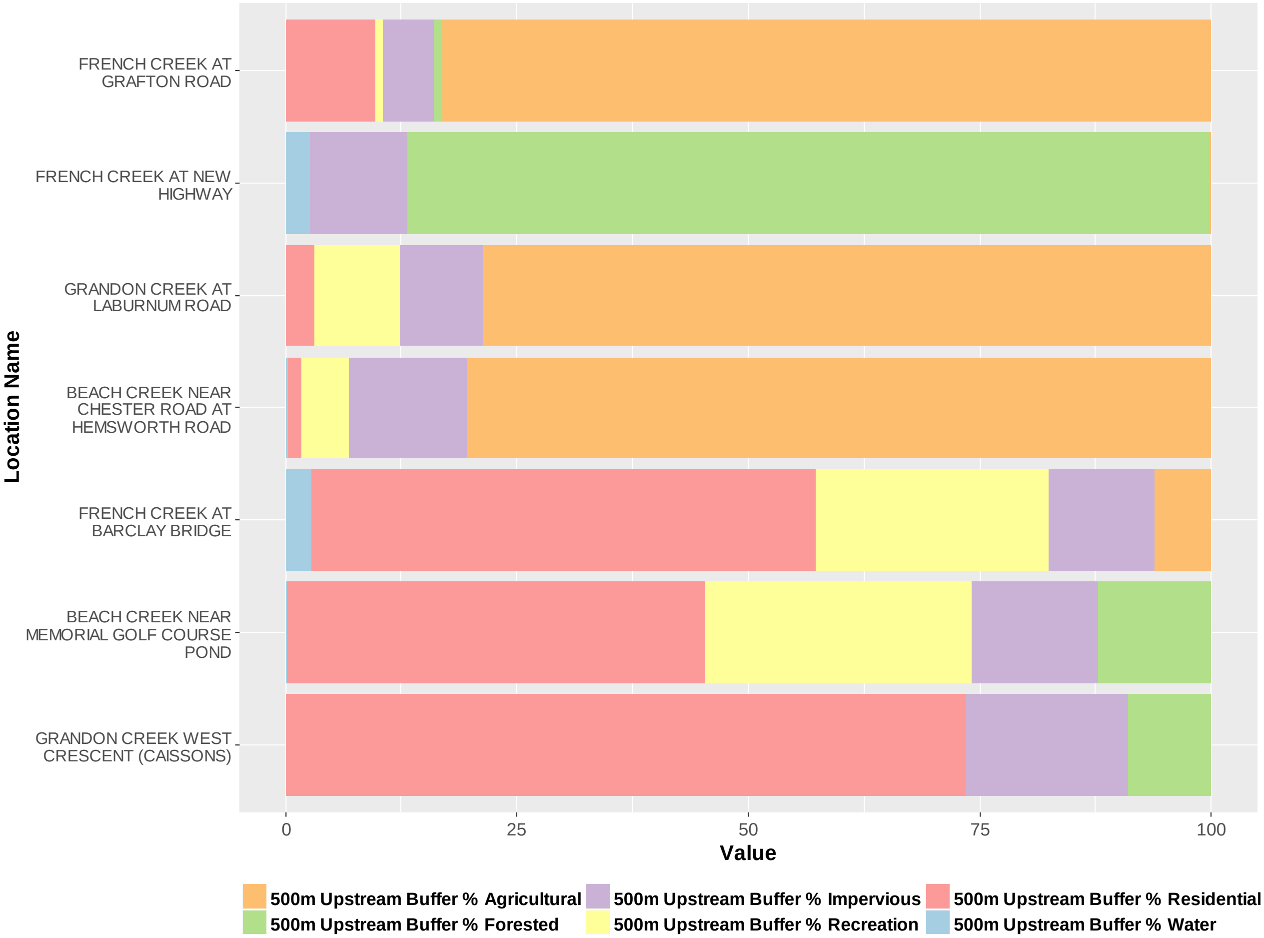


Figure A3. **Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 3 (French Creek).**

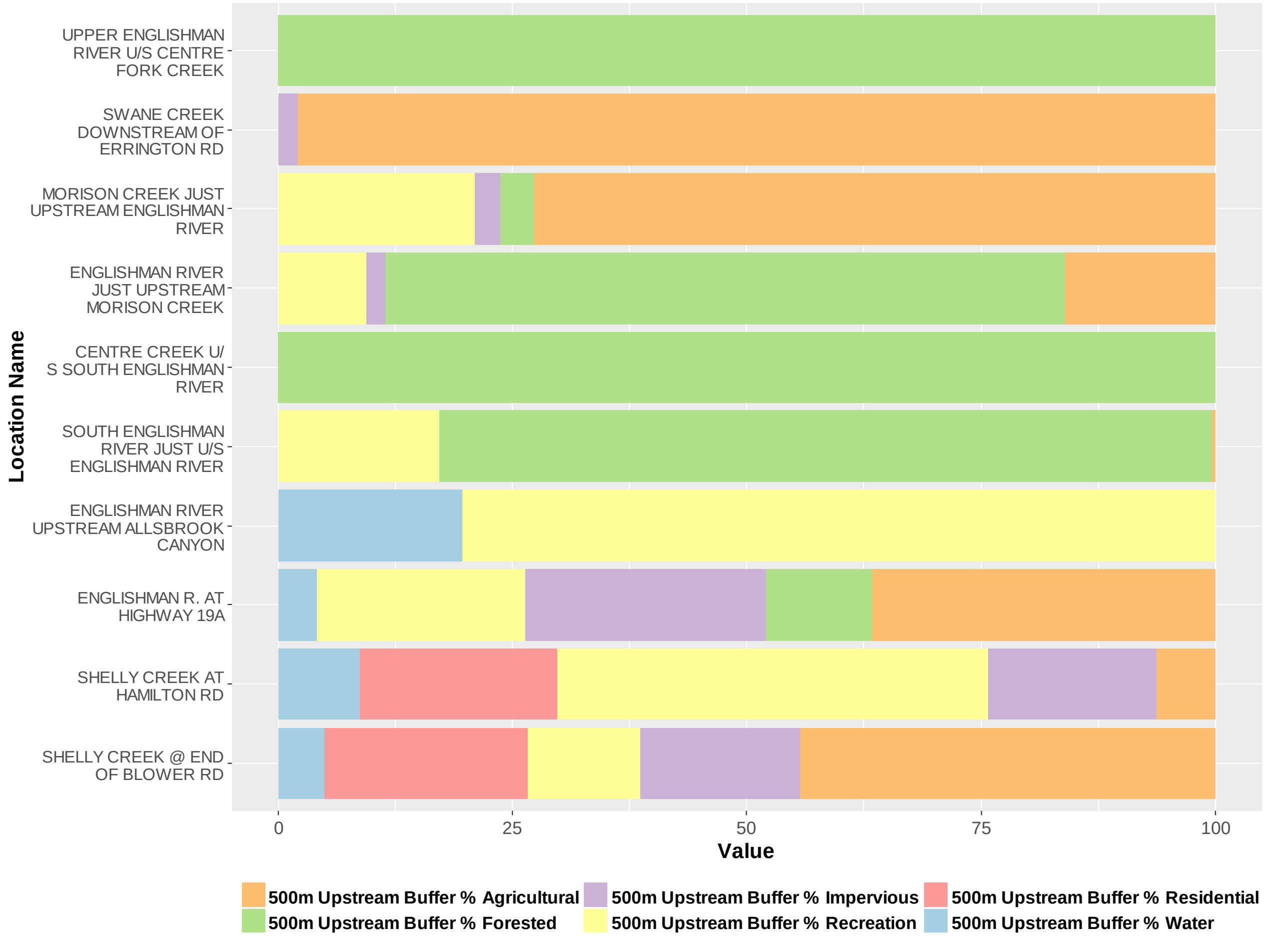


Figure A4. Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 4 (Englishman River).

Figure A5. Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 5-1 (South Wellington to Nanoose).

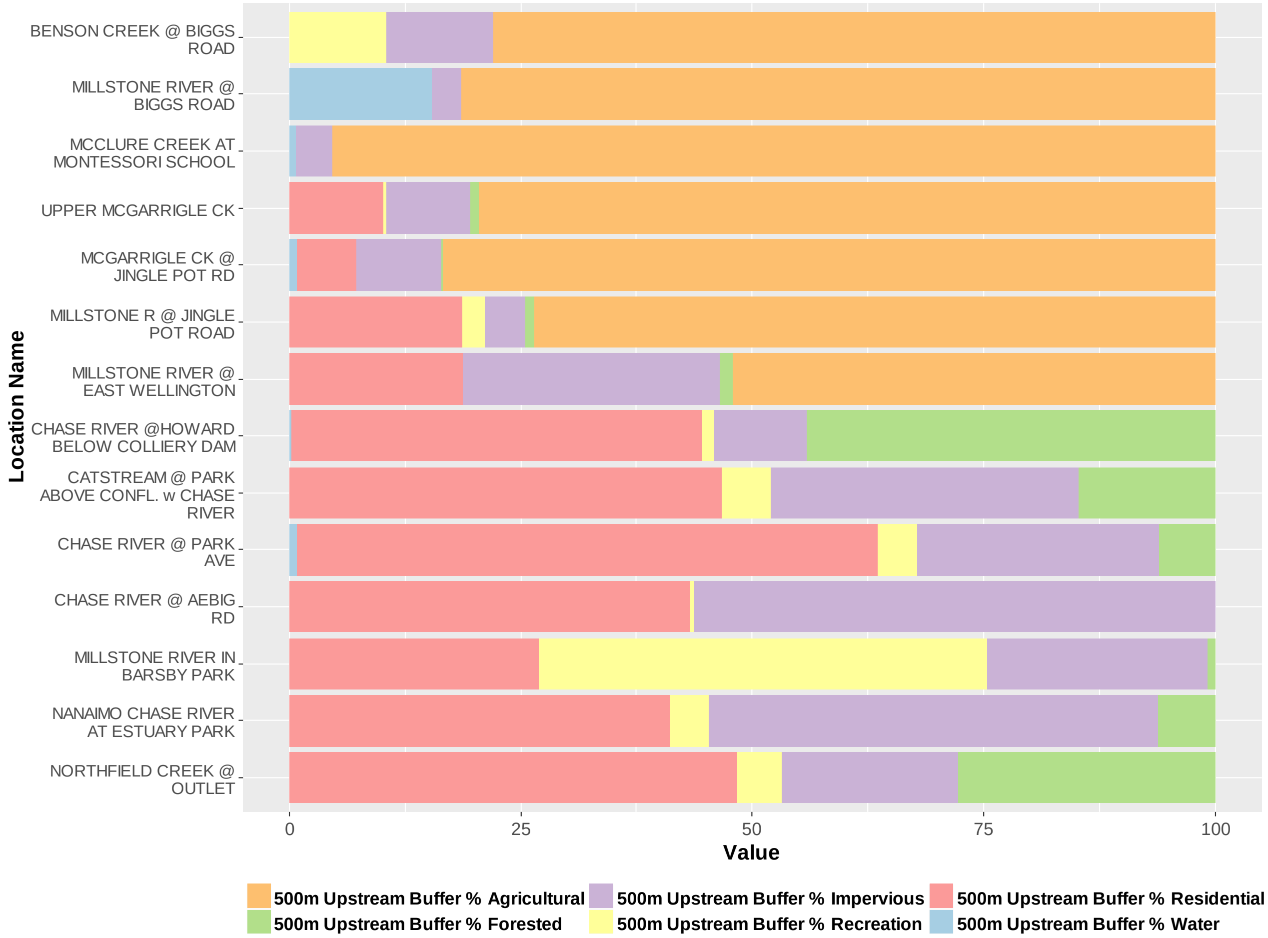


Figure A6. **Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 5-2 (South Wellington to Nanoose).**

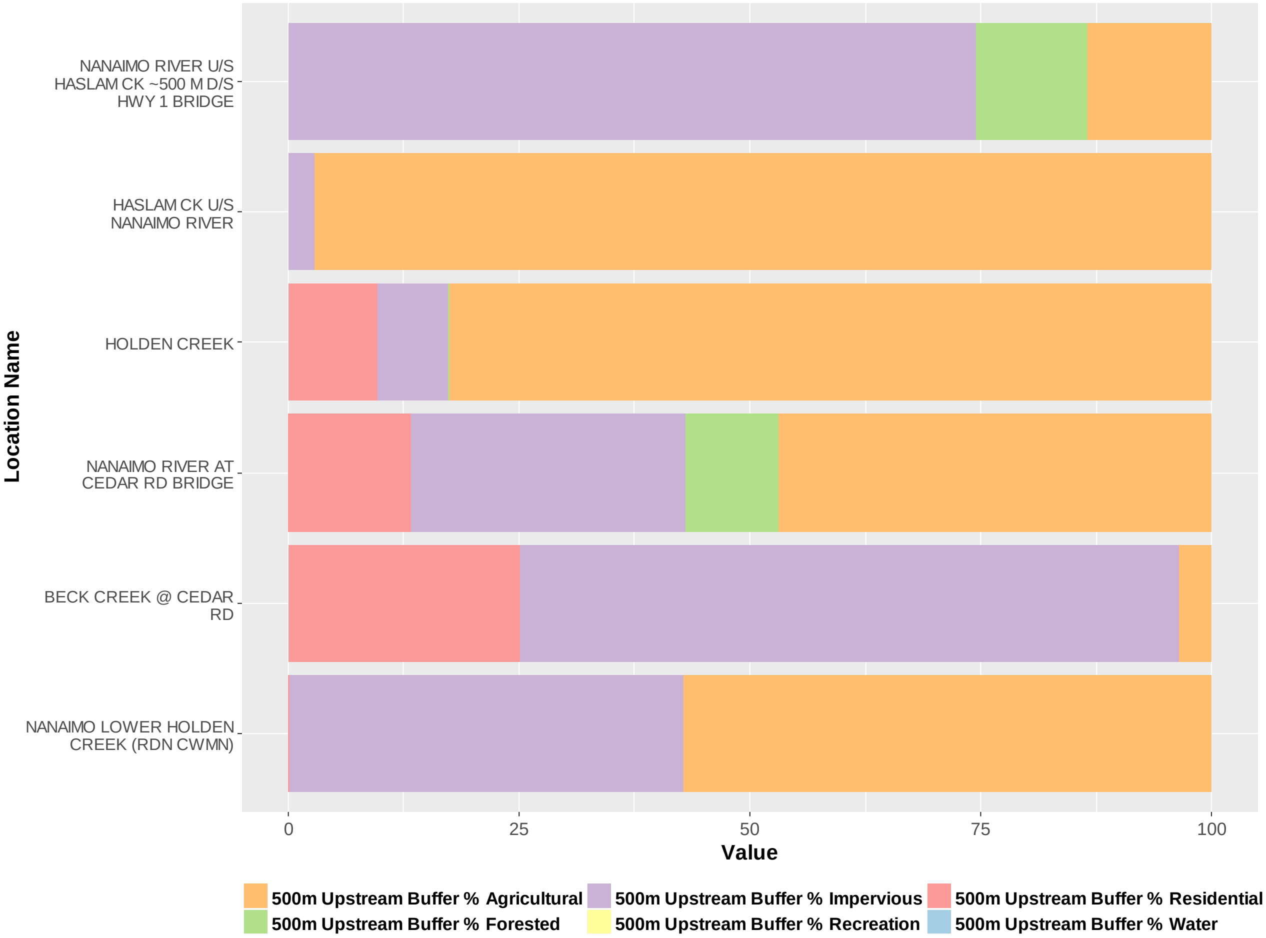


Figure A7. Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 6 (Nanaimo River).

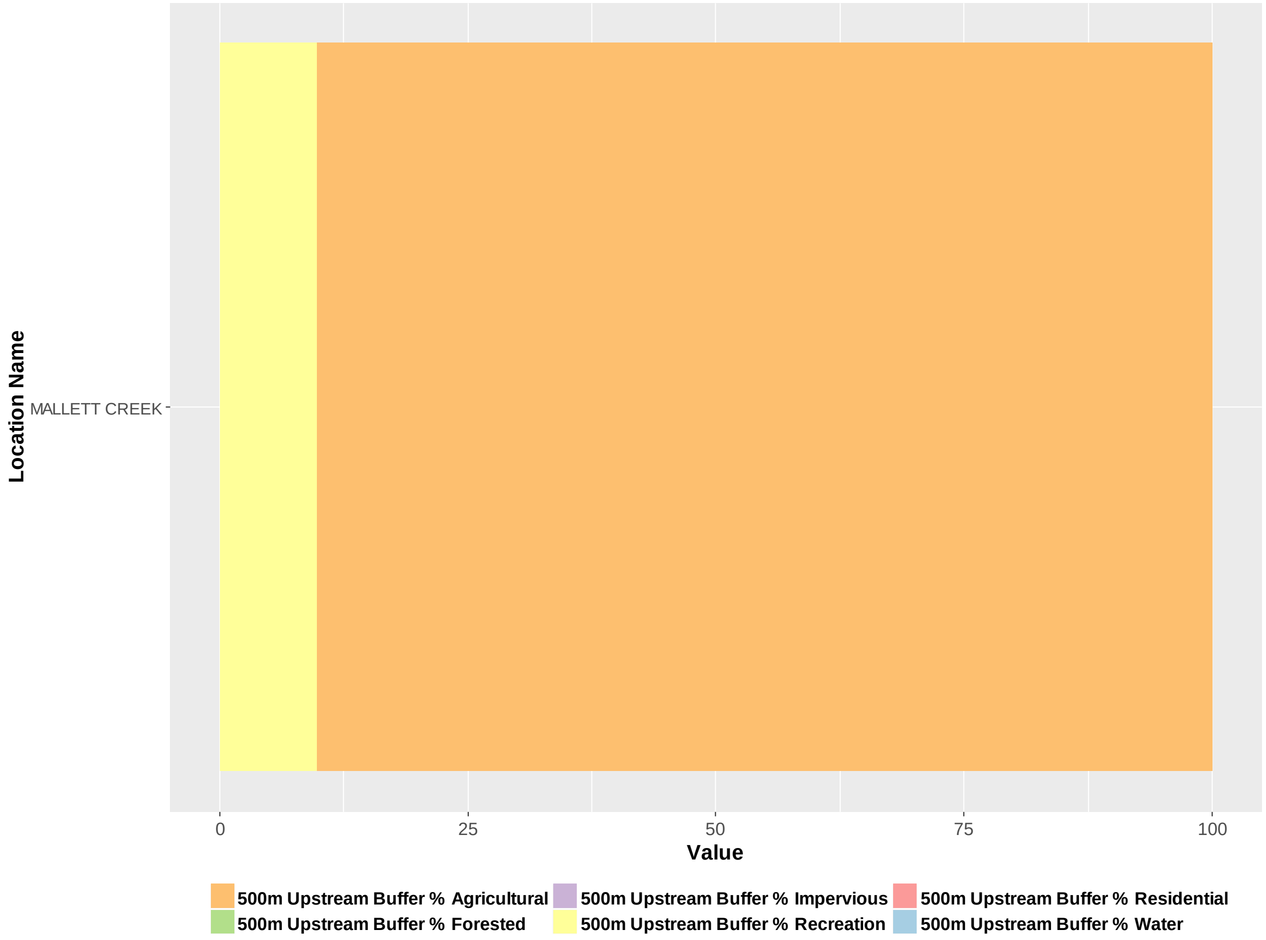


Figure A8. Percent land use composition for CWMN site 500m Upstream Buffer of Water Region 7 (Gabriola Island).

Appendix D Water Quality Summaries

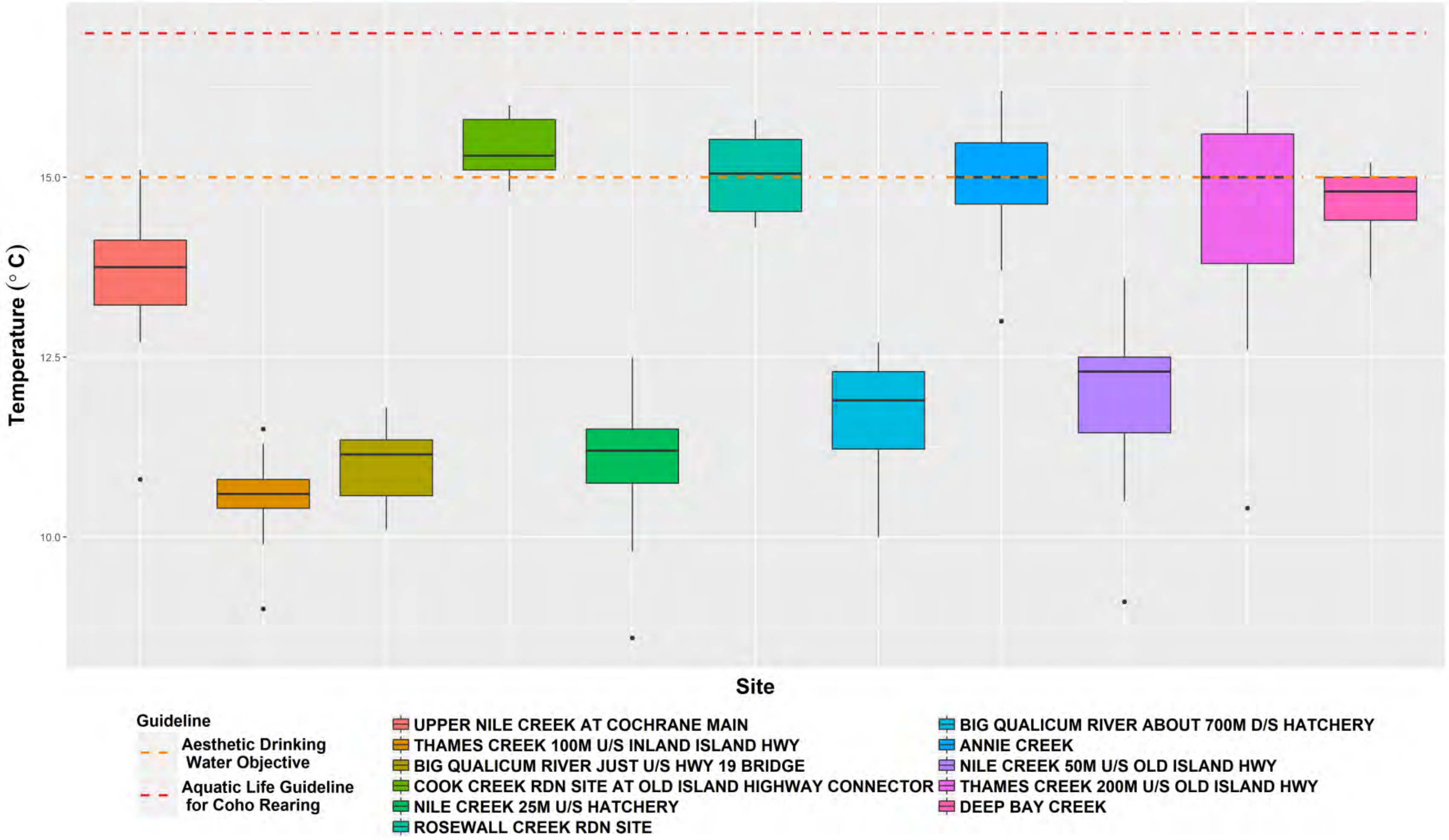


Figure A9. Summer 2011-2017 water temperature of CWMN sites in Water Region 1 (Big Qualicum) with Englishman River water quality objectives. See Figure 2-1 for how to interpret a boxplot.

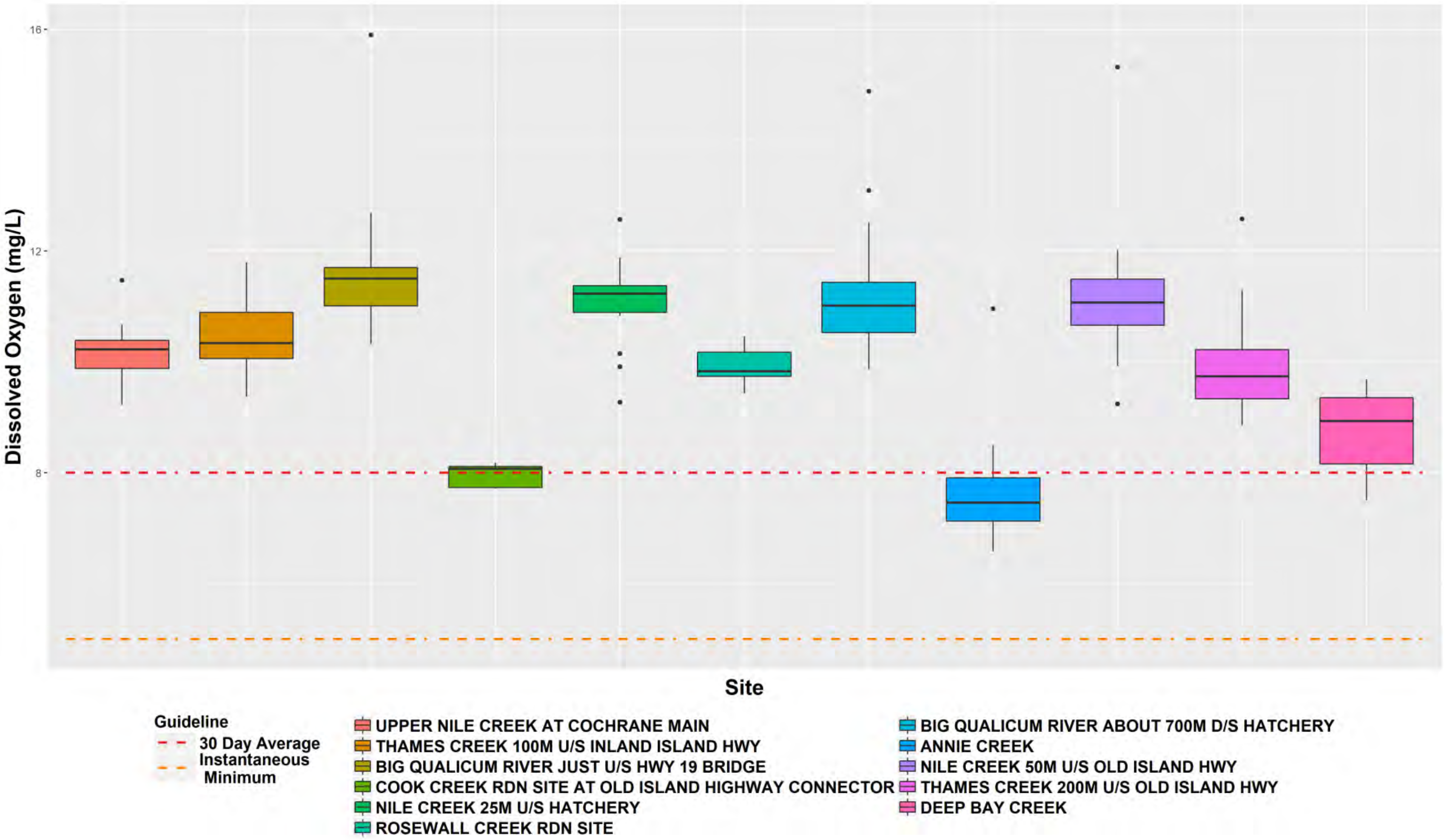


Figure A10. Summer 2011-2017 DO of CWMN sites in Water Region 1 (Big Qualicum) with BC Water Quality guidelines for Aquatic Life.

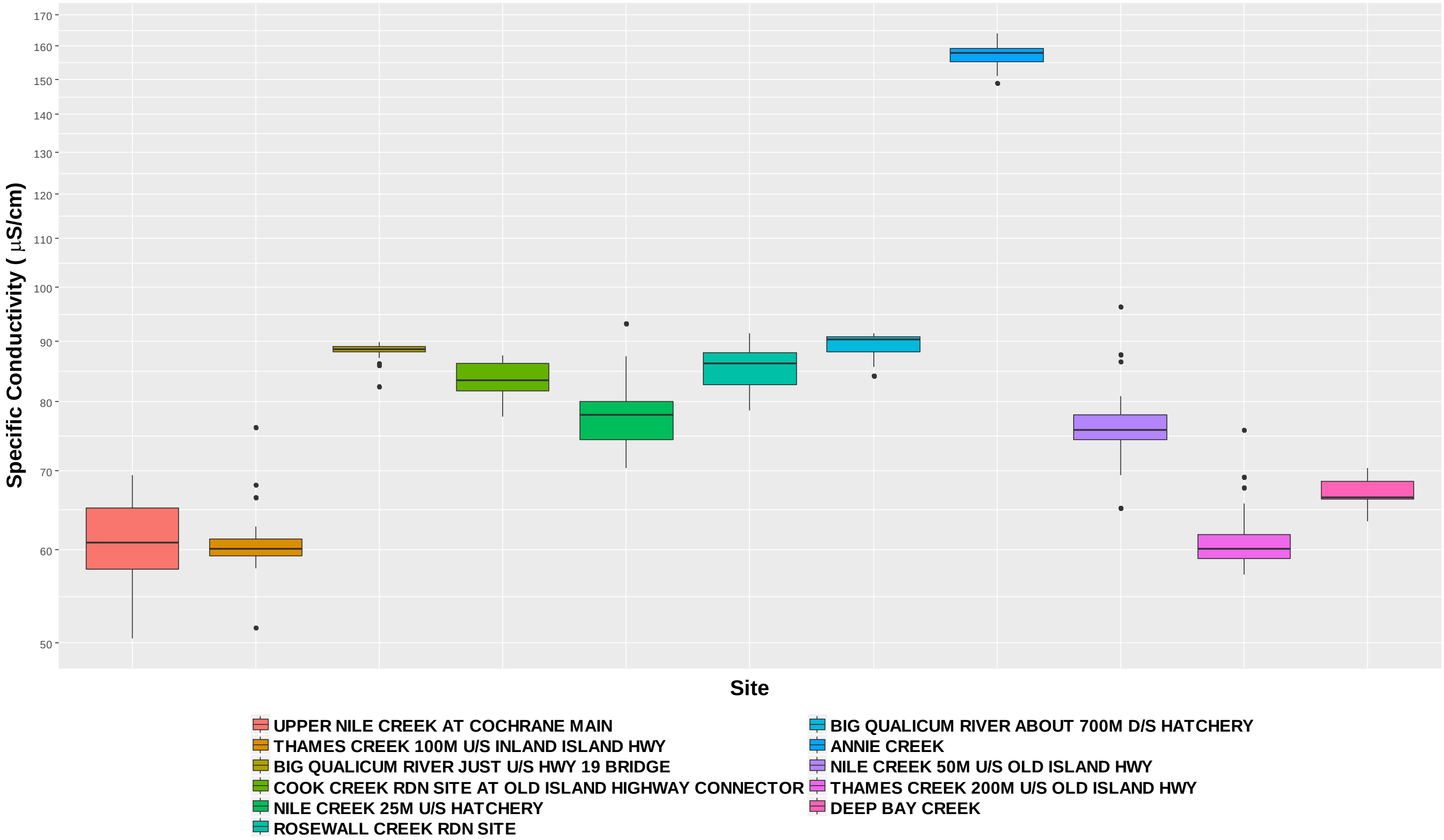


Figure A11. **Summer 2011-2017 specific conductivity of CWMN sites in Water Region 1 (Big Qualicum).**

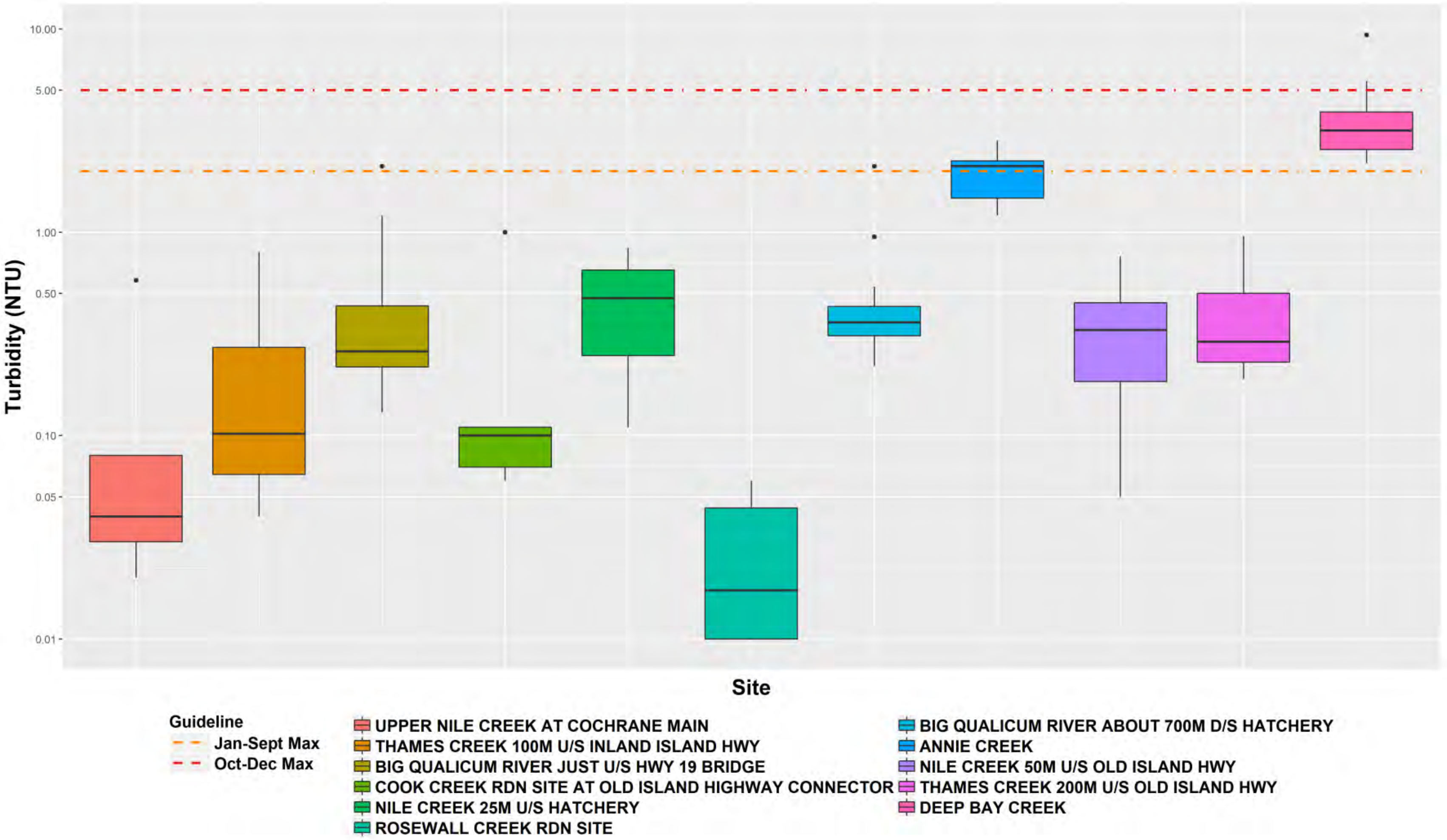


Figure A12. **Summer 2011-2017 turbidity of CWMN sites in Water Region 1 (Big Qualicum) with Englishman River water quality objectives.**

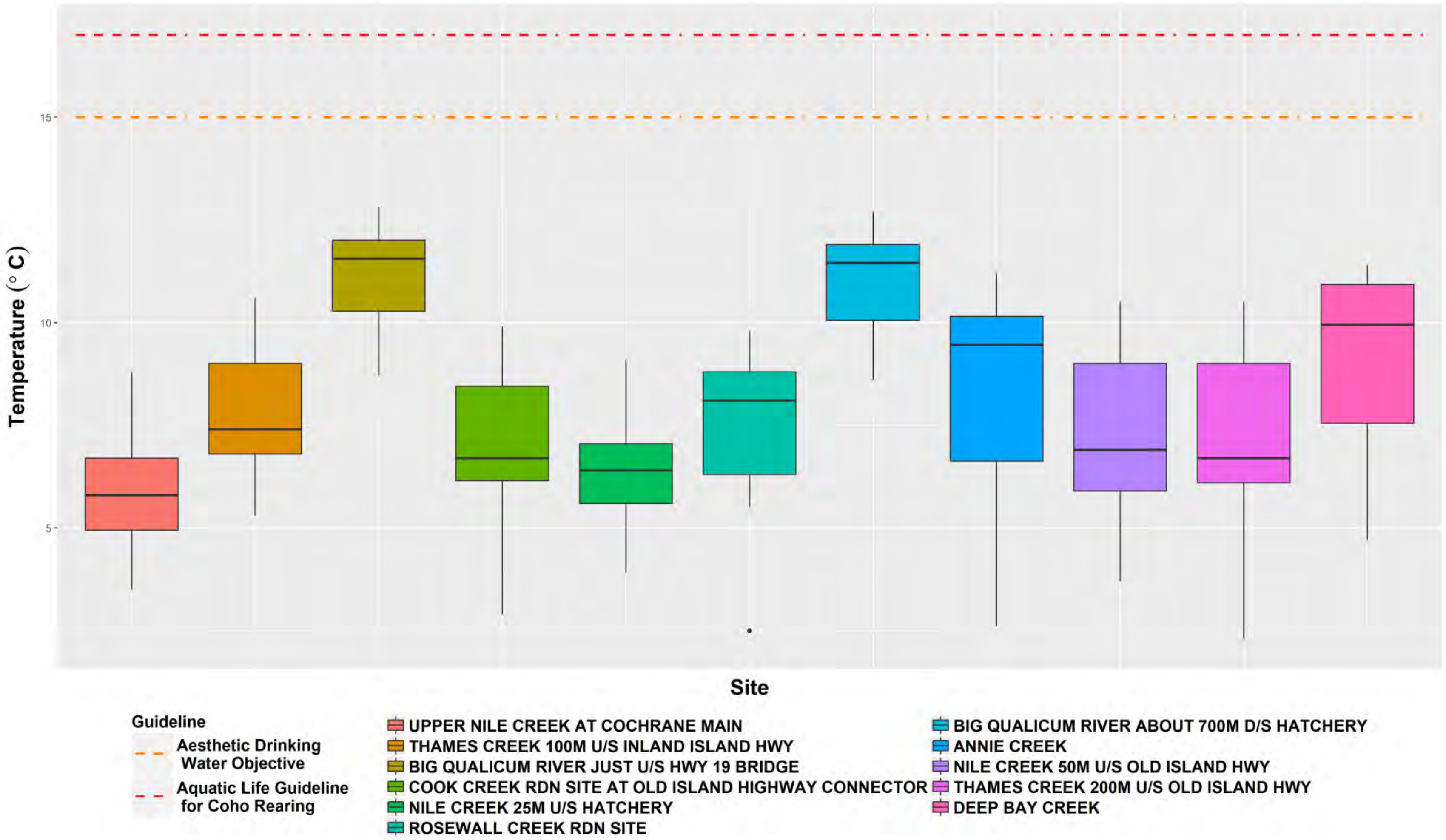


Figure A13. **Fall 2011-2017 water temperature of CWMN sites in Water Region 1 (Big Qualicum) with Englishman River water quality objectives.**

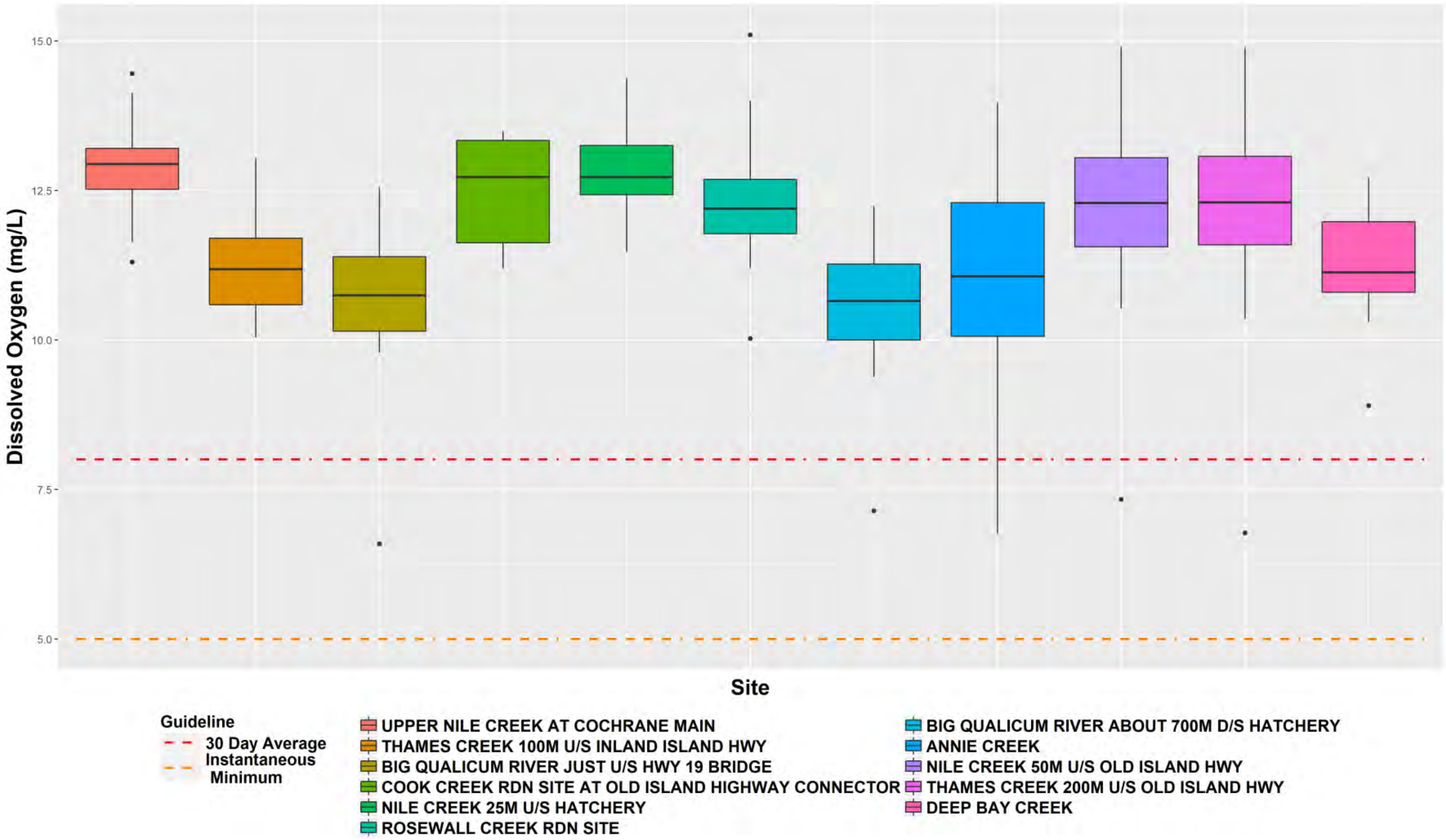


Figure A14. **Fall 2011-2017 DO of CWMN sites in Water Region 1 (Big Qualicum) with BC Water Quality guidelines for Aquatic Life.**

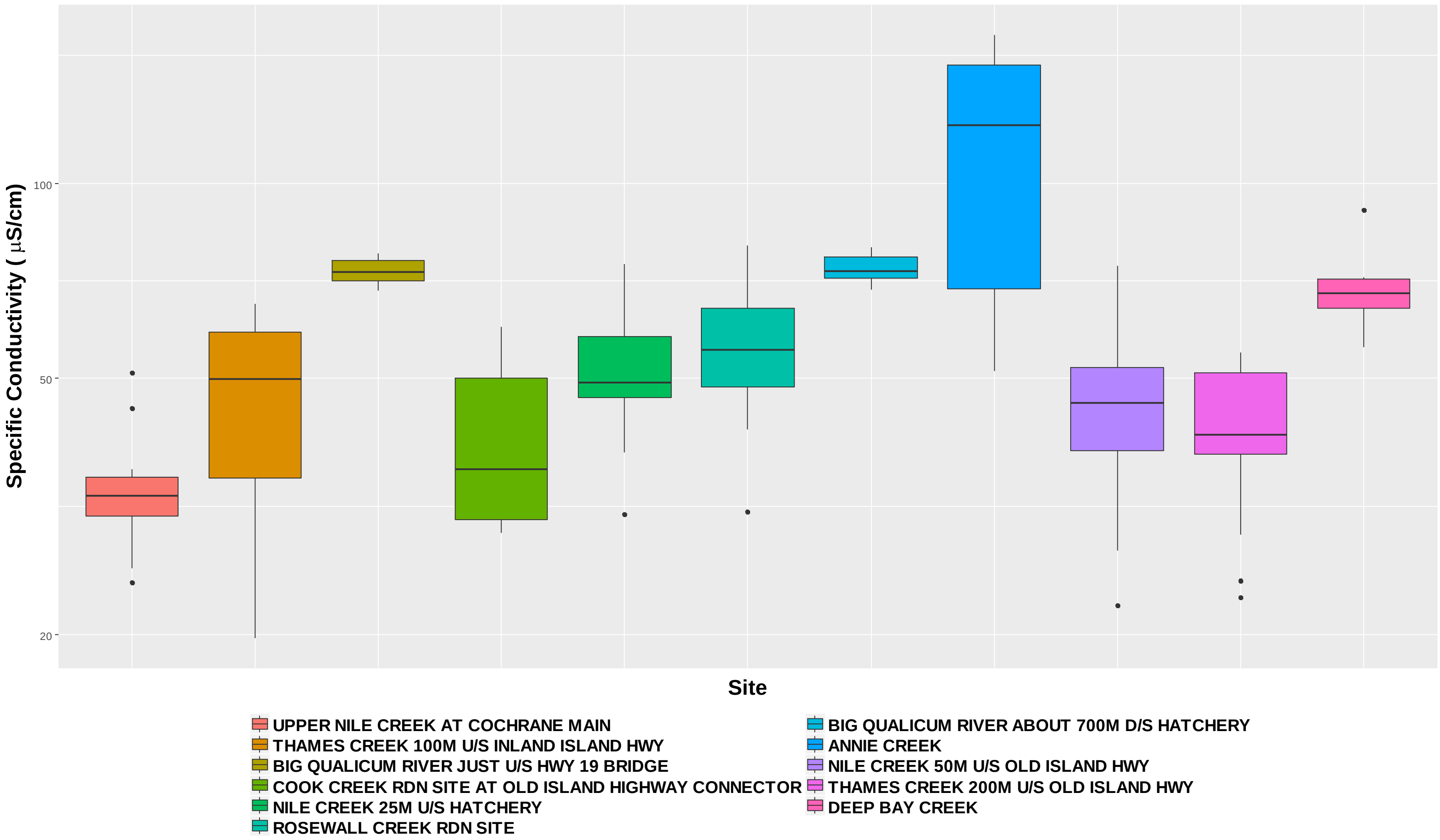


Figure A15. **Fall 2011-2017 specific conductivity of CWMN sites in Water Region 1 (Big Qualicum).**

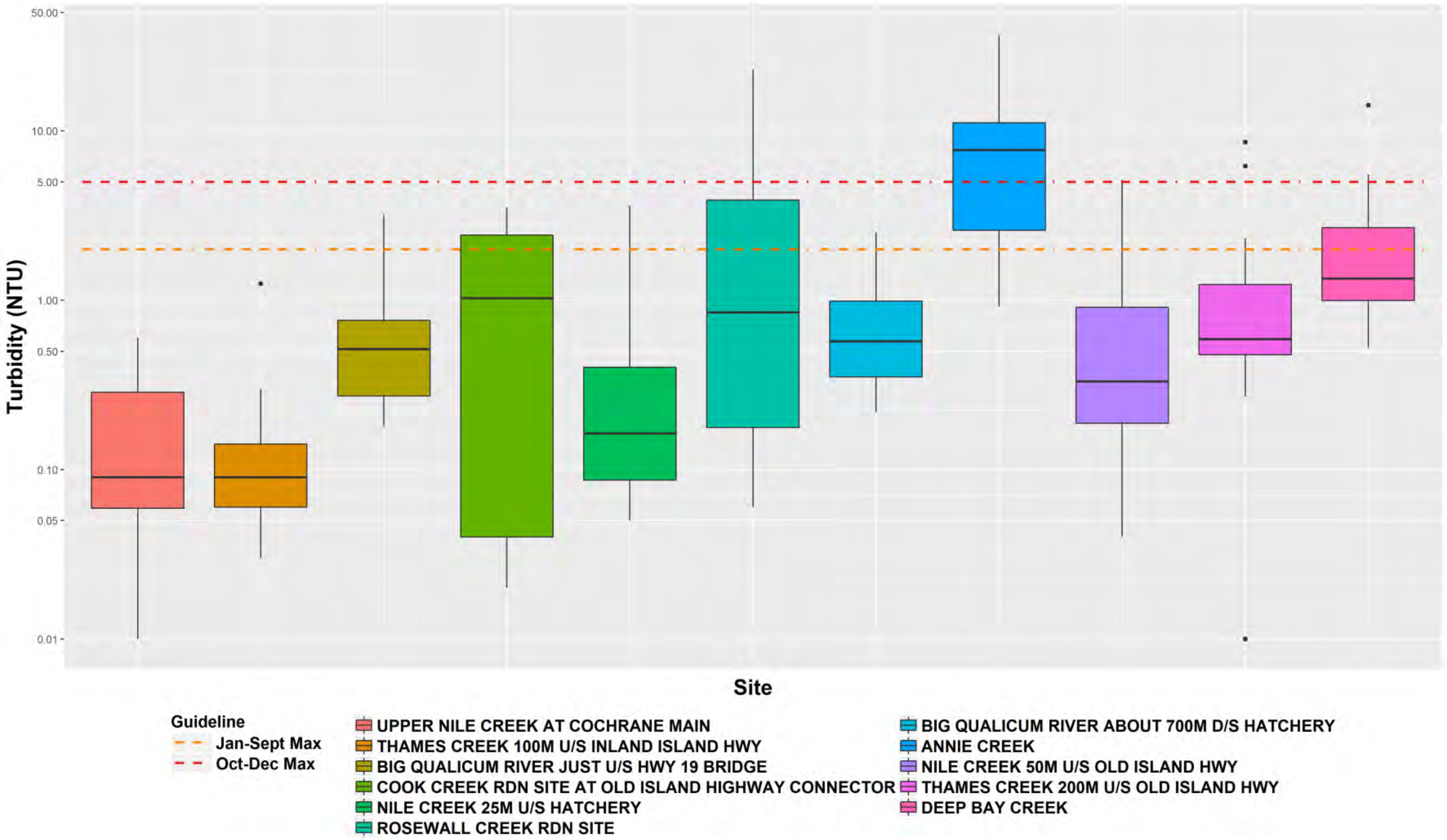


Figure A16. **Fall 2011-2017 turbidity of CWMN sites in Water Region 1 (Big Qualicum) with Englishman River water quality objectives.**

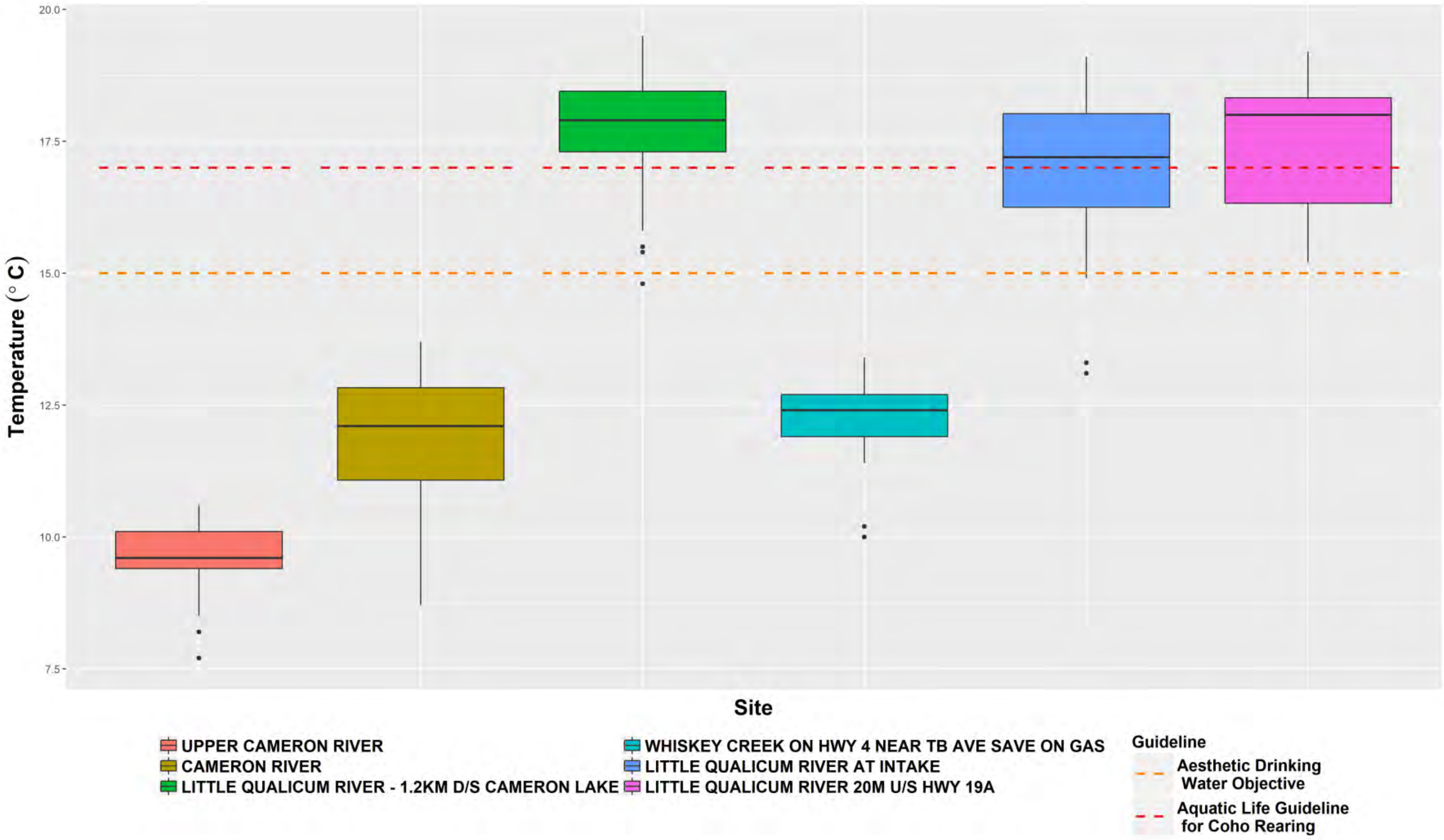


Figure A17. Summer 2011-2017 water temperature of CWMN sites in Water Region 2 (Little Qualicum) with Englishman River water quality objectives.

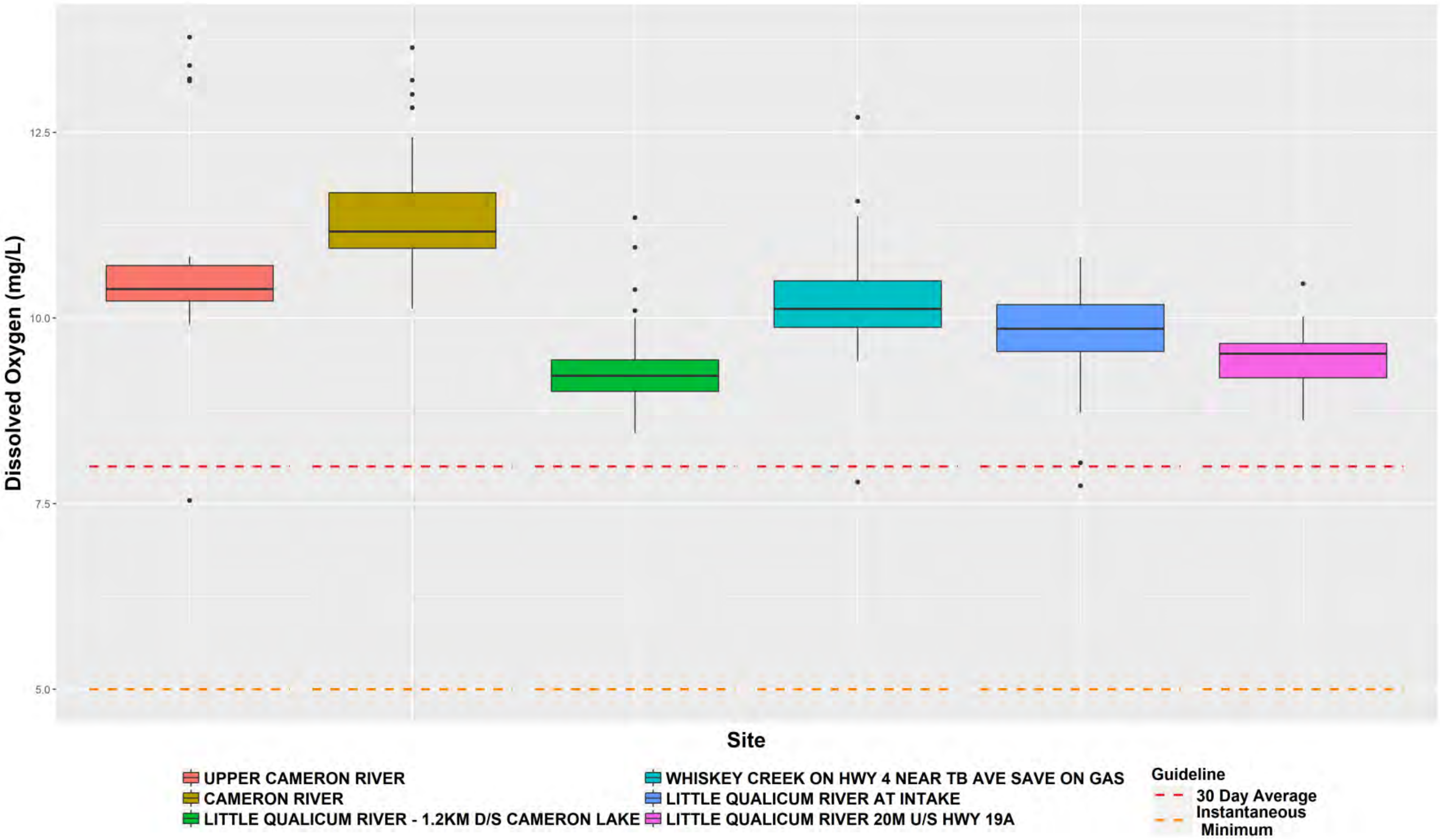


Figure A18. Summer 2011-2017 DO of CWMN sites in Water Region 2 (Little Qualicum) with BC Water Quality guidelines for Aquatic Life.

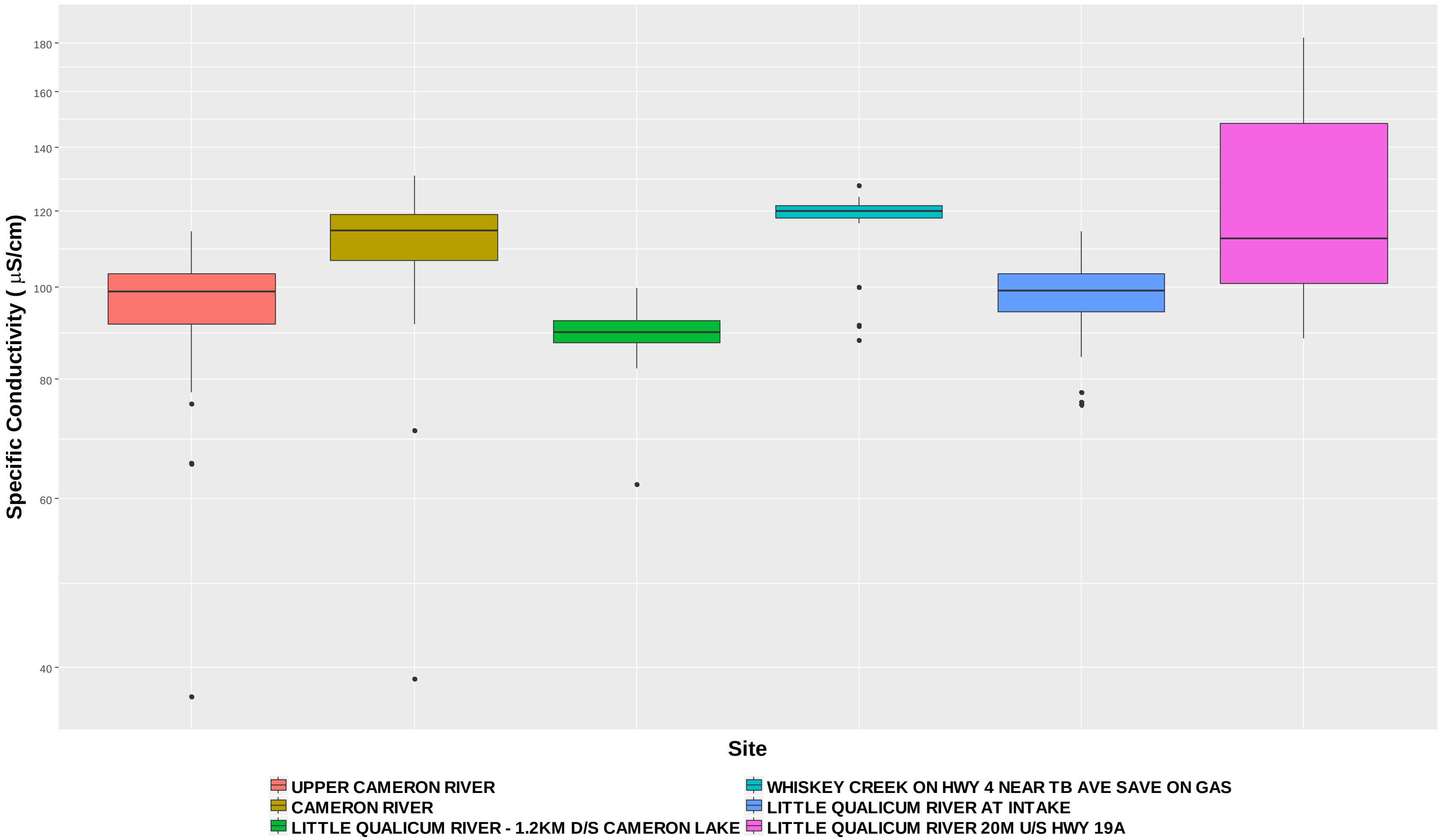


Figure A19. **Summer 2011-2017 specific conductivity of CWMN sites in Water Region 2 (Little Qualicum).**

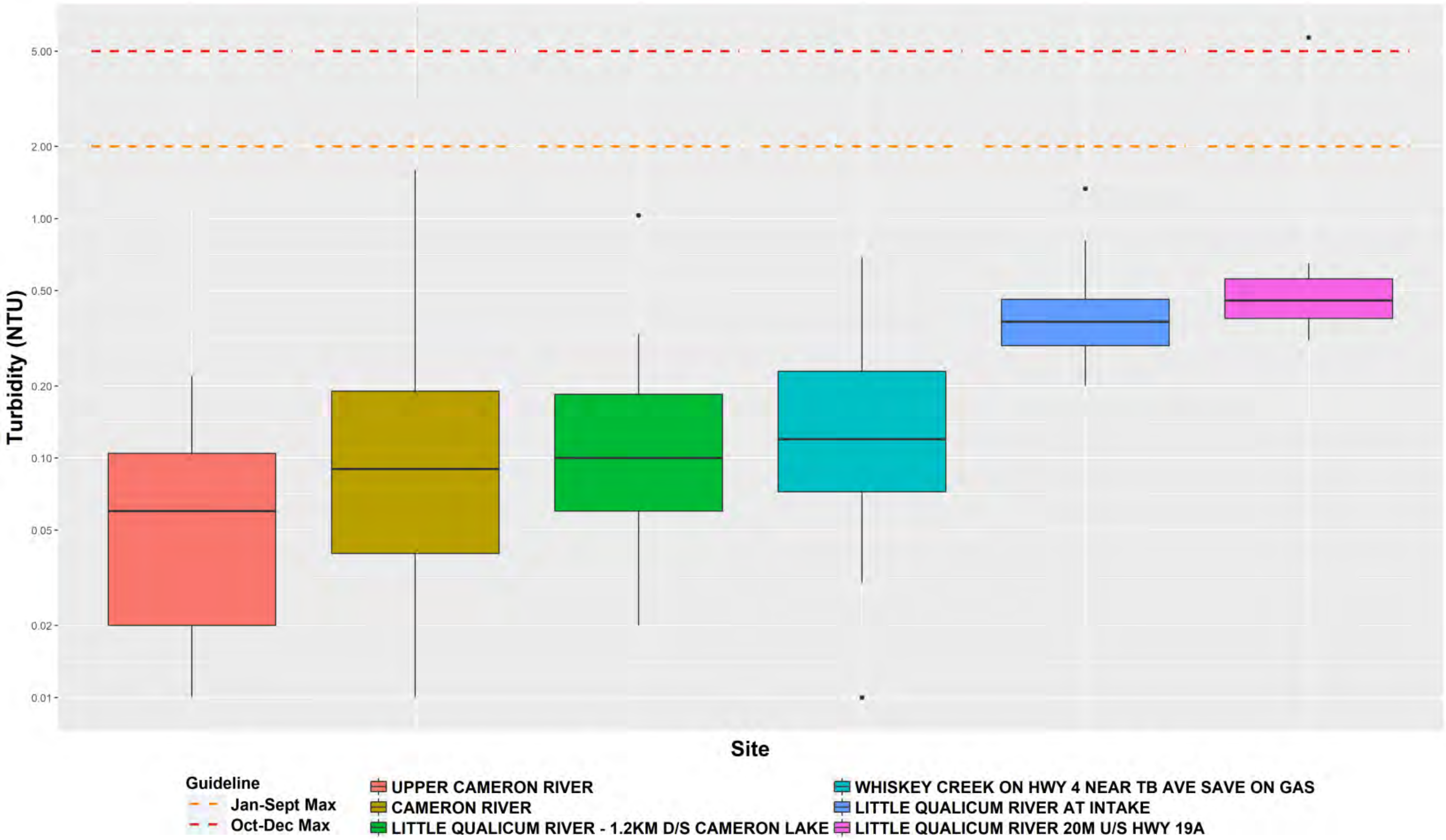


Figure A20. **Summer 2011-2017 turbidity of CWMN sites in Water Region 2 (Little Qualicum) with Englishman River water quality objectives.**

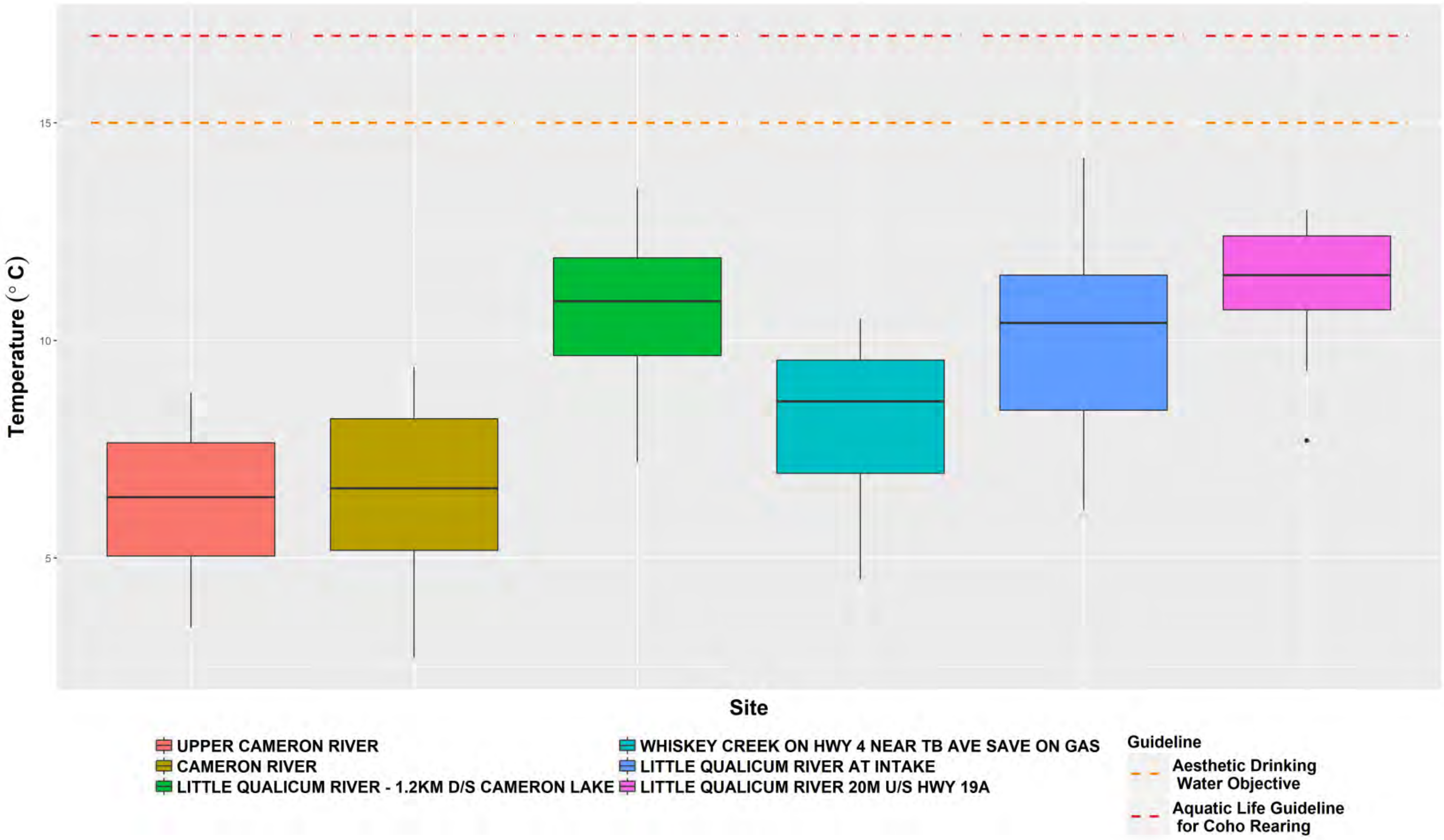


Figure A21. **Fall 2011-2017 water temperature of CWMN sites in Water Region 2 (Little Qualicum) with Englishman River water quality objectives.**

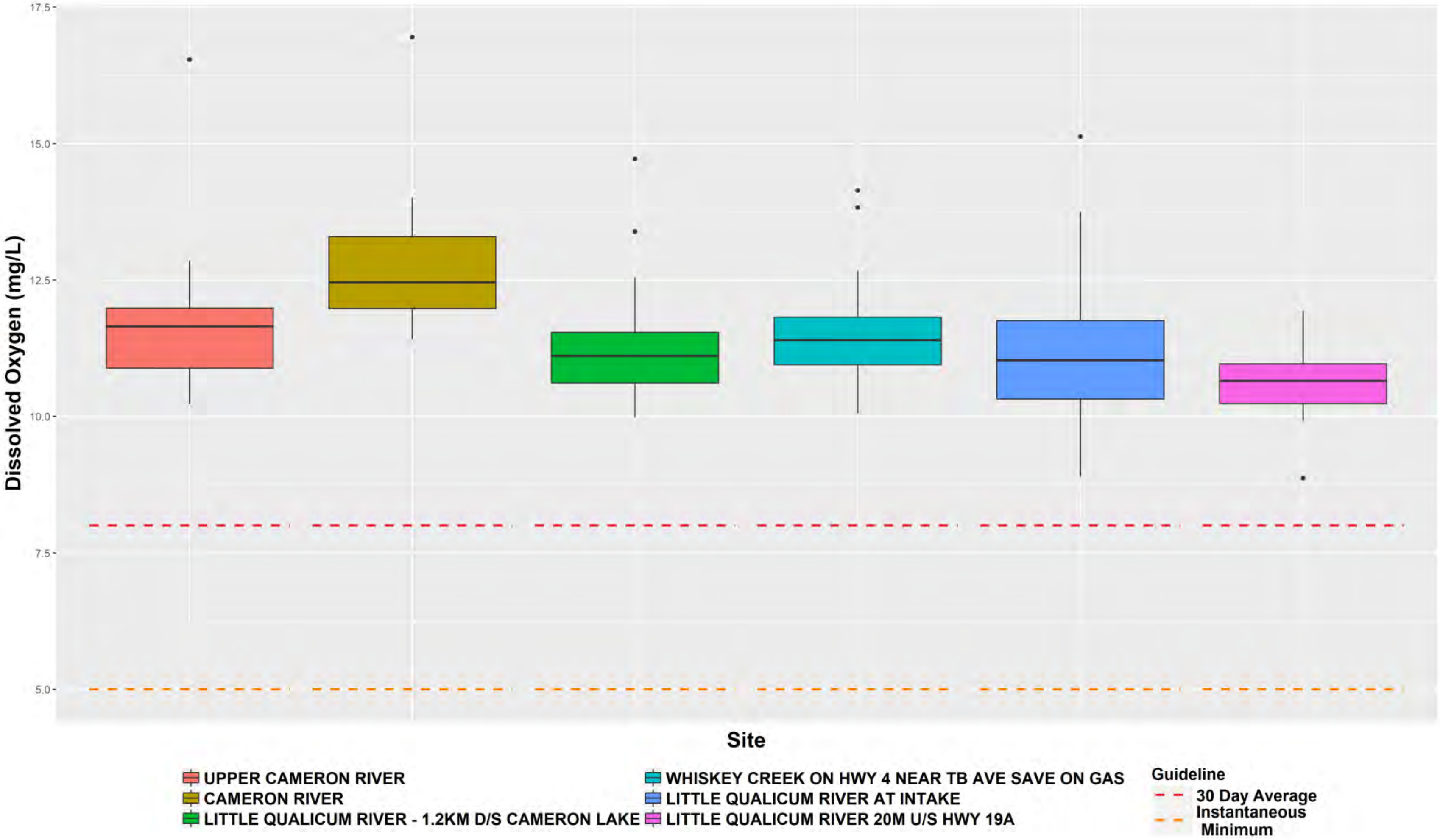


Figure A22. Fall 2011-2017 DO of CWMN sites in Water Region 2 (Little Qualicum) with BC Water Quality guidelines for Aquatic Life.

