Project Report Cover Page
UVic Sustainability Scholars Program

Assessing the Impacts of Nonpoint Source Pollution in the Cowichan River

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Date complete: August 26, 2024

Disclaimer

This report is a product of the UVic Sustainability Scholars Program, a partnership between UVic and various on- and off-campus organizations offering internship opportunities to graduate students working on sustainability-focused research projects that advance sustainability in the region. This project was conducted under the mentorship of the Cowichan Watershed Board staff.

Territorial Acknowledgement

I acknowledge and respect the lək̓ʷəŋən peoples on whose territory the university stands and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.

I would also like to acknowledge and respect the people of the Cowichan Tribes, whose traditional territory/ancestral lands this project focuses on. They have inhabited this region for thousands of years, and their relationship with the river and salmon continues to this day.

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ABSTRACT

Trends in water quality in the Cowichan River on southern Vancouver Island are analyzed, with a focus on identifying the impacts of nonpoint source pollution and quantifying human-ecosystem interactions. Statistical analysis of water quality data from 1990 to 2024 reveals that nutrient levels, particularly phosphorus, frequently exceeded water quality objectives, especially downstream of the Lake Cowichan sewage treatment outfall. While the outfall is a known contributor of nutrients, mass flow analysis suggests that substantial amounts of nutrients and E. coli also originate from non-point sources, likely agricultural runoff and failing septic systems. The findings highlight the need for continued comprehensive water quality management in the Cowichan Watershed that addresses both point and nonpoint sources of pollution to safeguard ecosystem health and protect valuable salmon populations. The results are discussed in the context of climate change and increasing urbanization/human activity, and recommendations are provided to guide future mitigation and water quality monitoring efforts.

1.0 - Background

1.1 - Introduction

The Cowichan Watershed is located on south-central Vancouver sland and covers an area of approximately 930 km^2, with a mountainous topography achieving a maximum elevation of 1483m and descending to sea level (S. B. Foster & Allen, 2015). The 47 km-long Cowichan River flows out of Cowichan Lake, and east through the municipalities of Lake Cowichan and Duncan before emptying into the Pacific Ocean at Cowichan Bay. The watershed and surrounding area experiences warm, dry summers and mild rainy winters, with hydrology affected by both groundwater and precipitation effects, including snowmelt (S. Foster, 2014; S. B. Foster & Allen, 2015).

The river is of great cultural and historical significance, particularity to the people of the Cowichan Tribes who have inhabited the region for thousands of years (Cowichan Tribes, 2024; Government of BC, 2023). It remains for them a vital food source, hosting tens of thousands of spawning chinook, coho, chum, and steelhead salmon each year, and four species of trout. The Cowichan is a designated heritage river, and its estuary is recognized as one of the world's most biologically important areas for fish and wildlife (CVRD, 2024). In addition to its ecological importance and natural beauty, the river provides recreational value for fishing, swimming, and paddling, and is a major draw for the tourism industry on which the surrounding communities rely heavily on. The history of the river and its strong ties to the people is storied with community efforts to monitor and maintain the water quality of the river.

1.2 - Historical Disturbances & Climate Change

A series of human disturbances have been documented for the river, starting as far back as the 1890's when logging began (Pike et al., 2017). To facilitate log driving, explosives were used to blast through waterfalls and other impediments to downstream log movement. This effectively reduced the number of waterfalls from 29 to 2, and the number of rapids from 130 to about 5, resulting in major morphological changes to the river. In the decades leading up to the 1960's, dredging was performed to protect a flood plain near Duncan from flooding. Dredged materials were deposited on river banks, cutting off many side channels, which are important fish habitat (Pike et al., 2017).

Another significant human alteration occurred in the 1950's with the installation of the weir at the outflow of Cowichan Lake. This allowed for long term water storage at the lake, and the ability to supplement summer low flows for the river with controlled releases of water, reducing the risk of low water levels which could harm fish. Analysis of streamflow pre and post weir confirmed that the median discharge improved from 0.425 cubic meters per second (cms) in September of 1944 to 7.50 cms afterwards (Pike et al., 2017). Surface water diversions have also played a large role in influencing steamflow, with the number of water licenses tripling from 167 licenses to 501, and the number of wells increasing from 445 to 2843 between 1954 and 2012 (Pike et al., 2017). A steady increase in industrial, agricultural, and urban developments in the region have also increased stress on groundwater resources in the region.

The effects of climate change have been apparent in the region over the past 30 years. While no significant changes in average annual precipitation have been observed, the frequency and severity of drought events during spring and summer months has been increasing (Pike et al., 2017; Wade et al., 2021), contributing to decreased summer river flows. The effects of low flow events are exacerbated by increased temperatures in the region, likely as a direct result of climate change (Ayers et al., 2017; Pike et al., 2017). Furthermore, climate models predict further changes in water flow regimes and water temperatures, along with increased sea level rise which could impact the estuary (Madrone Environmental Services, 2013; Wade et al., 2021).

In a culmination of all these factors combined with human-caused contaminants, an estimated 84,000 steelhead were reported to have died during an extreme low flow event in August of 2023 (Marlow, 2023; Mehta, 2024; Thompson, 2023). Based on samples and testing following the event, the Department of Fisheries and Oceans (DFO) said in a statement that the cause of the event appears to be wide diurnal fluctuations in pH and dissolved oxygen in the water (Marlow, 2023). These conditions may be due to the excess algae growth and decay caused by low flows, high temperatures, and high levels of nutrients like nitrogen and phosphorus, which can come from a variety of human-caused sources. Despite ongoing monitoring and mitigation efforts, this tragic event was a shock to the community, and a reminder that even more urgent action is needed to protect the salmon and their habitat, preserve the integrity of the natural ecosystem, and ensure that the Cowichan remains a safe, sustainable river for people to enjoy.

1.3 - Water Quality, Monitoring Efforts, & Impacts

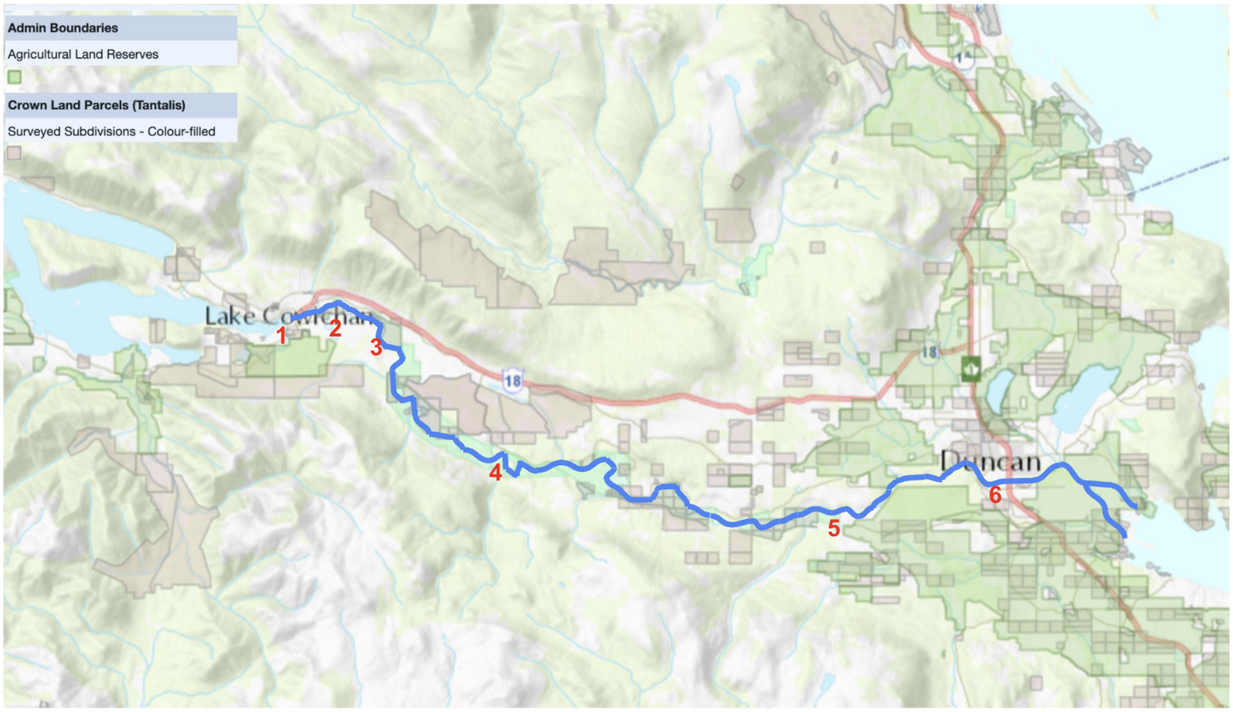
Today, there are a number of human-caused contaminants thought to be adversely affecting the health of the watershed. Notably, there is a sewage treatment outfall for the community of Lake Cowichan, which discharges a maximum average of 2,200 cubic meters per day into km 44.6 of the river (Pynn, 2023). A second outfall pipe is located near the community of Duncan.

While the focus for the community has been on mitigating impacts of the sewage outfall, the effects of other non-point sources have been a concern for experts since the late 1990’s (Ministry of Environment, 2000). For example, that same study found that levels of fecal coliform bacteria exceeded desirable levels in the river, and that the sewer discharge was not a significant contributor in 1999. This sentiment was echoed in a 2011 report which stated that fecal coliform and E coli results exceeded water quality objectives (WQO) and the origin was attributed to non-point sources. This has been a recurring theme in a number of technical reports from the BC government published since then, with levels of fecal coliform and E coli being regularly exceeded (Barlak et al., 2021; Madrone Environmental Services, 2013; Ministry of Environment, 2000; Preikshot 2019). Studies have shown that contaminants can enter local waterways from poorly managed septic systems (Geary & Lucas, 2019; Iverson et al., 2017, 2018; Reay, 2004) and through agricultural runoff (Kato et al., 2009; Smorong & Saso, 2021; Tiwari & Pal, 2022; Xia et al., 2020). Between the communities of Lake Cowichan and Duncan there is a large rural population including riverfront homes, and agricultural and industrial activity. The residential population on this stretch relies on private septic systems. A study published in 2021 analyzed past data, with microbial source tracking indicating that contaminants came from anthropogenic sources (Barlak et al., 2021), with potential candidates including runoff, aging septic systems, fertilizers, pesticides, forestry, and industrial sources. Furthermore, the authors (Ministry of Environment, 2000) reported that high nutrient levels were causing excessive algae growth, and expressed concern about potential anoxic water conditions negatively affecting fish populations (the very issue leading to the 2023 fish mortality event). In a report summarizing 2002, 2003, and 2008 WQO attainment, it was found that phosphorus and cadmium exceeded WQO’s (Obee, 2011). For the years 2012-2014, parameters that failed to meet objectives included E. Coli, dissolved oxygen, turbidity, total phosphorus, total copper, total zinc, and temperature (Smorong & Saso, 2021).

Figure 1 shows the full length of the Cowichan River, in blue, with each of the six monitoring station locations chosen for this study in red. Overlaid on the map are agricultural land reserves highlighted in green, and surveyed subdivisions in beige, from the BC Government’s online mapping tool (BC Government, 2024). The sewage outfall for the town of Lake Cowichan is located downstream of the municipality between stations 2 and 3, and is thought to contribute significant levels of nutrients - particularly phosphorus - into the river. Rural subdivisions dominate the middle section of the river between stations 3 and 5, and agricultural land is present around stations 1,2,5, and 6. The urban centers of Lake Cowichan and Duncan are small and closely concentrated around stations 1 and 6, respectively (BC Government, 2024). The sewage outfall for Duncan and the Municipality of North Cowichan is downstream of station 6.

Figure 1.

Cowichan River Map View



Note. A map view showing the path of the Cowichan River (blue) from the headwaters of Lake Cowichan to Cowichan Bay. The six water quality monitoring stations used in this study are shown in red. Agricultural land reserves are overlaid in green, and surveyed subdivisions in beige. The sewage effluent for the town of Lake Cowichan empties into the river in between stations 2 and 3.

In 1989, a number of specific water quality objectives were set to help protect the integrity of the river (Obee, 2011). These guidelines were subsequently revised in 2011, and included updates to total phosphorus, temperature, turbidity, some heavy metals, and bacteriological parameters. Guidelines for total phosphorus previously had no defined goals, and were introduced in 2011 to ≤ 5 µg/L (mean) and ≤ 7 µg/L (max) based on 5 samples in 30 days (Obee, 2011). Guidelines for metals copper, zinc, and lead were updated, and those for E coli. Guidelines for fecal coliforms, enterococci, total chlorine residual, and copper-8-quinolinolate were removed in an effort to focus mitigation efforts on what were deemed the most important parameters (Obee, 2011). These water quality objectives will be discussed further in the results section.

There have been ongoing community efforts to mitigate human impacts on the watershed. The Cowichan Valley Regional District (CVRD) has worked to bring sewage treatment practices for smaller septic treatments systems up to provincial standards. The quality of treated sewage managed by the Joint Utility Board for Duncan and North Cowichan has improved significantly over the years, with an 80% reduction in the amount of phosphorus entering the river (Straker et al., 2010). The CVRD has also put incentives in place for homeowners to install more water efficient technologies (Smorong & Saso, 2021). Collaboration between forestry companies, municipalities, and the CVRD has led to the implementation of best management practices for protecting groundwater resources, and the town of Lake Cowichan have explored strategies to reduce the amount of treated effluent discharged directly into the river (Smorong & Saso, 2021).

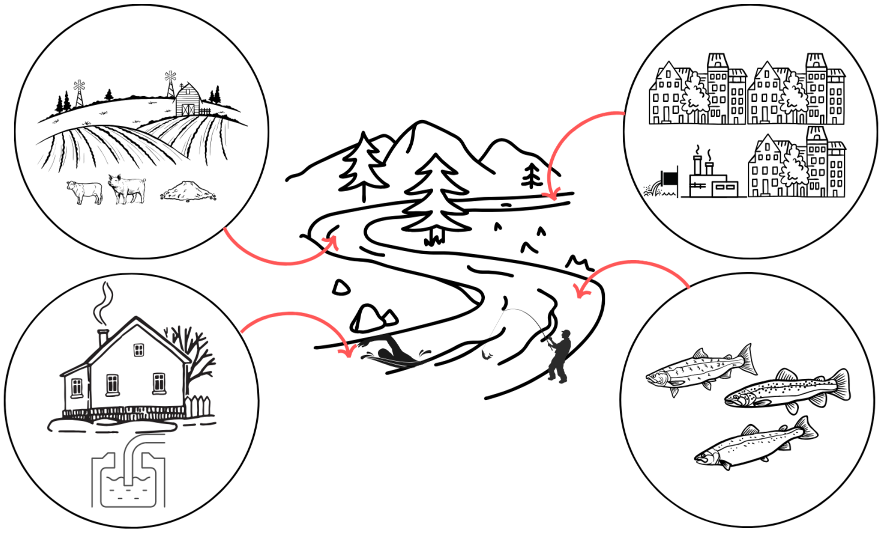
1.4 - Project Goals

Over the past several decades, various organizations have made efforts to monitor the water quality, flow volume, and overall ecosystem health of the river. However, this data varies greatly in resolution, quality, and consistency, and is scattered in various formats from different organizations, and from different monitoring stations over various time periods. Thus, it is difficult to build a larger picture of the Cowichan River watershed's history. Sewage effluent, agricultural land, urban runoff, aging septic systems, and urban and industrial activity are all likely sources of water contamination, as depicted in Figure 2. However, to which degree each is affecting the water is not well understood. This project aims to synthesize and analyze historical and present-day water quality data on the Cowichan River from Lake Cowichan downstream to Highway #1, attempt to link contaminants with their most probable sources, and tell the story of the watershed in data. Statistical methods are used to identify long-term trends in seven organic contaminants and seven heavy metals at six different monitoring stations along the river, as shown in Figure 1, from 1990 to present day. These monitoring stations were chosen because they had the most consistent data and because they are relatively evenly spaced along the river. The parameters (contaminants) chosen for analysis were selected because they are known to be human-caused and have the potential to negatively impact ecosystems. The contaminants and their effects on the natural ecosystem are discussed further in section 3.0. There is a second sewage outfall for the community of Duncan located after station 6 (Figure 1). While the focus of this paper is on the stations up-river of station 6, a brief analysis of the downstream effects of this second outfall are included in the provided addendum.

