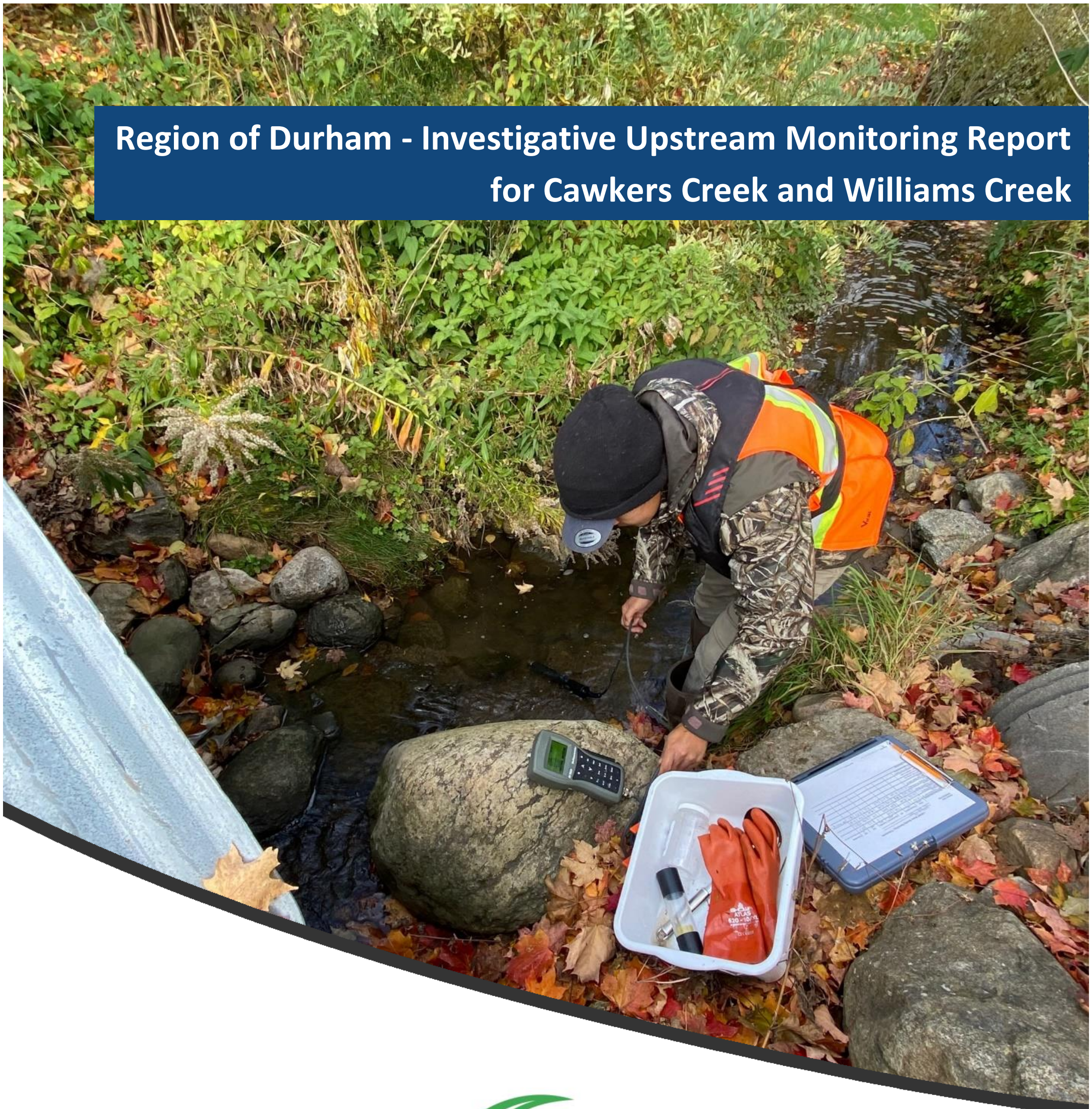
# Region of Durham - Investigative Upstream Monitoring Report for Cawkers Creek and Williams Creek



KAWARTHA CONSERVATION

Discover · Protect · Restore

## Who we are

We are a watershed-based organization that uses planning, stewardship, science, and conservation lands management to protect and sustain outstanding water quality and quantity supported by healthy landscapes.

## Why is watershed management important?

Abundant, clean water is the lifeblood of the Kawarthas. It is essential for our quality of life, health, and continued prosperity. It supplies our drinking water, maintains property values, sustains an agricultural industry, and contributes to a tourism-based economy that relies on recreational boating, fishing, and swimming. Our programs and services promote an integrated watershed approach that balance human, environmental, and economic needs.

## The community we support

We focus our programs and services within the natural boundaries of the Kawartha watershed, which extend from Lake Scugog in the southwest and Pigeon Lake in the east, to Balsam Lake in the northwest and Crystal Lake in the northeast – a total of 2,563 square kilometers.

## Our history and governance

In 1979, we were established by our municipal partners under the *Ontario Conservation Authorities Act*. The natural boundaries of our watershed overlap the six municipalities that govern Kawartha Conservation through representation on our Board of Directors. Our municipal partners include the City of Kawartha Lakes, Region of Durham, Township of Scugog, Township of Brock, Municipality of Clarington, Municipality of Trent Lakes, and Township of Cavan Monaghan.

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## Acknowledgements

We would like to acknowledge that many Indigenous Nations have longstanding relationships, both historic and modern, with the territories upon which we are located.

Today, this area is home to many Indigenous peoples from across Turtle Island. We acknowledge that our watershed forms a part of the treaty and traditional territory of the south-eastern Anishinaabeg.

It is on these ancestral and Treaty lands that we live and work. To honour this legacy, we commit to being stewards of the natural environment and undertake to have a relationship of respect with our Treaty partners.

The region of Kawartha Lakes was referred to as *Gau-wautae-gummauh*, a glistening body of water, in anishinaabemowin. We are thankful to have an opportunity to work with Indigenous Peoples in the continued stewardship and care of this beautiful region.

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## Abbreviations

%: Percentage
%CV: Coefficient of variation
µg/L: Micrograms per liter
µS/cm: Microsiemens per centimeter
$^{o}C$: Degree Celsius
CCME: Canadian Council of Ministers of the Environment
Cl: Chloride
Cond: Conductivity
CWQG: Canadian Water Quality Guideline
DO: Dissolved Oxygen
ERC: Ecological Reference Condition
*et al.* : et alibī (latin phrase) meaning and other authors
FNU: Formazin Nephelometric Unit
ha: Hectare
kg: Kilograms
$km^2$: Square kilometers
$m^3/s$: Cubic metre per second
mg/L: Milligrams per liter
*n*: Sample size
$NH_3$-N: Ammonia-Nitrogen
$NO_2$-N: Nitrite-Nitrogen
$NO_3$-N: Nitrate-Nitrogen
NTU: Nephelometric Turbidity Unit
*p:* p-value
PRC: Physical Reference Condition
PWQO: Provincial Water Quality Objectives
Temp: Temperature
TKN: Total Kjeldahl Nitrogen
TN: Total Nitrogen
TP: Total Phosphorus
TSS: Total suspended solids
Turb: Turbidity
yr: Year
*ρ:* Spearman's rho

## Executive Summary

From 2018 to 2021, the Durham Region Investigative Upstream Monitoring project assessed nine sites on two different tributaries of concern: Cawkers Creek and Williams Creek. The goal of this project was to identify potential areas of concern within each tributary using both water quality and quantity measurements. By identifying these hot spots, a more focused approach can be used for stewardship to help remediate areas that may be negatively impacted by surrounding activities. By remediating and restoring these areas, the water and habitat quality will dramatically be improved, both locally and in the areas downstream.