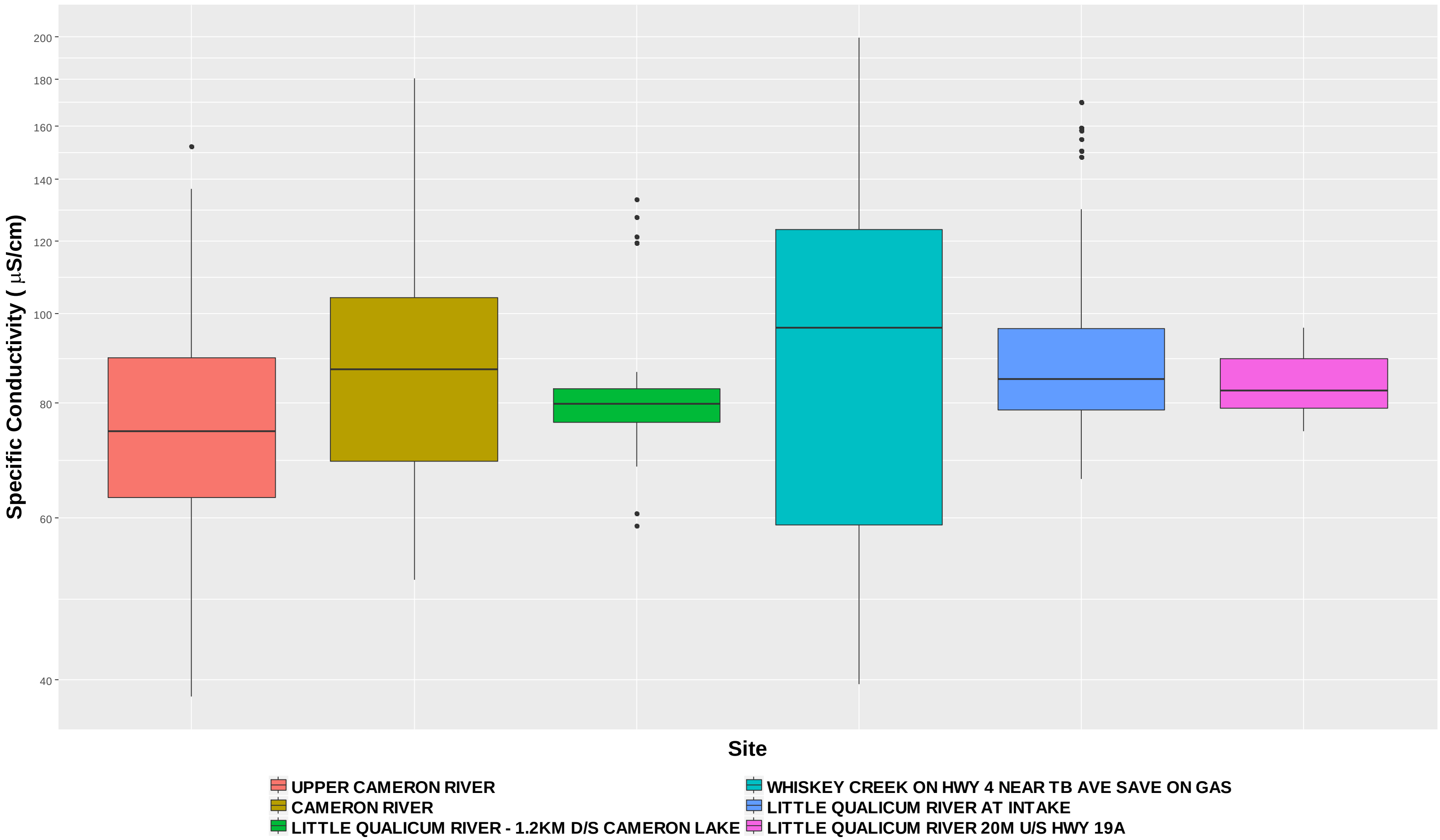


Figure A23. **Fall 2011-2017 specific conductivity of CWMN sites in Water Region 2 (Little Qualicum).**

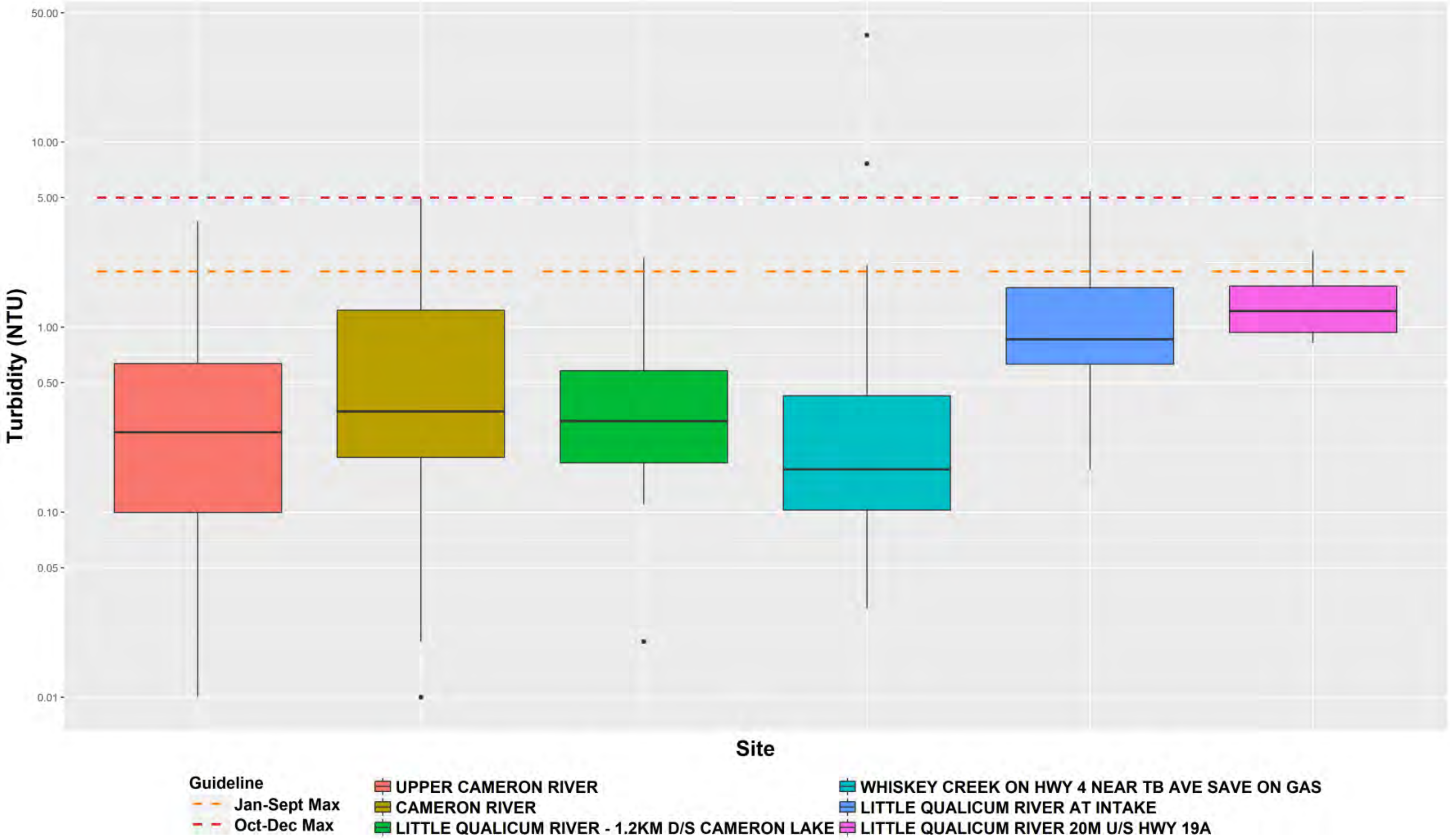


Figure A24. Fall 2011-2017 turbidity of CWMN sites in Water Region 2 (Little Qualicum) with Englishman River water quality objectives.

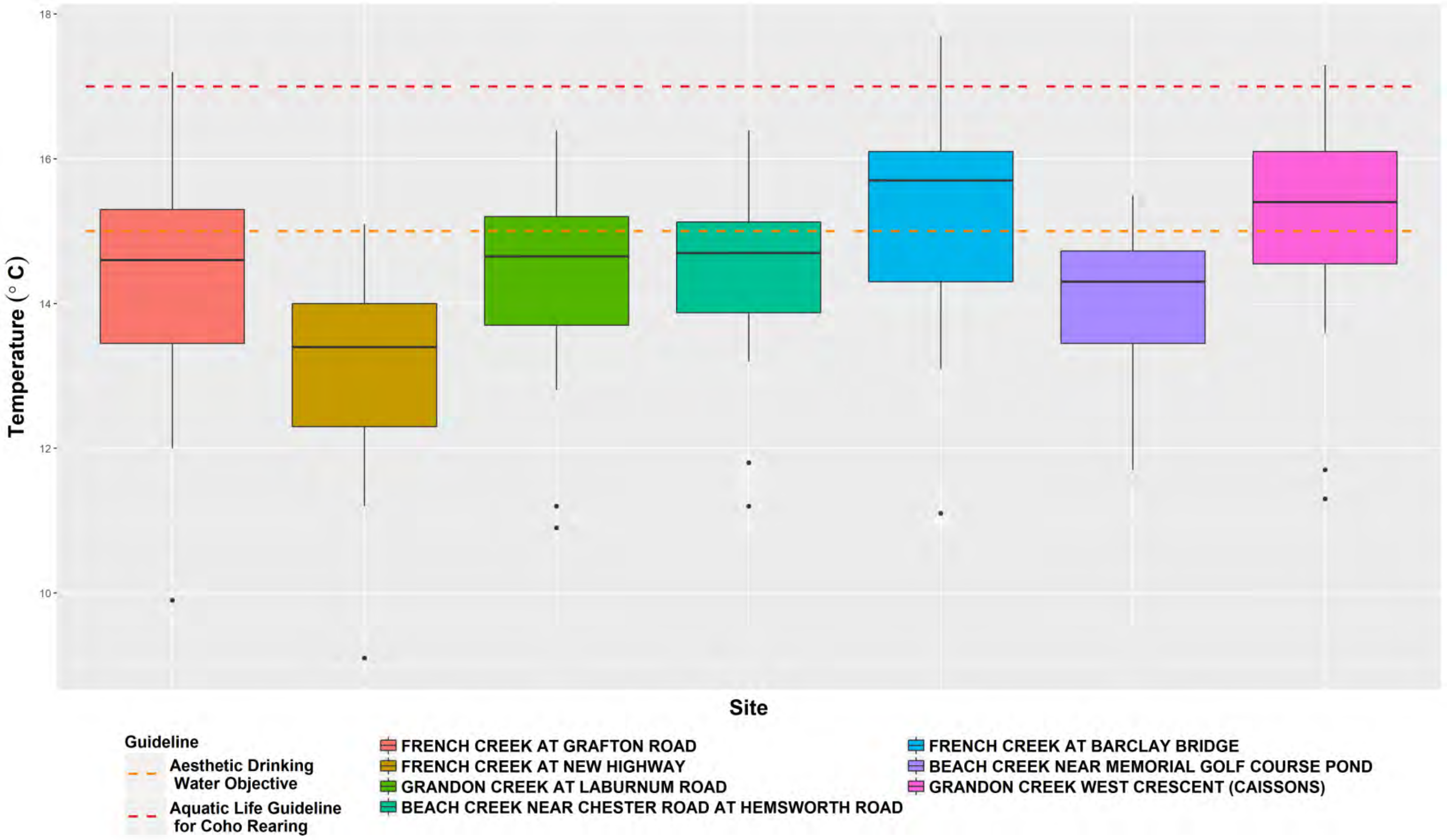


Figure A25. **Summer 2011-2017 water temperature of CWMN sites in Water Region 3 (French Creek) with Englishman River water quality objectives.**

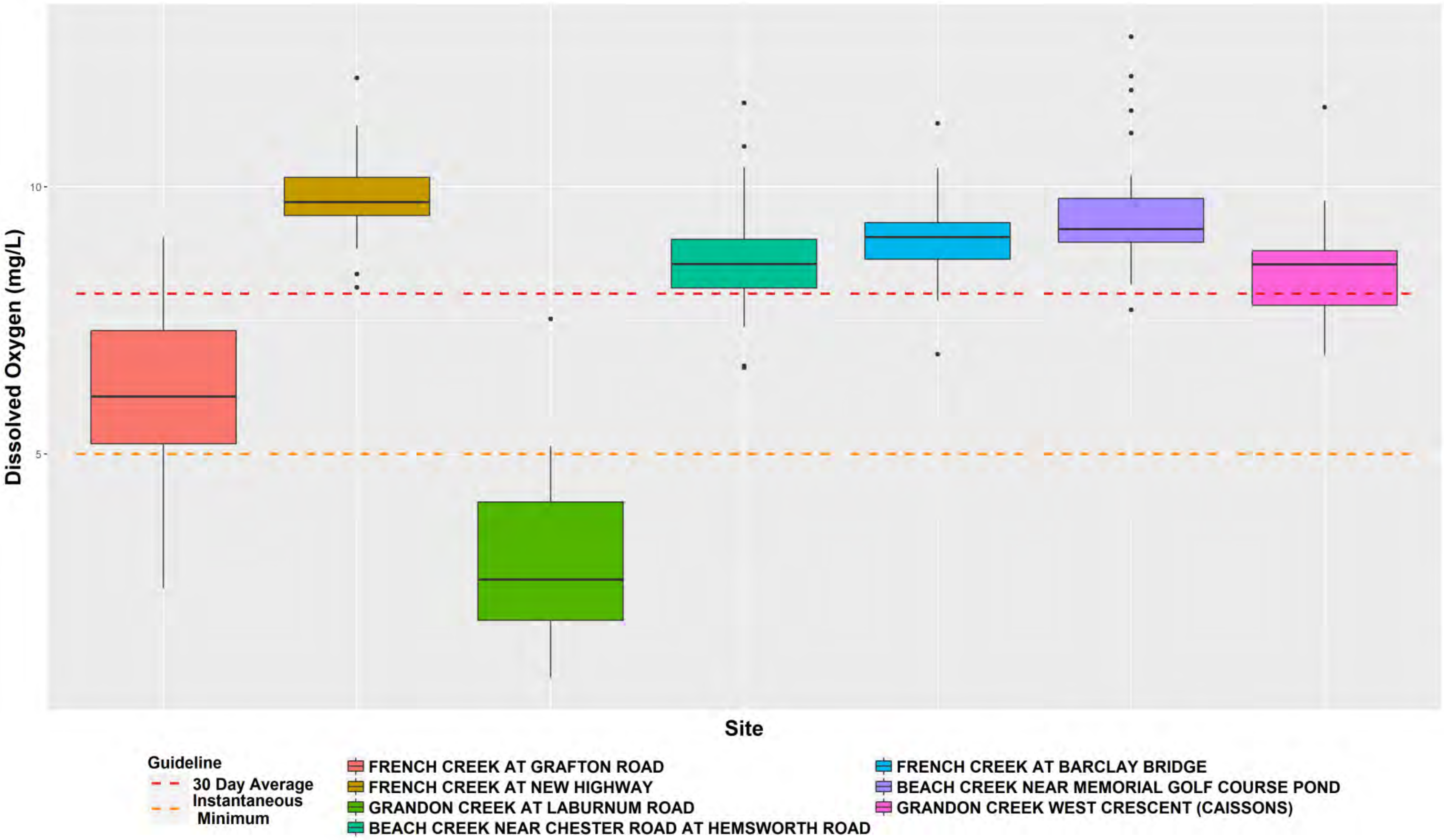


Figure A26. **Summer 2011-2017 DO of CWMN sites in Water Region 3 (French Creek) with BC Water Quality guidelines for Aquatic Life.**

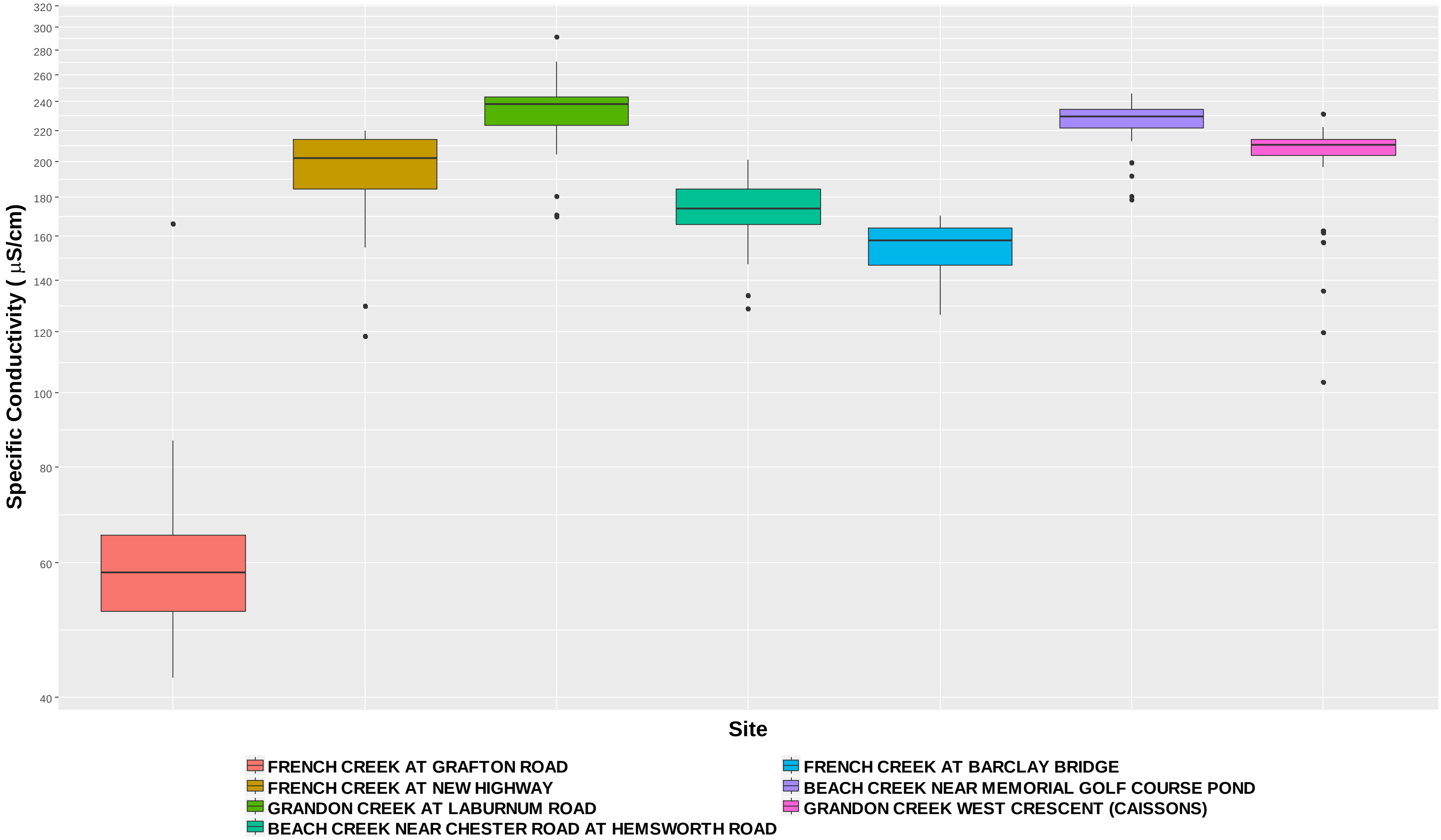


Figure A27. **Summer 2011-2017 specific conductivity of CWMN sites in Water Region 3 (French Creek).**

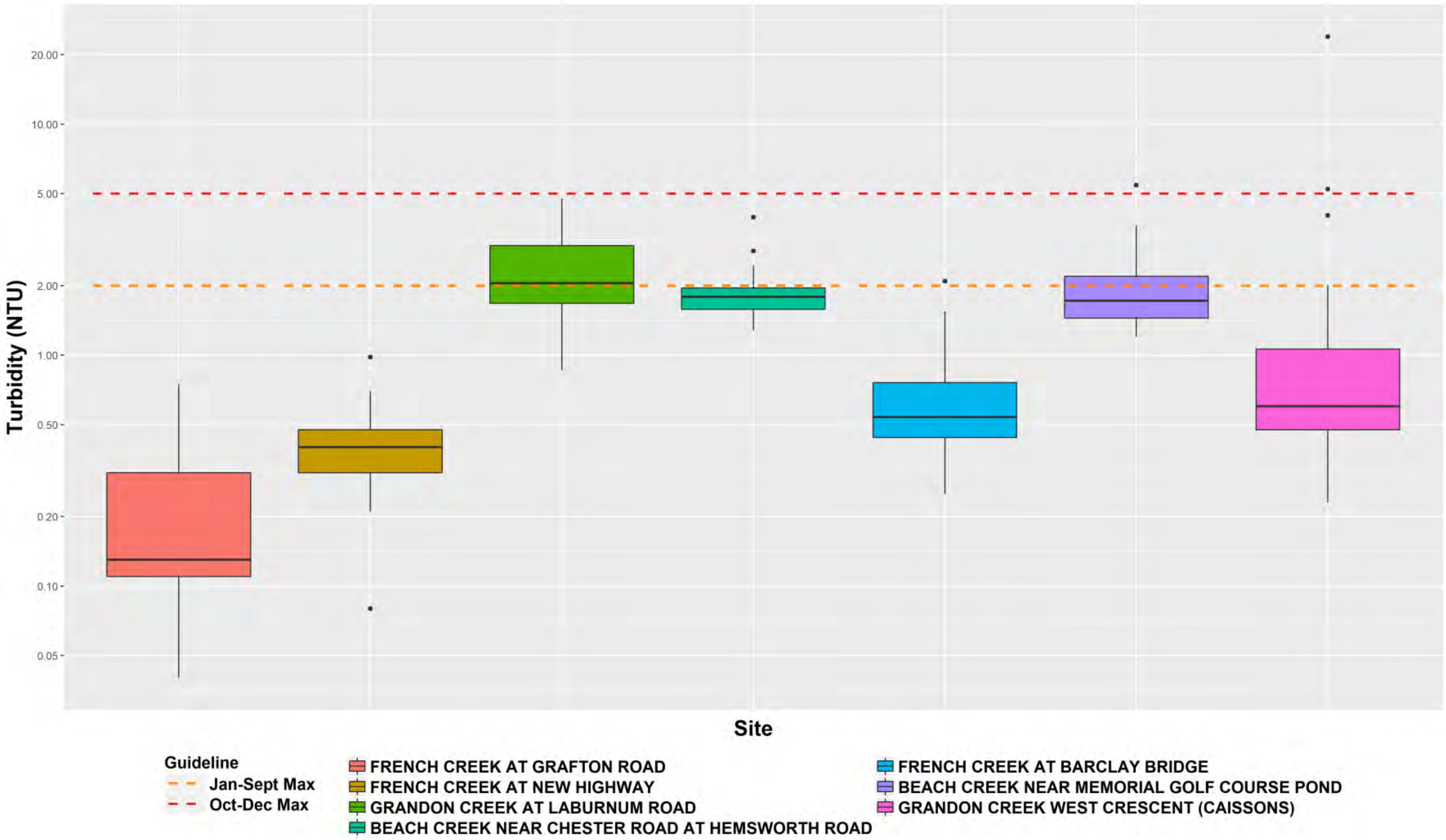


Figure A28. **Summer 2011-2017 turbidity of CWMN sites in Water Region 3 (French Creek) with Englishman River water quality objectives.**

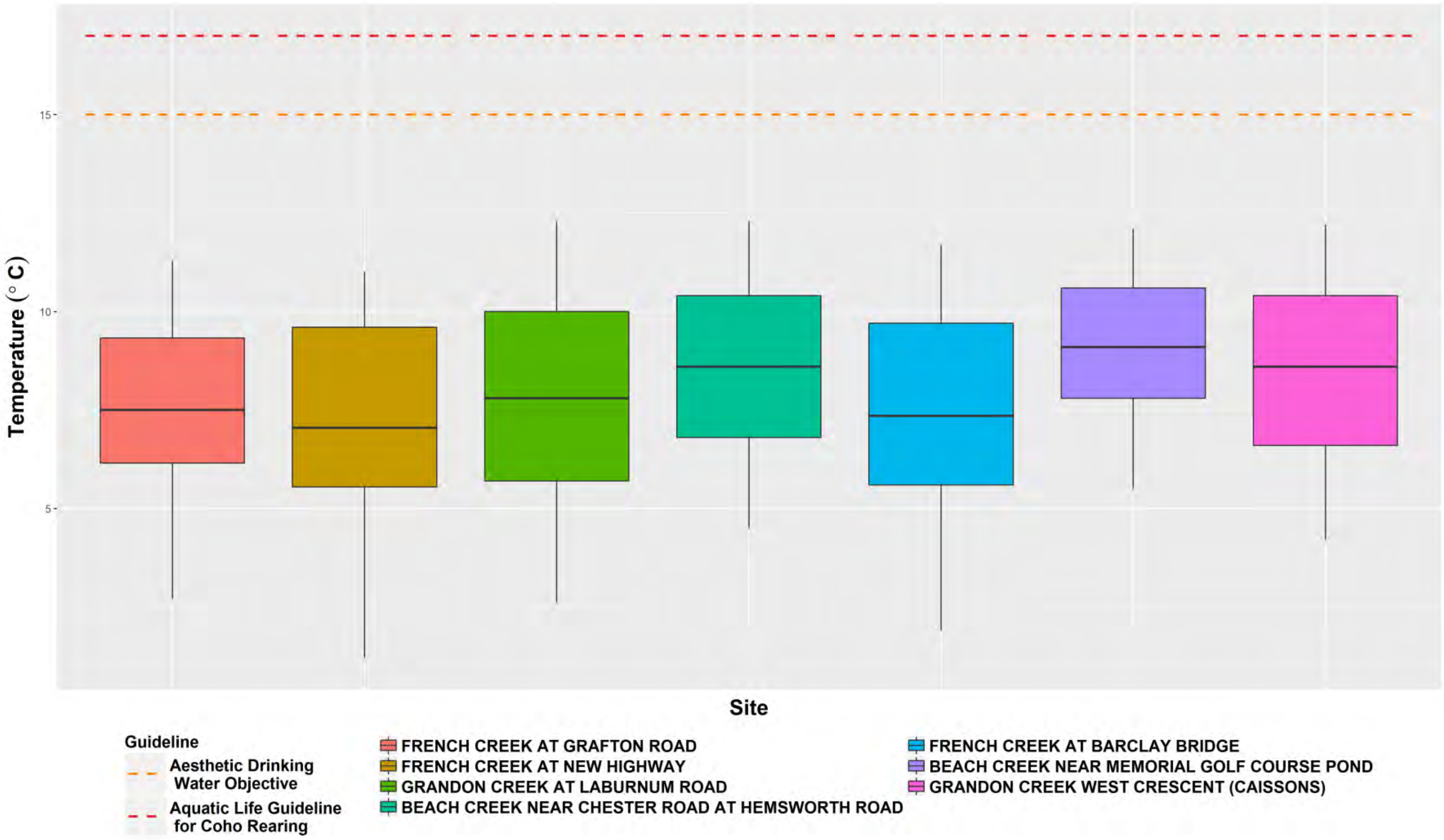


Figure A29. **Fall 2011-2017 water temperature of CWMN sites in Water Region 3 (French Creek) with Englishman River water quality objectives.**

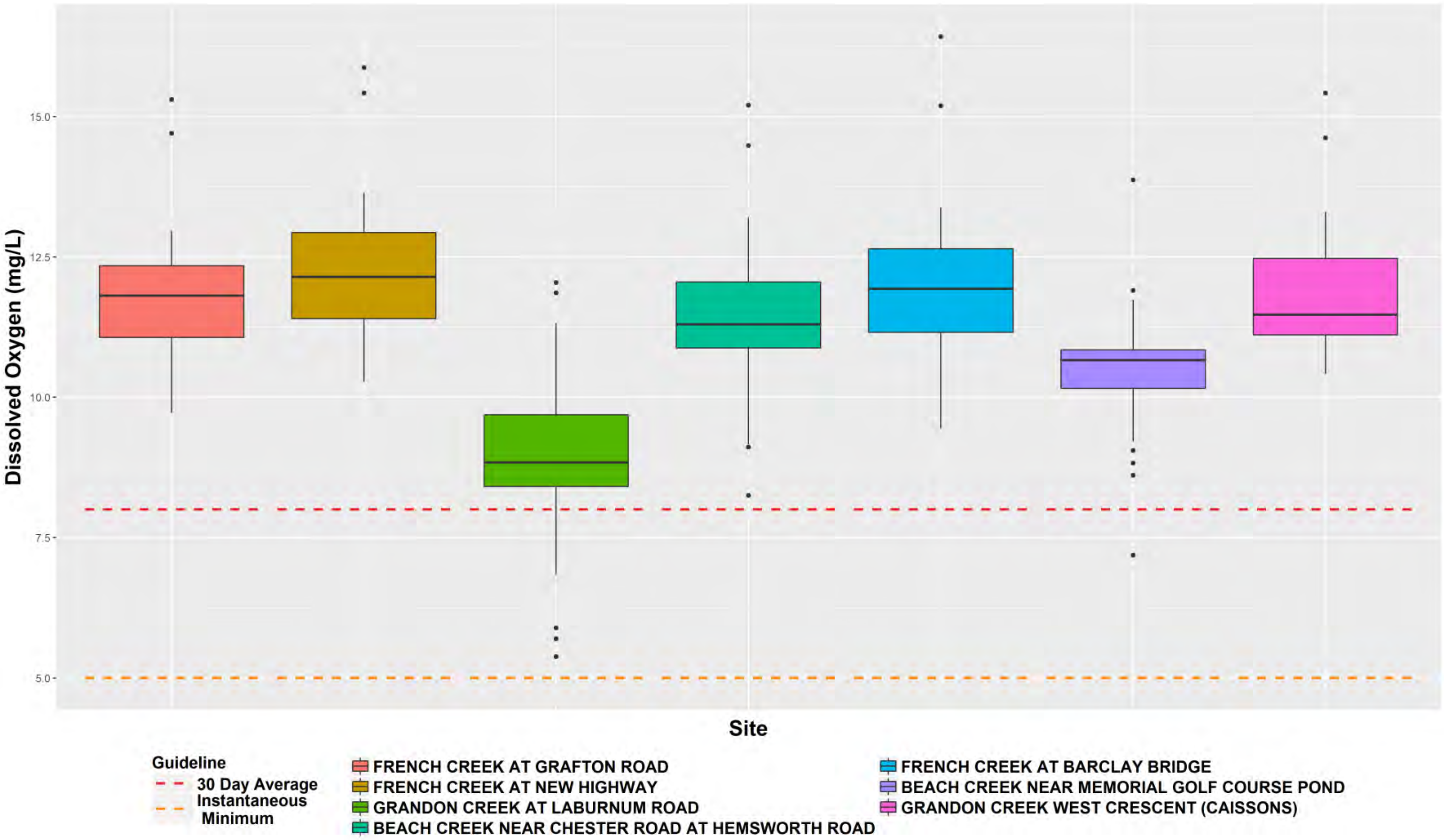


Figure A30. Fall 2011-2017 DO of CWMN sites in Water Region 3 (French Creek) with BC Water Quality guidelines for Aquatic Life.

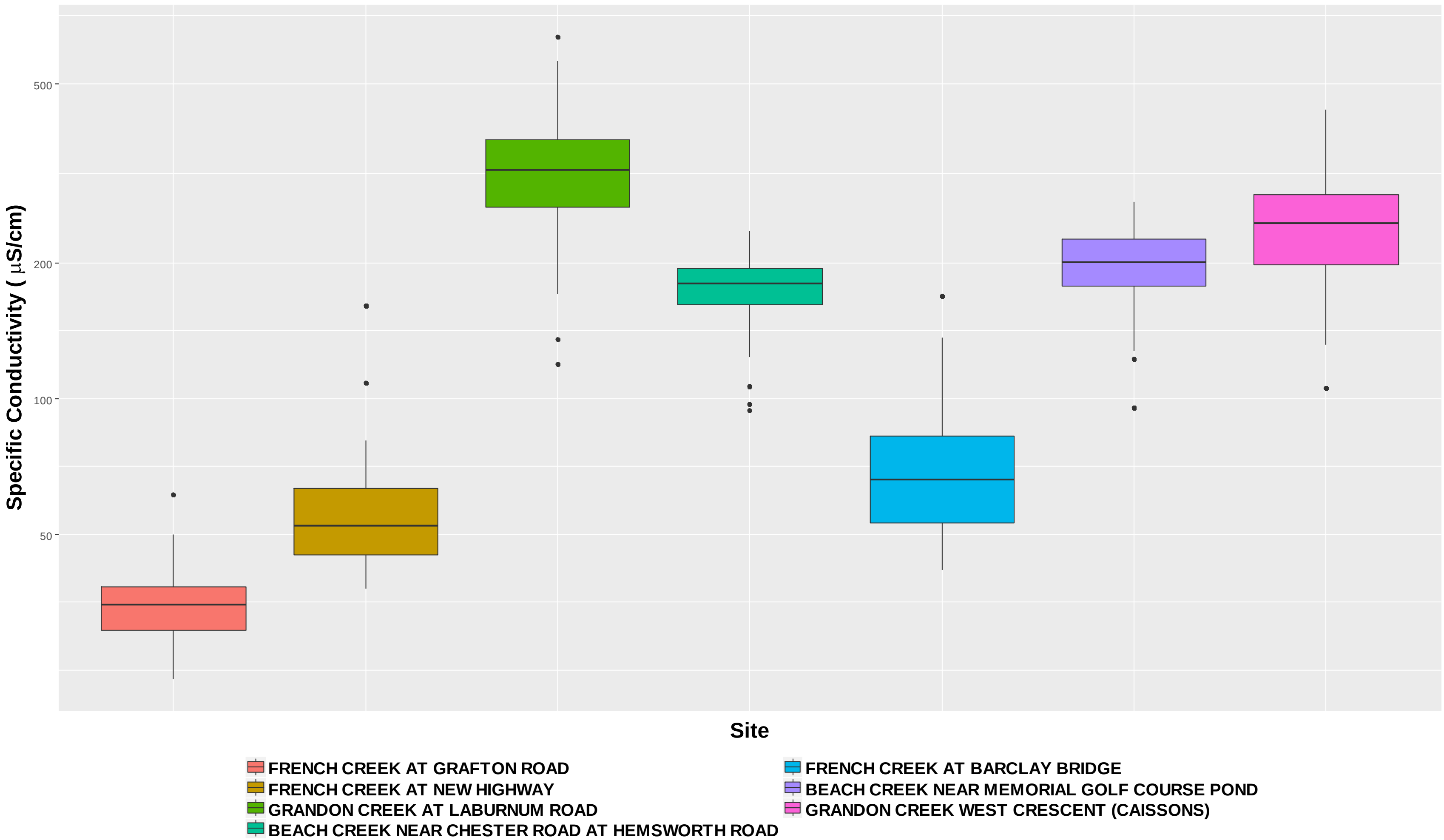


Figure A31. **Fall 2011-2017 specific conductivity of CWMN sites in Water Region 3 (French Creek).**

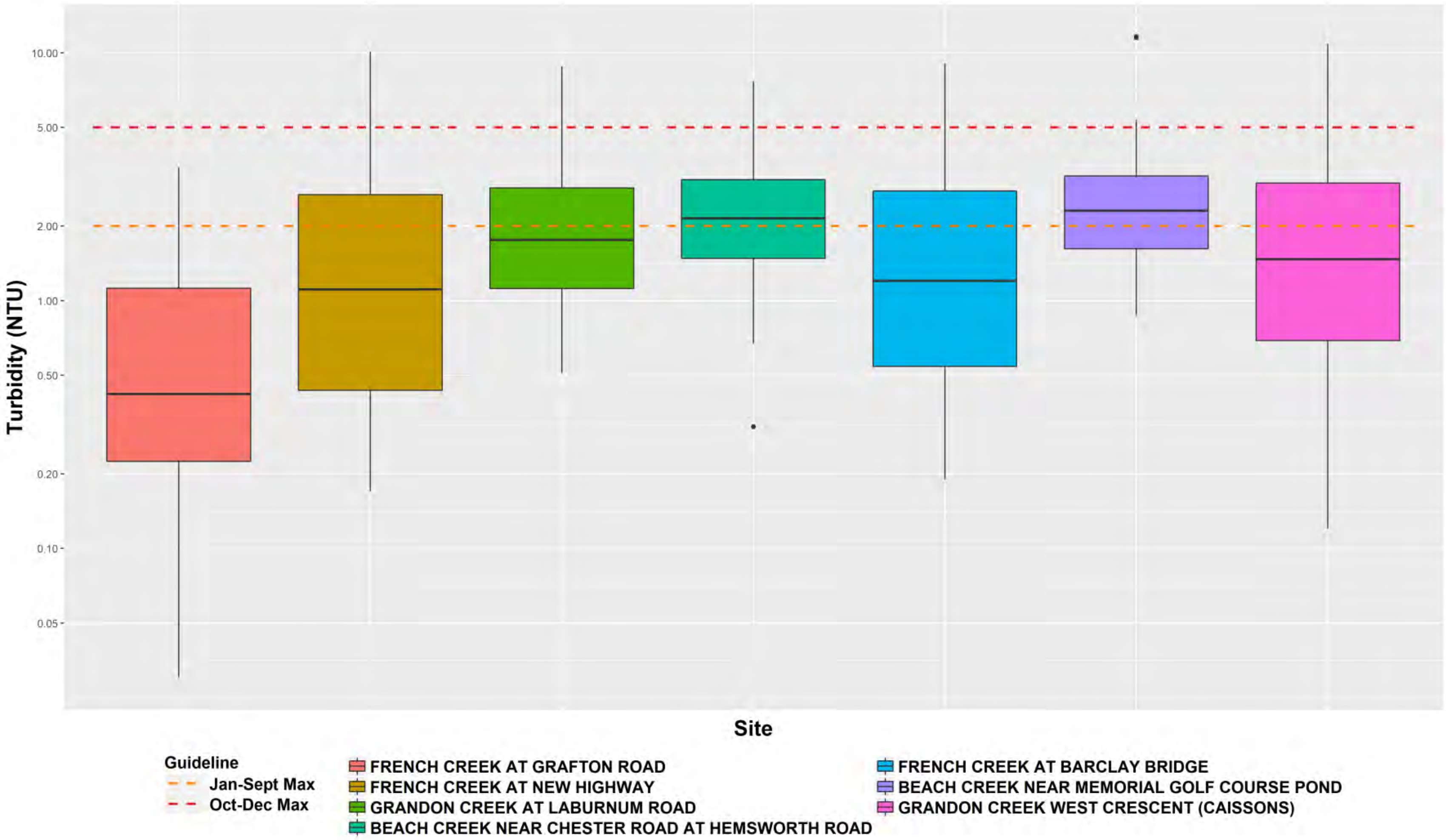


Figure A32. **Fall 2011-2017 turbidity of CWMN sites in Water Region 3 (French Creek) with Englishman River water quality objectives.**

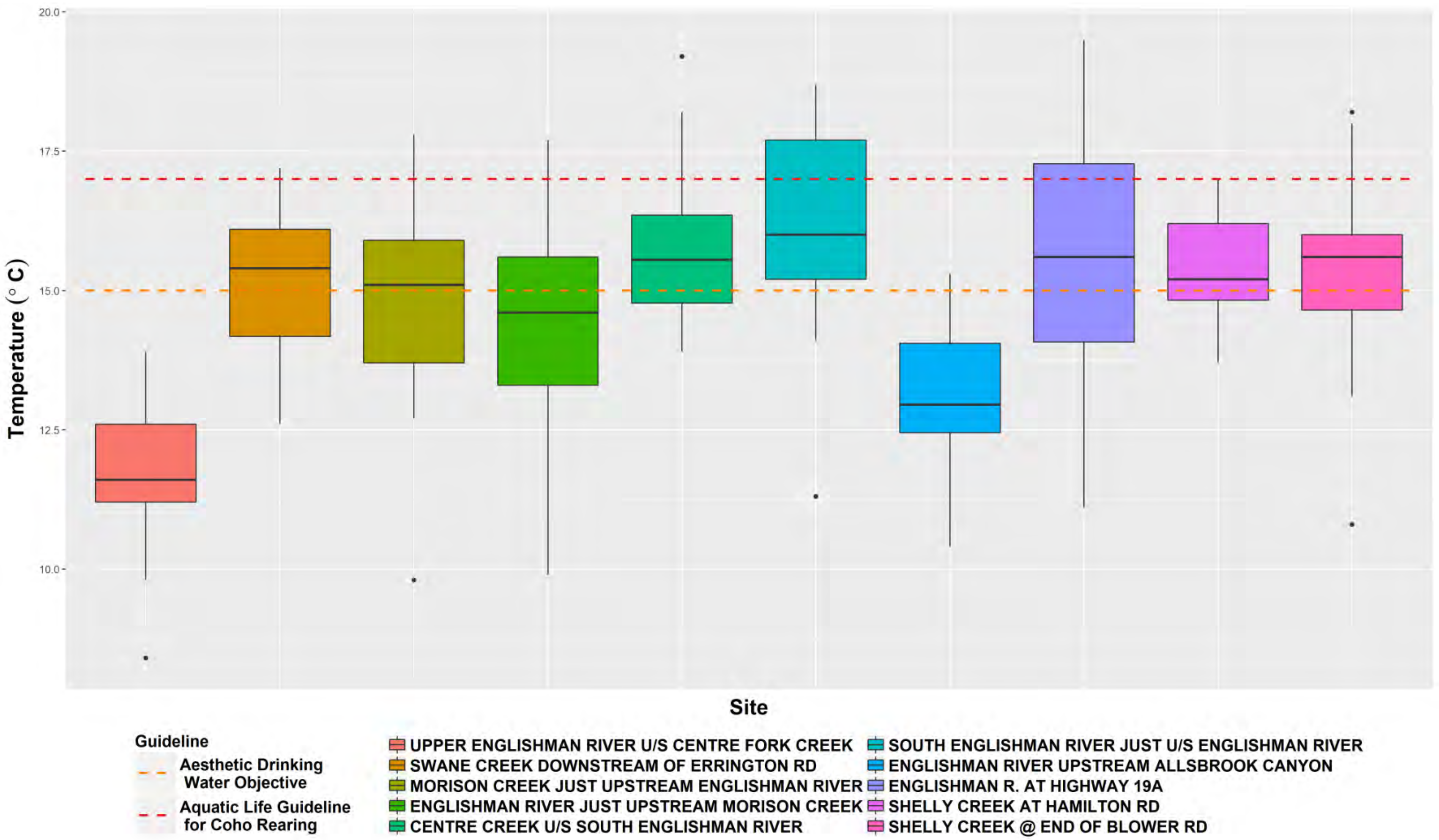


Figure A33. **Summer 2011-2017 water temperature of CWMN sites in Water Region 4 (Englishman River) with Englishman River water quality objectives.**

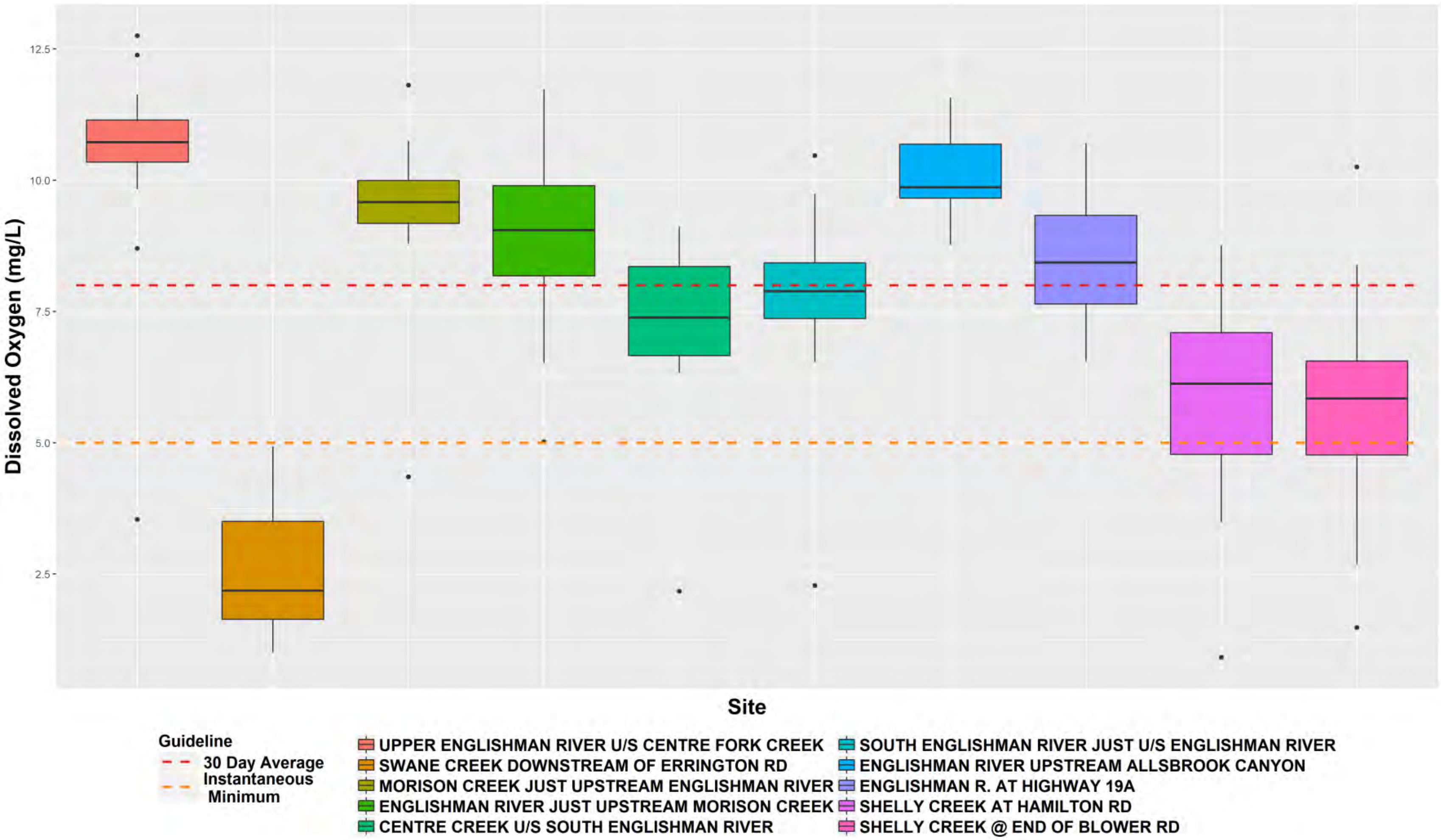


Figure A34. **Summer 2011-2017 DO of CWMN sites in Water Region 4 (Englishman River) with BC Water Quality guidelines for Aquatic Life.**

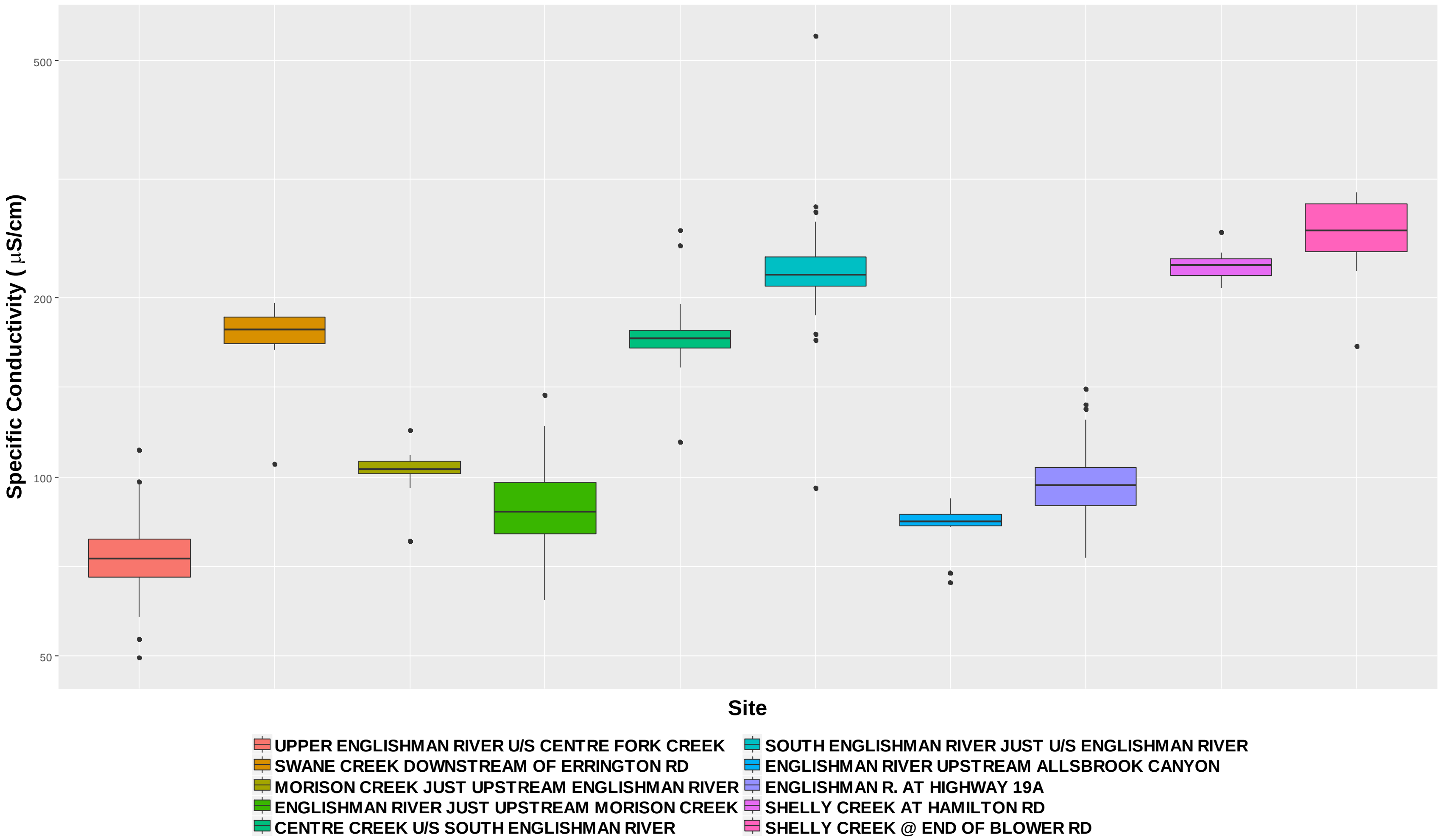


Figure A35. **Summer 2011-2017 specific conductivity of CWMN sites in Water Region 4 (Englishman River).**

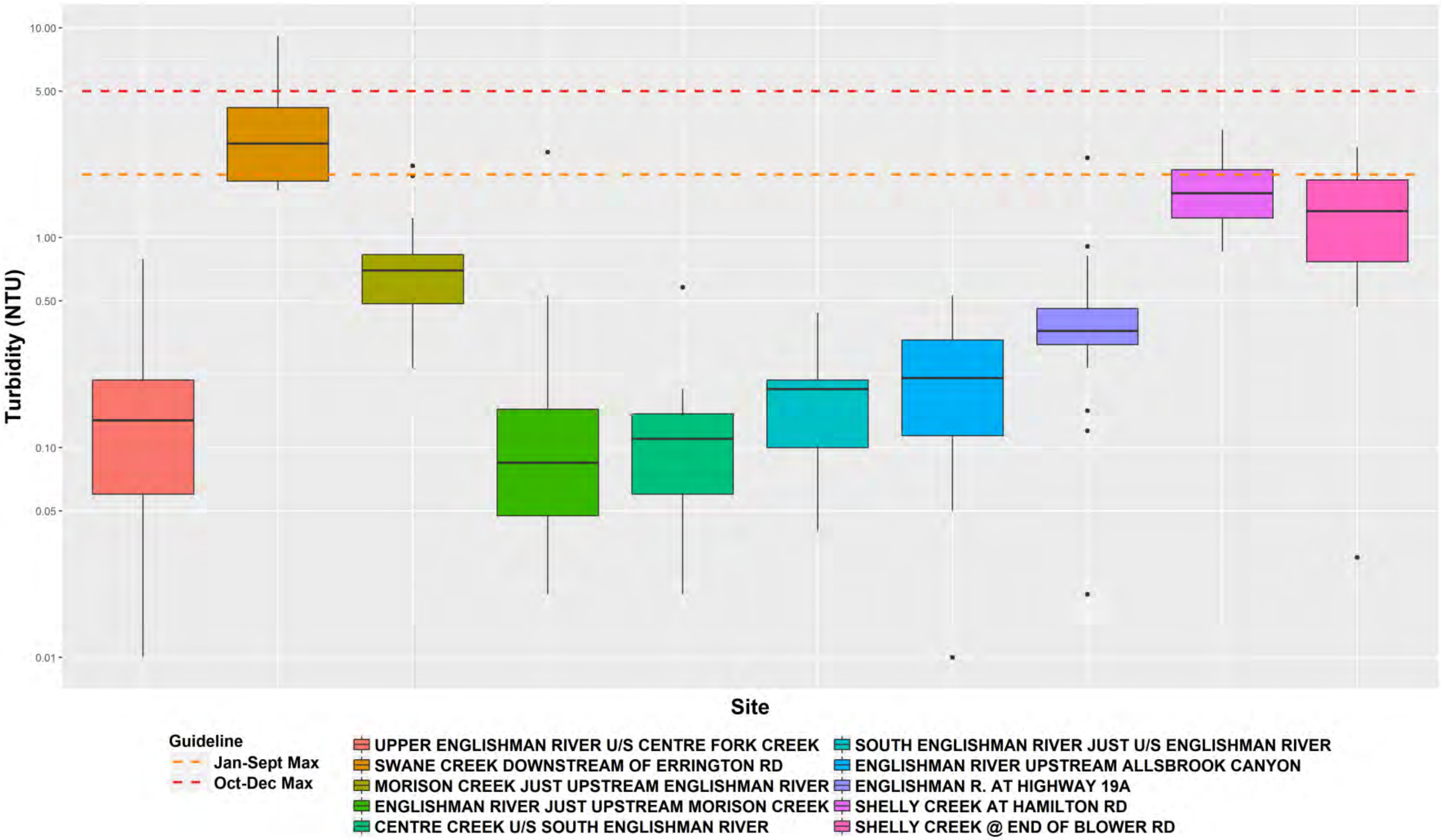


Figure A36. **Summer 2011-2017 turbidity of CWMN sites in Water Region 4 (Englishman River) with Englishman River water quality objectives.**

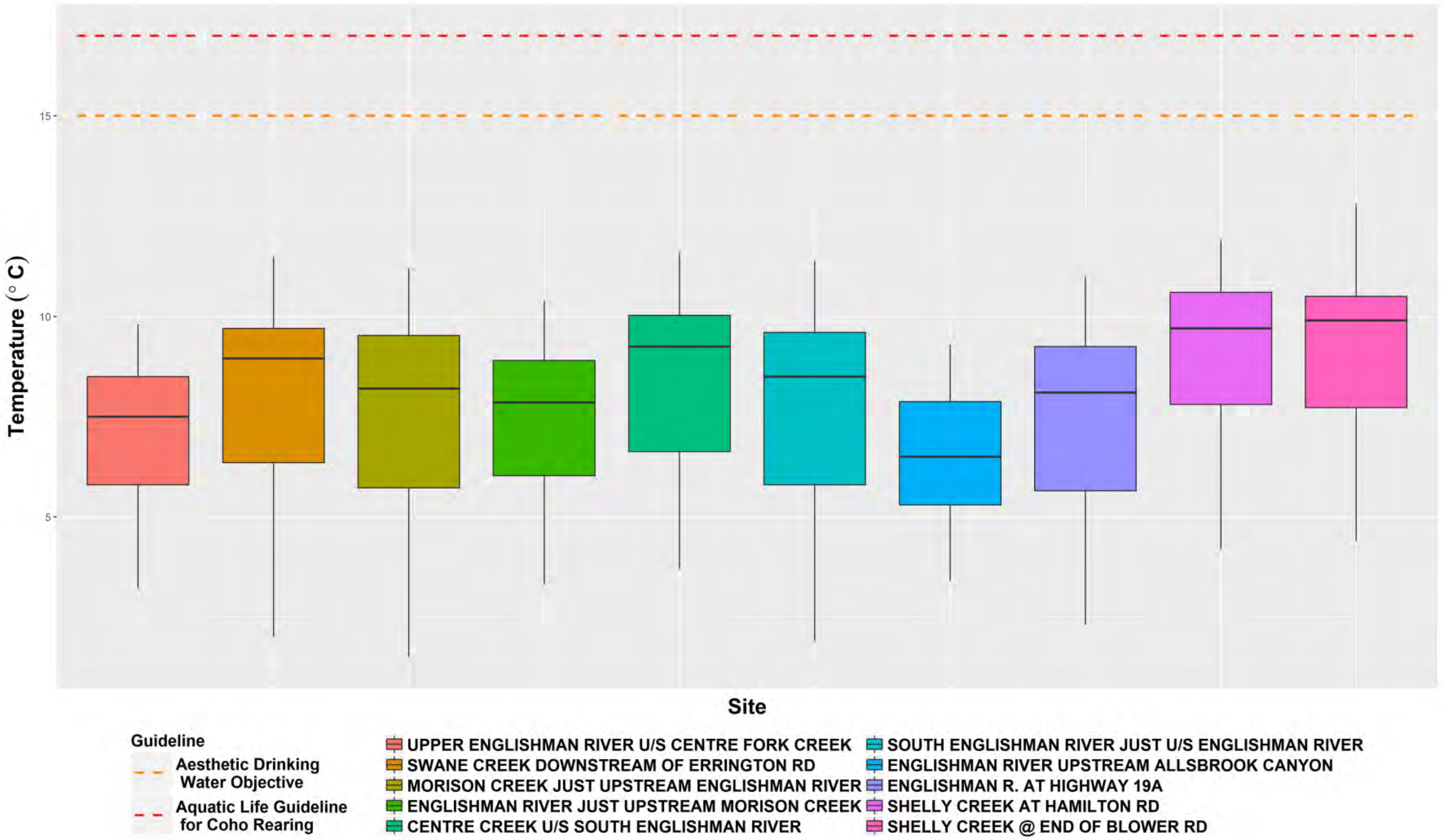
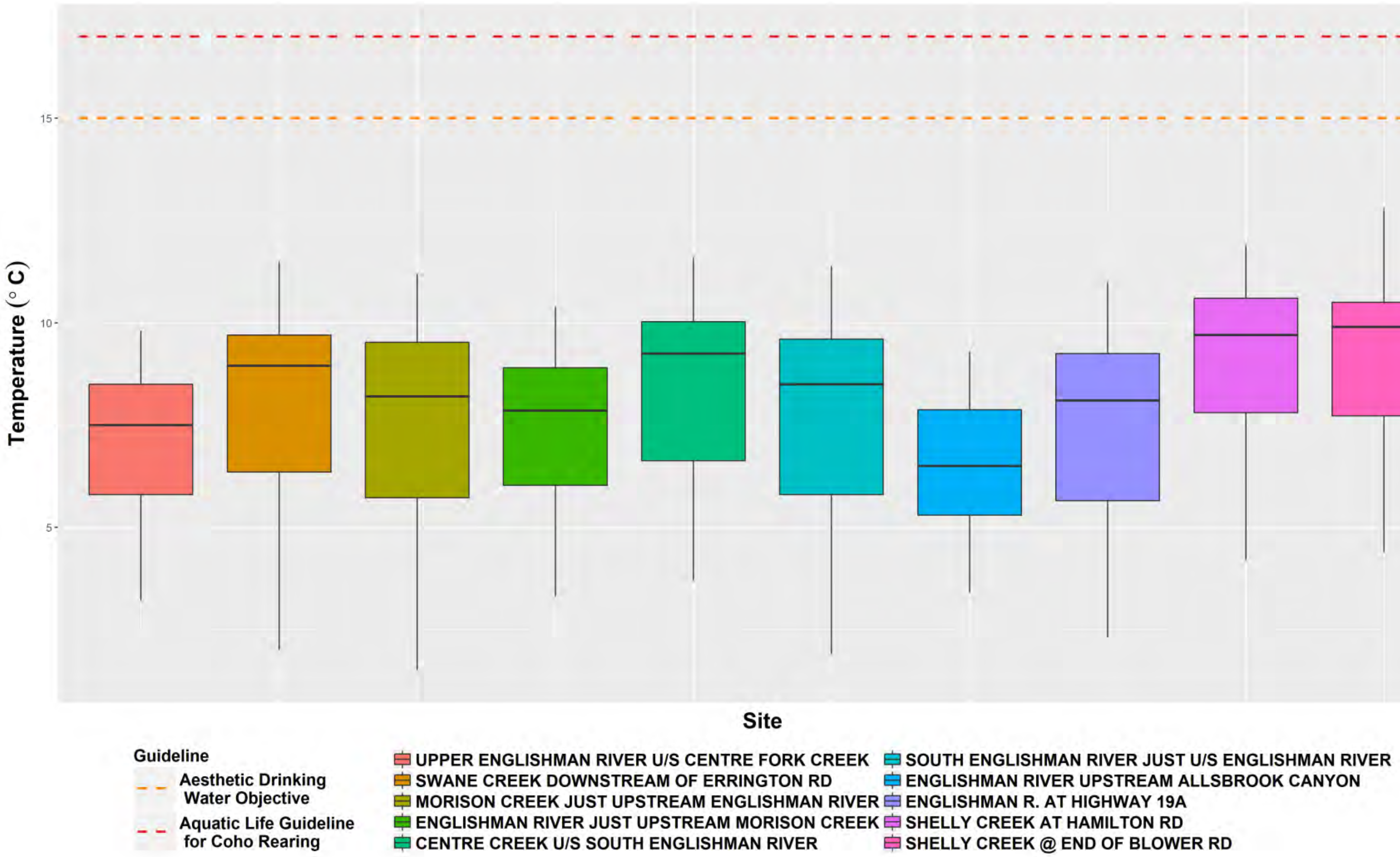


Figure A37. **Fall 2011-2017 water temperature of CWMN sites in Water Region 4 (Englishman River) with Englishman River water quality objectives.**



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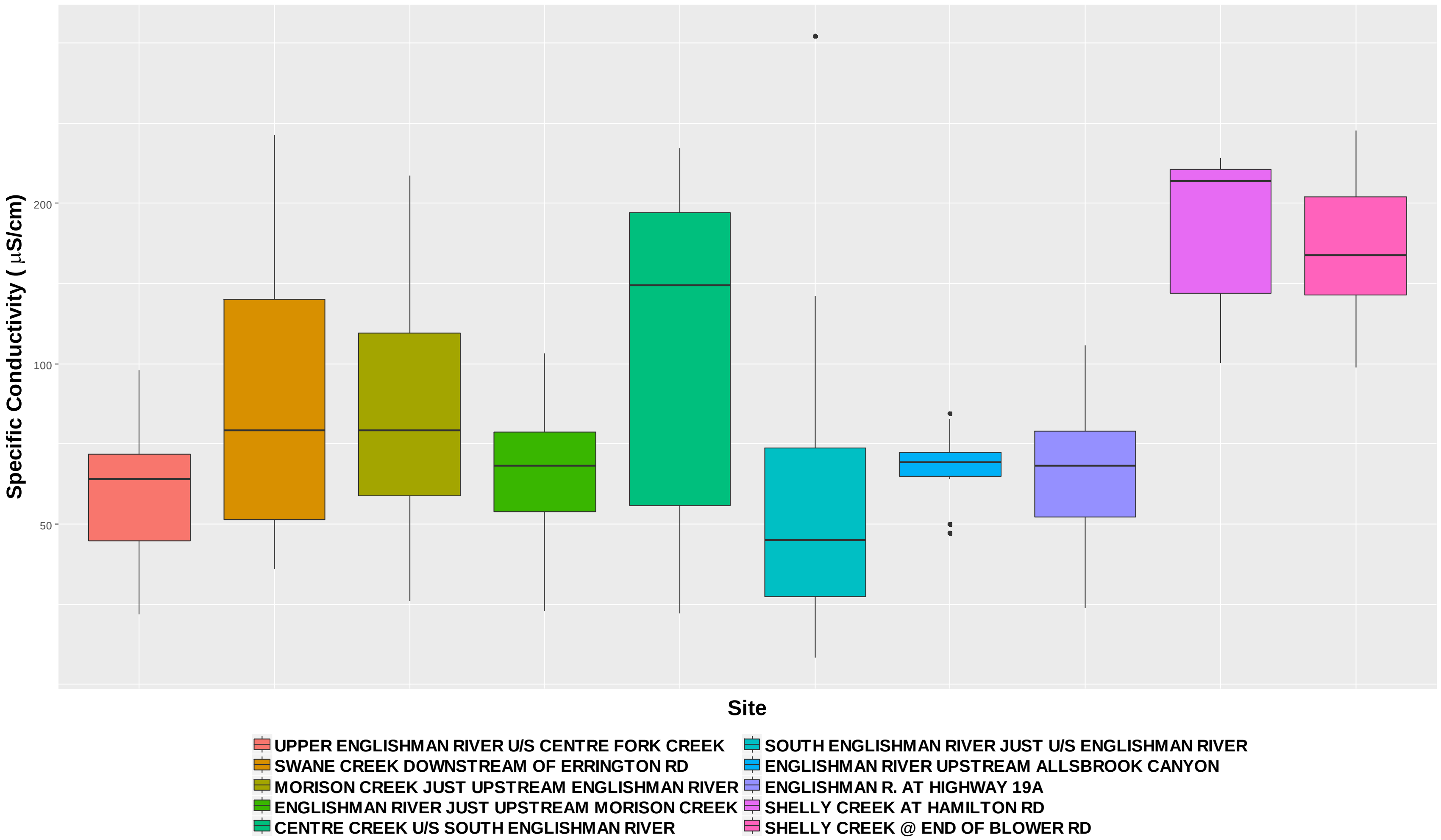


Figure A39. **Fall 2011-2017 specific conductivity of CWMN sites in Water Region 4 (Englishman River).**