Contaminant mass loadings are calculated to account for changing water flow levels, and to assess mass flows in and out of the river and between stations. While there have been significant efforts to analyze and mitigate the effects of the sewage outfall, little work has been directed at specifically identifying the origins of non-point sources. This paper attempts to distinguish which contaminants are coming from the sewage outfall and which are coming from other, non-point sources. It also seeks to synthesize, analyze, and interpret past water quality data, and to provide a literature review of pathways and methods for water contamination which are relevant to the study region. Overall, the aim is to help inform future water quality monitoring efforts, to estimate the impacts of non-point sources and identify likely candidates, and to explore mitigation strategies for non-point sources.

Figure 2.

Graphical representation of river inputs



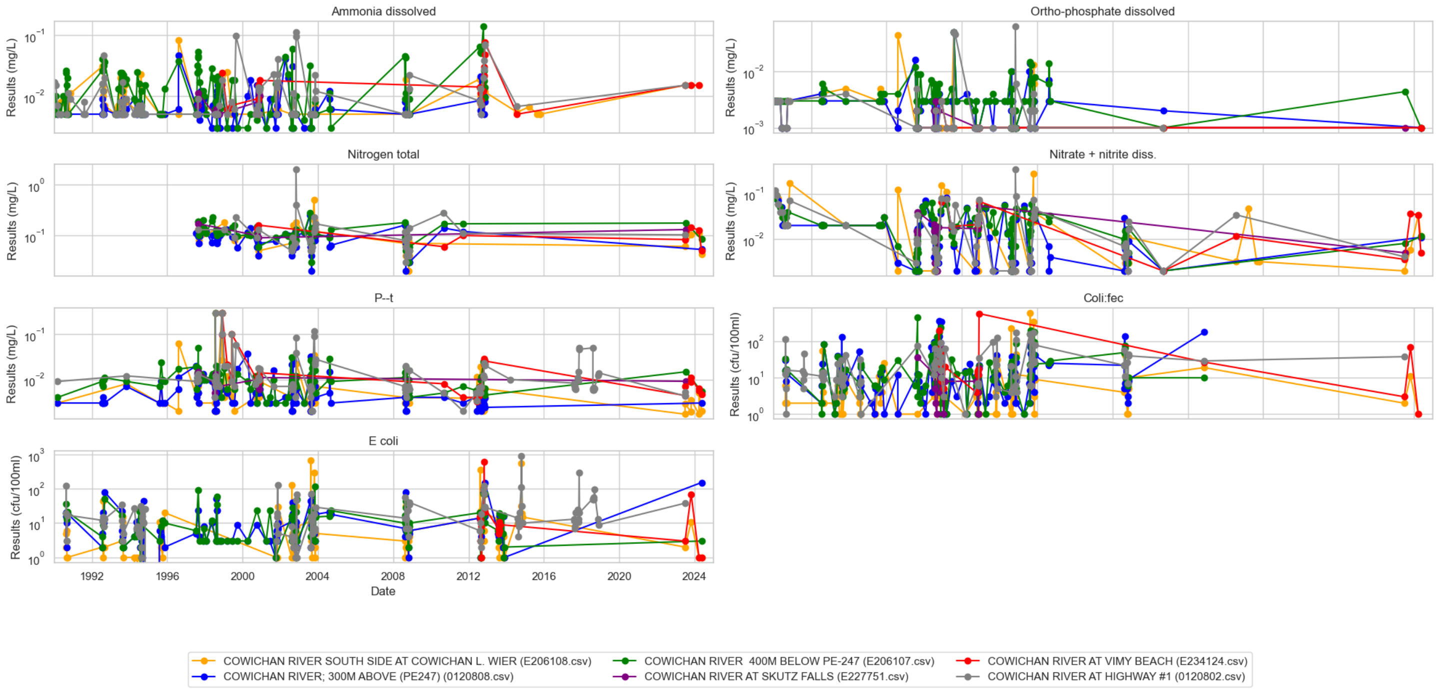
Note.
Graphical representation showing various possible contaminants which may be negatively impacting the ecosystem health of the Cowichan River. Depicted is agricultural land which produces runoff (upper left), private septic system leakage (lower left), urban runoff and sewage effluent (upper right). The river is a vital spawning ground for several species of salmon (lower right) and hosts important recreational activities for the community.

2.0 - Methods, Data, & Preliminary Analysis

Contaminant concentration data was obtained as .csv (comma separated values) files from the Government of British Columbia's EMS database, which contains an amalgamation of data from a variety of organizations, locations, and time periods (Ministry of Environment and Climate Change, 2024). A python script was used to organize the data by monitoring station and parameter and for all further analysis. Duplicate and blank (used for equipment benchmark) samples were filtered out. Where appropriate, data was filtered by date and separated into seasons for independent analysis. Figure 3 shows time series data for the nutrients of interest over the study period. Unfortunately, the water monitoring program experienced intermittent outages from the early 2000's onwards, and so data is limited in recent decades.

Figure 3.

Time series concentration data for organic contaminants, 1990-2024



Note. Plot showing time series data from six water quality monitoring stations for the length of the study period (1990-2024), with the y axis on a log scale. This figure draws attention to the issue of data availability, as the water quality monitoring program has been intermittent, making analysis more difficult.

Various statistical methods were used to analyze long term trends during the study period. Because the majority of sampling has taken place in the summer (June, July, August) and fall (September, October, November), these two seasons are the primary focus for this study. During the summer months, the hot dry weather leads to lower river flows, with extreme low values usually occurring in August. This period is of particular interest due to the potential for increased contaminant concentrations and water temperatures, during which time the 2023 fish mortality event occurred. In the fall, precipitation increases in the region, and consequently so does river flow volume and runoff from the surrounding basin, having other potential implications for contaminant loading.

For lack of better data, seasonal averages over the study period are sometimes examined to have sufficient data for meaningful analysis. A combined Theil-Sen + Mann Kendall test was used to analyze long term trends in the data for various parameters to determine whether or not concentrations of the contaminants have been increasing over the course of the study period. These results are displayed in Appendix A1 and A2. On an overall annual basis, only E coli was found to have a statistically significant increase over the course of the study period. All other parameters were found to either remain relatively steady or decrease slightly. It is important to note that less data in recent years could skew results, and so this should be taken with a grain of salt. It is also important to note that certain hydrological phenomena are not directly captured in this analysis, but are highly relevant. For example, the *duration* of the low flow events is an important metric, and is discussed in the results section. When looking only at summer months, of the seven parameters across six stations, only three out of forty-two of the parameters were found to have statistically significant overall trends. Fecal coliform below the Town of lake Cowichan sewage outfall was the only parameter to show a significantly significant increase.

One of the other stipulations is that increased variability and extreme flow events are increasing in frequency and magnitude. The trend in maximum recorded concentrations was calculated to assess if extreme values have been increasing. The standard deviation of the parameters is also analyzed, and trends and confidence intervals were calculated to assess trends in standard deviation as a way of measuring variability. Results indicate that either no trends exist or that insufficient data exists to make a claim for all stations, i.e. no significant trend in standard deviation or maximum values was observed, with the exception of ortho-phosphate. These results are displayed in detail in Appendix B. As another measure of variability, Leven's p test was used to assess the variability of the water quality over the years across all stations, where a p value less than 0.05 indicates significant changes in variability. While measuring trends in standard deviation can capture long term steady increases or decreases in variability, Levene's test can capture variability between years, rather than overall change over many years. These results, shown in Appendix C, suggest that nutrient contaminant levels have tended to vary significantly year to year over the course of the study period, with the notable exception of total nitrogen.

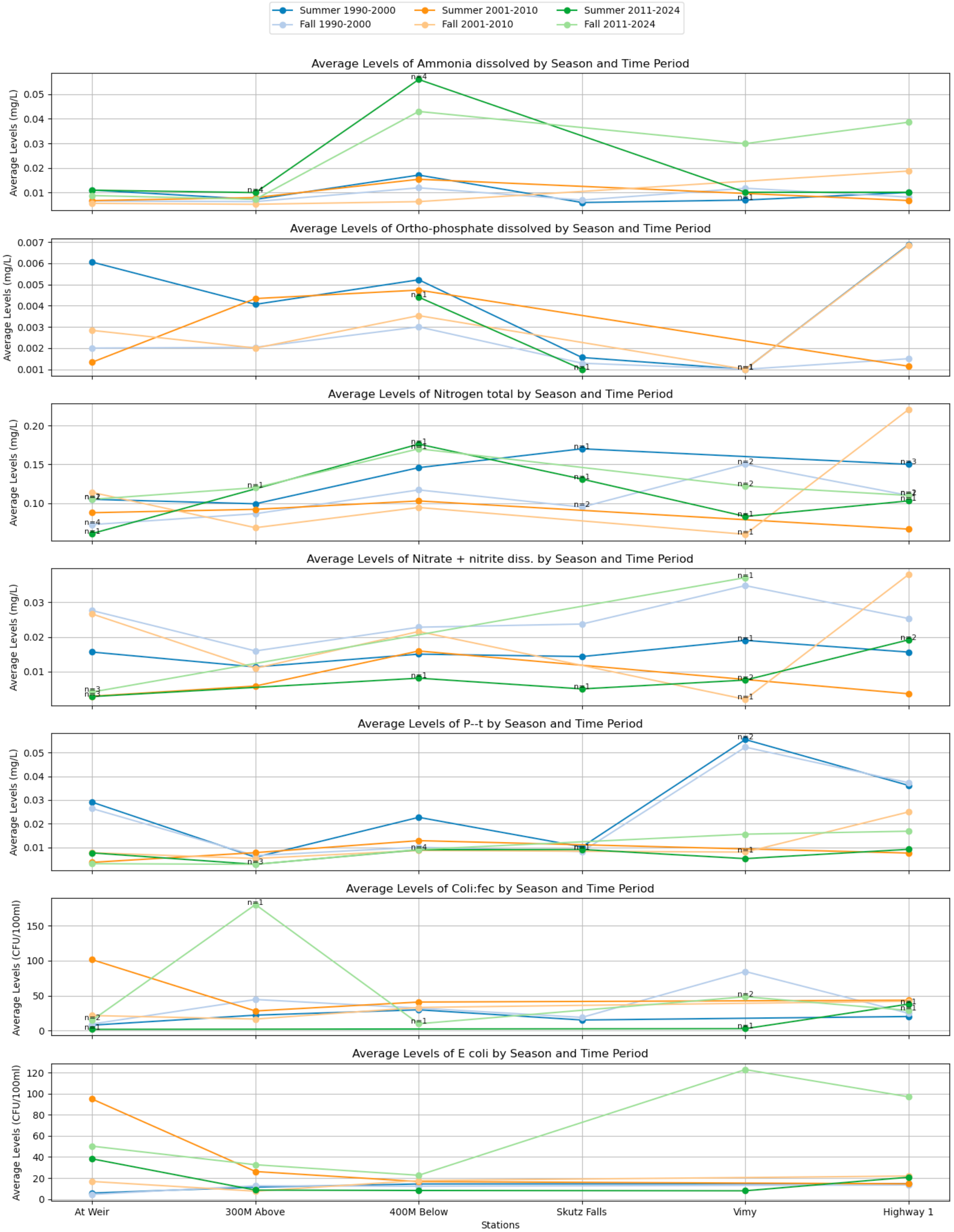
With the available data we are not able to identify much in the way of statistically meaningful increases (or changes for that matter) in contaminant concentration levels (mean or max), or any significant increases in variability. It is possible that a higher resolution of data in recent years would tell a different story. Another explanation is that, as previously mentioned, the duration of extreme events and temperature are driving factors in negative watershed impacts. A full hydrological and statistical analysis is beyond the scope of this study. Furthermore, the relative homogeneity of many of the parameters over the years provides some justification for assessing data from the whole study period to draw conclusions about present day issues.

Figure 4 shows average concentration levels along the river for summer and fall, over three time periods: 1990-2000 (blue), 2000-2010 (orange), 2010-2024 (green). These results more than anything point to a lack of available data. There was insufficient available data to identify statistically significant trends in concentration levels at different monitoring stations on shorter timescales, or to identify meaningful differences in the three decades depicted. Furthermore, this lack of data makes it difficult to find any meaningful correlation between contaminant levels and high/low flows. A separate analysis of how maximum values are changing over time did not yield any meaningful trends, nor did analysis of summer-only trends.

While lack of data is a persistent problem in making confident claims about long term trends, differences in results between monitoring stations and how that has changed over the years provides valuable insight into the evolving health of the watershed. No statistically significant correlation was found between flow volume and contaminant levels. Again, there may be insufficient data to make the claim that no correlation exists. However, by examining aggregated data spatially for study period, some interesting patterns emerge. To account for the effects of changing flow volume, the mass loading in kg of each chosen parameter at each monitoring station was estimated using the concentration (mg/L) and hydrometric flow data (m3/s) averaged from two hydrological stations. These results provide further insight into the sources of the contaminants, and will be discussed in Section 3.2.

Figure 4.

Average contaminant levels by station and season



Note. Average recorded levels (mg/L for nutrients, CFU/100ml for fecal coliform), by monitoring station. The stations on the x axis progress down river from left to right, and the data is separated into three different decades (1990-2000, 2000-2010, and 2010-2024 with blue, orange, and green respectively). The lighter shade of each color represents fall data (characterized by high precipitation) and the darker shade represents summer (characterized by low flows and warm temperatures). The n values indicate data points where 5 or fewer recordings were made. This figure points to a lack of available data which makes it difficult to identify differences in the three time periods.

3.0 - Results & Discussion

Figure 5.

Seasonal box plot results by station

3.1 - Nutrients & Organic Contaminants

Figure 5 shows concentration levels at each station for the parameters of interest in the form of seasonal box plots, containing data from the entire study period (1990-2024), with summer on the left and fall on the right. A recurring trend observed is that median contaminant levels increase after the sewage outfall, and then taper off further down the river. This observation is particularly present during the summer months (for example, nitrogen, nitrate + nitrite dissolved, phosphorous). This is consistent with concerns about the sewage outfall leading to increased nutrient levels, especially in the summer when flows are lower. However, a competing trend is apparent primarily in the winter months, where in many cases median nutrient levels continually rise as we progress down the river. It is possible that these elevated levels could be due to increased runoff caused by increased precipitation and higher flow volumes during these months. Increased precipitation may carry contaminants from surrounding industrial and residential activities to the river and its tributaries (Kato et al., 2009; Stein, 2023). The middle line on the box plots shows the median value, and the boxes show the upper and lower quartiles. The whiskers show the upper and lower extremes, and any other points are statistical outliers / single data points. Individual results will be discussed in more detail in the following subsections.

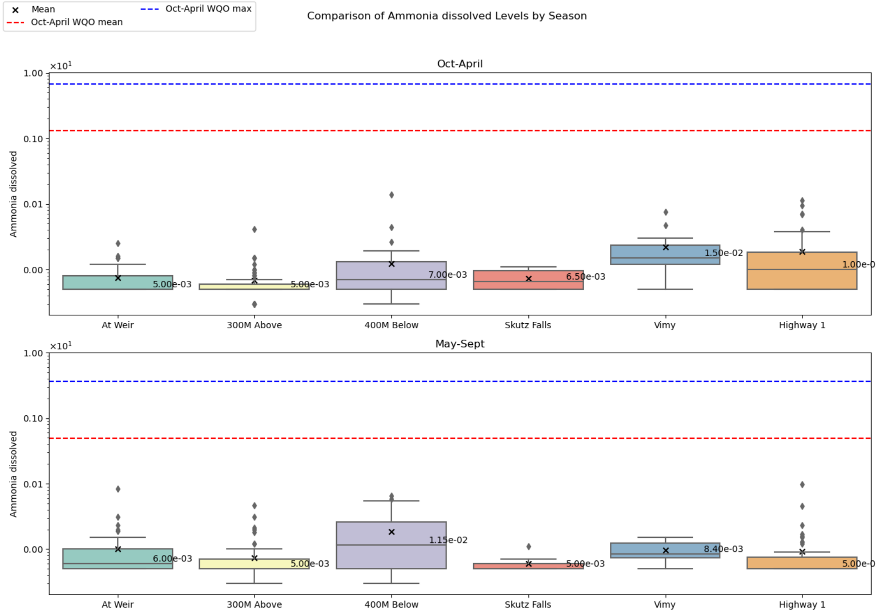
3.1.1 - Ammonia Dissolved

The water quality objectives set for dissolved ammonia levels in 2011 were 1.31 and 6.83 mg/L (mean and max respectively) for October-April, and 0.49 and 3.61 mg/L for May-September, as shown in Figure 6 (note that this differs from the seasons defined in Figure 5 to align with

Figure 6.