Upstream catchment area (ha), water quality (mg/L) and discharge measurements ($m^3$/s) were used to calculate loadings (kg/ha/yr) at each site, which helps us indicate if there are excessive amounts of various compounds entering the stream over a given amount of time. Water quality results were compared against the Ontario Provincial Water Quality Objectives (PWQO) and the Canadian Water Quality Guidelines (CWQG) for the Protection of Aquatic Life. By using both the PWQO and CWQG we can ensure that water quality is satisfactory for the protection of aquatic life and for recreational use.

All parameters were found to be higher than those found in natural waterways indicating that human influence is impacting these streams. Williams Creek is dominated by urban land cover, while Cawkers Creek is mostly used for agriculture. Among both streams, exceedances of nutrients, chloride and suspended solids were found. For ammonia, concern sites are CC4 and WC3, for nitrate: CC5 and WC2, for phosphorus: CC3 and WC2, for chloride: CC4 and WC2, and for total suspended solids: CC2 and WC3.

## Introduction

The Lake Scugog watershed is located within the Michi Saagiig Nishnaabeg territory and is covered under the Williams Treaties (1923) - Rice Lake Treaty No. 20 (1818). Since the mid-1800s, it has seen dramatic changes to both its land cover and water quality. Damming in the Town of Lindsay has artificially created a shallow lake.

Excessive nutrient input and poor land use practices, e.g., deforestation, wetland removal, riparian elimination, have led to degradation of water and habitat quality, rapid eutrophication, and risk of harmful algae blooms (Thomas et al., 2018; Keatly et al., 2011). These types of conditions can negatively impact the health of our environment (Conley et al., 2009; Schindler et al., 2016), human health (Anderson et al., 2002), and the local economy (Dodds et al., 2009). Thus, it is imperative to implement actions to reduce excessive nutrients from entering local waterbodies.

Knowing this, it has served as a major recreation area for both residents and tourists who are looking for a connection with the water's edge. In 2015, it was estimated that approximately 492,000 hours were spent fishing Lake Scugog (OMNR, 2015 fishing survey). Currently, the lake is close to 6,600 ha in size and has a watershed area of 14,100 ha (Kawartha Conservation, 2010), where almost 51% of its land use is agriculture (Government of Ontario, 2015) and only 5.8% of the Lake Scugog Watershed is developed (Government of Ontario, 2015). The Lake Scugog watershed also holds many important tributaries, some of which have been assessed to be critical Walleye (*Sander vitreus*) spawning habitat (Kawartha Conservation, 2019) and an ideal habitat for Brook Trout (*Salvelinus fontinalis*) (Kawartha Conservation, 2017).

Changes in land use can both improve and degrade water as well as impact the quality of various habitats (Wang *et al.*, 1997; Lorenz and Field, 2013; Debues *et al.*, 2019; Eimer et al, 2020). While intensive land use such as agriculture and urbanization can increase nutrient and contaminant loadings, restoration and rehabilitation have been shown to vastly improve water and habitat quality (Osborn and Kovacic, 1993; Lorenz and Field, 2013).

The goal of this project is to identify 'hot spots' that may have elevated nutrient loading within the two tributaries of concern, Cawkers and Williams Creeks.

# Methods

## Study Area

The two 'tributaries of concern', Cawkers Creek and Williams Creek, both located within the Town of Port Perry (Population 9,453, Statistics Canada, 2017) in the Township of Scugog, Region of Durham (Figure 2) were chosen because they were identified in the Lake Scugog Environmental Management Plan (LSEMP) (Kawartha Conservation, 2010) as often exceeding the Provincial Water Quality Objectives (PWQO) for phosphorus (Kawartha Conservation, 2010). These exceedances can result in excessive and uncontrollable algae-blooms and degraded water quality. Both Cawkers and Williams Creeks have been assessed to house various degraded habitats (Kawartha Conservation, 2019).

Originally, there were nine (9) monitoring sites across both tributaries. However, some sites were dropped (WCN1 and WCN2) due to safety concerns in late 2019 and sporadic monitoring caused by the COVID-19 Pandemic occurred in 2020. In 2021, only seven (7) sites were monitored, four (4) on Williams Creek and three (3) on Cawkers Creek.

Of the two tributaries, Cawkers is larger. Land cover differs dramatically, where Cawkers Creek is predominately agriculture while Williams Creek is predominately urbanized (Figure 2). This is unsurprising as much of Port Perry is found within the small watershed of Williams Creek, while only a small portion of Port Perry is found within the much larger watershed of Cawkers Creek. The watershed of Cawkers Creek also extends past Port Perry to the south (Figure 1), encompassing agricultural fields and natural features such as forests and swamps (Figure 2).