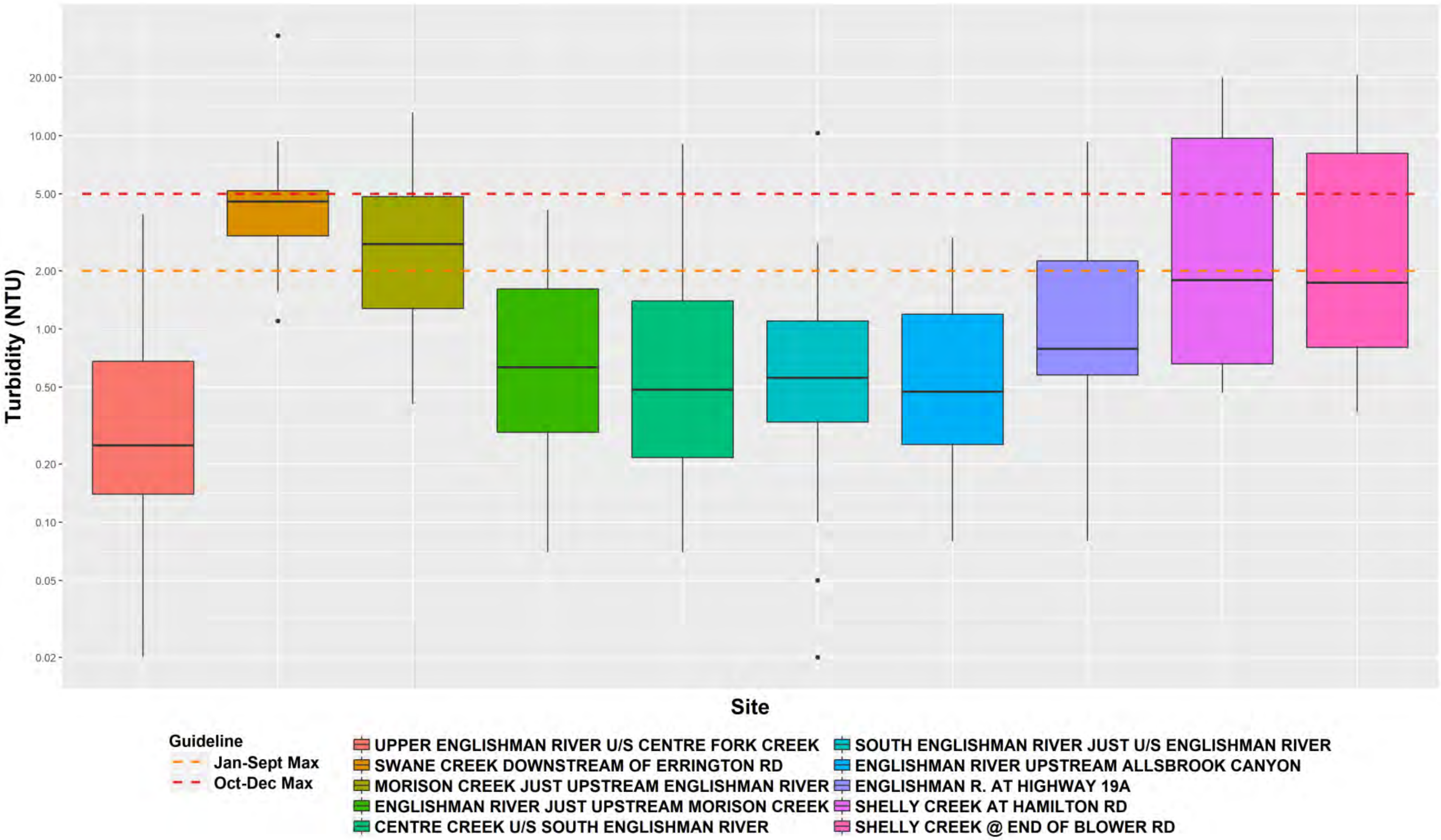


Figure A40. **Fall 2011-2017 turbidity of CWMN sites in Water Region 4 (Englishman River) with Englishman River water quality objectives.**

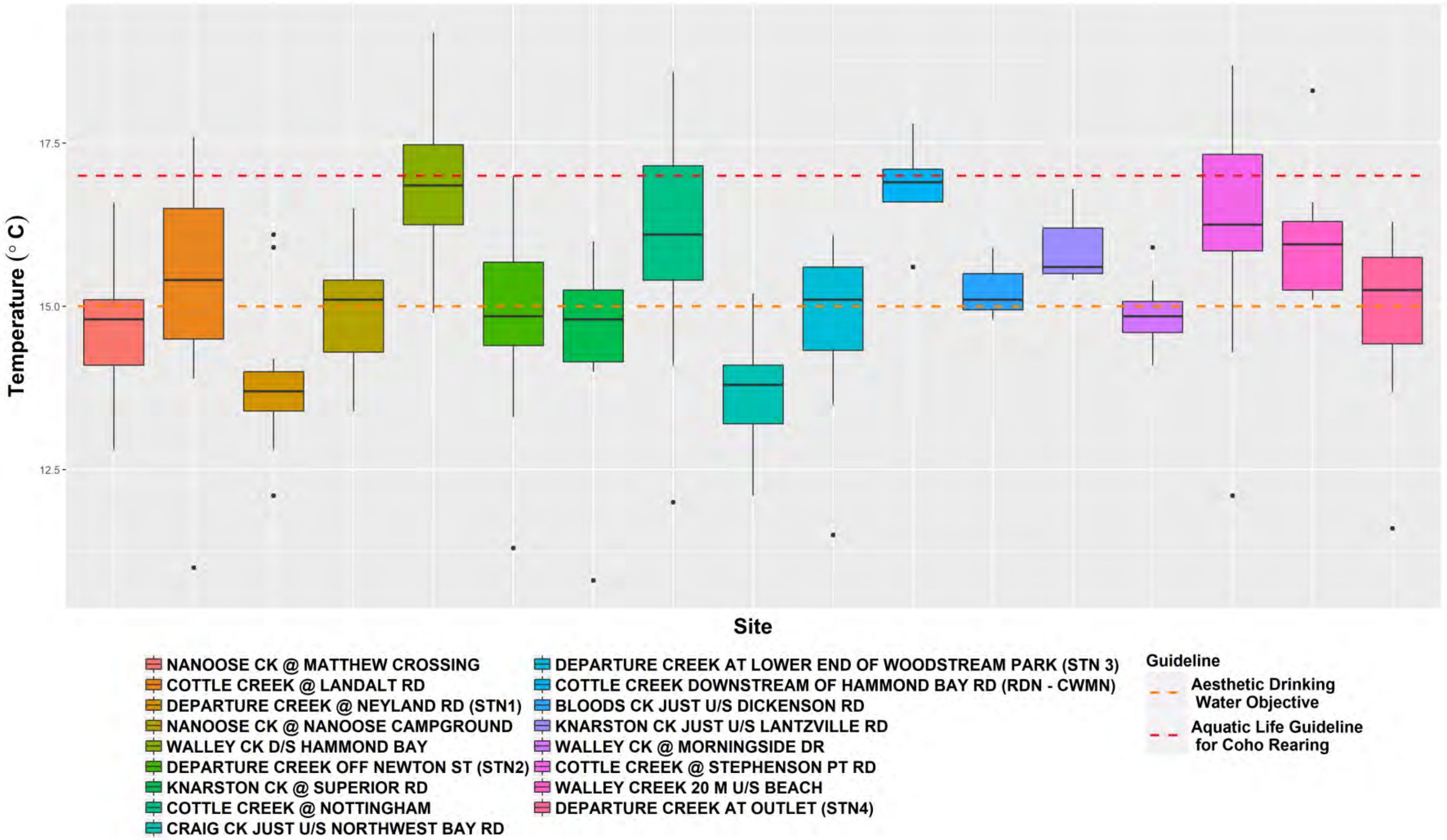


Figure A41. **Summer 2012-2017 water temperature of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with Englishman River water quality objectives.**

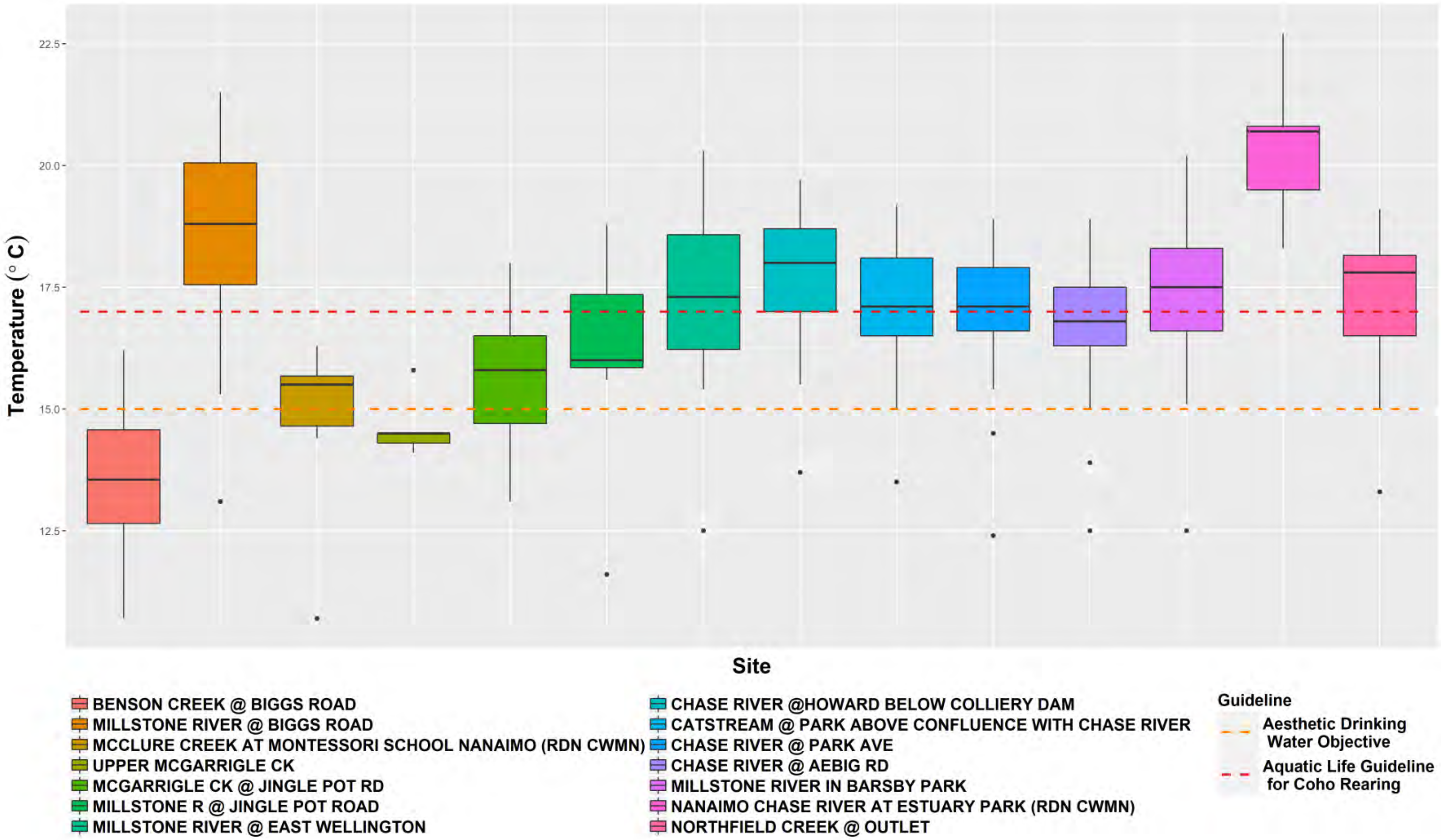


Figure A42. Summer 2012-2017 water temperature of CWMN sites in Water Region 5-2 (South Wellington to Nanoose) with Englishman River water quality objectives.

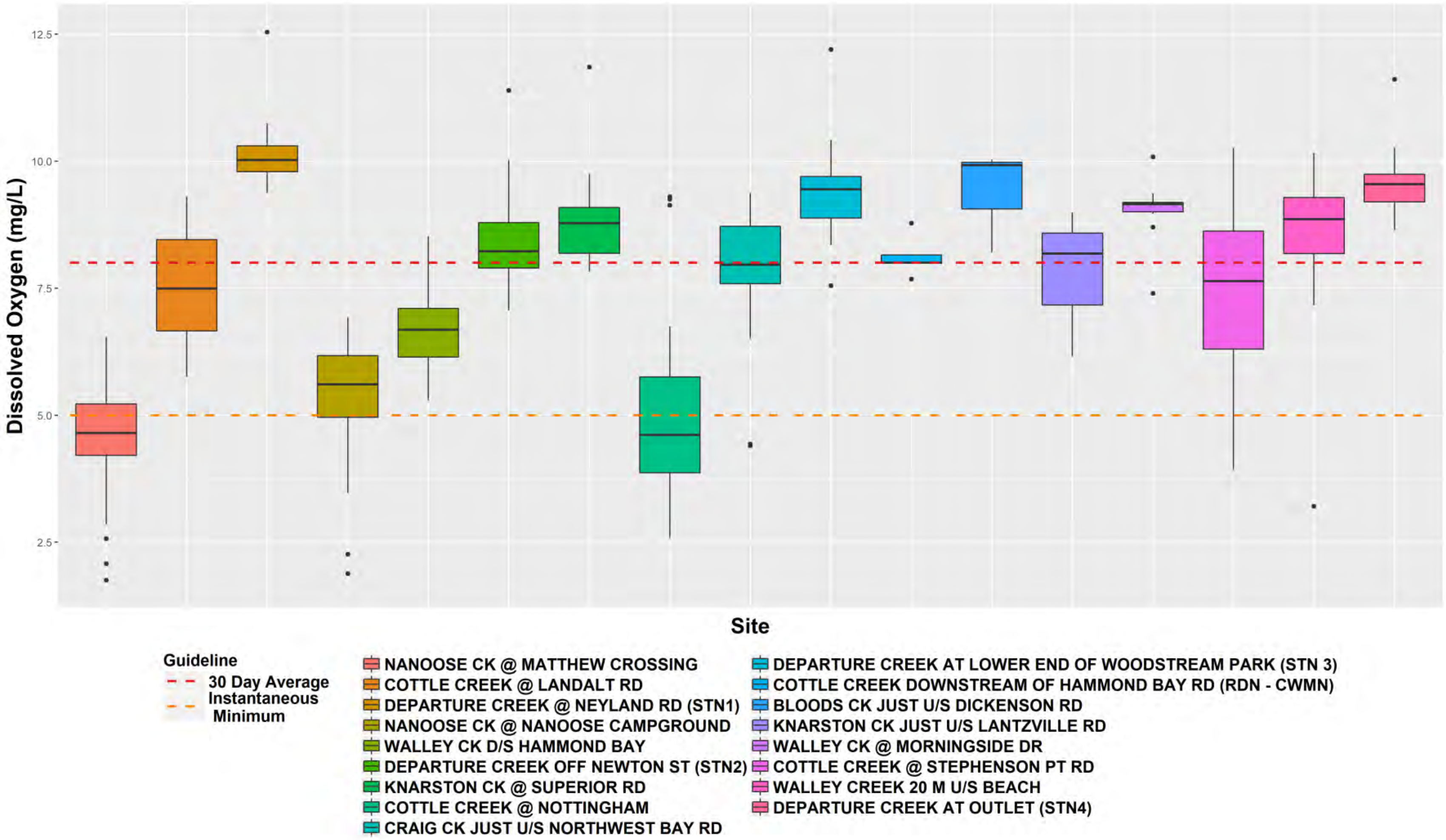
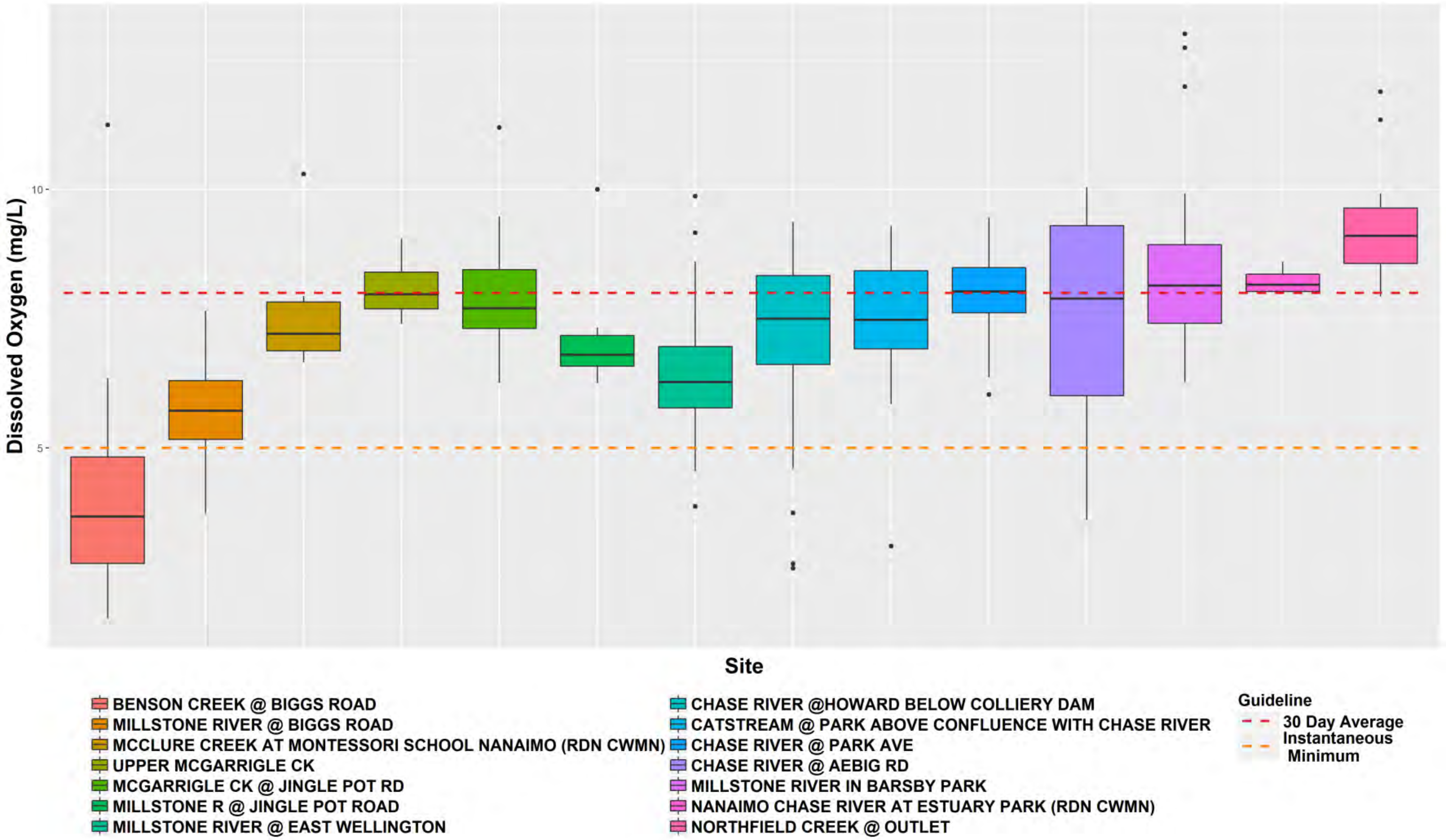


Figure A43. **Summer 2012-2017 DO of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with BC Water Quality guidelines for Aquatic Life.**



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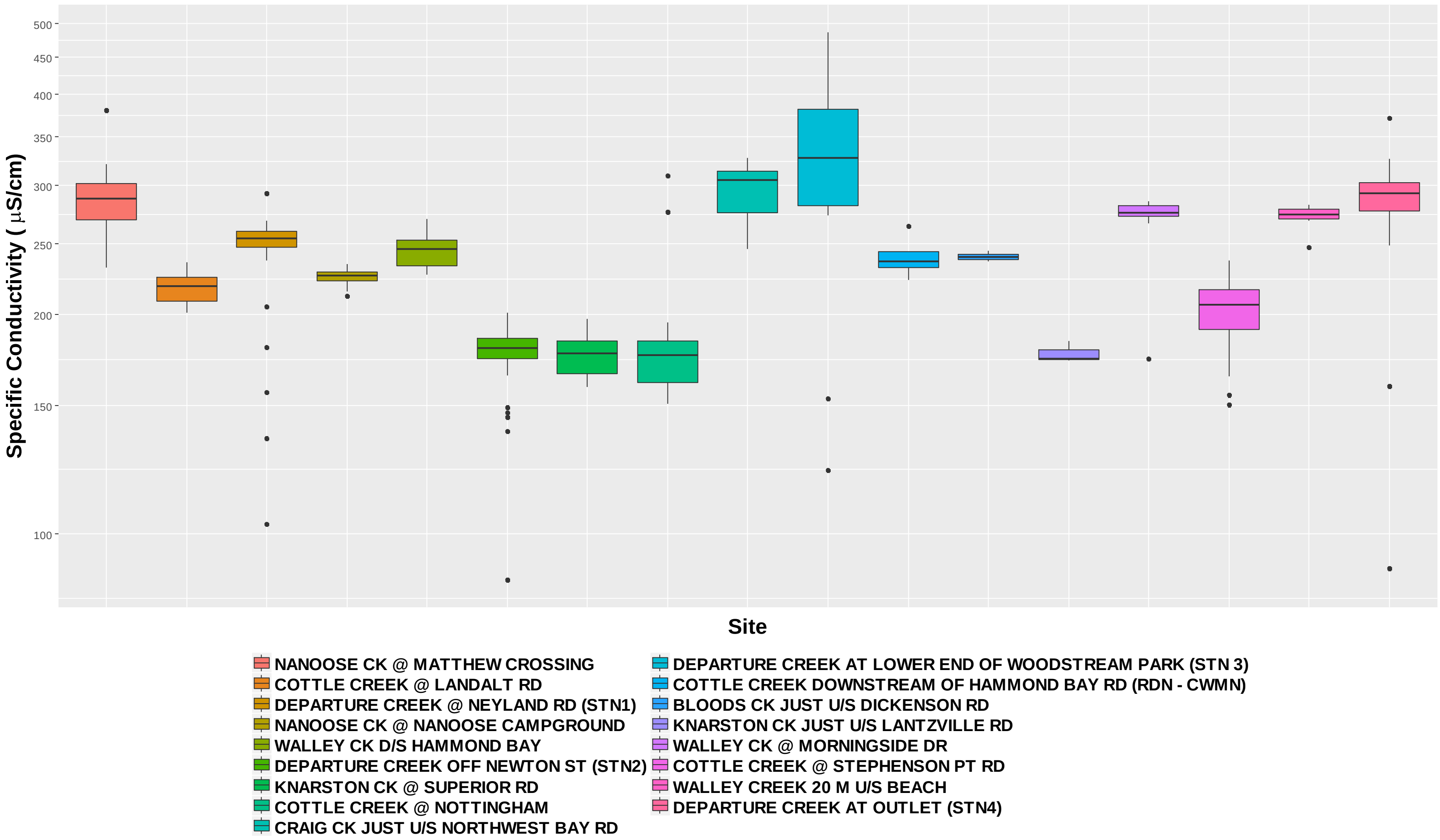

Figure A45. **Summer 2012-2017 specific conductivity of CWMN sites in Water Region 5-1 (South Wellington to Nanoose).**

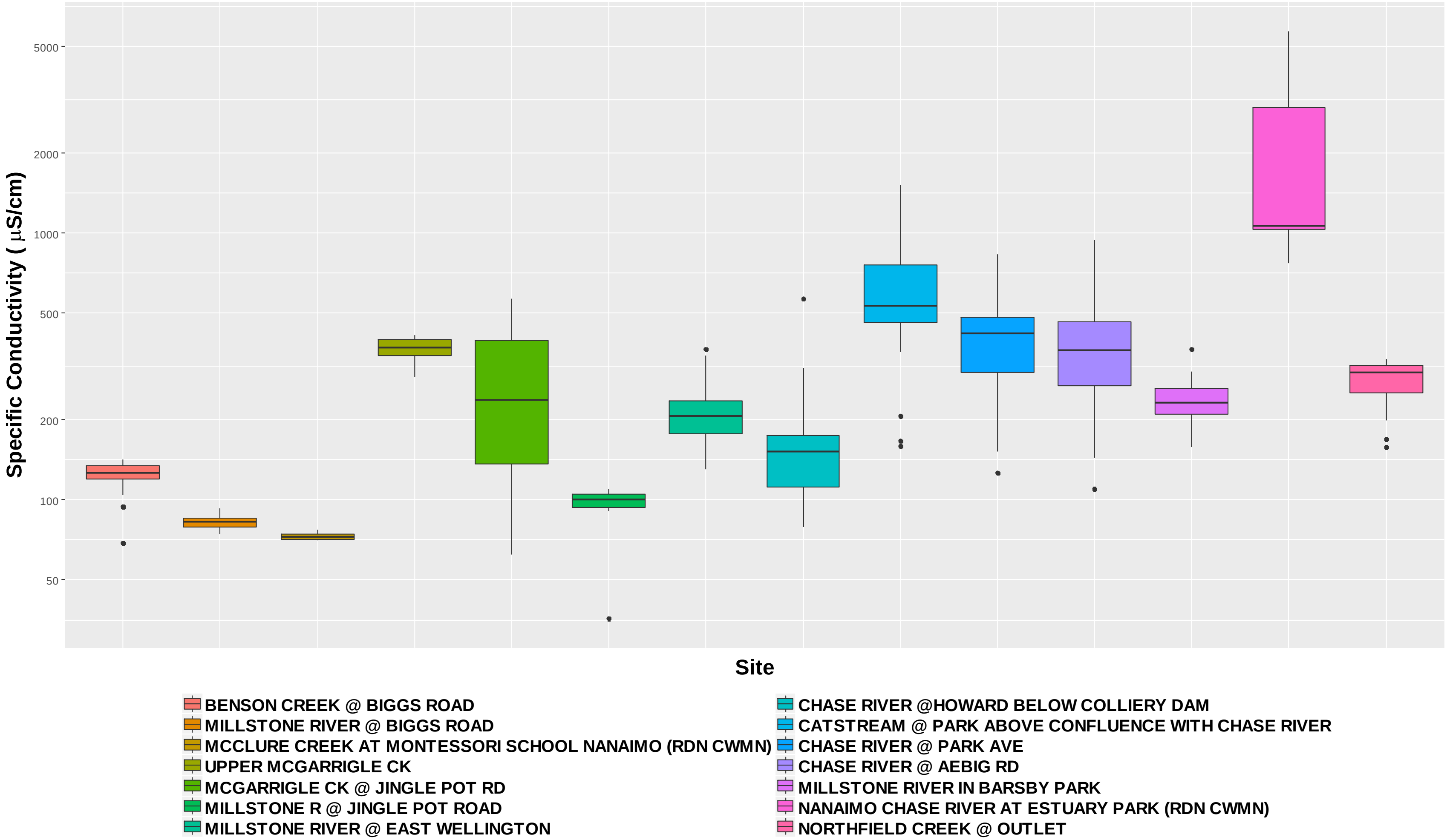

Figure A46. **Summer 2012-2017 specific conductivity of CWMN sites in Water Region 5-2 (South Wellington to Nanoose).**

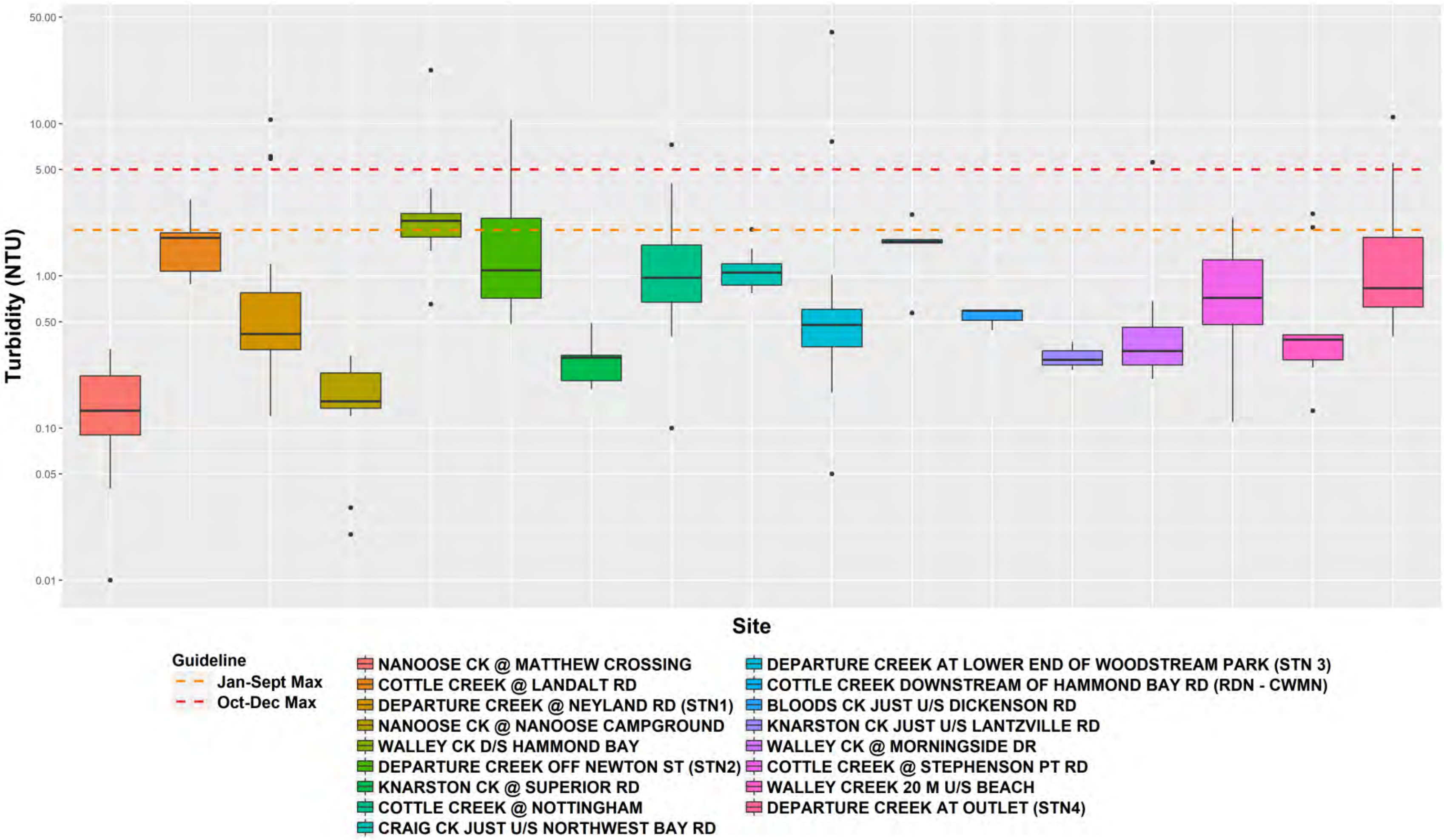

Figure A47. **Summer 2012-2017 turbidity of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with Englishman River water quality objectives.**

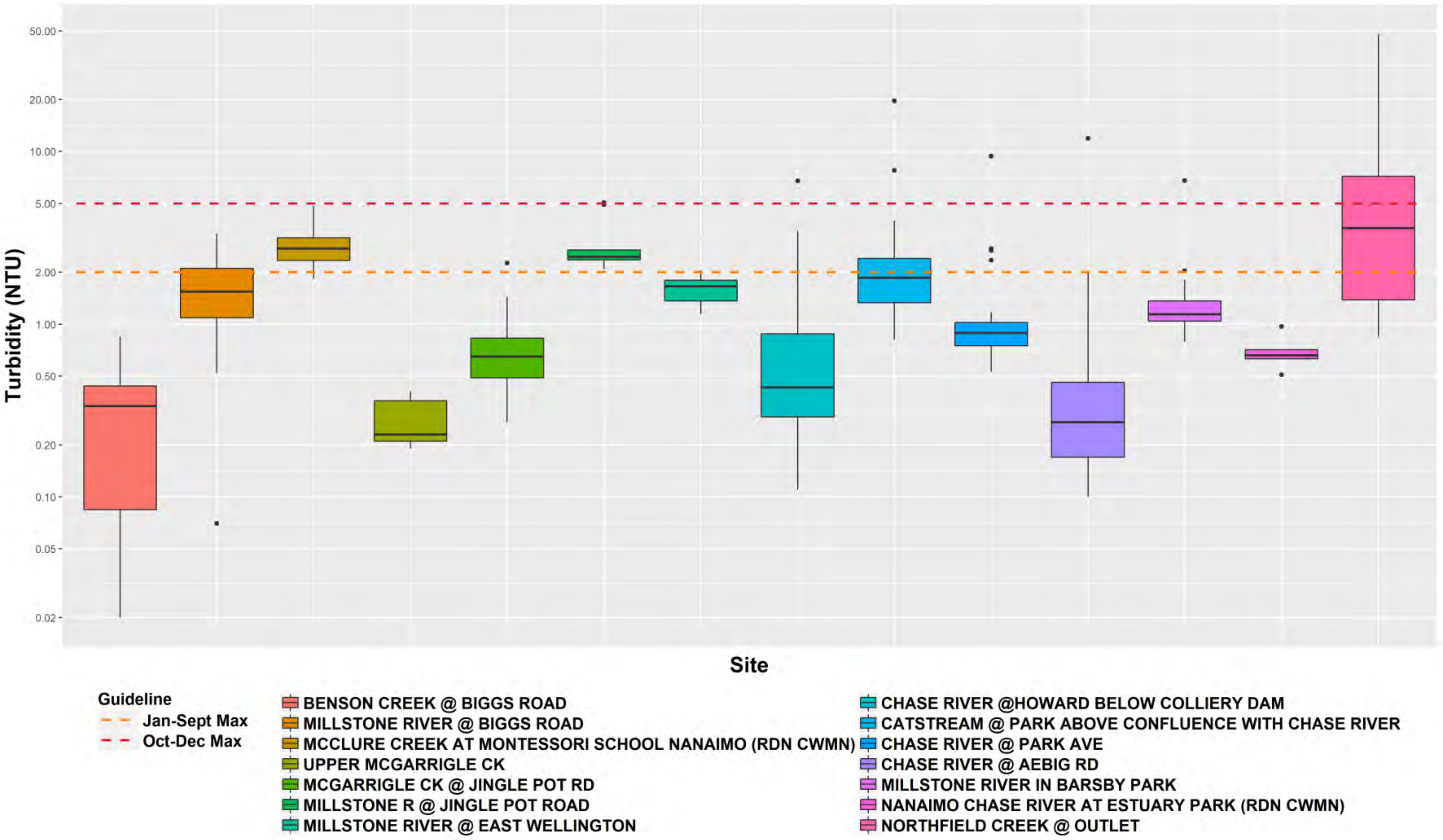

Figure A48. Summer 2012-2017 turbidity of CWMN sites in Water Region 5-2 (South Wellington to Nanoose) with Englishman River water quality objectives.

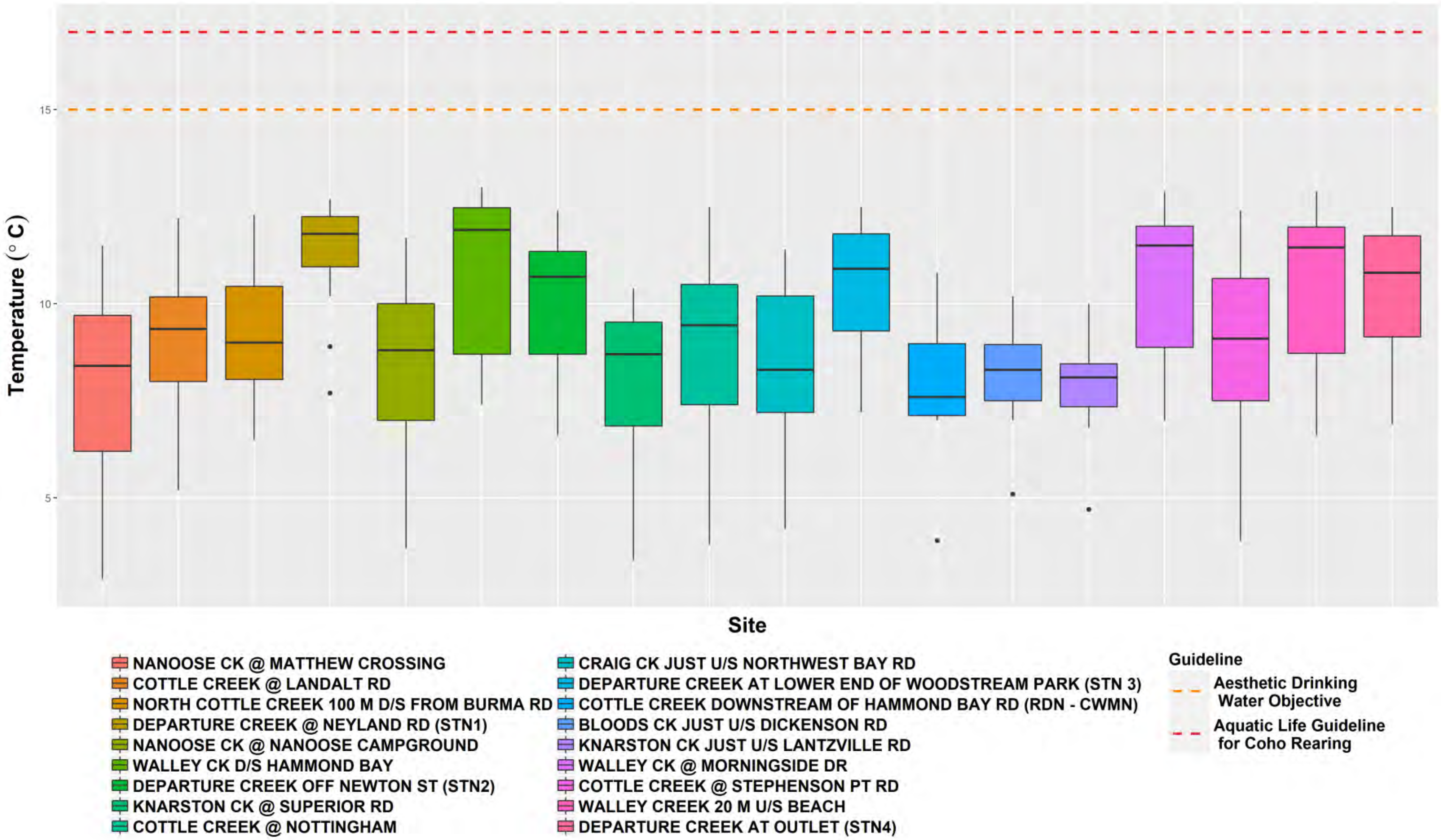

Figure A49. **Fall 2012-2017 water temperature of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with Englishman River water quality objectives.**

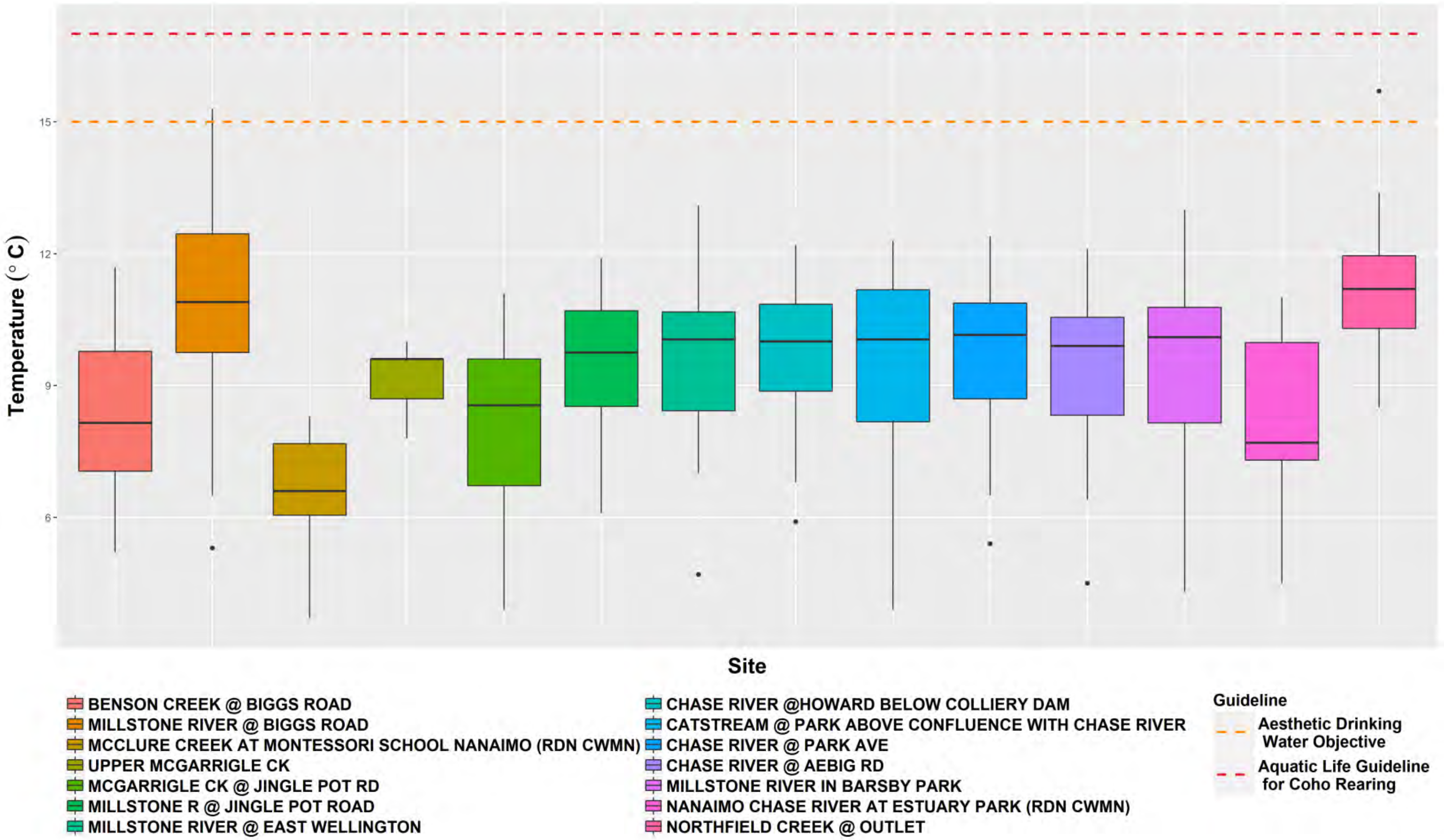

Figure A50. Fall 2012-2017 water temperature of CWMN sites in Water Region 5-2 (South Wellington to Nanoose) with Englishman River water quality objectives.

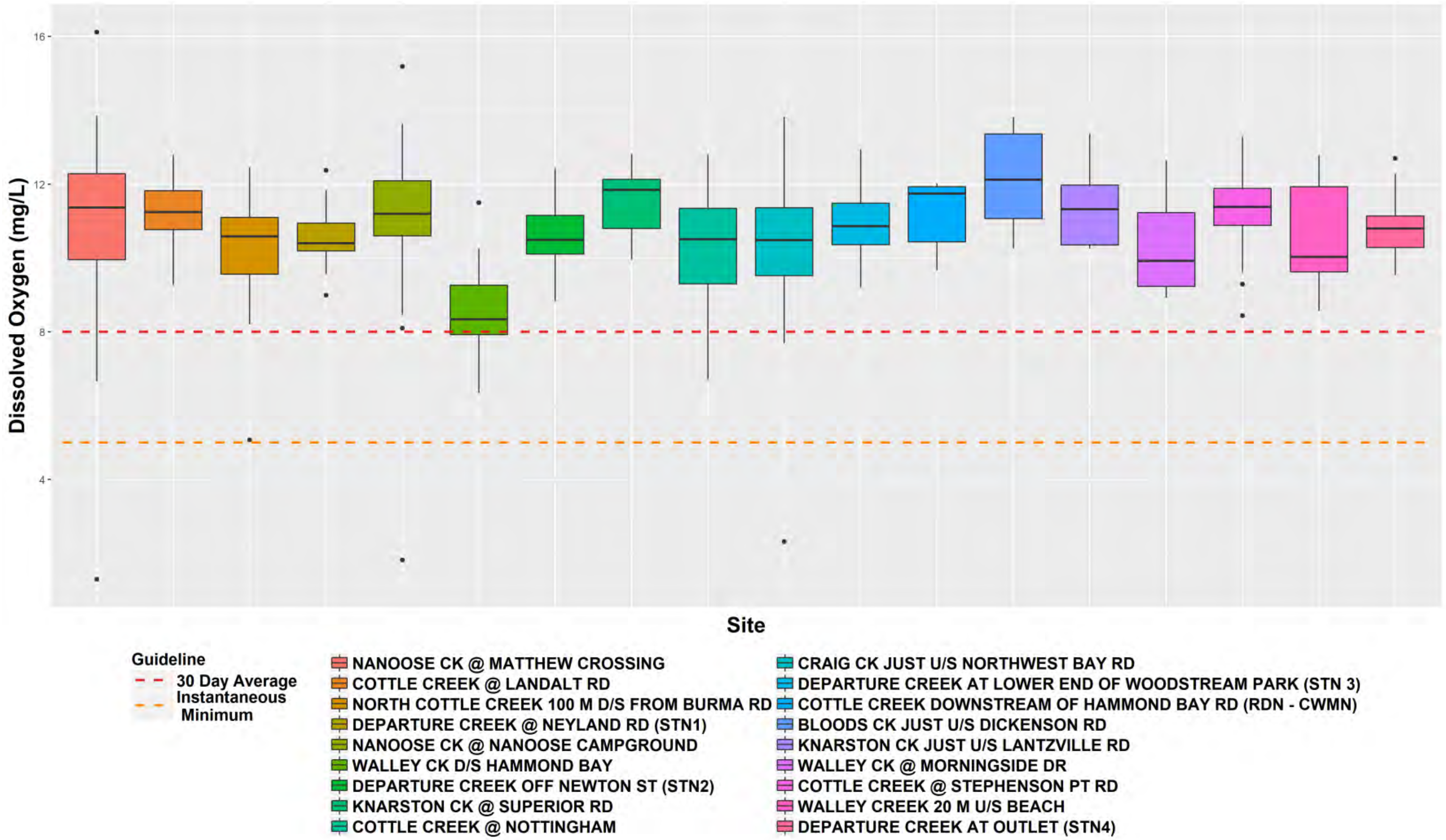

Figure A51. **Fall 2012-2017 DO of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with BC Water Quality guidelines for Aquatic Life.**

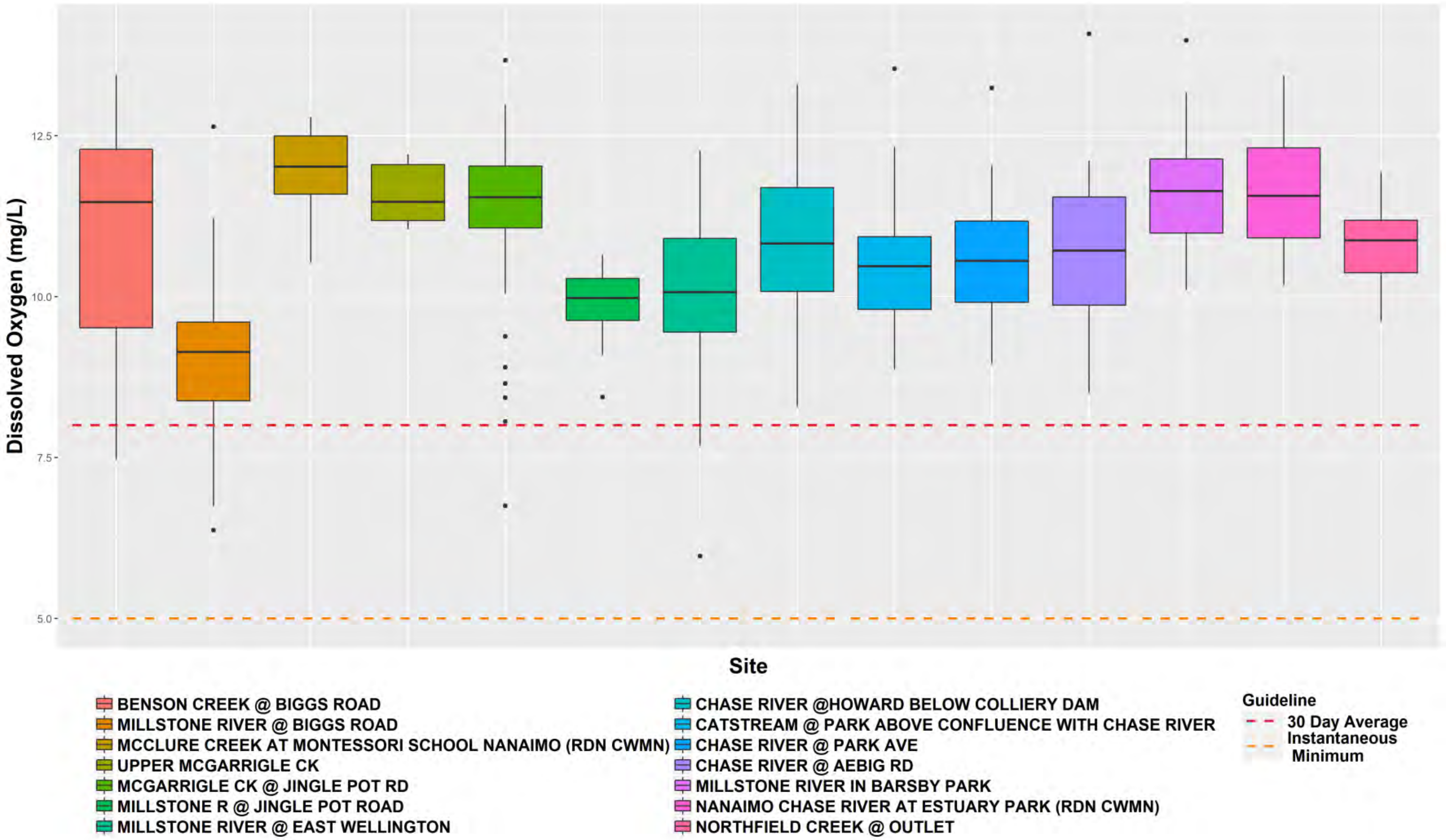

Figure A52. **Fall 2012-2017 DO of CWMN sites in Water Region 5-2 (South Wellington to Nanoose) with BC Water Quality guidelines for Aquatic Life.**

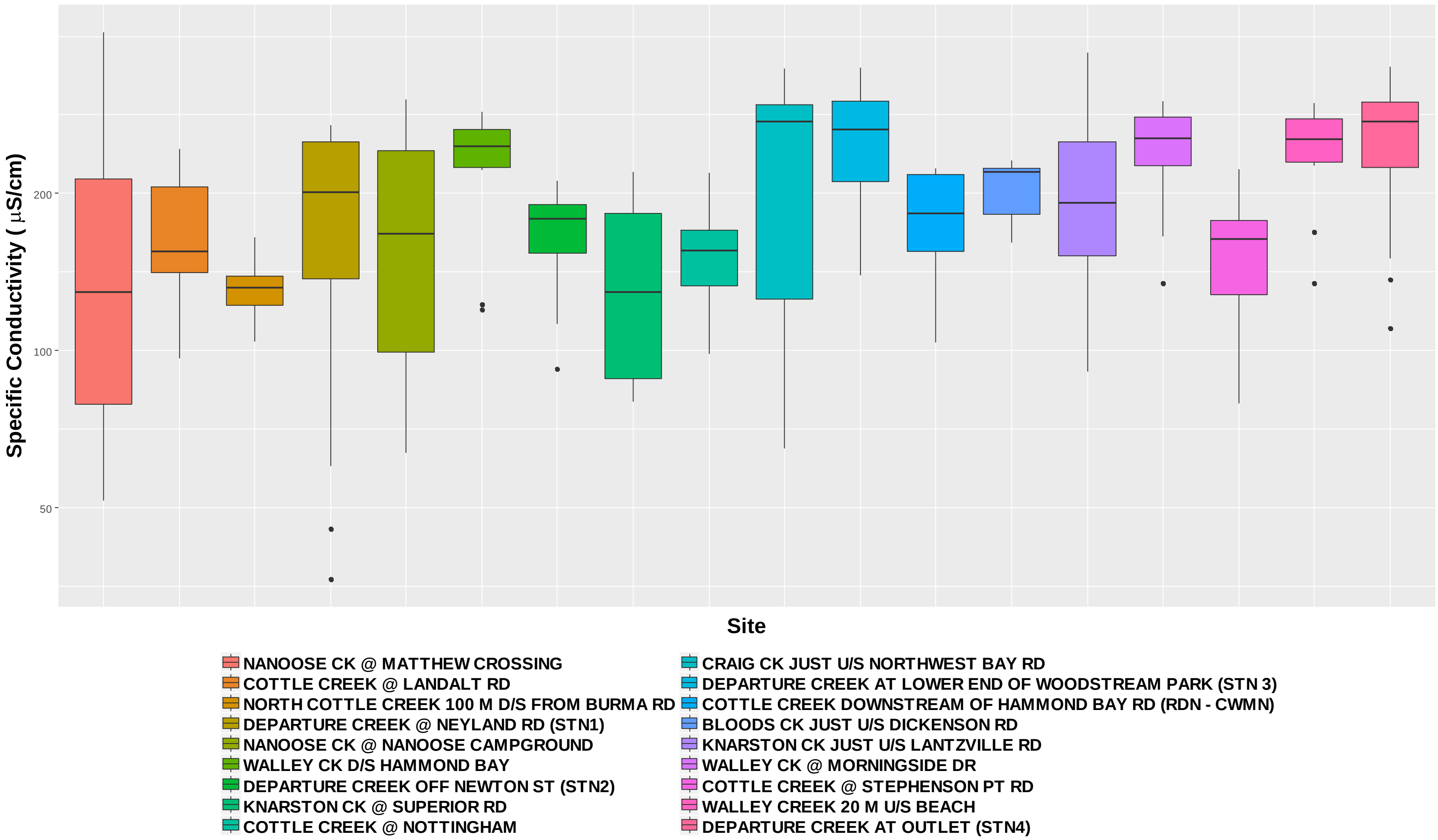

Figure A53. **Fall 2012-2017 specific conductivity of CWMN sites in Water Region 5-1 (South Wellington to Nanoose).**

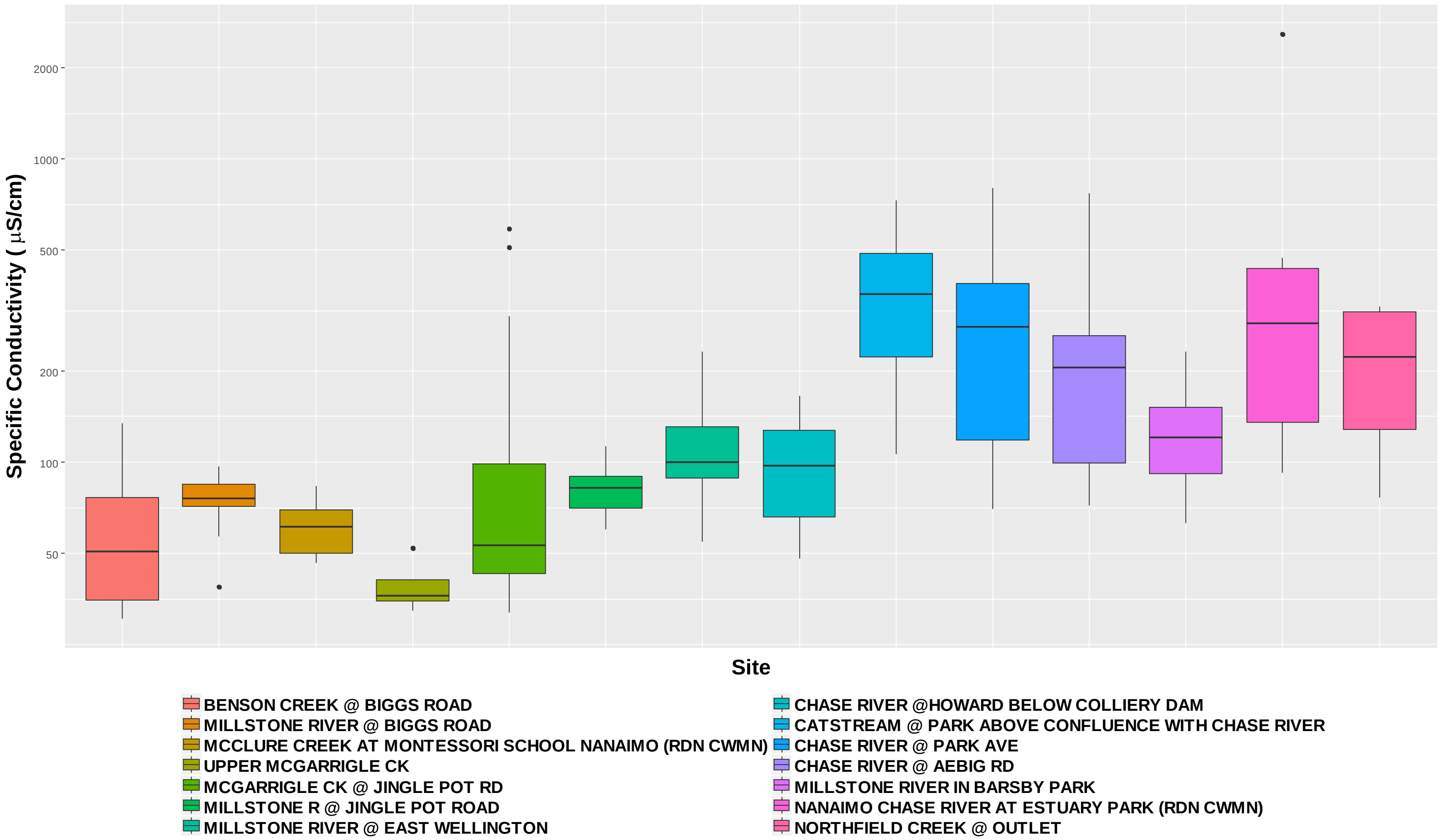

Figure A54. Fall 2012-2017 specific conductivity of CWMN sites in Water Region 5-2 (South Wellington to Nanoose).

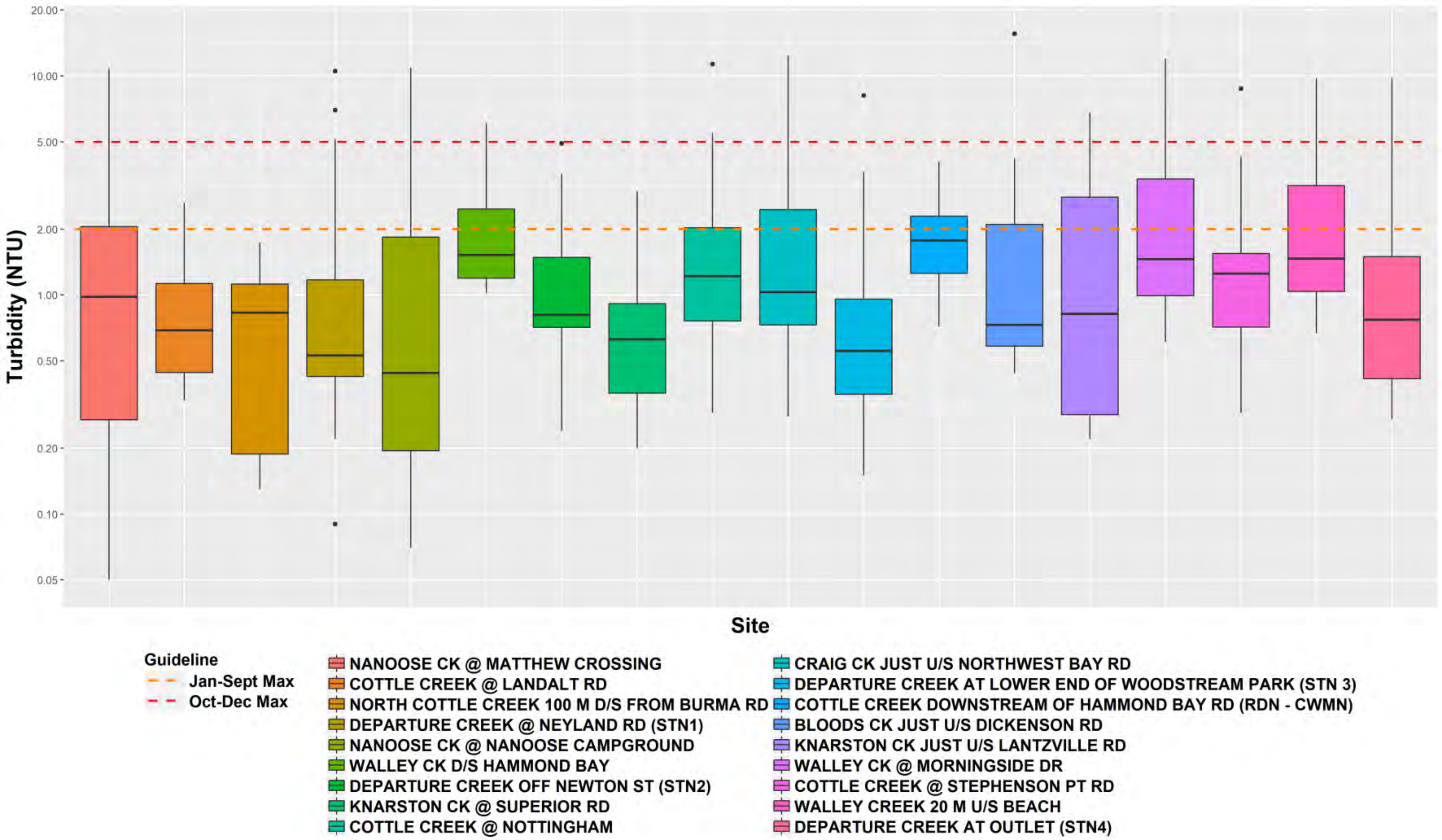

Figure A55. Fall 2012-2017 turbidity of CWMN sites in Water Region 5-1 (South Wellington to Nanoose) with Englishman River water quality objectives.

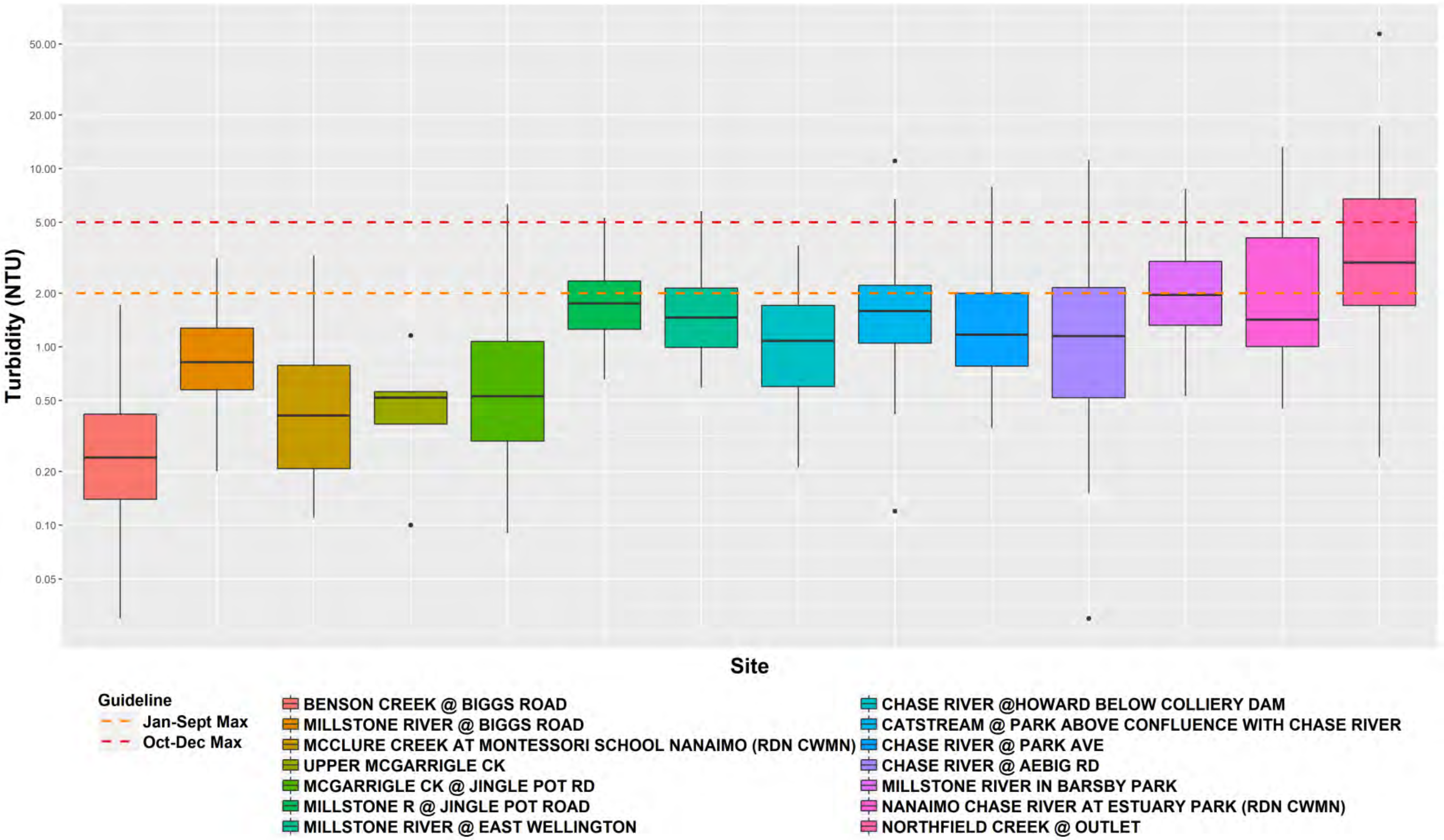

Figure A56. **Fall 2012-2017 turbidity of CWMN sites in Water Region 5-2 (South Wellington to Nanoose) with Englishman River water quality objectives.**

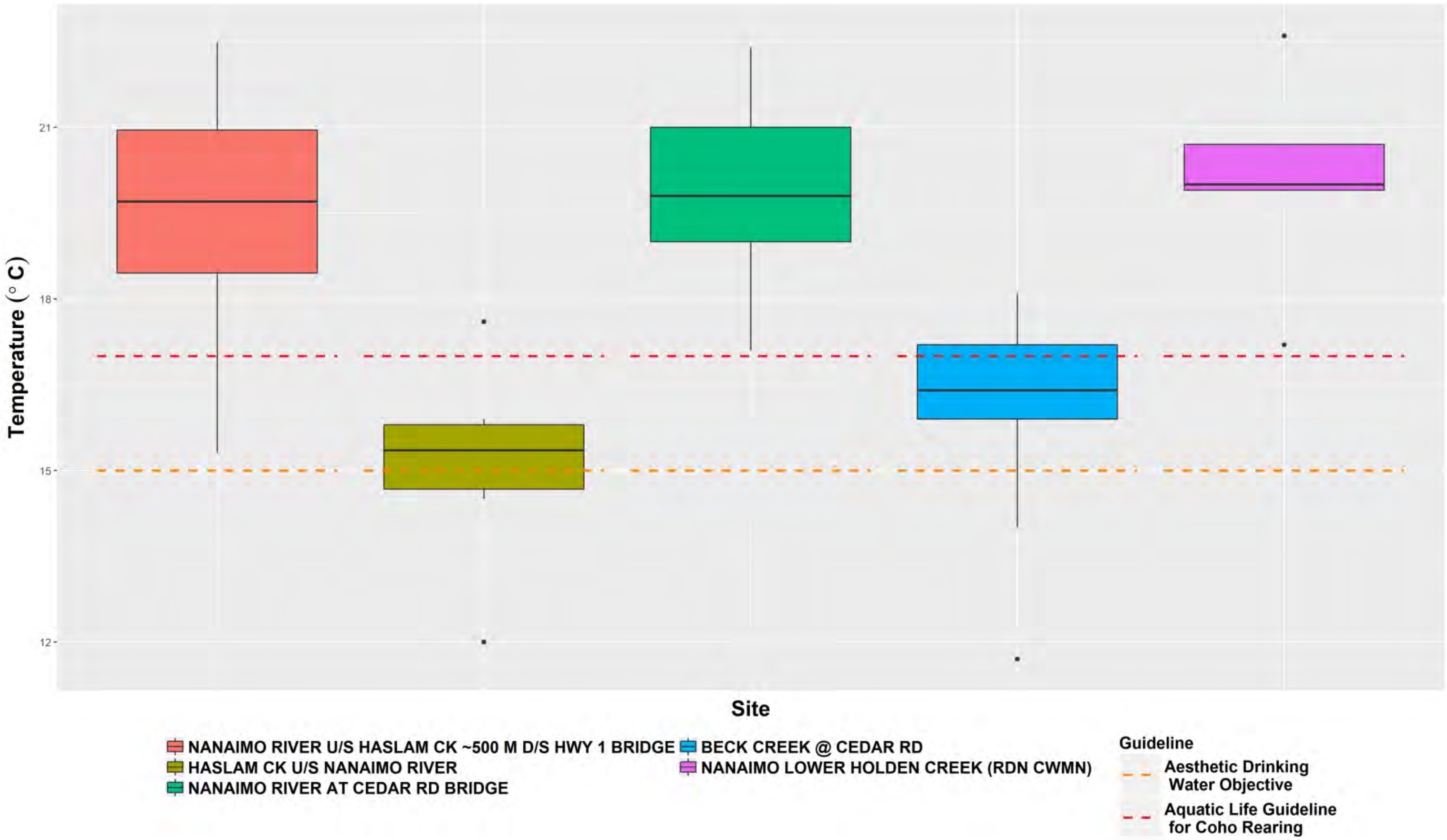

Figure A57. Summer 2011-2017 water temperature of CWMN sites in Water Region 6 (Nanaimo River) with Englishman River water quality objectives.

