Technical Memorandum

Date: September 5, 2023
To: **Lauren Fegan**
Monitoring Network Coordinator, Drinking Water & Watershed Protection
Regional & Community Utilities, Regional District of Nanaimo
6300 Hammond Bay Road, Nanaimo, BC, V9T 6N2
From: Luke Crevier
- GIS / Data Analyst | Analytics Team Lead

Authors: Luke Crevier
- GIS / Data Analyst | Analytics Team Lead

Mary Ann Olson-Russello
- Senior Natural Resource Biologist

File: 23-4635 |1.0
Subject: **Regional District of Nanaimo Community Watershed Monitoring Network Data Analysis (2011-2022)**

1.0 INTRODUCTION

Ecoscape Environmental Consultants Ltd. (Ecoscape) was retained by The Regional District of Nanaimo (the RDN) in February of 2023 to provide an assessment of longitudinal water quality data collected in multiple stream networks near Nanaimo, BC for the Community Watershed Monitoring Network (CWMN). This assessment included:

1. Data acquisition, clean-up, and proofing for 67 active sample locations
2. The creation of box plots and other figures to visualize parameters of interest
3. Outlier tabulation
4. Upslope-area drainage delineation and buffer creation for priority monitoring locations
5. Trend analysis for sites with sufficient historical sampling events
6. Contextualization of identified trends in relation to the RDN monitoring and stewardships node framework (Figure 1)
7. Preparation of this memorandum to summarize the methods and results of the components outlined above

Ecoscape performed the assessment and provided corresponding deliverables (see Table 1) to the RDN digitally via a shared cloud directory. This memorandum provides a summary of the key components of the assessment.

Table 1. Summary list of deliverables provided to the RDN.

Item	Deliverable(s) Description
1.	Excel database of consolidated historical / 2022 data for turbidity, dissolved oxygen, temperature, and specific conductivity
2.	Excel database of 2022 outliers identified for turbidity, dissolved oxygen, temperature, and specific conductivity
3.	Excel database of Mann-Kendall trend analysis summaries

Table 1. Summary list of deliverables provided to the RDN.	
Item	**Deliverable(s) Description**
4.	Box plots for turbidity, dissolved oxygen, temperature, and specific conductivity, grouped by water region as applicable
5.	Time series plots with Mann-Kendall trendlines
6.	Geodatabase of upslope-area basin and buffer feature classes
7.	Summary memorandum

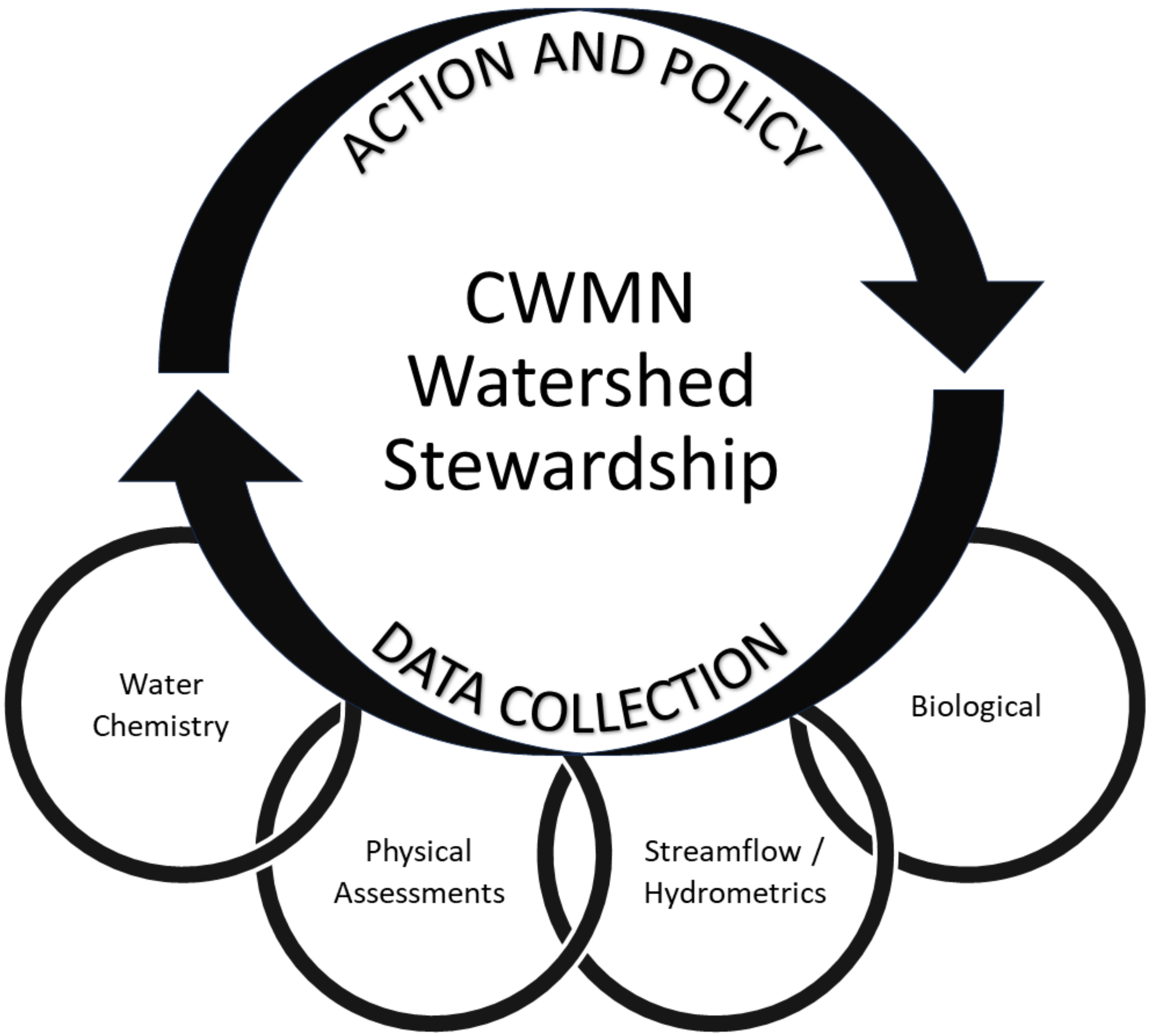

Figure 1. Simplified representation of the CWMN Watershed Monitoring and Stewardship Node Framework. This figure is adapted from a draft provided by Lauren Fegan and is intended only as a reference pending completion of the node framework by the RDN / Fuselight.

2.0 ASSESSMENT METHODS

All data clean-up and analysis was performed with R (R Core Team, 2023) and figures were created using the ggplot2 library (Wickham, 2016).

2.1. Surface Parameter Measurement Data Retrieval and Proofing

The parameters of interest for this assessment were: dissolved oxygen, turbidity, temperature, and specific conductivity. These data are available via the provincially maintained Environmental Monitoring System (EMS) database (available at https://a100.gov.bc.ca/pub/ems/). Ecoscape used this portal to retrieve the data for all parameters of interest for the monitoring group “RDN Community Monitoring Program” for the year of 2022. Ecoscape loaded and reformatted the resultant file into a single long-formatted 2022 Community Watershed Monitoring Network (CWMN) dataset. Ecoscape then combined this 2022 data with historical data (already prepared in previous iterations of this assessment) to produce a master longitudinal dataset containing all historical data in addition to the most-recent CWMN data.

Ecoscape provided this master dataset to the RDN as “nanaimo_master_data_2022.xlsx”. In addition, Ecoscape provided to the RDN a list of outliers that represented potential transcription or measurement errors. The RDN reviewed these potential errors, the field sheets, and the monitoring equipment as appropriate and provided a list of corrections. In advance of these corrections being updated on the EMS database, Ecoscape accommodated the revisions to the data within the analysis pipeline; the final “nanaimo_master_data_2022.xlsx” therefore includes these corrections.

2.2. Exceedance Analysis

Ecoscape used relevant instantaneous and 30-day parameter-specific guideline values from the BC Ministry of Environment and, when applicable, specific water quality objectives for the Englishman River (Barlak et al., 2010) to assess whether measured values exceeded those guidelines. To determine if a sample measurement exceeded the instantaneous guideline, the sample value was compared to the relevant guideline. If that value was greater than the guideline for temperature, specific conductivity, or turbidity, or if that value was lower than the guideline for dissolved oxygen, that sample was considered to have exceeded the instantaneous guideline.

To determine if a sample site exceeded the 30-day guideline, Ecoscape determined the mean sample value within each sampling “season” (i.e., Summer or Fall sampling efforts that consisted of multiple sampling events within a thirty-day period) and compared that mean value to the 30-day guideline. If that mean value was greater than the guideline for temperature, specific conductivity, or turbidity, or if that value was lower than the guideline for dissolved oxygen, that sample was considered to have exceeded the 30-day guideline.

Ecoscape provided summary tables that describe the above results. The summary table for 30-day guideline exceedance also indicates whether a site location had been successfully sampled at least five times within the sampling season to qualify for 5-in-30 guideline assessment. The instantaneous guideline summary table is provided as “instantaneous_exceedance_summary.xlsx” and the 30-day guideline summary is provided as “summary_30_day_exceedances.xlsx”.

2.3. Outlier Identification

Ecoscape identified any values that fall outside the typical range of values for each parameter at each sample location. Ecoscape classified a value as an outlier if it falls outside of the range defined by:

$$[Lower\ Quartile - (1.5 \times Interquartile\ Range), \qquad Upper\ Quartile + (1.5 \times Interquartile\ Range)]$$

Ecoscape tabulated these outliers individually and provided some other basic summary statistics on a per-site, per-parameter, per-season level. These tables are provided as "Outliers_Summary_Stats.xlsx".

2.4. Graphs by Water Region

Ecoscape prepared figures for all water regions (groupings based on watershed / geographical location / group size) for all parameters of interest. These figures consist of box plots generated from historical data overlaid with point graphics that indicate historical outliers and data collected in 2022. Ecoscape provided these plots to the RDN for initial review. Based on comments from the RDN, Ecoscape further refined these plots by further subsetting sample locations into different clusters to better visualize parameters according to the scale that was best suited to the parameter or water region. Functionally, this meant that sample locations with values consistently high relative to other locations within a common water region were reclassified from their water region into special "high-value" groups for the purpose of graphical display.

All graphs are provided in a figures deliverables packet folder that was further subdivided into water quality parameter subfolders.

2.5. Basin Delineation

The RDN requested that Ecoscape determine upslope area basin delineations for a number of CWMN monitoring stations for which delineation was not undertaken in the original analysis (Plewes et al., 2018). In that original assessment, Ecoscape used a 2-meter resolution Digital Elevation Model (DEM) that the RDN provided, interpolated to a 5-meter resolution, as the input for an upslope area algorithm. For the assessment of novel delineations, Ecoscape used this same 5-meter interpolated DEM as the basis for interpretation.

The RDN provided a list of CWMN surface water monitoring locations for which watersheds needed to be delineated (Table 2); this list included the unique EMS number for each location and indicated the priority level for the delineation of each monitoring location. Ecoscape focused efforts on the delineation of sites with a priority level of 1 or 2 in order to complete delineation to a degree of accuracy that matches that achieved in the original report (Plewes et al., 2018).

With fewer sites of interest relative to the initial assessment, Ecoscape identified a few instances where modifications to the originally-derived basins was necessary to reconcile the novel basin boundaries and the existing basin boundaries. These changes were due to a few key factors: some Freshwater Atlas / RDN watercourses used to 'burn in' streamlines are not up-to-date based on existing satellite imagery and therefore directed flow incorrectly; and that to reconcile these issues in interpretation Ecoscape included a layer that denotes culverts (Ministry of Transportation Culverts, 2012). The original basins for which revisions were required are listed in Table 3.

Beyond the revisions required to existing basins, the delineation of some of the novel basins presented an additional challenge in reconciling the basin coordinates with both the directions to the sites and the topography implied by the DEM. See CWMN site "Unknown Tributary (Haley Creek) 15m d/s Yellow Point Rd" (EMS Number E321393) for an example of a site where the listed coordinates do not clearly match the directions to the site; the difference between the coordinates listed and the site indicated by the access directions is greater than 350 meters. Such mismatches indicate a potential need for a thorough review of site coordinates to update any sites coordinates that are not accurately representative of the sampling location.

For all Priority 1 and Priority 2 CWMN sites (see Table 2), Ecoscape generated upslope areas in addition to a 500-meter upstream area buffer centered on the CWMN site.

The spatial components of this assessment are provided in an Esri File Geodatabase as Feature Classes. These feature classes included are:

1. The novel basin delineations for the Priority 1 and Priority 2 sites (see Table 2)
2. The 500-meter upslope area buffers for the Priority 1 and Priority 2 sites (see Table 2)
3. The original basins for which refinement was required (see Table 3)

Table 2. Prioritized list of EMS sites targeted for upslope area basin delineation.

Priority Level	Water Region Code	EMS Number	Geographic Description
1	WR 2	E318150	Harris Creek on north/downstream side of Hwy 4
1	WR 3	E318151	Morningstar Creek 100m u/s Lee Rd W
1	WR 5 - 1	E318233	Walley Ck 100 m d/s McGuffie Rd
1	WR 5 - 2	E321394	Beaver Creek d/s Avonlea Rd bridge
1	WR 5 - 2	E325371	Cat Stream d/s Wakesiah Ave
1	WR 5 - 2	E325372	Cat Stream 10m u/s Pine St
1	WR 5 - 2	E325373	Cat Stream at end of Albion St
1	WR 6	E318152	Wexford Ck just d/s Douglas Ave
1	WR 6	E318153	Wexford Ck just d/s Tenth St
1	WR 6	E318154	Wexford Ck ~20m d/s confluence of N and main arm
1	WR 6	E318155	South Wexford Ck at Community Park (Glenford Pl)
1	WR 6	E318172	Wexford Ck just u/s seniors complex
1	WR 6	E321395	Richards Creek 5m u/s Frames Rd
2	WR 6	E321392	Holden Creek 10m d/s Tiesu Rd
2	WR 6	E321393	Unknown Tributary (Haley Creek) 15m d/s Yellow Point Rd
3	WR 5 - 1	E294009	Bloods Creek just u/s Aulds Rd
3	WR 5 - 1	E294012	Knarston Ck @ Hydro Bridge
3	WR 5 - 1	E294014	Bonnell Creek just u/s 142-124 main @ ~1km
3	WR 5 - 1	E294015	Bonnell Creek @ ~km4 Sundew Main
3	WR 5 - 1	E294016	Bonnell Creek near Nanoose Station Rd @ Railway
3	WR 5 - 1	E294018	Nanoose Creek just u/s 142 main (km 4)
4	WR 5 - 1	E294011	Slogar Brook (Steward Ck)

Table 3. List of CWMN sites for which watershed delineation was revised to accommodate novel site delineations.