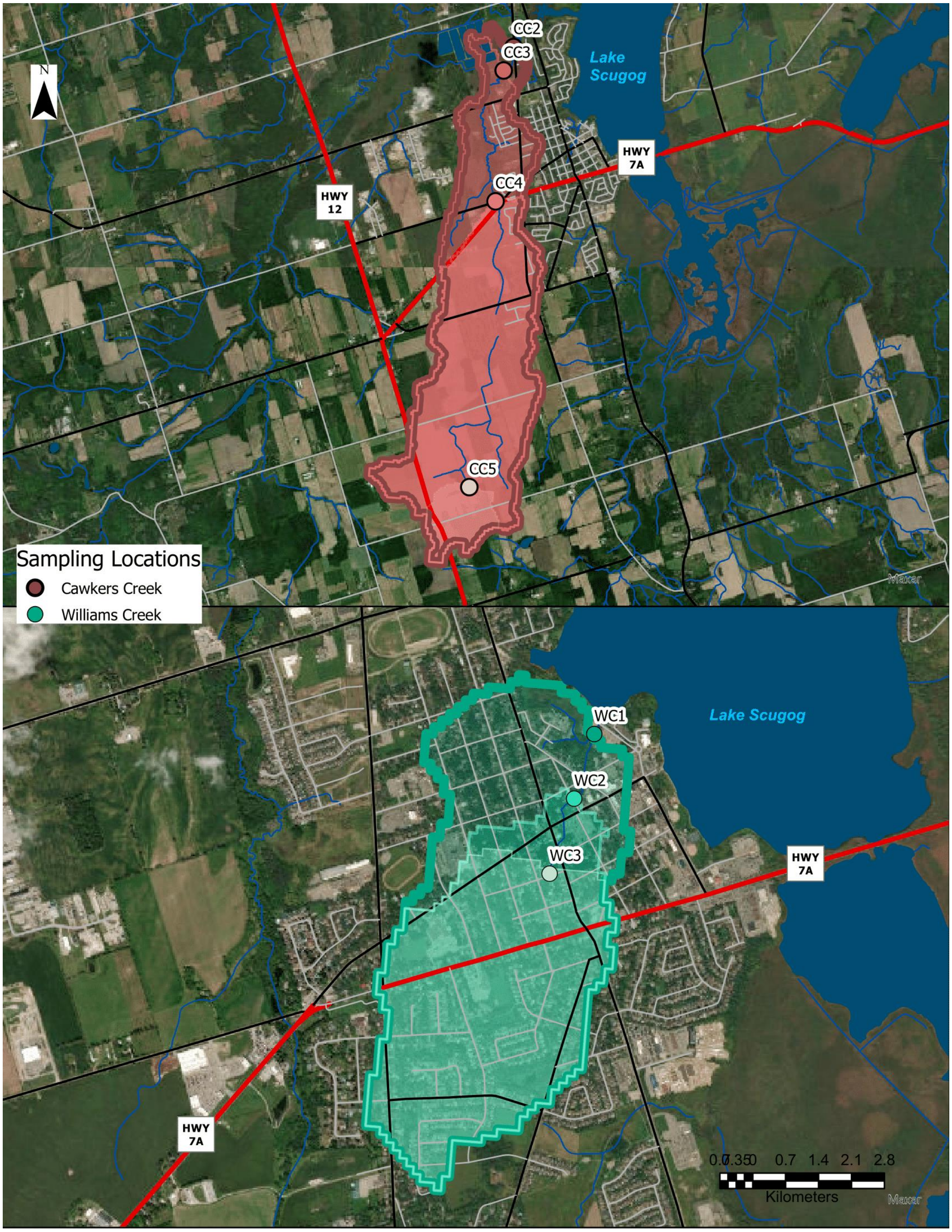



**Figure 1.** Site location and watershed of each sampling location for Cawkers Creek (n=4) and Williams Creek (n=3).

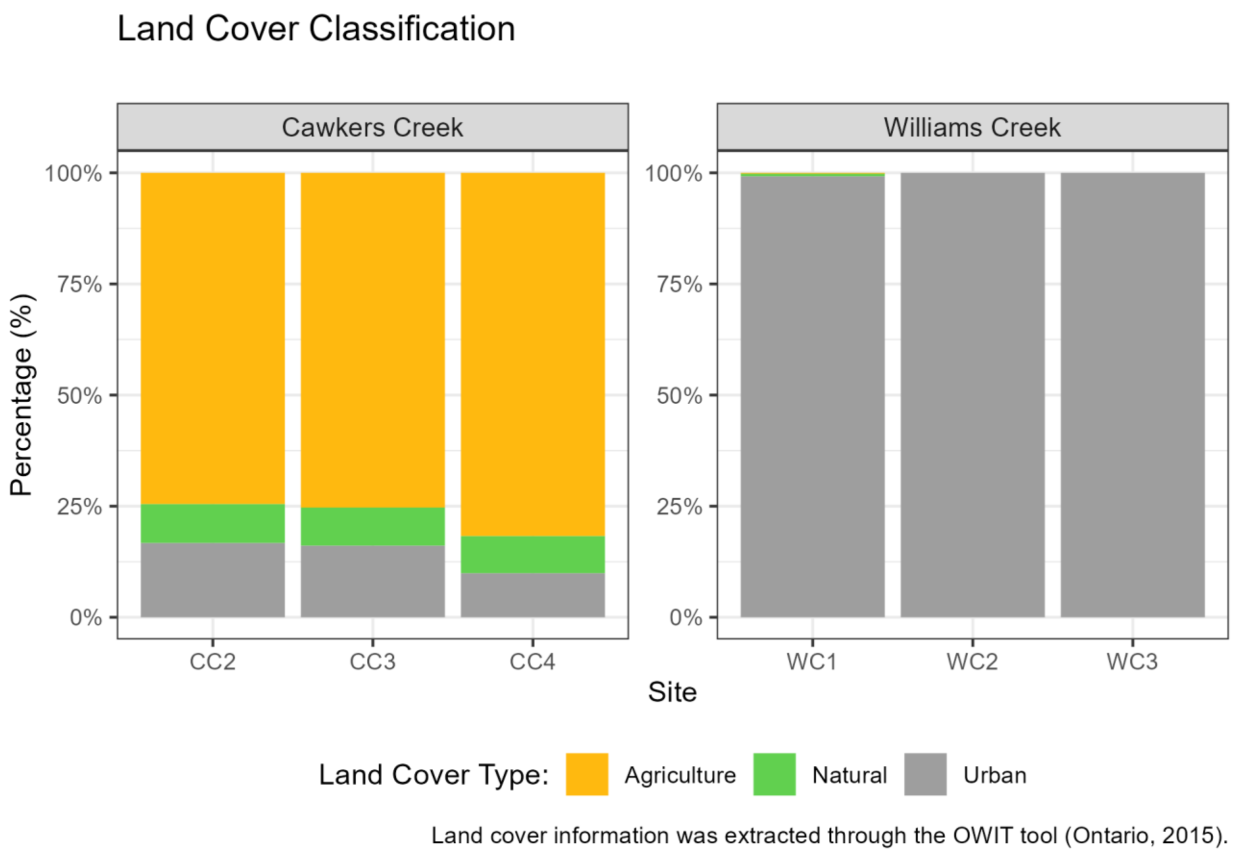



**Figure 2.** Major land cover (agriculture, natural, and urban) percentages (%) for each sampling site.

**Table 1**. Site location (easting and northing) and drainage area for all nine sites.

| Tributary | Site | Easting | Northing | Drainage Area (ha) |
|---|---|---|---|---|
| Cawkers Creek | CC2 | 663431 | 4886985 | 1024.6 |
| | CC3 | 663265 | 4886621 | 1000.1 |
| | CC4 | 663148 | 4879942 | 777.2* |
| | CC5 | 663148 | 4879942 | 88.1* |
| Williams Creek | WC1 | 664453 | 4885759 | 145 |
| | WC2 | 664411 | 4885529 | 102.3 |
| | WC3 | 664268 | 4885028 | 0.92 |
| | WCN1 | 664078 | 4886150 | n/a |
| | WCN2 | 663831 | 4886410 | n/a |

*Used the nearest watercourse point.

## Field and Laboratory Methods

Each site (Figure 2) was monitored monthly during the ice-free period from April to October 2018 – 2021. Note that sites were only sampled once in 2020 due to the COVID-19 Pandemic. At each site, a water quality surface sample and a discharge measurement were taken. Instant discharge measurements ($m^3/s$) were calculated by measuring the velocity and the cross-sectional area of the site using a Flow-tracker. The sample container was triple rinsed with the targeted water prior to sampling to help reduce any contamination within the water sample. Surface water was sampled 0.15-0.3 m below the surface of the water. Field parameters such as Water Temperature (Temp.), pH, Conductivity (Cond), Dissolved Oxygen (DO), and Turbidity (Turb) were all measured in the field with a water quality meter. Samples were kept cool (<4°C) during transport and stored to help reduce potential changes in the water sample and were sent to Caduceon Environmental Laboratories for chemical analysis, i.e., Chloride (Cl), Nitrite-N ($NO_2$-N), Nitrate-N ($NO_3$-N), Ammonia-N ($NH_3$-N), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP) and Total Suspended Solids (TSS).

By combining same day water quality concentrations, knowing the area of the upstream catchment, and collecting discharge values, we can calculate loadings through the following equation:

$$Loading = \frac{(Concentration \times Discharge)}{Area}$$

Annual loading values are calculated through the sum of all daily discharge per year and are expressed in kg/ha/yr.

## Data Analysis

Additional data were combined into this project, including:

- Additional water quality data from the Lake Scugog Environmental Management Plan, extracted and compiled from 2018-2021. (No instant discharge)
- Land cover and catchment characteristics were obtained by the Southern Ontario Land Resource Information System (SOLRIS) through the Ontario Watershed Information Tool (OWIT) (Government of Ontario, 2015).

All data analysis was performed with the statistical program known as R (R Core Team, 2021). Percent coefficient of variation (%CV) for pH followed that of Canchola *et al*., (2017). Areas where there were no observations were left as *NA*, while values below detection limits were addressed using the R package - NADA (Lopaka, 2020). Total Nitrogen values were calculated through the sum of Nitrite-N, Nitrate-N, and Total Kjeldahl Nitrogen. Almost all parameters were significantly different than a normal distribution and did not fit the assumptions of linearity.

Many observations of discharge and water quality were missing from the dataset. Monthly average discharge values were used in substitute to sites with observations of water quality with no discharge values. Similarly, median values of water quality parameters were used in substitute for sites with discharge values and no observation of water quality. Site WCN1 and CC5 were excluded from loading calculations as they had no observations for discharge and with few observations of water quality.