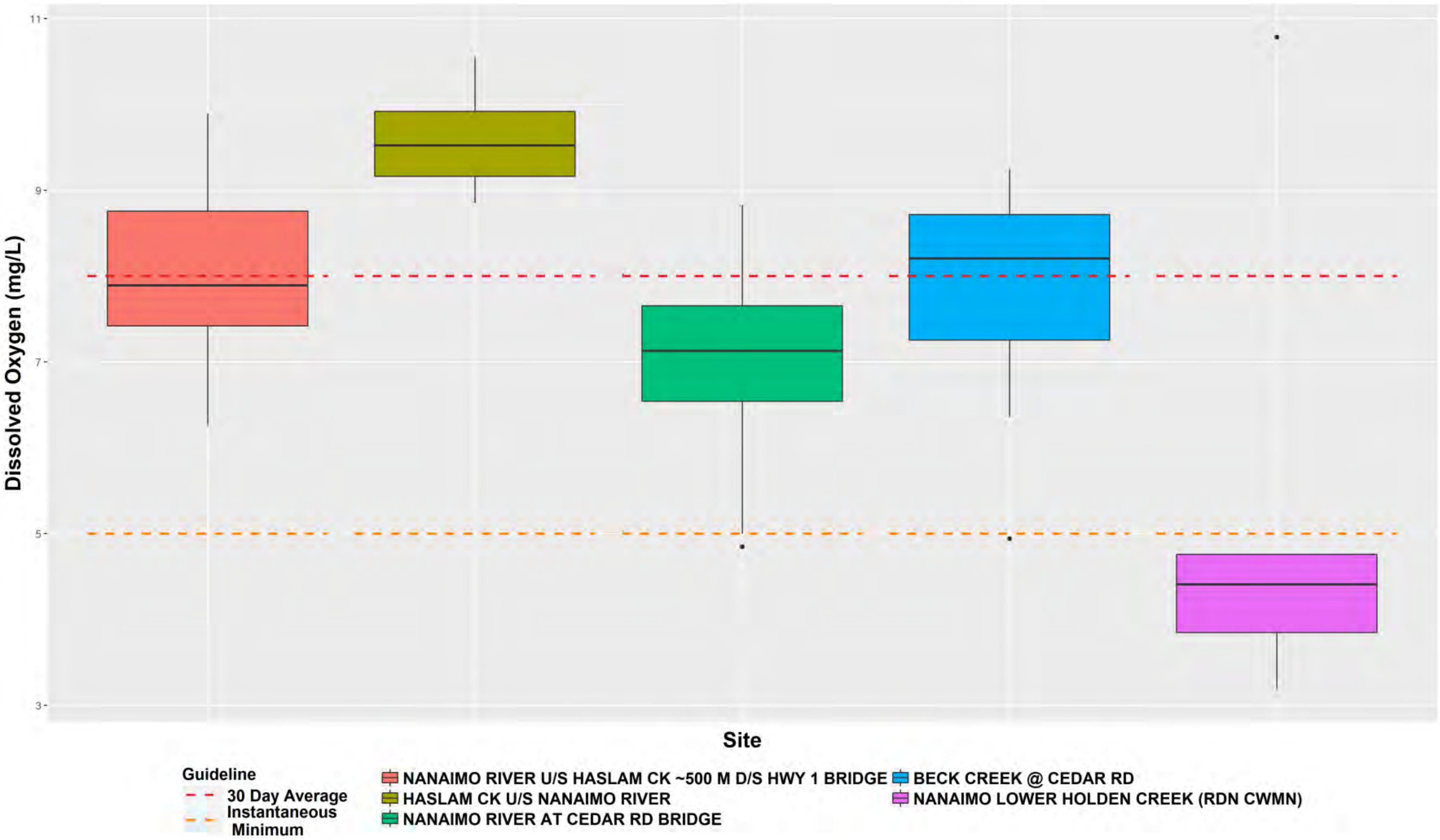

Figure A58. Summer 2011-2017 DO of CWMN sites in Water Region 6 (Nanaimo River) with BC Water Quality guidelines for Aquatic Life.

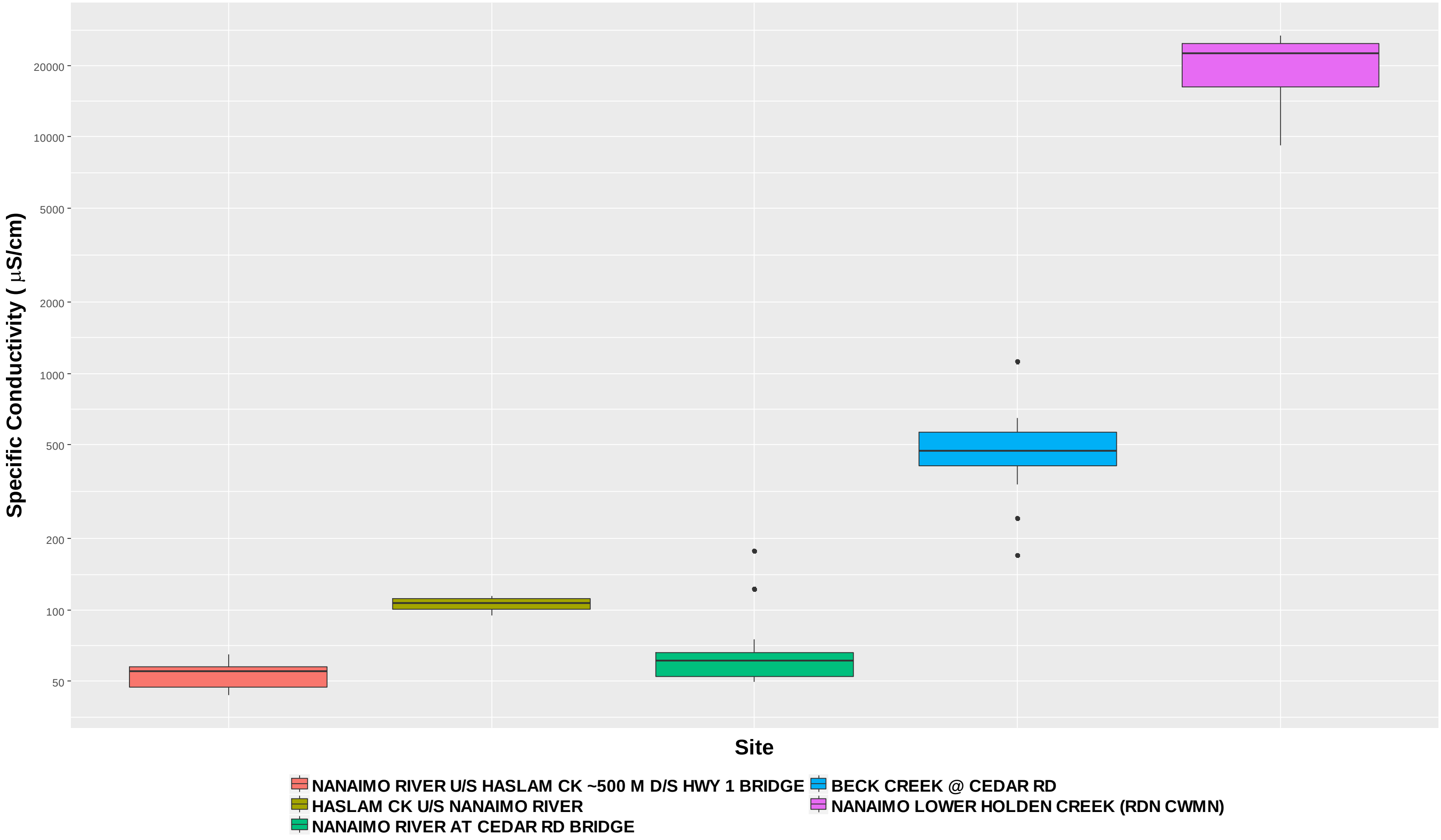

Figure A59. **Summer 2011-2017 specific conductivity of CWMN sites in Water Region 6 (Nanaimo River).**

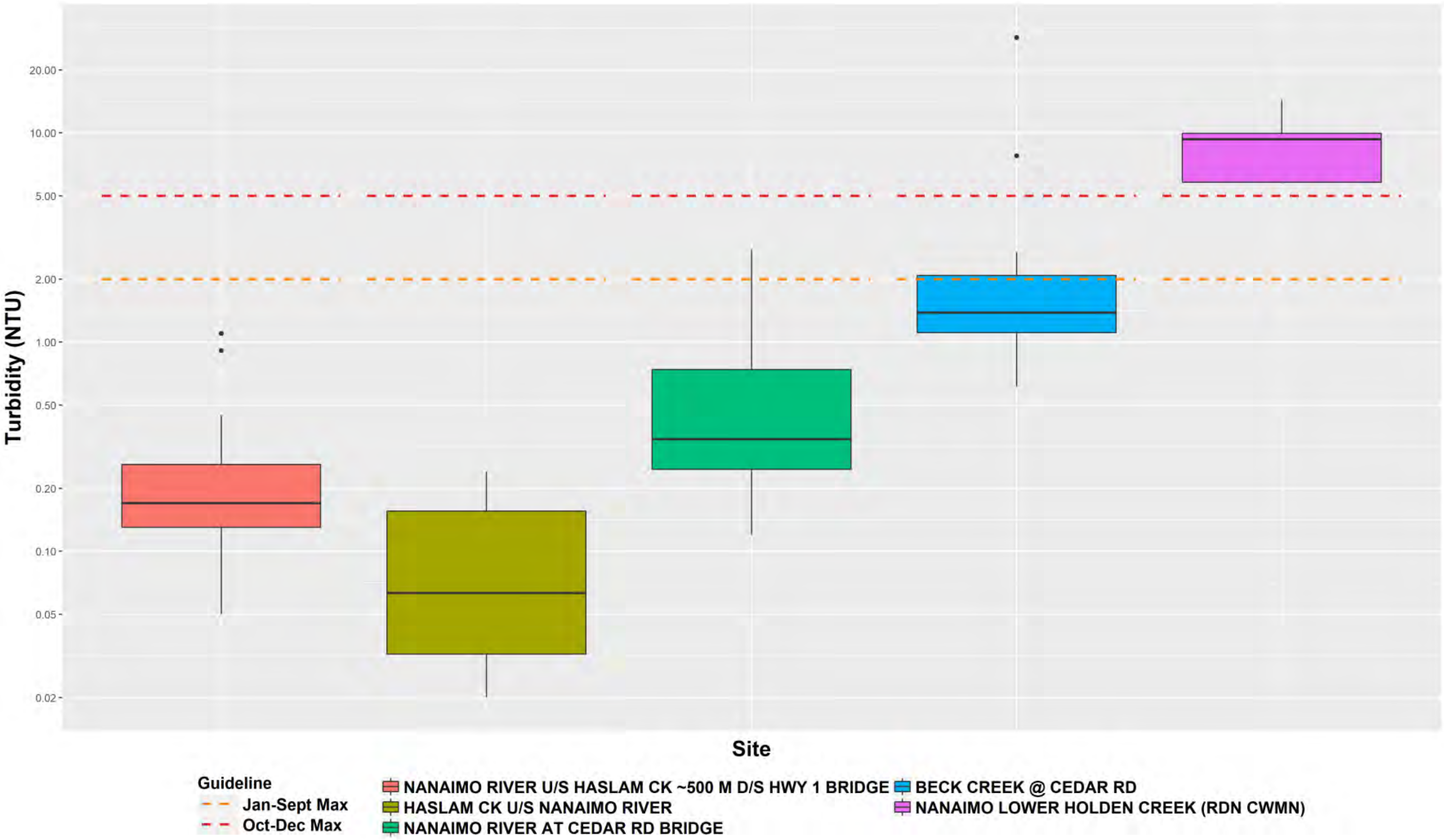

Figure A60. **Summer 2011-2017 turbidity of CWMN sites in Water Region 6 (Nanaimo River) with Englishman River water quality objectives.**

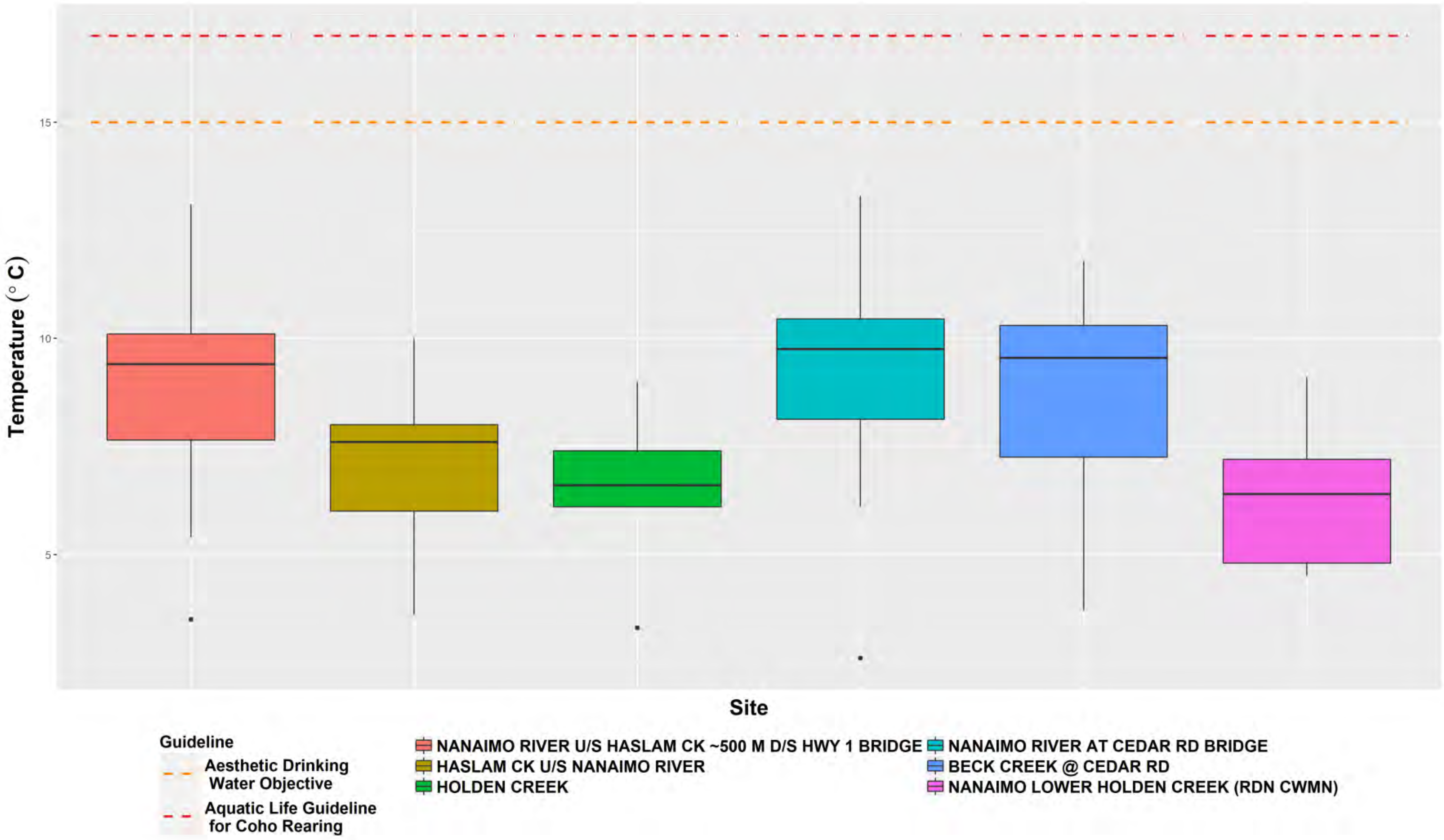

Figure A61. **Fall 2011-2017 water temperature of CWMN sites in Water Region 6 (Nanaimo River) with Englishman River water quality objectives.**

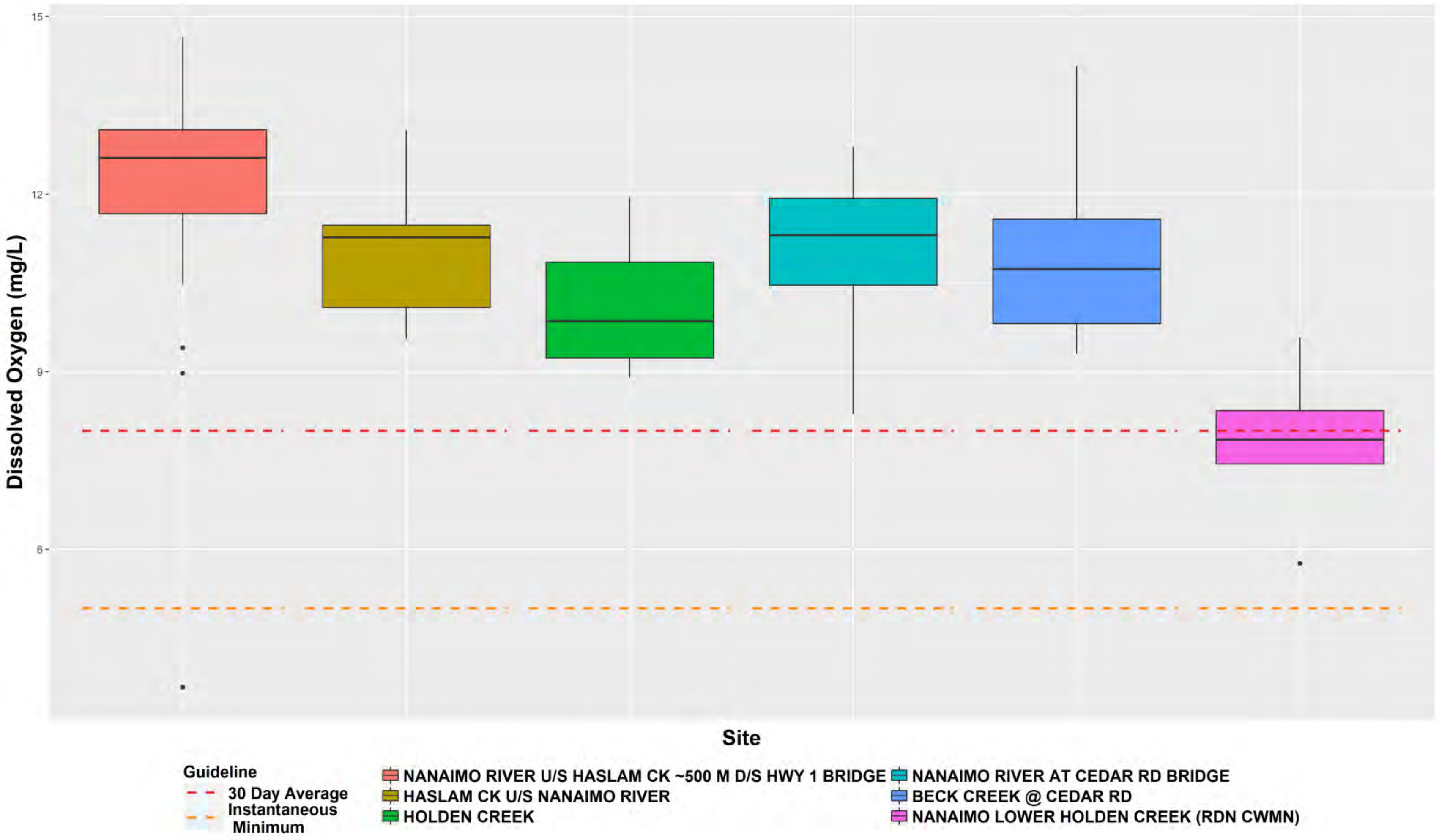

Figure A62. **Fall 2011-2017 DO of CWMN sites in Water Region 6 (Nanaimo River) with BC Water Quality guidelines for Aquatic Life.**

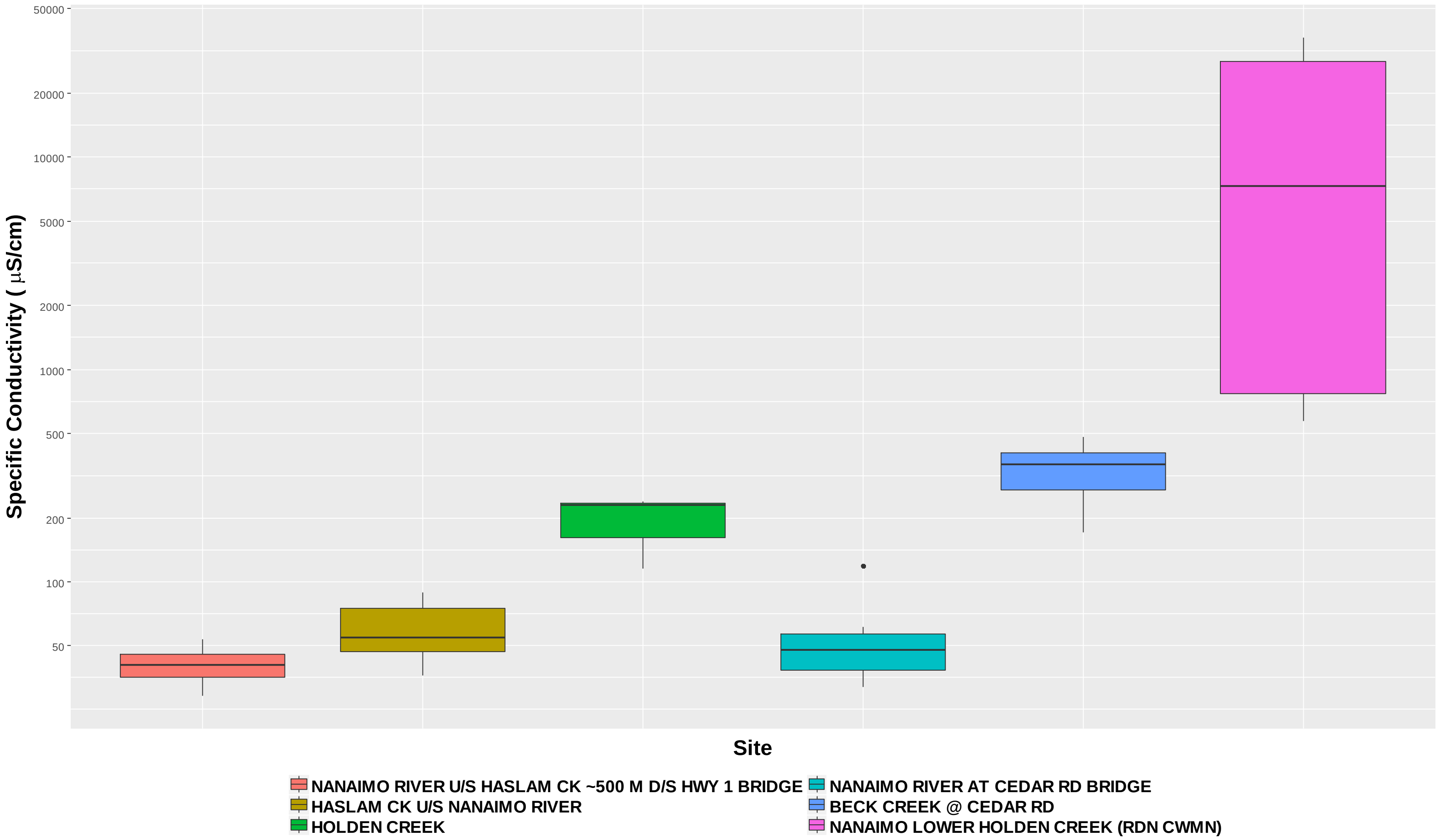

Figure A63. **Fall 2011-2017 specific conductivity of CWMN sites in Water Region 6 (Nanaimo River).**

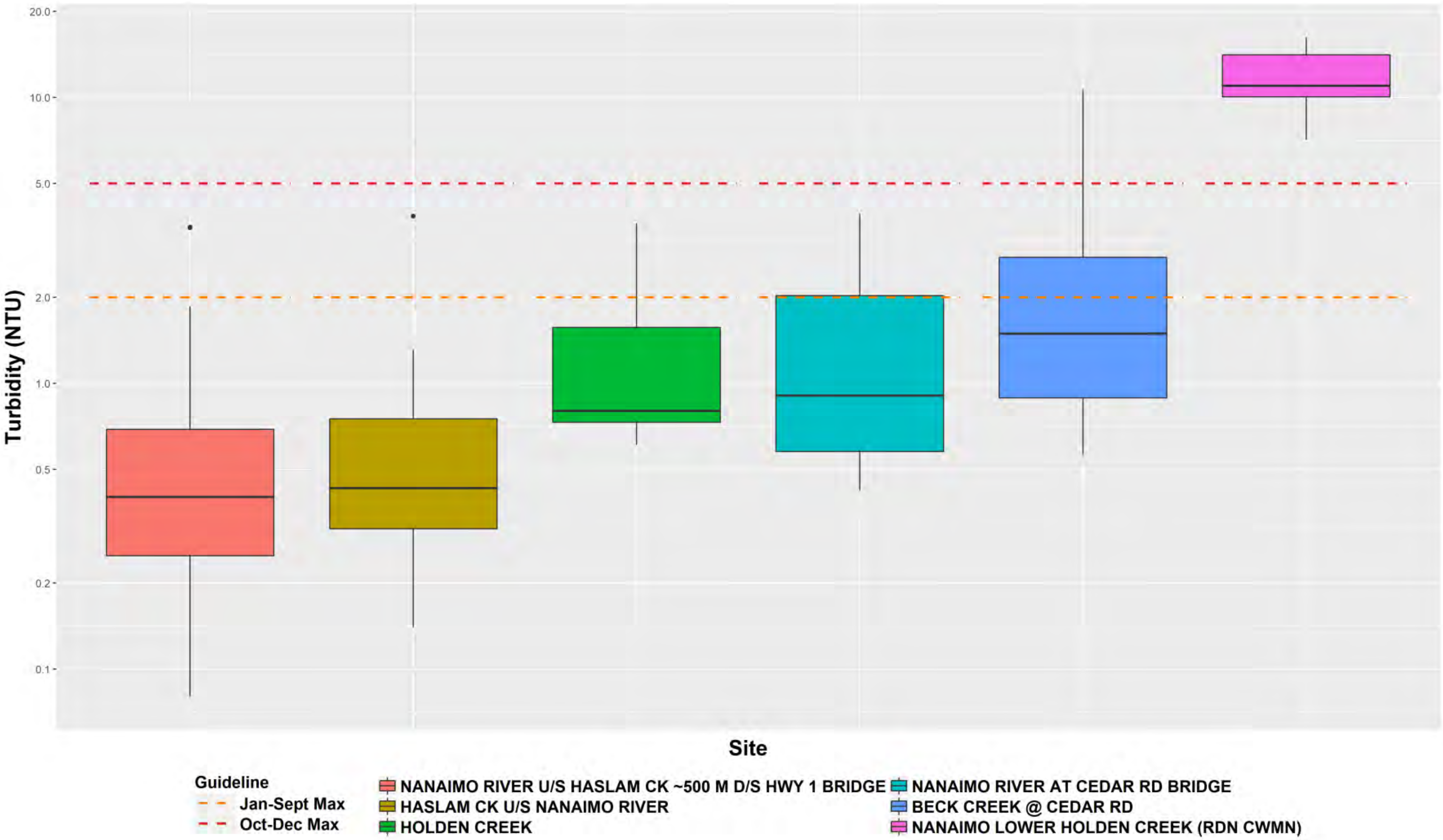

Figure A64. **Fall 2011-2017 turbidity of CWMN sites in Water Region 6 (Nanaimo River) with Englishman River water quality objectives.**

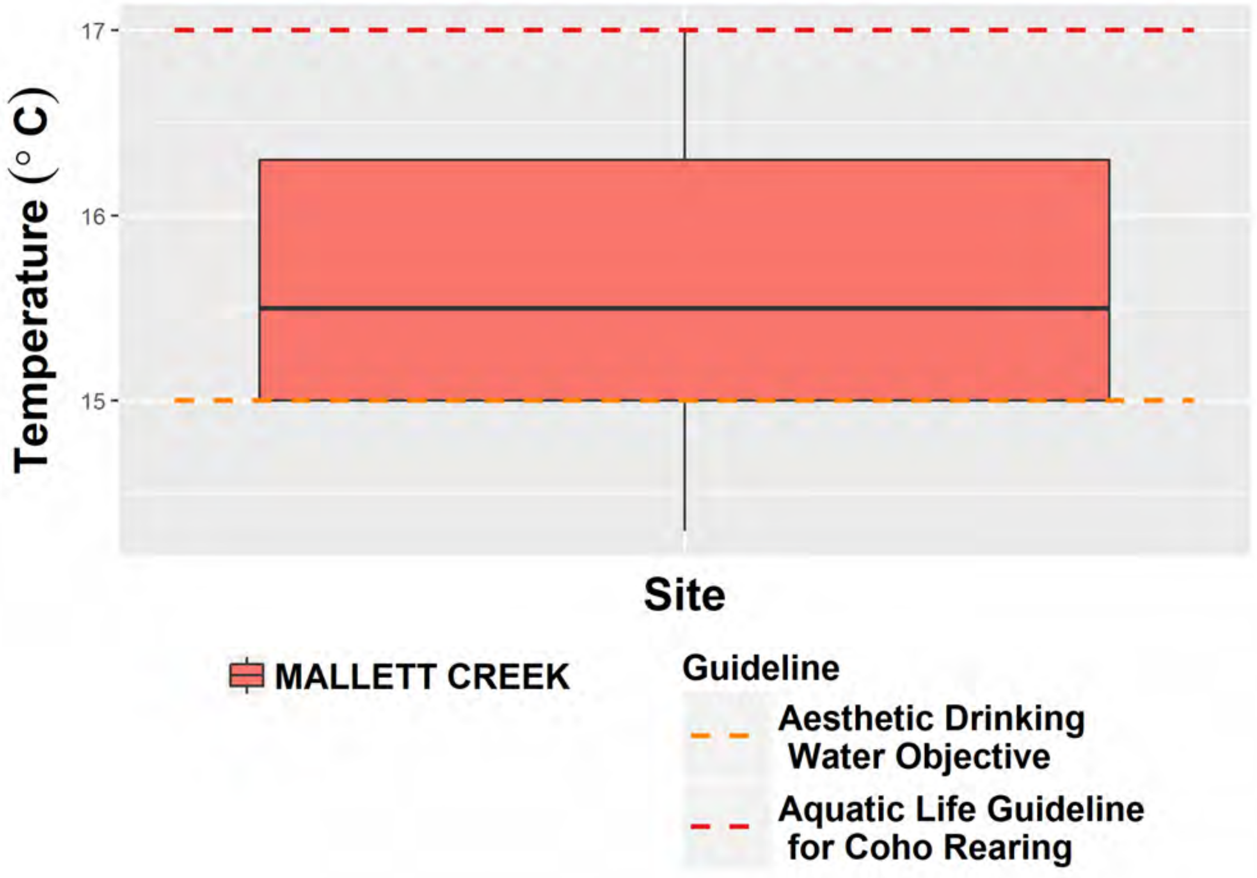

Figure A65. **Summer 2015-2017 water temperature of CWMN sites in Water Region 7 (Gabriola Island) with Englishman River water quality objectives.**

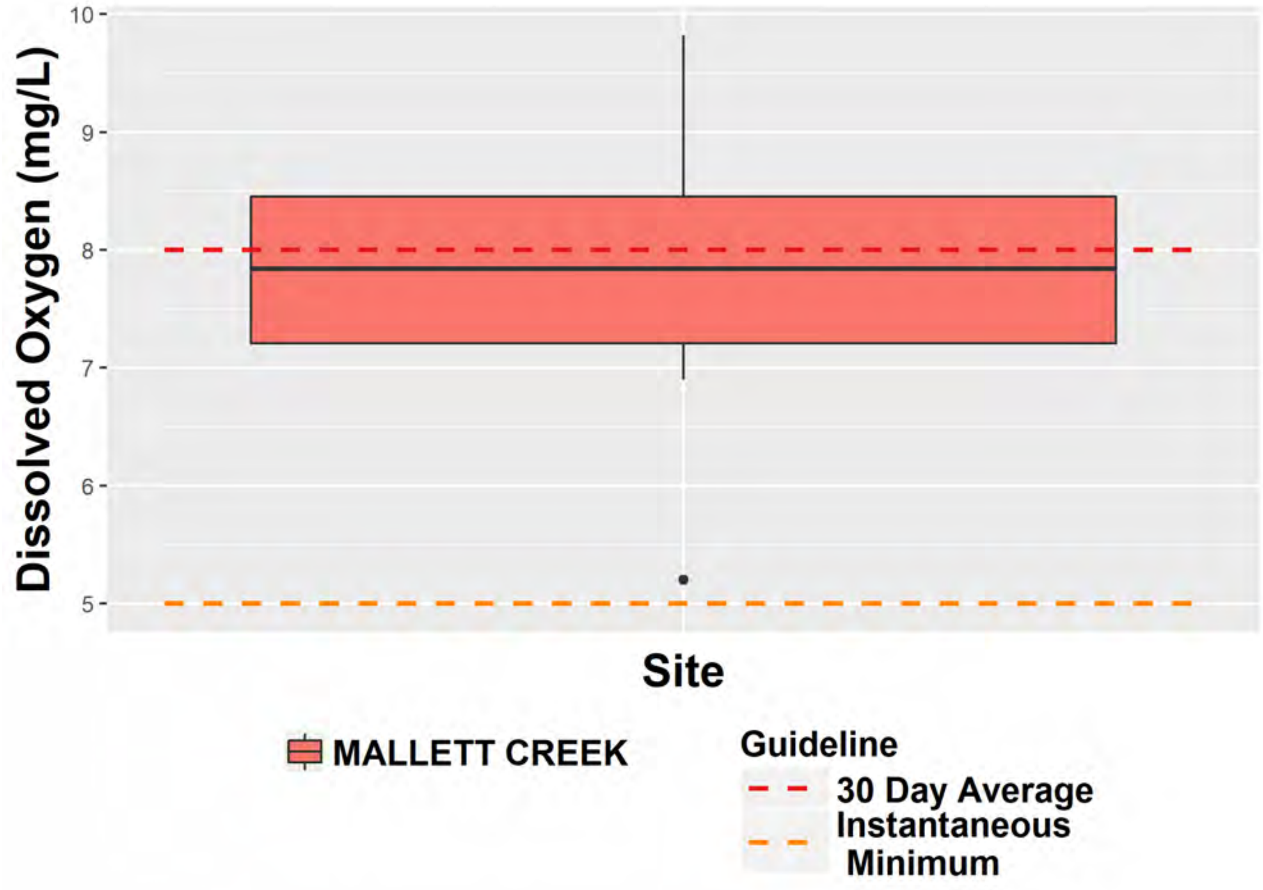

Figure A66. Summer 2015-2017 DO of CWMN sites in Water Region 7 (Gabriola Island) with BC Water Quality guidelines for Aquatic Life.

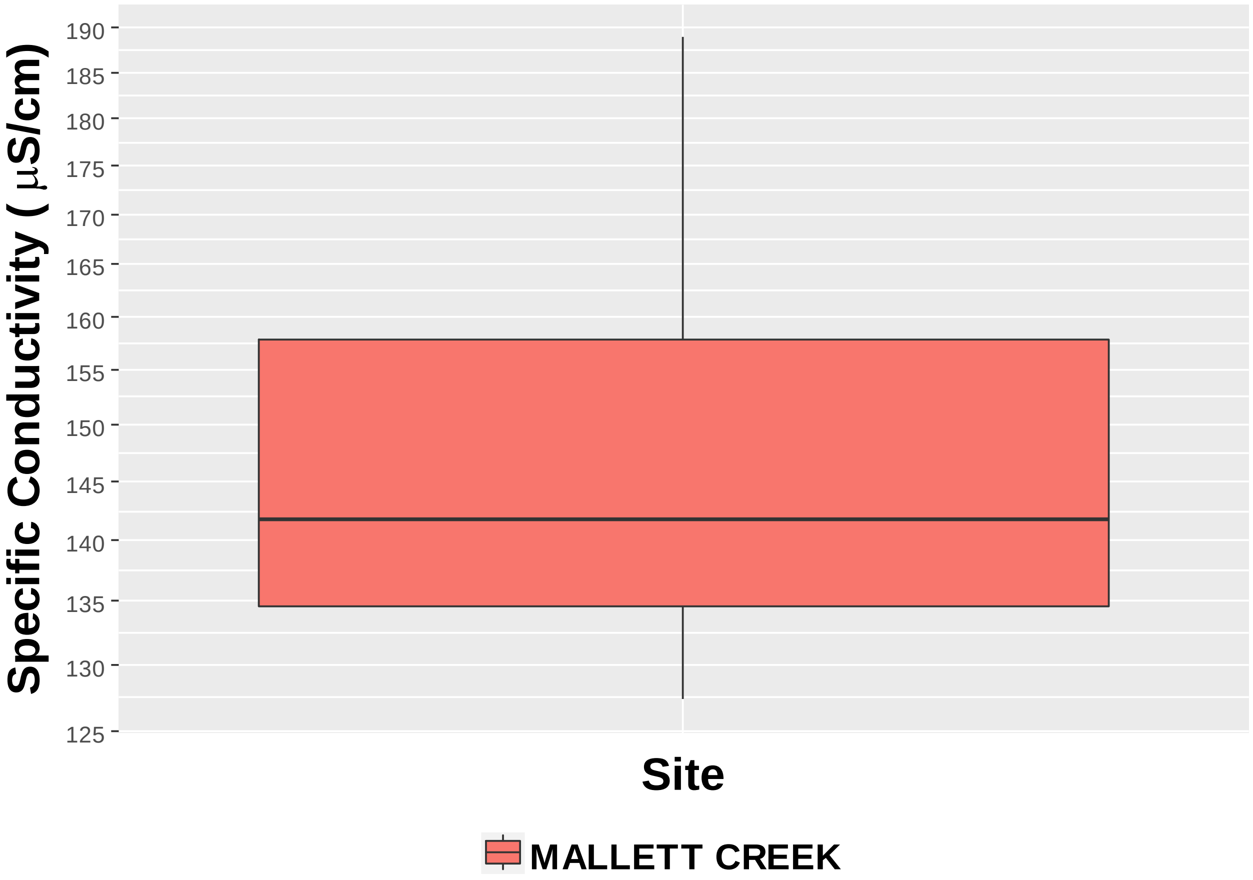

Figure A67. Summer 2015-2017 specific conductivity of CWMN sites in Water Region 7 (Gabriola Island).

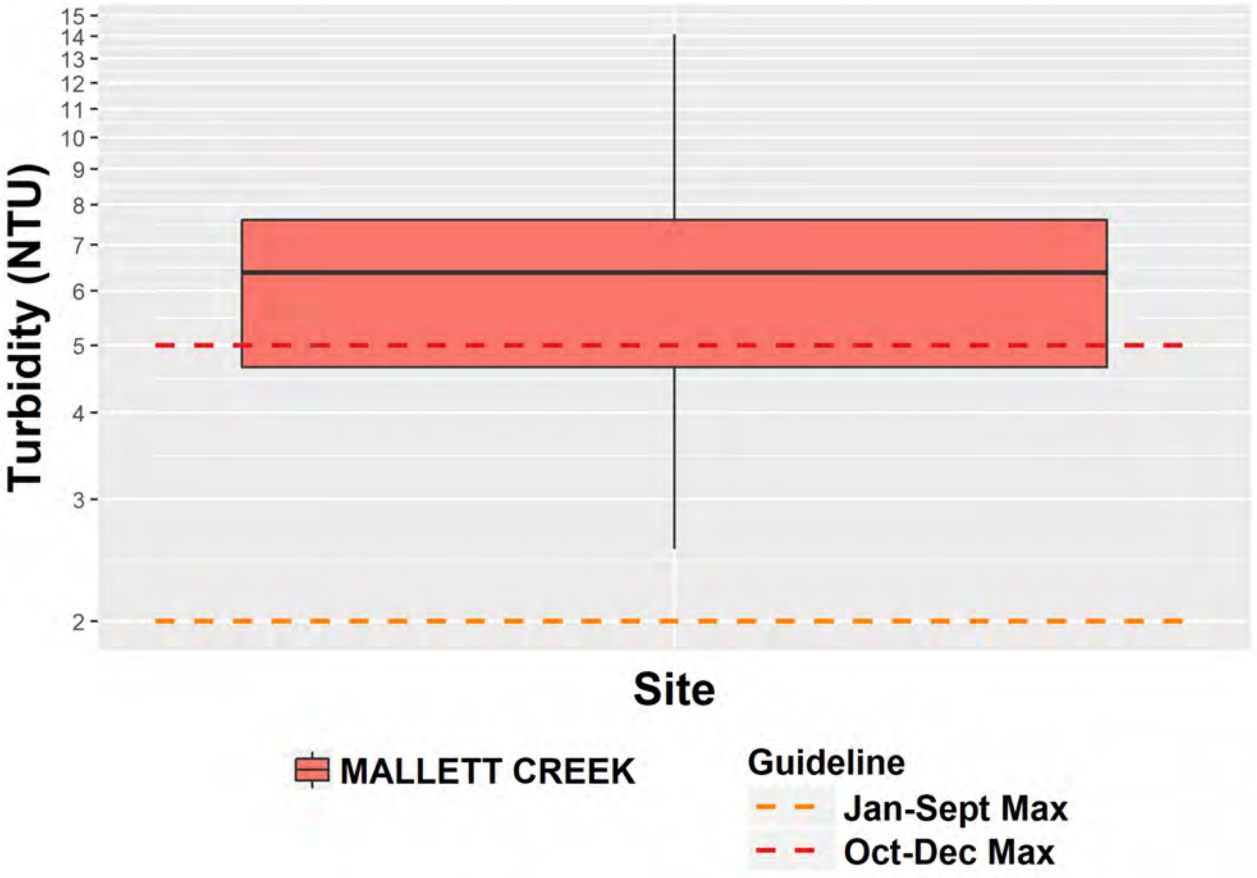

Figure A68. Summer 2015-2017 turbidity of CWMN sites in Water Region 7 (Gabriola Island) with Englishman River water quality objectives.

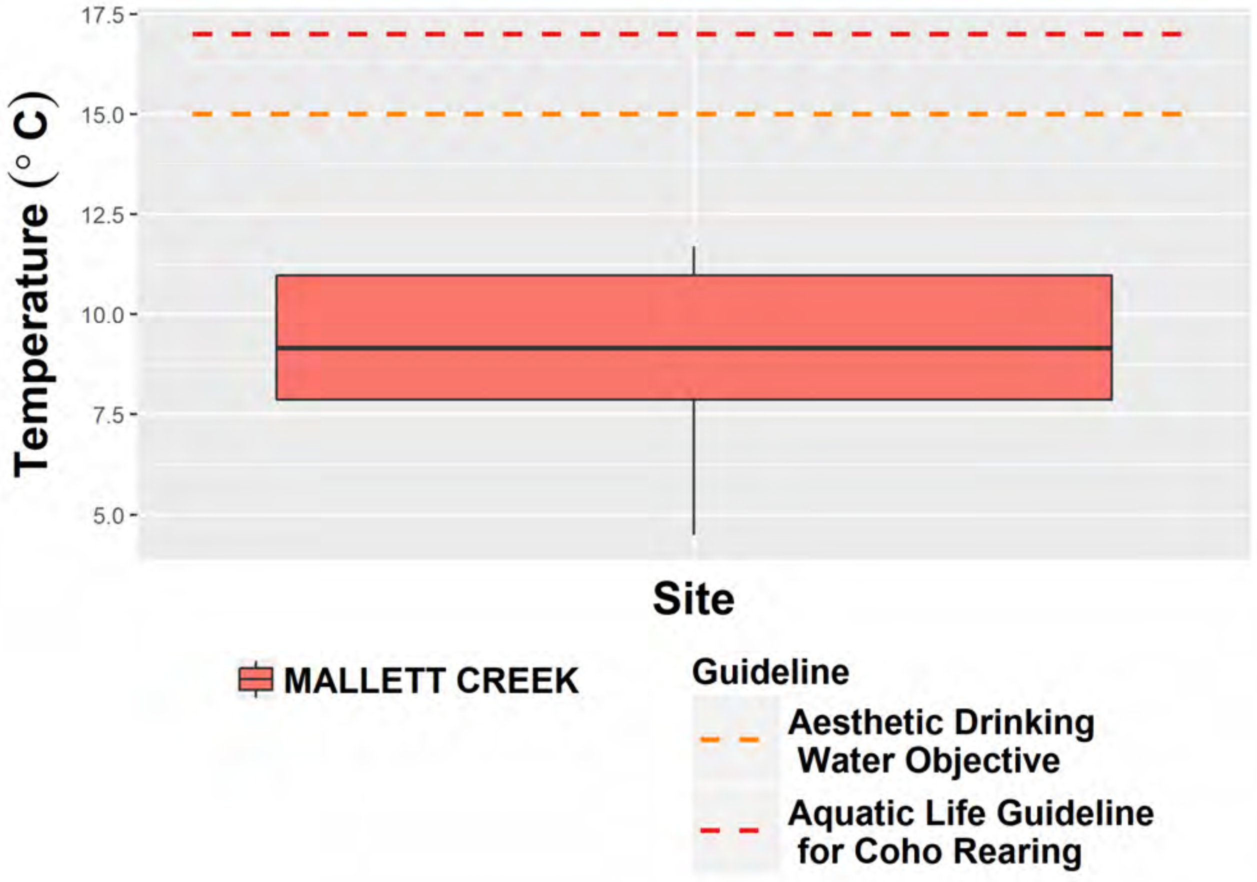

Figure A69. **Fall 2015-2017 water temperature of CWMN sites in Water Region 7 (Gabriola Island) with Englishman River water quality objectives.**

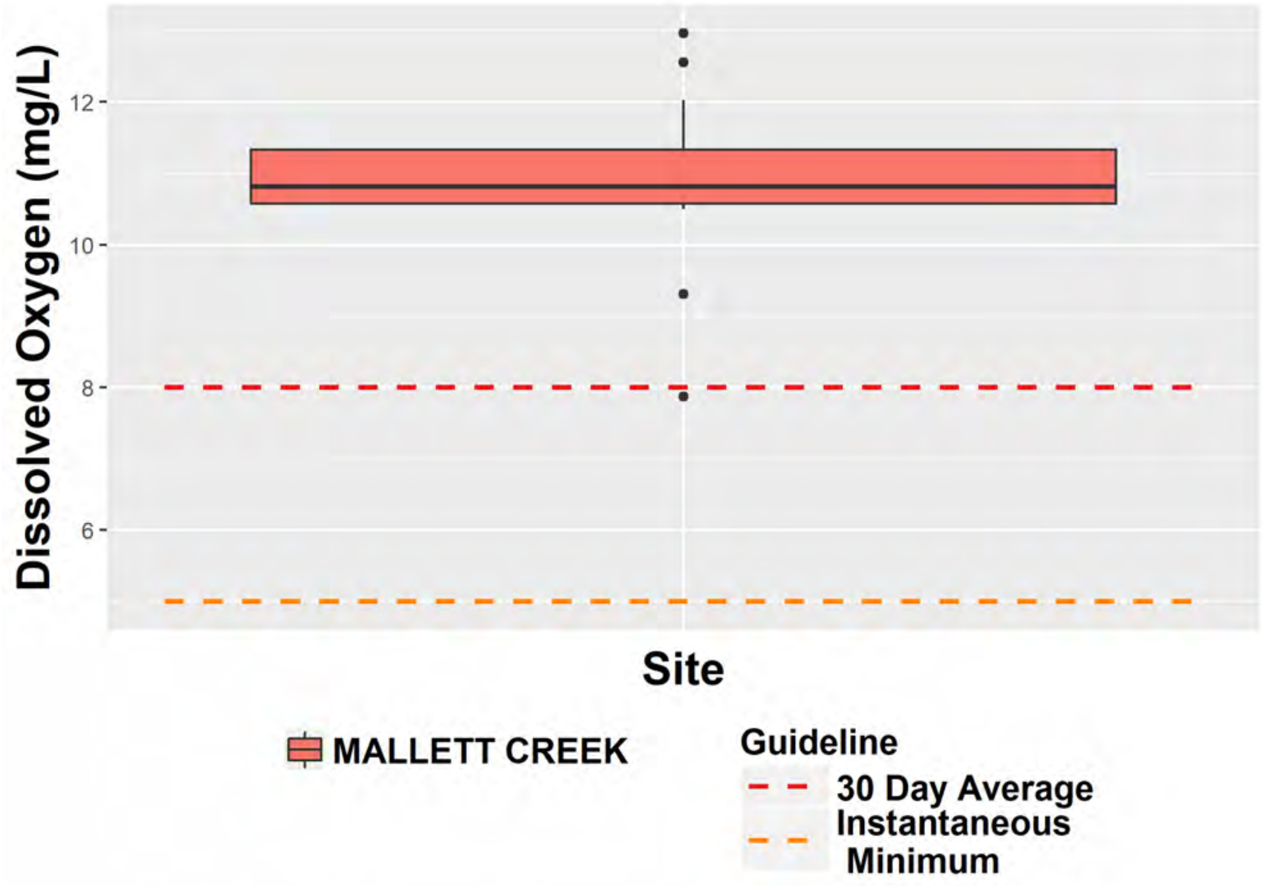

Figure A70. **Fall 2015-2017 DO of CWMN sites in Water Region 7 (Gabriola Island) with BC Water Quality guidelines for Aquatic Life.**

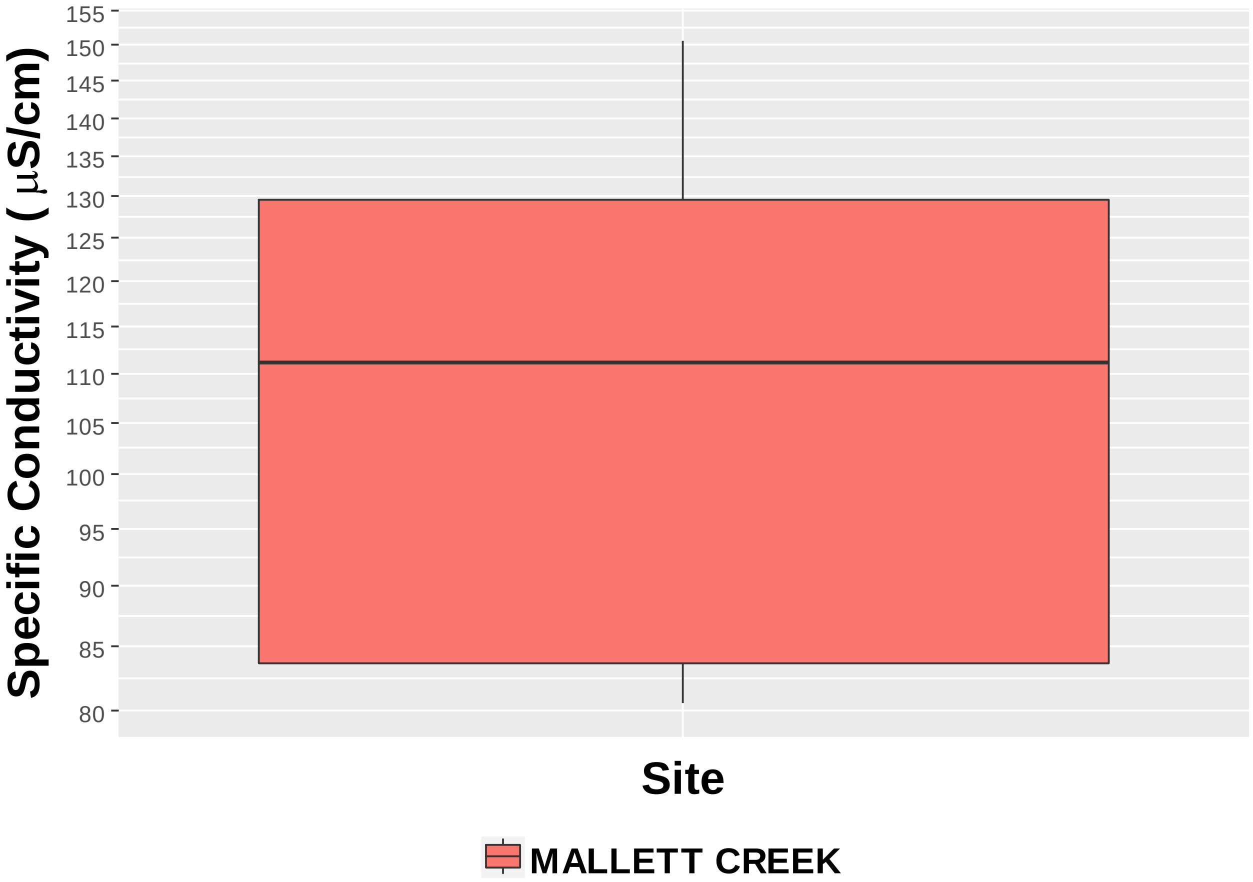

Figure A71. **Fall 2015-2017 specific conductivity of CWMN sites in Water Region 7 (Gabriola Island).**

Figure A72. **Fall 2015-2017 turbidity of CWMN sites in Water Region 7 (Gabriola Island) with Englishman River water quality objectives.**

Appendix E Flow, Rainfall and Temperature Analysis

Table A1 Summary of Spearman rank correlation test for rainfall by Water Region and site including Spearman's rank correlation coefficient (strength and direction of relationship), p-value (<0.05 is statistically significant) and sample size (n).

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E286550	Cond	-0.56	0.00	25	THAMES CREEK 100M U/S INLAND ISLAND HWY	Big Qualicum
E286550	Temp	0.46	0.02	25	THAMES CREEK 100M U/S INLAND ISLAND HWY	Big Qualicum
E286553	Temp	0.35	0.04	35	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286550	Turbidity	0.41	0.04	25	THAMES CREEK 100M U/S INLAND ISLAND HWY	Big Qualicum
E286553	Turbidity	0.31	0.07	35	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286553	DO	-0.28	0.11	35	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286553	Cond	-0.26	0.13	35	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286549	Cond	0.23	0.28	25	THAMES CREEK 200M U/S OLD ISLAND HWY	Big Qualicum
E286549	Turbidity	-0.19	0.36	25	THAMES CREEK 200M U/S OLD ISLAND HWY	Big Qualicum
E286549	Temp	0.05	0.80	25	THAMES CREEK 200M U/S OLD ISLAND HWY	Big Qualicum
E286550	DO	0.04	0.84	25	THAMES CREEK 100M U/S INLAND ISLAND HWY	Big Qualicum
E286549	DO	-0.01	0.97	25	THAMES CREEK 200M U/S OLD ISLAND HWY	Big Qualicum
E285669	Turbidity	0.51	0.00	35	UPPER CAMERON RIVER	Little Qualicum
E256394	Turbidity	0.41	0.01	37	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E268993	Cond	-0.43	0.02	31	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E285669	Cond	-0.37	0.03	35	UPPER CAMERON RIVER	Little Qualicum
E220635	Temp	0.36	0.03	36	CAMERON RIVER	Little Qualicum
E220635	Turbidity	0.30	0.07	36	CAMERON RIVER	Little Qualicum
E285669	Temp	0.30	0.08	35	UPPER CAMERON RIVER	Little Qualicum
E256394	Cond	-0.29	0.09	37	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E287697	Turbidity	0.31	0.10	30	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E220635	DO	-0.27	0.11	36	CAMERON RIVER	Little Qualicum
E287697	Cond	-0.26	0.17	30	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E287697	Temp	0.25	0.18	30	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E268993	Turbidity	0.21	0.25	31	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E256394	DO	0.10	0.54	37	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E256394	Temp	0.09	0.61	37	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E268993	DO	-0.09	0.62	31	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E285669	DO	-0.06	0.72	35	UPPER CAMERON RIVER	Little Qualicum
E287697	DO	0.04	0.84	30	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E268993	Temp	-0.04	0.84	31	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E220635	Cond	-0.03	0.88	36	CAMERON RIVER	Little Qualicum
E243024	Turbidity	0.80	0.00	36	FRENCH CREEK AT GRAFTON ROAD	French Creek
E288092	Turbidity	0.75	0.00	37	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288091	Turbidity	0.71	0.00	37	GRANDON CREEK AT LABURNUM ROAD	French Creek
E243022	Turbidity	0.72	0.00	36	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E288093	Turbidity	0.71	0.00	37	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E243021	Turbidity	0.71	0.00	36	FRENCH CREEK AT NEW HIGHWAY	French Creek
E288090	Turbidity	0.65	0.00	37	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288093	Cond	-0.62	0.00	37	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E243021	DO	-0.46	0.01	36	FRENCH CREEK AT NEW HIGHWAY	French Creek
E288091	Cond	-0.44	0.01	37	GRANDON CREEK AT LABURNUM ROAD	French Creek
E243021	Temp	0.43	0.01	36	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243022	Temp	0.41	0.01	36	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E243022	DO	-0.40	0.02	36	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E288090	Cond	-0.40	0.02	37	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E243024	Cond	-0.40	0.02	36	FRENCH CREEK AT GRAFTON ROAD	French Creek

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E288092	Temp	0.37	0.02	37	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E243024	Temp	0.35	0.03	36	FRENCH CREEK AT GRAFTON ROAD	French Creek
E288091	Temp	0.34	0.04	37	GRANDON CREEK AT LABURNUM ROAD	French Creek
E243022	Cond	-0.34	0.05	36	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E288093	Temp	0.32	0.06	37	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E243021	Cond	-0.31	0.06	36	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243024	DO	-0.27	0.11	36	FRENCH CREEK AT GRAFTON ROAD	French Creek
E288090	Temp	0.26	0.12	37	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288093	DO	0.25	0.13	37	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E288092	Cond	-0.14	0.43	37	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288091	DO	0.08	0.62	37	GRANDON CREEK AT LABURNUM ROAD	French Creek
E288092	DO	0.06	0.71	37	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288090	DO	0.02	0.91	37	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E248835	Cond	-0.03	0.90	30	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
121580	DO	-0.02	0.91	31	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
E248836	Temp	0.50	0.01	29	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
121580	Turbidity	0.68	0.00	31	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
E248836	Cond	-0.20	0.30	29	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E248834	DO	-0.38	0.04	30	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248834	Temp	0.47	0.01	30	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248834	Turbidity	0.62	0.00	30	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E290452	Cond	-0.22	0.28	26	SHELLY CREEK @ END OF BLOWER RD	Englishman River
E248835	DO	-0.37	0.05	30	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E248835	Temp	0.42	0.02	30	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E282969	Turbidity	0.59	0.00	30	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E248834	Cond	-0.44	0.01	30	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248836	DO	-0.21	0.28	29	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E282969	Temp	0.38	0.04	29	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E248836	Turbidity	0.59	0.00	29	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
121580	Cond	-0.52	0.00	31	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
E282969	DO	-0.15	0.44	30	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
121580	Temp	0.35	0.05	31	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
E248835	Turbidity	0.38	0.04	30	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E282969	Cond	-0.61	0.00	30	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E290452	DO	0.09	0.65	26	SHELLY CREEK @ END OF BLOWER RD	Englishman River
E290452	Temp	0.23	0.26	26	SHELLY CREEK @ END OF BLOWER RD	Englishman River
E290452	Turbidity	0.31	0.13	26	SHELLY CREEK @ END OF BLOWER RD	Englishman River
E290483	Cond	-0.63	0.00	30	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290469	DO	0.05	0.78	31	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290470	Temp	0.38	0.03	31	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290484	Turbidity	0.76	0.00	29	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290469	Cond	-0.50	0.00	31	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290470	DO	0.09	0.64	31	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290471	Temp	0.36	0.05	31	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290483	Turbidity	0.70	0.00	29	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290479	Cond	-0.49	0.01	30	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E290471	DO	-0.07	0.72	31	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290472	Temp	0.33	0.07	31	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290475	Turbidity	0.67	0.00	31	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E294017	Cond	-0.42	0.03	25	CRAIG CK JUST U/S NORTHWEST BAY RD	South Wellington to Nanoose
E290472	DO	-0.25	0.17	31	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290473	Temp	0.31	0.09	30	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290481	Turbidity	0.65	0.00	30	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E294020	Cond	-0.41	0.04	25	NANOOSE CK @ MATTHEW CROSSING	South Wellington to Nanoose
E290473	DO	0.15	0.43	30	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290475	Temp	0.28	0.13	31	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290485	Turbidity	0.62	0.00	29	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290485	Cond	-0.37	0.05	30	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290475	DO	-0.04	0.81	31	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290469	Temp	0.18	0.34	31	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290471	Turbidity	0.60	0.00	31	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290470	Cond	-0.34	0.06	31	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290478	DO	-0.01	0.94	32	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290481	Temp	0.14	0.45	30	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290473	Turbidity	0.59	0.00	30	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290484	Cond	-0.33	0.07	30	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290479	DO	0.16	0.41	30	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E294019	Temp	0.15	0.48	25	NANOOSE CK @ NANOOSE CAMPGROUND	South Wellington to Nanoose

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E290472	Turbidity	0.58	0.00	31	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290475	Cond	-0.31	0.09	31	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290480	DO	0.22	0.24	30	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E294020	Temp	0.13	0.54	25	NANOOSE CK @ MATTHEW CROSSING	South Wellington to Nanoose
E290480	Turbidity	0.56	0.00	30	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290486	Cond	-0.30	0.11	29	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290481	DO	0.03	0.88	30	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290484	Temp	-0.12	0.54	30	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E294019	Turbidity	0.60	0.00	25	NANOOSE CK @ NANOOSE CAMPGROUND	South Wellington to Nanoose
E294019	Cond	-0.32	0.12	25	NANOOSE CK @ NANOOSE CAMPGROUND	South Wellington to Nanoose
E290483	DO	0.07	0.72	30	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E294017	Temp	0.09	0.66	25	CRAIG CK JUST U/S NORTHWEST BAY RD	South Wellington to Nanoose
E294017	Turbidity	0.55	0.00	25	CRAIG CK JUST U/S NORTHWEST BAY RD	South Wellington to Nanoose
E290480	Cond	-0.29	0.12	30	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290484	DO	0.25	0.18	30	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290478	Temp	0.07	0.70	32	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290470	Turbidity	0.48	0.01	31	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290471	Cond	-0.26	0.16	31	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290485	DO	0.28	0.14	30	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290483	Temp	0.04	0.85	30	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E294020	Turbidity	0.52	0.01	25	NANOOSE CK @ MATTHEW CROSSING	South Wellington to Nanoose
E290481	Cond	-0.22	0.25	30	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose

EMS.ID	analyte	tau	p-value	n	LOCATION.NAME	WaterRegion
E290486	DO	-0.11	0.57	30	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290479	Temp	0.02	0.91	30	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290486	Turbidity	0.46	0.01	29	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290472	Cond	-0.14	0.46	31	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E294017	DO	0.29	0.17	25	CRAIG CK JUST U/S NORTHWEST BAY RD	South Wellington to Nanoose
E290486	Temp	0.02	0.91	30	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290479	Turbidity	0.45	0.01	30	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290473	Cond	-0.12	0.51	30	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E294019	DO	0.25	0.22	25	NANOOSE CK @ NANOOSE CAMPGROUND	South Wellington to Nanoose
E290485	Temp	0.02	0.93	30	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290469	Turbidity	0.30	0.10	31	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290478	Cond	0.00	0.99	32	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E294020	DO	0.25	0.22	25	NANOOSE CK @ MATTHEW CROSSING	South Wellington to Nanoose
E290480	Temp	0.01	0.96	30	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290478	Turbidity	0.25	0.16	32	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290487	Temp	-0.02	0.91	30	BECK CREEK @ CEDAR RD	Nanaimo River
E290487	DO	0.08	0.66	30	BECK CREEK @ CEDAR RD	Nanaimo River
E287699	Temp	0.11	0.53	35	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E287699	Cond	-0.28	0.10	35	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E287699	DO	0.28	0.10	35	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E290487	Cond	-0.39	0.03	30	BECK CREEK @ CEDAR RD	Nanaimo River
E290487	Turbidity	0.41	0.03	29	BECK CREEK @ CEDAR RD	Nanaimo River
E287699	Turbidity	0.67	0.00	35	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River

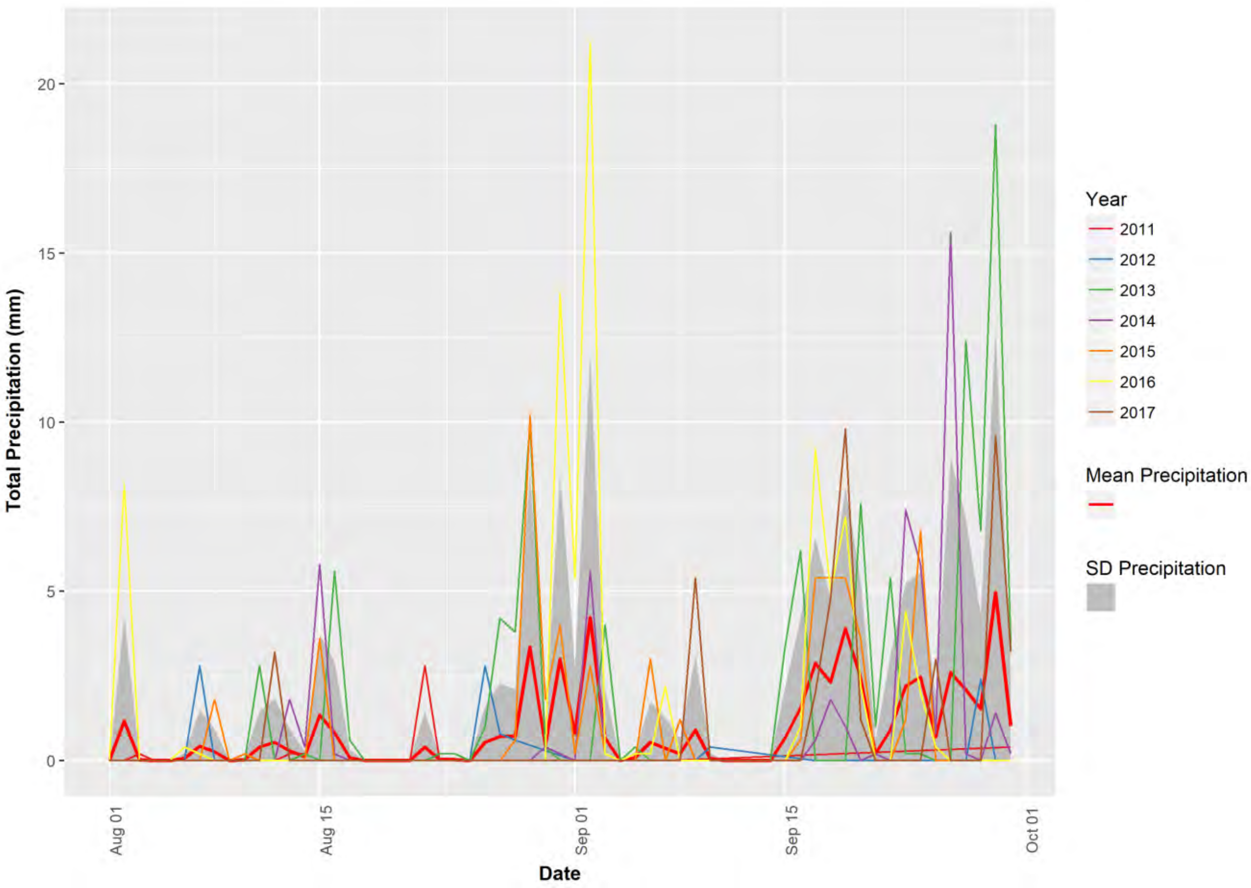

Figure A73. Summer rainfall at Ballenas Island.