Dissolved ammonia

the specific WQO's). No values have been recorded above these objectives. Ammonia is a form of nitrogen that occurs naturally in both aquatic and terrestrial ecosystems, from sources including plant & animal excretion and the decomposition of organisms and microorganisms (Eddy, 2005; Ritter, 2002). When it comes to anthropogenic sources, ammonia is produced for fertilizers and other industrial products, biomass burning, and human waste, and can enter waterways through agricultural runoff or urban water discharges (Eddy, 2005; O. US EPA, 2016). While other forms of nitrogen are known to cause problems via over enrichment of waters, ammonia has direct toxic effects which can adversely affect aquatic life. Elevated levels of ammonia in waterways can inhibit ammonia excretion in fish or result in net ammonia uptake, which can lead to high concentrations of ammonia in blood plasma, leading to reduced swimming performance, slower growth, and even convulsions and death (Eddy, 2005; Randall & Tsui, 2002).



Note. Box plot results for dissolved ammonia, with water quality objectives shown in the blue and red horizontal lines representing the maximum and average WQO values respectively.

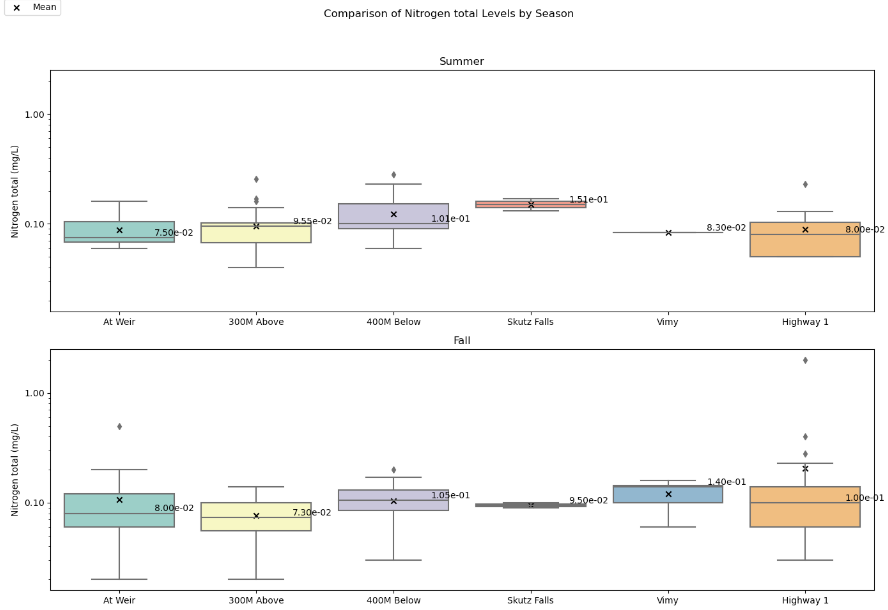
Median contaminant levels increase after the outfall, and a wider range of values are reported. In Oct-April which encompasses the wet season, levels appear to continue to increase after the outfall, whereas in the dry season levels are generally lower after the outfall. Ammonia levels do tend to be lower in summer months due to uptake by plants and decreased ammonia solubility at higher water temperatures (O. US EPA, 2015), and higher precipitation generally increases ammonia levels in surface waters due to runoff from agricultural and other sources (Jia et al., 2021; Stein, 2023). Median ammonia levels at Vimy Ridge and Highway #1 are higher by up to 50% in the October-April season (Figure 6), and both of these stations are in relatively close proximity to agricultural land as seen in Figure 1, which could be a possible cause. However, Ammonia levels remain well below the water quality objectives. Increases in agricultural or industrial activity near the river should consider the potential impacts of increased ammonia runoff.

3.1.2 - Nitrogen Total

No water quality objective has been set for total nitrogen. However, excess nitrogen beyond natural levels in waterways is one of the main causes of algal blooms in freshwater systems (Blaas & Kroeze, 2016; Rabalais, 2002; O. US EPA, 2013a). Nitrogen levels appear to be slightly elevated after the outfall, and decrease slightly towards the downstream end of the river, suggesting that the sewage outfall may be a contributor (Figure 7). However, this effect is not as pronounced as many forms of phosphorus, which will be discussed in the following sections. Anthropogenic sources of nitrogen include wastewater including treated wastewater, agricultural runoff from manure and chemical fertilizers, urban stormwater runoff, and fossil fuel use from industrial, power generation, & transportation industries (Howarth, 2008; O. US EPA, 2013a). Sewage effluent discharge into rivers has been found to increase levels of both nitrogen and phosphorus (Waiser et al., 2011), leading to similar eutrophication issues faced on the Cowichan River (Costanzo et al., 2001; Ho et al., 1992). Thus, it is unsurprising that levels appear higher after the outfall. The fate of nitrogen after it enters the waterway is complex, as some of it may be absorbed and re-released into the environment through microbial reactions (Lavelle et al., 2019; Zhang et al., 2021), sediment interactions (Land et al., 2016; Su et al., 2024), and changes in environmental conditions (Land et al., 2016; Lavelle et al., 2019). However, since there are several significant tributaries entering the river downstream of the lake (Pike et al., 2017), one might expect that some level of effluent nutrient dilution would occur. Acceptable nutrient levels vary greatly from site to site and depend on a variety of factors. While no guidelines have been specified for the Cowichan River specifically, the BC provincial government has recommended guidelines for protection of aquatic life for nitrate and nitrite individually, as well as ammonia, but not total nitrogen (Nordin & Pommen, 2009). These guidelines are also dependent on temperature and pH, making it more difficult to apply to this study due to a lack of data. For another comparison, the United States Environmental Protection Agency (EPA) defines guidelines for the “western forested mountains”, which consists of the coastal pacific northwest, with a climate similar to that of British Columbia. The aggregate nutrient reference condition for total nitrogen is stated as 0.12 mg/L (25th percentile) (O. US EPA, 2013b), which is of the same order of magnitude of the median values in Figure 7 (median value 0.123 mg/L in the summer at station “400m Below”). Because anthropogenic sources of nitrogen have been identified and are a key factor in eutrophication, development of a unique WQO for total nitrogen or other forms of nitrogen may be a consideration for future water quality monitoring efforts. Another interesting takeaway is that total nitrogen is the only parameter to have remained extremely consistent in terms of variability over the course of the study period (Appendix C). All other parameters were found to vary consistently year-to-year, based on available data. This could mean that there is a source of anthropogenic nitrogen that has remained relatively unchanged.

Figure 7.

Total nitrogen



Note. Box plot results for total nitrogen. No specific water quality objectives have been set for total nitrogen; however, nitrogen is an important limiting nutrient in biological reactions leading to eutrophication.

3.1.3 - Nitrate + Nitrite Diss.

Nitrates and nitrites consist of nitrogen bonded with two and three oxygen molecules respectively, and in high enough concentrations in water they can be harmful to humans (Galaviz-Villa et al., 2010). Dissolved nitrate and nitrite show a distinct trend of peaking after the sewage outfall and then tapering off in the summer, while continuing to rise during the fall months, as shown in Figure 5. In addition to the effects of sewage effluent, studies have found that poorly managed septic systems can lead to nitrogen, including nitrates, contaminationof groundwater (Aravena et al., 1993; Nitka et al., 2019; L. Wang et al., 2013). The observed continual increase in nitrate levels downstream of the outfall, where rural subdivisions are prevalent (Figure 1), could be attributed to aging septic systems in these areas. This is particularly noticeable during periods of high precipitation. Increased rainfall can overwhelm septic systems, leading to flooding and a rise in the water table, which can further exacerbate groundwater contamination (Arnade, 1999; Tamang, 2020). This suggests that failing septic systems may be a significant source of nitrogen pollution in the river. The potential impacts of septic systems will be discussed further in sections 3.2 and 3.3.

Note. Box plot results for dissolved ammonia, with water quality objectives shown in the blue and red vertical lines representing the maximum and average WQO values respectively.

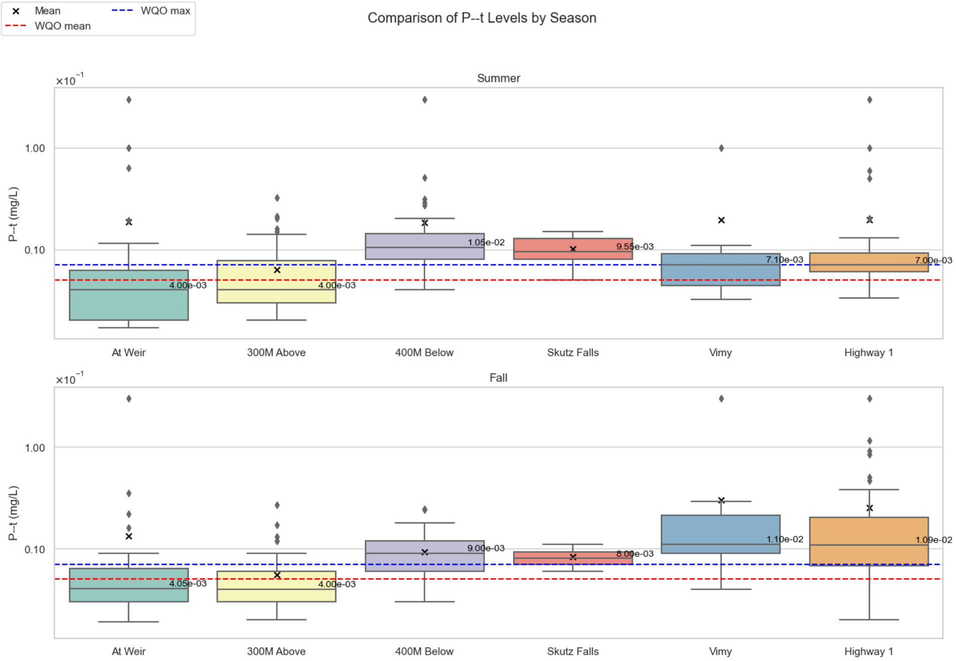
3.1.4 - Ortho-Phosphate Dissolved

Ortho-phosphate is important because it is one of the main chemical forms of phosphorus directly available for organisms to use, and is oftentimes a controlling factor in primary production (Maruo et al., 2016). Levels of ortho-phosphate exhibit high variability, however still appear to loosely follow the prevailing trend of increasing after then outfall and then tapering off downstream, more prominently in the summer, as shown in Figure 5. Statistical analysis also suggests that levels of ortho-phsophate have become increasingly more variable since the 1990’s (Appendix B). This form of phosphate occurs naturally and is present in low concentrations in freshwater, however excess amounts can come from anthropogenic sources such as partially treated sewage, agricultural runoff, and lawn fertilizers (Maher & Woo, 1998; Water Research Center, 2020). The reactions and interplay between different forms of phosphorus is complex and beyond the scope of this study. The WQO’s set for the Cowichan River are based on total phosphorus, which includes ortho-phosphate and other forms, as discussed in the following section.

3.1.5 - Phosphorus Total

Figure 8.

Total phosphorus



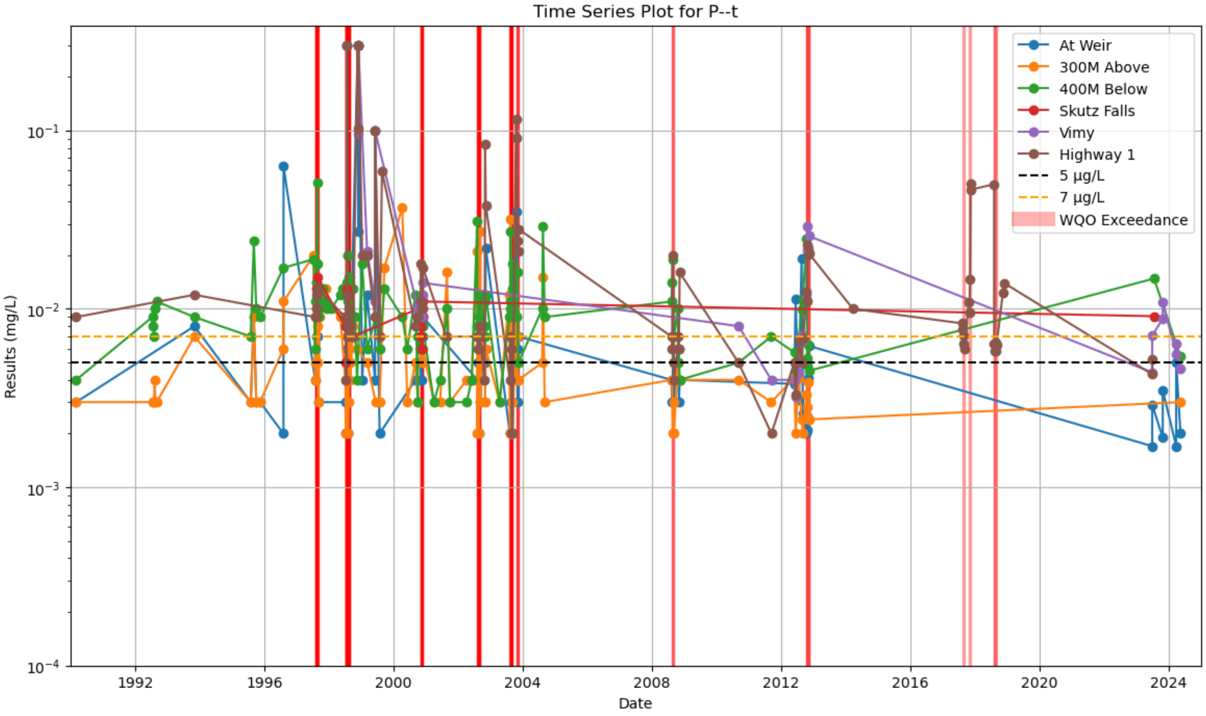
Note. Box plot results for total phosphorus. Water quality objectives shown in the blue and red horizontal lines representing the maximum and mean objectives respectively. These water quality objectives are based on 5 measurements over a 30-day period.

Phosphorus is, like nitrogen, one of the primary drivers of excessive eutrophication including algae growth (Blaas & Kroeze, 2016; Su et al., 2024; Tiwari & Pal, 2022; O. US EPA, 2013a), which can originate from both treated sewage effluent and septic systems (Ho et al., 1992; Iverson et al., 2018; Tamang, 2020) as well as other sources including agricultural and urban runoff (Blaas & Kroeze, 2016; Hart et al., 2004). Figure 8 shows total phosphorus levels in mg/L at all stations in summer and fall, with the WQO’s shown as vertical dotted lines in red (mean) and blue (max). Median levels are dramatically higher (double or more) immediately after the outfall, a clear indication that the effluent discharge is a significant source of phosphorus. Levels exhibit the same pattern of being diluted after the outfall in the summer, with a steady increase in the fall. Even without further analysis, it appears as though recorded values have often exceeded WQO’s over the course of the study period. Just like nitrogen, phosphorus may be reacted/absorbed and re-released in a complex interplay between plants, animals, and environmental conditions (Su et al., 2024; Zhang et al., 2021) .

Water quality objectives for the Cowichan River are defined in terms of five samples within a thirty-day period (Obee, 2011). To assess this, a rolling 30-day window across the dataset was analyzed and occurrences where 5 or more samples exceeded WQO’s were recorded, as shown in Figure 9. Time series data is shown for each station throughout the study period, with red vertical lines highlighting exceedance periods (5µg/L mean, 7µg/L max). These periods tend to align with instances where data is abundant, so we can presume that other occurrences were not captured. A list of the exceedances with their dates, values, and station locations is available in Appendix D.

Figure 9.

Phosphorus water quality exceedances



Note. Time series plot showing past occurrences of water quality objective exceedances for phosphorus, indicated with red vertical lines. These water quality objectives are based on 5 measurements over a 30-day period.