# Results & Discussion

## Dissolved Oxygen

Dissolved oxygen (DO) indicates well oxygenated waters throughout both tributaries. Aquatic organisms such as fish, need dissolved oxygen for daily activities and for egg incubation. At prolong low levels of oxygen can lead to death. Only two sites **(CC4 and WC1**) failed to meet proper DO concentrations for the Canadian Water Quality Guidelines (CWQG) or for early stages of fish (Figure 3). Note failed observations were seen when compared against the Provincial Water Quality Objectives (PWQO) for DO (Figure 3). This suggests that there is adequate dissolved oxygen within these streams for both early and other stage life. Observations of DO in this study was found to be lower that those reported 2019 (Kawartha Conservation, 2019). This difference may be the result of different timing of observation where those reported in 2019 was during the springtime where water temperatures are colder and thus have a higher capacity to hold oxygen, whereas observations of DO for this study were taken during the early summer – early fall period where higher water temperatures resulted in lower dissolved oxygen.

### pH

The pH of the water signifies how acid, i.e., lemon juice or alkaline, e.g., soap, it is. pH can dictate how other compounds interact with one another, for example, acidic waters can allow for certain toxic metals to be more available. For Ontario, the Provincial Water Quality Objectives sets limits of pH at greater (>) than 6.5 and less than (<) 8.5 (Ontario Ministry Environment and Energy, 1994). In this study, six observations (8%) found to exceed the threshold. Compared to Kawartha Conservation data (2019), pH values found in this study were slightly more acidic.

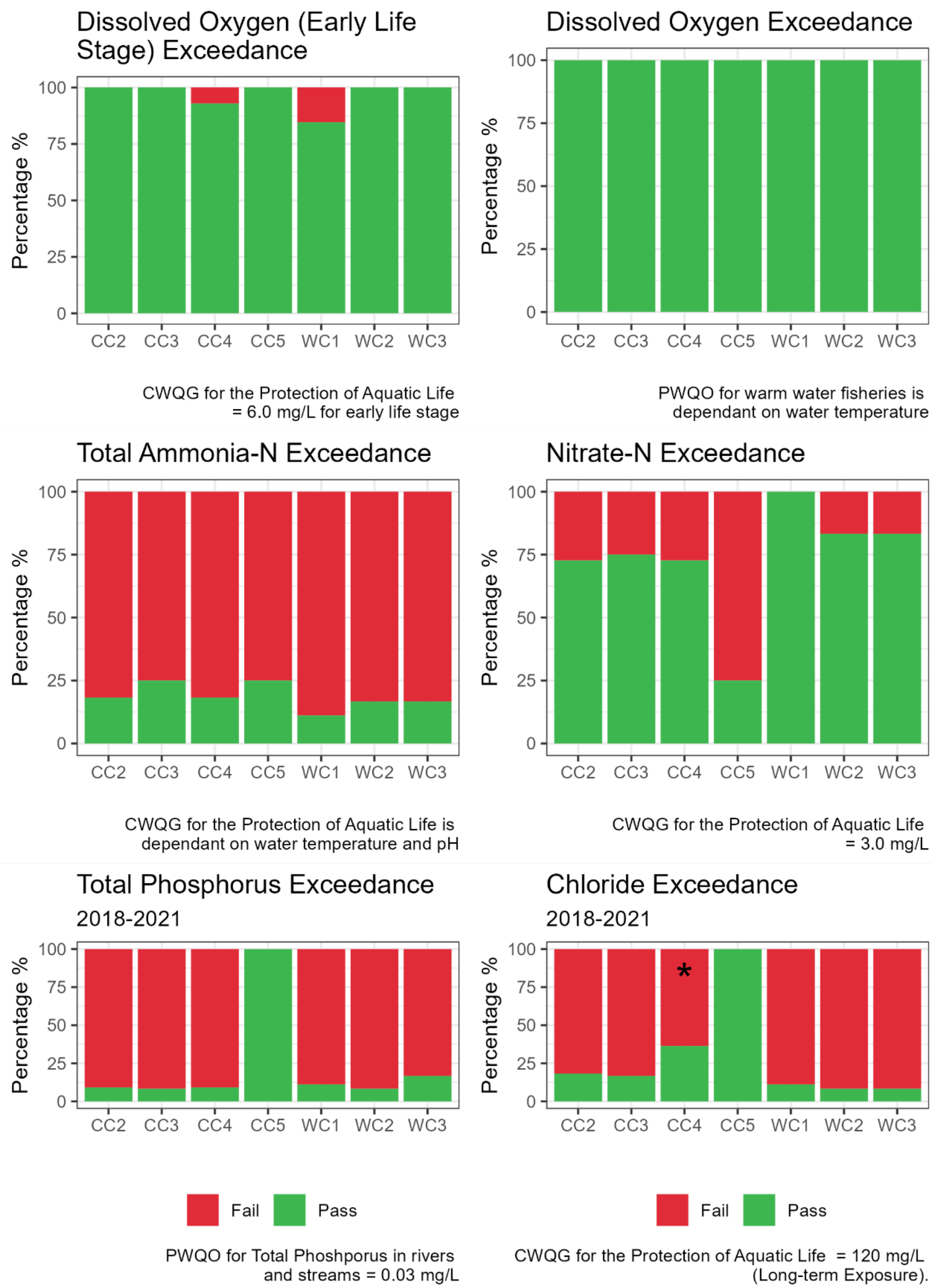



**Figure 1.** Percentage of exceedances per parameter (compared to the PWQO and CWQG) and site. * Indicate that samples have also exceeded short-term exposure guidelines.

**Table 2.** Summary statistics of selective physical and chemical parameters for all Cawkers Creek (*n*=4), Williams Creek (*n*=4), and for sites (*n*=8).