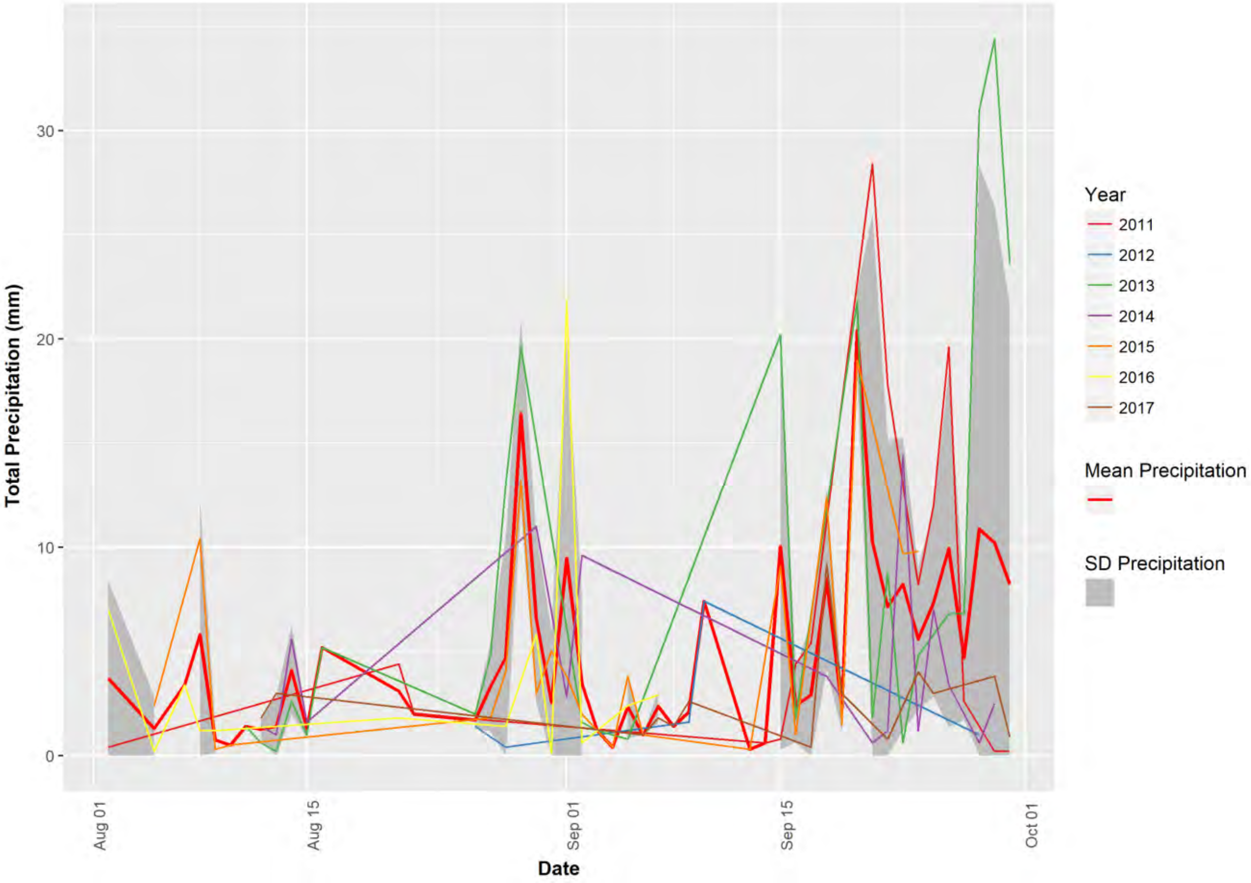

Figure A74. **Summer rainfall at Big Qualicum Hatchery.**

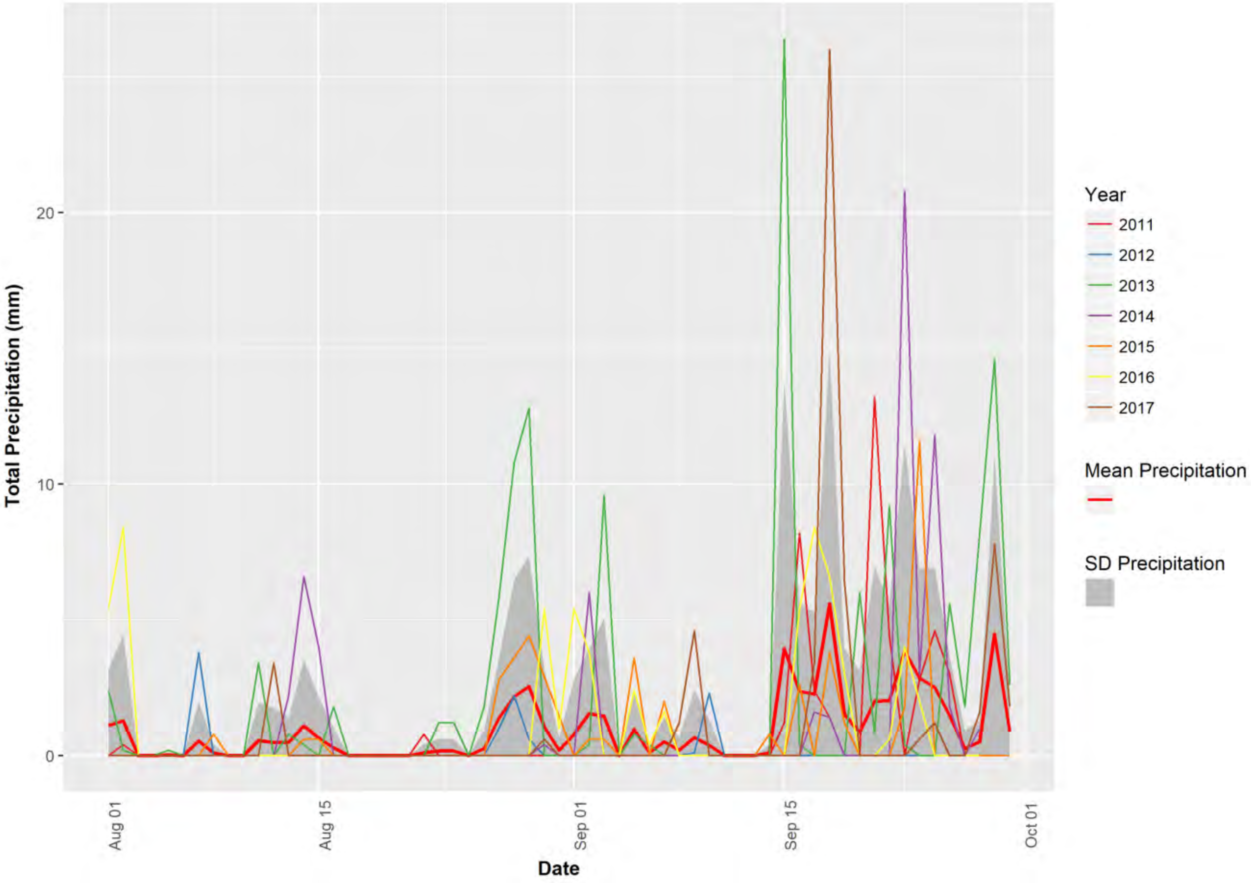

Figure A75. **Summer rainfall at Entrance Island.**

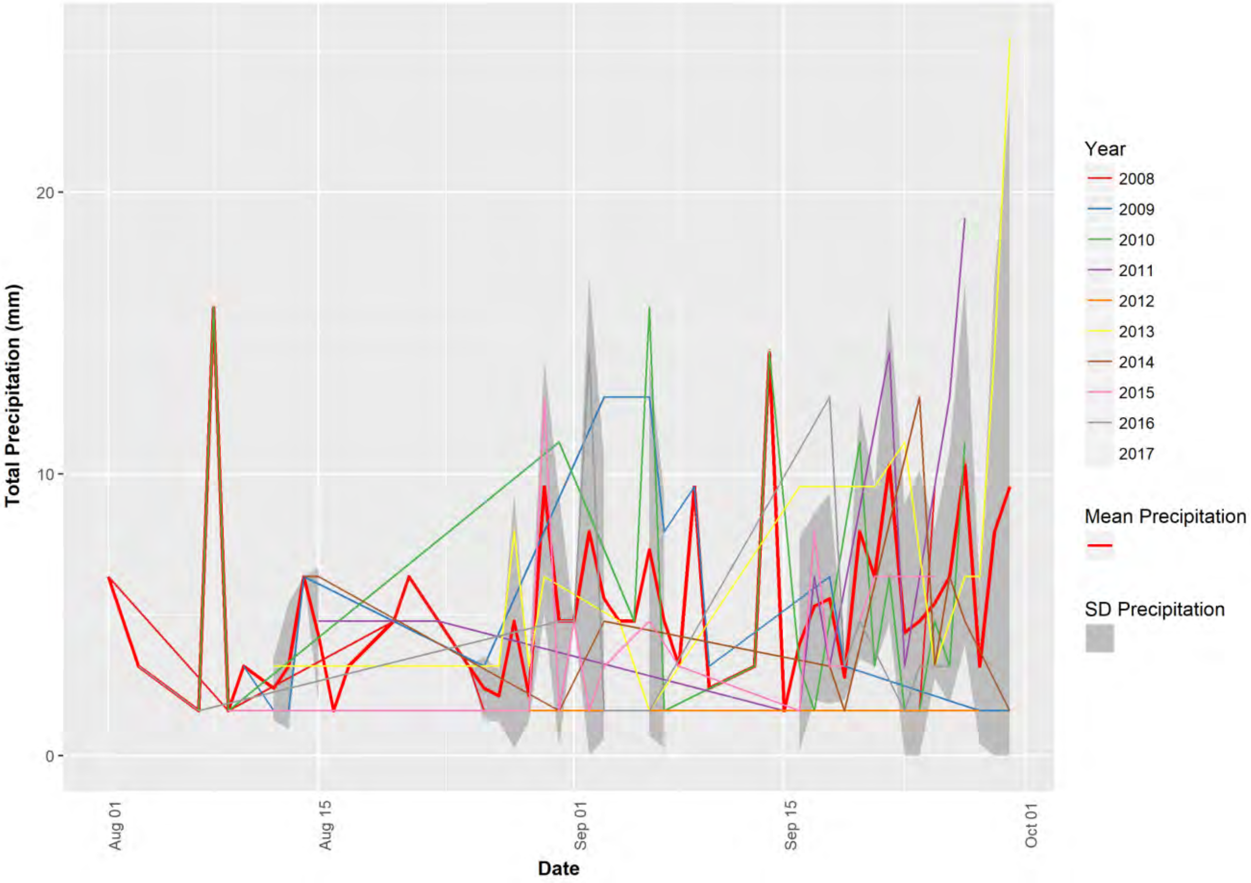

Figure A76. **Summer rainfall at Fair Winds Golf Course.**

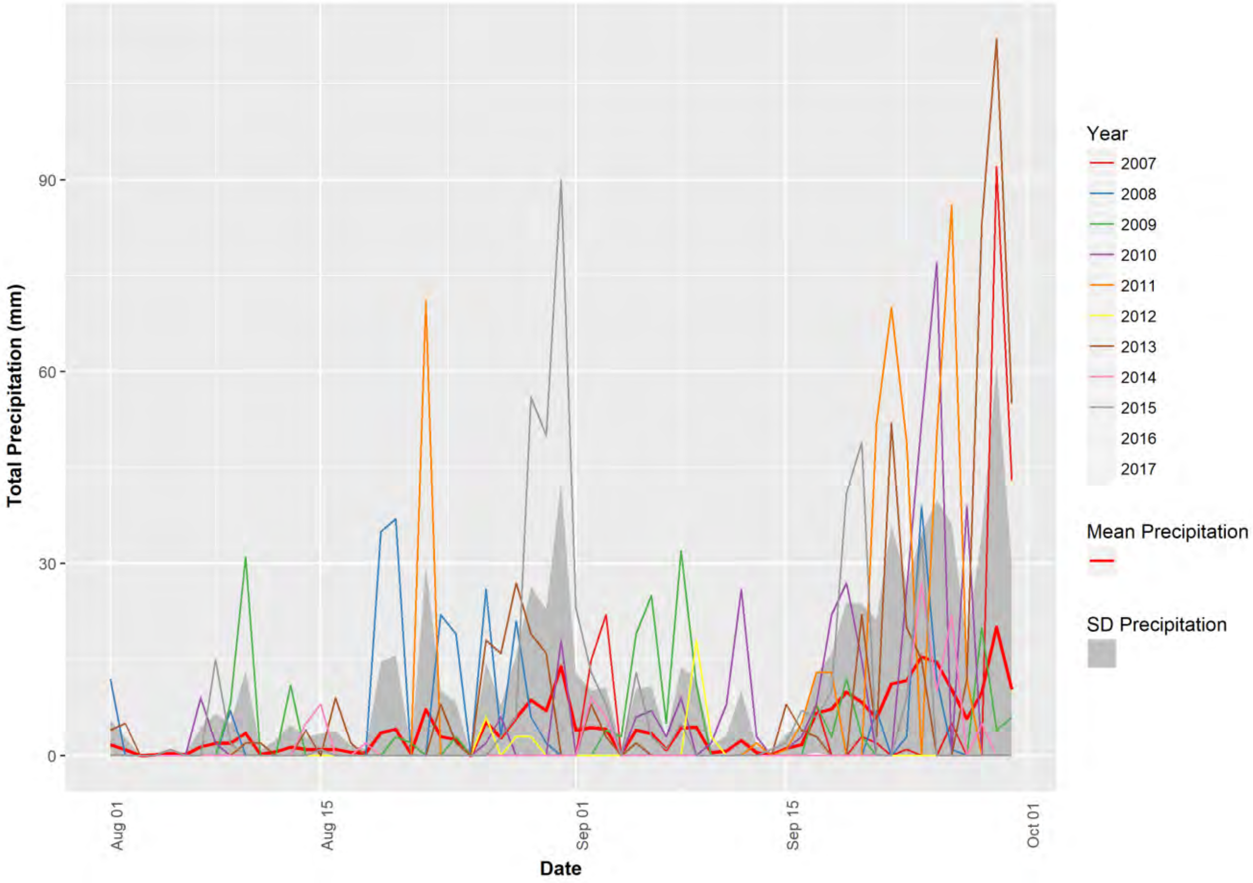

Figure A77. **Summer rainfall at Jump Creek.**

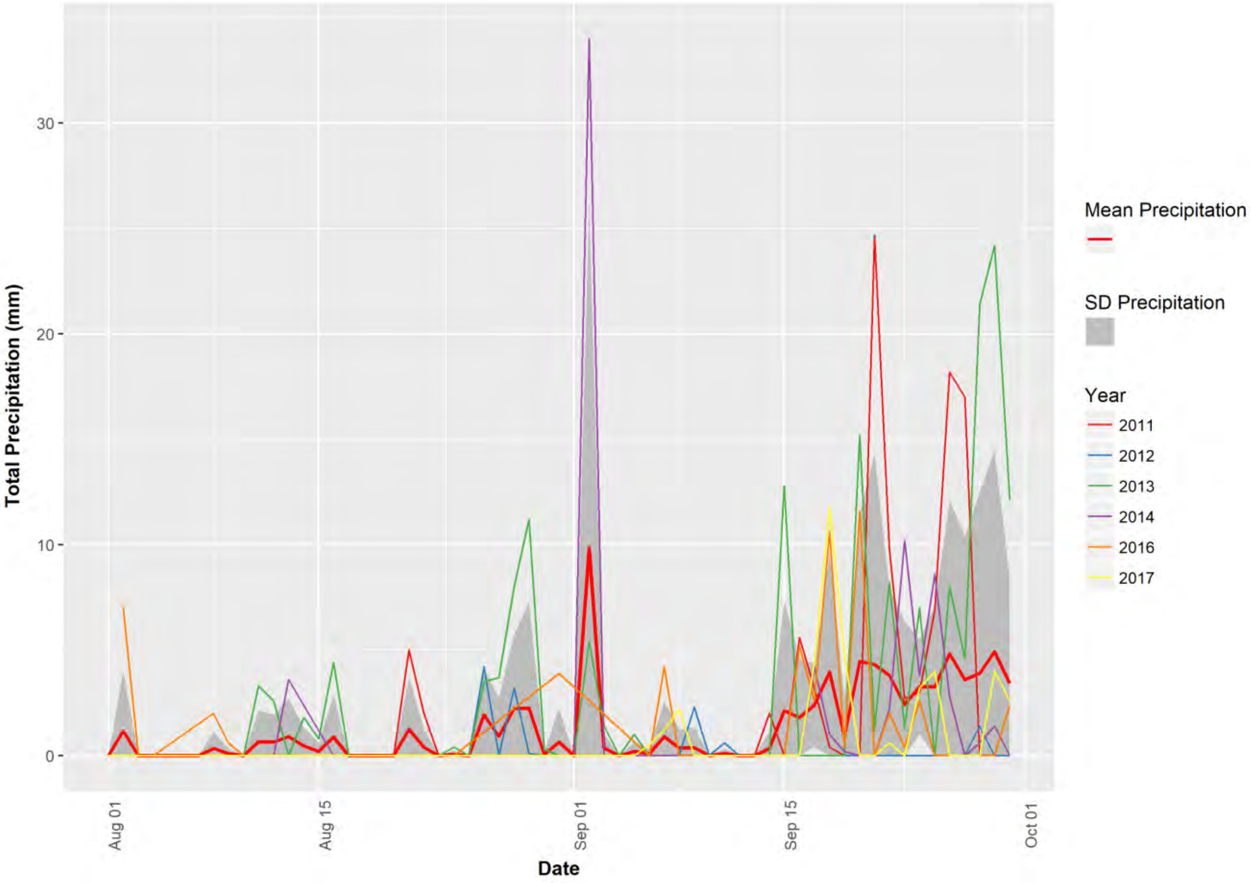

Figure A78. **Summer rainfall at Little Qualicum Hatchery.**

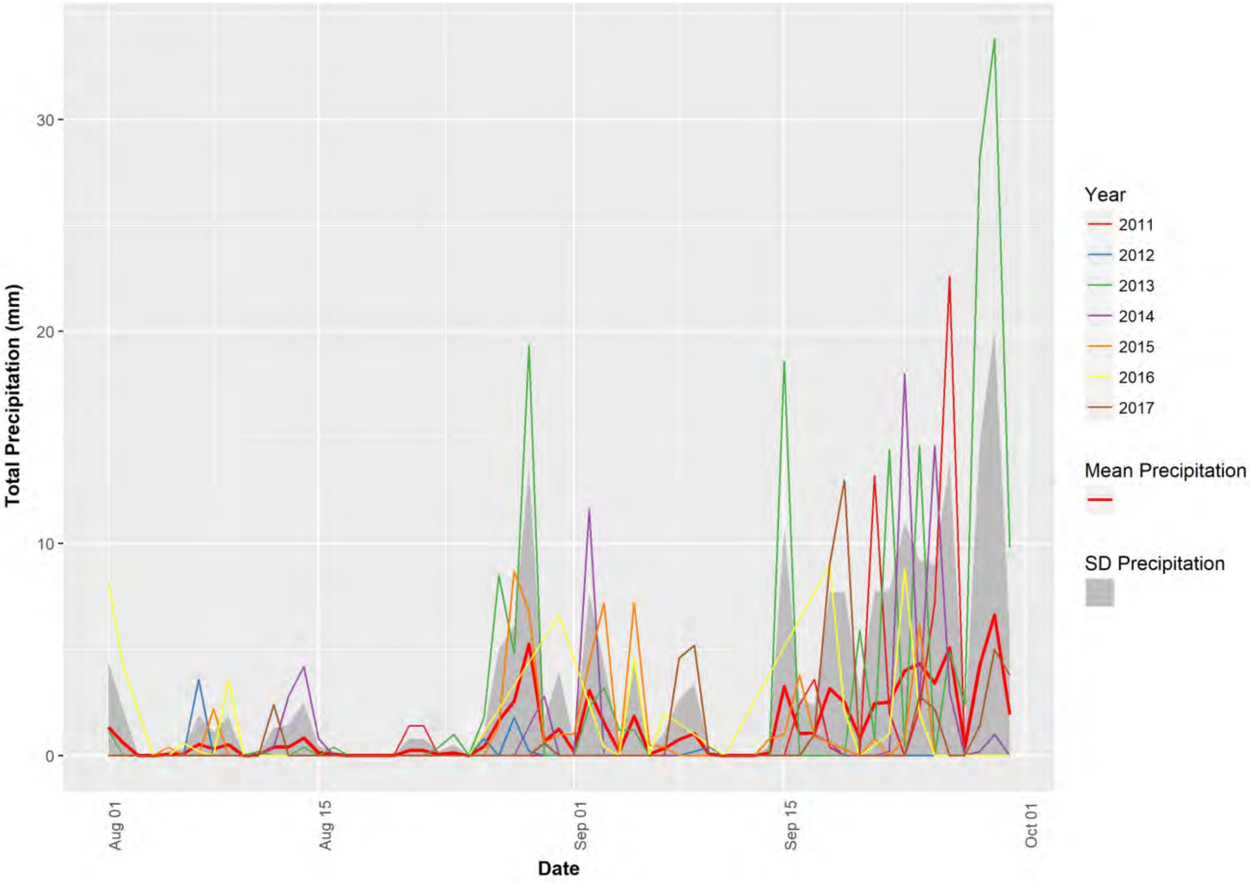

Figure A79. **Summer rainfall at Nanaimo A.**

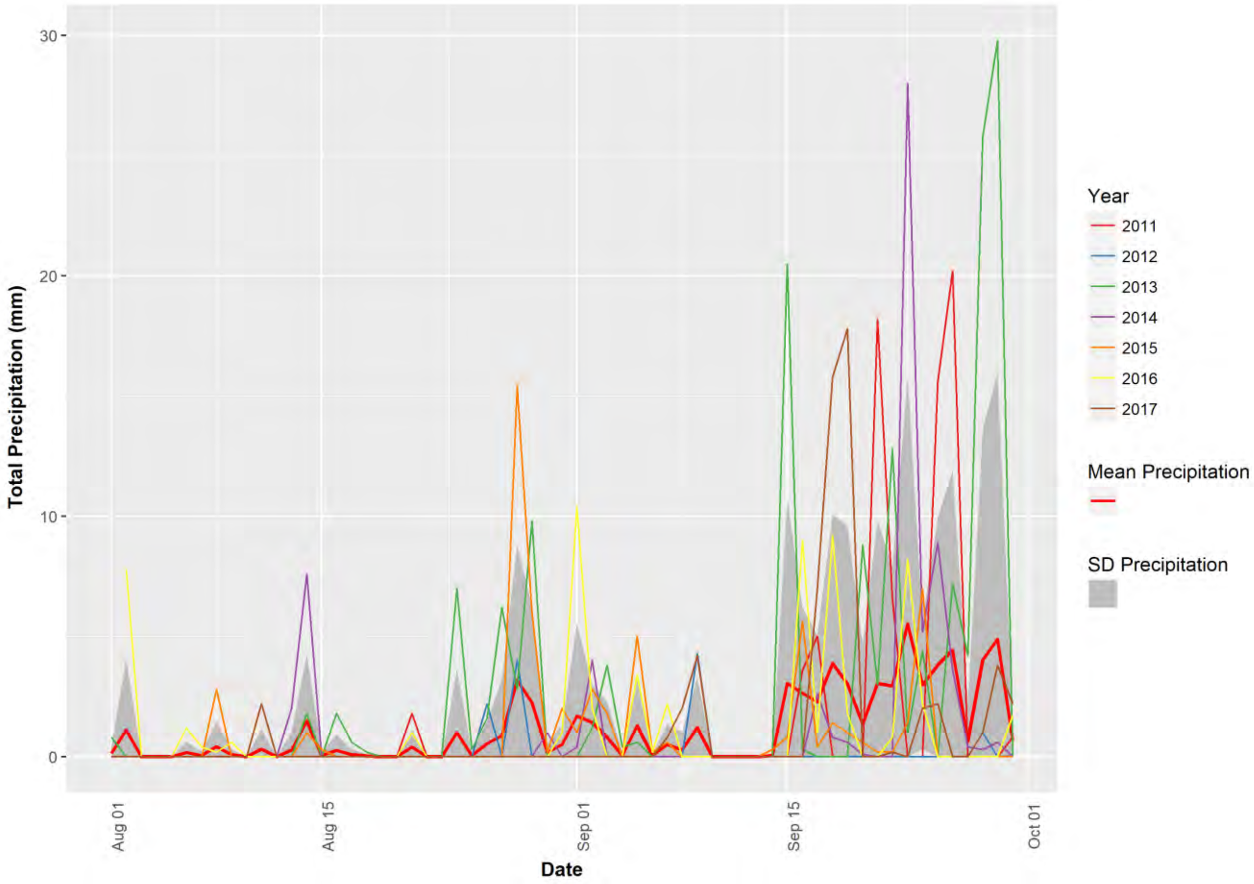

Figure A80. **Summer rainfall at Nanaimo City Yard.**

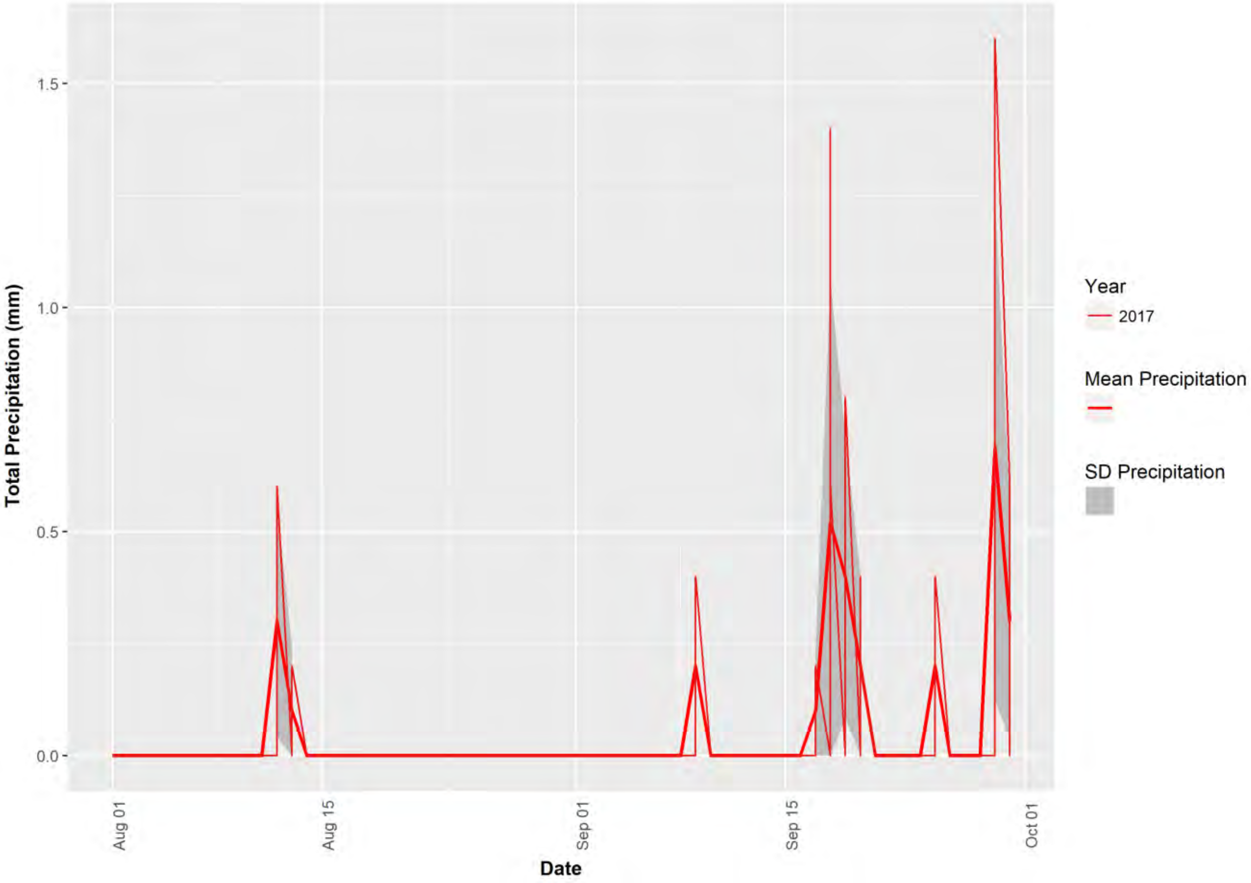

Figure A81. **Summer rainfall at Parksville.**

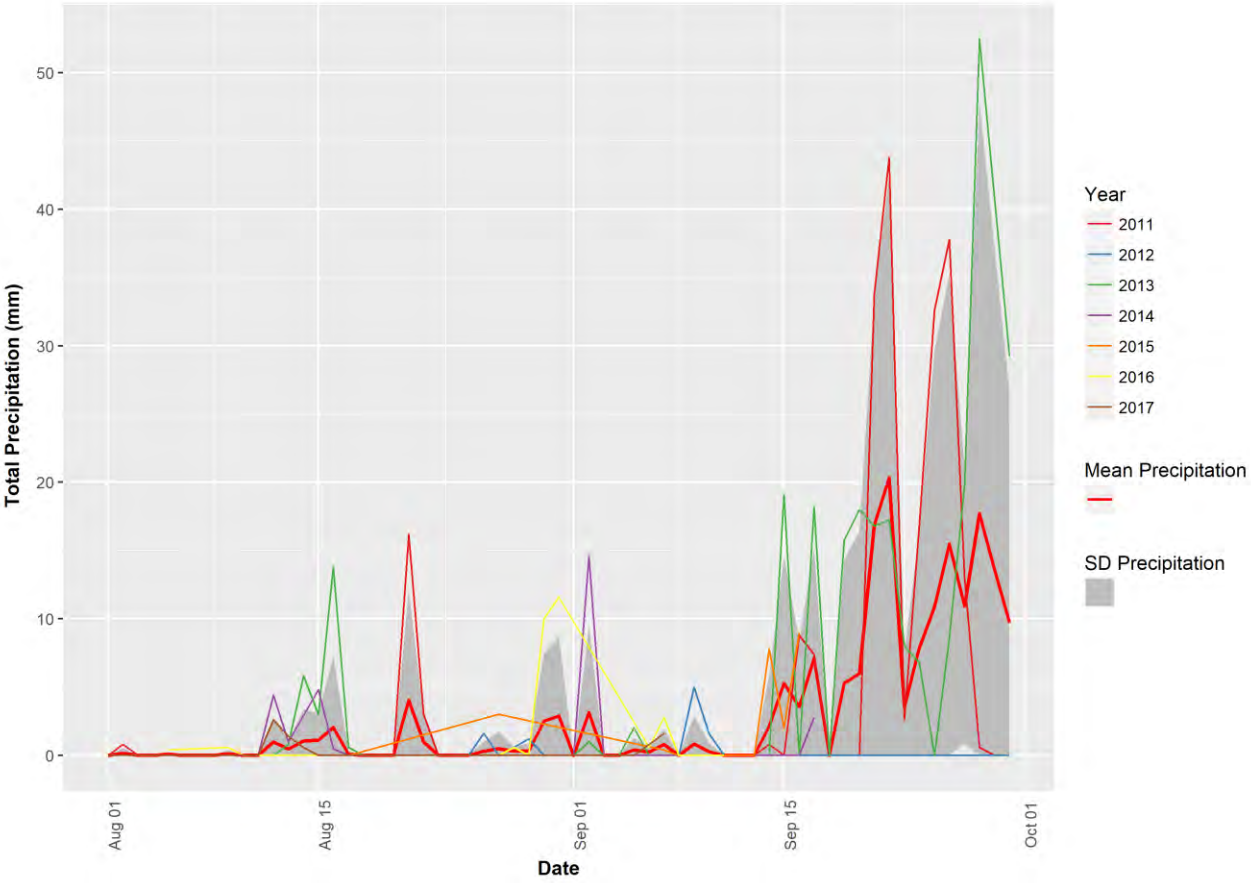

Figure A82. Summer rainfall at Cox Lake, Port Alberni.

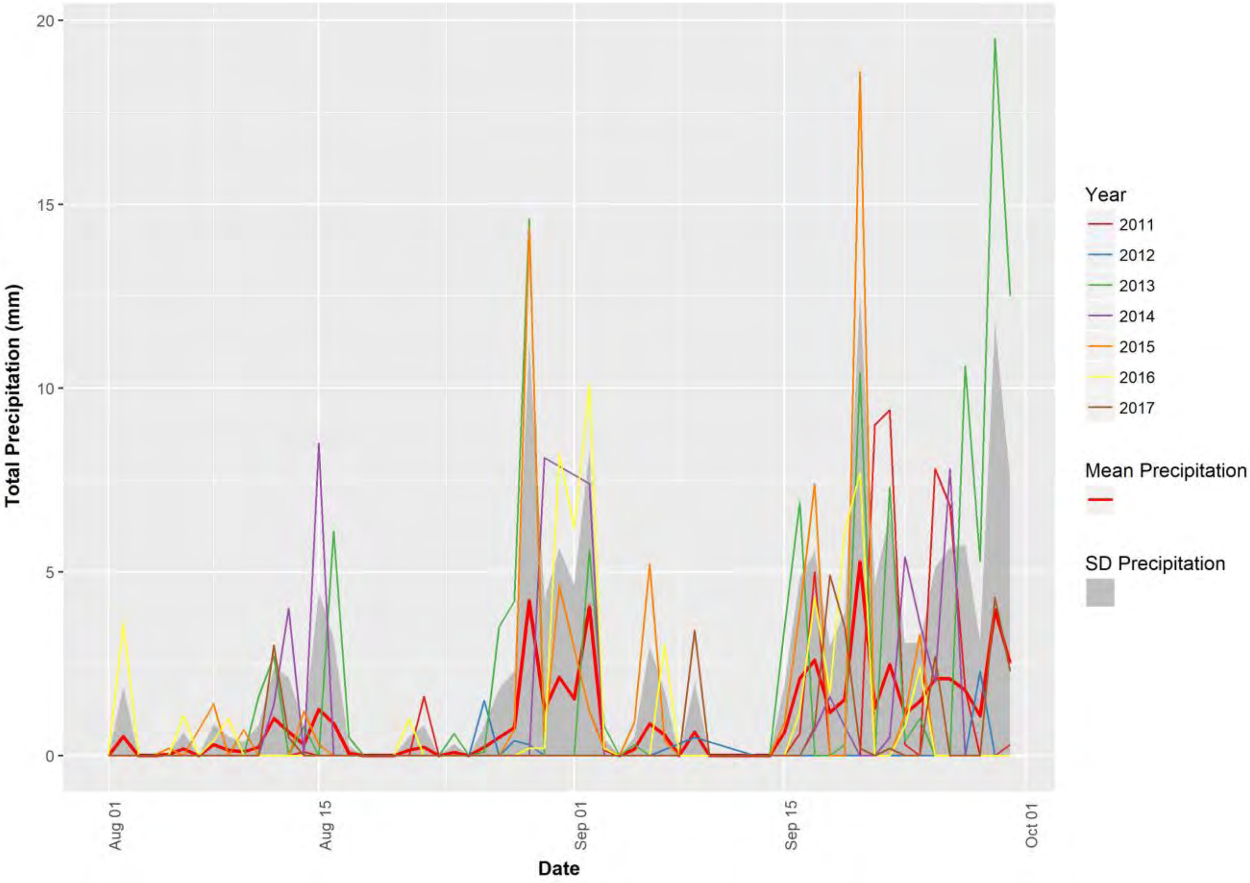

Figure A83. **Summer rainfall at Qualicum Beach Airport.**

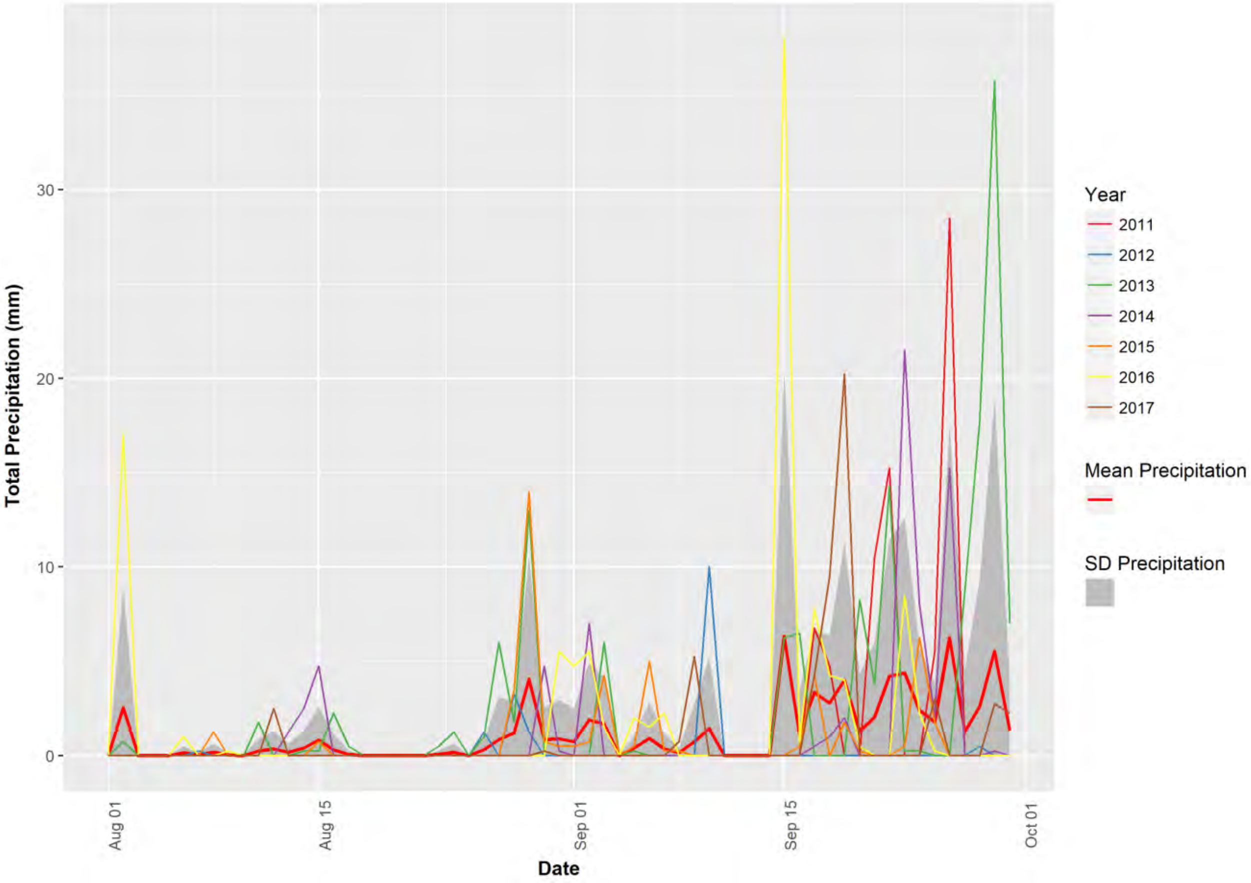

Figure A84. **Summer rainfall at RG City Hall.**

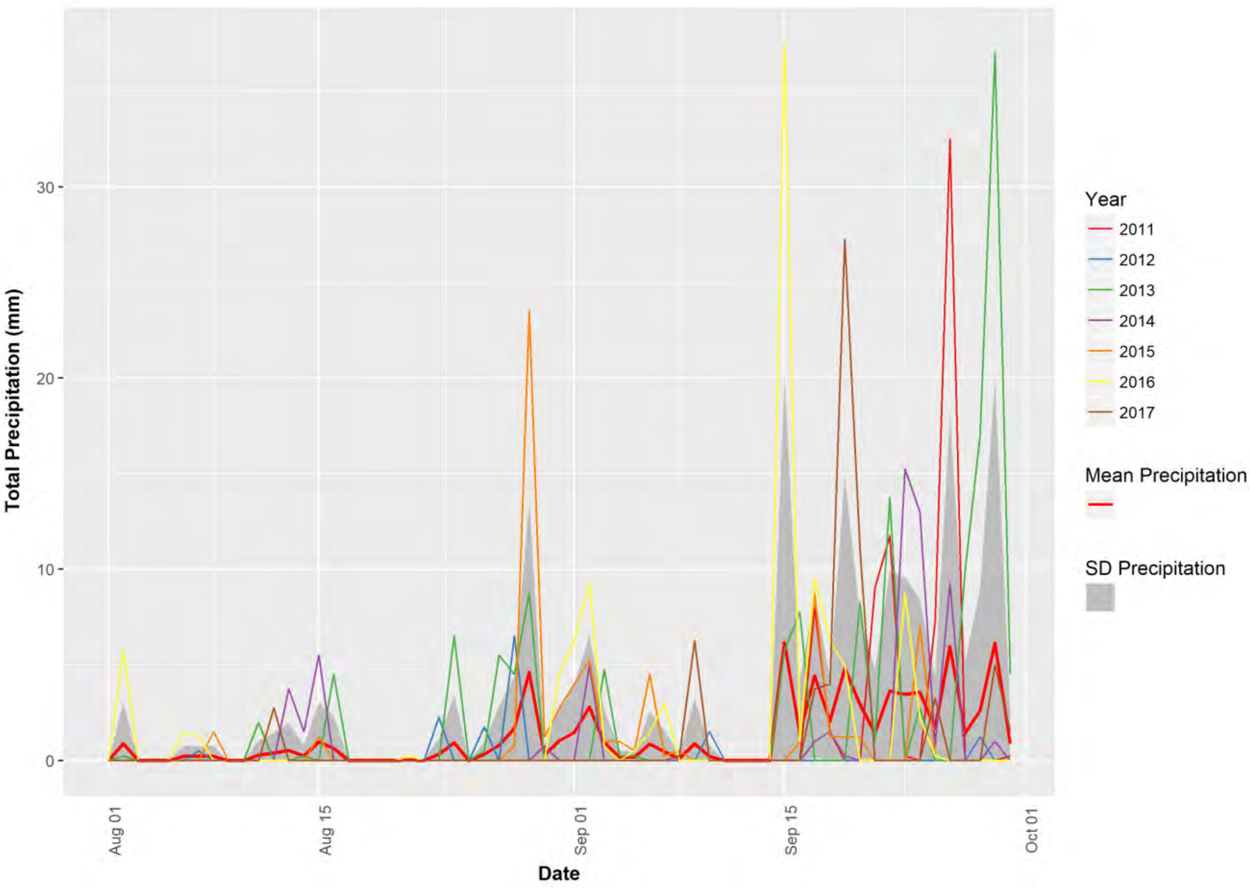

Figure A85. **Summer rainfall at RG Fire hall.**

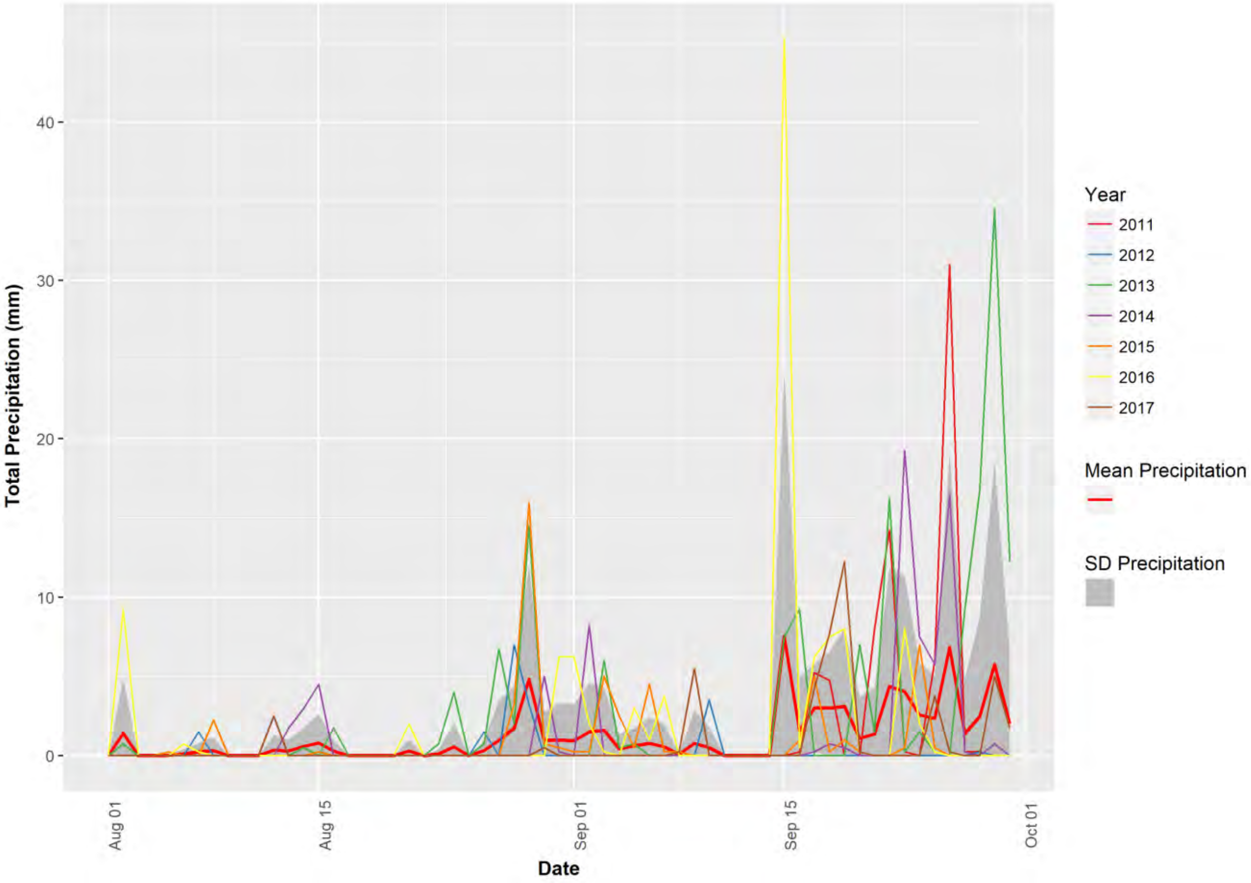

Figure A86. **Summer rainfall at RG Fire hall 4.**

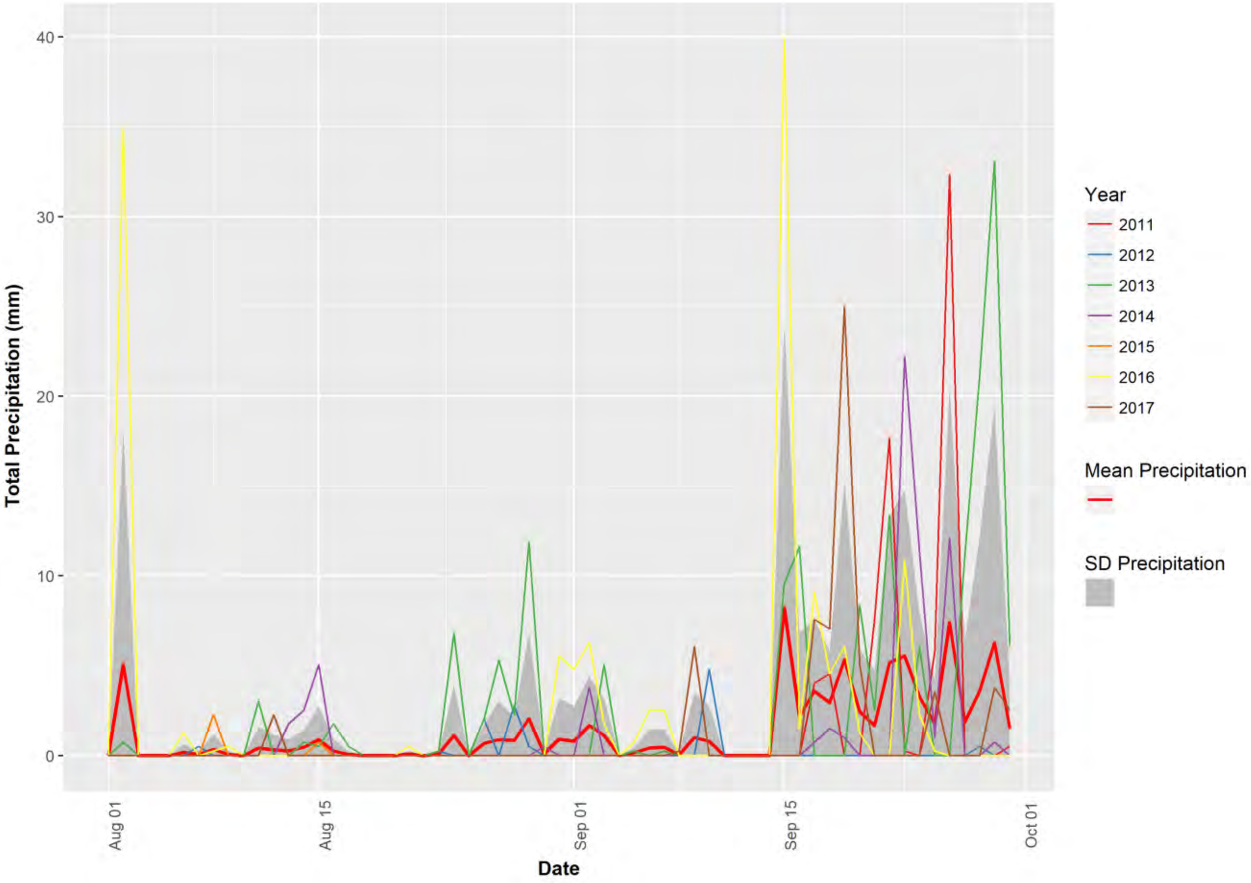

Figure A87. **Summer rainfall at RG Public Works.**

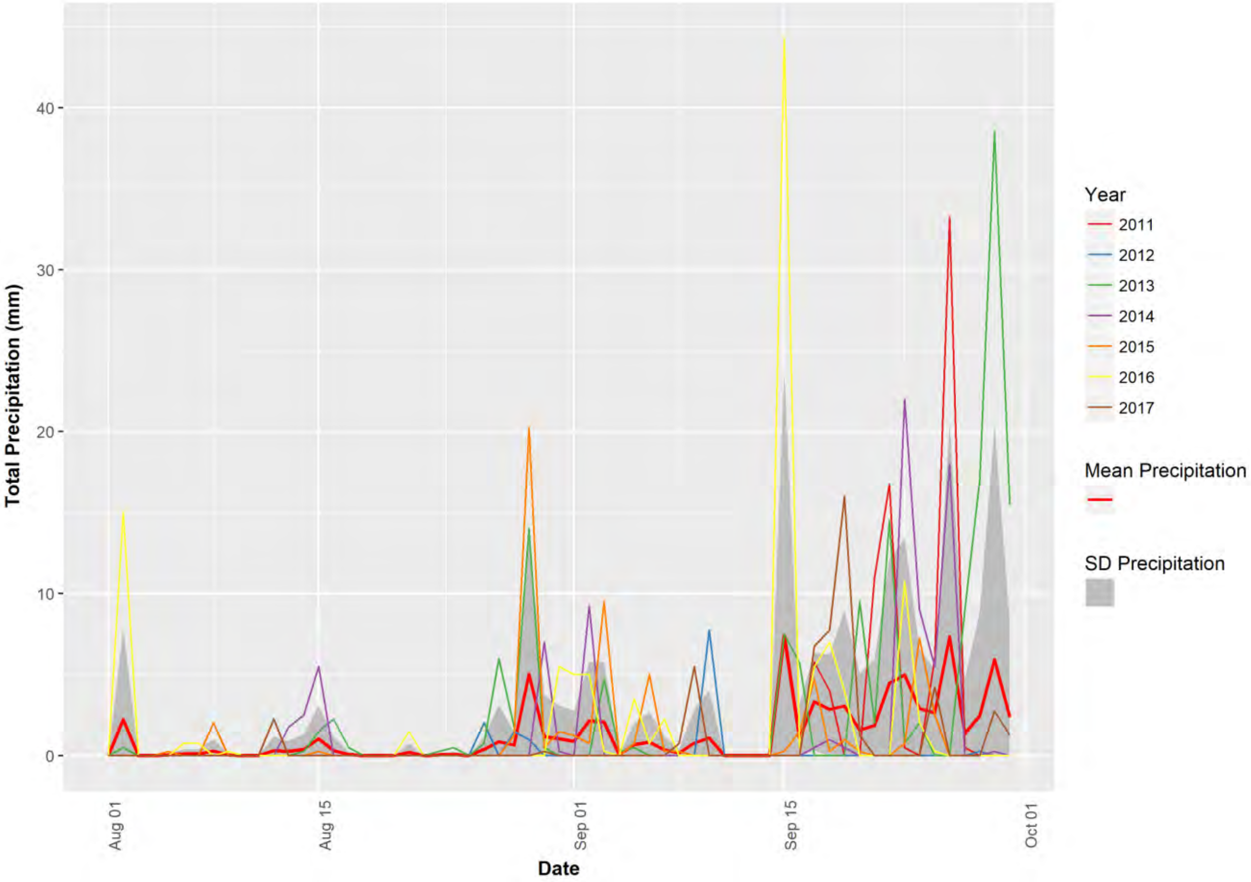

Figure A88. **Summer rainfall at RG Reservoir.**

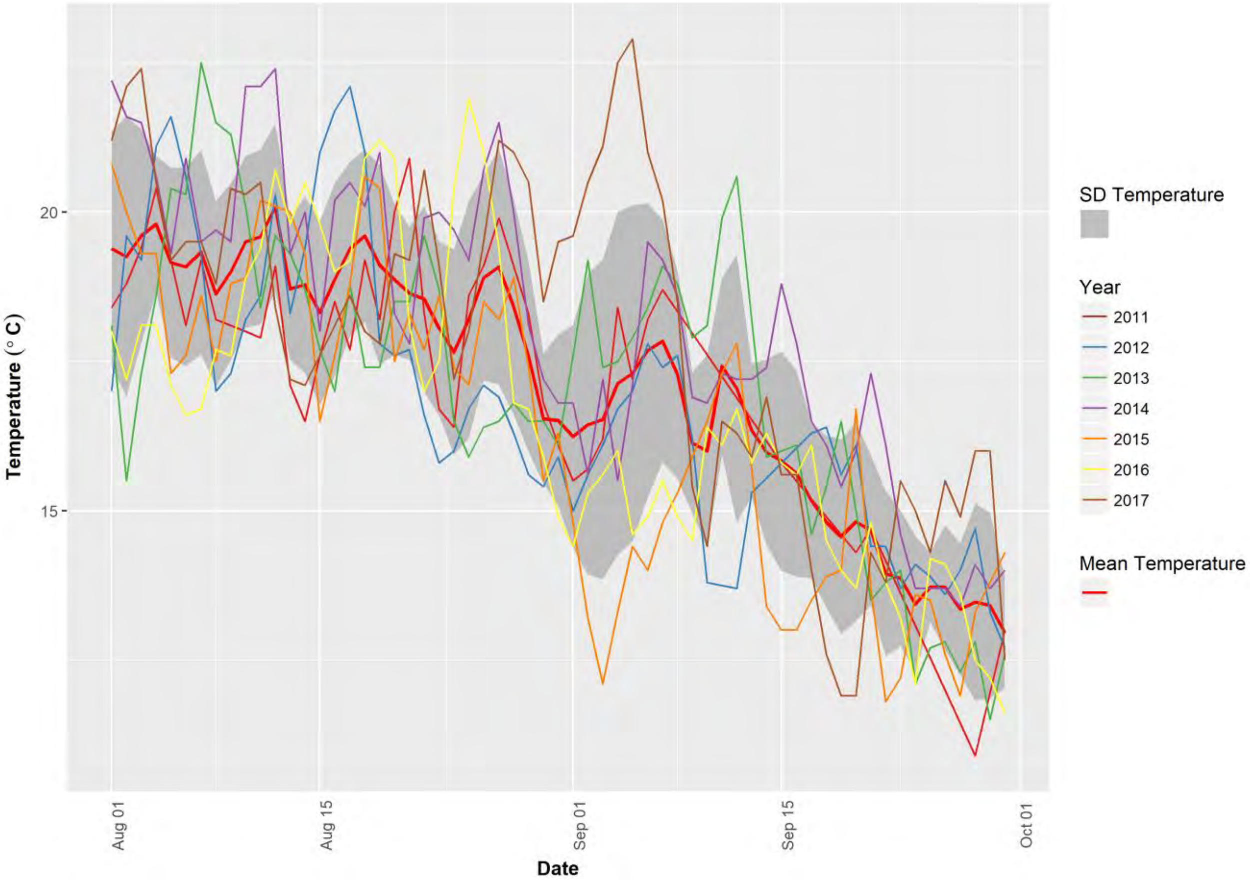

Figure A89. **Summer temperature at Ballenas Island.**

Figure A90. **Summer temperature at Entrance Island.**

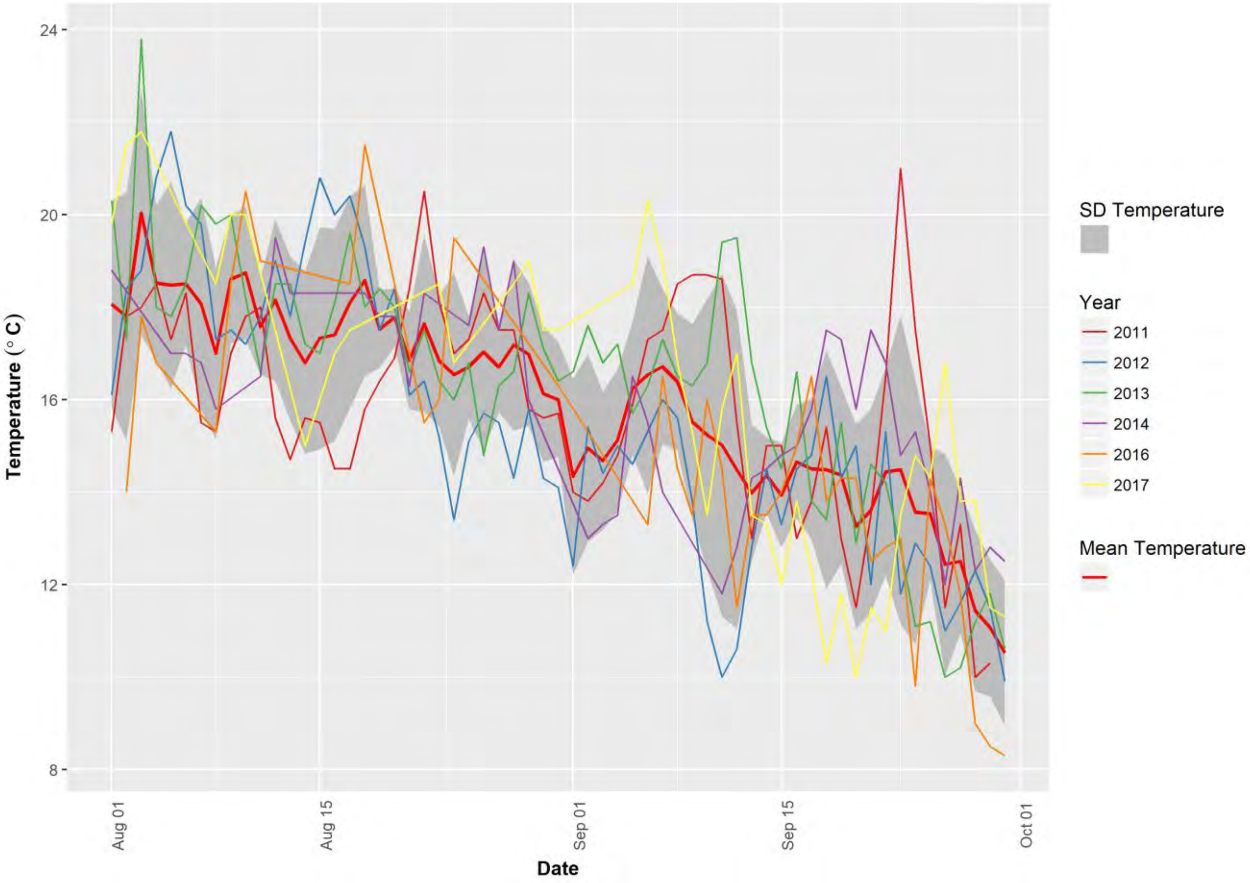

Figure A91. **Summer temperature at Little Qualicum Hatchery.**

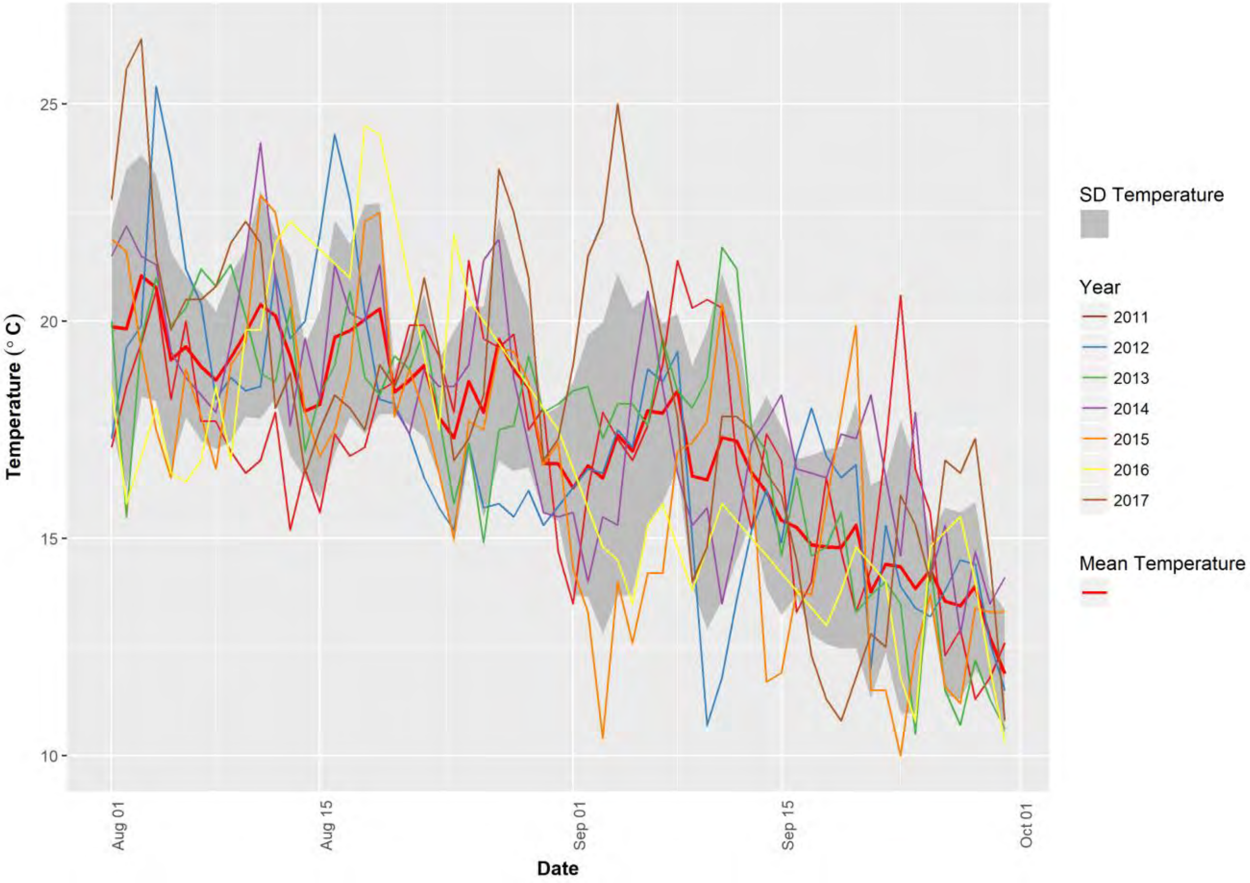

Figure A92. Summer temperature at Nanaimo A.

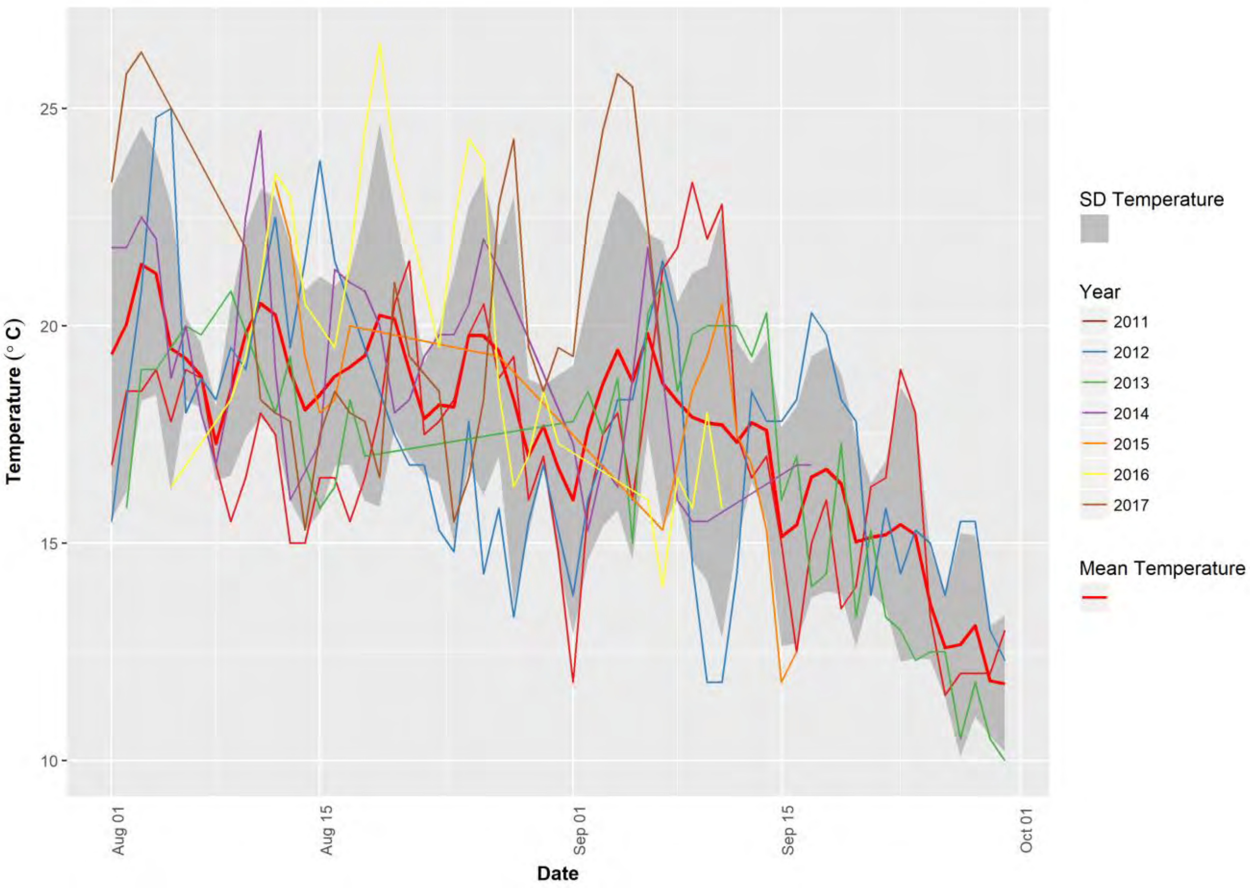

Figure A93. **Summer temperature at Cox Lake, Port Albernie.**

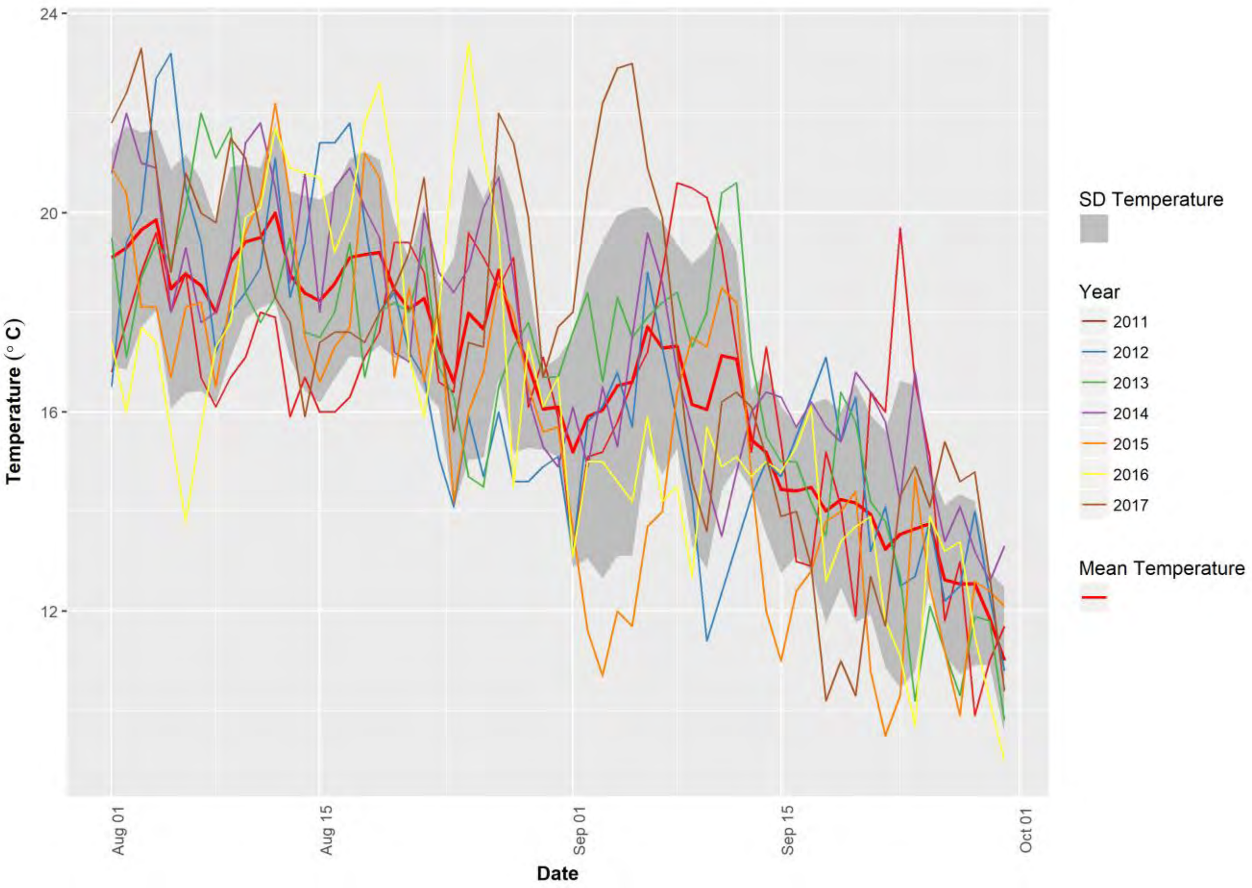

Figure A94. Summer temperature at Qualicum Beach Airport.

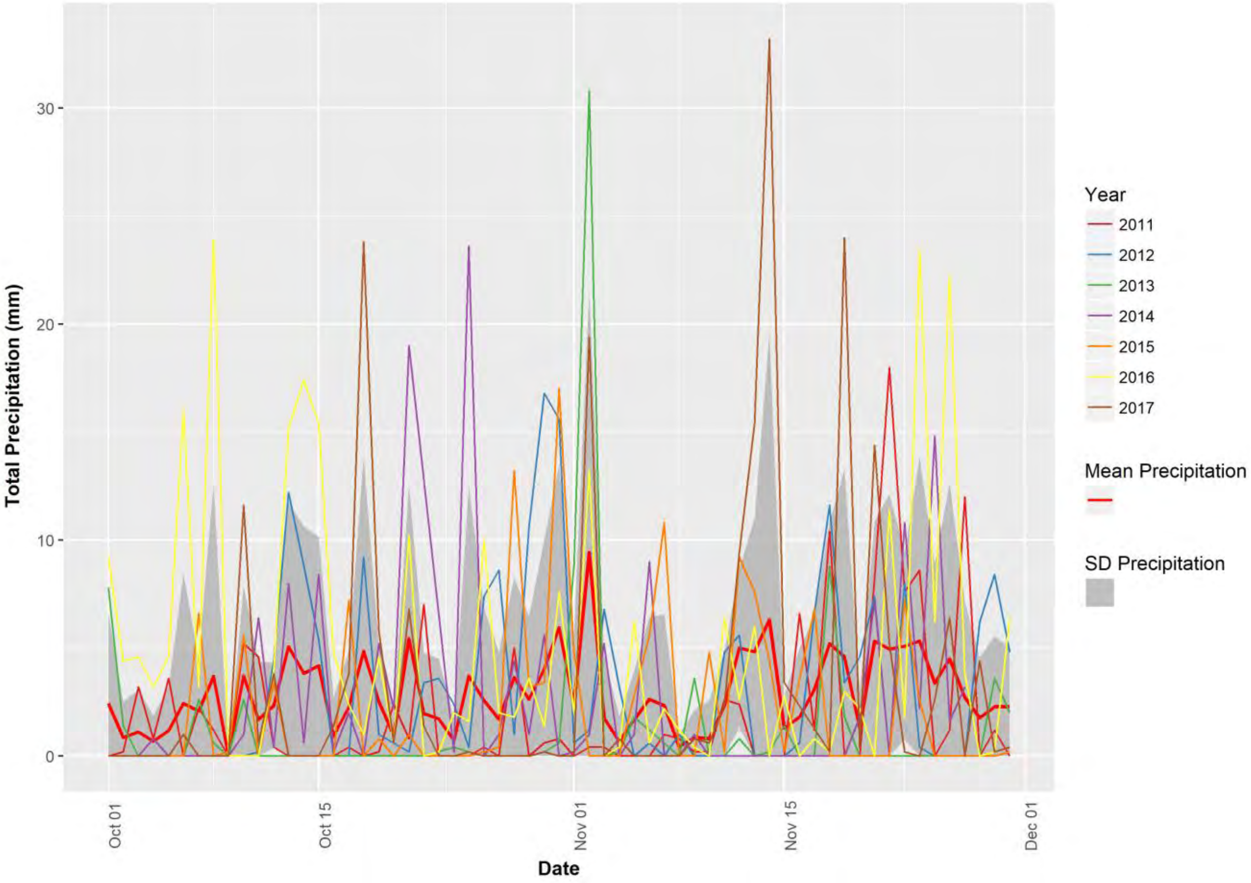

Figure A95. Fall Rainfall at Ballenas Island.