Water Region Code	EMS Number
E306256	Walley Ck d/s Hammond Bay
E306257	Walley Ck @ Morningside Dr
E306434	Walley Creek 20m u/s beach
E290487	Beck Creek @ Cedar Rd
E290480	Millstone River @ East Wellington
E290481	Millstone River in Barsby Park
E306294	Millstone River @ Jingle Pot Road
E290478	Millstone River @ Biggs Road
E294010	Bloods Creek just u/s Dickenson Rd

2.6. Trend Analysis

Ecoscape used Seasonal Mann-Kendall tests to identify and assess the direction and statistical significance of trends in water quality measurements over time (2011-2022). 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 time periods from different years. Only sites that were sampled for at least six years in both summer and fall were included in the trend analysis. Water quality measures that had significant trends over time were graphed with Thiel-Sen estimator slope trend lines to aid in the visual interpretation of trend directions (Sen, 1968). Tests were performed using the "Kendall" package version 2.2.1 in R (McLeod, 2022). A comprehensive summary of all site / parameter trends, including both cases where trends were detected and cases where there was no significant trend detected, was tabulated and were provided to the RDN as a supplemental database. These trends were reviewed to derive recommendations on a watercourse level to inform future amelioration and monitoring efforts.

2.7. Systematic Trend Analysis

The RDN is developing a monitoring and stewardship nodes framework to represent the integrated nature of stewardship policy / management action and watershed monitoring efforts. This model (see Figure 1 for a simplistic representation) frames management action and watershed monitoring as a part of a repeated cycle that allows an adaptive management approach to a dynamic system with diverse stakeholder and ecological goals. The RDN has defined four key nodes to the watershed monitoring component of this cycle: water chemistry, physical assessments, streamflow / hydrometric / groundwater monitoring, and biological.

Ecoscape reviewed the trend analysis results in the context of these four key nodes with the goal of systematically identifying the node that is most appropriate to target for parameter amelioration or for further assessment efforts. To structure this approach, Ecoscape associated parameters with the Random Forest model results obtained in the original assessment of the CWMN (Plewes et al. 2018). These models identified associations between surface water quality parameters and various landscape, anthropogenic, topographical, physical, and chemical characteristics (see Table A1 for a summary of these key model predictors and the node with which they are associated). Since the Random Forest models identified key characteristics that influence given parameters, Ecoscape associated any significantly increasing or decreasing trends with their most influential predictors to highlight landscape characteristics of import for a specific parameter and sample location. The Random Forest models were originally parameterized on the separated fall and summer datasets, so this trend analysis review was applied likewise to the significant trends identified for the individual seasons.

3.0 RECOMMENDATIONS

3.1. Trend-based Recommendations

3.1.1 Seasonal Mann-Kendall Trend Recommendations

Ecoscape identified a number of trends using a seasonal Mann-Kendall analysis and makes recommendations below based on the identified trends. When multiple sample locations on the same watercourse were identified as having significant trends, Ecoscape makes a watercourse-level recommendation; otherwise, Ecoscape's recommendation is associated with the sample location indicated.

On Annie Creek (Figure A1), Chase River (Figure A18), Upper Cameron River (Figure A4), Nanoose Creek (Figure A13), and Rosewall Creek (Figure A3), significantly increasing trends in dissolved oxygen were detected. These trends indicate an improvement in this parameter- no specific action required barring future changes to this trend direction or sudden exceedances.

On the Chase River, specific conductivity is significantly increasing at the Cat Stream sample location (Figure A18). The higher specific conductivity values are likely influenced by anthropogenic sources such as urban development and road run-off. An evaluation of the surrounding landscape to identify potential sources of contaminants is warranted given these values. Of note is that Cat Stream is located adjacent to a stormwater outlet (Plewes et al. 2018)- it is possible that discharge from this outlet contributes to elevated conductivity values.

On Walley Creek (Figure A14) specific conductivity is increasing and appears to be consistently higher in the summer sampling season, likely due to low flows during that period. The values are still within a reasonable range, but continued monitoring is warranted. If the indicated trend continues, it is likely that targeted amelioration should be considered.

On the Millstone River (Figure A17) at Biggs Road there is a degrading trend in both dissolved oxygen and turbidity. Ecoscape recommends a riparian assessment to determine if there has been a loss of riparian vegetation or some other potential cause of the degrading trends. Such an assessment is warranted to understand the functionality of the creek, identify sediment inputs, highlight opportunities to enhance fish habitat, and detail the condition of riparian vegetation. Based on the findings of this assessment, riparian restoration may be warranted. Additionally, activities and influences that impact Brannen Lake upstream of the sampling location on Millstone River at Biggs Road are likely to affect the water quality parameters downstream; assessment of the water quality and the overall lake health of Brannen Lake would likely provide valuable insight as to the trends observed in Millstone River.

On the Big Qualicum River, decreasing temperature trends were identified at two sites (Figure A2). These trends represent a general improvement relative to the 17 °C Aquatic Life Guideline for Coho rearing. No specific action required.

On the Little Qualicum River, the Mann-Kendall analysis identified an increasing trend in turbidity (Figure A5). However, values are still minimal and within a reasonable range. No specific action required to mitigate this trend, but continued monitoring of turbidity on the Little Qualicum is recommended.

At Beach Creek, there is an increasing trend in turbidity (Figure A6) that represents a degradation of that parameter in addition to consistent exceedances in both the summer and fall seasons in past and recent years. Individual exceedances may be due to rain events, but the consistency in the degrading trend and the exceedances in both seasons indicates that there is likely a more static underlying cause. An assessment of the surrounding landscape is warranted in an effort to determine overall cause and assess what measures need to be taken to address the degrading trend in turbidity. Such an assessment will guide targeted amelioration actions, which likely include improvements to storm water management and enhancement of riparian vegetation.

At Grandon Creek, dissolved oxygen appears to be slowly increasing (Figure A7) but values in summer are notably low relative to the instantaneous minimum guideline of 5 mg / L. Even though this parameter increase represents an overall improvement, Ecoscape recommends targeted nutrient sampling and further analysis to better understand the cause of the overall low dissolved oxygen value and identify any possible measures that may increase the rate of improvement.

At Center Creek, dissolved oxygen and temperature parameters are both trending towards improvement (Figure A8), though the rate of change appears to be slow. Continued monitoring for both is recommended since there are yet cases where the measured values meet or exceed guidelines.

On the Upper Englishman River, specific conductivity is degrading (Figure A9). Specific conductivity values are still relatively low, but are increasing at a rate of roughly 1 µS/cm per year. Mean values in 2022 were also higher in both summer and fall than any corresponding values in previous years. It is possible that this increase is driven by a land use change towards higher levels of anthropogenic influence. An evaluation of the surrounding landscape to identify potential sources of contaminants is warranted to identify if ameliorative actions are required to forestall a continued increase in the rate of degradation.

Turbidity is also increasing on the Upper Englishman River (Figure A9), but the slope of the trend is low. Additionally, the higher than normal turbidity in the fall of 2021 may have contributed to the identification of this trend, since the overall values in summer are reasonably consistent. Due to this lack of strong, clear direction, no specific new action is recommended, but monitoring should be continued.

At Shelly Creek, there are improving trends in temperature, turbidity, and dissolved oxygen (Figure A11); monitoring of these parameters should continue, since there are still exceedance cases at locations where these trends were identified, but no specific amelioration action is recommended. At Hamilton Road, however, specific conductivity is degrading. As was the case on the Englishman River upstream of Centre Fork Creek (Figure A9), conductivity values in 2022 were elevated relative to earlier years. It is possible that this increase is driven by anthropogenic sources of contamination on the landscape. Values are still relatively low, but it is possible that an evaluation of the landscape may identify sources of pollution that can be addressed with the aim of flattening the slow degrading trend.

Temperature at Swayne Creek is decreasing (Figure A10), which represents an improvement in this parameter. Continued monitoring is recommended, since summer temperatures are still high (but not recently exceeding) relative to the Aesthetic Drinking Water Objective of 15°C, but no action is required.

3.1.2 Systemic Trend Parameter Highlights

Ecoscape associated parameters with the summer- and fall-specific Random Forest model results obtained in the original assessment of the CWMN (Plewes et al. 2018) with all sample locations to identify, for all significant trends, the landscape parameters most likely to influence those trends. In the original analysis, the ten most influential parameters in each season on each parameter were identified (Figure A 20, Figure A 21). For the purposes of highlighting only those predictors with the greatest impact on the parameters of interest, Ecoscape has extracted the three most important predictors for each parameter in each season. For all trends identified using the non-seasonal Mann-Kendall analysis (in keeping with the original season-agnostic Random Forest model) Ecoscape has indicated the three most important predictors that influence each parameter (Table A2). These predictors can be referenced to give a broad sense of the key characteristics that may be further assessed in the case of degrading parameters.

3.2. General Recommendations

Ecoscape highlights here a number of recommendations for possible future works in the effort to inform stewardship efforts in the RDN and bolster knowledge about the physical, chemical, and biological components of the surface water quality in the CWMN.

3.2.1 Coordinates Review

Review the coordinates of CWMN surface water quality sampling locations (see section 2.5). The GPS coordinates for many of the sampling locations were collected over a decade ago. Over this time span, available GPS technology and accuracy has improved substantially. Ideally, these revised GPS fixes could be recorded with a dedicated high-resolution GPS device (such as one of the Arrow range from Eos Positioning Systems, https://eos-gnss.com/), but recording locations with a modern cell phone or tablet may achieve more accurate results than were possible in the early years of the CWMN monitoring program. This effort would provide not only a more accurate and precise record of where sampling events occur but would also provide ground truthing for the location of stream beds, which can improve the accuracy and confidence of basin delineation efforts.

3.2.2 Basin Delineation Review

Should the coordinate review (section 3.2.1) be undertaken, it may be possible to further refine the existing upslope areas. If the location of the monitoring (EMS) site for which a basin has been delineated is modified, that basin will no longer reflect the upslope area for the revised EMS site location. In cases where there is little change in GPS coordinates, any required modifications to the basin boundaries should be slight. However, in cases where the revised coordinates differ substantially from the original, basin boundaries may shift notably. Additionally, this refinement could include the review of stream network direction, Ministry of Transportation and Infrastructure road drainage system, and culverts to better characterize flow direction and upstream areas.

3.2.3 Accommodation of Biological Metrics

At present, the systematic approach used to identify CWMN nodes to target for increased monitoring or amelioration is based primarily on measurements of the physical and anthropogenic landscape. Using these measurements to identify nodes of interest will by default omit potential biological descriptors. A more involved review than could be achieved in this assessment by senior biologists may help identify critical biological metrics that could improve the prioritization of nodes.

3.2.4 Characterization of Novel Basins

With the delineation of novel basins for the additional CWMN sites (see section 2.5), the outer boundaries of the upslope area associated with these added sites are now defined. One possible next step in expanding the information associated with these sites is to summarize the land cover, physical topography, and anthropogenic impact in these added basins. In some cases, the newly defined basins represent sub-regions of existing basins and so the key spatial layers for this summary have already been consolidated and proofed (Plewes et al. 2018). In other instances, the basins delineated fall outside of the boundaries of the initial assessment; spatial layers may need to be obtained and validated for such basins.

3.2.5 Random Forest Model Rerun

Should the landscape characteristics for the novel basins (section 3.2.4) be pursued, it would make available additional information to the Random Forest approach used in Ecoscape's original assessment. Rerunning a version of the Random Forest analysis that includes the characterized novel basins should provide more refined model results.

4.0 LIMITATIONS

This memo has been prepared by Ecoscape and is intended for the sole and exclusive use of the RDN for the purposes set out in this report and to provide context for the assessment deliverables provided by Ecoscape to the RDN. Ecoscape has prepared this memo with the understanding that all available information on the past, present, and proposed conditions of the datasets have been disclosed. Ecoscape has relied upon personal communications with the RDN and other information sources to corroborate the documents and other records available for this assessment. The RDN has also acknowledged that for Ecoscape to properly provide the professional service, Ecoscape is relying upon full disclosure and accuracy of this information.

Any use of this report by a third party, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Ecoscape accepts no responsibility for damages, if any, suffered by any third party as a result of actions or decisions made based on this report.