| Tributary | Statistic | °C<br>Temp. | mg/L<br>DO | µS/cm<br>Cond | pH | FNU<br>Turb | mg/L<br>Cl | mg/L<br>$NO_2$-N | mg/L<br>$NO_3$-N | mg/L<br>$NH_3$-N | mg/L<br>TKN | mg/L<br>TN | mg/L<br>TP | mg/L<br>TSS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cawkers Creek | Count | 48 | 48 | 47 | 41 | 37 | 38 | 37 | 30 | 38 | 38 | 38 | 31 | 35 |
| | Mean | 14.72 | 9.09 | 1146.44 | 7.81 | 5.64 | 211.66 | 0.11 | 3.22 | 0.09 | 0.75 | 0.06 | 8.61 | 3.50 |
| | Median | 16.61 | 8.21 | 1065.00 | 7.81 | 3.40 | 175.00 | 0.02 | 1.90 | 0.07 | 0.65 | 0.06 | 6.00 | 1.63 |
| | %CV | 32.74 | 26.37 | 43.78 | 12.04 | 117.89 | 84.09 | 190.48 | 105.04 | 94.74 | 87.93 | 65.28 | 118.73 | 93.13 |
| | Min | 4.30 | 5.47 | 147.80 | 9.39 | 0.95 | 9.00 | 0.00 | 0.15 | 0.01 | 0.25 | 0.01 | 3.00 | 0.00 |
| | Max | 22.00 | 14.94 | 3195.00 | 7.43 | 36.02 | 964.00 | 0.84 | 12.10 | 0.51 | 4.50 | 0.16 | 55.00 | 12.51 |
| | 10th | 6.41 | 6.74 | 650.24 | 8.51 | 1.02 | 38.26 | 0.01 | 0.27 | 0.04 | 0.42 | 0.02 | 3.00 | 0.70 |
| | 90th | 19.89 | 12.64 | 1626.60 | 7.58 | 13.23 | 394.30 | 0.26 | 7.15 | 0.12 | 0.90 | 0.12 | 11.00 | 7.63 |
| Williams Creek | Count | 44 | 44 | 44 | 38 | 35 | 34 | 34 | 27 | 34 | 34 | 34 | 27 | 40 |
| | Mean | 17.67 | 9.49 | 1556.36 | 7.84 | 7.86 | 324.35 | 0.33 | 1.39 | 0.11 | 0.88 | 0.07 | 12.33 | 1.75 |
| | Median | 18.79 | 9.00 | 1474.00 | 7.88 | 3.40 | 305.00 | 0.02 | 0.84 | 0.09 | 0.65 | 0.06 | 8.00 | 2.03 |
| | %CV | 25.27 | 23.41 | 53.07 | 6.15 | 115.76 | 51.71 | 174.92 | 85.17 | 73.61 | 55.35 | 56.20 | 70.36 | 81.04 |
| | Min | 8.70 | 5.53 | 540.00 | 8.40 | 0.40 | 94.20 | 0.00 | 0.10 | 0.02 | 0.33 | 0.02 | 4.00 | 0.00 |
| | Max | 26.20 | 15.32 | 5343.00 | 7.42 | 35.06 | 883.00 | 2.03 | 4.00 | 0.41 | 2.20 | 0.14 | 32.00 | 4.43 |
| | 10th | 9.33 | 7.46 | 747.80 | 8.25 | 1.09 | 143.60 | 0.01 | 0.34 | 0.04 | 0.47 | 0.03 | 5.00 | 0.00 |
| | 90th | 22.22 | 12.62 | 2124.50 | 7.59 | 21.65 | 514.00 | 1.07 | 3.34 | 0.22 | 1.30 | 0.13 | 24.60 | 3.92 |
| All | Count | 92 | 92 | 91 | 79 | 72 | 72 | 71 | 57 | 72 | 72 | 72 | 58 | 75 |
| | Mean | 16.13 | 9.28 | 1344.65 | 7.82 | 6.72 | 264.88 | 0.21 | 2.35 | 0.10 | 0.81 | 0.06 | 10.34 | 2.56 |
| | Median | 17.70 | 8.54 | 1239.00 | 7.86 | 3.40 | 224.00 | 0.02 | 0.91 | 0.08 | 0.65 | 0.06 | 6.50 | 2.01 |
| | %CV | 0.30 | 0.25 | 0.52 | 9.21 | 1.18 | 0.68 | 2.03 | 1.16 | 0.84 | 0.72 | 0.61 | 0.93 | 1.01 |
| | Min | 4.30 | 5.47 | 147.80 | 9.39 | 0.40 | 9.00 | 0.00 | 0.10 | 0.01 | 0.25 | 0.01 | 3.00 | 0.00 |
| | Max | 26.20 | 15.32 | 5343.00 | 7.42 | 36.02 | 964.00 | 2.03 | 12.10 | 0.51 | 4.50 | 0.16 | 55.00 | 12.51 |
| | 10th | 9.20 | 6.90 | 661.00 | 8.33 | 1.07 | 86.04 | 0.01 | 0.27 | 0.04 | 0.43 | 0.02 | 3.00 | 0.00 |
| | 90th | 20.99 | 12.71 | 2038.00 | 7.58 | 15.76 | 483.80 | 0.84 | 5.86 | 0.19 | 1.20 | 0.13 | 22.20 | 6.27 |

## Total Phosphorus

Concentrations of total phosphorus (TP) were found to be consistently above PWQO guidelines for streams and rivers across most sites (0.03 mg/L; Ontario Ministry Environment and Energy, 1994). At levels below 0.03 mg/L, excessive plant growth should be eliminated, where higher concentrations can lead to rapid eutrophication which can result in poor water quality and the lost of aquatic life. Only site CC5 on Cawkers Creek had no exceedances (Figure 3 and Figure 4), however most observations throughout the four years at this site (CC5) indicate that this is an ephemeral site and should not be confused and compared to other perennial tributary sites.

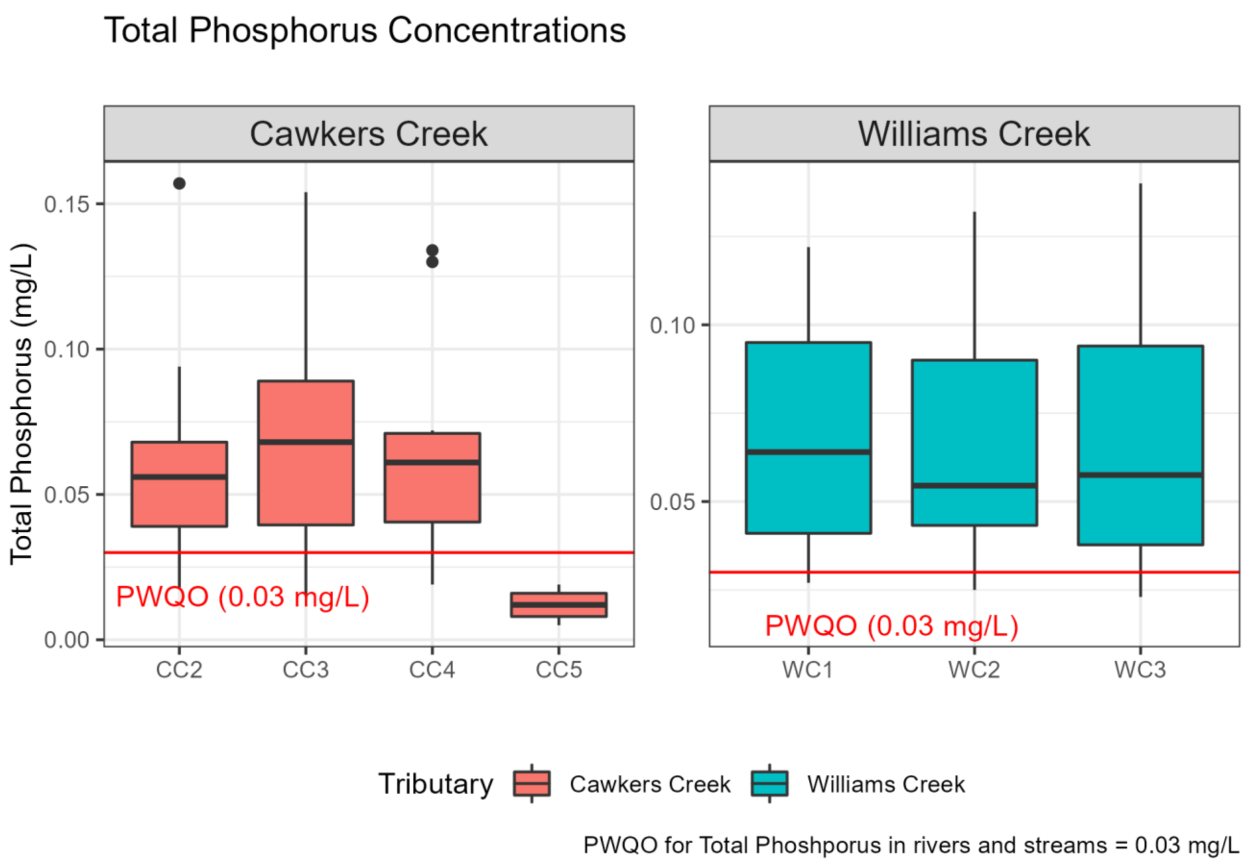
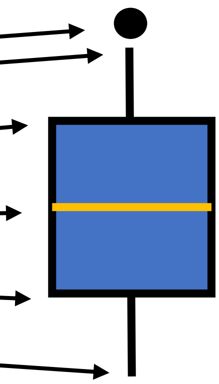



**Figure 2.** Total Phosphorus concentrations across seven sites. The red horizontal line indicates the PWQO for total phosphorus in rivers and streams (0.03 mg/L; Ontario Ministry Environment and Energy, 1994).

**How to read boxplots (Box and Wiskers)**

A boxplot is a graph that shows the spread of the data, along with six key summary points:

1. Possible outliers
2. Maximum value
3. Upper quantile (75%)
4. Median (50%)
5. Lower quantile (25%)
6. Minimum value



Quantile is a cut-off point when the data is ordered largest to smallest.