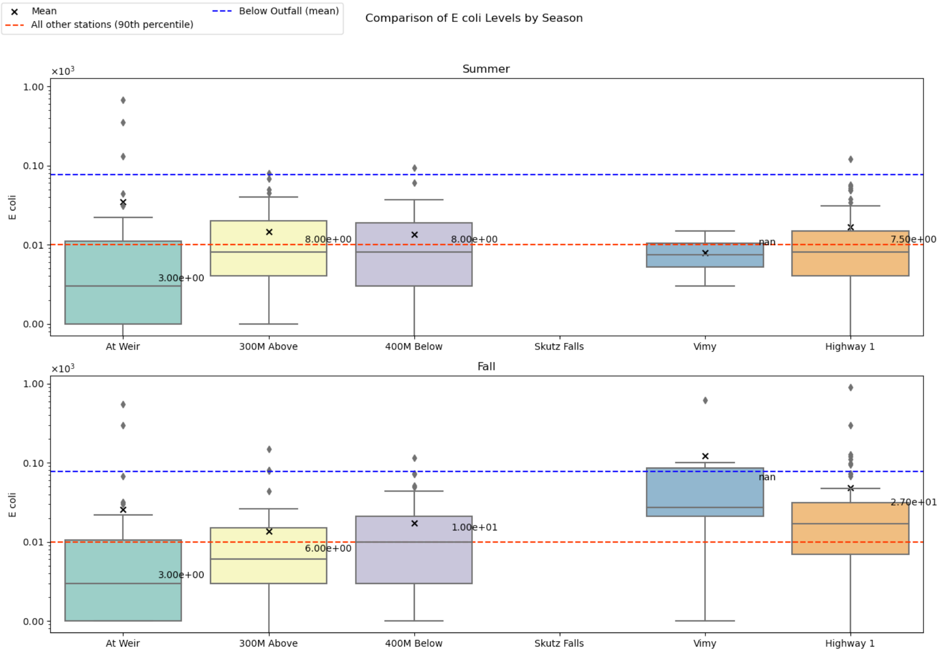
The majority of these were recorded at the stations above (21 occurrences) and below (22 occurrences) the Town of Lake Cowichan sewage outfall between 1997 and 2012, followed by 11 at Highway #1, 8 at the weir, 3 at Skutz Falls and 2 and Vimy. The vast majority occurred during the dry season in July, August, and September. It should be noted that 2011 guidelines are shown throughout even though the guidelines from 1998 existed prior. The four most recent events in 2017 and 2018 were recorded at Highway #1, however, because data is missing from recent years it is likely that exceedances occurred and were not recorded. These results suggest that WQO's for total phosphorus are often exceeded both 300M above and 400M below the sewage outfall, however, it should be noted that some stations have more recorded samples than others which could skew results. Despite the outfall being cited as a driving cause of phosphorus in the river, these results indicate that contributions may be coming from other sources.

3.1.7 - Fecal Coliform & E Coli

The presence of E coli, a member of the fecal coliform group of bacteria, is a strong indicator of contamination from sewage or animal waste, which can contain many types of disease containing organisms harmful to humans (USGS, 2018). E coli is often found in the gastrointestinal tract and feces of warm-blooded animals. Figure 10 shows E coli levels across stations in CFU (colony forming units) per 100ml. Here, the water quality objectives shown are for the 400M below station (blue horizontal line) and for all other stations (red vertical line). The objective for the 400M below station is based on the 90th percentile, and for all other stations it is based on a geometric mean (Obee, 2011). CFU counts appear to rise further downstream in the fall months, and remain relatively steady after the weir in the summer. Sources of bacteria include leaking septic systems, improperly functioning wastewater treatment plants, storm water runoff, animal carcasses, and runoff from animal manure and animal pens (Coleman et al., 2013). The fact that levels are higher mid-river during high precipitation months might suggest that increased runoff and/or overwhelmed septic systems are a factor (Arnade, 1999; Tamang, 2020). Total fecal coliform counts are shown in Figure 5 and exhibit a similar pattern in levels down the river, with a noticeable large number of outliers. Fecal coliform CFU are detected by performing counts of colonies that form on a 0.65 micron filter and incubated at 44.5 ºC for 22-24 hours, whereas E coli counts are performed on a 0.45 micron filter at 35 ºC (USGS, 2018). The presence of fecal coliform is indicative of fecal contamination; however, E coli is generally a preferred indicator as it provides more direct evidence. This is because E coli is a specific species which can be more reliably linked to gastrointestinal illnesses and pathogens (Francy et al., 1993; R. 08 US EPA, 2013).

Figure 10.

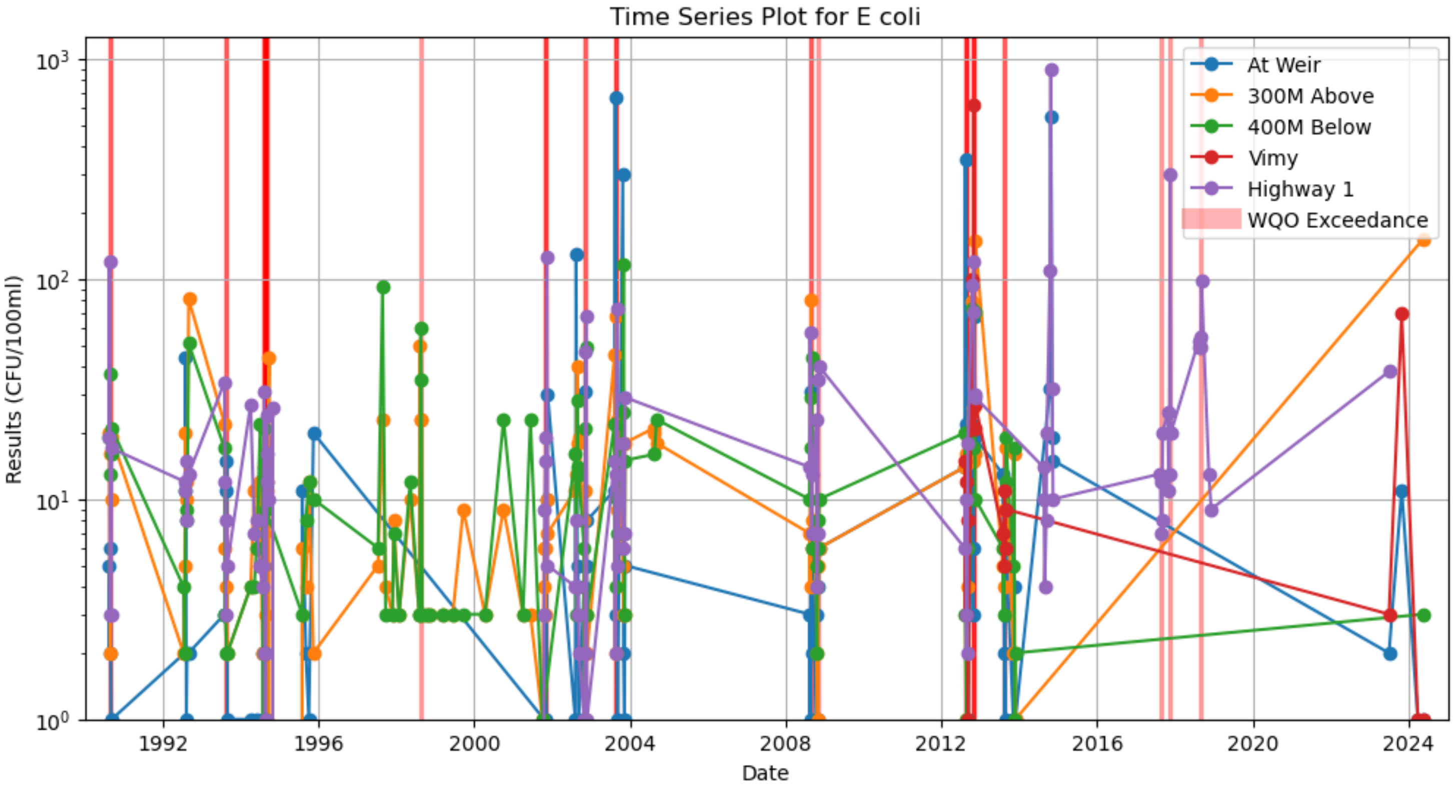
E. coli



Note. Box plot results for E. Coli. Water quality objectives for the 400M below station (blue horizontal line) and for all other stations (red vertical line). The objective for the 400M below station is based on the 90th percentile, and for all other stations it is based on a geometric mean. These water quality objectives are based on 5 measurements over a 30-day period.

Figure 11 shows past water quality exceedances based on a 30-day rolling window for objectives for "400M below" and for all other stations. The occurrences of E coli WQO's being exceeded and their locations are listed in Appendix E. The 2011 90th percentile objectives for below the outfall were not found to be exceeded, and other exceedances occurred at Highway #1 (18 occurrences), 300M above (9), at the weir (7), and at Vimy Ridge (3). The former three stations are all within close proximity to agricultural land (Figure 1), and over half of the occurrences were recorded in September-November, which is consistent with the line of thinking that increased agricultural runoff during high precipitation months could be a factor. Studies have indicated that E coli can survive for longer than 30 days under certain conditions (Avery et al., 2008; Blaustein et al., 2013; Flint, 1987; Rhodes & Kator, 1988), so it is also possible that effluent contributions persist throughout the sampling period. These results further emphasize the potential negative impacts of agricultural land and/or aging septic systems.

3.2 - Mass Flow Analysis

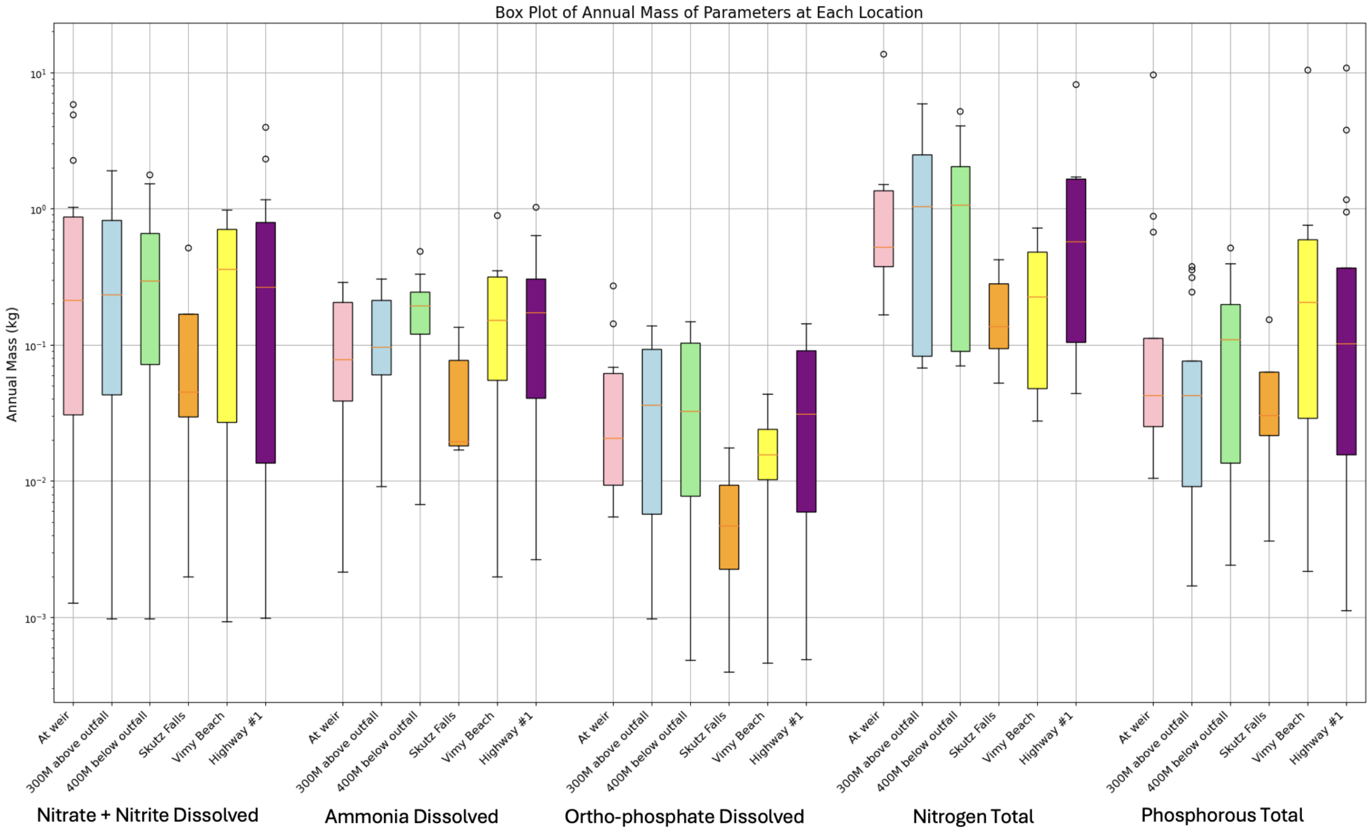


Note. Time series plot showing past occurrences of water quality objective exceedances for E. Coli, indicated with red vertical lines. These water quality objectives are based on 5 measurements over a 30-day period.

Although concentration data is important for its effects on fish and humans, flow rates in the river are highly variable seasonally, and also on shorter scales in response to precipitation or drought events. Because these events can impact concentrations, it can be difficult to identify the sources of contamination with concentration data alone. Additionally, changes in precipitation patterns and human activity have led to changes in the hydrological regime of the Cowichan River since the 1990's (Pike et al., 2017). In order to isolate contaminants from the effects of changing flow volume, the mass loading in kg was calculated across the dataset. Aggregate flow data in cubic meters per second for the study period was collected for the study period from two hydrological stations, one near the community of Lake Cowichan and one near Duncan (Figure 1). For lack of better data, the average of these two stations was used for mass calculations. Figure 12 shows box plot results of annual mass in kg for each station. The prevailing trend shows median mass loading values increase and peak after the outfall, reach a low mid river, and then increase again at the lower river. While there tends to be a significant increase immediately after the outfall, there are notable exceptions.

Figure 12.

Mass loading of organic contaminants



Note. The masses of contaminants were calculated using aggregated river flow and contaminant concentrations. A distinct pattern emerges where median mass values peak after the sewage outfall, drop in the mid river, then rise again at the lower river.

While the median concentration of dissolved ortho-phosphate appears to increase after the outfall, the median mass loading actually decreases, with only slightly higher upper and lower quartiles. In contrast, a significant jump in total phosphorus is observed after the outfall, followed by a decrease and then a subsequent increase, suggesting potential contributions from other sources besides the outfall. However, it's important to consider that the uptake and re-release of phosphorus by organisms within the river system could also influence these patterns. For nitrogen, the median mass loading values are only marginally higher after the outfall, with similar upper and lower quartiles, indicating that the amount of nitrogen in the water is rarely higher after the outfall. Additionally, the nitrogen values exhibit a decrease in the middle section of the river before increasing again downstream.