5.0 REFERENCES

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APPENDIX A.: FIGURES

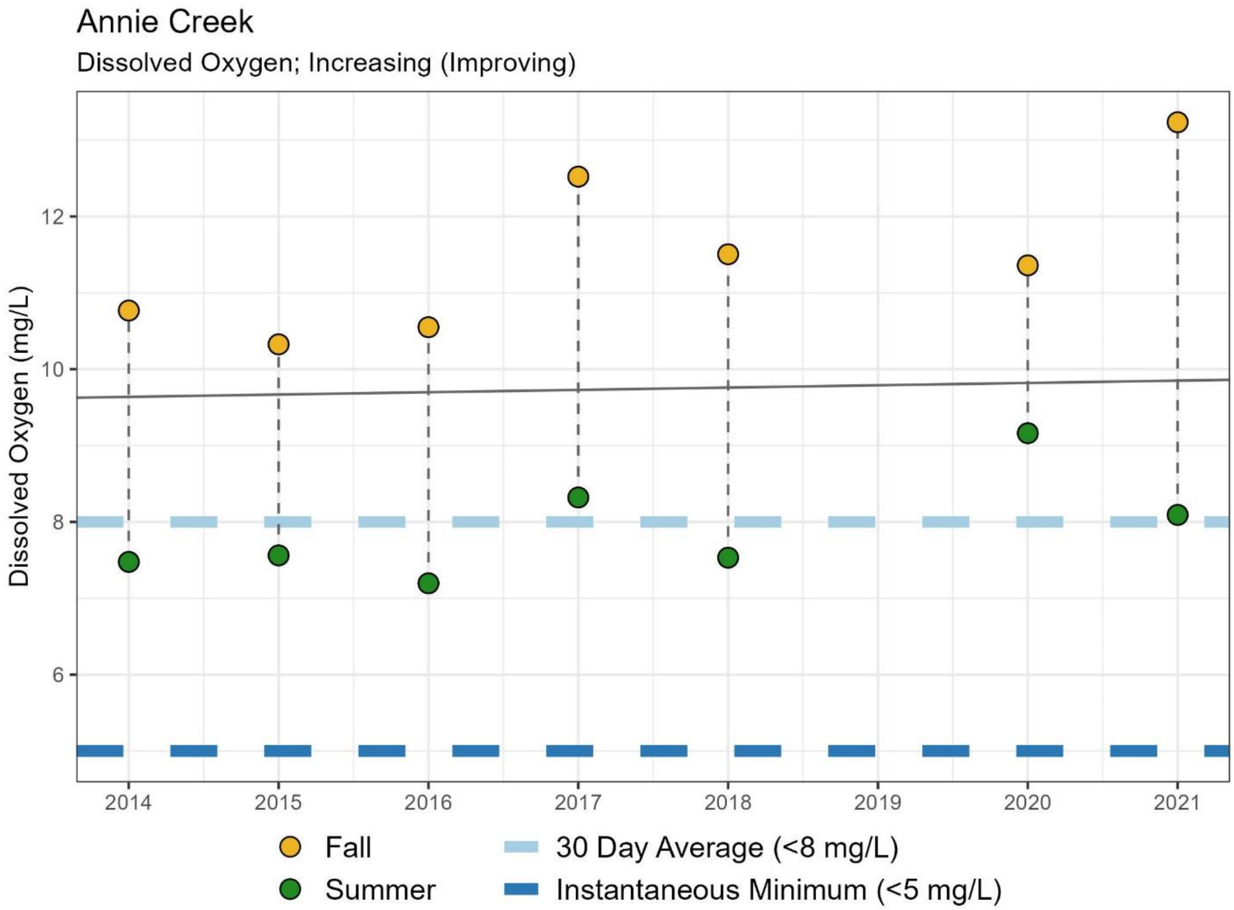
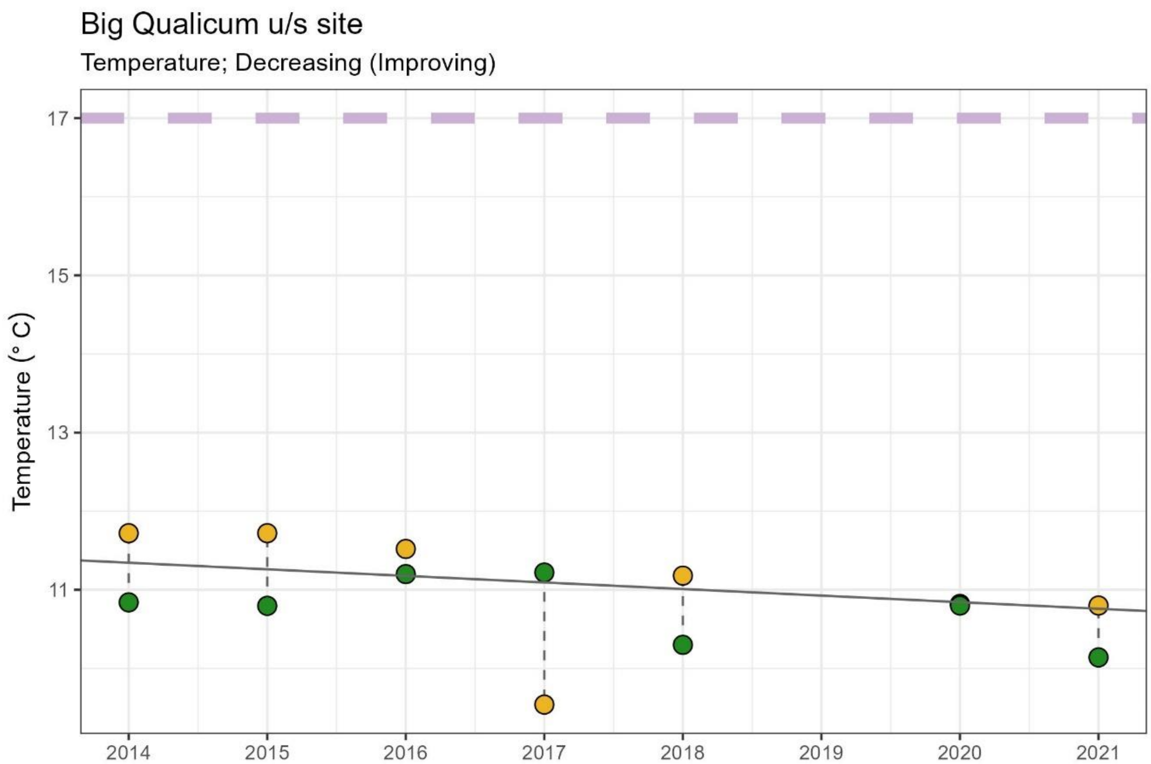


Figure A1 Trend in Dissolved Oxygen at Annie Creek.



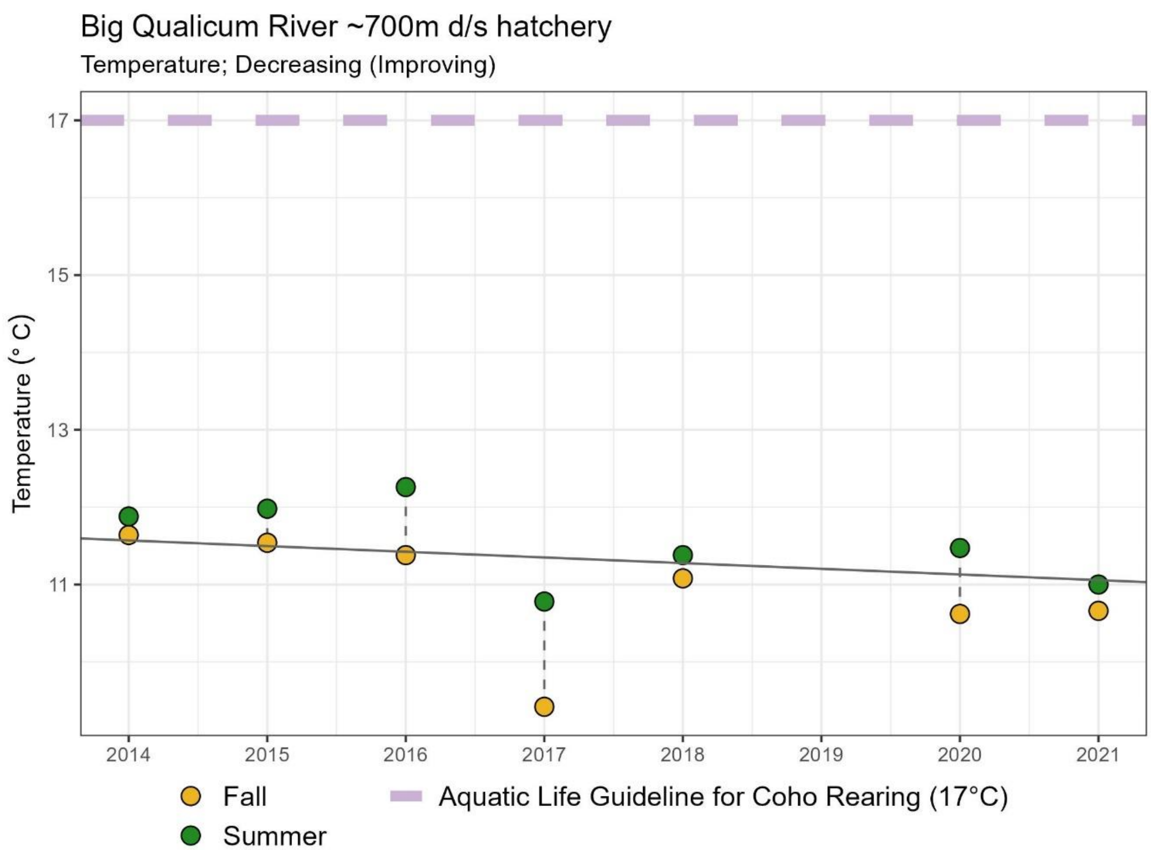


Figure A2 Trends in Temperature in the Big Qualicum River

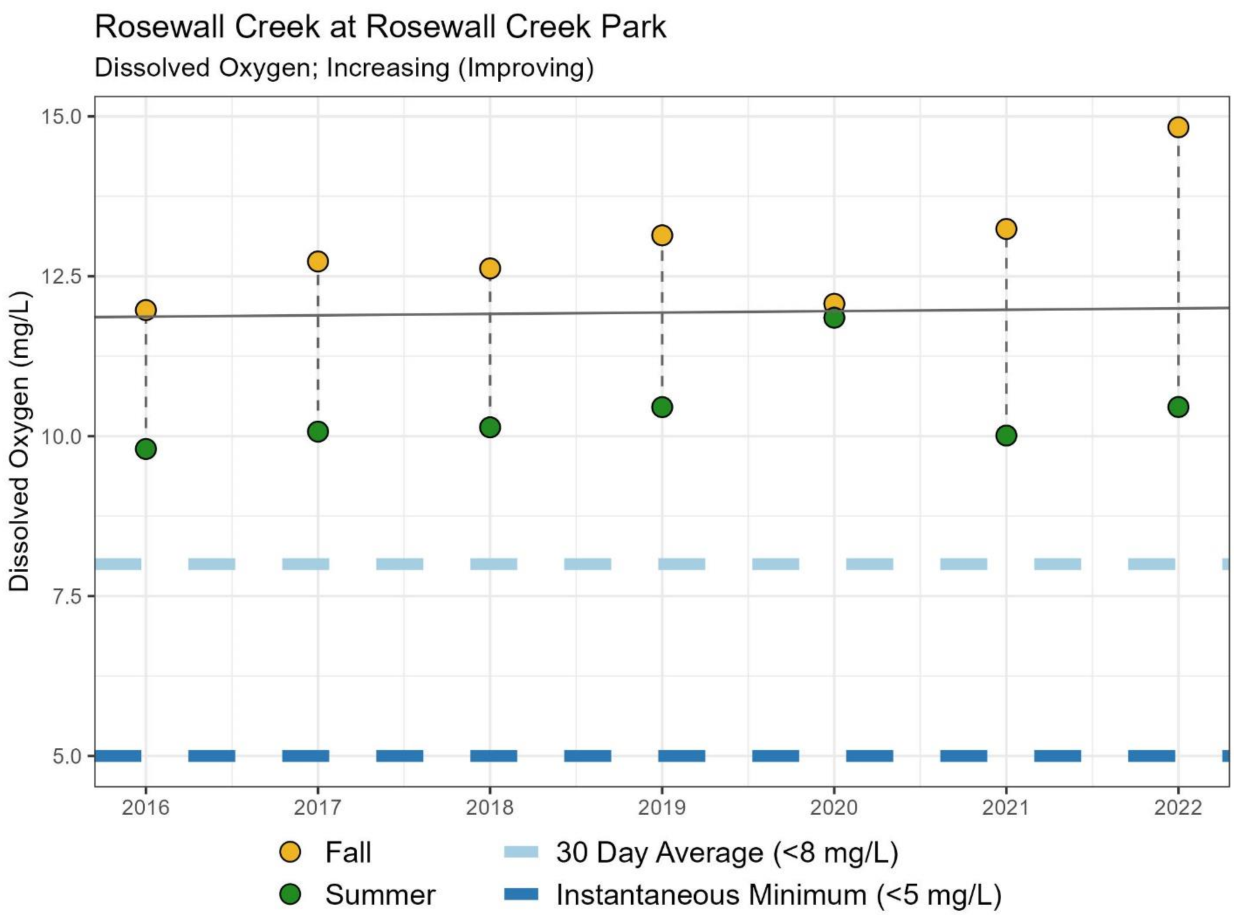


Figure A3 Trend in Dissolved Oxygen at Rosewall Creek Park.

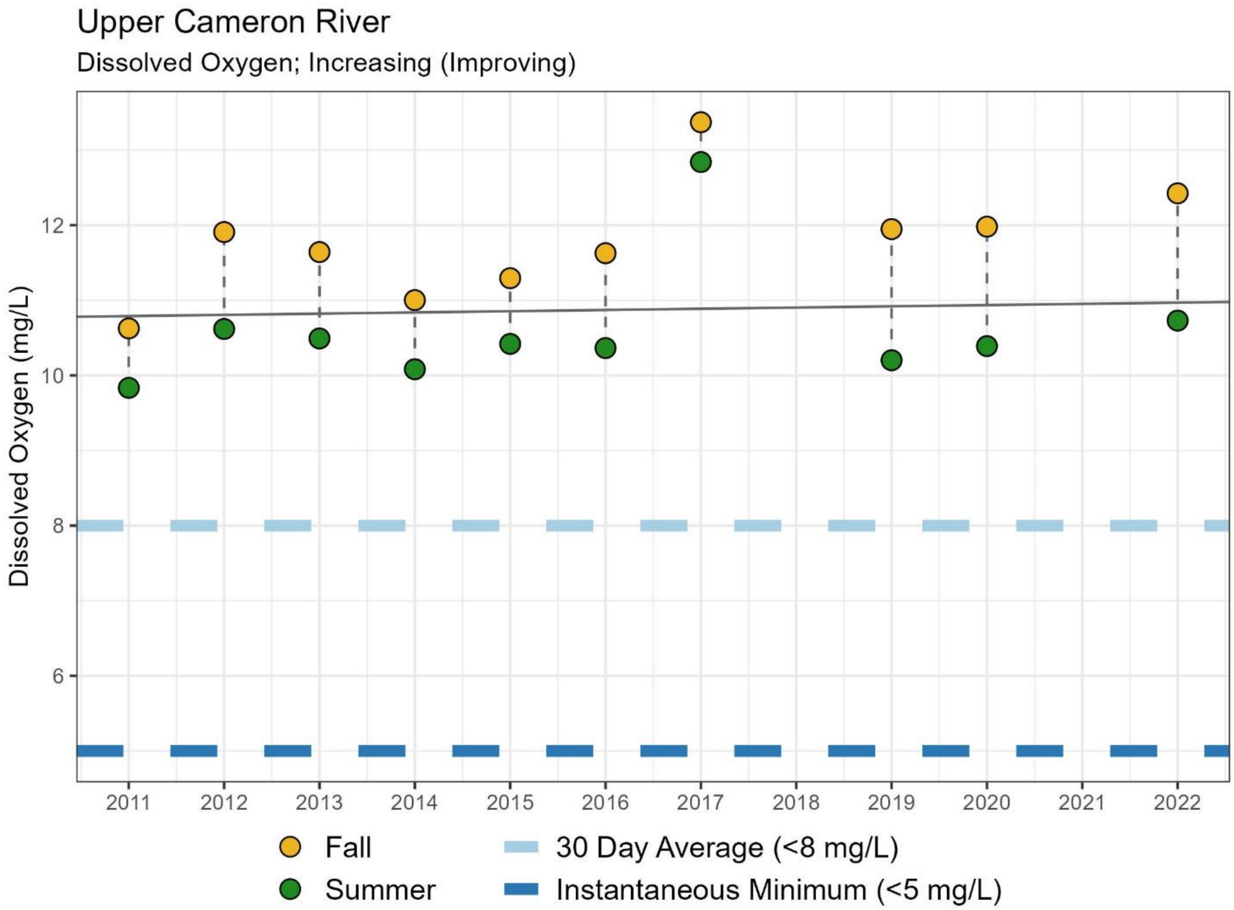


Figure A4 Trend in Dissolved Oxygen at Upper Cameron River.