Total phosphorus (TP) concentrations were generally higher in Williams Creek than Cawkers Creek (Table 2, Figure 2). Concentrations of TP for Cawkers Creek were slightly lower than those found for 2004-2008, average = 0.068 mg/L (Kawartha Conservation, 2010).

Between sites, CC3 had the most exceeded observation (91.7%) for Cawkers Creek while WC2 had the most exceeded observation Williams Creek (Figure 1). Priority sites with elevated levels of total phosphorus are **CC3 and WC2**.

When comparing Total Nitrogen (TN) to Total Phosphorus (TP) data, it is apparent that phosphorus is the limiting factor for excessive phytoplankton growth within Cawkers and Williams Creeks. Implementing stewardship projects focused on phosphorous reduction, combined with continuous improvements to stormwater management will help address elevated TP concentration.

## Nitrogen

Nitrogen is also an essential nutrient for plant and animal growth. Similar to phosphorus, too much nitrogen can lead to degraded water quality, excessive plant and algae growth, and rapid eutrophication. For this study, a variety of nitrogen forms found in the environment were assessed, these were Ammonia-Nitrogen ($NH_3$-N), Nitrite-Nitrogen ($NO_2$-N), Nitrate-Nitrogen ($NO_3$-N), and Total

Kjeldahl Nitrogen (TKN). Some forms of nitrogen in this study show elevated concentrations when compared to natural concentration of inland waterways (McNeely *et al.*, 1979), indicating that all tributaries are being influenced by human activities. Figures of ammonia-nitrogen and nitrite-nitrogen can be found in Appendix B – Figure A1, A2.

## Ammonia

Ammonia, like phosphorus, contribute to the fertility of the water. Natural sources of ammonia are mainly from decomposition of organic matter (plants, animals, and animal waste) and should not exceed 0.1 mg/L in freshwater systems (McNeely and Deyer 1979).

This is of concern as elevated concentrations will prevent proper waste disposal in organisms, leading to a build up of toxins and potentially, death. Across all sites, concentrations of ammonia were consistently higher within Williams Creek (Figure 5), where no observations of ammonia were lower than 0.1 mg/L, indicating human influence in ammonia concentrations. When compared to the PWQO guidelines (Ontario Ministry Environment and Energy, 1994), no observations were found higher than the guideline values. However, exceedances in ammonia were found when compared to CWQG Guidelines for the protection of aquatic life (Figure 3). Ammonia exceeded CWQG were similar across sites and tributaries, for Cawkers Creek in 75.0-81.8% of the samples and 83.3-88.9% for all samples in Williams Creek. Because of the similar exceedance percentage across sites, remediation work should focus on the most upstream sites, i.e, **CC4** for Cawkers Creek and **WC3** for Williams Creek (Figure 1; Figure 3), as this has the potential benefit of reducing contaminants downstream.

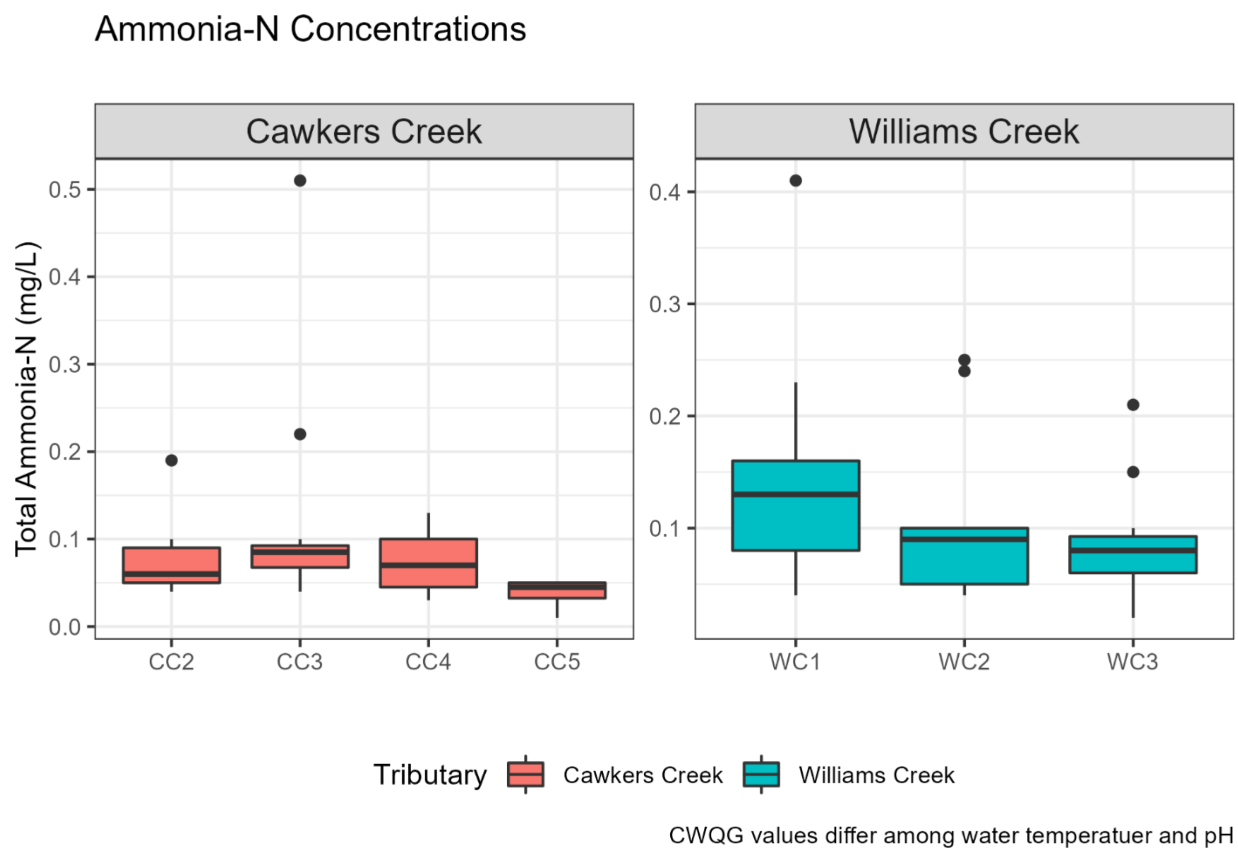



**Figure 3.** Ammonia-N concentrations across seven sites between Cawkers and Williams Creek.

## Nitrate

Through nitrification, nitrite is rapidly converted to nitrate, where it is at its most stable form. When compared to the CWQG of 3.0 mg/L, many observations exceeded this threshold indicating potential negative effects to aquatic organisms such as fish and benthic invertebrates (CCME, 2012) (Figure 3 and 6).