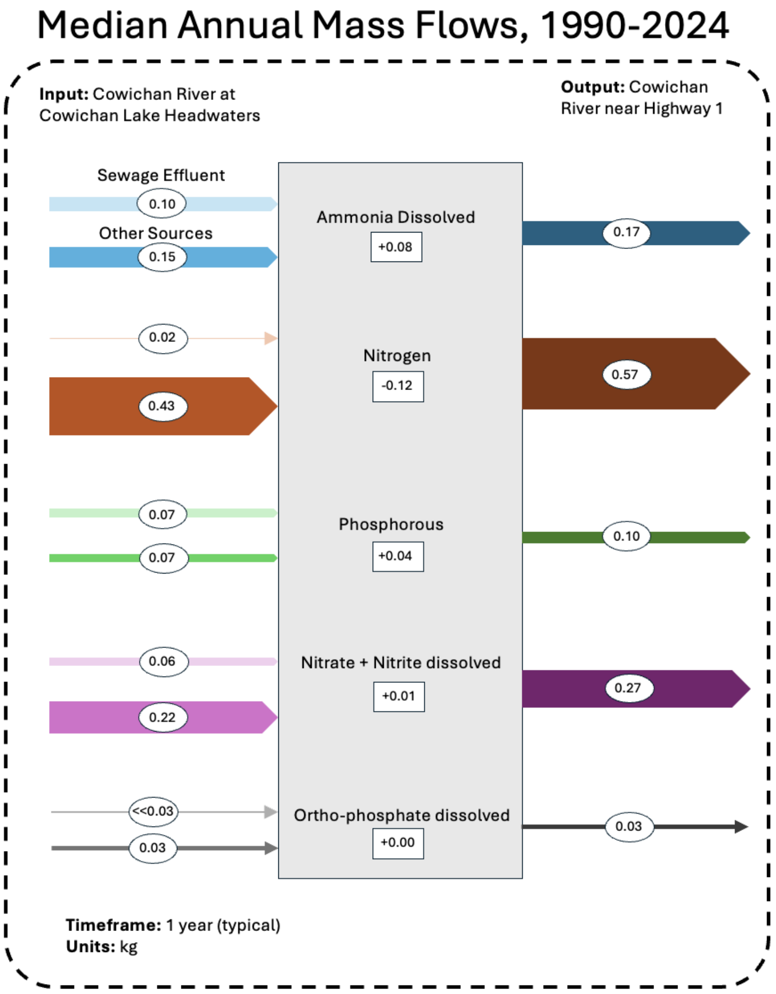
To estimate the mass of contaminants originating from the outfall versus other, non point sources, it was assumed that the amount of contaminant 400M below the outfall versus 300M above all originated from the outfall. It was then assumed that the difference between the highest and lowest levels achieved *after* the outfall is equal to the contribution from non-point sources. Based on these principles, median mass flows in and out of the river were calculated for each parameter, as shown in Figure 13. Here the arrow width is representative of kg contaminant for a typical year during the study period. The values within the middle grey box (called “stocks”) refer to the amount required to mass-balance the system for what is going in at the headwaters and out at Highway #1 (i.e., the difference between the output and the combined inputs). A positive value here indicates that the mass exiting the system exceeds the starting mass, pointing to contributions from tributaries or other sources along the river. A negative stock indicates the opposite, and implies that some contaminant was reacted or absorbed into the environment. For example, looking at Nitrate + Nitrite dissolved, the diagram indicates that for a typical year 0.06 kg originates from the sewage effluent (upper arrow), and 0.22 kg originates from other nonpoint sources (lower arrow). A very small amount (+0.01) in the grey box indicates that 0.01 kg are added from other points along the river, and finally 0.27 kg are exiting the system. The results of this simplified "one box model" tell a different story than the concentration data, and reveals that significant levels of contaminants may be coming from sources other than the sewage outfall. This is particularly prevalent with total nitrogen, with the vast majority coming from non-point sources. Even for total phosphorus, only half is attributed to the sewage effluent. It is important to note the following assumptions/simplifications for this diagram:

- The arrows show ***median mass flow values***, and are meant to show the mass through the system on a typical year, based on the best available data from 1990-2024
- The section of the river between the outfall at Lake Cowichan and Highway #1 is being treated as a black box with a single input and output, not accounting for the internal dynamics of the river, such as the uptake and re-release of nutrients.
- This picture does not account for extreme events within a given year, such as extended periods of low flow, high temperature, or precipitation/drought, all of which are important considerations for addressing the 2023 fish kill event and other ecological challenges. Rather, the purpose of this exercise is to attempt to determine the origin of the contaminants and quantify them.
- While a seasonal mass flow diagram might be interesting to see, the issue with the dry season lies in low flows leading to high nutrient *concentrations*, and less so the total mass. Thus, the seasonal analysis is focused on concentration as discussed in section 3.1.

While this diagram is an oversimplification of the dynamics of the contaminants and river system, the results for nitrogen are noteworthy in that they reveal a story not told by the concentration data alone. When river flow levels are accounted for, it is found that median mass loadings of total nitrogen are rarely higher after the sewage

Figure 13.

Mass flow diagram



Note. Mass flow diagram representing a simplified input/output model of the river, with Sankey arrows for each parameter. The mass flows are based on median values for a typical year over the study period (1990-2024) based on the data available. By looking at mass loadings before and after the sewage outfall, the contributions from effluent versus non-point sources are estimated.

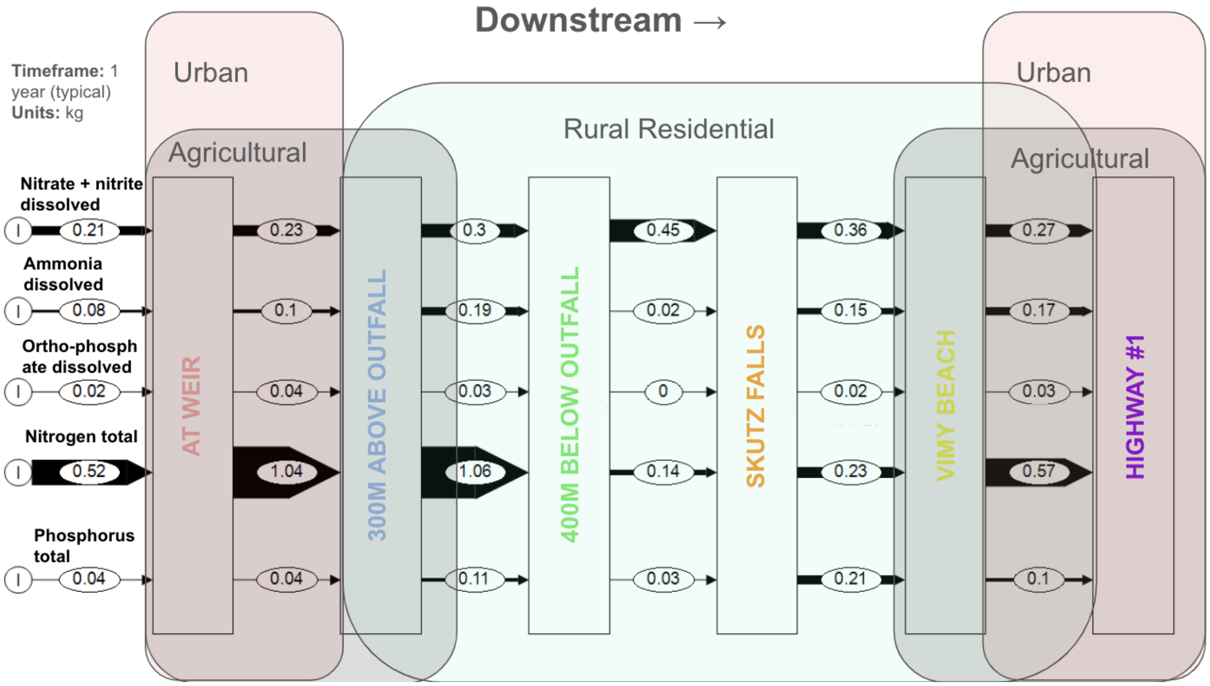
outfall, even though the concentration appears to be higher (Figure 7). For the two forms of nitrogen ammonia and nitrate + nitrite, it is also found that more originates from nonpoint sources than from the outfall, but to a lesser degree. Both of the above exhibited significant increases in concentration after the outfall.

Figure 14 shows mass flows between monitoring stations. Note that flow arrows correspond to measurements taken at the station name which they are pointing to, not where they are coming from. Phosphorus is often considered a primary contributor to excessive algae growth, and the sewage effluent is a known source of phosphorus in the river (Pike et al., 2017; Smorong & Saso, 2021). This is consistent with the results as we see median levels of phosphorus more than double after the outfall. However, the observed decrease and subsequent increase in phosphorus levels mid-river suggest that other non-point sources may also be contributing. Again, this section of the river is primarily rural residential, and so septic fields are a potential source of phosphorus. Unlike total phosphorus, levels of ortho-phosphate do not appear to be affected by the sewage outfall, but do exhibit a similar decrease mid river followed by a subsequent increase, pointing to non-point source origins.

The fact that the median mass of nitrogen after the outfall is only very marginally higher than before suggests that the effluent is not a major contributor of nitrogen. Rather, the results indicate that a significant amount of nitrogen comes from non-point sources located between the weir and the station upstream of the outfall. This area is characterized by agricultural and urban land use. The large decrease in nitrogen levels observed after the outfall suggests that it may be reacting with other substances or being taken up by organisms in the environment. However, the subsequent increase in nitrogen levels further downstream suggests that septic systems or rural areas may be contributing additional nitrogen, or that there is significant re-release of nitrogen back into the water. Other possible sources include fertilizers, and it's worth noting that ammonia and nitrate levels also increase mid-river. Dissolved nitrate + nitrite levels are highest mid river in rural residential zones, and reduce slightly at the upper and mid rivers.

Figure 14.

Multi-flow diagram



Note. Mass flow diagram showing Sankey arrows between six water quality monitoring stations for total phosphorus, total nitrogen, ortho-phosphate, ammonia, and nitrate + nitrite. The masses were calculated using river flow volume data and concentration data. Numbers are based on median masses for a typical year during the study period (1990-2024).

This mass flow analysis could be applied to different time frames in future studies. For example, examining the mass flows over the last 10 years, or for individual years from different time periods, could provide insights into recent trends. A higher resolution could help link contaminant mass loadings to specific climate events or disruptive human activities. Additionally, this study was limited by data availability, and future research could build upon this framework with more robust datasets to further investigate the sources of nonpoint source contaminants.

3.3 - Non-point contamination sources

3.3.1 - Septic Systems

The towns of Lake Cowichan and Duncan have reported 2021 populations of 3,325 and 4,944 respectively (Statistics Canada, 2022), which does not include the rural population in between the two. In 2011, an estimated two-thirds of single dwelling homes in the Cowichan Valley Regional District's (CVRD) electoral area (population 35,698) relied on private septic systems, amounting to 7,883 single dwelling homes (CVRD, 2013). The span in between Lake Cowichan and Duncan consists of rural homes on septic systems, many of which are riverfront properties, or are located alongside tributaries which enter the river (McKean, 1989; Smorong & Saso, 2021). Unfortunately, no reliable data exists on the housing density along the river, and determining the number of aging/poorly managed septic systems is a difficult task. A study of historical disturbances found that the number of wells and water licenses in 2012 had, unsurprisingly, increased dramatically since the 1950's, including along most of the length of the river (Pike et al., 2017). In addition to impacting the groundwater and surface water hydrology of the river, many of these homes presumably relied on septic systems. As previously mentioned, river contamination including nutrients and fecal matter have been attributed to anthropogenic sources with the help of microbial source tracking (Barlak et al., 2021). Beyond that, limited studies have focused on the impacts of septic systems in the region.

Studies have shown that poor performance from aging septic systems and agricultural runoff may contribute to the movement of contaminants through ground and surface waters to estuaries and the surrounding ecosystem (Geary & Lucas, 2019; Withers et al., 2011). The impacts of aging septic systems have long been understood as hazardous for river ecosystems including fish and humans, contributing sickness-causing bacteria and excessive nutrient loading including nitrogen and phosphorus (House et al., 1993; Iverson et al., 2018; Withers et al., 2011). Dispersed, non-point contaminant sources are often masked by a major point source (like the sewage outfall at Lake Cowichan), making it difficult to isolate the effects of non-point sources (House et al., 1993; Iverson et al., 2017; Sowah et al., 2017). One study from Sowah et al. sought to isolate the impact of septic systems on fecal pollution in streams in suburban watersheds, including an analysis of 24 different watersheds with septic system densities ranging from 8 - 373 systems per square kilometer. Human-associated markers were measured under baseflow conditions over a 3-year period, in areas with multiple sources of fecal contamination. Through multivariable regression analysis including factors like septic system density, forest cover, impervious area, and average distance to streams, their model explained 74% of variation in human fecal pollution in the spring season, which is characterized by high baseflow conditions and a low water table (Sowah et al., 2017). These results somewhat contradict suggestions that high water tables are likely to lead to septic system leakage (Arnade, 1999; Tamang, 2020), and indicate a strong septic system impact through groundwater recharge. However, the study still finds moderate positive correlations for summer and fall (0.47 and 0.31 respectively). It is important to note that this study was conducted in Georgia, United States, which differs in climate and hydrological regime compared to the Cowichan Valley. Notably, the study also found that septic system density and proximity to water sources were the strongest predictors for septic based fecal pollution.

A study by Iverson et al. estimated bacterial exports for six watersheds, half of which were managed via sewer systems and the other half through septic systems. Through sampling over the course of a year they found that during baseflow conditions, watersheds with septic systems experienced higher E coli concentrations in waterways and exports compared to watersheds with established sewer systems (Iverson et al., 2017). These and number of studies support the notion that high septic system density, high water flow events, and the relative age of the system are all associated with export of nutrients (phosphorus and nitrogen) and E coli (Iverson et al., 2017, 2018; Sowah et al., 2017; Tamang et al., 2022; Withers et al., 2011). These results are consistent with some of the observations that mid and lower rivers experience higher concentrations of nutrients and E coli during winter months. The CVRD has been raising awareness among residents by providing information on their website and hosting workshops about septic system care and maintenance (CVRD, 2013).

3.3.2 - Agricultural impacts

The Cowichan Valley has an agricultural history dating back to the late 1800's to early 1900's, beginning with the opening of the Cowichan Creamery in 1895, which operated for 93 years before closing in 1988 (Cowichan Region Agriculture Profile, 2024). The valley also had a significant seed business and was an exporter of chicks, cattle, and tree fruit between the two world wars. An estimated 15.8% of the land in the CVRD is considered to have a climate suitable for agriculture. About one third of the CVRD is within the Cowichan Basin which drains into the river and bay, and more than 530 water licenses have been issued to divert water from streams and lakes and over 1300 wells to draw groundwater from the aquifers, one of the many human factors that has been altering the hydrological regime in the valley. Today, there are 685 farms in the CVRD, consisting of cattle ranching (103), hog and pig (3), poultry and egg production (59), sheep and goats (46), other animal production (157), oilseed and grain (2), vegetables and melons (37), fruit and nut trees (74), greenhouse, nursery & floriculture (87), and other crop farming (117) (Cowichan Region Agriculture Profile, 2024). On an annual basis, there are 946 beef cows throughout 112 farms and 3,582 dairy cows on 41 farms, as well as 335,968 and 668,126 kg of chickens and turkeys respectively, in addition to a variety of other livestock.

Non-point pollution from agriculture is a globally known cause of eutrophication (Xia et al., 2020), leading to excessive algae growth including harmful blue-green algae (Luna Juncal et al., 2023), and persistent cause of concern for environmental agencies (Government of Canada, 2014; US EPA, 2015). Agricultural runoff is excess surface runoff from irrigation and rainfall (M. Wang et al., 2018), and commonly contains nitrates, ammonium, heavy metals, phosphorus compounds, and persistent organic pollutants (POP's) (Xia et al., 2020). Nitrogen and phosphorus are key limiting nutrients for the growth of aquatic plants, and hence are important factors in limiting eutrophication. Human caused eutrophication is known to negatively impact the health of aquatic ecosystems worldwide, and heavy metals and persistent organic pollutants (POP's) can accumulate in organisms leading to various health risks, including pollution of drinking water (Luna Juncal et al., 2023; Xia et al., 2020). These pollutants can arise from not only livestock, but from use of pesticides and fertilizers (US EPA, 2016; Xia et al., 2020). As the global population grows and concerns about climate change, food security, and biodiversity loss intensify, farmers face mounting pressure to increase food production with less fertilizers and land(Cardinale et al., 2012; Luna Juncal et al., 2023; Xia et al., 2020). Thus, the limiting of agricultural runoff pollution is a pressing issue not just for the Cowichan River but on a global scale. For small, climate-vulnerable coastal communities like Lake Cowichan and Duncan, continuing to provide local food production while mitigating environmental impacts will be vital in ensuring long-term food sovereignty and independence.

On the Cowichan, agricultural land reserves are concentrated at the upper and lower river, particularly surrounding Duncan (Figure 1), where active farmland can also be seen on satellite imagery. A detailed account of agriculture and its potential impacts on the river is beyond the scope of this study. However, given significant farmland surrounding parts of the river and within the drainage basin, and the quantities of agricultural land with livestock, it is reasonable to suspect that these lands could be contributing excess nutrients and other contaminants to the river (Obee, 2011; Smorong & Saso, 2021). Results in Figure 12 show a significant increase in nitrogen levels at the upper river, before the sewage outfall, however studies on the region have suggested that aging septic from float houses or rural properties on the edge of the sewer system may be a more likely cause (Barlak et al., 2021; Pike et al., 2017). Between Vimy Beach and Highway #1, a more than doubling in median nitrogen values is observed, which may be attributable to the farmland surrounding uncan. We also see a significant increase in phosphorus and ammonia in this area compared to the mid river.

3.3.3 - Contaminants of emerging concern

There are a number of other potential contaminants which could be impacting the river ecosystem, and should not be overlooked. One notable example is the tire preservative 6PPD, which has in recent years been a cause of concern for river and salmon health in British Columbia and across the Pacific Northwest (Darling, 2024; Kwan, 2024; Owen, 2024). The toxin, sometimes abbreviated as 6PPD-Q, forms when the tire preservative 6PPD reacts with ozone in the atmosphere (US EPA, 2023). The chemical compound 6PPD is used as a rubber additive to prevent tires from breaking down via reactions with oxygen species in the air, and is released through wear and contact with the road. Attributed to urban runoff from rainfall, studies have shown 6PPD-Q is lethally toxic to salmon, sometimes after only a few hours of exposure (French et al., 2022; Tian et al., 2021). The toxin has been found in Victoria and Nanaimo in lethal doses (Durling, 2024; van Reeuwyk, 2023), and considerable community efforts have been dedicated to mitigation, such as the Friends of Bowker Creek Society in Victoria (*Friends of Bowker Creek Society*, 2024). The findings suggest a strong correlation with high vehicle traffic areas and heavy rainfall events which carry contaminants to nearby waterways. The BC Conservation Foundation with its partners, Cowichan Tribes and the Cowichan Lake and River Stewardship Society, have started assessing 6PPD-Q along 4 tributaries at the upper river and 1 in the lower river, however results are not yet published. [1] In May of 2024 the members of the community in North Cowichan wrote an open letter to the city council, the CVRD, and the MP urging a ban on the use of 6PPD in tires in the region (Lake Cowichan Gazette, 2024). Other potential contaminants of emerging concern which may arise from septic systems, sewage effluent, and urban runoff include chemicals from pharmaceuticals and household cleaning products (Chen et al., 2006; Koné et al., 2013; Metcalfe et al., 2004; Richards et al., 2015).