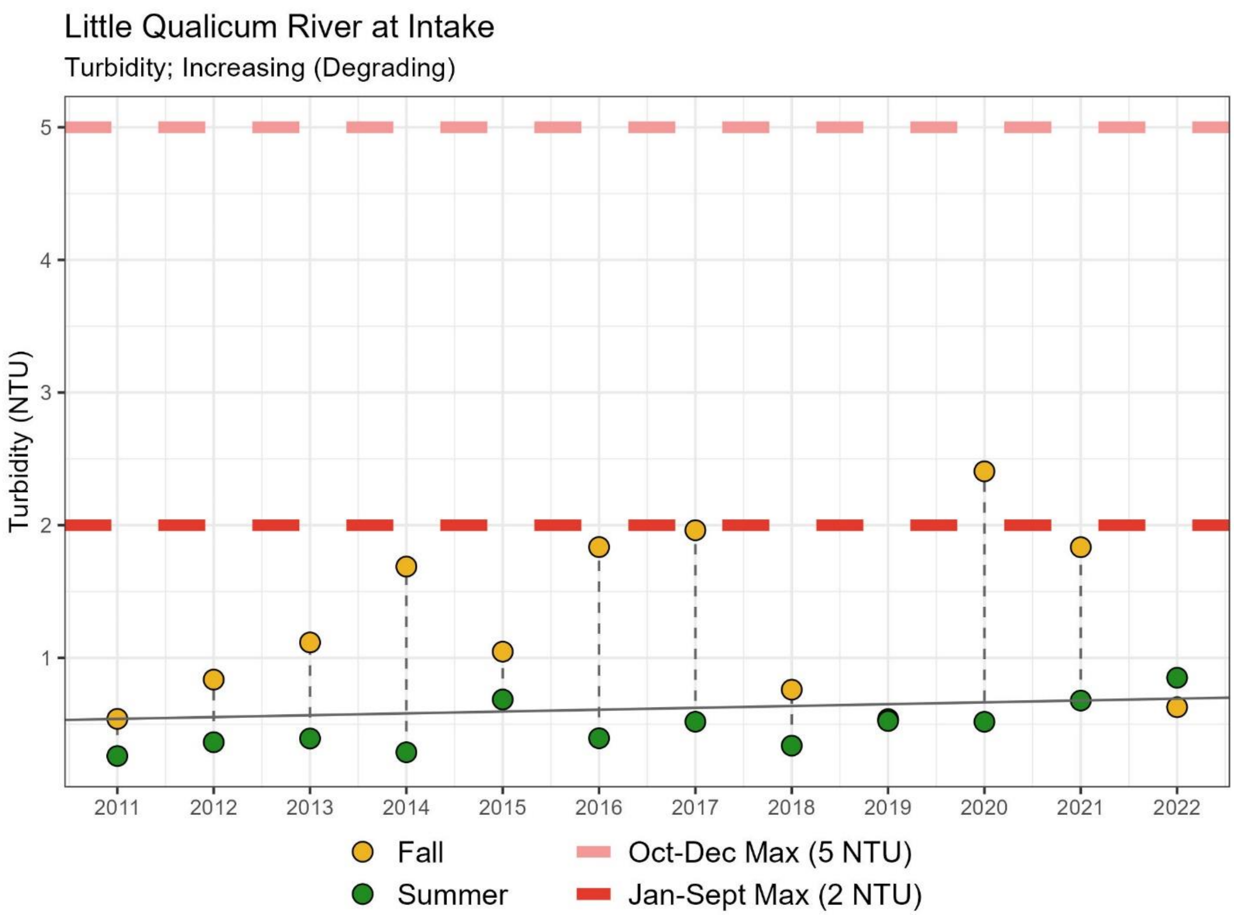


Figure A5 Trend in Turbidity at the Intake on Little Qualicum River.

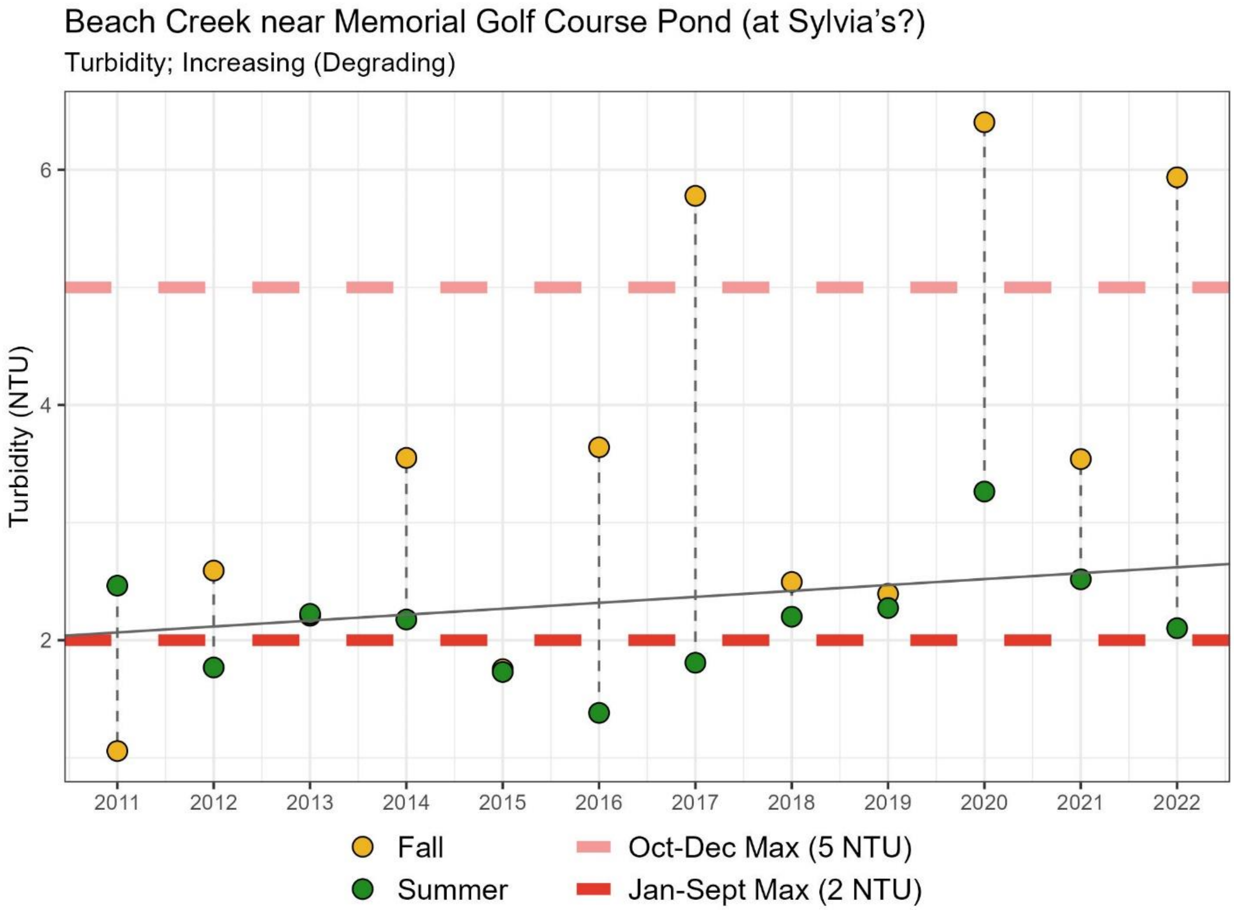


Figure A6 Trend in Turbidity on Beach Creek.

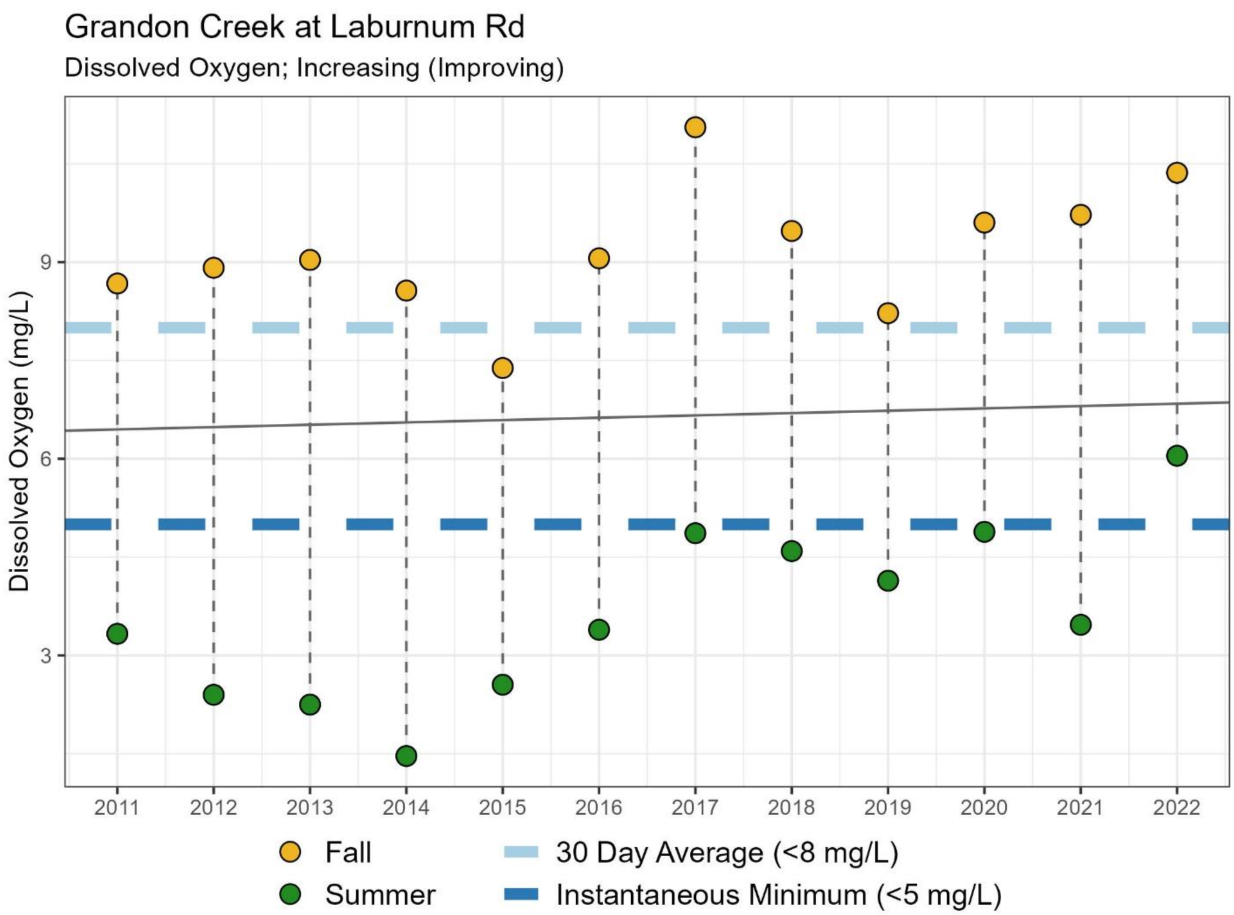


Figure A7 Trend in Dissolved Oxygen on Grandon Creek.

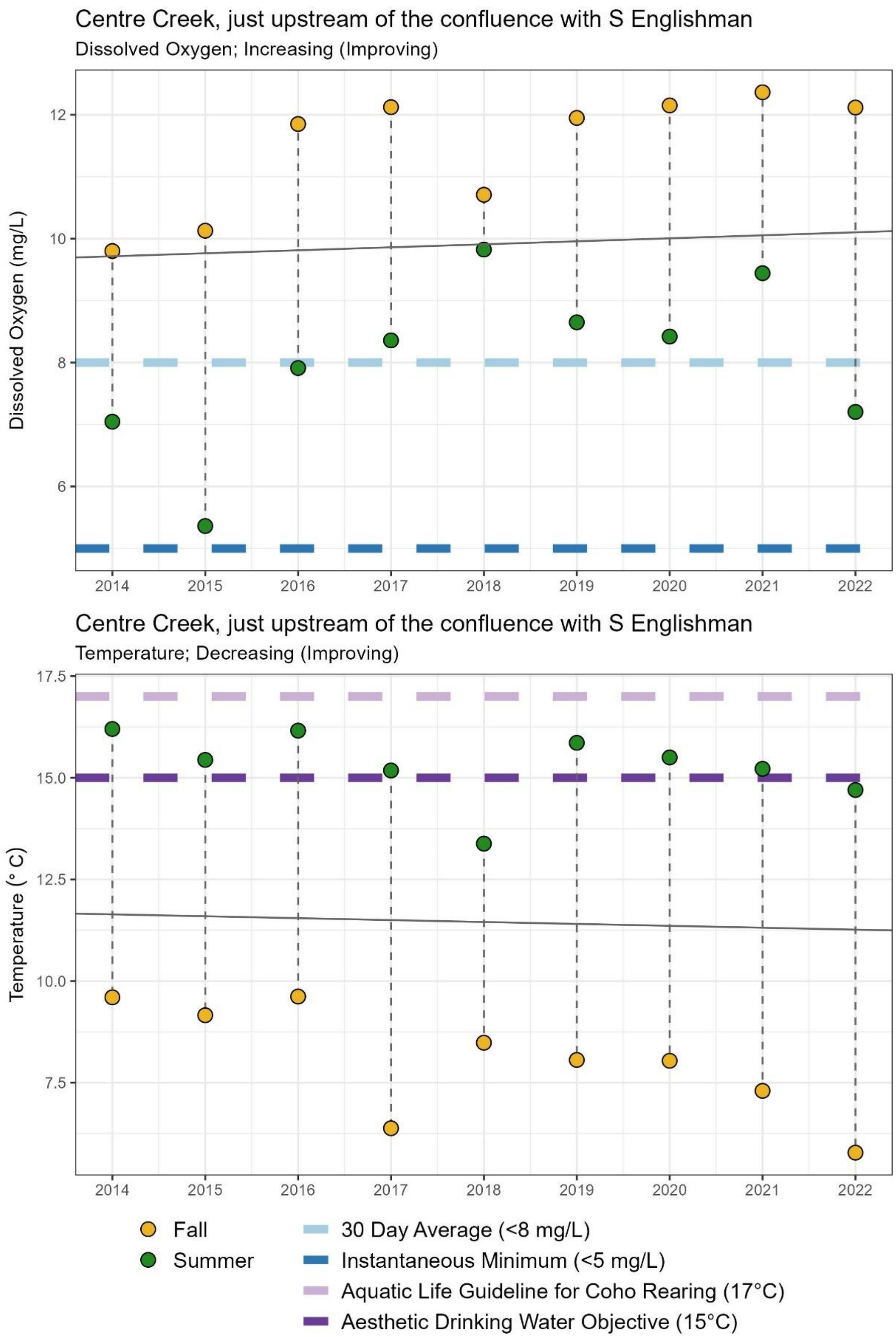


Figure A8 Trends in Dissolved Oxygen and Temperature on Centre Creek.