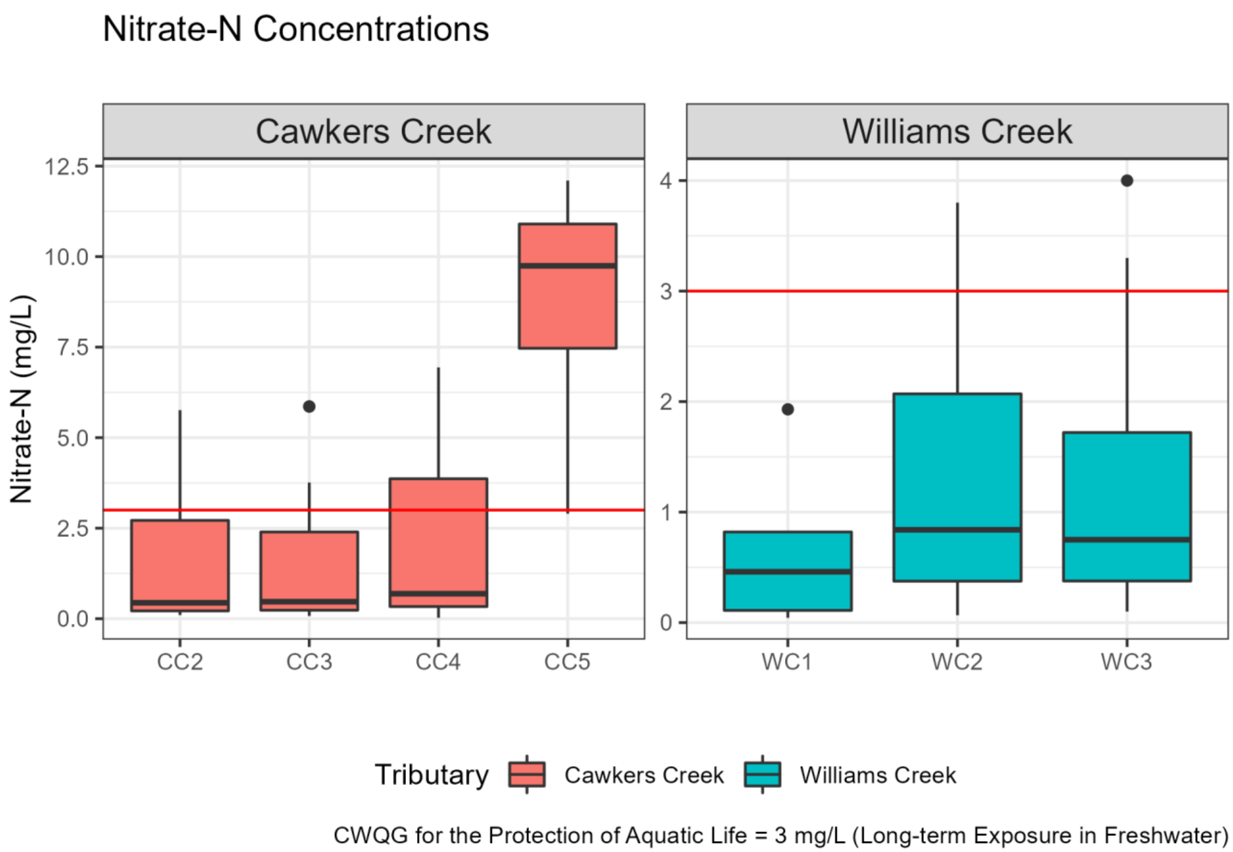



**Figure 4.** Nitrate-N concentrations across seven sites.

Concentrations of nitrate found in WC1 were all below the 3.0 mg/L threshold for the protection of aquatic life, as this site has an urbanization cover of 99.2% (Table 1, Figure 1, 6). Exceedances were found at WC2 and WC3, thus drivers of higher nitrate levels may be due to upstream processes. Some sources of nitrate in urbanized areas have been found to be in sewage, soil, and fertilizers, but also from atmospheric deposition (Schindler *et al.*, 2006; Buda and DeWalle, 2009; Divers *et al.*, 2014; Yang and Toor, 2017). Between the two sites (WC2 and WC3), WC2 had a slightly higher median and 90$^{th}$ percentile, thus WC2 should be more of a priority.

For Cawkers Creek, concentrations of nitrate were highest among CC5 (Table 2, Figure 4), however, site visits during this study indicated that this site is an ephemeral stream (often found dry with no flow) that is governed largely by surface runoff. Using the Ontario Watershed Information Tool at the nearest downstream site, it is estimated that 92% of the watershed for CC5 is classified as agriculture lands (Appendix Figure B3). Satellite imagery confirms this can strongly suggest row crops utilizing in upgradient fields. Land use classification and satellite imagery, confirms the higher nitrate concentration found in CC5. Strategize mitigation techniques through stewardship activities and the implementation of agricultural Best Management Practices (BMPs) in collaboration with adjacent landowners will help reduce nitrate levels acceptable levels. Priority sites with elevated nitrate levels are **CC5** and **WC2**.

## Total Nitrogen

Total Nitrogen (TN) was calculated per sample through the sum of nitrate, nitrite, and TKN. Thus, patterns of TN will follow that of its most predominate form. Generally, nitrate was the most predominant form of nitrogen in Cawkers Creek, where it accounted for 53% of all total nitrogen amounts, thus it is expected that patterns of TN (Figure 5) would follow that of nitrate-n (Figure 4). Working towards a reduction of nitrate (see nitrate section above) would dramatically reduce the overall nitrogen levels in the Cawkers Creek watershed.

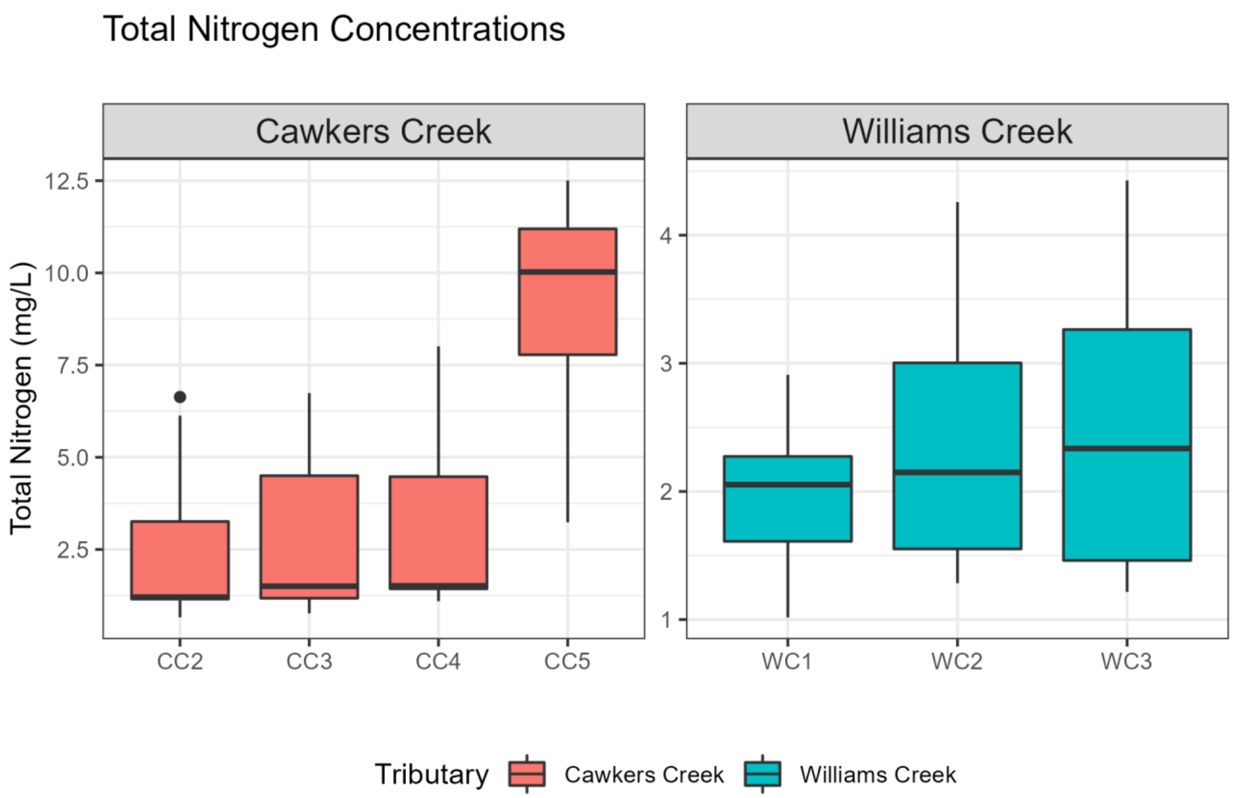



**Figure 5.** Total Nitrogen (TN) concentrations across seven sites.

Nitrate was not found to be the predominate form of nitrogen in Williams Creek, Total Kjeldahl Nitrogen was the predominate species at 44% of total nitrogen amounts followed by nitrate at 42%. Both parameters suggest that the urban runoff (Williams Creek is heavily urbanized; Table 2) constitutes large inputs of ammonia, organic nitrogen and nitrate containing compounds, possibly from garden fertilizers, pet waste, and vehicle exhaust. Similarly, to Cawkers Creek, actions towards the reduction of ammonia and nitrate inputs would greatly reduce nitrogen levels.