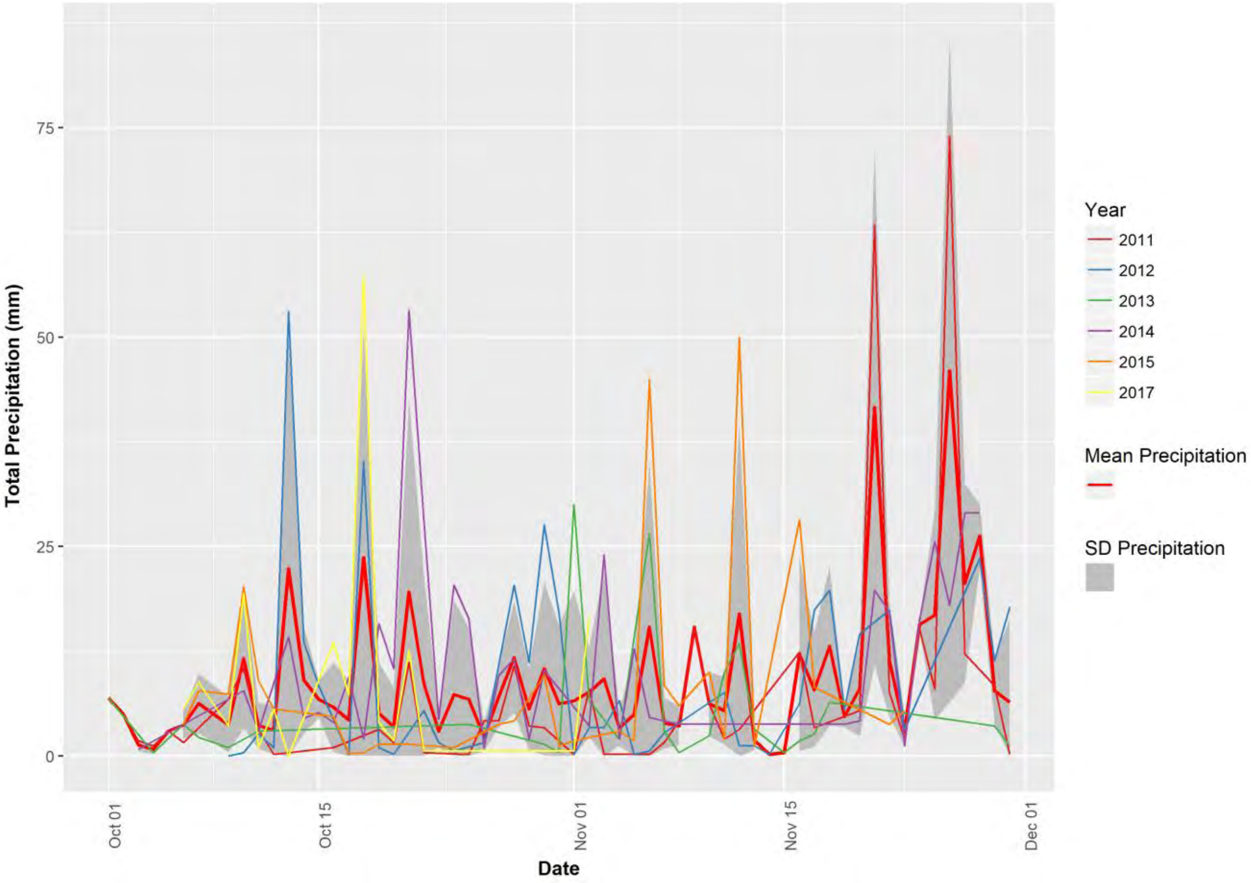

Figure A96. **Fall Rainfall at Big Qualicum Hatchery.**

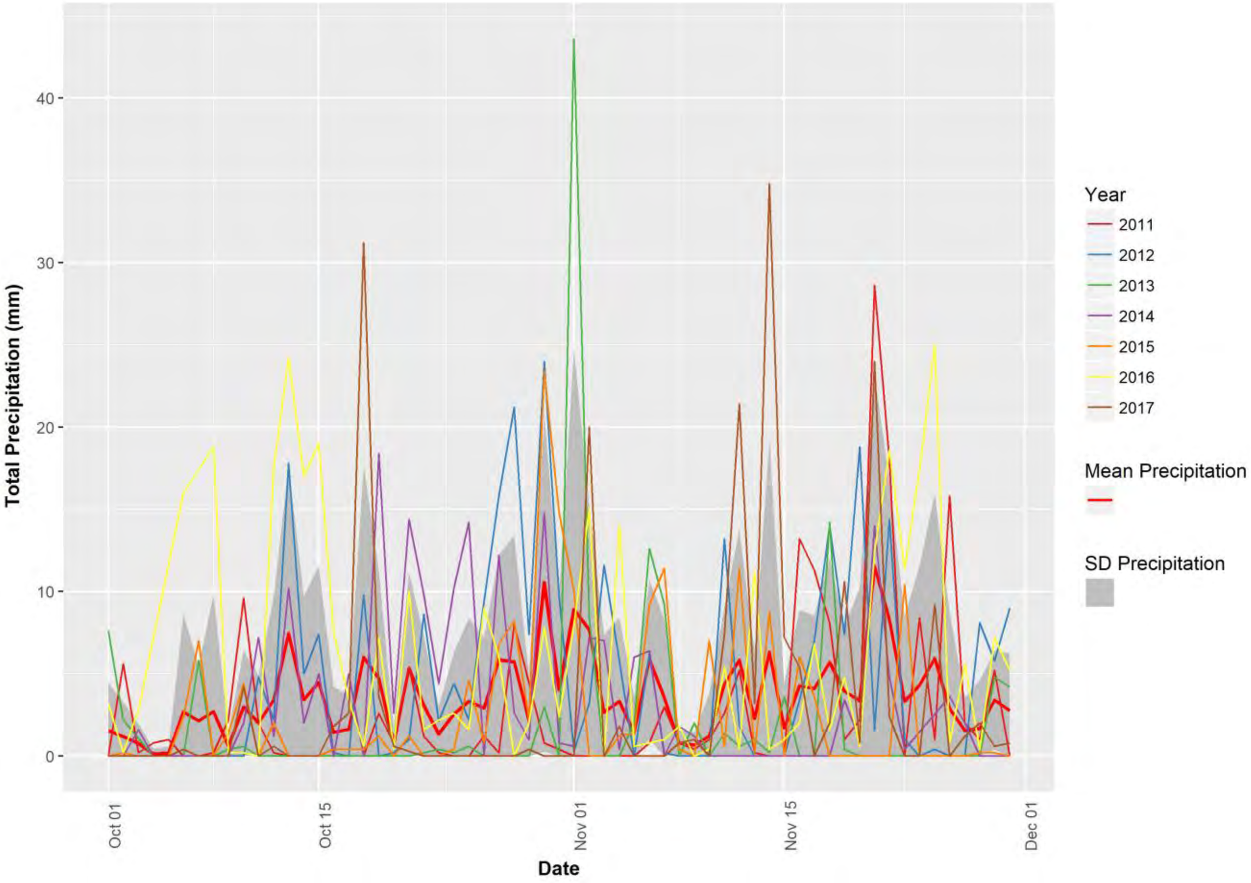

Figure A97. **Fall Rainfall at Entrance Island.**

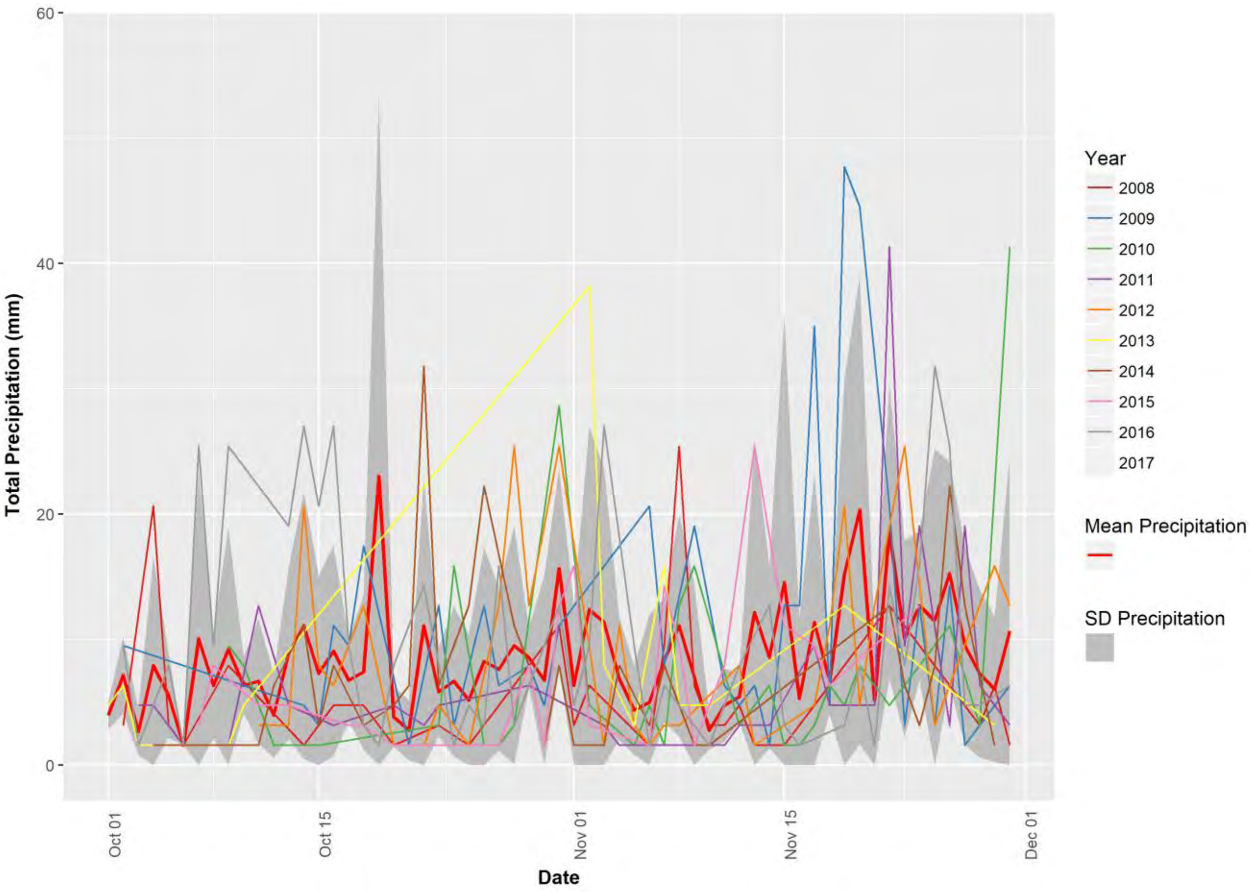

Figure A98. **Fall Rainfall at Fairwinds Golf Course.**

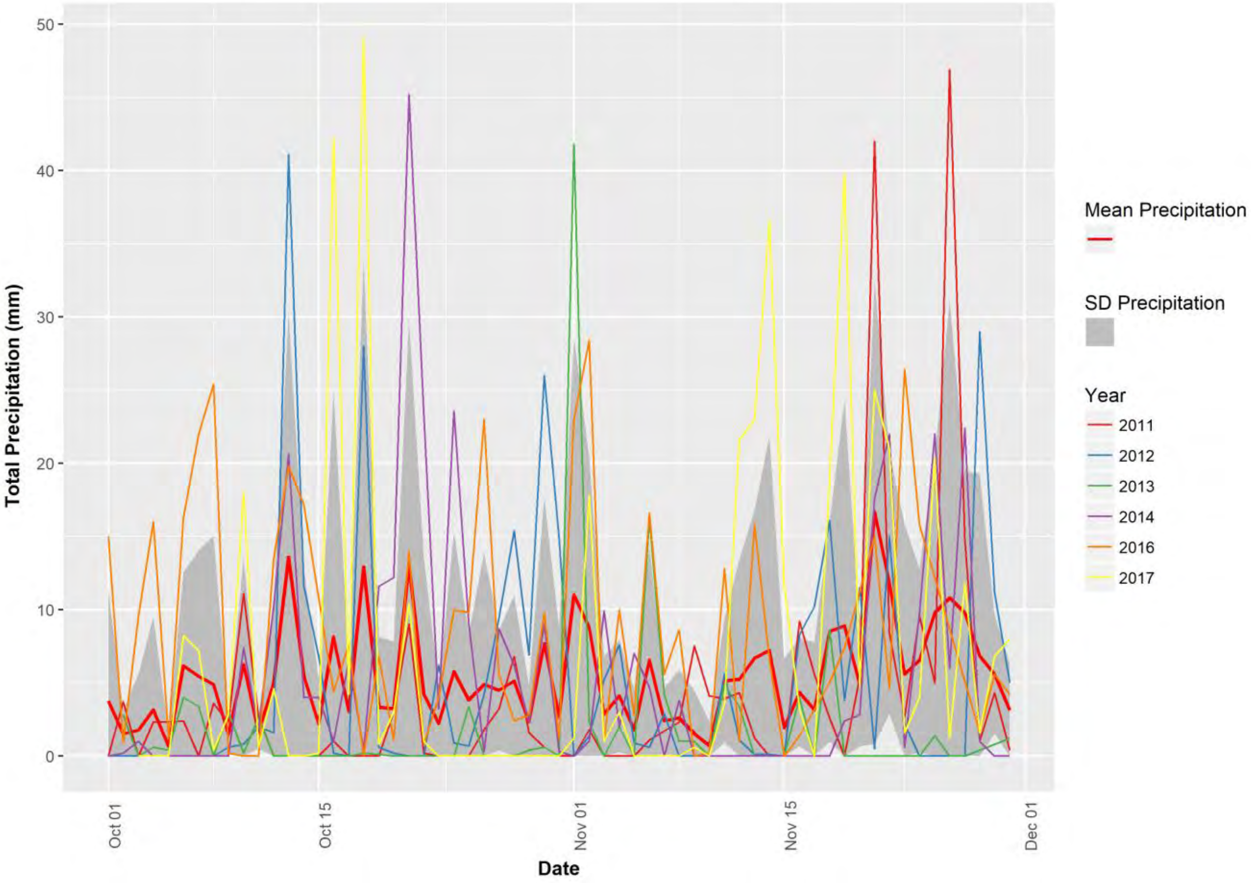

Figure A99. **Fall Rainfall at Little Qualicum Hatchery.**

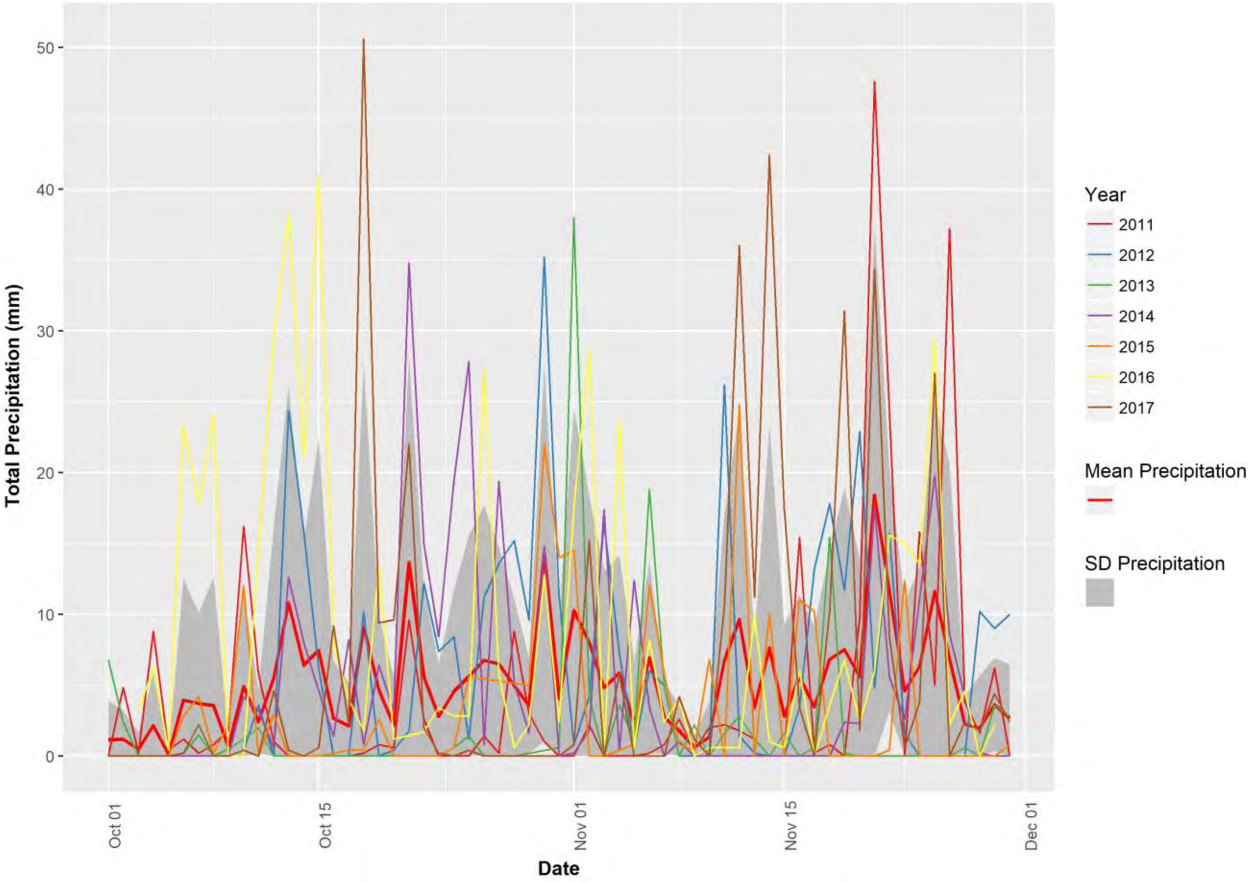

Figure A100. **Fall Rainfall at Nanaimo A.**

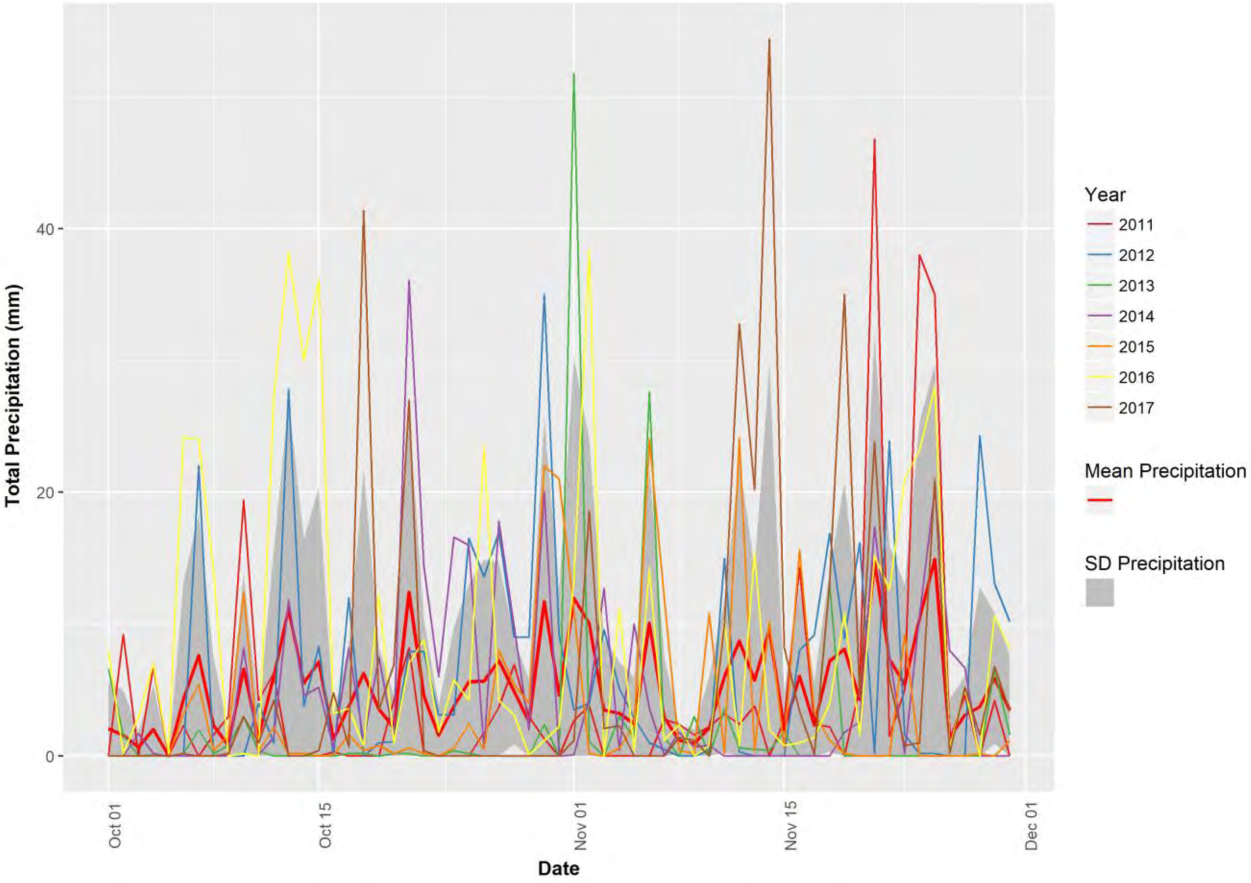

Figure A101. **Fall Rainfall at Nanaimo City Yard.**

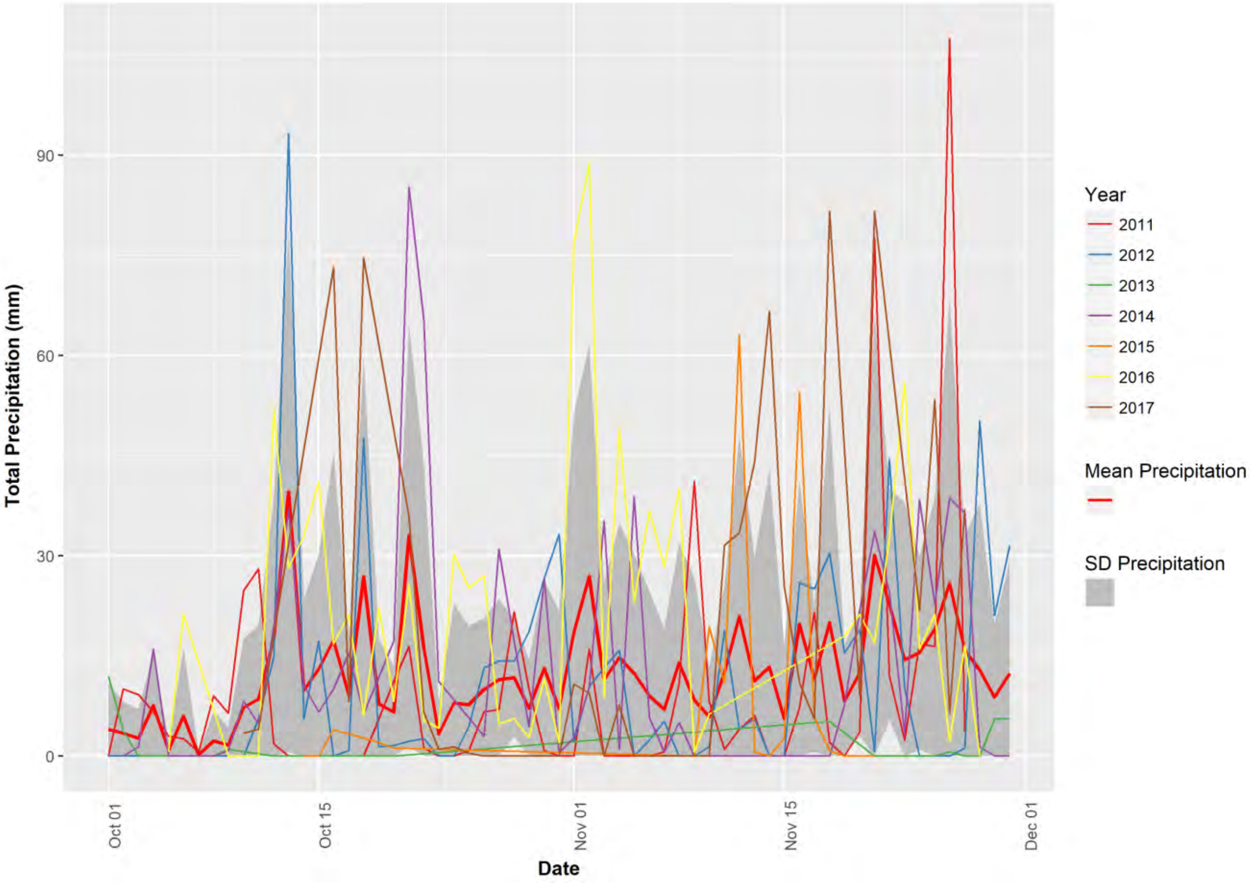

Figure A102. **Fall Rainfall at Cox Lake, Port Alberni.**

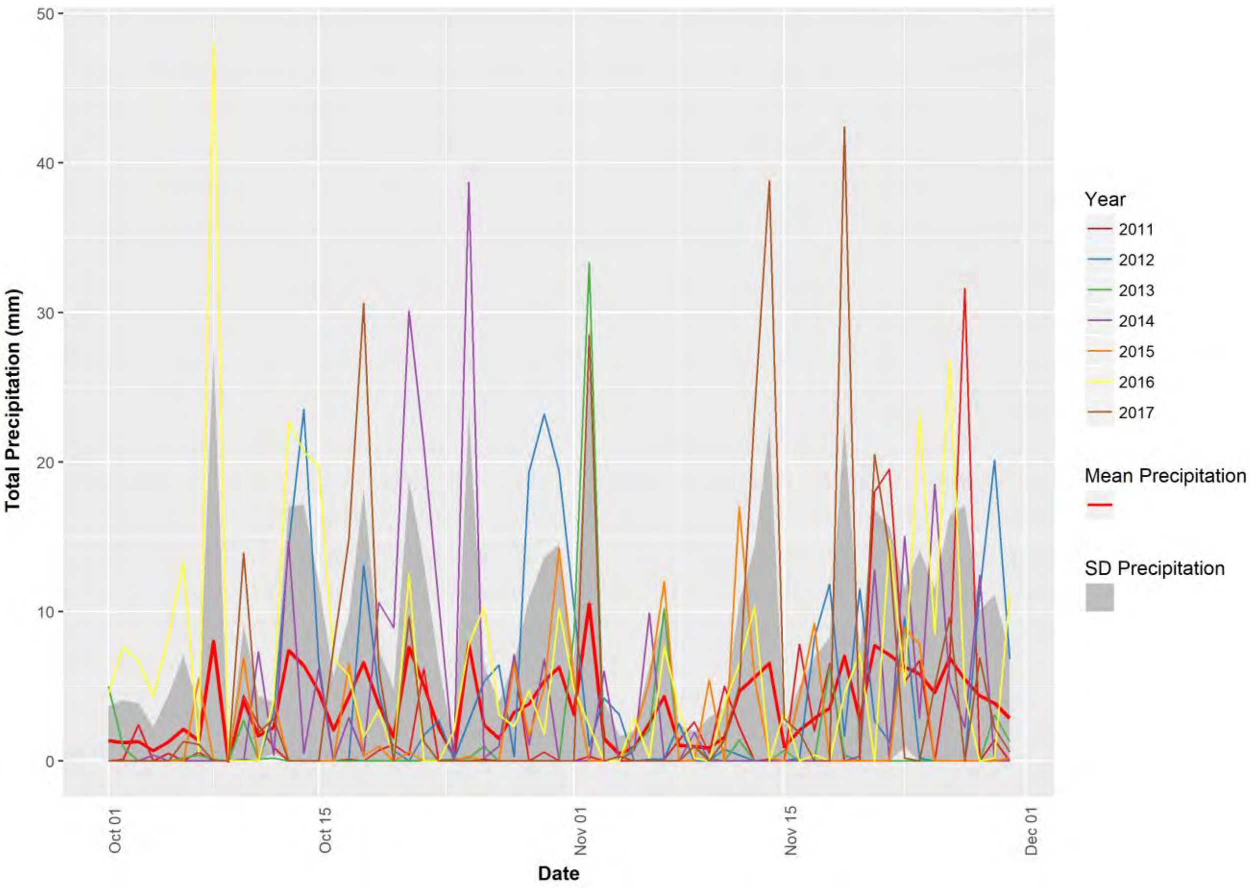

Figure A103. **Fall Rainfall at Qualicum Beach Airport.**

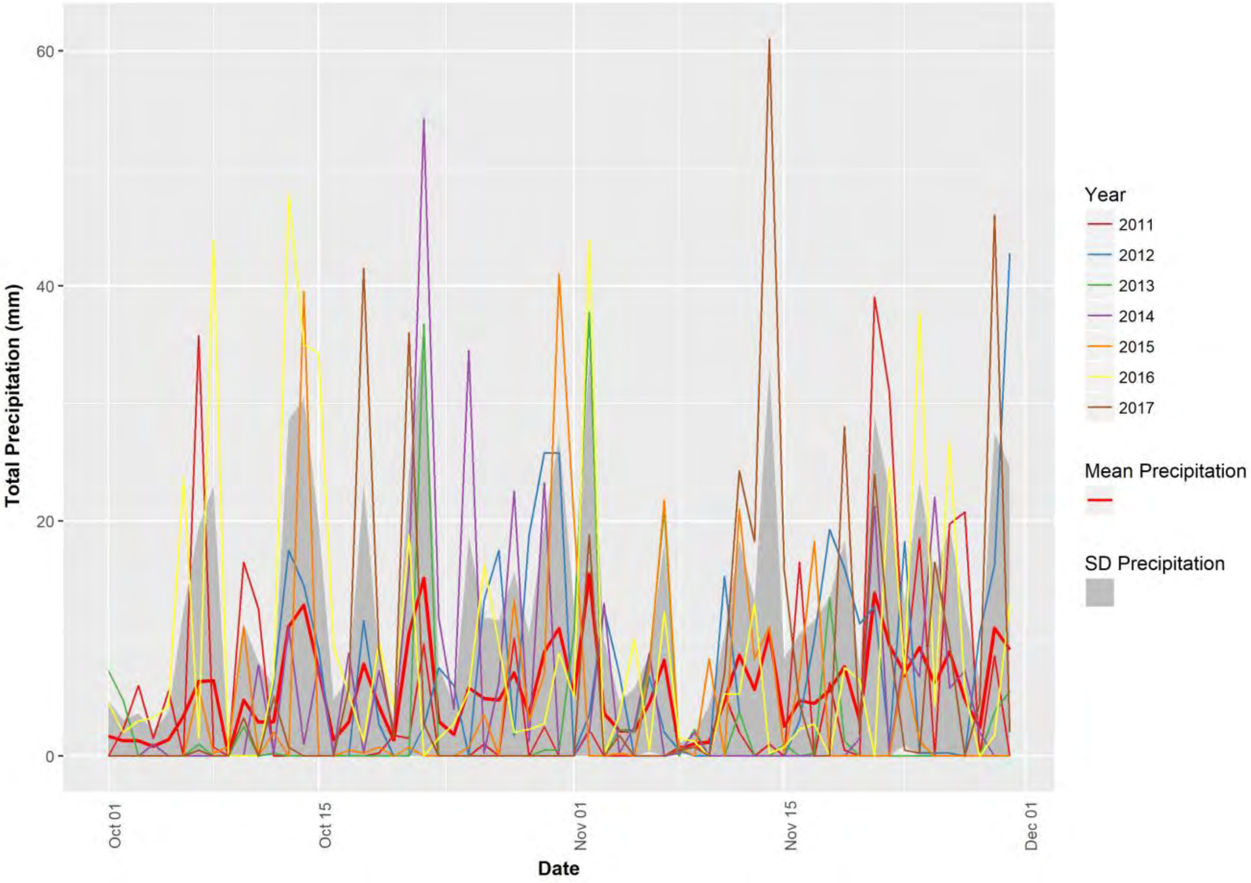

Figure A104. **Fall Rainfall at RG City Hall.**

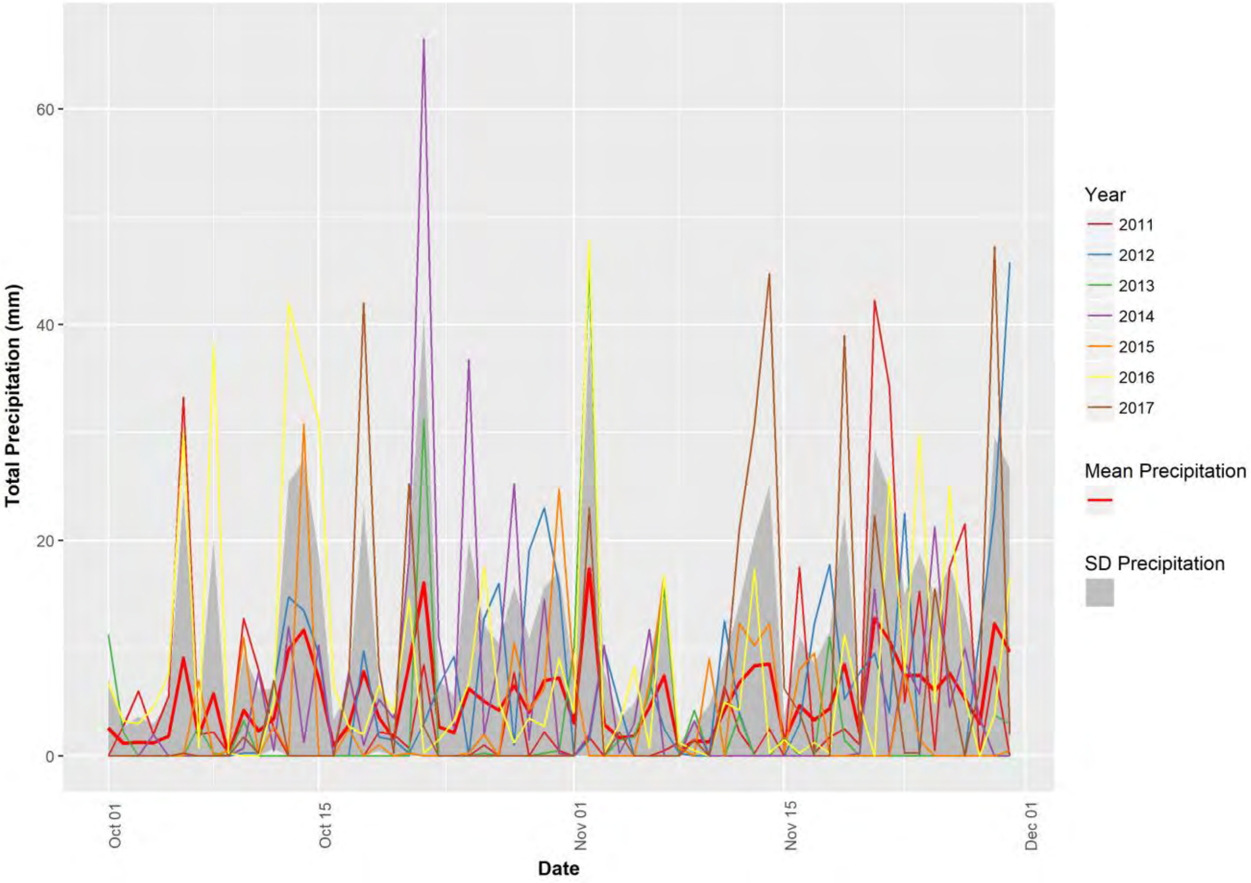

Figure A105. Fall Rainfall at RG Fire hall 3.

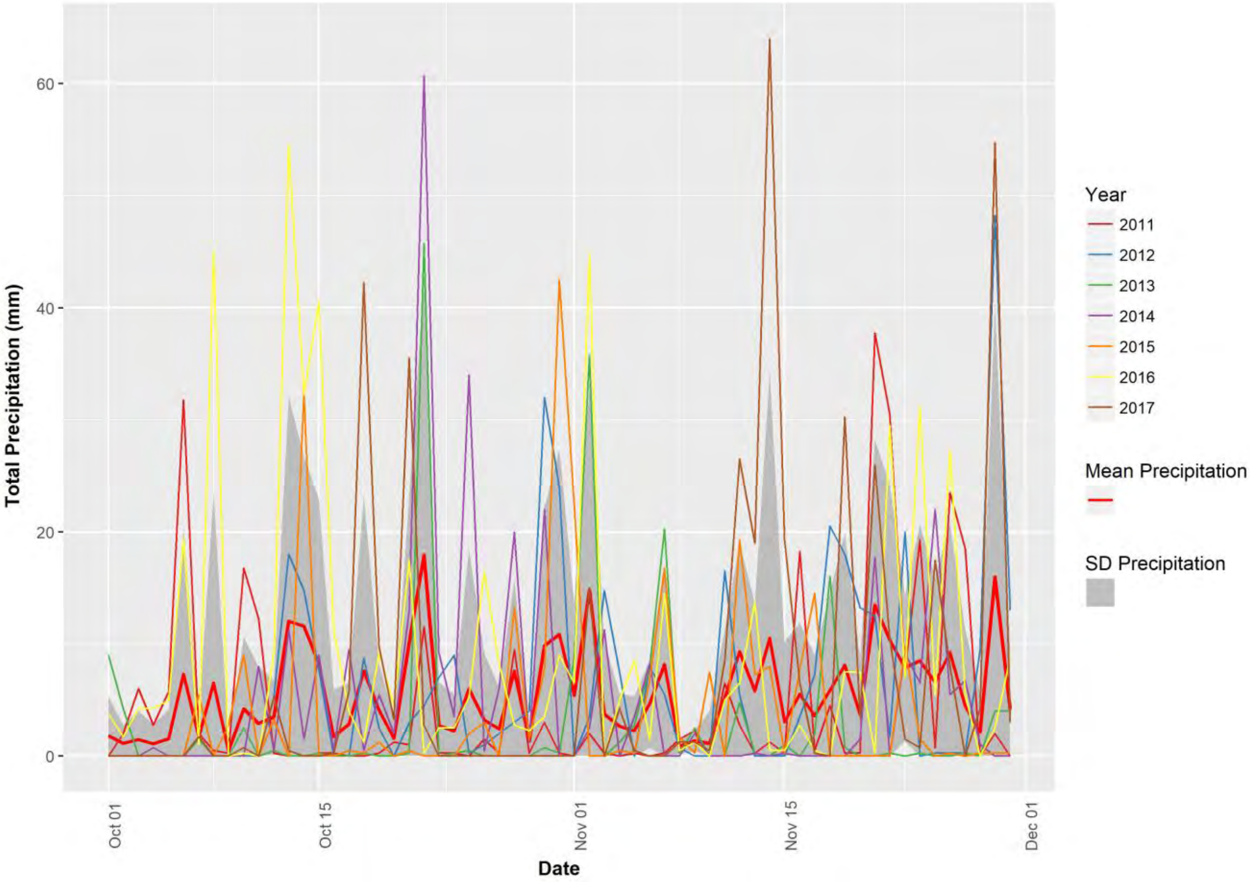

Figure A106. **Fall Rainfall at RG Fire hall 4.**

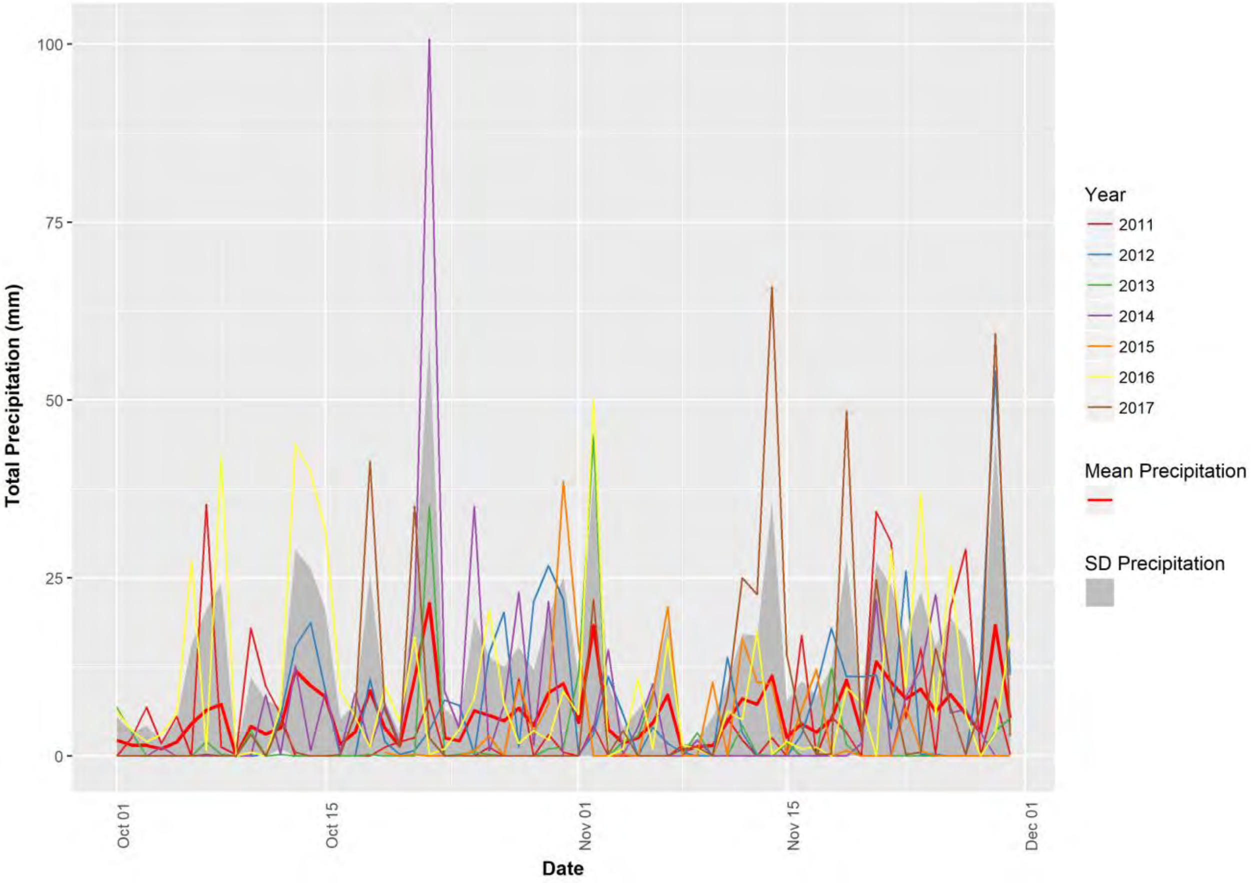

Figure A107. Fall Rainfall at RG Public Works.

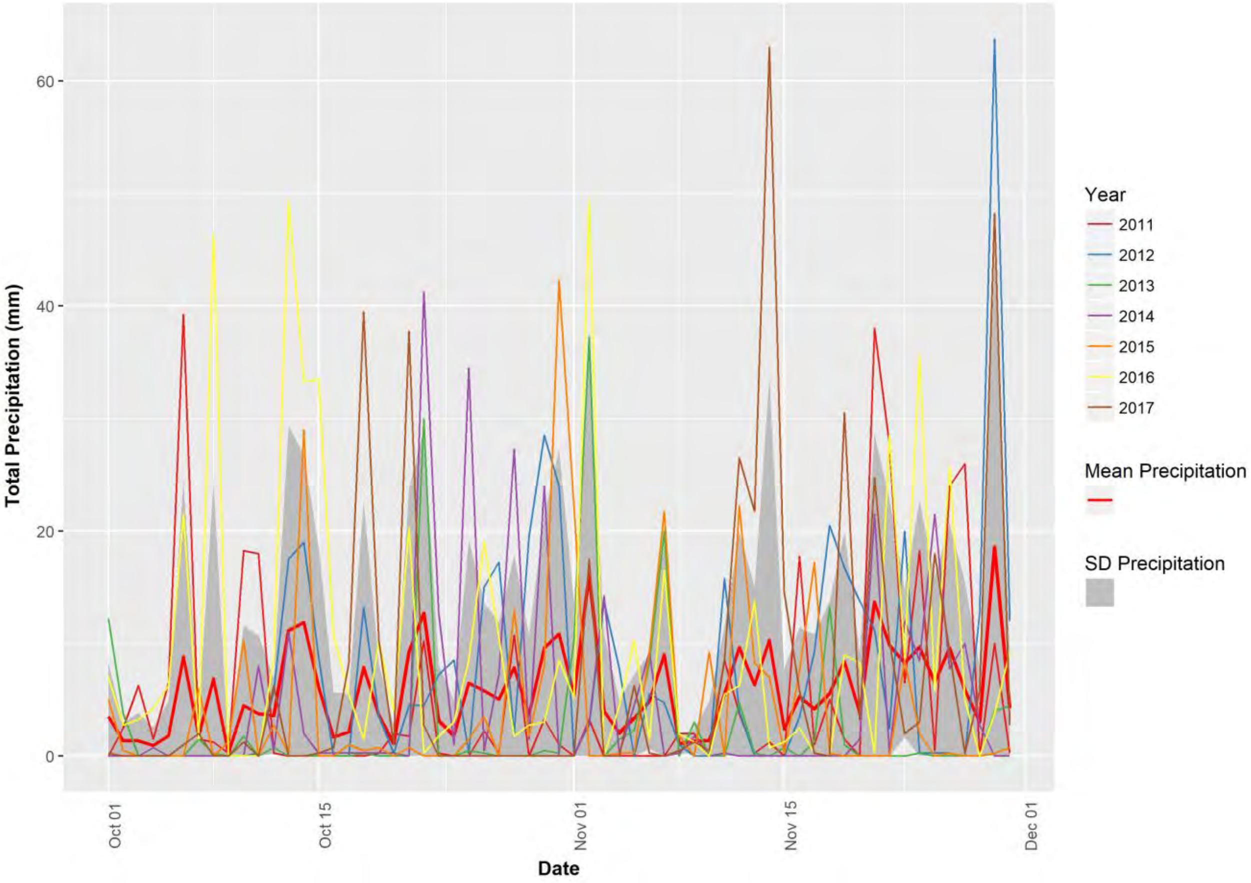

Figure A108. **Fall Rainfall at RG Reservoir.**

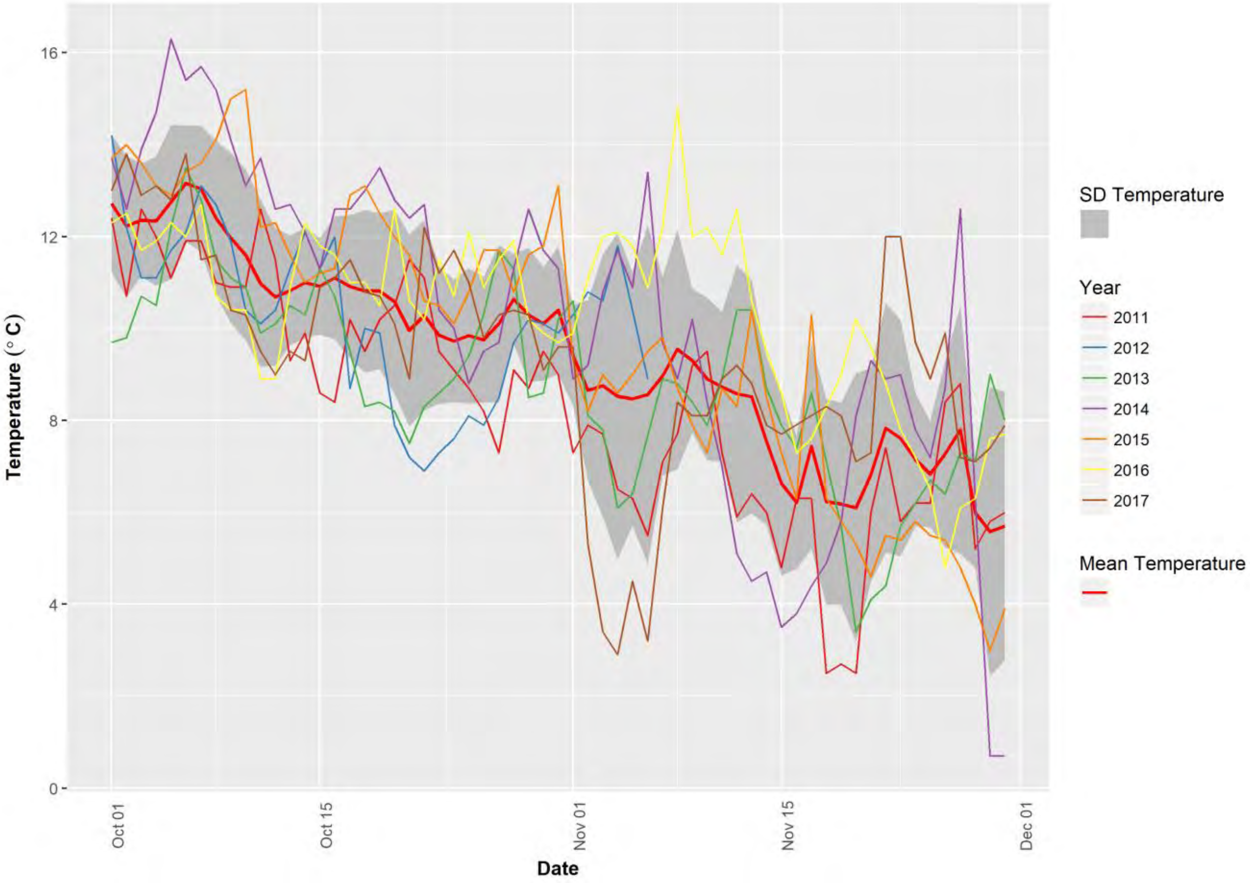

Figure A109. **Fall Temperature at Ballenas Island.**

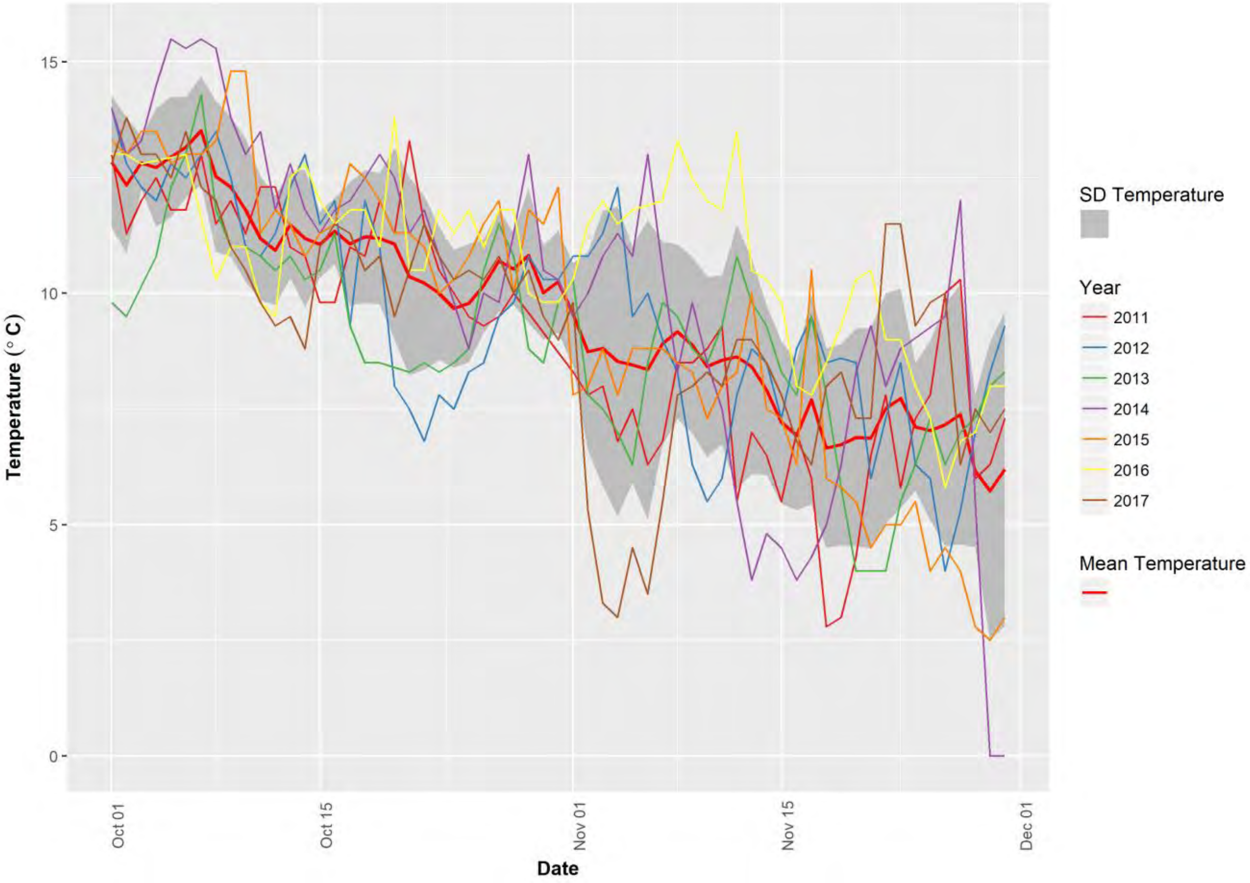

Figure A110. **Fall Temperature at Entrance Island.**

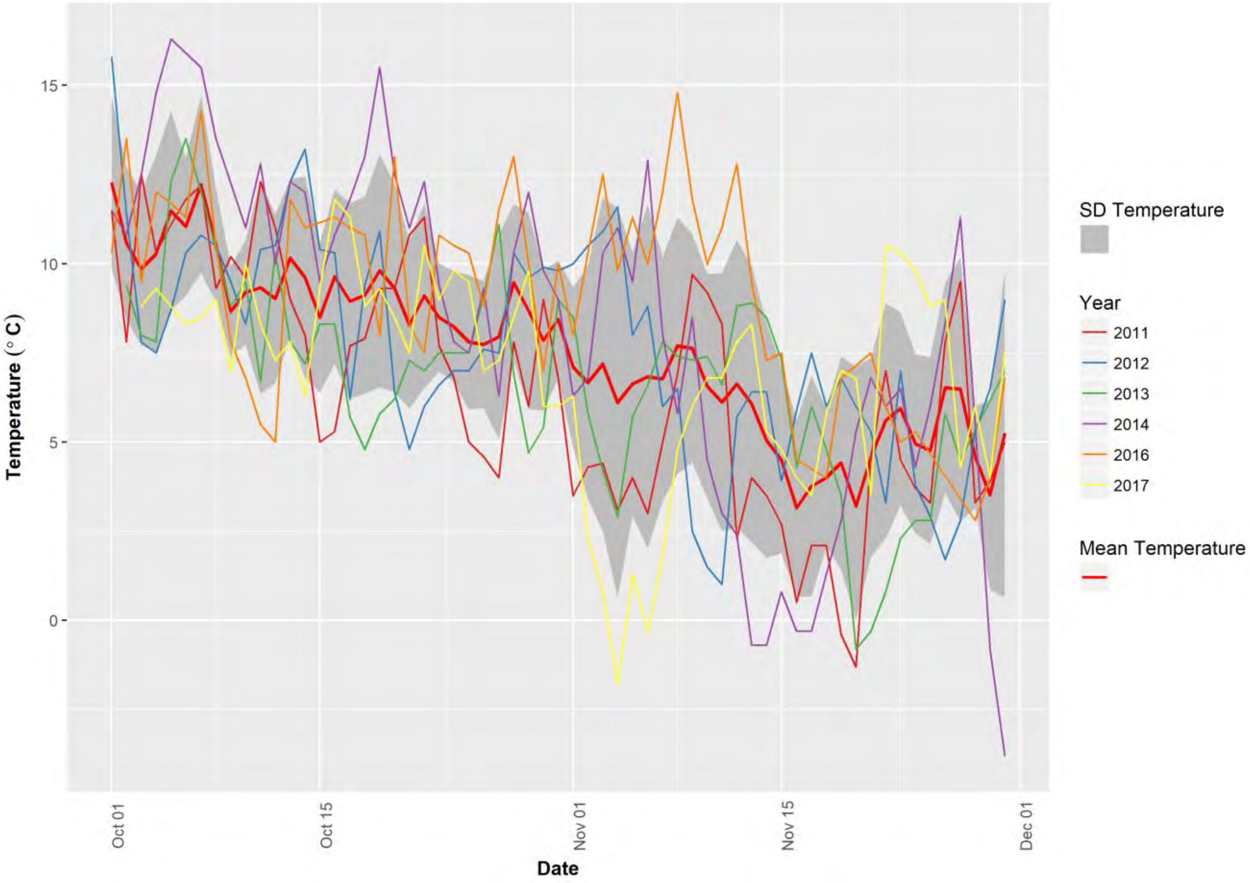

Figure A111. **Fall Temperature at Little Qualicum Hatchery.**

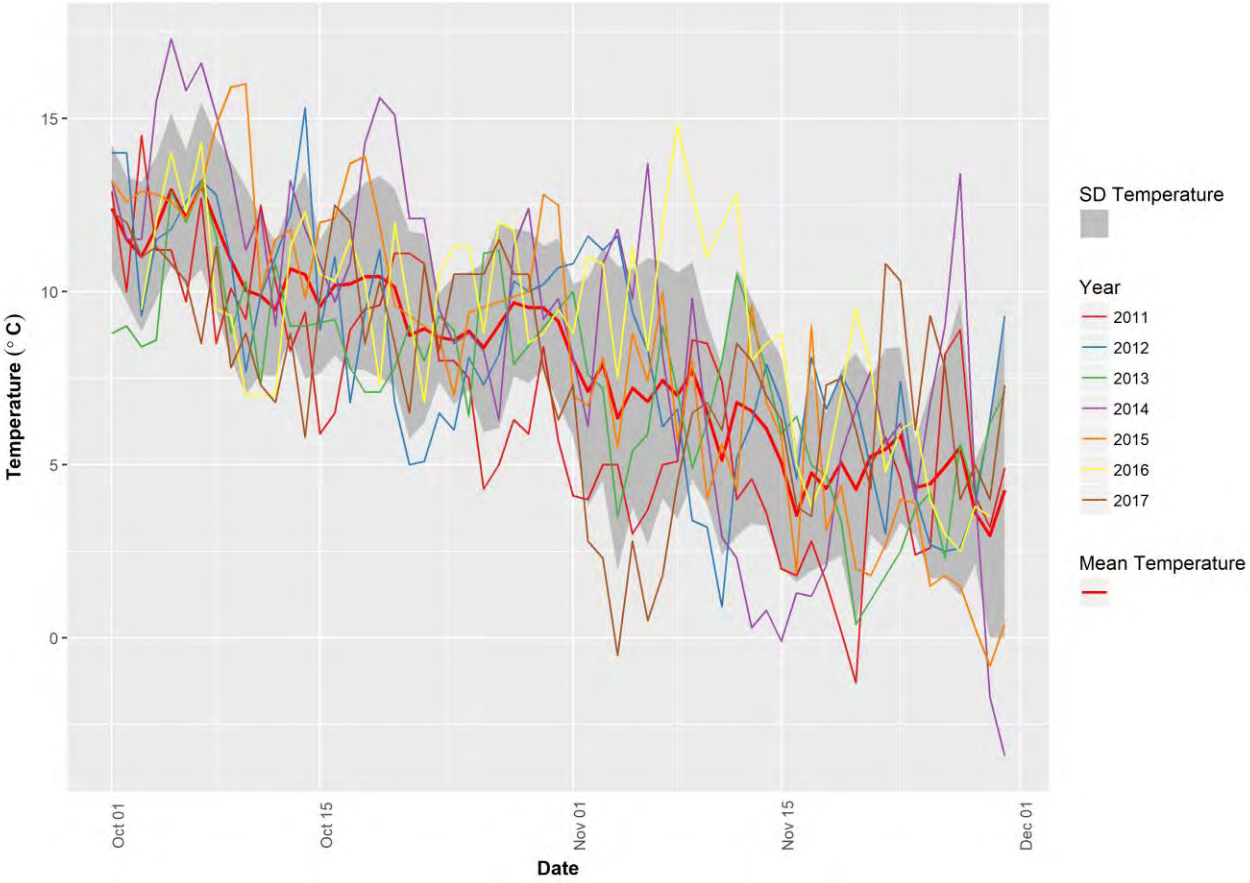

Figure A112. **Fall Temperature at Nanimo A.**

Figure A113. Fall Temperature at Cox Lake, Port Alberni.

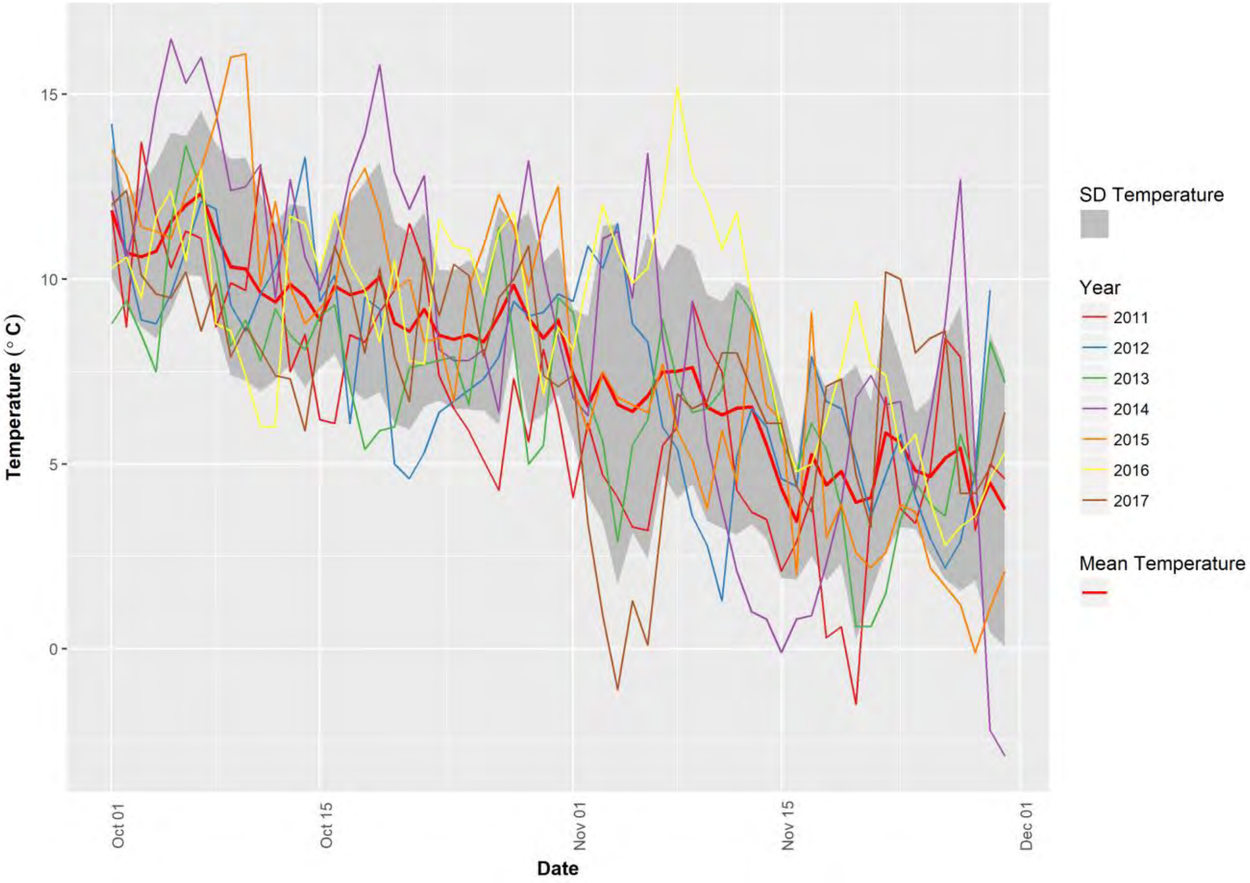

Figure A114. **Fall Temperature at Qualicum Beach Airport.**

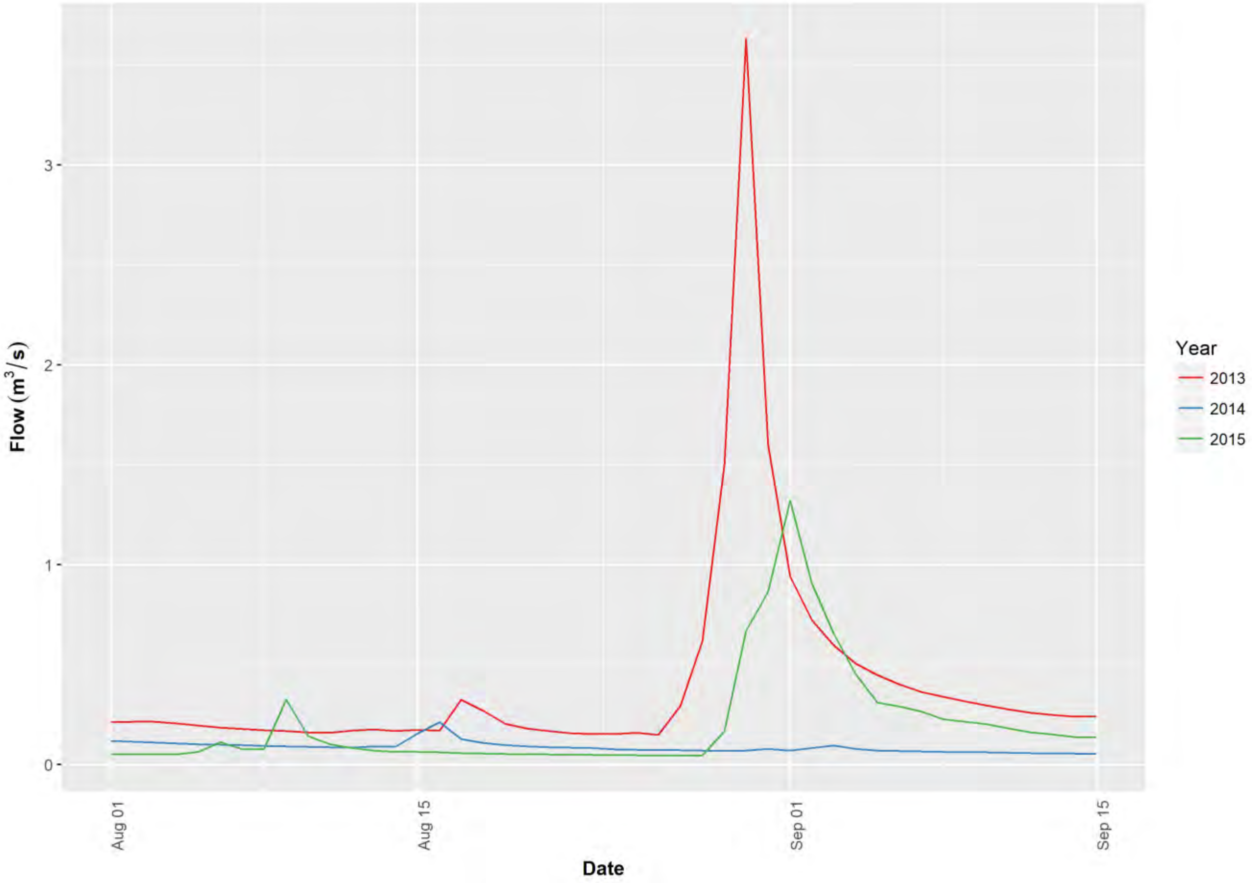

Figure A115. **Summer Flow data from Rosewall Creek 75 m downstream of Hwy 19a Bridge.**

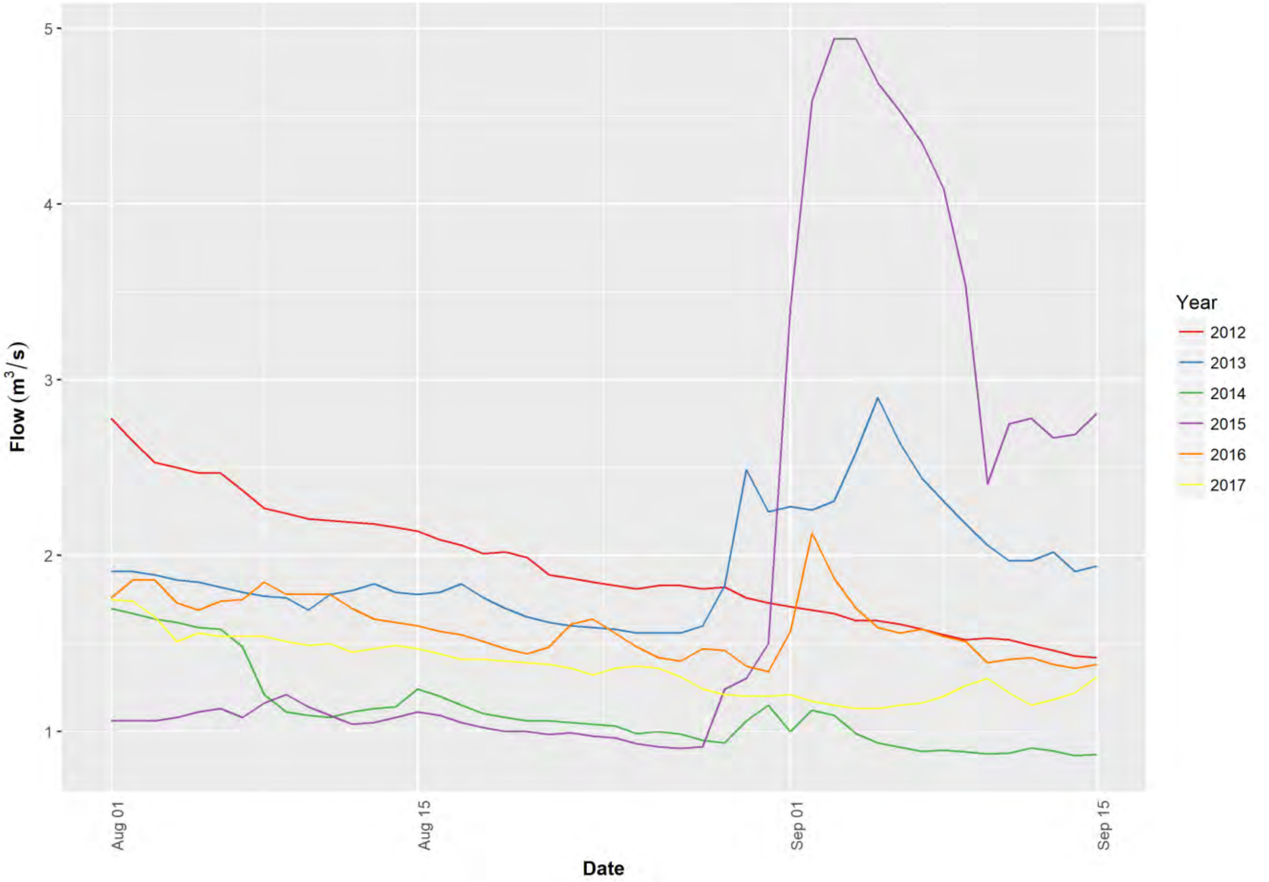

Figure A116. **Summer Flow data from Little Qualicum River near Qualicum Beach.**

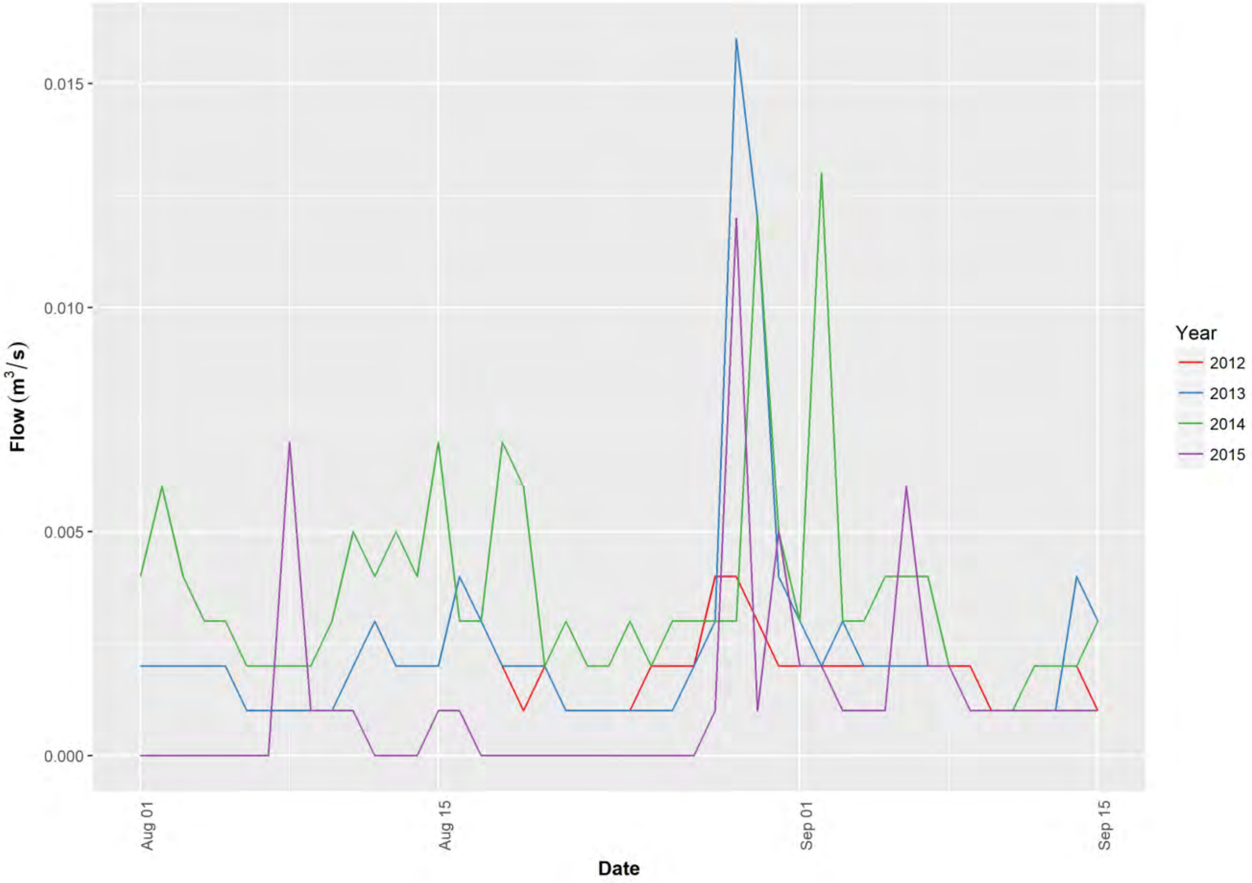

Figure A117. Summer Flow data from Grandon Creek 35 m upstream of Old Island Highway 19a.