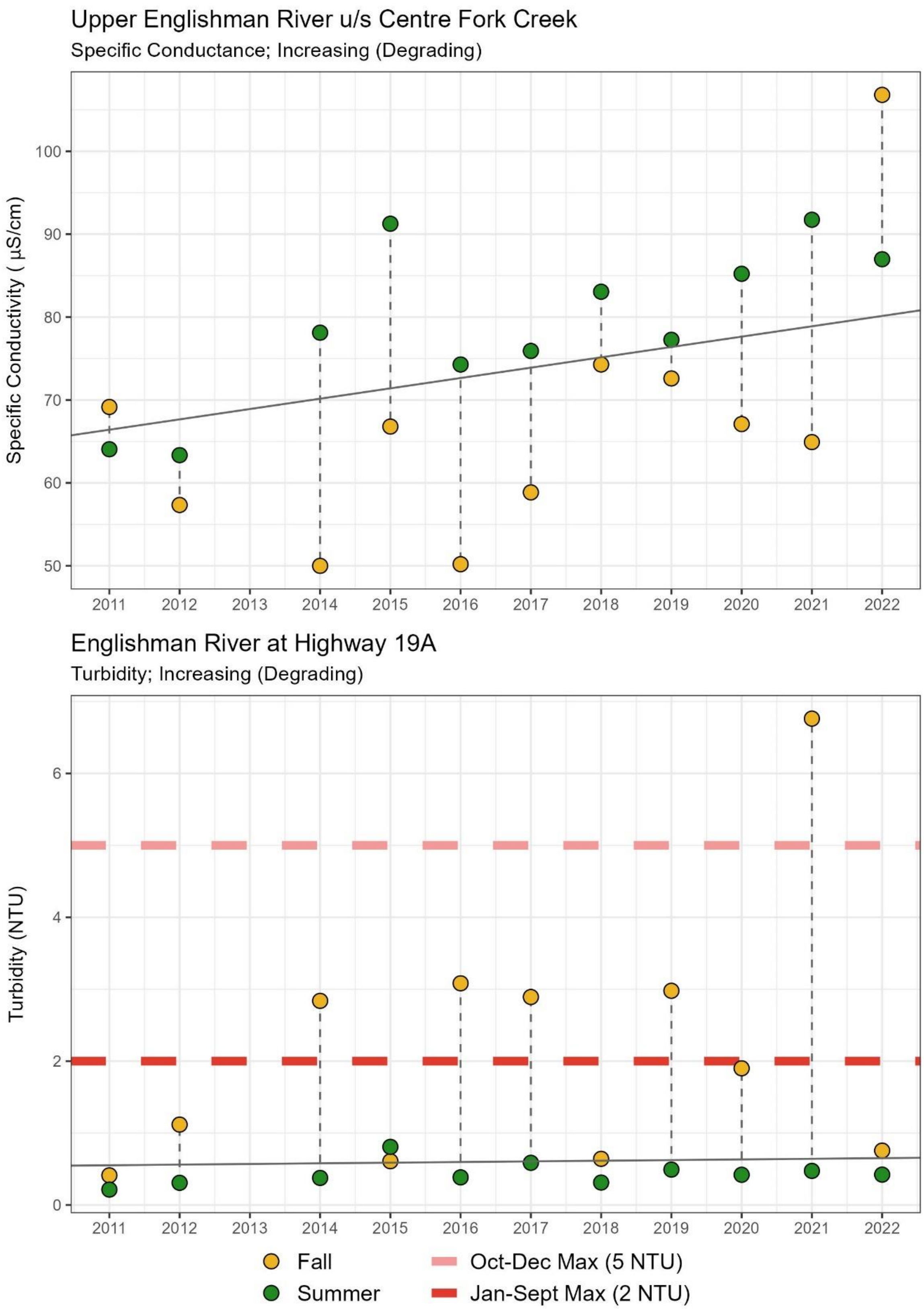


Figure A9 Trends in Specific Conductance and Turbidity on Englishman River.

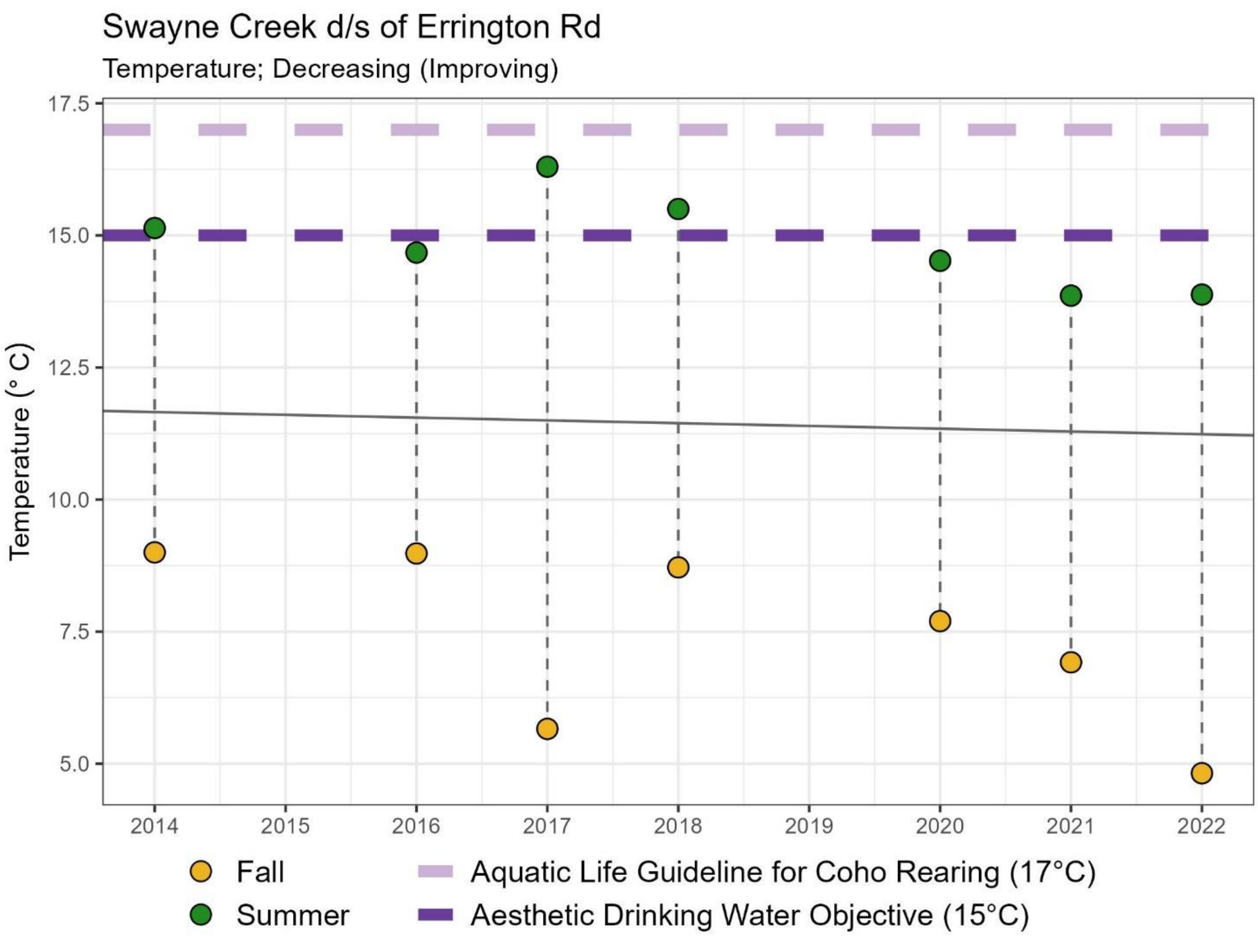


Figure A10 Trend in Temperature at Swayne Creek.

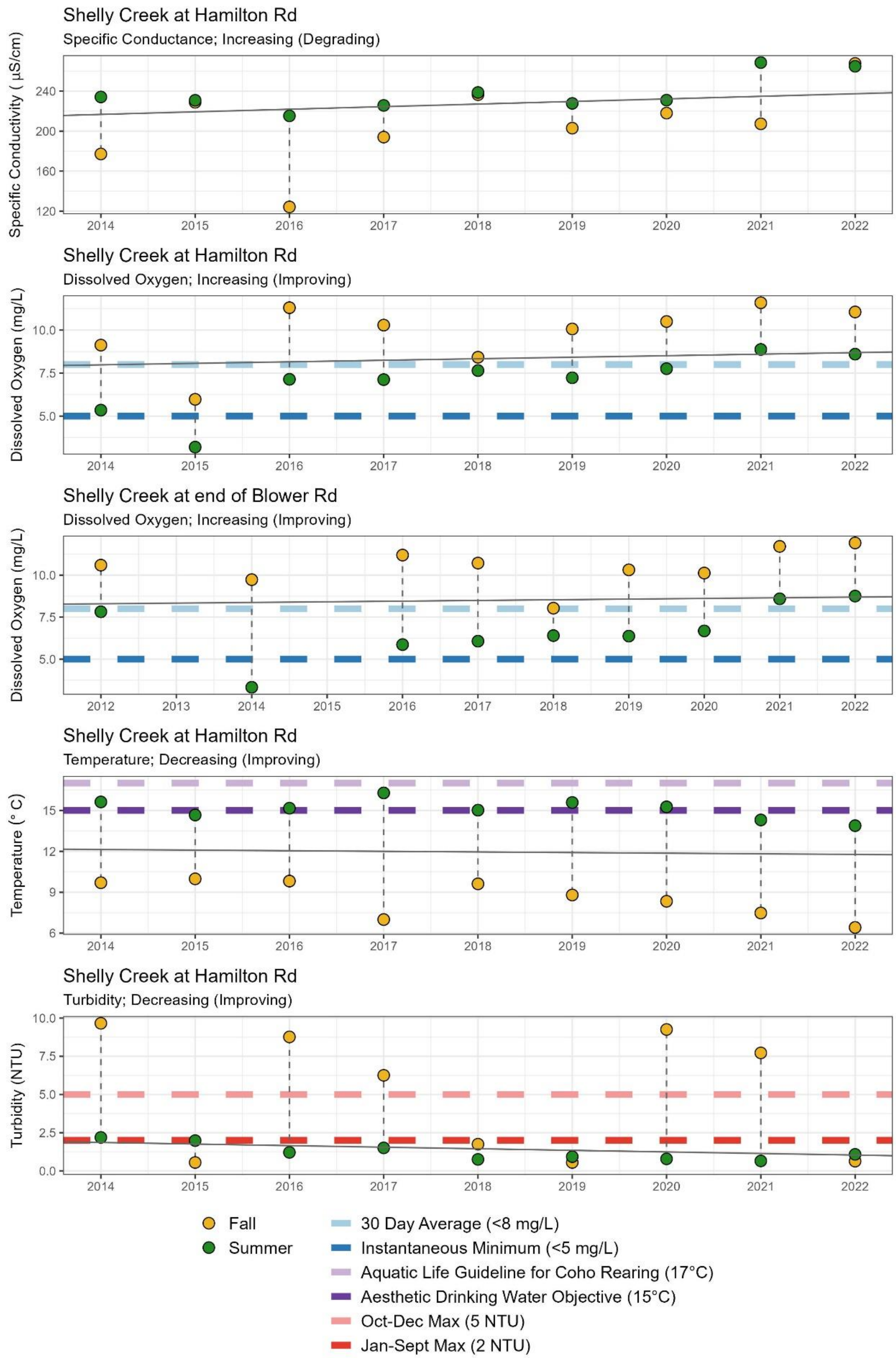


Figure A11 Trends in four parameters on Shelly Creek.

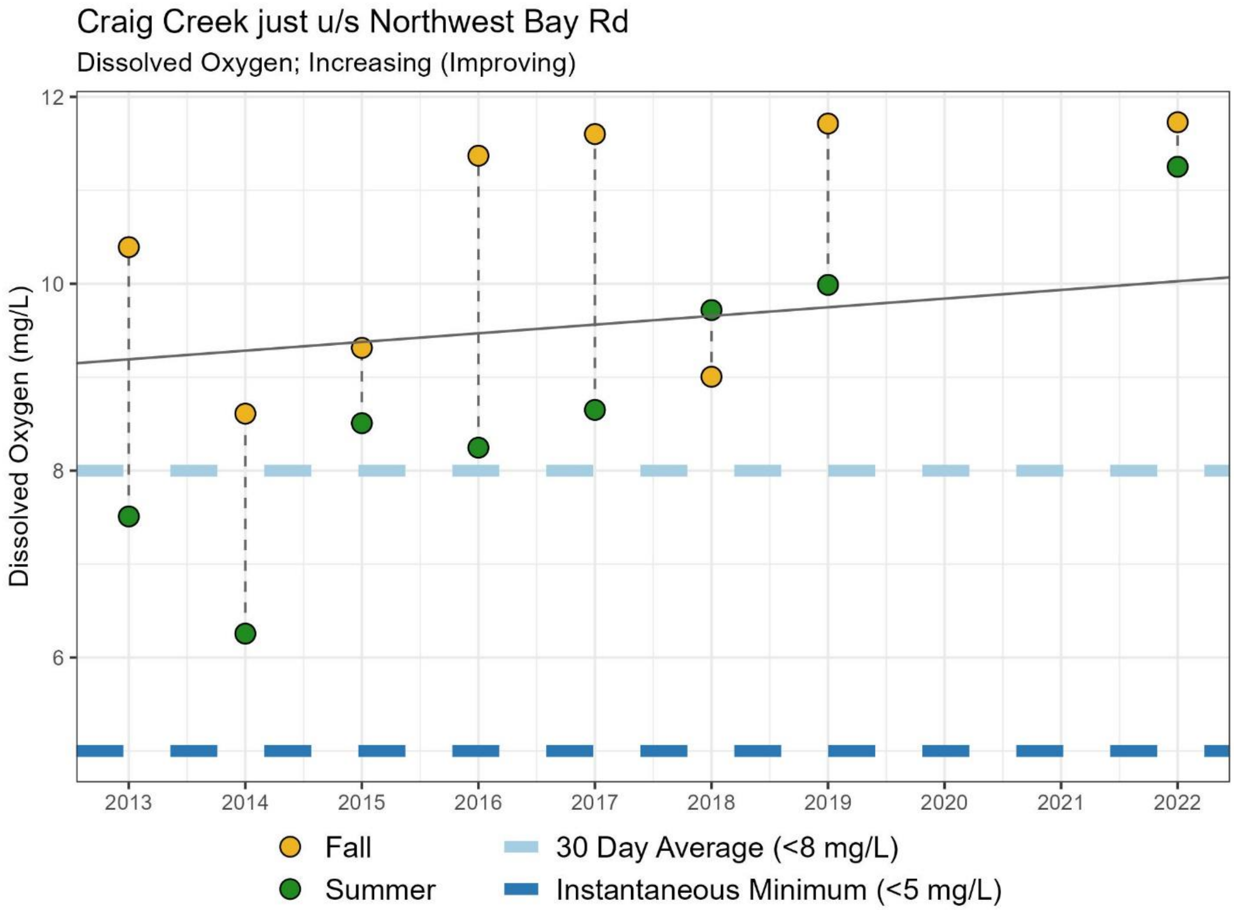


Figure A12 Trend in Dissolved Oxygen at Craig Creek.