3.3.4 - Heavy Metals

The water quality initiative in place for the Cowichan River also includes testing for heavy metals. A similar analysis was undertaken for the metals lead, zinc, cadmium, nickel, calcium, and copper. A mass flow analysis for heavy metals was not completed because levels can vary between several orders of magnitude between metals, and this type of analysis was found to be less insightful. Box plots of the concentrations of the above metals at all six stations can be seen in Appendix F. Calculations of mass loadings are shown below in Figure 15. The prevailing trend, which is visible in the concentration data but much more prominent with the mass loadings, is that levels are high at the headwaters, decrease mid river, and then increase again at the lower river. Visually, this pattern suggests a clear correlation with housing density, suggesting that sources of heavy metals are dominated by urban and/or agricultural runoff (Figures 1, 14). Once again, we see that calculating the mass of contaminants to account for changing flow volume provides insight into the nature of the problem.

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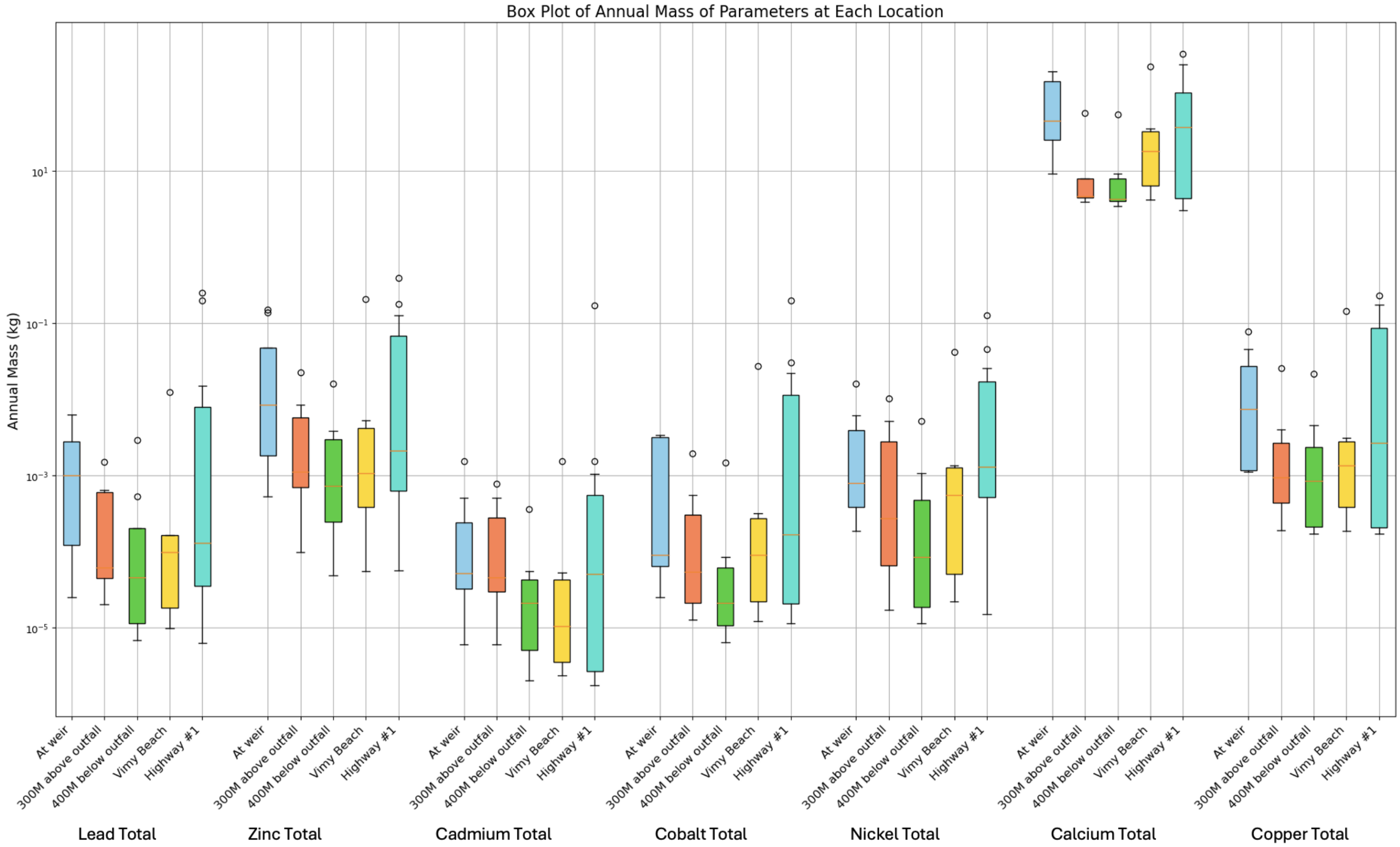
[1] See: https://cowichanwatershedboard.ca/document/water-quality-monitoring-location-in-the-cowichan-and-koksilah-watersheds/

Figure 15.

Heavy metal mass loadings



Note. The masses of heavy metals were calculated using aggregated river flow and concentration data. Heavy metals appear to closely correlate with housing density, rising near the communities at either end of the river and dipping mid river where rural homes and crown land dominate.

Water quality objectives have been set for copper (≤ 2 µg/L mean, ≤ 4 µg/L max), lead (≤ 4 µg/L mean, ≤ 11 µg/L max) and zinc (≤ 7.5 µg/L mean, ≤ 33 µg/L max). For copper and lead, only one exceedance was recorded in November of 2003, and no exceedances were recorded for zinc. Just as with the organic pollutants, data collection for heavy metals has been intermittent in the last few decades, and so it is possible that some occurrences were missed.

Heavy metals exist naturally in aquatic ecosystems, but excessively high concentrations can lead to health problems in both humans and fish. In humans, prolonged exposure to heavy metals has been linked to muscular dystrophy, Alzhiemer's, some cancers, damage to organs, and more (Oosthuizen, 2012; Zamora-Ledezma et al., 2021). In fish, it has been shown to damage/accumulate in organs including gills, liver, and kidneys, intestines, and muscles (Rashed, 2001; Shahjahan et al., 2022). Anthropogenic sources of heavy metals include industries like mining, combustion of fossil fuel, metal processing; agricultural materials like pesticides, inorganic fertilizers, and fungicides (Mushtaq et al., 2020; Vareda et al., 2019; Zamora-Ledezma et al., 2021). This means that heavy metals may be entering the Cowichan River from several different sources. Heavy metals are thought to be less of an immediate concern compared to nitrogen, phosphorus, and E coli (Barlak et al., 2021; Pike et al., 2017), however, anthropogenic sources of heavy metals have been identified, and should be considered for future water quality monitoring efforts as populations and industrialization continue to increase.

3.4 - Recommendations to enhance sustainability

Agricultural runoff and contaminants from septic systems appear to be the two main potential sources of non-point E. Coli and Nitrogen. The following sections will discuss possible mitigation strategies and recommendations for water quality monitoring efforts going forward.

3.4.1 - Recommendations for mitigation & circularity

One possible approach for enhanced sustainability is to incorporate concepts of circularity and industrial symbiosis into the community. The CVRD has ample farmland making use of chemical fertilizers, which may be entering waterways via runoff, and simultaneously a nutrient-rich sewage effluent is being constantly discharged into the river, both of which are potentially leading to excessive eutrophication. Several studies have explored the possibility of reusing treated sewage wastewater for agricultural irrigation (Fonseca et al., 2007; Greenberg & Thomas, 1954; Mishra et al., 2023; Pereira et al., 2011). However, this concept remains a topic of controversy among governments, authorities, and policy makers, and faces potential challenges regarding human and ecosystem health. In 2010, 39% of sewage sludge produced in the European Union was recycled for agricultural applications (Lamastra et al., 2018), however, this practice requires careful waste management practices, as sewage effluent can also contain harmful contaminants like heavy metals, organic pollutants, and pathogens (Lamastra et al., 2018; Mishra et al., 2023). According to the BC Government's municipal wastewater regulation, which is met by Lake Cowichan's treatment plant, effluent discharged into rivers must meet a 40:1 dilution ratio and have a total suspended solids (TSS) concentration of ≤ 45 mg/L (Government of BC, 2022). The British Columbia Government's municipal sewage regulation states permitted uses and standards for reclaimed water. For unrestricted public access, effluent must be treated to secondary standards, requiring chemical addition, filtration, disinfection, and emergency storage (*BC Reg 129/99 | Municipal Sewage Regulation*, 2010). It must also meet standards for turbidity, dissolved oxygen, and fecal organisms. The provider of the reclaimed water must ensure it is free from harmful pathogens, clean, odorless, non-irritating, and non-toxic. Agricultural metal limits should be followed, considering nutrient levels to protect crops. Before distribution, water quality must be confirmed through monitoring. Monitoring criteria are also outlined, with weekly monitoring of pH and dissolved oxygen, continuous monitoring of turbidity, and daily monitoring of coliform. Implementing this into practice would therefore require additional monitoring and treatment of effluent, as well as expert consultation and a desire and collaboration from the community. Future studies could investigate potential of larger island-wide sustainability initiatives involving reuse of treated sewage effluent for agricultural practices.

When it comes to agricultural impacts, there has been progress in mitigation strategies over the years. After identifying runoff-related water quality issues on local farms, Cowichan Watershed Board (CWB) members communicated with dairy farmers in the area, and used aerial imagery to show coliform contamination. A workshop on June 19, 2013, co-hosted by the BC Ministry of Agriculture and the CWB, covered water sampling results, manure management, and best practices (CWB, 2023). This led to a Group-based Environmental Farm Plan, offering funding for nutrient management improvements. In 2018, further outreach in the Koksilah watershed engaged farmers and various governmental bodies, focusing on water quality, riparian restoration, and agricultural education. These efforts should continue as new strategies for treating agricultural runoff emerge (Xia et al., 2020).

In 2012, significant fecal coliform contamination was detected in the Lower Koksilah watershed (the Koksilah River feeds into the Cowichan River near Duncan), Cowichan Bay, and Cowichan Bay Estuary, prompting DNA studies to identify contamination sources. The research aimed to trace the origins of fecal coliforms and enterococci. Results indicated that the high levels of fecal contaminants primarily originated from human and bovine sources. It is recommended that this type of study be performed along the Cowichan River, as E oli continues to be an issue. Since septic systems are a plausible source of E coli and nutrients, it is suggested that data on septic systems along the river be acquired, awareness about proper septic system care and maintenance continue to be promoted, and financial incentives be provided to homeowners to upgrade older systems if necessary. Collecting more data (number of homes on septic systems, age of homes/septic systems, etc.) will be particularly useful in future studies isolating and quantifying the effects of septic system pollution.

3.4.2 - Recommendations for water quality monitoring program

For the water quality monitoring program, it is recommended that the community explore development of WQO's for nitrogen, as it is a major limiting nutrient like phosphorus. Sampling for the tire preservative 6PPDQ should be expanded due to its known issues in neighboring areas. In general, non-point sources should be considered further, even if the near-term focus remains on effluent relocation. Sampling should be tailored to non-point sources, including areas where agricultural runoff and septic system contamination are likely. Emphasis should be placed on sampling before and after potential contamination sources on the main river or along its tributaries where human activity exists. A continuous community effort will be essential, involving collaboration between Cowichan Tribes, other levels of government, the community, and water quality experts. More data and increased sampling regularity are needed, acknowledging the associated costs and challenges. The evaluation of contaminants of emerging concern should continue, along with more detailed assessments on agricultural and septic system impacts, and waterway diversions.

4.0 - Conclusion

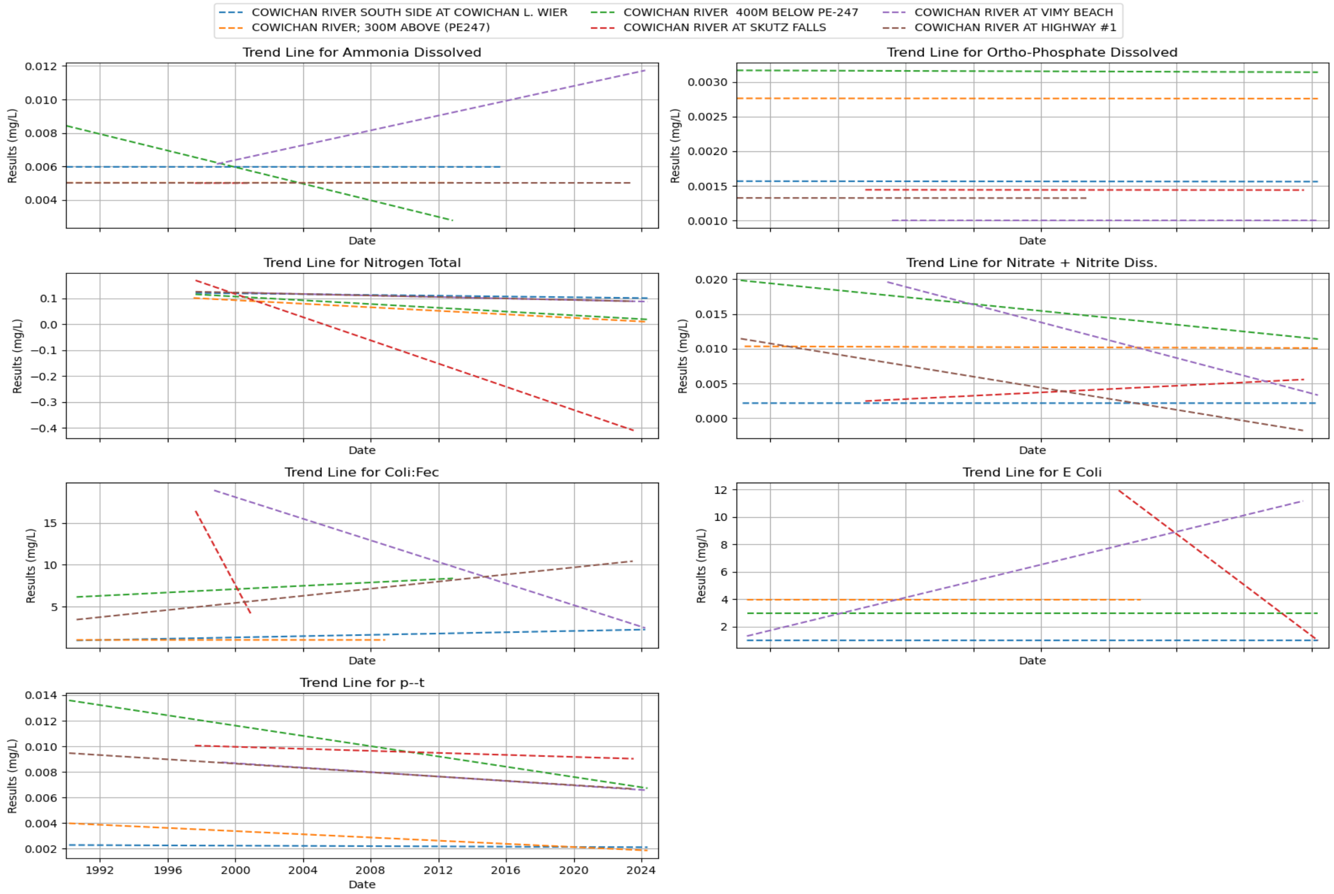
The combined effects of historical and continued human disturbances, water contamination, and climate change impacts have had a profound effect on the Cowichan River and its aquatic ecosystem. An analysis of water quality data from 1990 to 2024 has shown that nutrient levels, particularly phosphorus and nitrogen, have often exceeded water quality objectives. These high nutrient concentrations combined with unprecedented low flow events and high temperatures have been linked to excessive algae growth and subsequent anoxic water conditions, leading to inhabitable conditions for fish. The urgency of this issue was brought into the spotlight by a fish kill event in summer of 2023 when an estimated 80,000 spawning salmon are thought to have died.