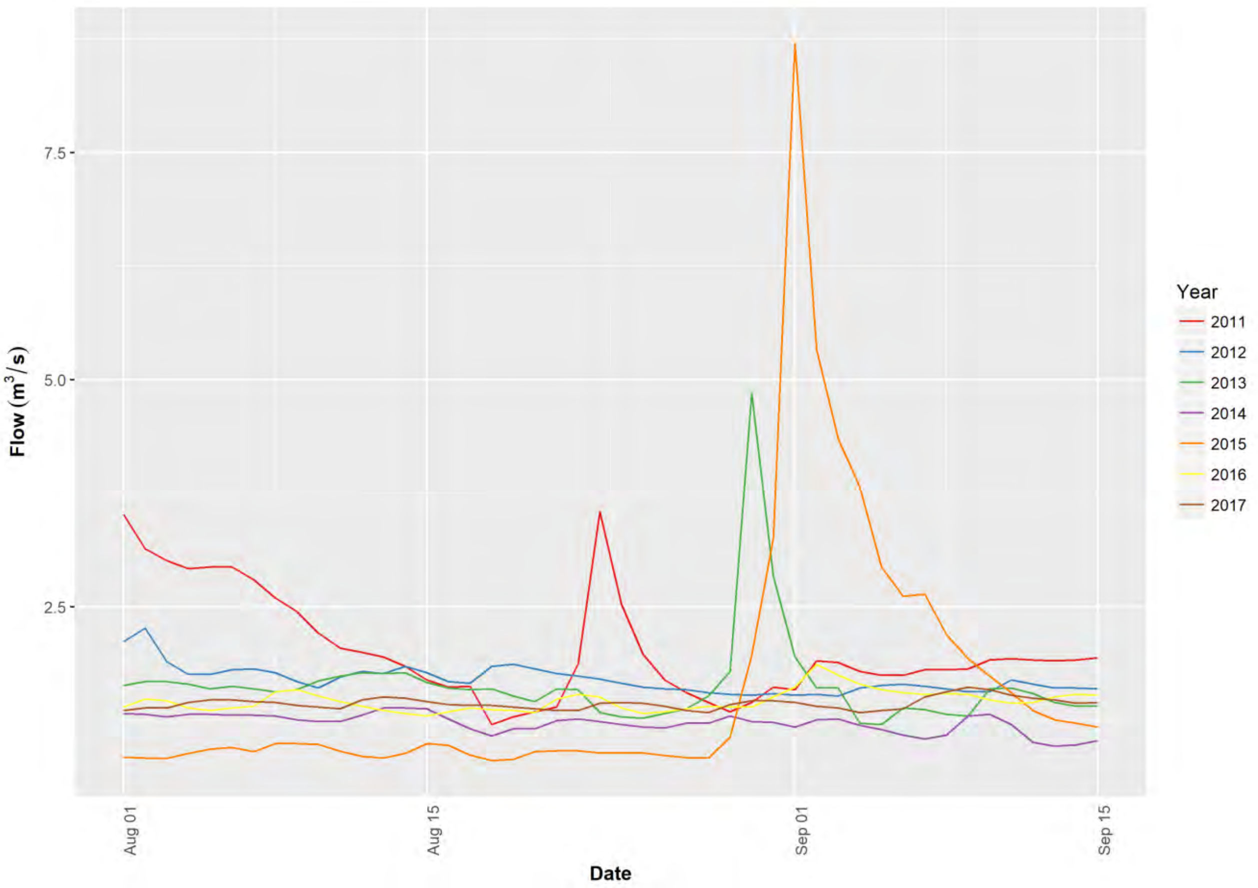

Figure A118. **Summer Flow data from Englishman River Near Parksville.**

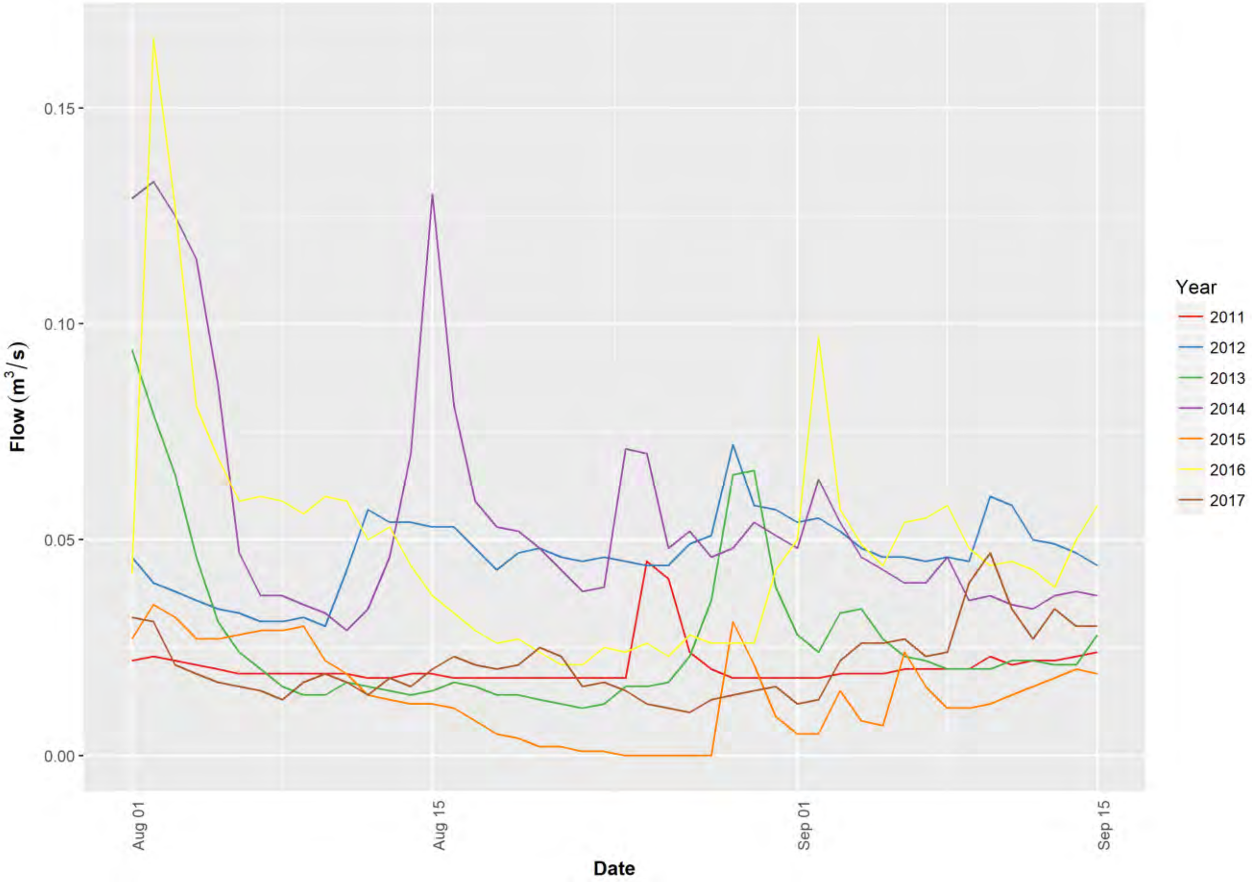

Figure A119. **Summer Flow data from Millstone River at Nanaimo.**

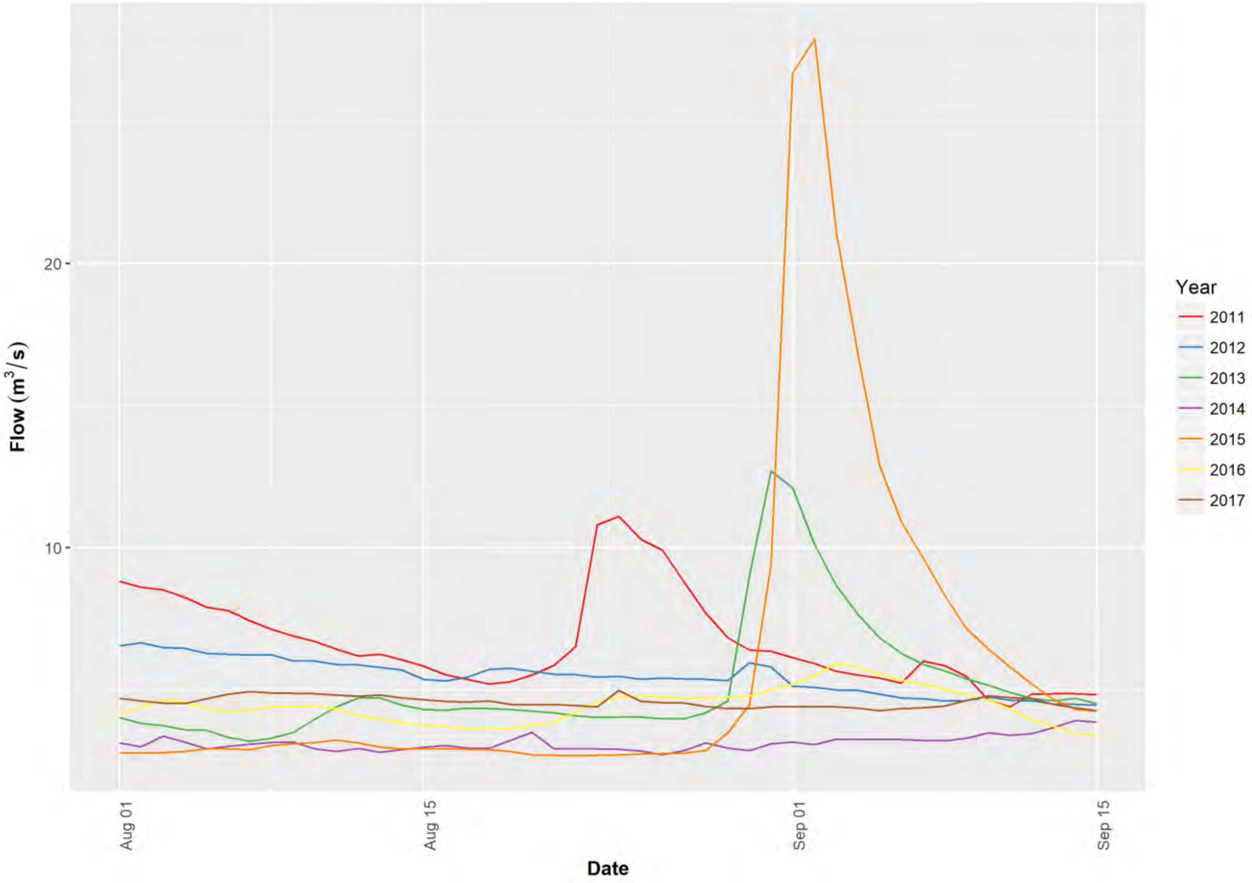

Figure A120. **Summer Flow data from Nanaimo River Near Cassidy.**

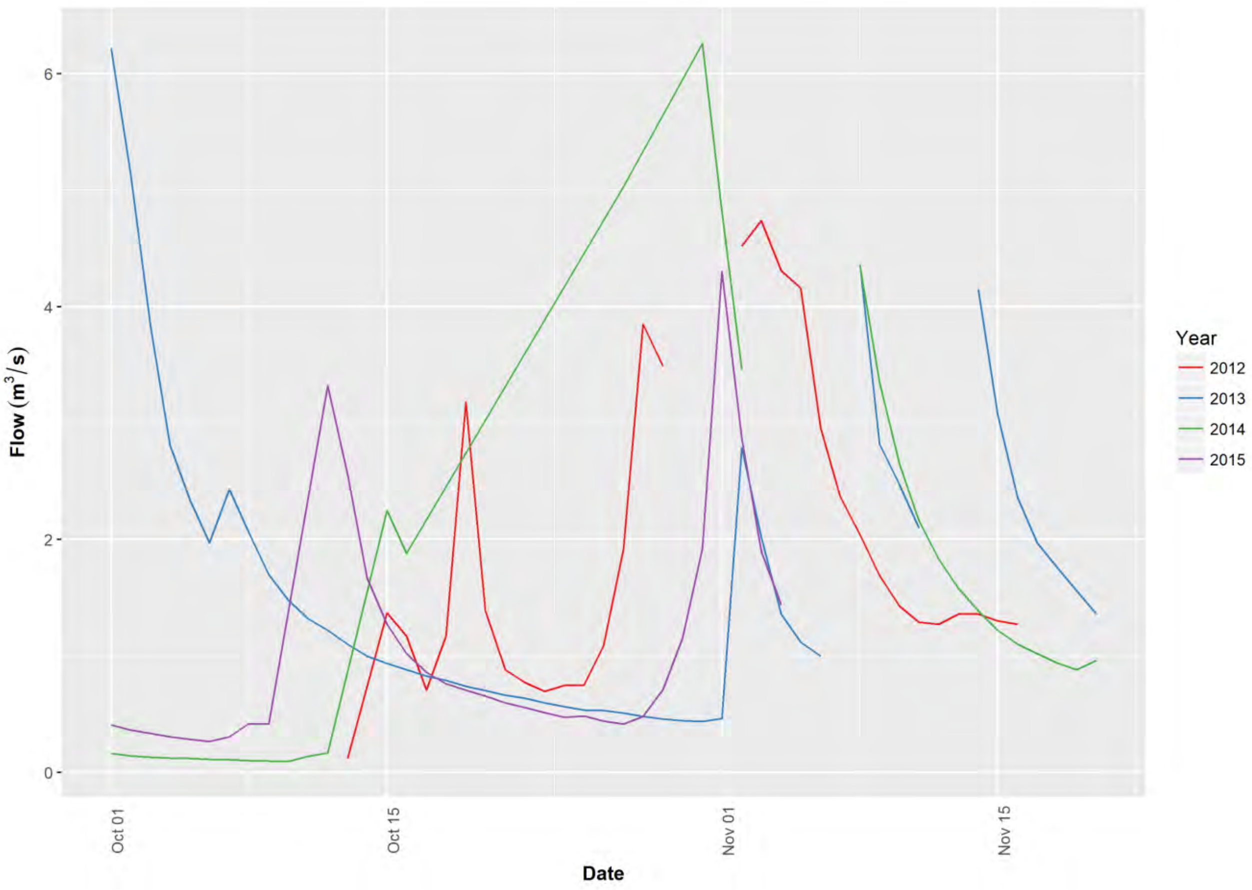

Figure A121. **Fall Flow data from Rosewall Creek 75 m downstream of Hwy 19a Bridge.**

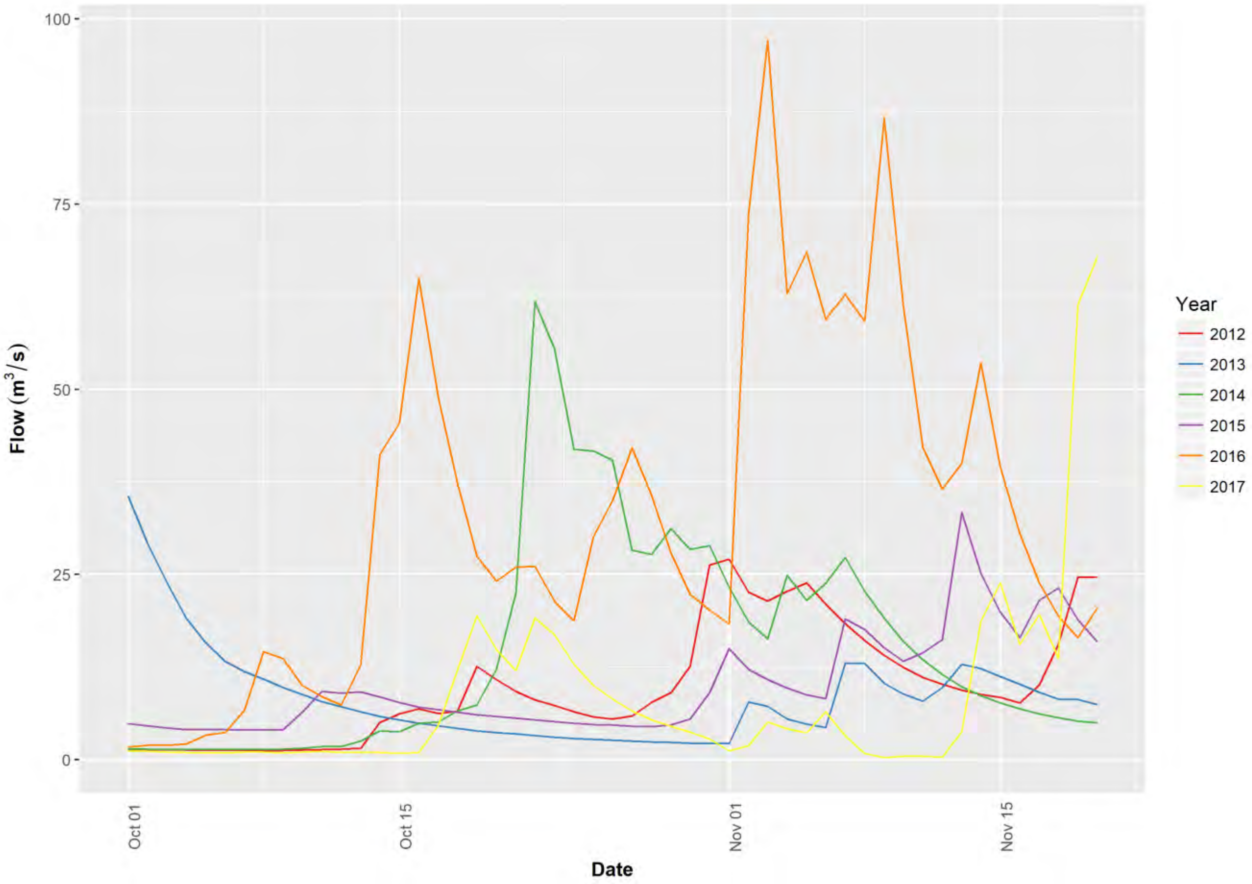

Figure A122. Fall Flow data from Little Qualicum River near Qualicum Beach.

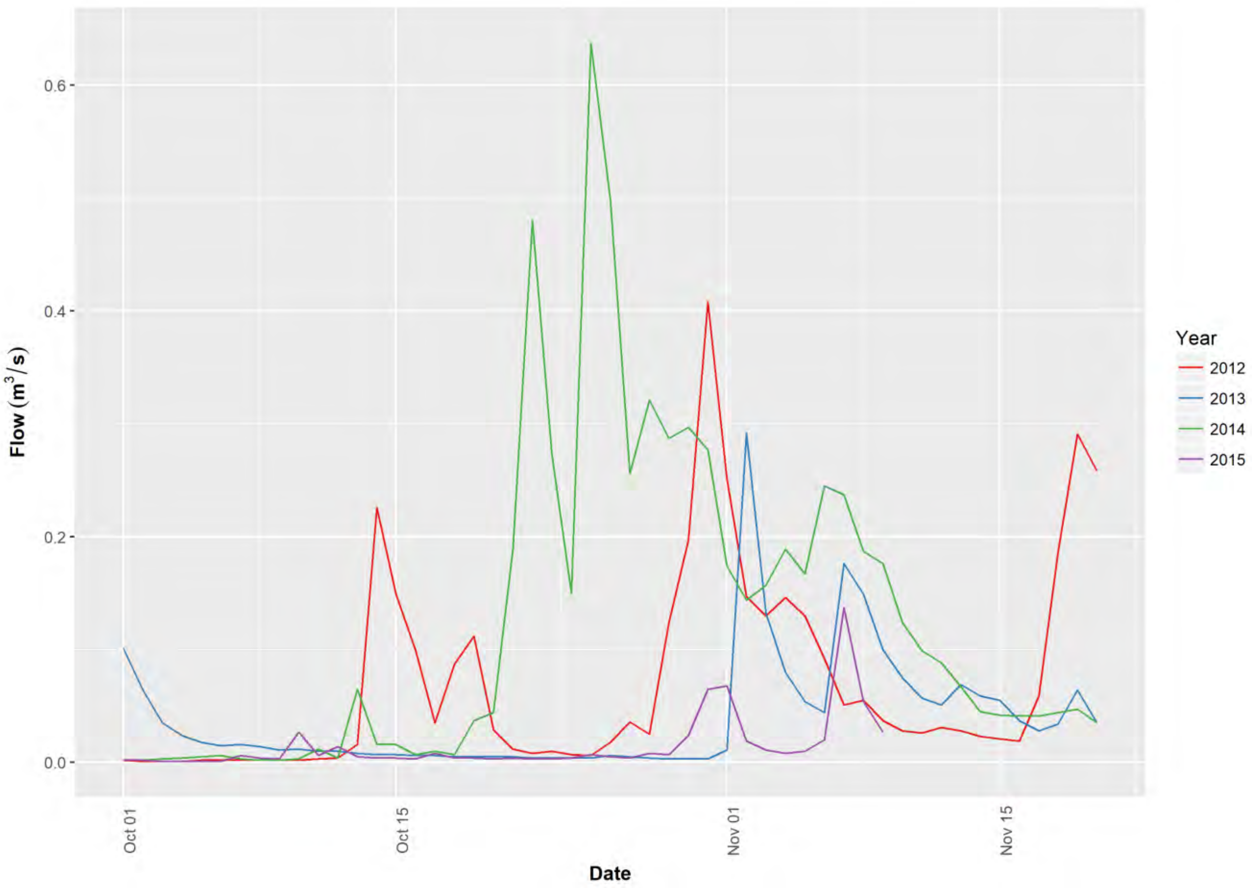

Figure A123. Fall Flow data from Grandon Creek 35 m upstream of Old Island Highway 19a.

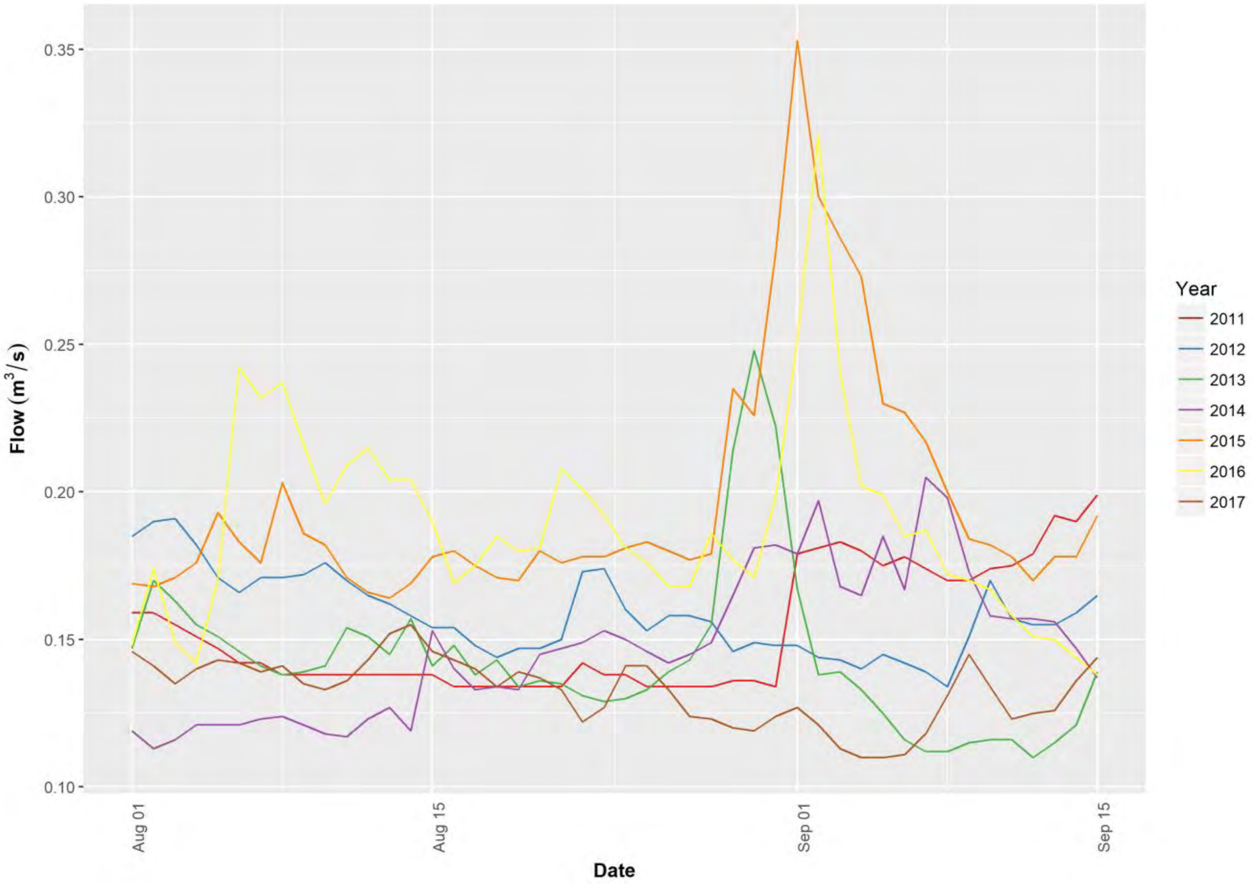

Figure A124. **Summer Flow data from Nile River Near Bowser.**

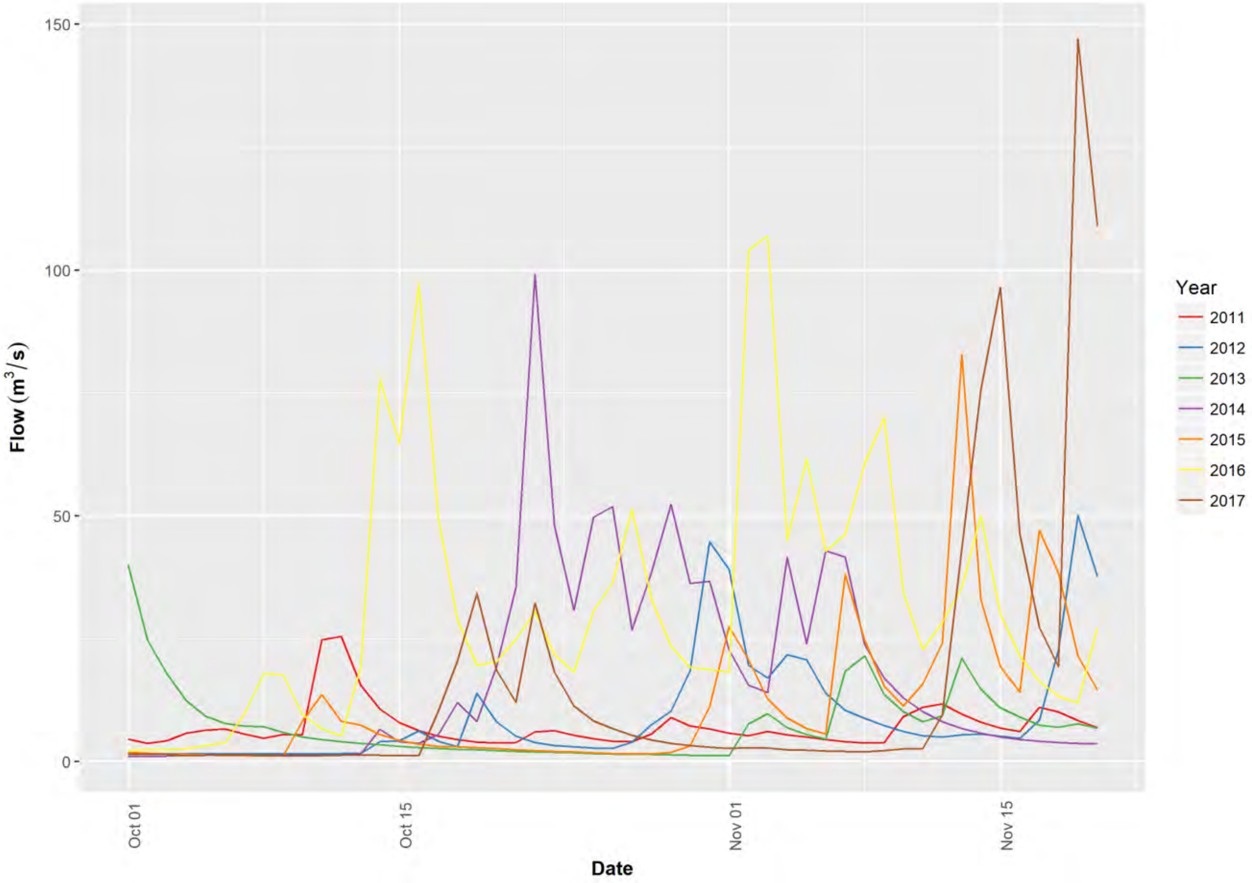

Figure A125. Fall Flow data from Englishman River Near Parksville.

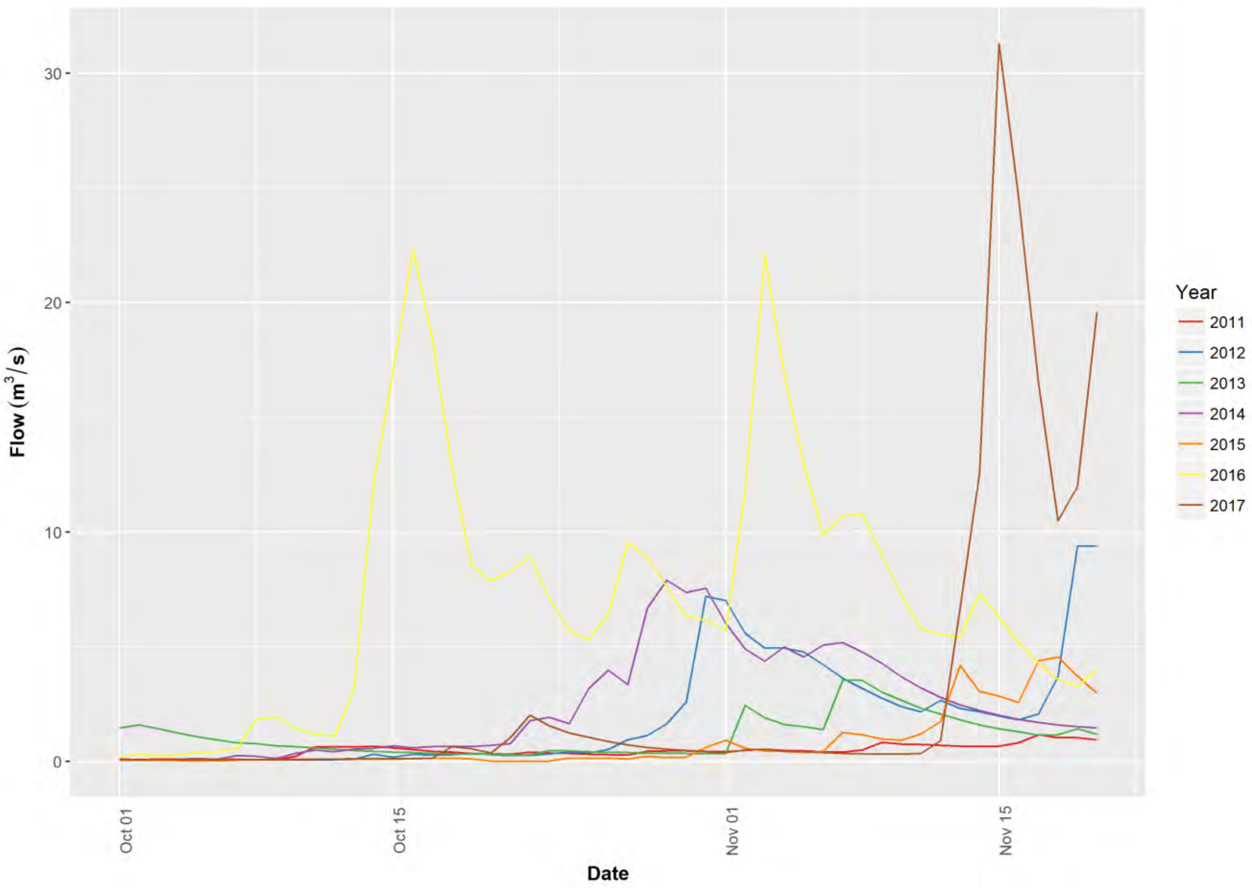

Figure A126. **Fall Flow data from Millstone River Near Nanaimo.**

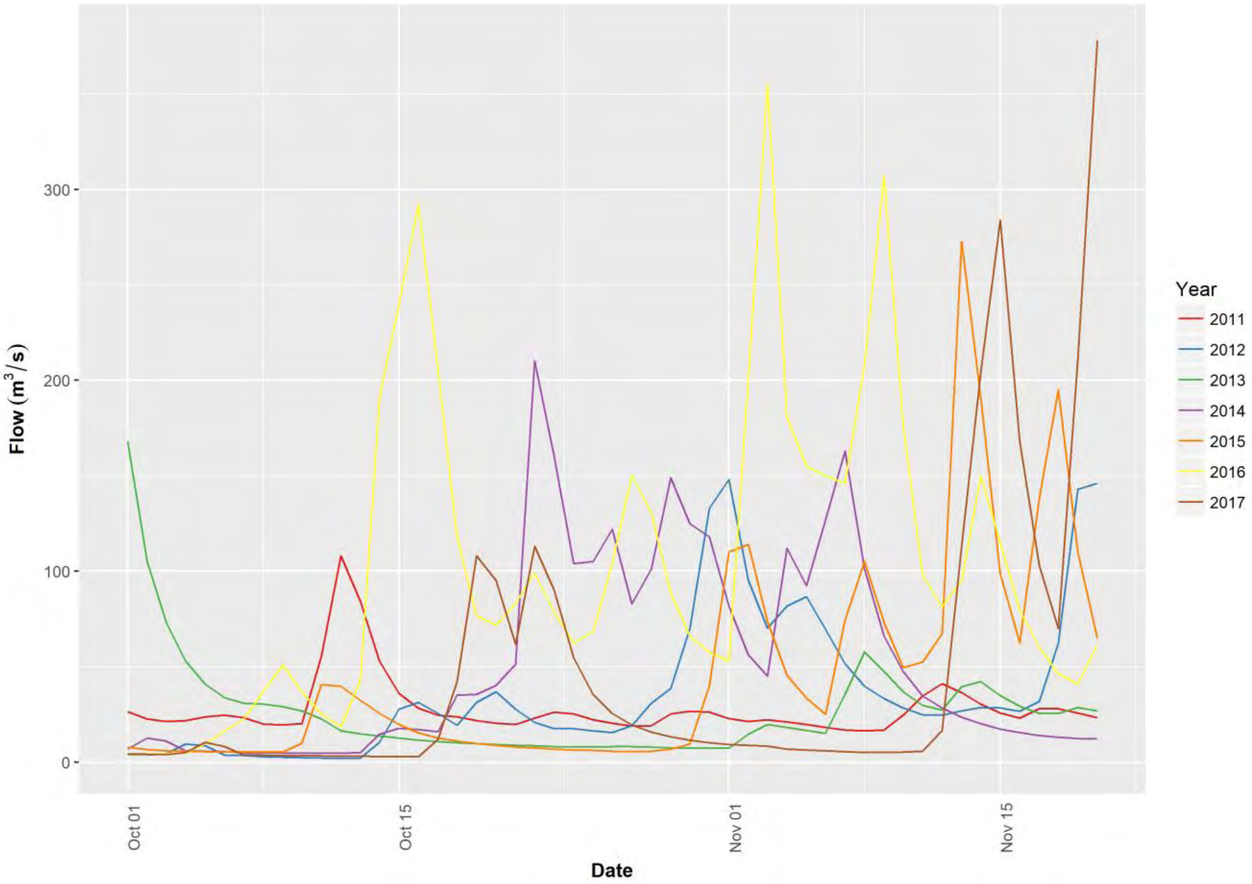

Figure A127. **Fall Flow data from Nanaimo River Near Cassidy.**

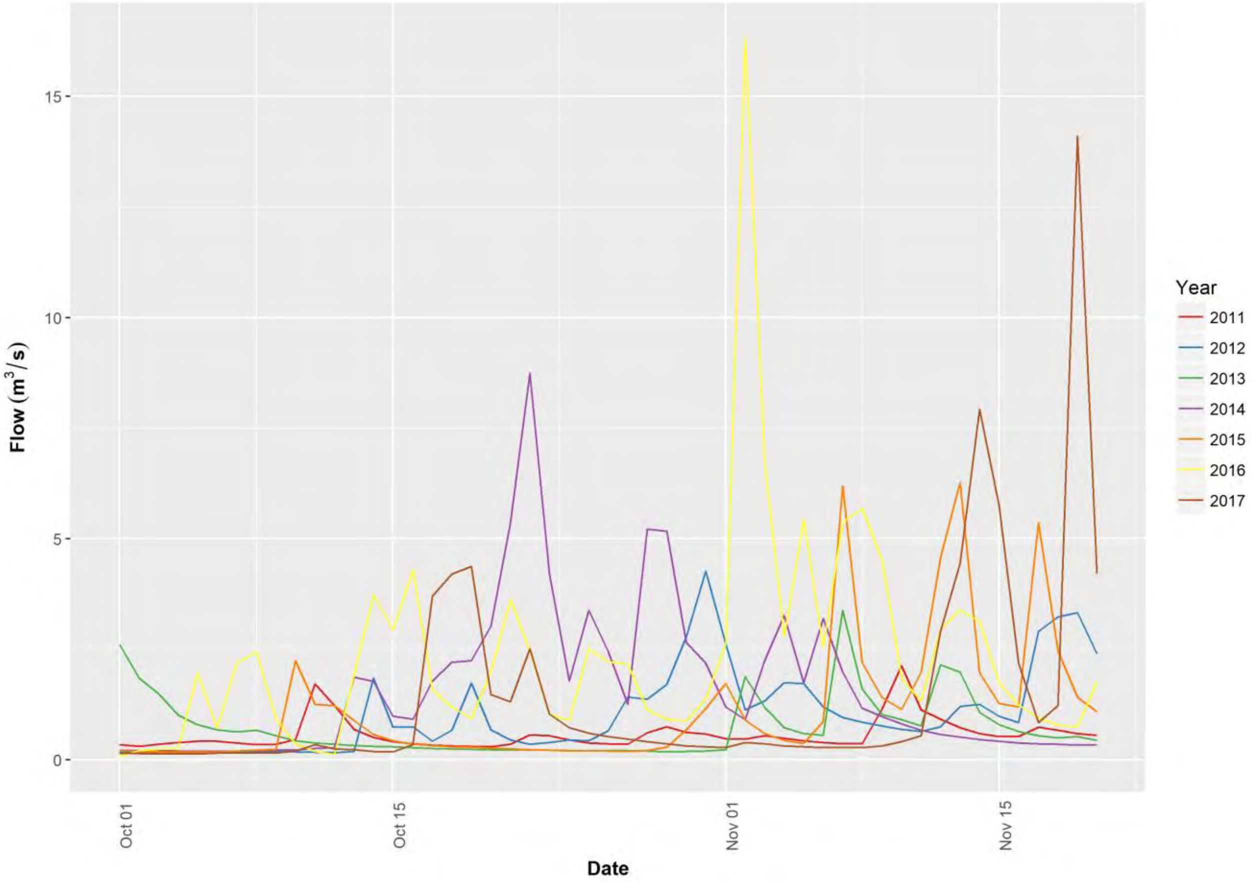

Figure A128. **Fall Flow data from Nile Creek Near Bowser.**

Appendix F Dissolved Oxygen and Temperature Graphs

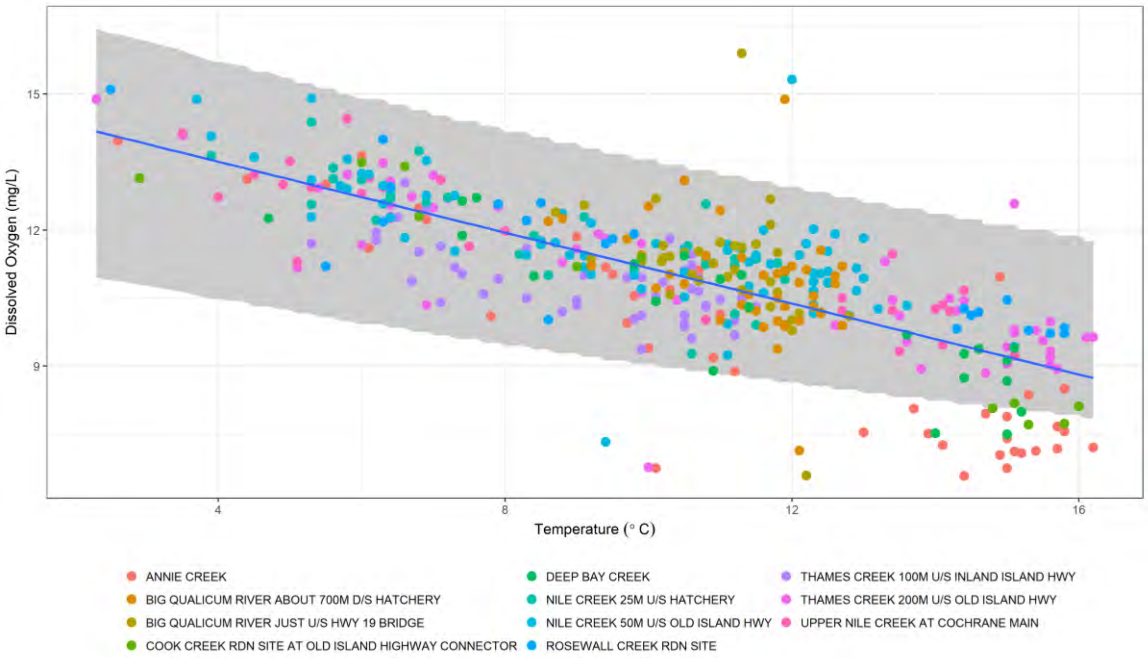

Figure A129. Big Qualicum Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

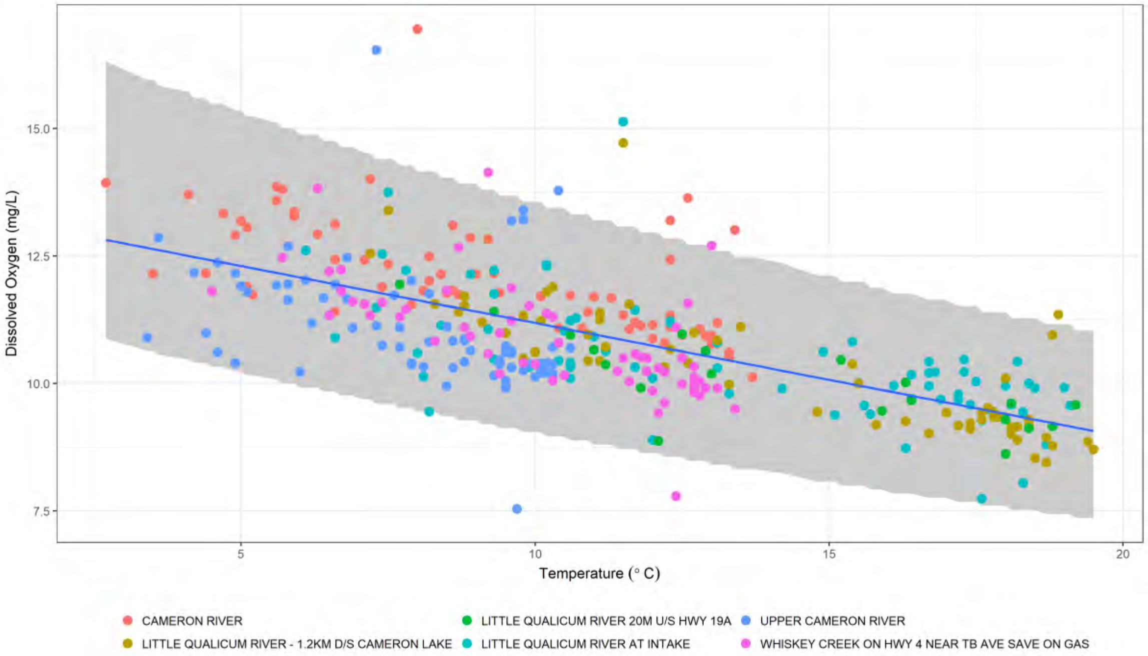

Figure A130. Little Qualicum Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

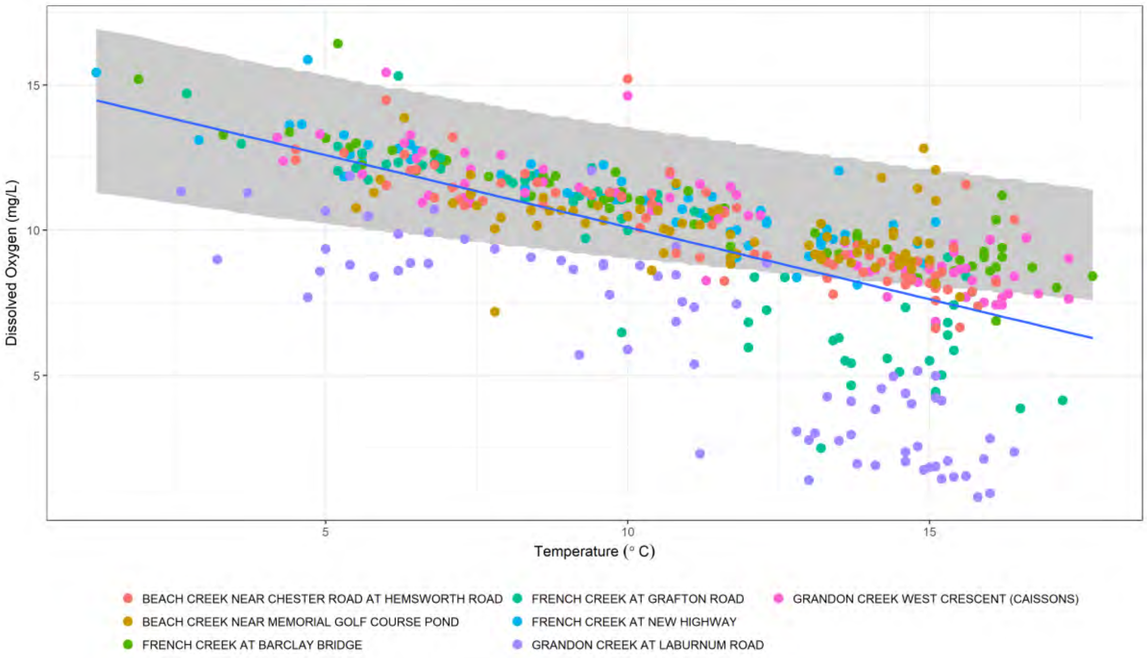

Figure A131. French Creek Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

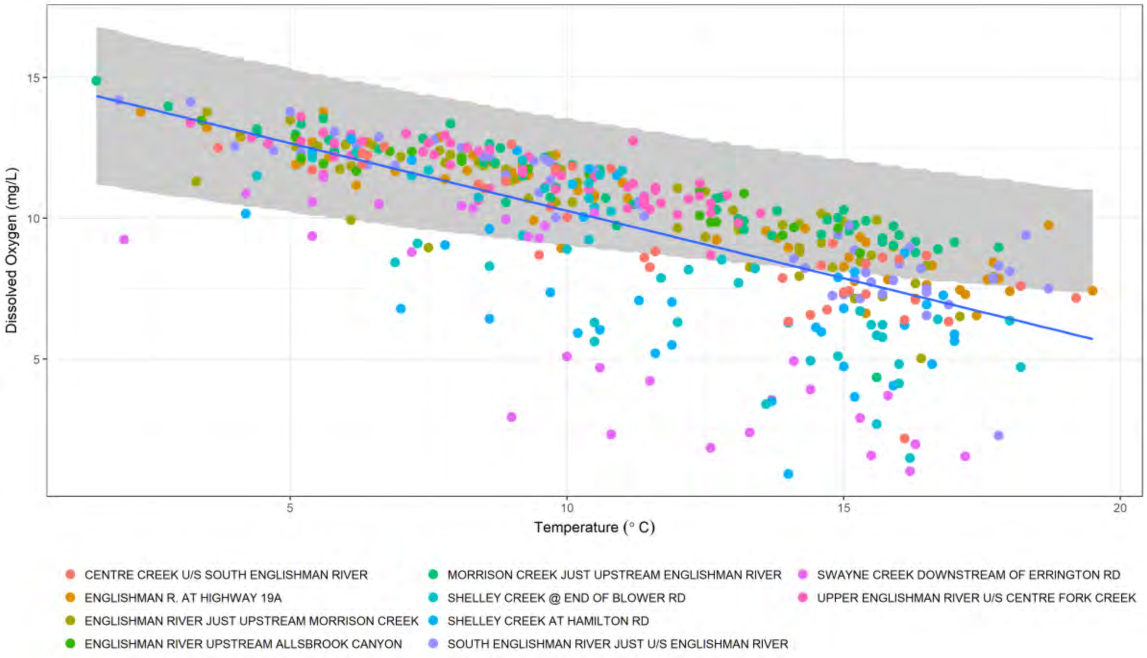

Figure A132. Englishman River Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

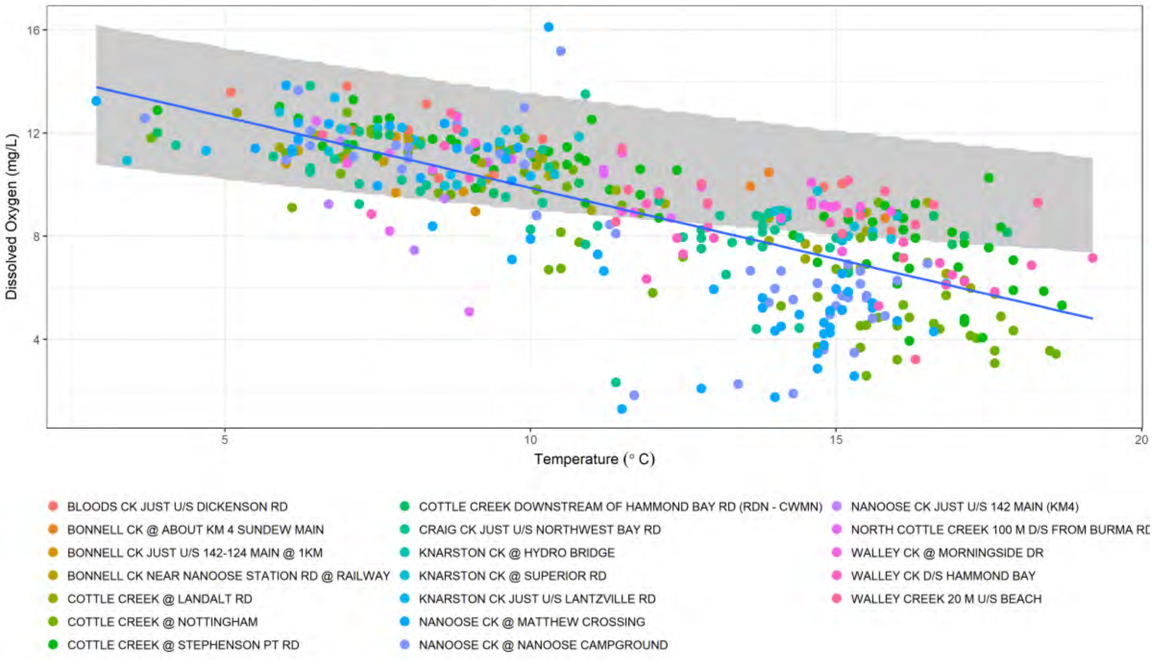

Figure A133. South Wellington to Nanoose Water Region (1 of 2) Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

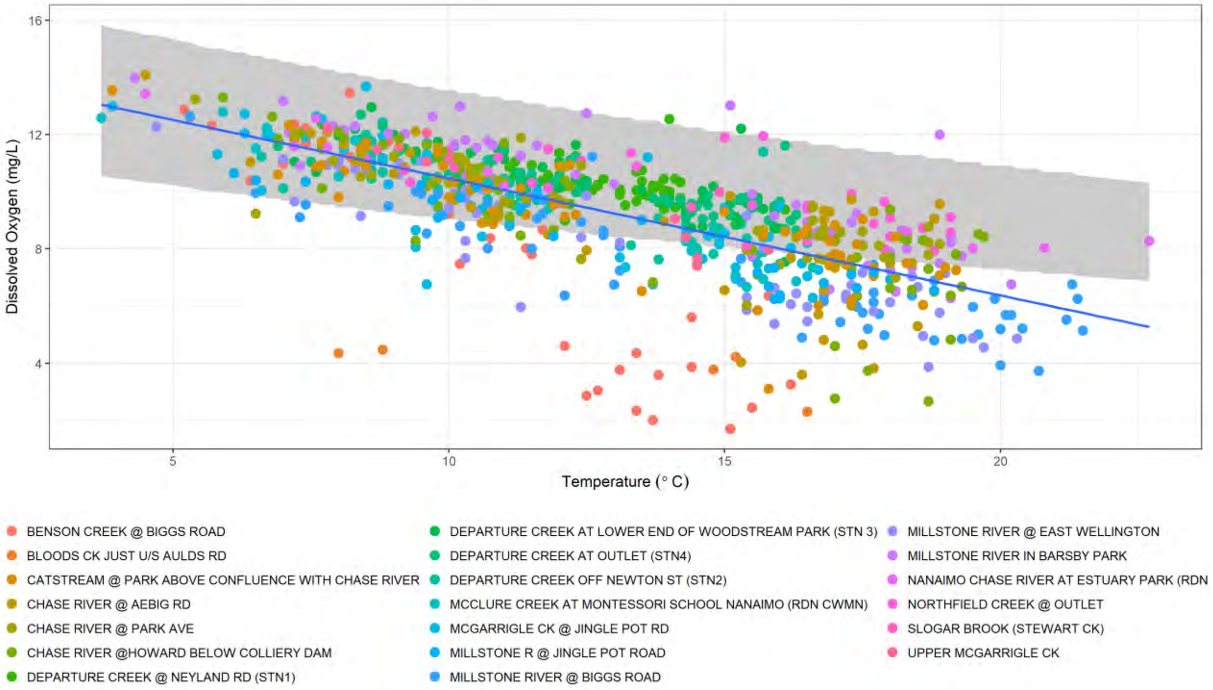

Figure A134. South Wellington to Nanoose Water Region (2 of 2) Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

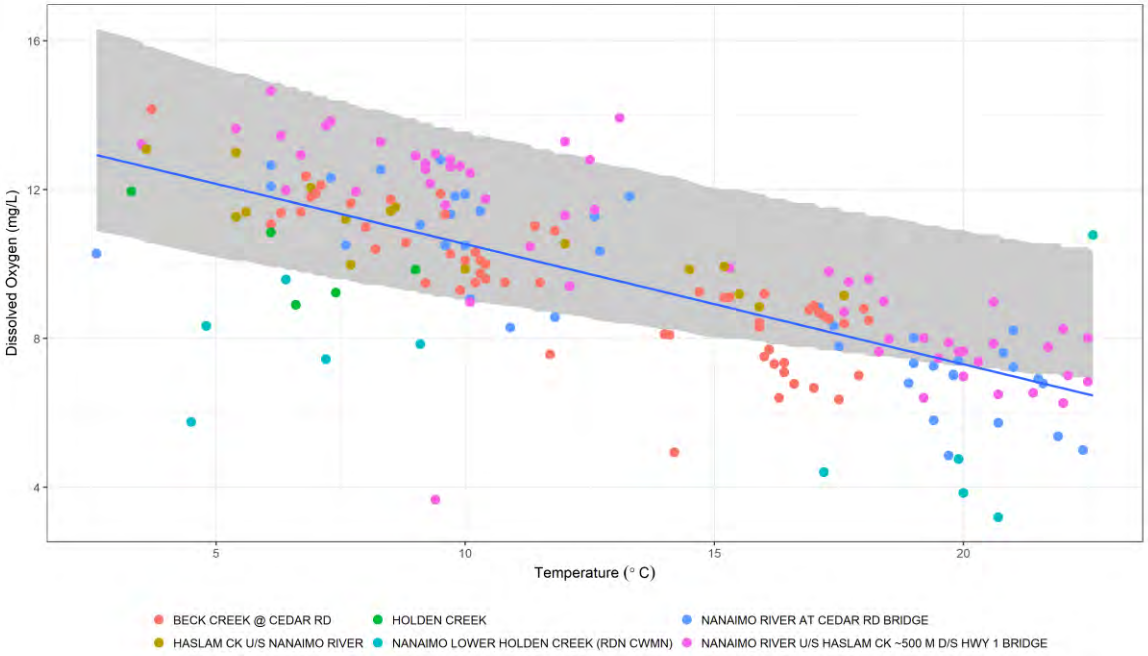

Figure A135. Nanaimo River Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

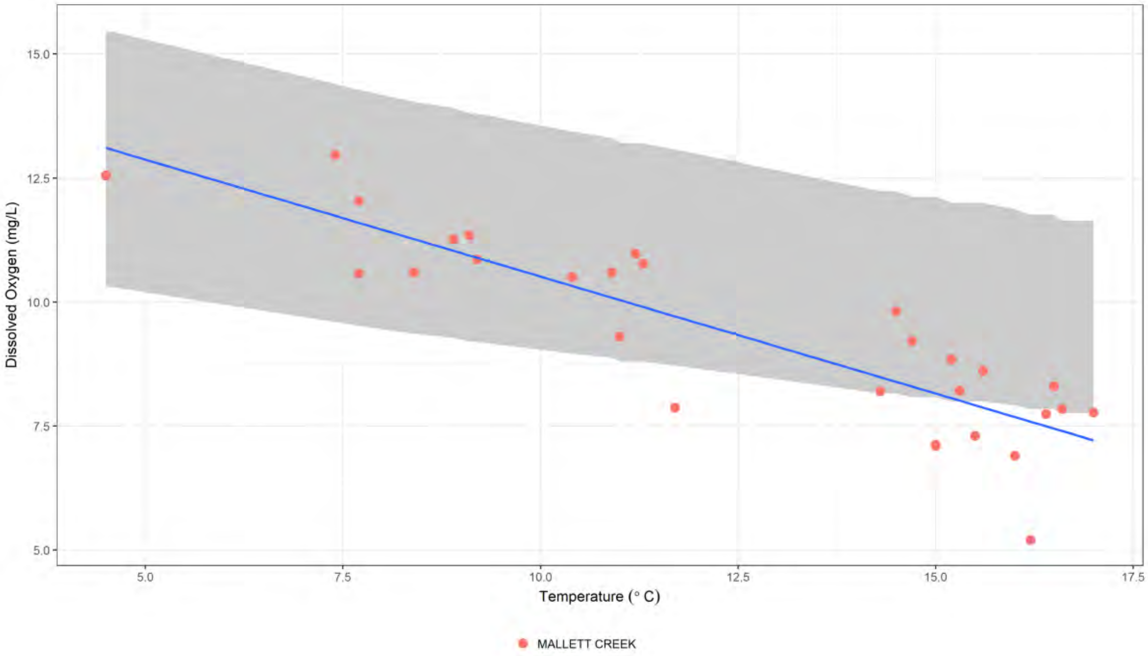

Figure A136. Gabriola Island Water Region Dissolved Oxygen and Water Temperature data for all available CWMN data. The grey shaded areas depicts ±20% of oxygen saturation.

Appendix G Trend Analysis Results

Table A2 Summary of seasonal Mann-Kendall trend analysis by Water Region and site including Kendall's tau coefficient (strength and direction of relationship), p-value (<0.05 is statistically significant) and sample size (n).