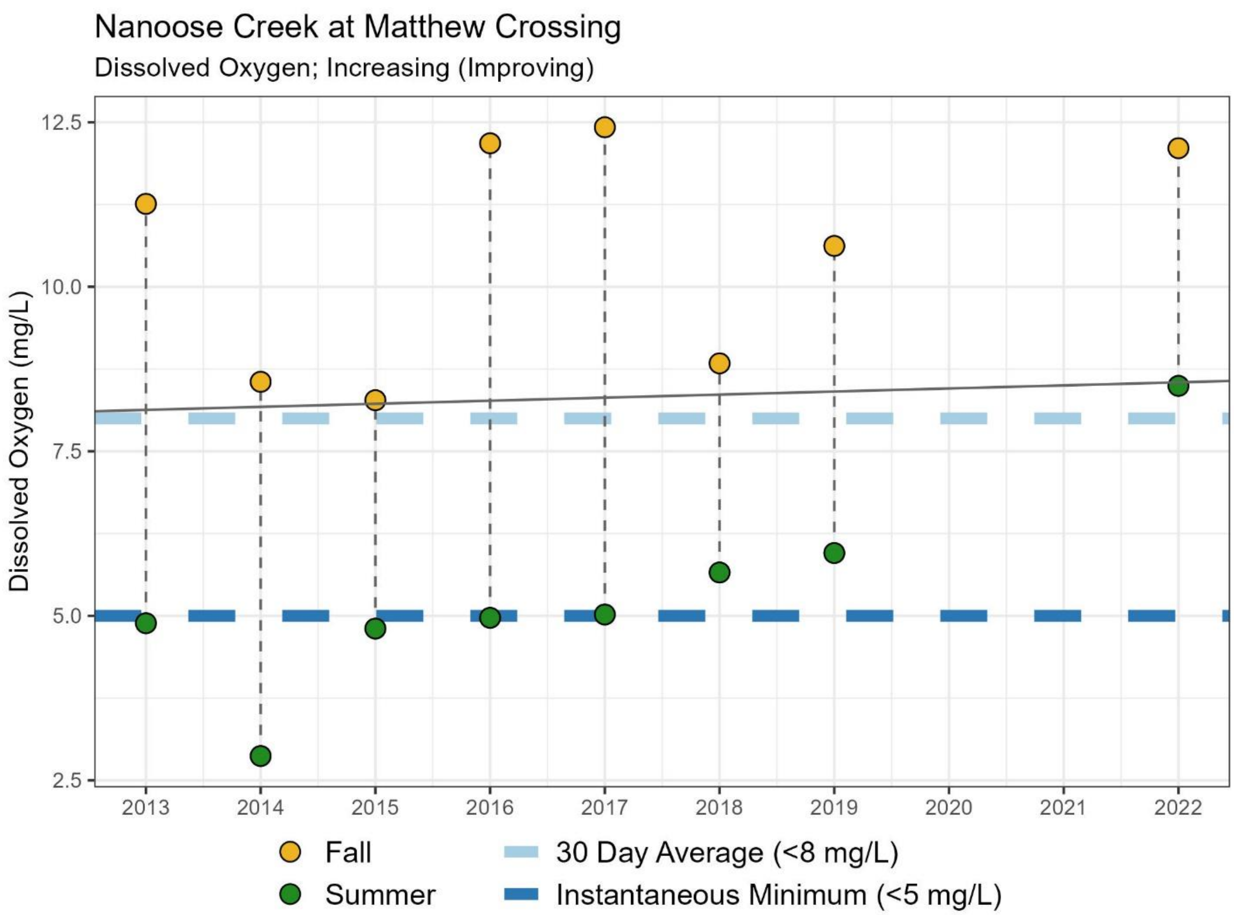


Figure A13 Trend in Dissolved Oxygen at Nanoose Creek.

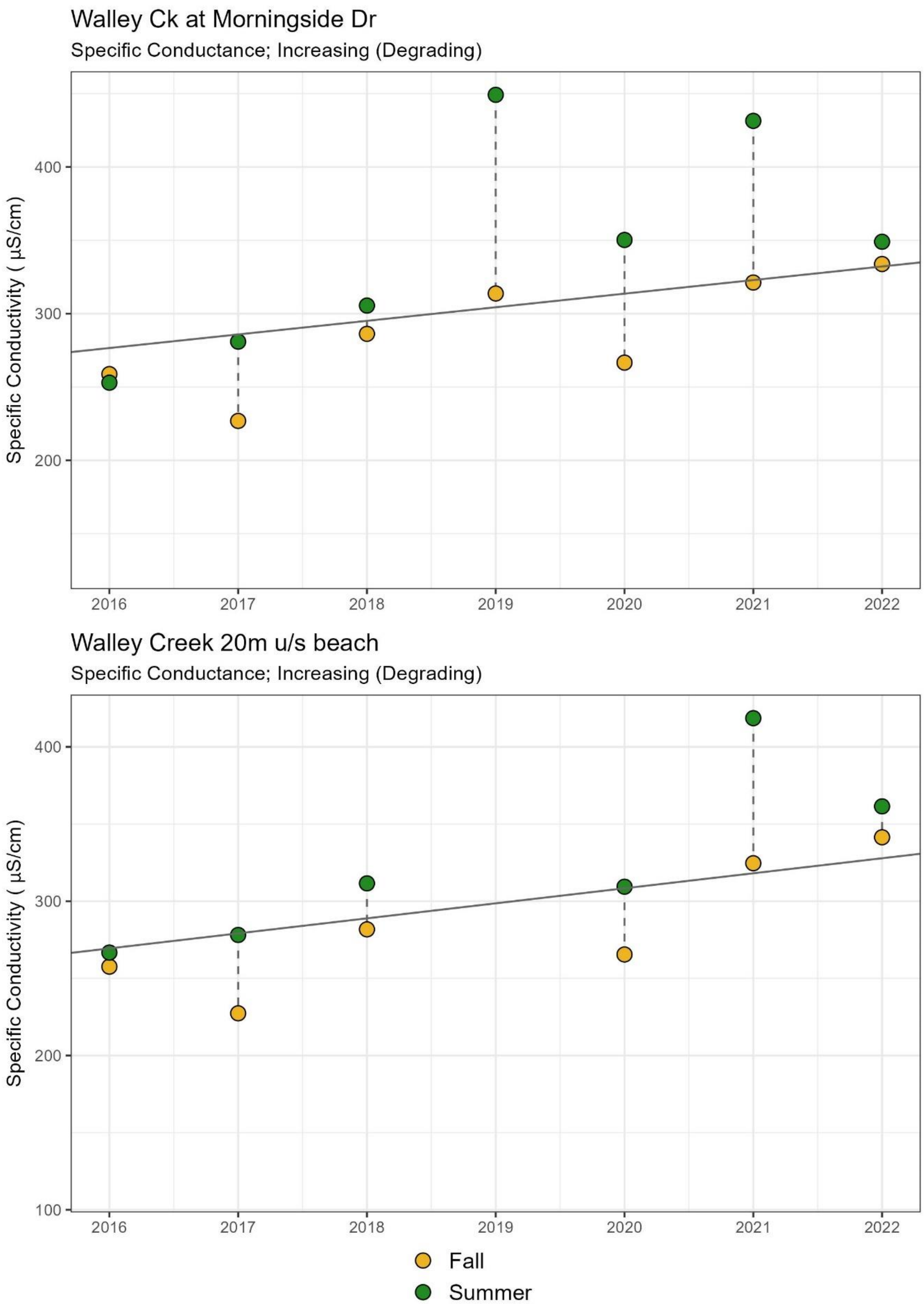


Figure A14 Trends in Specific Conductivity at Walley Creek.

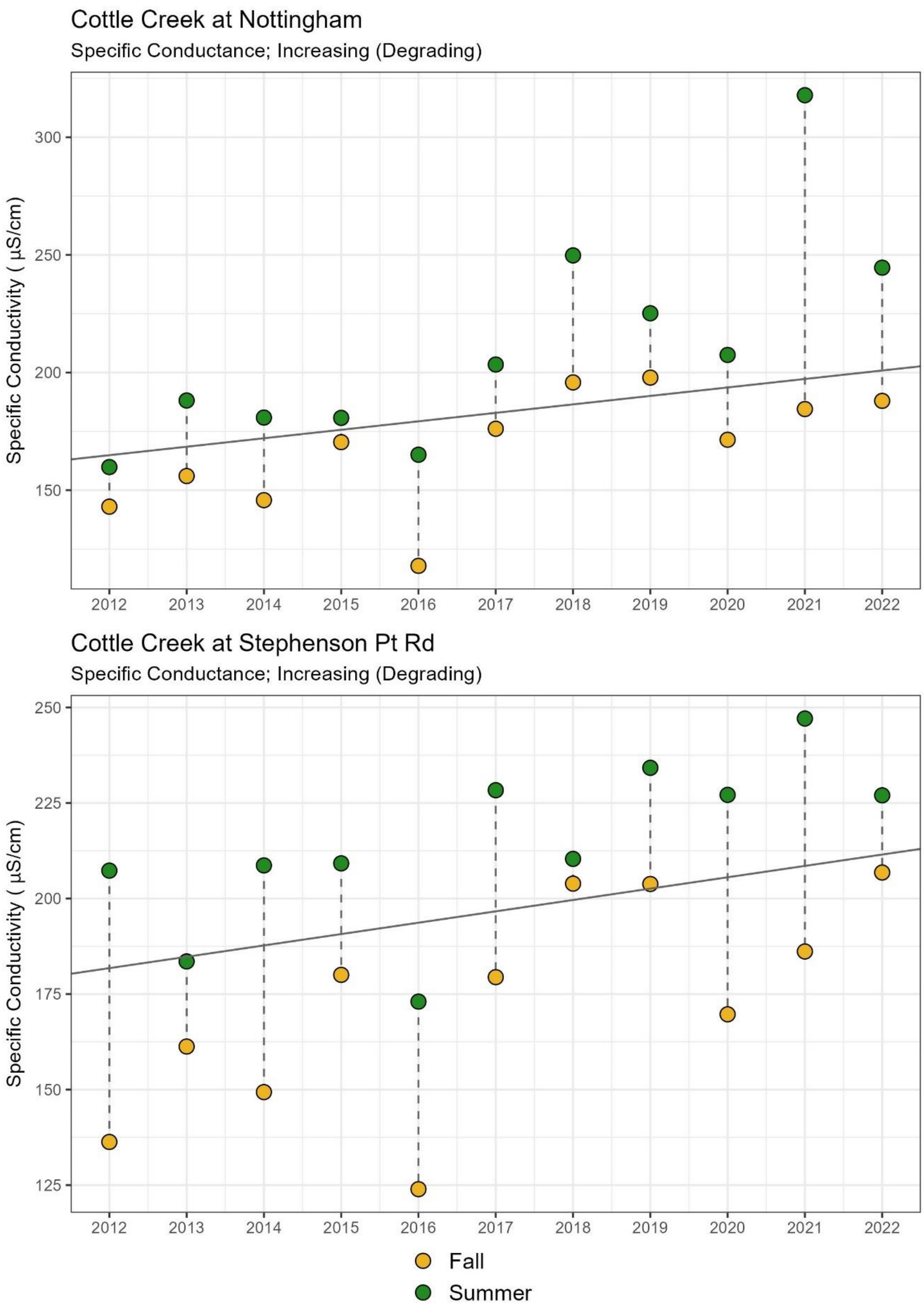


Figure A15 Trends in Specific Conductivity at Cottle Creek.

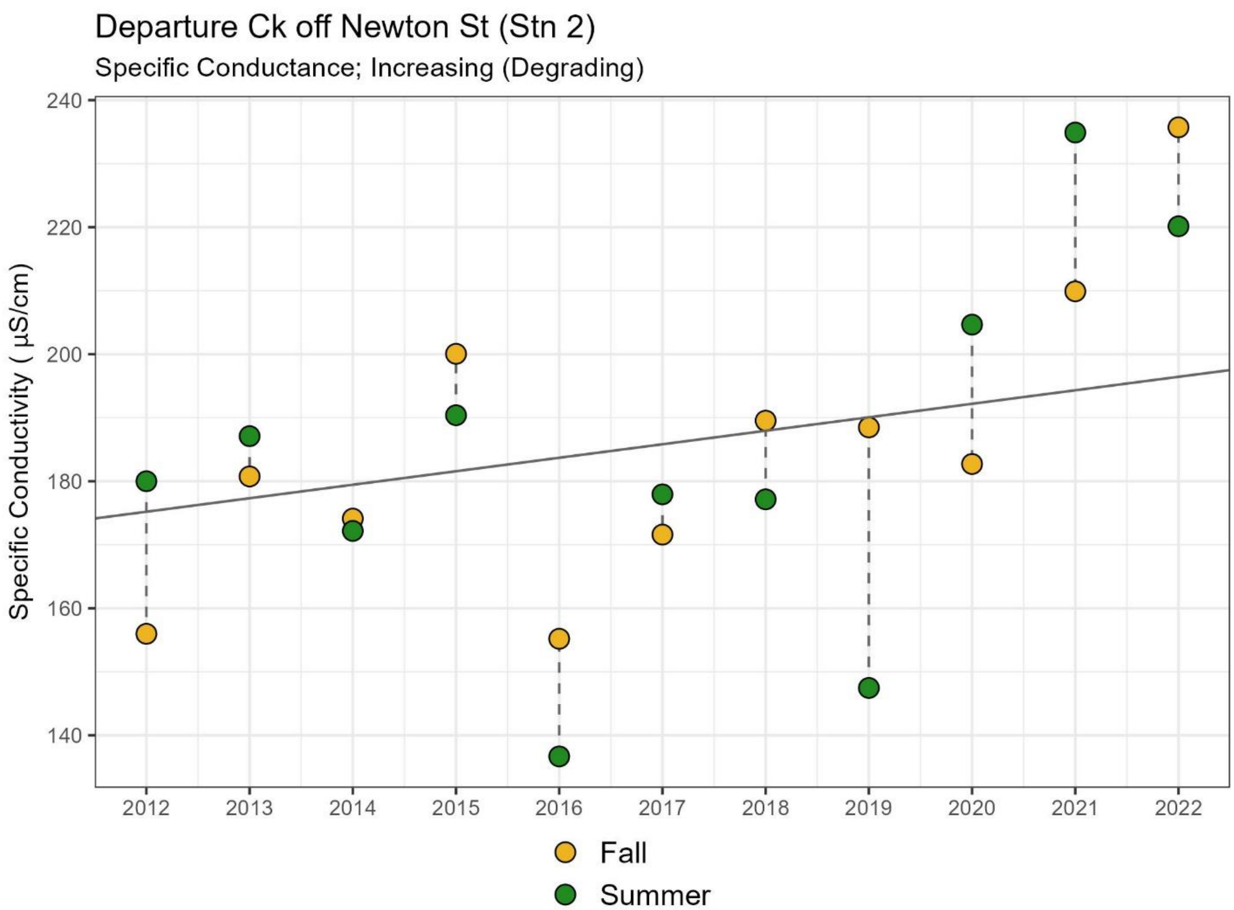


Figure A16 Trend in Specific Conductivity at Departure Creek.