Through collaboration between the Cowichan Watershed Board, Cowichan Tribes, BC government, federal government. CVRD, provincial experts and local non-government organizations, substantial progress has been made to mitigate these effects and prevent another fish kill event from happening. A plan is in place to relocate the lower river sewage outfall, a major source of nutrients, to the estuary. The Town of lake Cowichan is exploring upgrading its sewage treatment facility as well. However, mass flow analysis reveals that significant amounts of nutrients, as well as E coli, originate from non-point sources such as agricultural runoff and poorly managed septic systems. Thus, the impacts of non-point sources should not be overlooked and should be a strong consideration for the Cowichan River's water quality monitoring initiative. Although data availability was limited for this work, the mass flow analysis may serve as a framework for future works to assess the impacts of non-point sources. Higher resolution water quality data combined with data on agricultural land, housing density, and septic systems would be particularly useful for a more robust analysis of the Cowichan River or others.

Moving forward, efforts should focus on improving the existing water quality monitoring to better account for the contributions from non-point sources. This includes developing specific water quality objectives for nitrogen, enhancing the regularity and scope of sampling, keeping watch over heavy metals contamination, and considering emerging contaminants such as the tire preservative 6PPD-Q. Continued efforts to educate and engage the community, including the promotion of proper septic system maintenance and sustainable agricultural practices, will be essential for securing a healthy watershed for future generations.

Appendix

Appendix A1 - Mann-Kendall + Theil Sen Results Plot

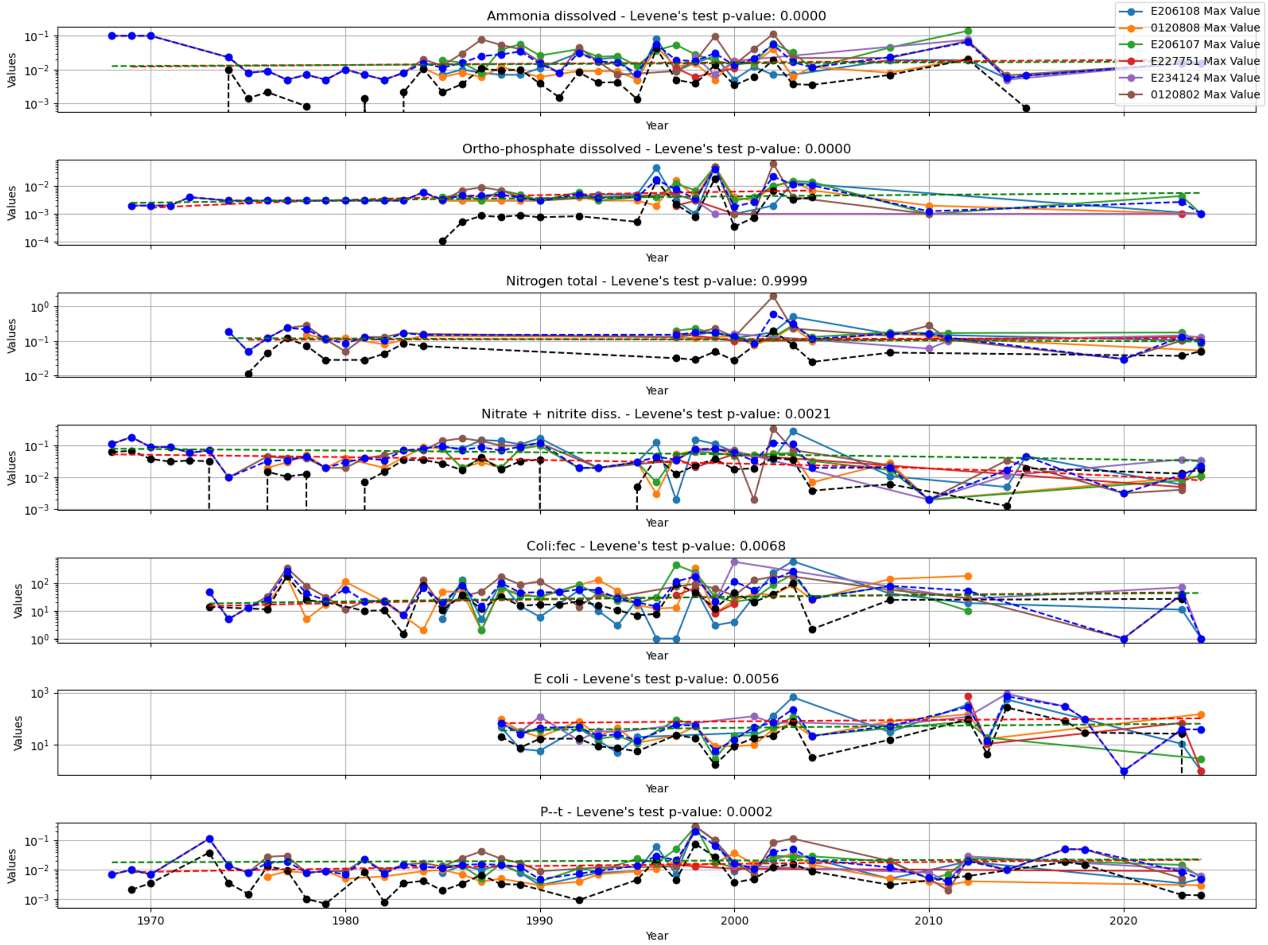


Appendix A2 - Mann-Kendall + Theil Sen Results Table

Parameter	Location	Trend	Intercept	Mann-Kendall Tau	P-value
Ammonia Dissolved	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	-2.86E-10	0.00617533	-0.1049743	0.18284006
Ammonia Dissolved	COWICHAN RIVER; 300M ABOVE (PE247)	-5.14E-11	0.00505874	-0.0322387	0.63388167
Ammonia Dissolved	COWICHAN RIVER 400M BELOW PE-247	-6.78E-07	0.50089616	-0.2387238	0.0001062
Ammonia Dissolved	COWICHAN RIVER AT SKUTZ FALLS	2.87E-10	0.00479104	0.1854734	0.40613178
Ammonia Dissolved	COWICHAN RIVER AT VIMY BEACH	6.05E-07	-0.4354243	0.19071033	0.22280056
Ammonia Dissolved	COWICHAN RIVER AT HIGHWAY #1	8.18E-11	0.00495226	0.05927128	0.42116337
Ortho-Phosphate Dissolved	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	-5.29E-10	0.00195101	-0.1989548	0.05620071
Ortho-Phosphate	COWICHAN RIVER; 300M ABOVE (PE247)	-3.54E-10	0.00301849	-0.1369172	0.07997704

Dissolved					
Ortho-Phosphate Dissolved	COWICHAN RIVER 400M BELOW PE-247	-2.10E-09	0.00469187	-0.1841911	0.0166361
Ortho-Phosphate Dissolved	COWICHAN RIVER AT SKUTZ FALLS	-3.80E-10	0.00171923	-0.2137079	0.29830279
Ortho-Phosphate Dissolved	COWICHAN RIVER AT VIMY BEACH	1.15E-26	0.001		
Ortho-Phosphate Dissolved	COWICHAN RIVER AT HIGHWAY #1	-3.60E-10	0.00158659	-0.1714313	0.11070358
Nitrogen Total	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	-2.06E-06	1.62559861	-0.1184629	0.3167233
Nitrogen Total	COWICHAN RIVER; 300M ABOVE (PE247)	-9.37E-06	6.93431476	-0.2579256	0.00180294
Nitrogen Total	COWICHAN RIVER 400M BELOW PE-247	-9.93E-06	7.35531767	-0.2498772	0.00334211
Nitrogen Total	COWICHAN RIVER AT SKUTZ FALLS	-6.12E-05	44.8366585	-0.3333333	0.75
Nitrogen Total	COWICHAN RIVER AT VIMY BEACH	-3.94E-06	2.99671938	-0.2857143	0.39875992
Nitrogen Total	COWICHAN RIVER AT HIGHWAY #1	-3.90E-06	2.97189816	-0.1478337	0.23251831
Nitrate + Nitrite Diss.	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	-1.15E-10	0.00224137	-0.0279346	0.74884023
Nitrate + Nitrite Diss.	COWICHAN RIVER; 300M ABOVE (PE247)	-2.01E-08	0.02495844	-0.1252235	0.08097063
Nitrate + Nitrite Diss.	COWICHAN RIVER 400M BELOW PE-247	-6.79E-07	0.51301166	-0.0861186	0.19068275
Nitrate + Nitrite Diss.	COWICHAN RIVER AT SKUTZ FALLS	3.29E-07	-0.2372403	0.03361463	0.85679441
Nitrate + Nitrite Diss.	COWICHAN RIVER AT VIMY BEACH	-1.75E-06	1.29887441	-0.0769231	0.76502485
Nitrate + Nitrite Diss.	COWICHAN RIVER AT HIGHWAY #1	-1.09E-06	0.80305808	-0.1753314	0.047174
Coli:Fec	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	0.00010624	-76.26416	0.15207167	0.05141871
Coli:Fec	COWICHAN RIVER; 300M ABOVE (PE247)	9.57E-09	1.00037775	0.02986905	0.63207995
Coli:Fec	COWICHAN RIVER 400M BELOW PE-247	0.0002741	-193.04105	0.04631695	0.46896467
Coli:Fec	COWICHAN RIVER AT SKUTZ FALLS	-0.0103287	7548.79654	-0.19518	0.22454156
Coli:Fec	COWICHAN RIVER AT VIMY BEACH	-0.0017695	1310.03496	-0.2222283	0.21576015
Coli:Fec	COWICHAN RIVER AT HIGHWAY #1	0.00058256	-419.90029	0.07377882	0.33530041
E Coli	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	4.46E-09	0.99776112	0.12789595	0.10896583
E Coli	COWICHAN RIVER; 300M ABOVE (PE247)	-2.24E-08	3.98184764	-0.0119399	0.86124804
E Coli	COWICHAN RIVER 400M BELOW PE-247	1.83E-10	3.00031383	-0.0009106	0.98983105
E Coli	COWICHAN RIVER AT VIMY BEACH	-0.0025457	1882.34034	-0.3308645	0.06834013
E Coli	COWICHAN RIVER AT HIGHWAY #1	0.00082037	-594.84642	0.20734478	0.00317604
p--t	COWICHAN RIVER SOUTH SIDE AT COWICHAN L. WIER	-1.37E-08	0.01225652	-0.1709913	0.04349328
p--t	COWICHAN RIVER; 300M ABOVE (PE247)	-1.70E-07	0.12751231	-0.215182	0.00216947
p--t	COWICHAN RIVER 400M BELOW PE-247	-5.50E-07	0.41297524	-0.2003144	0.00248348
p--t	COWICHAN RIVER AT SKUTZ FALLS	-1.08E-07	0.089173	-0.1314398	0.47630383
p--t	COWICHAN RIVER AT VIMY BEACH	-2.38E-07	0.18210878	-0.0923846	0.48681325
p--t	COWICHAN RIVER AT HIGHWAY #1	-2.30E-07	0.17634101	-0.157108	0.04105241

Appendix B - Std. dev / maximum value trends



Note. Trend slopes and confidence intervals were calculated for general trends and maximums. These results are stated and discussed below:

Ammonia Dissolved

1. **Trend (slope):** 0.00013468824113208294
    - **Intercept:** -0.2530404053494153
    - **95% CI for slope:** *-0.0003504629994790375, 0.0006083192882241405*
2. **Max Value Trend (slope):** 8.339328660370943e-05
    - **Intercept:** -0.15145425797265852
    - **95% CI for slope:** *-0.0002153237725223092, 0.0004715884326286596*

- The slopes for both the general trend and the max value trend are positive but very small, indicating a slight increasing trend in ammonia levels over time.
- However, the confidence intervals for the slopes include zero, which means these trends are not statistically significant at the 95% confidence level.

Ortho-Phosphate Dissolved

1. **Trend (slope):** 0.00015366450886046868
    - **Intercept:** -0.3010609754734404
    - **95% CI for slope:** *3.082752207725025e-05, 0.0002873416561591914*
2. **Max Value Trend (slope):** 5.7468807426851764e-05
    - **Intercept:** -0.11066176859244481
    - **95% CI for slope:** *8.410238131335084e-08, 0.00016637377850553907*

- The slopes for both trends are positive and small, indicating a slight increase in ortho-phosphate levels over time.
- The confidence intervals for the slopes are positive and do not include zero for the general trend, suggesting a statistically significant increasing trend. The max value trend also has a positive confidence interval, albeit very close to zero.

Nitrogen Total

1. **Trend (slope):** 0.00022552767384190886
    - **Intercept:** -0.3369121508741567
    - **95% CI for slope:** *-0.0017537872503693194, 0.0033337855750459537*
2. **Max Value Trend (slope):** -0.00047641857930983225
    - **Intercept:** 1.061224646271084
    - **95% CI for slope:** *-0.0019106789818303367, 0.0012913075907475579*

- The general trend slope is positive but small, while the max value trend slope is negative.
- The confidence intervals for both trends include zero, indicating no statistically significant trend in nitrogen total levels over time.

Nitrate + Nitrite Dissolved

1. **Trend (slope):** -0.0008044045887157605
    - **Intercept:** 1.6361752664882045
    - **95% CI for slope:** *-0.0014059858751654642, 0.00016510952472685643*
2. **Max Value Trend (slope):** -0.0008339956168538405
    - **Intercept: 1.721131908245006**
    - **95% CI for slope: [-0.0014701045465517761, 2.8337033756041263e-05]**

Both trends show a negative slope, suggesting a decreasing trend in nitrate + nitrite levels.However, the confidence intervals for the slopes include zero, indicating that these trends are not statistically significant.

Coliform

1. **Trend (slope): 0.6296251791614**
    - **Intercept:** -1227.4814826138693
    - **95% CI for slope:** [-0.4573982118656336, 2.3957620049126587]
2. **Max Value Trend (slope): 0.5003139099980856**
    - **Intercept:** -968.8116131630285
    - **95% CI for slope:** [-0.4107545558237306, 2.1118976614559126]

- The slopes for both trends are positive and relatively large, indicating an increasing trend in fecal coliform levels.
- However, the confidence intervals for the slopes include zero, indicating that these trends are not statistically significant.

E. Coli

1. **Trend (slope): 0.9999999626068539**
    - **Intercept:** -1919.9999999999607
    - **95% CI for slope:** [-0.6730771714845325, 4.744394852699989]
2. **Max Value Trend (slope): 0.8206896579615363**
    - **Intercept:** -1596.0381663220521
    - **95% CI for slope:** [-0.5457386985743632, 4.195312500639263]

- Both slopes are positive and large, suggesting an increasing trend in E. coli levels.
- However, the confidence intervals for the slopes include zero, indicating that these trends are not statistically significant.