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E286553	Cond	-0.19	0.396	14	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286553	DO	-0.143	0.524	14	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286553	Temp	0.333	0.137	14	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E286553	Turbidity	0.19	0.396	14	NILE CREEK 50M U/S OLD ISLAND HWY	Big Qualicum
E220635	Cond	-0.19	0.396	14	CAMERON RIVER	Little Qualicum
E220635	DO	0.0952	0.671	14	CAMERON RIVER	Little Qualicum
E220635	Temp	0.381	0.0893	14	CAMERON RIVER	Little Qualicum
E220635	Turbidity	0.19	0.396	14	CAMERON RIVER	Little Qualicum
E256394	Cond	-0.238	0.288	14	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E256394	DO	-0.238	0.288	14	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E256394	Temp	0.333	0.137	14	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E256394	Turbidity	0.714	0.00144	14	LITTLE QUALICUM RIVER AT INTAKE	Little Qualicum
E268993	Cond	-0.467	0.0629	12	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E268993	DO	0.333	0.184	12	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E268993	Temp	0	1	12	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E268993	Turbidity	0.0667	0.79	12	LITTLE QUALICUM RIVER - 1.2KM D/S CAMERON LAKE	Little Qualicum
E285669	Cond	-0.333	0.137	14	UPPER CAMERON RIVER	Little Qualicum
E285669	DO	0.286	0.203	14	UPPER CAMERON RIVER	Little Qualicum
E285669	Temp	0.333	0.137	14	UPPER CAMERON RIVER	Little Qualicum
E285669	Turbidity	-0.143	0.524	14	UPPER CAMERON RIVER	Little Qualicum
E287697	Cond	-0.0667	0.79	12	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E287697	DO	0.133	0.595	12	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E287697	Temp	0.0667	0.79	12	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum
E287697	Turbidity	0.133	0.595	12	WHISKEY CREEK ON HWY 4 NEAR TB AVE SAVE ON GAS	Little Qualicum

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E243021	Cond	0.286	0.203	14	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243021	DO	-0.0952	0.671	14	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243021	Temp	0	1	14	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243021	Turbidity	0.429	0.0559	14	FRENCH CREEK AT NEW HIGHWAY	French Creek
E243022	Cond	0.238	0.288	14	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E243022	DO	-0.333	0.137	14	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E243022	Temp	0.333	0.137	14	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E243022	Turbidity	-0.0476	0.832	14	FRENCH CREEK AT BARCLAY BRIDGE	French Creek
E243024	Cond	0.19	0.396	14	FRENCH CREEK AT GRAFTON ROAD	French Creek
E243024	DO	-0.429	0.0559	14	FRENCH CREEK AT GRAFTON ROAD	French Creek
E243024	Temp	0.333	0.137	14	FRENCH CREEK AT GRAFTON ROAD	French Creek
E243024	Turbidity	0.476	0.0337	14	FRENCH CREEK AT GRAFTON ROAD	French Creek
E288090	Cond	-0.286	0.203	14	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288090	DO	0.286	0.203	14	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288090	Temp	0.381	0.0893	14	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288090	Turbidity	0.429	0.0559	14	GRANDON CREEK WEST CRESCENT (CAISSONS)	French Creek
E288091	Cond	-0.429	0.0559	14	GRANDON CREEK AT LABURNUM ROAD	French Creek
E288091	DO	0.333	0.137	14	GRANDON CREEK AT LABURNUM ROAD	French Creek
E288091	Temp	0.0241	0.915	14	GRANDON CREEK AT LABURNUM ROAD	French Creek
E288091	Turbidity	0.19	0.396	14	GRANDON CREEK AT LABURNUM ROAD	French Creek
E288092	Cond	-0.524	0.0195	14	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288092	DO	-0.0952	0.671	14	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288092	Temp	0.458	0.0424	14	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288092	Turbidity	0.571	0.0108	14	BEACH CREEK NEAR CHESTER ROAD AT HEMSWORTH ROAD	French Creek
E288093	Cond	-0.238	0.288	14	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E288093	DO	0.143	0.524	14	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E288093	Temp	0.238	0.288	14	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
E288093	Turbidity	0.0476	0.832	14	BEACH CREEK NEAR MEMORIAL GOLF COURSE POND	French Creek
121580	Cond	0	1	12	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
121580	DO	-0.2	0.425	12	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
121580	Temp	0.4	0.111	12	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
121580	Turbidity	0.667	0.00789	12	ENGLISHMAN R. AT HIGHWAY 19A	Englishman River
E248834	Cond	0.133	0.595	12	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248834	DO	-0.533	0.0335	12	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248834	Temp	0.467	0.0629	12	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248834	Turbidity	0.333	0.184	12	ENGLISHMAN RIVER JUST UPSTREAM MORISON CREEK	Englishman River
E248835	Cond	-0.0667	0.79	12	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E248835	DO	-0.17	0.503	12	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E248835	Temp	0.4	0.111	12	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E248835	Turbidity	0.4	0.111	12	MORISON CREEK JUST UPSTREAM ENGLISHMAN RIVER	Englishman River
E248836	Cond	0.133	0.595	12	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E248836	DO	-0.267	0.288	12	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E248836	Temp	0.2	0.425	12	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E248836	Turbidity	0.267	0.288	12	SOUTH ENGLISHMAN RIVER JUST U/S ENGLISHMAN RIVER	Englishman River
E282969	Cond	0.0667	0.79	12	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E282969	DO	0	1	12	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E282969	Temp	0.267	0.288	12	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E282969	Turbidity	0.333	0.184	12	UPPER ENGLISHMAN RIVER U/S CENTRE FORK CREEK	Englishman River
E290469	Cond	0.2	0.425	12	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E290469	DO	0	1	12	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290469	Temp	0.2	0.425	12	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290469	Turbidity	0.2	0.425	12	DEPARTURE CREEK @ NEYLAND RD (STN1)	South Wellington to Nanoose
E290470	Cond	-0.133	0.595	12	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290470	DO	-0.133	0.595	12	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290470	Temp	0.305	0.228	12	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290470	Turbidity	-0.267	0.288	12	DEPARTURE CREEK OFF NEWTON ST (STN2)	South Wellington to Nanoose
E290471	Cond	-0.2	0.425	12	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290471	DO	-0.0667	0.79	12	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290471	Temp	0.133	0.595	12	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290471	Turbidity	0.2	0.425	12	DEPARTURE CREEK AT LOWER END OF WOODSTREAM PARK (STN 3)	South Wellington to Nanoose
E290472	Cond	-0.133	0.595	12	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290472	DO	-0.133	0.595	12	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290472	Temp	0.305	0.228	12	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290472	Turbidity	-0.267	0.288	12	DEPARTURE CREEK AT OUTLET (STN4)	South Wellington to Nanoose
E290473	Cond	0.267	0.288	12	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290473	DO	-0.267	0.288	12	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290473	Temp	0.2	0.425	12	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290473	Turbidity	0.0667	0.79	12	COTTLE CREEK @ NOTTINGHAM	South Wellington to Nanoose
E290475	Cond	0.267	0.288	12	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290475	DO	-0.0667	0.79	12	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290475	Temp	0.2	0.425	12	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose
E290475	Turbidity	0	1	12	COTTLE CREEK @ STEPHENSON PT RD	South Wellington to Nanoose

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E290478	Cond	0.0667	0.79	12	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290478	DO	-0.2	0.425	12	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290478	Temp	-0.0667	0.79	12	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290478	Turbidity	0.4	0.111	12	MILLSTONE RIVER @ BIGGS ROAD	South Wellington to Nanoose
E290479	Cond	0.4	0.111	12	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290479	DO	-0.133	0.595	12	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290479	Temp	0.0667	0.79	12	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290479	Turbidity	0.333	0.184	12	MCGARRIGLE CK @ JINGLE POT RD	South Wellington to Nanoose
E290480	Cond	-0.133	0.595	12	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290480	DO	0.2	0.425	12	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290480	Temp	0.2	0.425	12	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290480	Turbidity	0	1	12	MILLSTONE RIVER @ EAST WELLINGTON	South Wellington to Nanoose
E290481	Cond	0.133	0.595	12	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290481	DO	-0.0667	0.79	12	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290481	Temp	0.267	0.288	12	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290481	Turbidity	-0.0667	0.79	12	MILLSTONE RIVER IN BARSBY PARK	South Wellington to Nanoose
E290483	Cond	0.267	0.288	12	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290483	DO	0.133	0.595	12	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290483	Temp	0.305	0.228	12	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290483	Turbidity	0.0667	0.79	12	CHASE RIVER @ AEBIG RD	South Wellington to Nanoose
E290484	Cond	0.4	0.111	12	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290484	DO	0.133	0.595	12	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose

EMS.ID	analyte	tau	pvalue	n	LOCATION.NAME	WaterRegion
E290484	Temp	0.0667	0.79	12	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290484	Turbidity	0.2	0.425	12	CHASE RIVER @HOWARD BELOW COLLIERY DAM	South Wellington to Nanoose
E290485	Cond	-0.0667	0.79	12	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290485	DO	0.333	0.184	12	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290485	Temp	0.2	0.425	12	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290485	Turbidity	0.0667	0.79	12	CHASE RIVER @ PARK AVE	South Wellington to Nanoose
E290486	Cond	0.6	0.0168	12	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290486	DO	-0.267	0.288	12	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290486	Temp	0.267	0.288	12	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E290486	Turbidity	0.333	0.184	12	CATSTREAM @ PARK ABOVE CONFLUENCE WITH CHASE RIVER	South Wellington to Nanoose
E287699	Cond	0.143	0.524	14	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E287699	DO	-0.476	0.0337	14	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E287699	Temp	0.476	0.0337	14	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E287699	Turbidity	0.476	0.0337	14	NANAIMO RIVER U/S HASLAM CK ~500 M D/S HWY 1 BRIDGE	Nanaimo River
E290487	Cond	-0.267	0.288	12	BECK CREEK @ CEDAR RD	Nanaimo River
E290487	DO	0.133	0.595	12	BECK CREEK @ CEDAR RD	Nanaimo River
E290487	Temp	0.333	0.184	12	BECK CREEK @ CEDAR RD	Nanaimo River
E290487	Turbidity	-0.2	0.425	12	BECK CREEK @ CEDAR RD	Nanaimo River

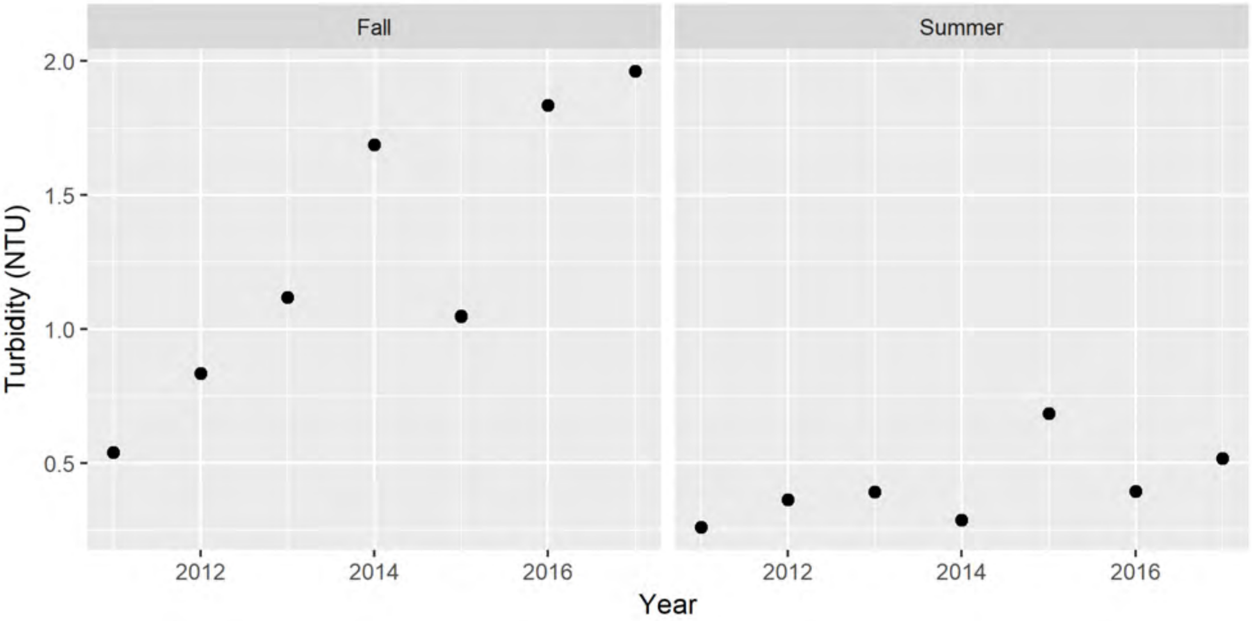

Figure A137. Mean fall and summer turbidity from 2011-2017 for Little Qualicum River at Intake.

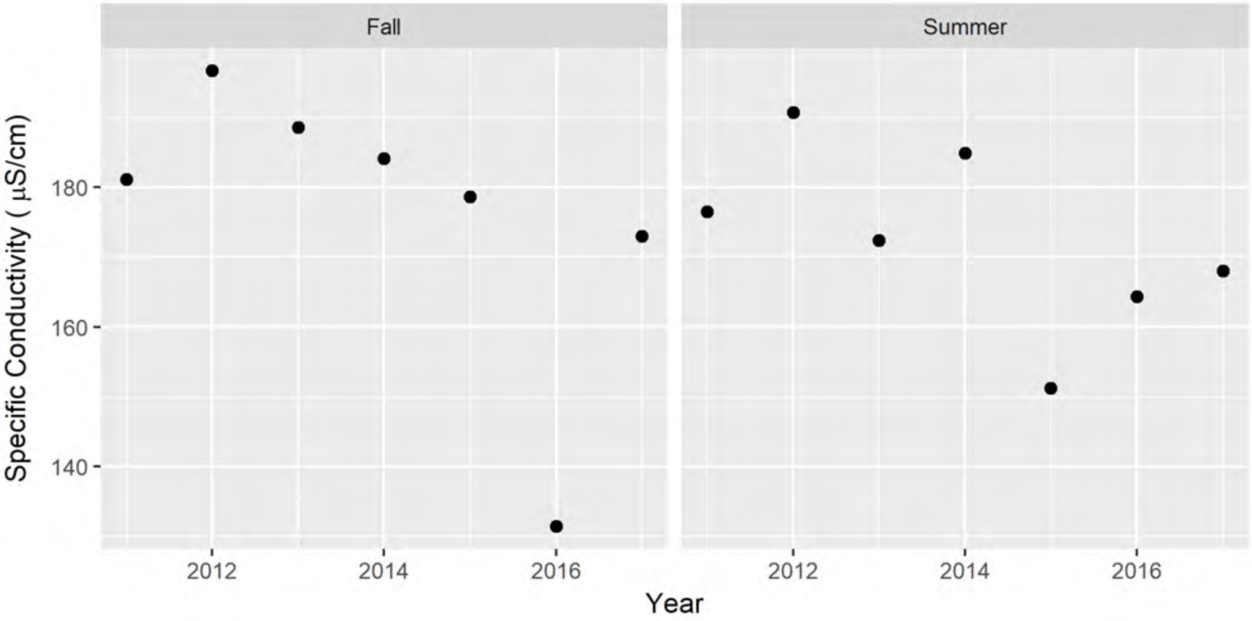

Figure A138. Mean fall and summer conductivity from 2011-2017 for Beach Creek near Chester Road at Hemsworth Rd.

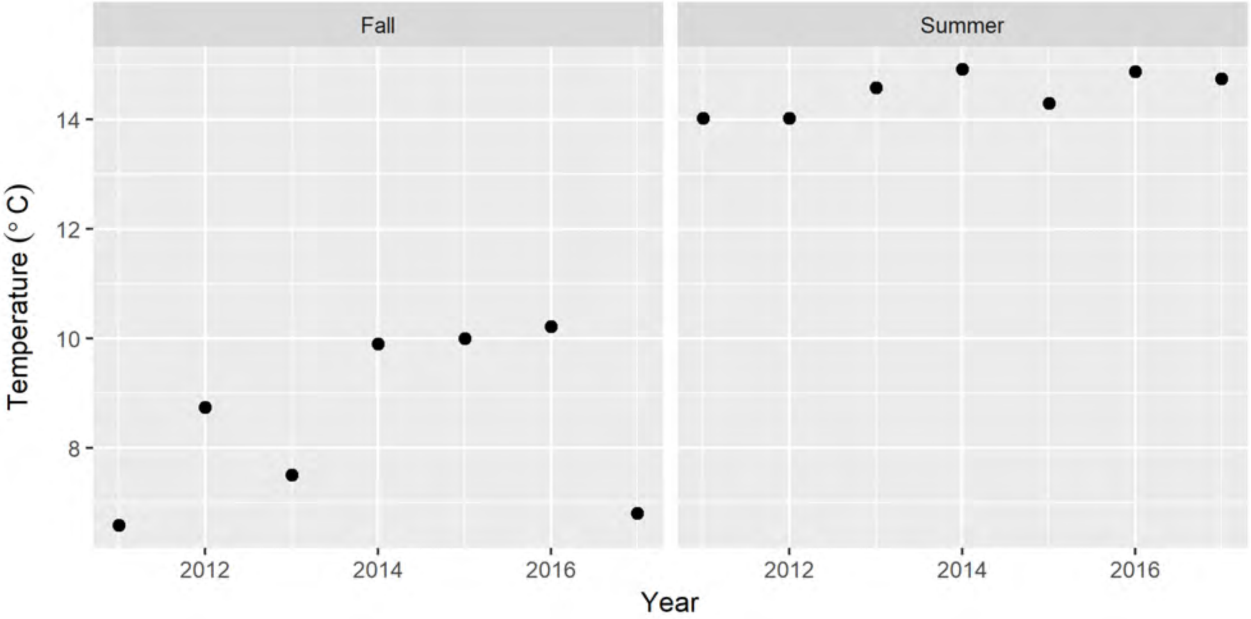

Figure A139. Mean fall and summer water temperature from 2011-2017 for Beach Creek near Chester Road at Hemsworth Rd.

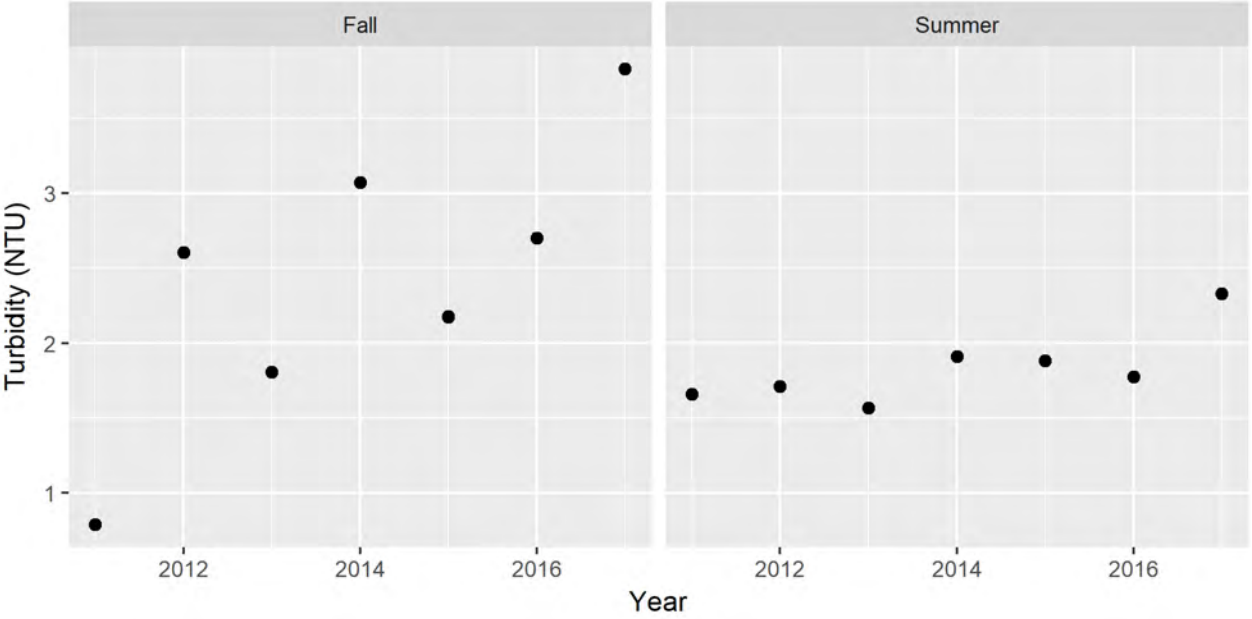

Figure A140. Mean fall and summer water turbidity from 2011-2017 for Beach Creek near Chester Road at Hemsworth Rd.

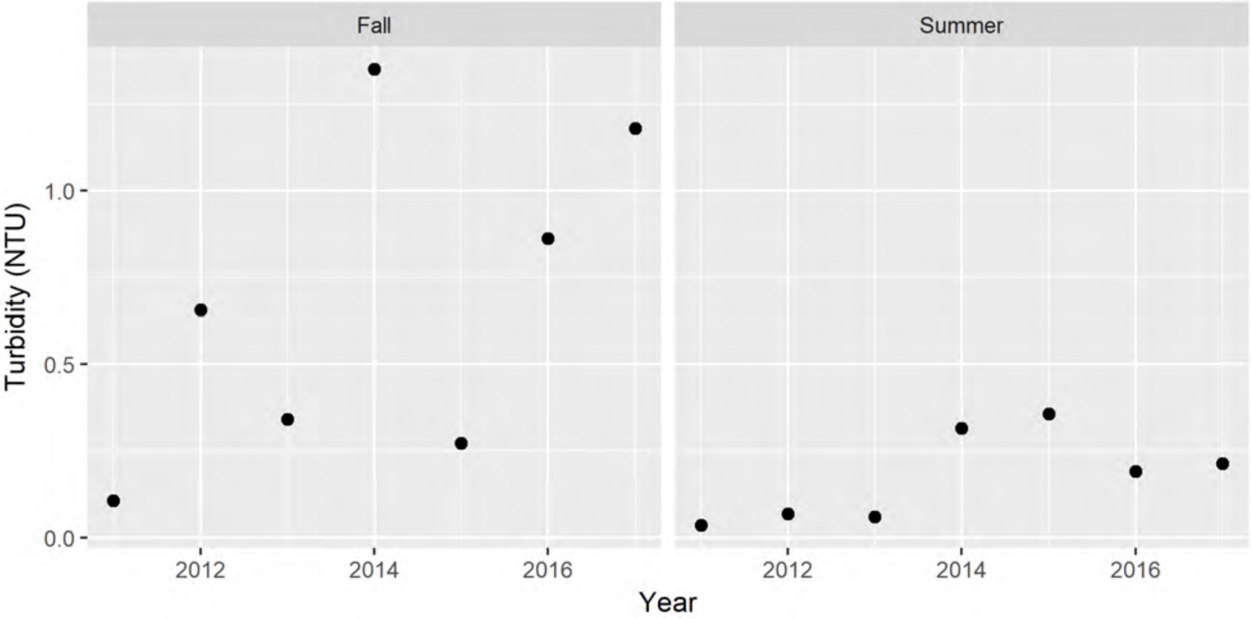

Figure A141. **Mean fall and summer water turbidity from 2011-2017 for French Creek at Grafton Rd.**

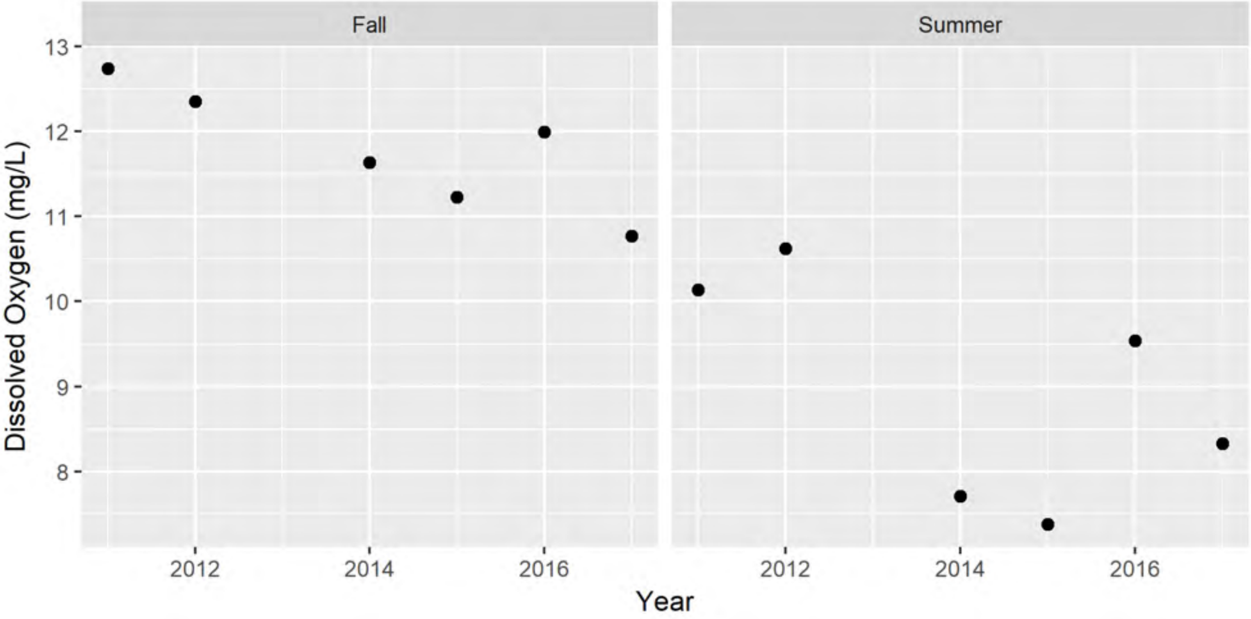

Figure A142. **Mean fall and summer DO from 2011-2017 for Englishman River Upstream of Morison Creek.**

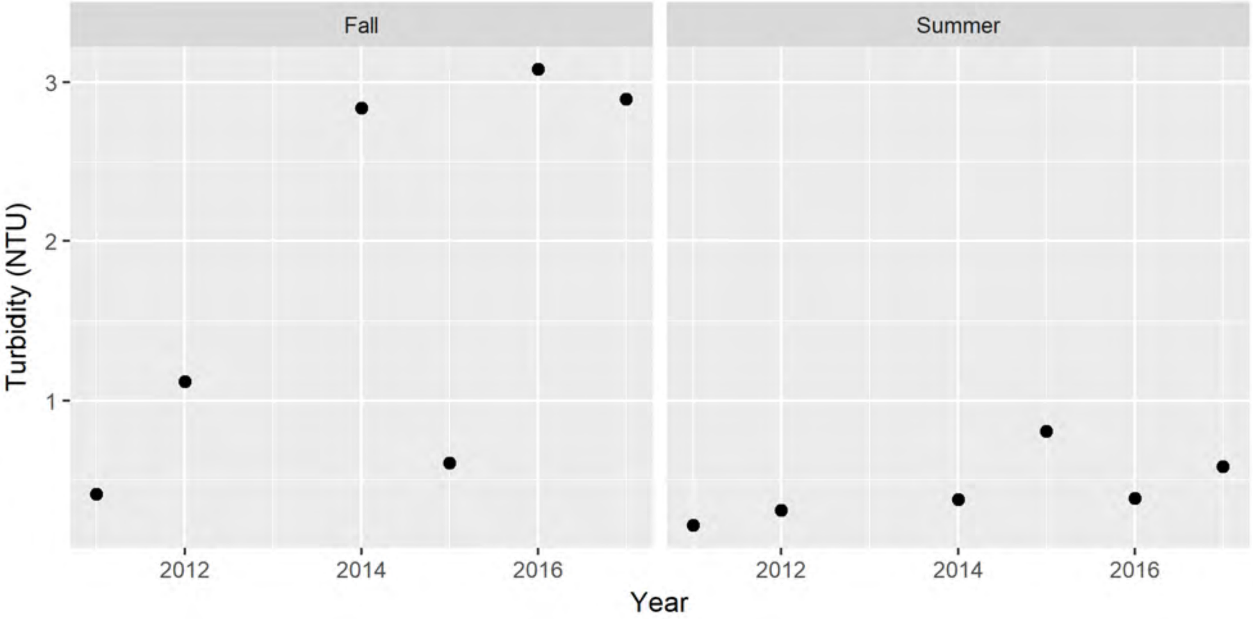

Figure A143. Mean fall and summer turbidity from 2011-2017 for Englishman River at Highway 19A.

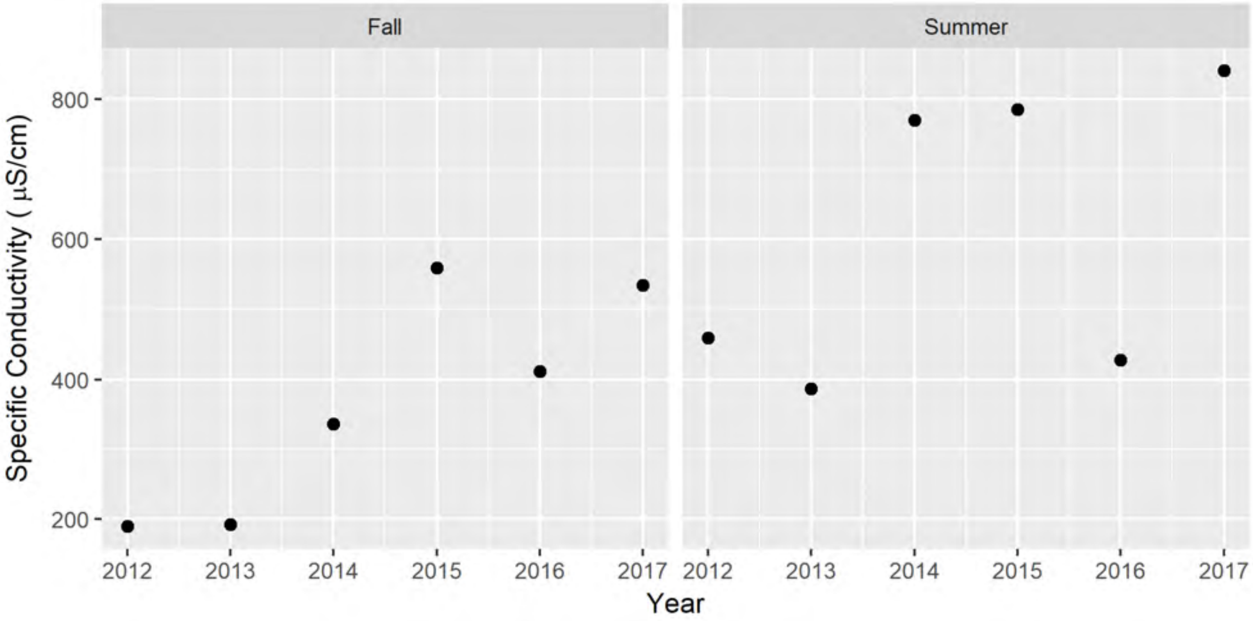

Figure A144. Mean fall and summer conductivity from 2011-2017 for Cat Stream.

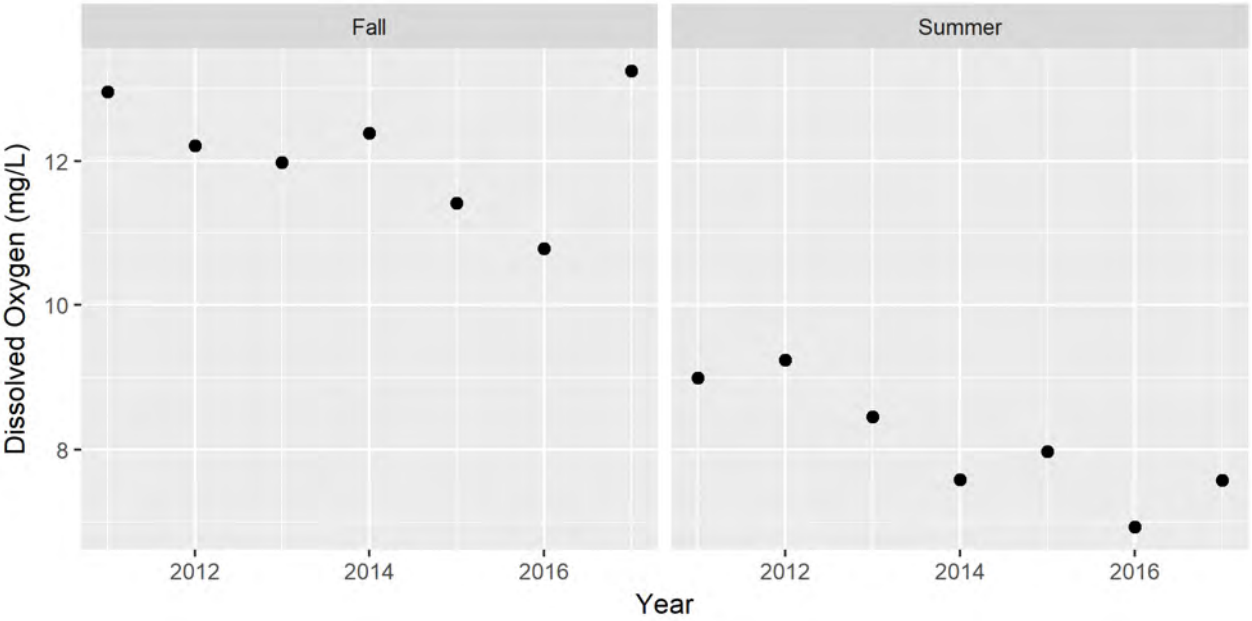

Figure A145. **Mean fall and summer DO from 2011-2017 for Nanaimo River Upstream of Haslam Creek.**

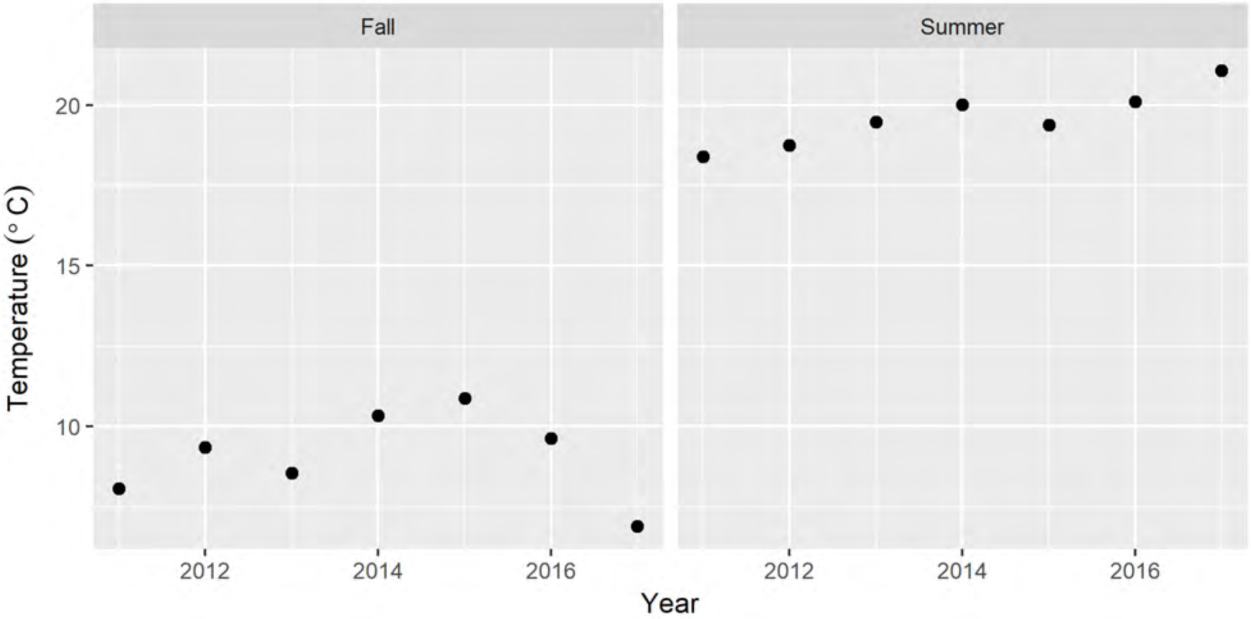

Figure A146. **Mean fall and summer water temperature from 2011-2017 for Nanaimo River Upstream of Haslam Creek.**

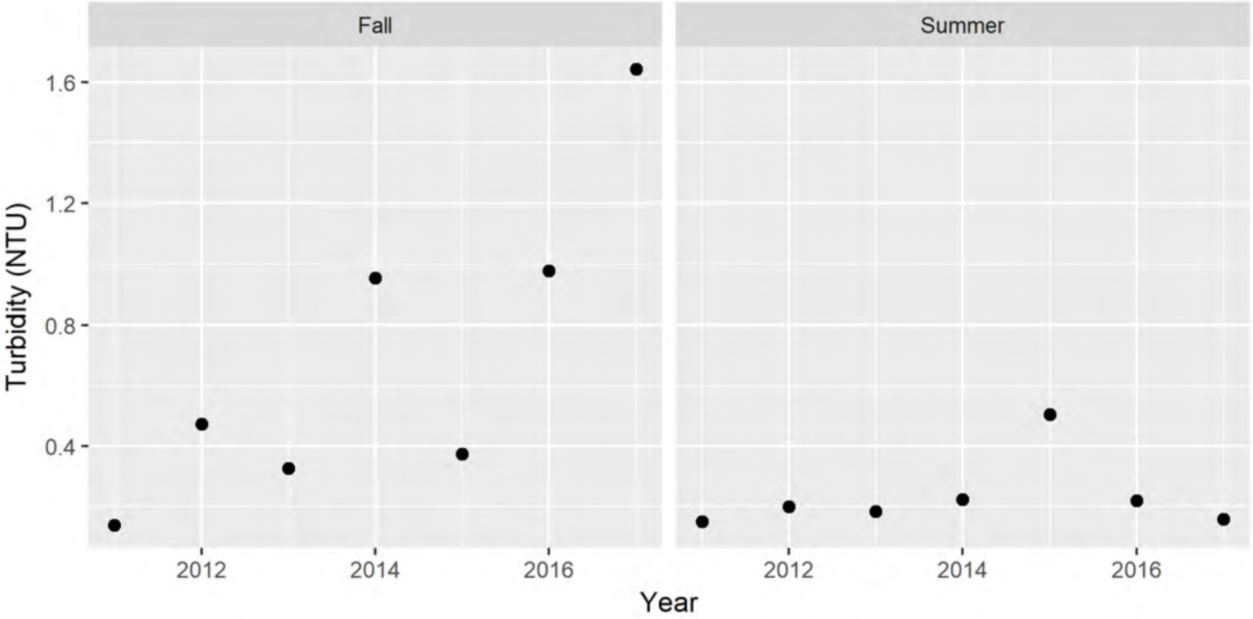

Figure A147. Mean fall and summer turbidity from 2011-2017 for Nanaimo River Upstream of Haslam Creek.

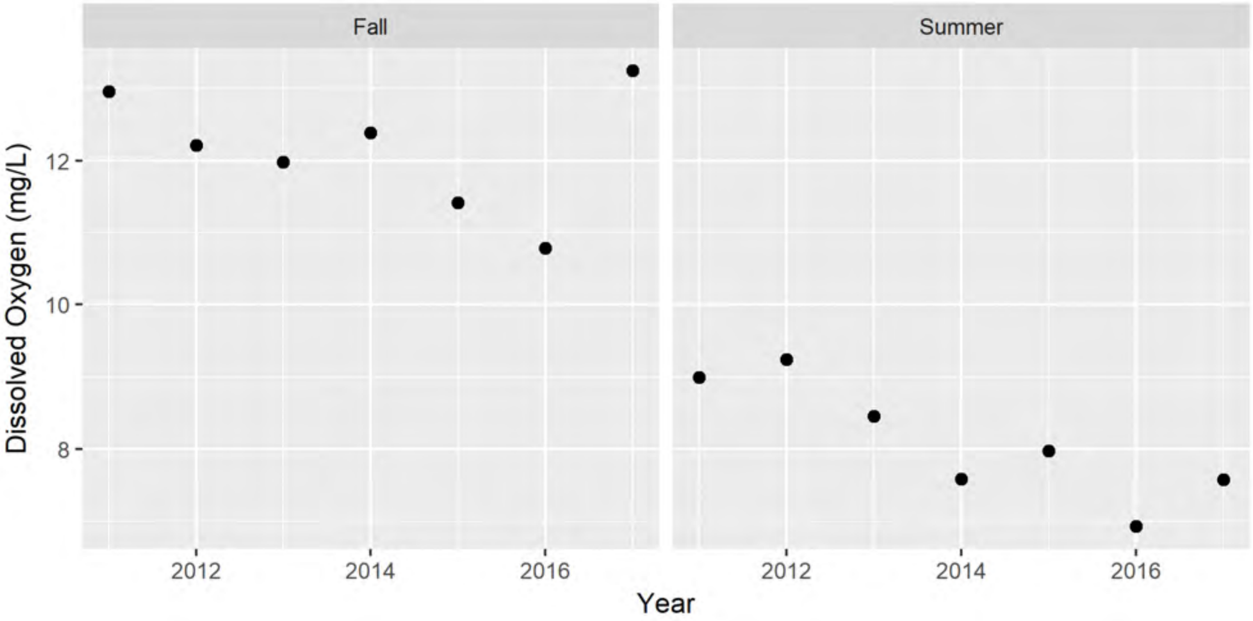

Figure A148. Mean fall and summer DO from 2011-2017 for Nanaimo River Upstream of Haslam Creek.

Appendix H Water Quality Models Supplemental Results

Table A3 Summary of water quality models with mean variance explained (R^2) and Mean Squared Error (MSE).

Model	R^2	MSE
Summer Conductivity	0.42	6116.77
Summer DO	0.25	2.89
Summer Temperature	0.13	3.42
Summer Turbidity	0.21	0.58
Fall Conductivity	0.53	3471.65
Fall DO	0.28	0.75
Fall Temperature	0.39	1.5
Fall Turbidity	0.37	0.25

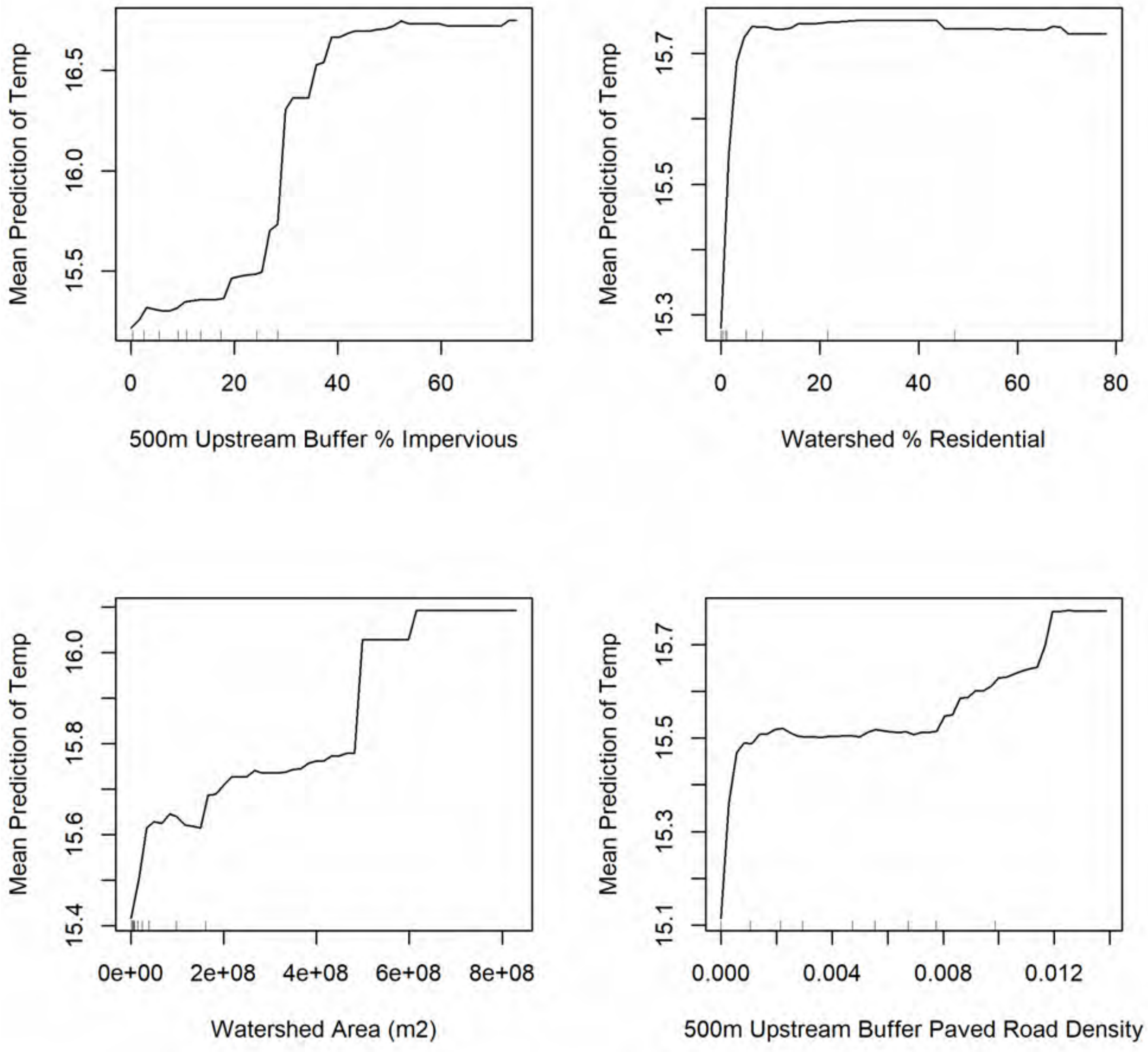

Figure A149. **Partial Dependence plots for top four predictors of summer water temperature model.**

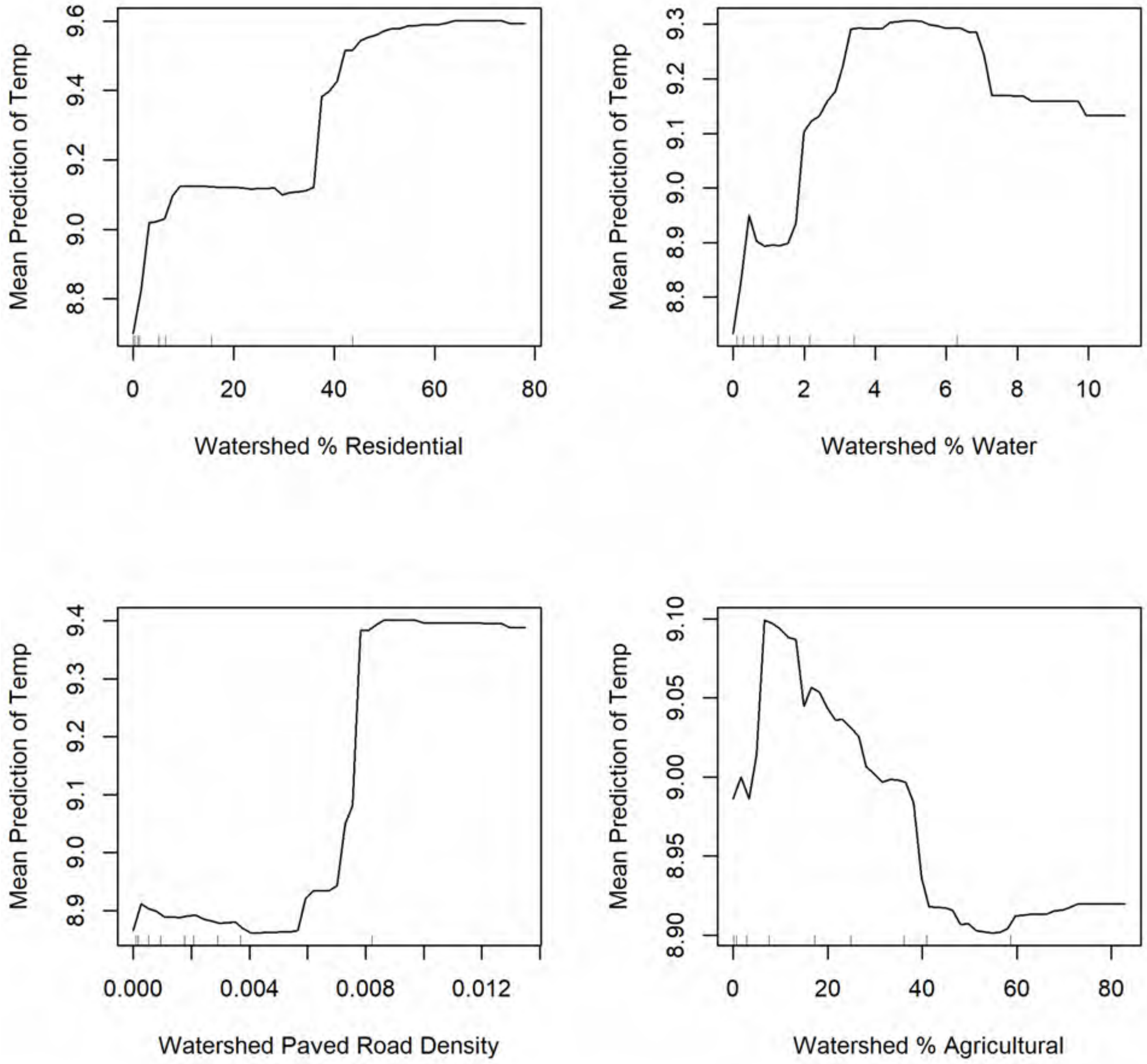

Figure A150. **Partial Dependence plots for top four predictors of fall water temperature model.**

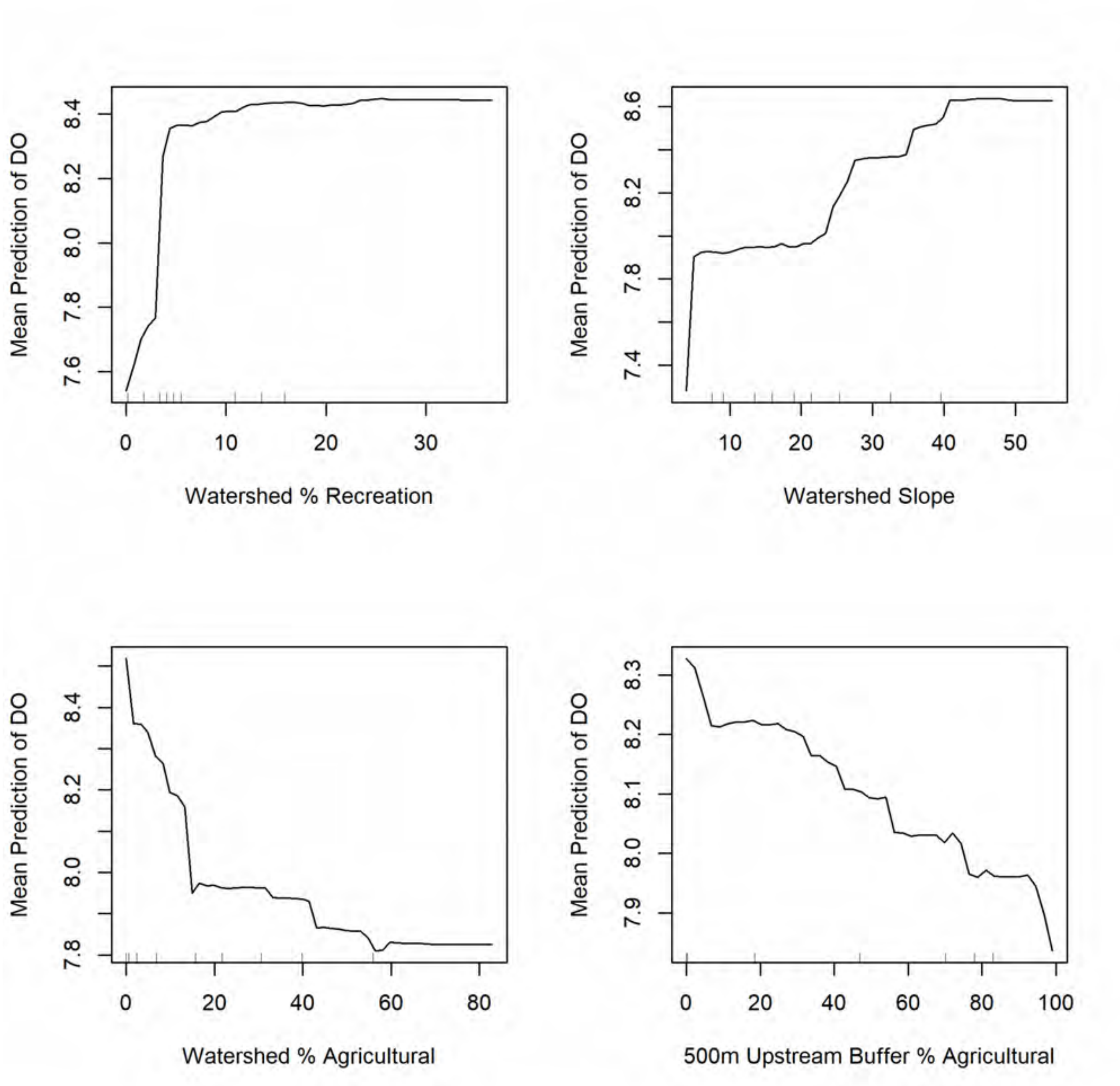

Figure A151. **Partial Dependence plots for top four predictors of summer DO model.**

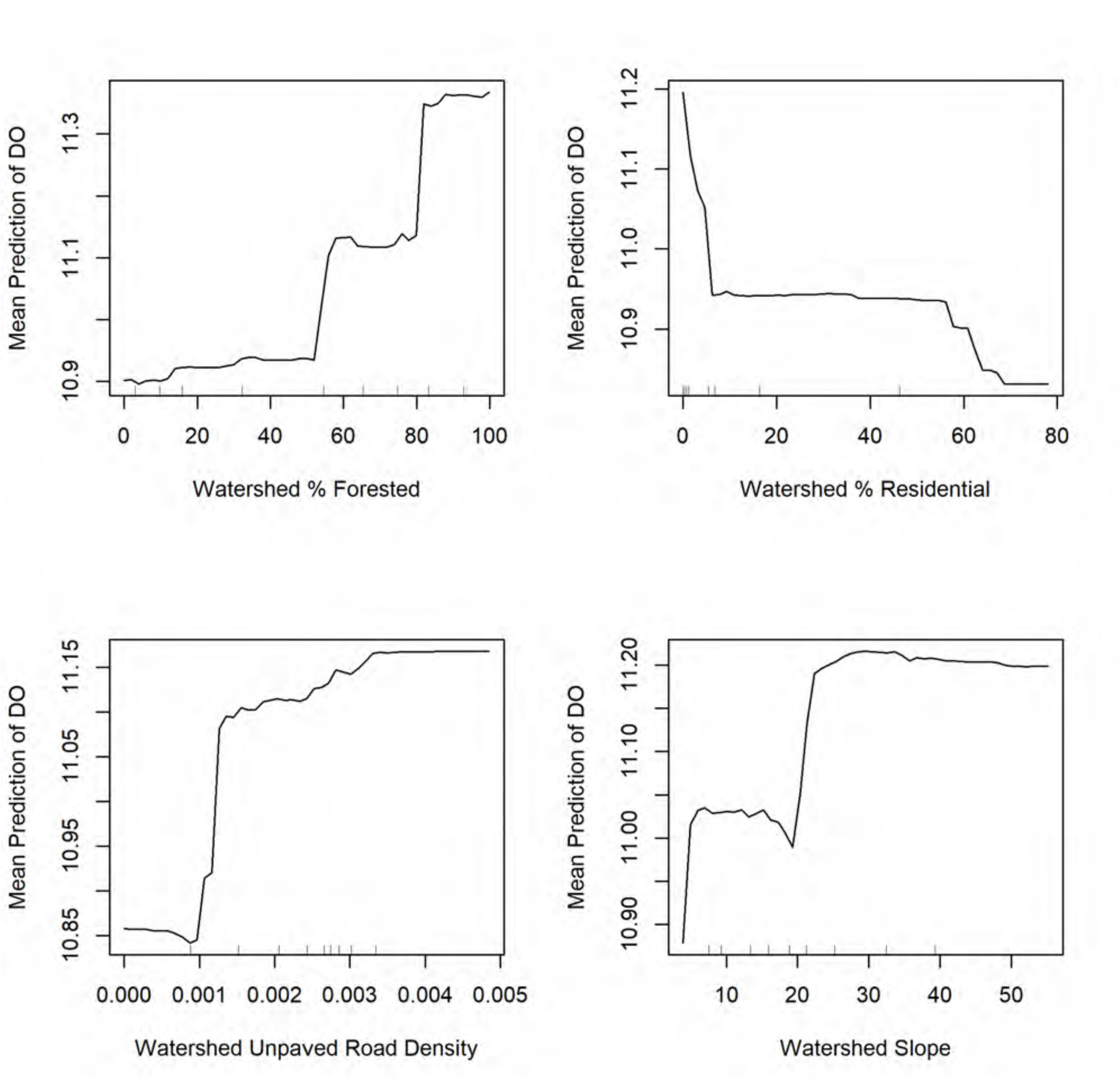

Figure A152. **Partial Dependence plots for top four predictors of fall DO model.**

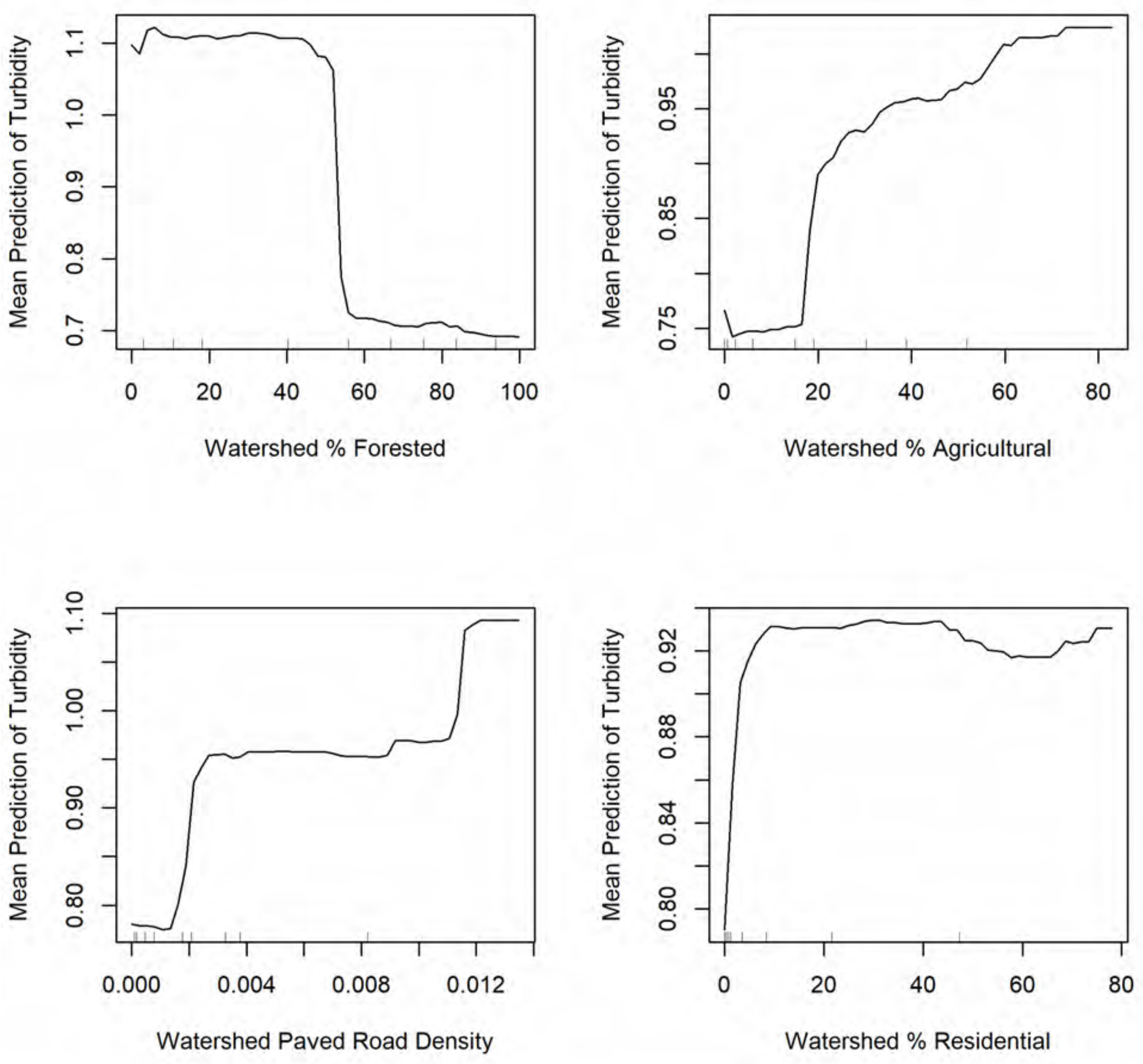

Figure A153. **Partial Dependence plots for top four predictors of summer turbidity model.**

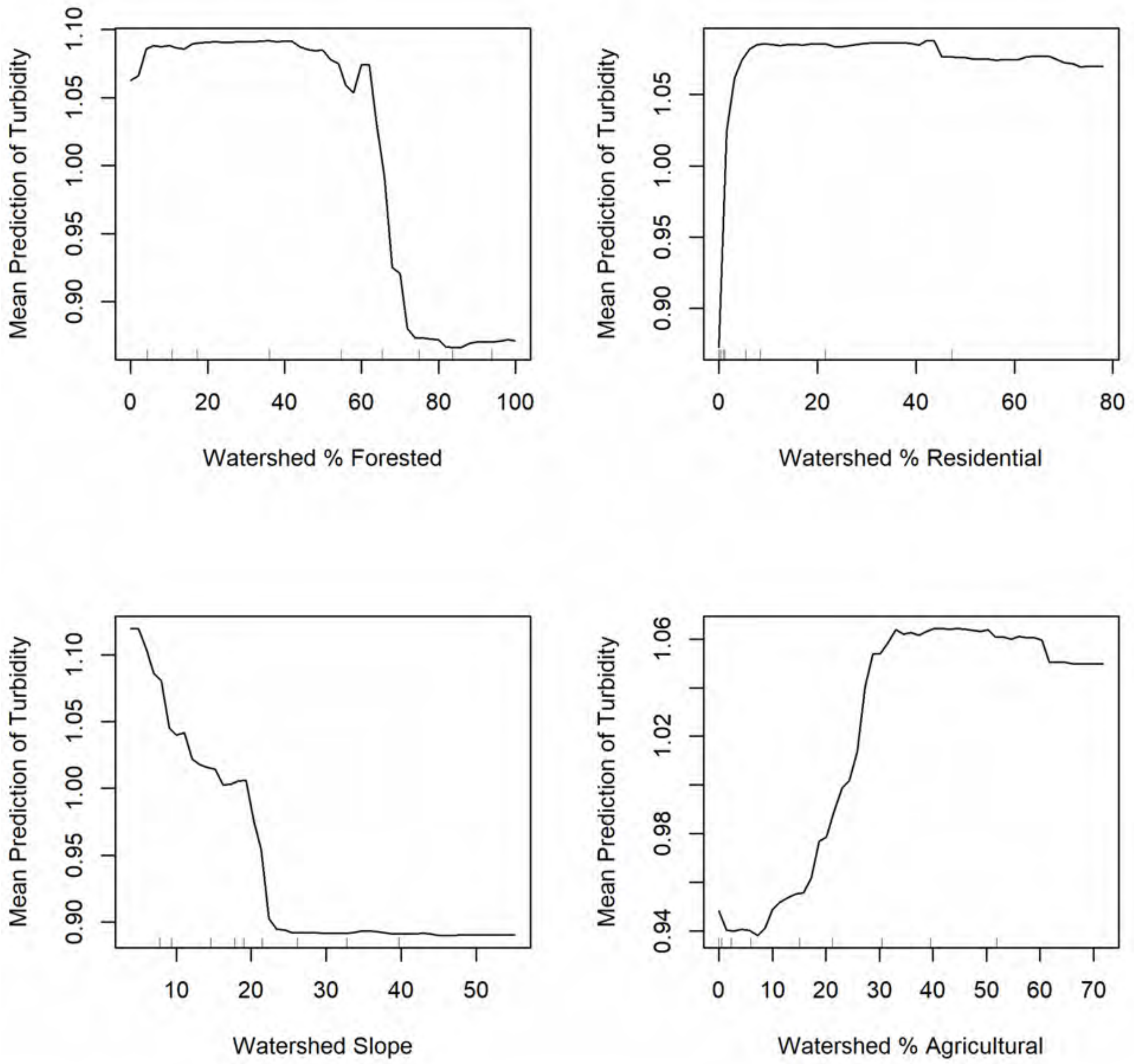

Figure A154. **Partial Dependence plots for top four predictors of fall turbidity model.**

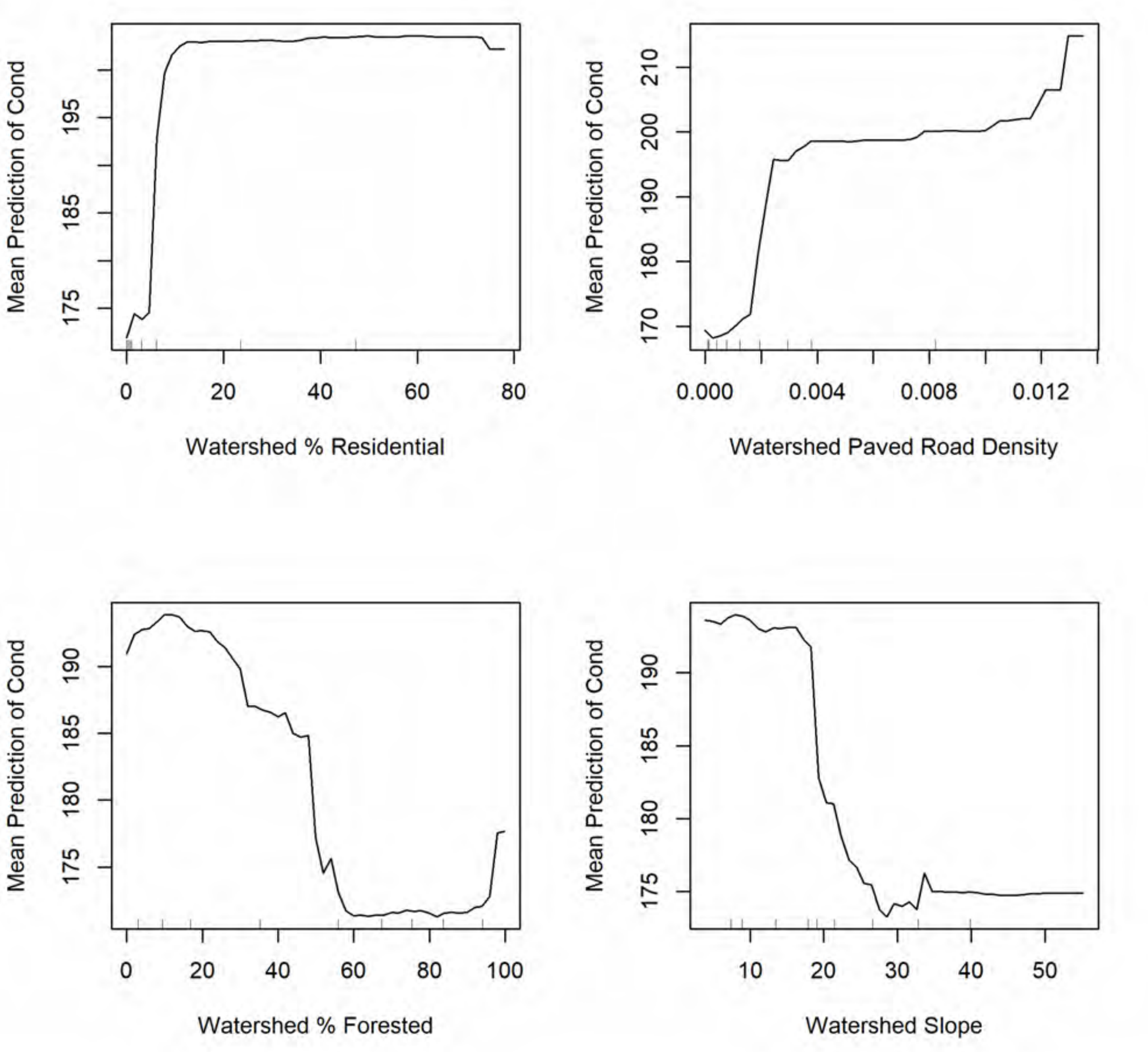

Figure A155. Partial Dependence plots for top four predictors of summer conductivity model.

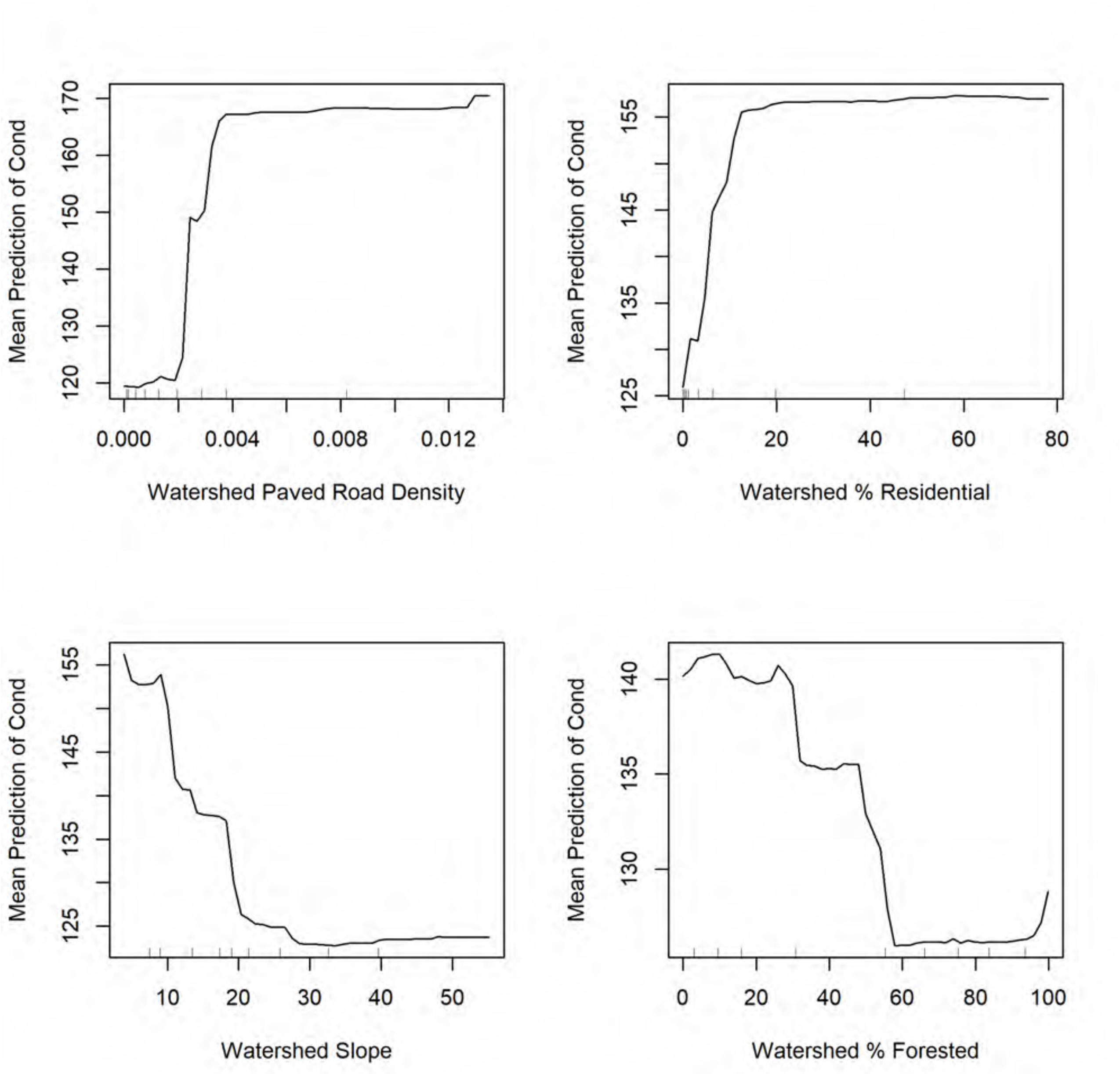

Figure A156. **Partial Dependence plots for top four predictors of fall conductivity model.**

Appendix I Rain Garden and Swale Figures

Figure A157. A well designed residential property with rain gardens and swale. Drawing provided by Larratt Aquatic Consulting and illustrated by Rebekah Massey.

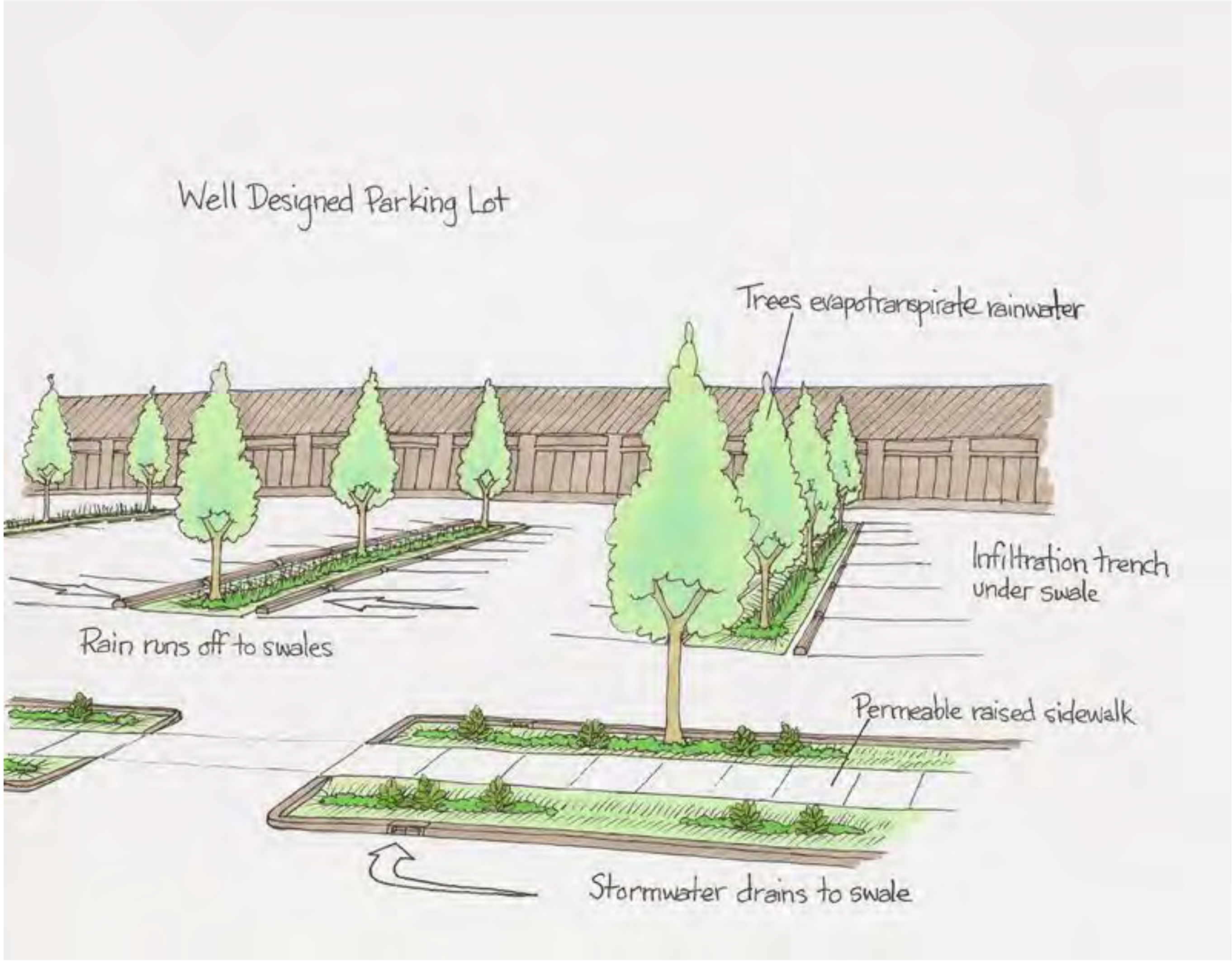

Figure A158. **A well designed parking lot with swales. Drawing provided by Larratt Aquatic Consulting and illustrated by Rebekah Massey.**