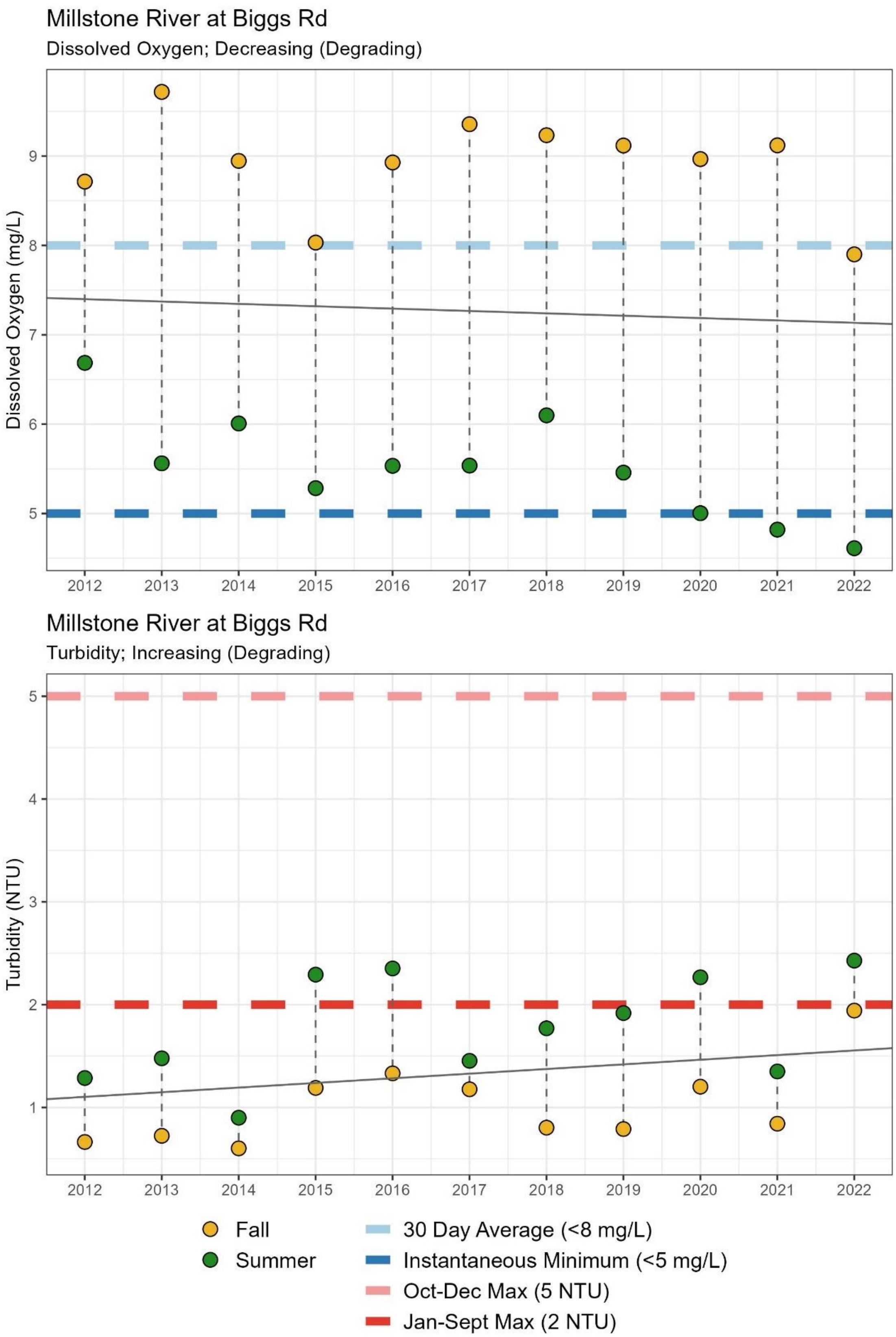


Figure A17 Trends in Dissolved Oxygen and Turbidity at Millstone River.

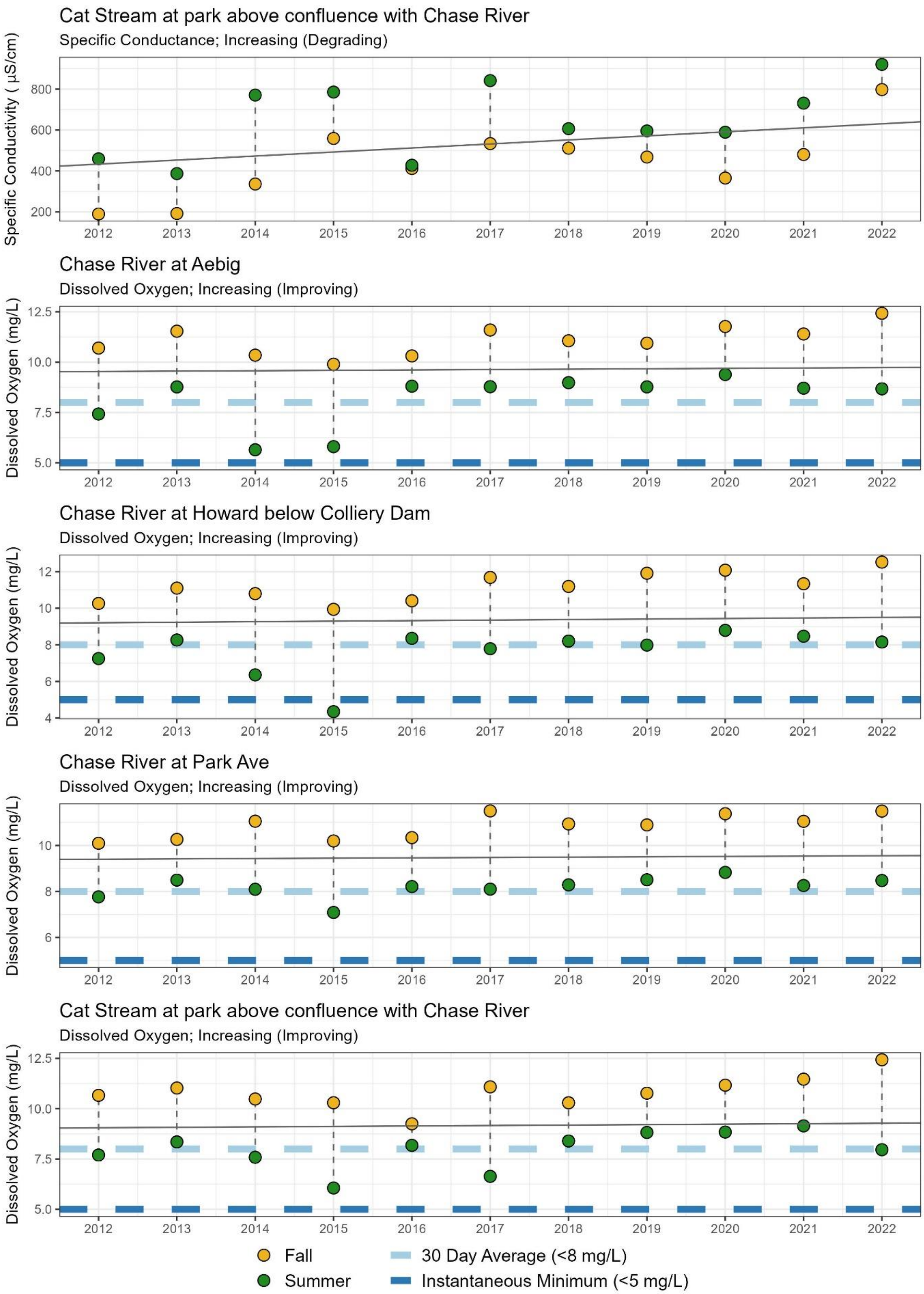


Figure A18 Trend in Specific Conductivity and Dissolved Oxygen at Chase River.

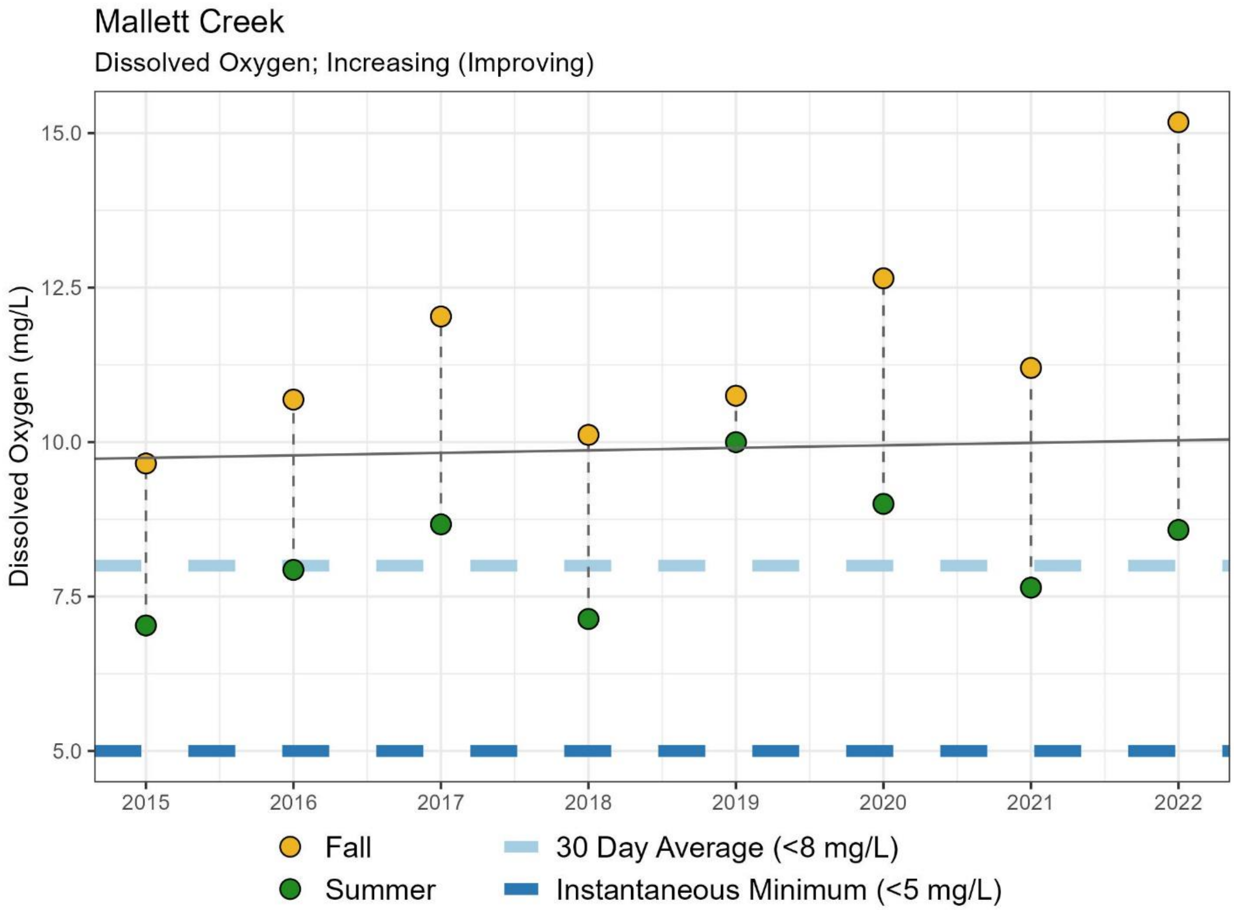


Figure A19 Trend in Dissolved Oxygen at Mallett Creek

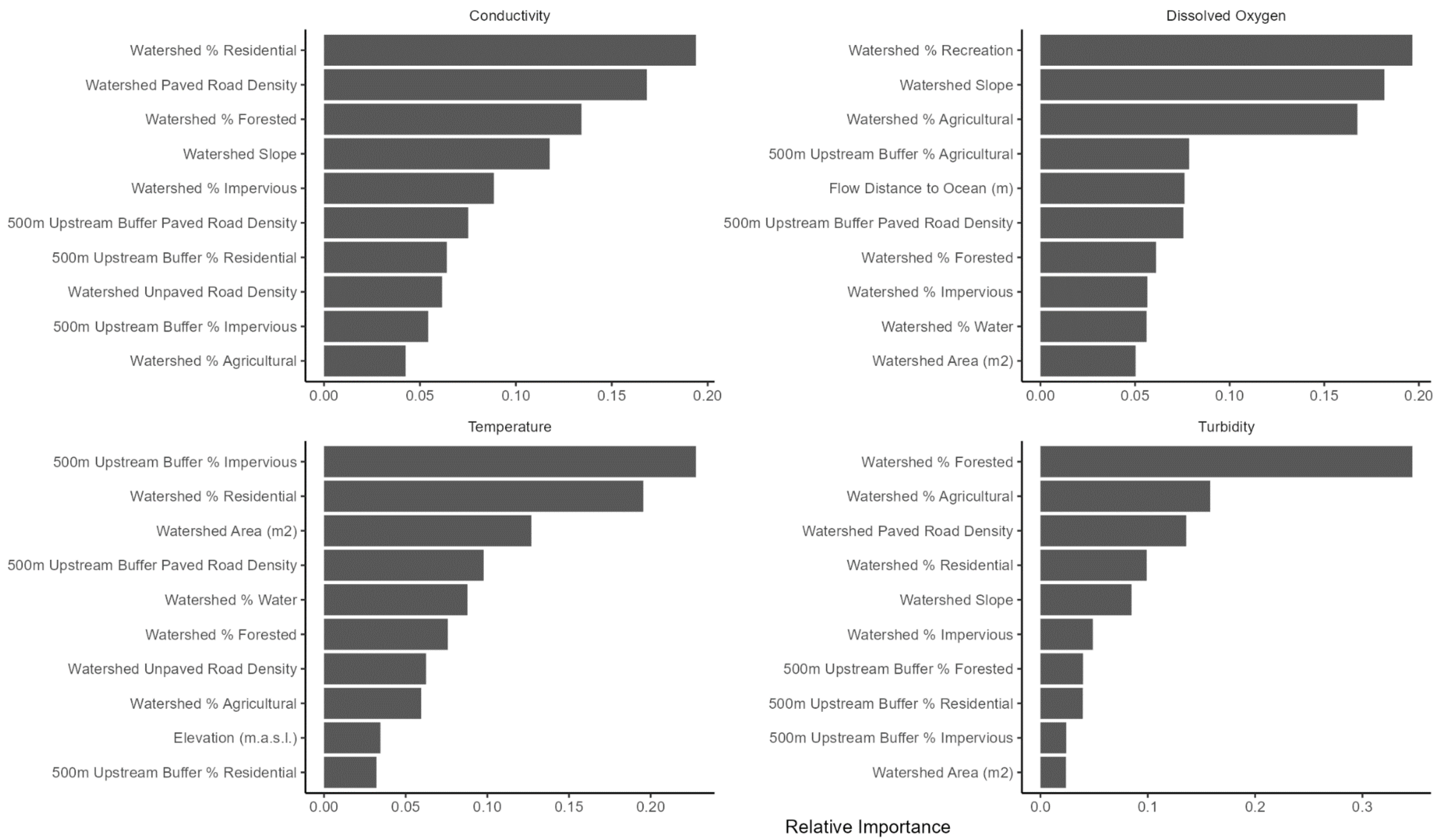


Figure A 20. Relative importance of predictors on key parameters in the summer season identified with a Random Forest model (Plewes et al. 2018).