Total phosphorus

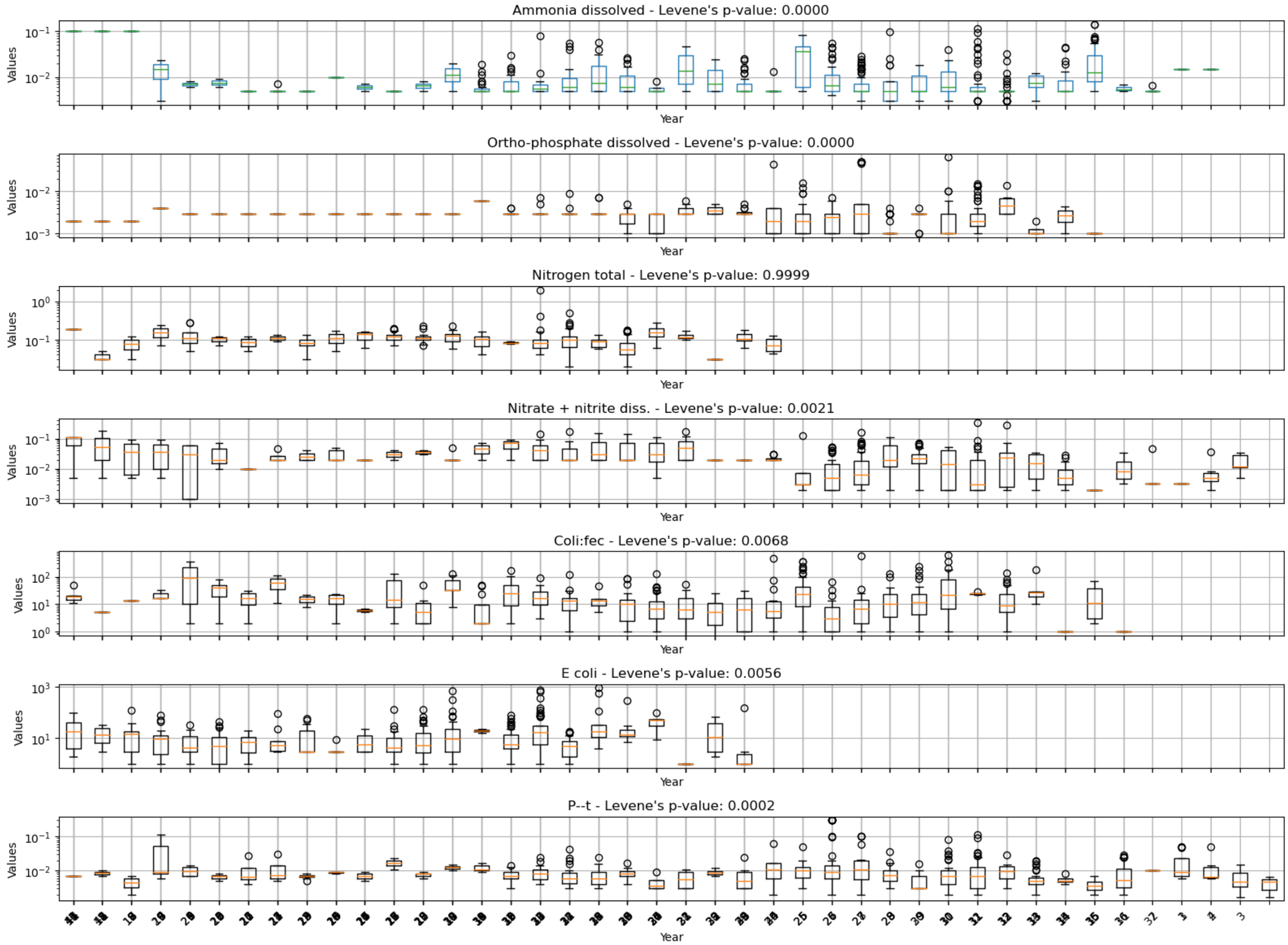
1. **Trend (slope): 0.00025047141268788413**
    - **Intercept:** -0.4848714953744534
    - **95% CI for slope:** [-0.00010951427571718718, 0.0006666344663384074]
2. **Max Value Trend (slope): 8.486351891158993e-05**
    - **Intercept:** -0.148922671016856
    - **95% CI for slope:** [-0.00010860527859166019, 0.0004285078418123903]

- The slopes for both trends are positive but small, indicating a slight increase in levels over time.
- The confidence intervals for the slopes include zero, indicating that these trends are not statistically significant.

Summary

- For most parameters, the observed trends (both general and max values) have small slopes, indicating minimal change over time.
- The confidence intervals for most slopes include zero, suggesting that the observed trends are not statistically significant at the 95% confidence level.
- The only parameter showing a statistically significant trend is ortho-phosphate dissolved for the general trend, with a small but positive slope.

Appendix C - Levene’s test results



Appendix D - WQO Exceedances: Total Phosphorus

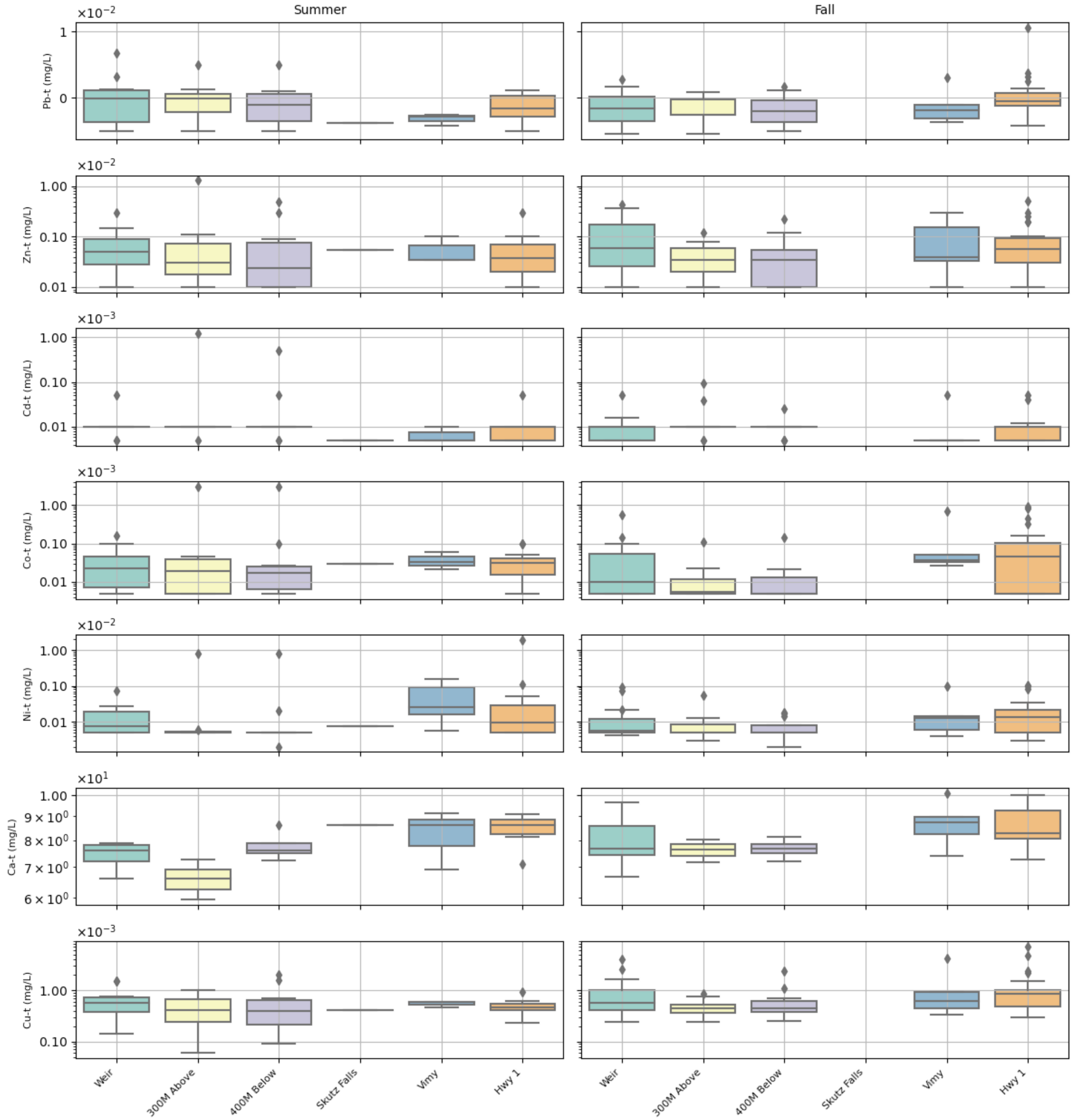
Start Date	End Date	Mean Value	Max Value	Station Name
1997-07-31 11:05	1997-08-27 13:00	0.0056	0.007	At Weir
1997-08-06 10:30	1997-09-03 13:00	0.0054	0.007	At Weir
1998-07-06 10:00	1998-07-30 14:00	0.0626	0.3	At Weir
1998-07-16 0:00	1998-08-05 0:00	0.0624	0.3	At Weir
1998-07-23 0:00	1998-08-13 0:00	0.0632	0.3	At Weir
2000-11-02 8:45	2000-11-30 9:15	0.0058	0.009	At Weir
2003-08-10 15:05	2003-09-07 13:50	0.0034	0.008	At Weir
2003-10-19 15:00	2003-11-16 14:15	0.0134	0.035	At Weir
1997-07-31 11:30	1997-08-25 10:30	0.0066	0.011	300M Above
1997-08-06 11:45	1997-08-27 13:35	0.0068	0.011	300M Above
1997-08-14 10:40	1997-09-03 13:10	0.0064	0.011	300M Above
1998-07-06 10:50	1998-08-04 0:00	0.0058	0.014	300M Above
1998-07-16 0:00	1998-08-04 8:45	0.0078	0.014	300M Above
1998-07-23 0:00	1998-08-06 0:00	0.0078	0.014	300M Above
1998-07-30 14:20	1998-08-11 0:00	0.007	0.014	300M Above
1998-08-04 0:00	1998-08-13 0:00	0.0076	0.014	300M Above
1998-08-04 8:45	1998-08-18 0:00	0.0058	0.014	300M Above
1998-08-06 0:00	1998-08-25 0:00	0.0046	0.008	300M Above
1998-08-11 0:00	1998-09-01 8:00	0.0052	0.008	300M Above
1998-08-13 0:00	1998-09-01 13:00	0.0054	0.008	300M Above
2000-11-02 8:55	2000-11-30 9:40	0.0056	0.007	300M Above
2002-08-06 12:50	2002-08-25 17:25	0.0074	0.021	300M Above
2002-08-07 9:45	2002-09-02 15:38	0.004	0.008	300M Above
2002-08-14 14:05	2002-09-03 12:30	0.009	0.027	300M Above
2002-08-20 0:00	2002-09-08 11:40	0.0088	0.027	300M Above
2003-08-05 12:00	2003-08-24 12:35	0.01	0.032	300M Above
2003-08-10 15:15	2003-09-01 13:40	0.008	0.032	300M Above
2003-08-17 17:25	2003-09-02 13:50	0.0082	0.032	300M Above
2003-08-19 13:00	2003-09-07 14:10	0.0082	0.032	300M Above
2003-10-19 15:15	2003-11-16 14:35	0.0056	0.009	300M Above
1997-07-31 11:45	1997-08-25 10:30	0.0192	0.051	400M Below
1997-08-06 12:05	1997-08-27 14:00	0.0216	0.051	400M Below
1997-08-14 11:00	1997-09-03 13:30	0.0212	0.051	400M Below
1998-07-06 11:10	1998-07-30 14:30	0.0696	0.3	400M Below
1998-07-16 0:00	1998-08-04 0:00	0.071	0.3	400M Below
1998-07-23 0:00	1998-08-04 8:50	0.0734	0.3	400M Below
1998-07-23 0:00	1998-08-05 0:00	0.0728	0.3	400M Below
1998-07-30 14:30	1998-08-11 0:00	0.015	0.02	400M Below
1998-08-04 0:00	1998-08-13 0:00	0.0154	0.02	400M Below
1998-08-04 8:50	1998-08-18 0:00	0.0138	0.02	400M Below
1998-08-05 0:00	1998-08-25 0:00	0.0114	0.015	400M Below
1998-08-11 0:00	1998-09-01 8:00	0.012	0.015	400M Below
1998-08-13 0:00	1998-09-01 13:30	0.0128	0.015	400M Below
2000-11-02 9:05	2000-11-30 9:50	0.007	0.008	400M Below
2002-08-06 13:45	2002-08-25 17:50	0.0126	0.031	400M Below

2002-08-07 10:10	2002-09-02 15:45	0.0088	0.012	400M Below
2002-08-14 14:20	2002-09-03 13:30	0.009	0.012	400M Below
2002-08-20 0:00	2002-09-08 11:50	0.0098	0.012	400M Below
2003-08-05 12:45	2003-08-24 12:50	0.0134	0.027	400M Below
2003-08-10 15:25	2003-09-01 13:50	0.0134	0.027	400M Below
2003-08-17 17:35	2003-09-02 15:45	0.014	0.027	400M Below
2003-08-19 13:00	2003-09-07 14:15	0.0154	0.027	400M Below
2008-08-10 15:15	2008-09-07 12:20	0.0112	0.019	400M Below
2012-10-15 9:30	2012-11-13 9:30	0.0091	0.0246	400M Below
1998-07-06 12:15	1998-08-05 0:00	0.0084	0.013	Skutz Falls
1998-07-16 0:00	1998-08-13 0:00	0.0092	0.013	Skutz Falls
2000-11-02 9:25	2000-11-30 10:10	0.0082	0.011	Skutz Falls
2000-11-02 10:10	2000-11-30 11:05	0.0112	0.014	Vimy
2012-10-15 10:15	2012-11-13 10:00	0.02194	0.029	Vimy
1997-07-31 15:00	1997-08-27 9:30	0.0106	0.013	Highway 1
1998-07-06 14:10	1998-07-30 12:30	0.0664	0.3	Highway 1
1998-07-16 0:00	1998-08-05 0:00	0.0662	0.3	Highway 1
1998-07-23 0:00	1998-08-13 0:00	0.0674	0.3	Highway 1
2000-11-02 11:10	2000-11-30 11:30	0.0132	0.018	Highway 1
2003-10-19 16:00	2003-11-16 16:00	0.056	0.116	Highway 1
2008-08-10 16:00	2008-09-07 12:20	0.0084	0.02	Highway 1
2012-10-15 10:45	2012-11-13 10:30	0.01738	0.0227	Highway 1
2017-08-08 14:13	2017-09-05 14:05	0.0071	0.0083	Highway 1
2017-10-24 13:10	2017-11-21 12:58	0.02638	0.0501	Highway 1
2018-08-07 11:00	2018-08-28 12:37	0.0149	0.05	Highway 1
2018-08-07 11:00	2018-09-04 12:40	0.00616	0.0065	Highway 1

Appendix E - WQO Exceedances: E Coli

Start Date	End Date	Exceedance Value	Station Name
1993-08-04 13:15	1993-08-31 12:38	13.4	At Weir
2001-10-24 0:00	2001-11-21 0:00	22	At Weir
2002-10-27 11:55	2002-11-24 11:30	21.8	At Weir
2003-08-10 15:05	2003-09-07 13:50	406.4	At Weir
2008-08-10 14:50	2008-09-07 12:00	21	At Weir
2012-08-06 17:55	2012-09-04 18:00	218.8	At Weir
2012-10-15 9:00	2012-11-13 9:00	49.6	At Weir
1990-08-15 14:55	1990-09-12 13:25	19.6	300M Above
1994-07-27 14:45	1994-08-25 13:00	11.2	300M Above
1994-08-11 12:35	1994-09-08 14:10	12.4	300M Above
1994-08-16 12:15	1994-09-08 14:15	13.2	300M Above
1994-08-25 13:00	1994-09-08 14:25	11.6	300M Above
1994-09-08 14:00	1994-09-27 10:30	31.2	300M Above
1998-08-04 0:00	1998-09-01 8:00	39.2	300M Above
2003-08-10 15:15	2003-09-07 14:10	58.8	300M Above
2008-08-10 15:01	2008-09-07 12:10	51.2	300M Above
2012-08-06 18:20	2012-09-04 17:45	17.8	300M Above
2012-10-15 9:15	2012-11-13 9:15	121.6	300M Above
2013-07-29 10:55	2013-08-26 10:40	13.8	300M Above
2012-08-06 17:40	2012-09-04 16:10	13.8	Vimy
2012-10-15 10:15	2012-11-13 10:00	412	Vimy
2013-07-30 9:50	2013-08-27 11:25	10.2	Vimy
1990-08-15 14:20	1990-09-12 11:25	80.2	Highway 1
1993-08-04 11:35	1993-08-31 10:50	25.2	Highway 1
1994-07-27 10:35	1994-08-25 11:15	20.6	Highway 1
1994-08-02 11:15	1994-08-25 11:55	20.6	Highway 1
1994-08-11 11:50	1994-08-25 12:59	19.4	Highway 1
1994-08-16 11:05	1994-09-08 9:40	10.4	Highway 1
1994-08-25 11:15	1994-09-08 10:40	20.8	Highway 1
1994-08-25 11:55	1994-09-08 10:50	20.8	Highway 1
2001-10-17 11:24	2001-11-14 0:00	83.2	Highway 1
2001-10-24 0:00	2001-11-21 0:00	83.2	Highway 1
2002-10-28 12:10	2002-11-25 12:10	59.6	Highway 1
2003-08-10 16:30	2003-09-07 13:15	49.8	Highway 1
2008-10-13 14:30	2008-11-11 12:00	38	Highway 1
2012-08-06 16:15	2012-09-04 15:45	14.8	Highway 1
2012-10-15 10:45	2012-11-13 10:30	109.6	Highway 1
2017-08-08 14:13	2017-09-05 14:05	17.2	Highway 1
2017-10-24 13:10	2017-11-21 12:58	188.8	Highway 1
2018-08-07 11:00	2018-09-04 12:40	80.8	Highway 1

Appendix F - Heavy metal box plot results



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