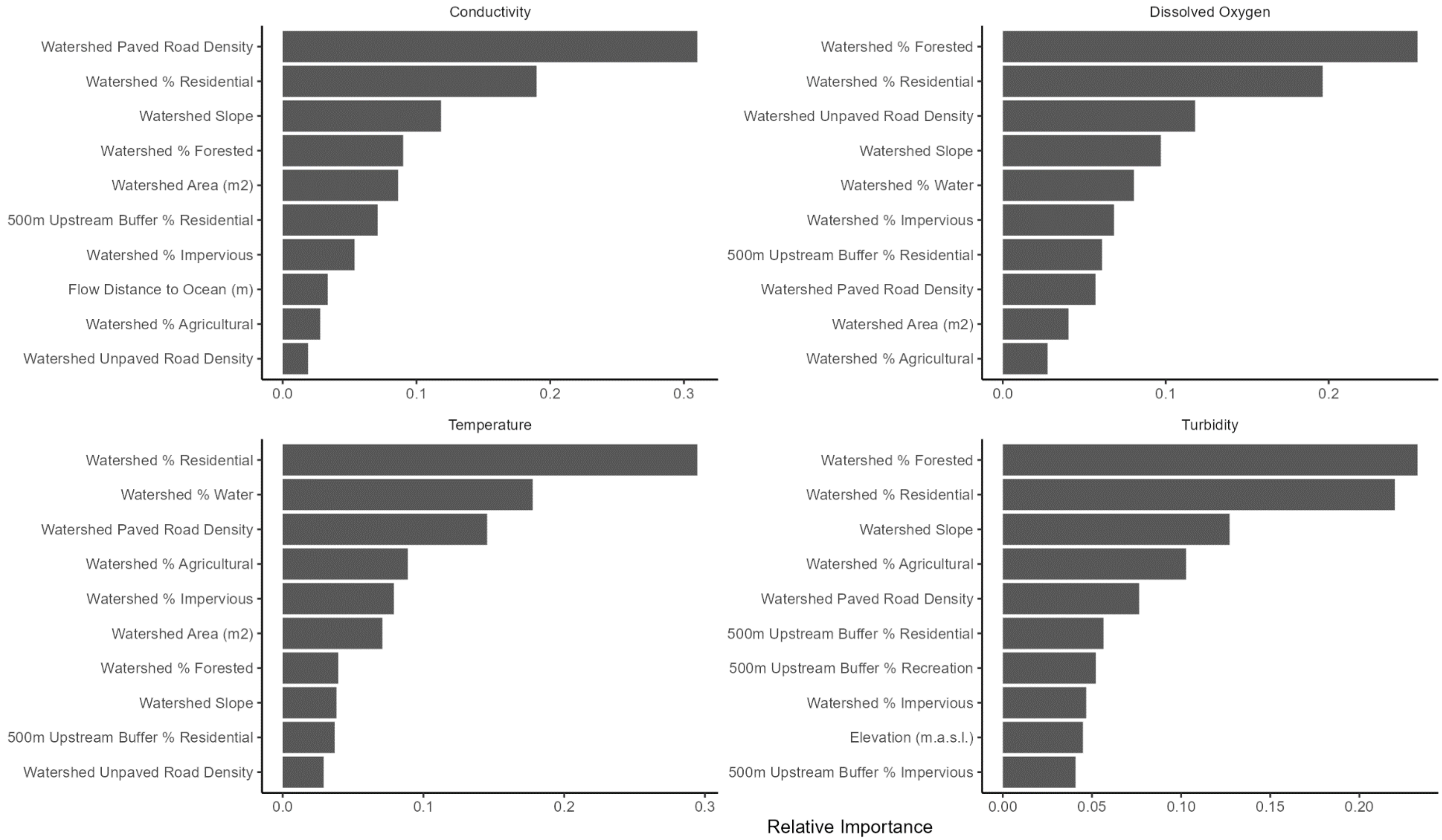


Figure A 21. Relative importance of predictors on key parameters in the fall season identified with a Random Forest model (Plewes et al. 2018).

APPENDIX B.: TABLES

Table A1. Summary of key predictors of parameter response in Random Forest modeling performed in Ecoscape's in-depth assessment of the CWMN watersheds.

Season	Parameter	Importance	Predictor	Associated Node
Summer	Conductivity	1	Watershed % Residential	Physical Assessments
		2	Watershed Paved Road Density	
		3	Watershed % Forested	
		4	Watershed Slope	Streamflow / Hydrometric / Groundwater
		5	Watershed % Impervious	Physical Assessments
		6	Buffer Paved Road Density	
		7	Buffer % Residential	
		8	Watershed Unpaved Road Density	
		9	Buffer % Impervious	
		10	Watershed % Agricultural	
	Dissolved Oxygen	1	Watershed % Recreation	Physical Assessments
		2	Watershed Slope	Streamflow / Hydrometric / Groundwater
		3	Watershed % Agricultural	Physical Assessments
		4	Buffer % Agricultural	
		5	Flow Distance to Ocean (m)	Streamflow / Hydrometric / Groundwater
		6	Buffer Paved Road Density	Physical Assessments
		7	Watershed % Forested	
		8	Watershed % Impervious	
		9	Watershed % Water	
		10	Watershed Area (m2)	
	Temperature	1	Buffer % Impervious	Physical Assessments
		2	Watershed % Residential	
		3	Watershed Area (m2)	
		4	Buffer Paved Road Density	
		5	Watershed % Water	
		6	Watershed % Forested	
		7	Watershed Unpaved Road Density	
		8	Watershed % Agricultural	
		9	Elevation (m.a.s.l.)	
		10	Buffer % Residential	
	Turbidity	1	Watershed % Forested	Physical Assessments
		2	Watershed % Agricultural	
		3	Watershed Paved Road Density	
		4	Watershed % Residential	
		5	Watershed Slope	Streamflow / Hydrometric / Groundwater
		6	Watershed % Impervious	Physical Assessments

Table A1. Summary of key predictors of parameter response in Random Forest modeling performed in Ecoscape's in-depth assessment of the CWMN watersheds.

Season	Parameter	Importance	Predictor	Associated Node
		7	Buffer % Forested	
		8	Buffer % Residential	
		9	Buffer % Impervious	
		10	Watershed Area (m2)	
Fall	Conductivity	1	Watershed Paved Road Density	Physical Assessments
		2	Watershed % Residential	
		3	Watershed Slope	Streamflow / Hydrometric / Groundwater
		4	Watershed % Forested	Physical Assessments
		5	Watershed Area (m2)	
		6	Buffer % Residential	
		7	Watershed % Impervious	
		8	Flow Distance to Ocean (m)	Streamflow / Hydrometric / Groundwater
		9	Watershed % Agricultural	Physical Assessments
		10	Watershed Unpaved Road Density	
	Dissolved Oxygen	1	Watershed % Forested	Physical Assessments
		2	Watershed % Residential	
		3	Watershed Unpaved Road Density	
		4	Watershed Slope	Streamflow / Hydrometric / Groundwater
		5	Watershed % Water	Physical Assessments
		6	Watershed % Impervious	
		7	Buffer % Residential	
		8	Watershed Paved Road Density	
		9	Watershed Area (m2)	
		10	Watershed % Agricultural	
	Temperature	1	Watershed % Residential	Physical Assessments
		2	Watershed % Water	
		3	Watershed Paved Road Density	
		4	Watershed % Agricultural	
		5	Watershed % Impervious	
		6	Watershed Area (m2)	
		7	Watershed % Forested	
		8	Watershed Slope	Streamflow / Hydrometric / Groundwater
		9	Buffer % Residential	Physical Assessments
		10	Watershed Unpaved Road Density	
	Turbidity	1	Watershed % Forested	Physical Assessments
		2	Watershed % Residential	

Table A1. Summary of key predictors of parameter response in Random Forest modeling performed in Ecoscape's in-depth assessment of the CWMN watersheds.

Season	Parameter	Importance	Predictor	Associated Node
		3	Watershed Slope	Streamflow / Hydrometric / Groundwater
		4	Watershed % Agricultural	Physical Assessments
		5	Watershed Paved Road Density	
		6	Buffer % Residential	
		7	Buffer % Recreation	
		8	Watershed % Impervious	
		9	Elevation (m.a.s.l.)	
		10	Buffer % Impervious	

Table A2. Sample locations at which significant trends were detected using a Mann-Kendall trend analysis approach. First, second, and third predictors indicate the three most important predictors identified by a Random Forest Model (Plewes et al., 2018) for the given parameter.

Geographic Description	EMS Number	Season	Parameter	Trend	First Predictor	Second Predictor	Third Predictor
Beach Creek near Chester Rd at Hemsworth Rd	E288092	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
Beach Creek near Memorial Golf Course Pond (at Sylvia's?)	E288093	Fall	Turbidity	Degrading	Watershed % Forested	Watershed % Residential	Watershed Slope
Big Qualicum River ~700m d/s hatchery	E298598	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Big Qualicum u/s site	E298597	Fall	Temperature	Degrading	Watershed % Residential	Watershed % Water	Watershed Paved Road Density
Centre Creek, just upstream of the confluence with S Englishman	E299852	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Centre Creek, just upstream of the confluence with S Englishman	E299852	Fall	Temperature	Degrading	Watershed % Residential	Watershed % Water	Watershed Paved Road Density
Chase River at Howard below Colliery Dam	E290484	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Chase River at Park Ave	E290485	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Cottle Creek at Nottingham	E290473	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Cottle Creek at Nottingham	E290473	Fall	Conductivity	Degrading	Watershed Paved Road Density	Watershed % Residential	Watershed Slope
Cottle Creek at Stephenson Pt Rd	E290475	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Cottle Creek at Stephenson Pt Rd	E290475	Fall	Conductivity	Degrading	Watershed Paved Road Density	Watershed % Residential	Watershed Slope
Cottle Creek d/s of Hammond Bay Rd	E309186	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density

Table A2. Sample locations at which significant trends were detected using a Mann-Kendall trend analysis approach. First, second, and third predictors indicate the three most important predictors identified by a Random Forest Model (Plewes et al., 2018) for the given parameter.

Geographic Description	EMS Number	Season	Parameter	Trend	First Predictor	Second Predictor	Third Predictor
Craig Creek just u/s Northwest Bay Rd	E294017	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Departure Ck at outlet (Stn 4)	E290472	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density
Departure Ck off Newton St (Stn 2)	E290470	Fall	Conductivity	Degrading	Watershed Paved Road Density	Watershed % Residential	Watershed Slope
French Creek at Barclay Bridge	E243022	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
French Creek at Grafton Rd	E243024	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
Grandon Creek at Laburnum Rd	E288091	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Grandon Creek at Laburnum Rd	E288091	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Grandon Creek at West Crescent (Caissons)	E288090	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
Little Qualicum River at Intake	E256394	Summer	Dissolved Oxygen	Degrading	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Little Qualicum River at Intake	E256394	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density
Mallett Creek	E304070	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Millstone River at Biggs Rd	E290478	Summer	Dissolved Oxygen	Degrading	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Millstone River at East Wellington	E290480	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density

Table A2. Sample locations at which significant trends were detected using a Mann-Kendall trend analysis approach. First, second, and third predictors indicate the three most important predictors identified by a Random Forest Model (Plewes et al., 2018) for the given parameter.

Geographic Description	EMS Number	Season	Parameter	Trend	First Predictor	Second Predictor	Third Predictor
Millstone River in Barsby Park	E290481	Summer	Dissolved Oxygen	Degrading	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Morrison Creek u/s from Englishman River	E248835	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Nanaimo River u/s Haslam Ck ~500m d/s hwy bridge	E287699	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
Nanoose Creek at Matthew Crossing	E294020	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Nanoose Creek at Matthew Crossing	E294020	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)
Nanoose Creek at Nanoose Campground	E294019	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Rosewall Creek at Rosewall Creek Park	E306374	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density
Shelly Creek at Hamilton Rd	E287131	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Shelly Creek at Hamilton Rd	E287131	Summer	Turbidity	Degrading	Watershed % Forested	Watershed % Agricultural	Watershed Paved Road Density
Shelly Creek at Hamilton Rd	E287131	Fall	Temperature	Degrading	Watershed % Residential	Watershed % Water	Watershed Paved Road Density
Shelly Creek at end of Blower Rd	E290452	Summer	Dissolved Oxygen	Improving	Watershed % Recreation	Watershed Slope	Watershed % Agricultural
Shelly Creek at end of Blower Rd	E290452	Fall	Temperature	Degrading	Watershed % Residential	Watershed % Water	Watershed Paved Road Density
Swayne Creek d/s of Errington Rd	E308186	Fall	Temperature	Degrading	Watershed % Residential	Watershed % Water	Watershed Paved Road Density

Table A2. Sample locations at which significant trends were detected using a Mann-Kendall trend analysis approach. First, second, and third predictors indicate the three most important predictors identified by a Random Forest Model (Plewes et al., 2018) for the given parameter.

Geographic Description	EMS Number	Season	Parameter	Trend	First Predictor	Second Predictor	Third Predictor
Thames Creek 200m u/s Old Island Hwy	E286549	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Upper Cameron River	E285669	Fall	Dissolved Oxygen	Improving	Watershed % Forested	Watershed % Residential	Watershed Unpaved Road Density
Upper Englishman River u/s Centre Fork Creek	E282969	Summer	Conductivity	Degrading	Watershed % Residential	Watershed Paved Road Density	Watershed % Forested
Walley Ck at Morningside Dr	E306257	Fall	Conductivity	Degrading	Watershed Paved Road Density	Watershed % Residential	Watershed Slope
Whiskey Creek on Hwy 4, TB Ave Save on Gas	E287697	Summer	Temperature	Degrading	500m Upstream Buffer % Impervious	Watershed % Residential	Watershed Area (m2)