## Chloride

Chloride (Cl) is a naturally occurring element that is strictly found in seawater, inland salt lakes, salt wells, and chloride minerals originating from prehistoric dried-up oceans, thus, it is rarely found in high concentrations in inland lakes (Nagpal *et al.*, 2003) such as those in the Kawarthas. In recent times, chloride has been found in elevated concentrations due to its usage for de-icing, wastewater treatment, fertilizer, and dust suppressants. Its most common usage is de-icing by the application of road salts aimed to reduce ice related accidents during the winter season. Once dissolved, it flows from roads and urban areas into streams and rivers, where it contributes to higher conductivity levels that can negatively affect aquatic life.

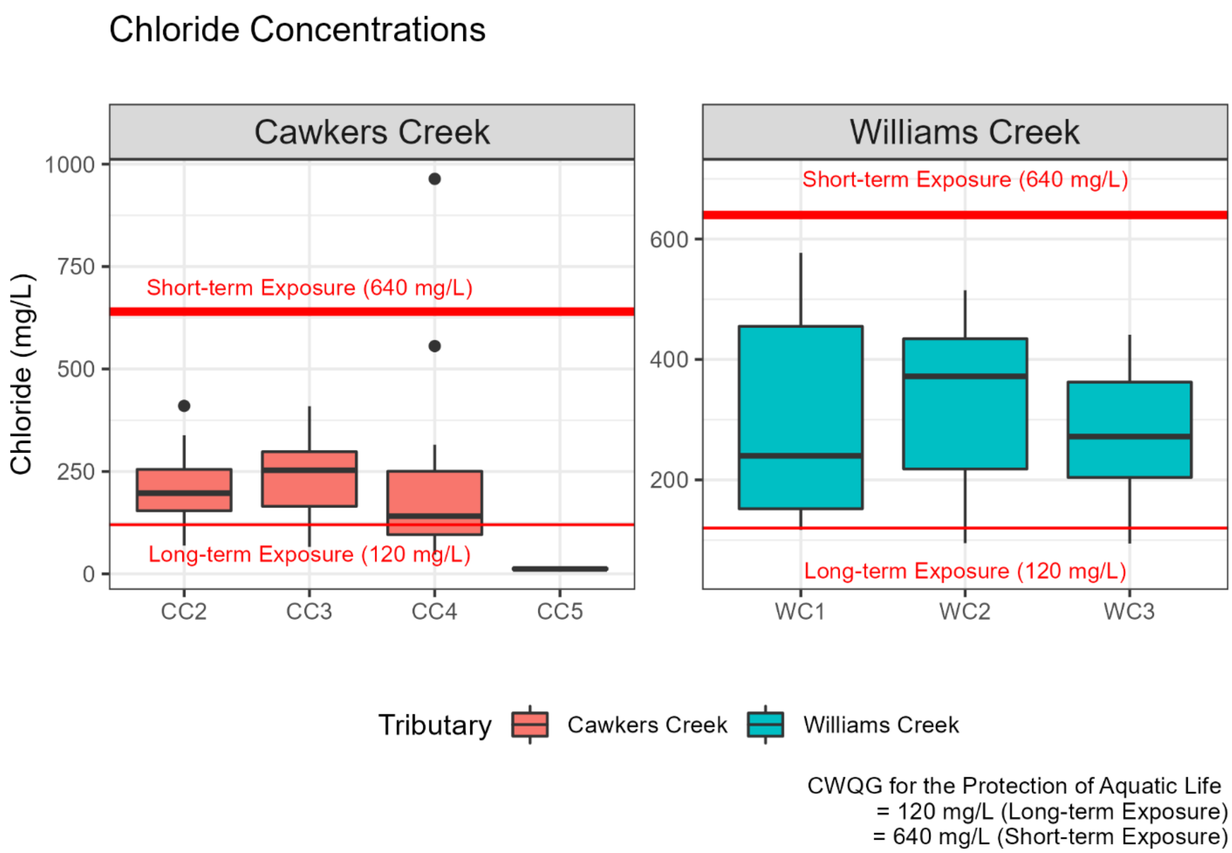



**Figure 6.** Chloride concentrations across seven sites. Red lines indicate the CWQG for short-term (bold) and long-term (regular) exposure limits for the protection of aquatic life (CCME, 2011).

Across all sites, chloride concentrations ranged from 9.0 to 964.0 mg/L, with an average of 264.88 mg/L (Table 2), which exceed the CWQG value of 120 mg/L for the protection of aquatic life (CCME, 2011). In fact, observations of Cl exceeded this guideline 77.8% of the time, as seen in Figure 3. In addition, two observations found within CC4 exceeded the short-term exposure threshold (Table 2, Figure 8), which can result in lethal impacts to aquatic organism in less than 24 hrs (CCME, 2011). Heavy urbanization and transportation land use (Figure 1) on Hwy 7A, Old Simcoe Rd, and Simcoe Rd are both direct drivers for such high Cl concentrations within Cawkers Creek due to its proximity to these roadways. These high traffic, multi-lane roadways have been found to have significantly higher salt applications during the winter months, resulting in increased concentrations of chloride entering these creeks (Cooper *et al.*, 2014).

We have found a strong correlation between conductivity readings and chloride levels for both Cawkers Creek and Williams Creek (Figure 9). This suggests that the input of chloride containing salts, likely from road salt application, is a significant contributor to the increased chloride content in these creeks and streams.

When applied, chloride can be retained in the systems for a prolonged period resulting in delayed, long-term effects on aquatic species as shown in Figure 8. Even after the winter months (during the summer periods of June, July, and August), elevated concentrations of chloride can be found to exceed CWQG value for long-term exposure (Lawson and Jackson, 2021). Median concentrations per site were found to affect 0.2% (CC5) to 22.5% (WC2) of biological taxa, most of which were invertebrate species with one amphibian species, the spotted salamander (*Ambystoma maculatum*) (CCME, 2011). These higher concentrations of chloride found throughout the summer may continue to impact aquatic life during the growing and mating season. Higher chloride levels outside of the winter period has been suggested to be the result of the contamination of shallow groundwater systems (Sorichetti et al., 2022) which is tend flushed out during rain events (Martin et al., 2004; Kincaid et al., 2009; Upper Midwest Water Science Center, 2019).

Remediation priority should be made for sites **CC4** and **WC2** as both have the highest median concentrations in their respective tributaries (Figure 8).

## Total Suspended Solids

The clarity of the water can impact the aesthetic of the waterbody and the organisms that live within it. Murky waters are often associated with an increased number of suspended solids that may originate from biotic (phytoplankton, algae) and abiotic (sand, silt, clay) sources. These particles can bind to organic and inorganic contaminants allowing for further dispersal from point sources (Bodo, 1989). In the water, suspended solids can also impact the gills of aquatic organisms and macroinvertebrates along with harming critical spawning nests for various fish species (Bash *et al.*, 2001; Tuttle-Raycraft and Ackerman, 2019). In developed areas with non-natural land covers, i.e., agricultural or urban, concentrations of TSS can be elevated due to poor land management (Howell *et al.*, 2012; Culp *et al.*, 2013).

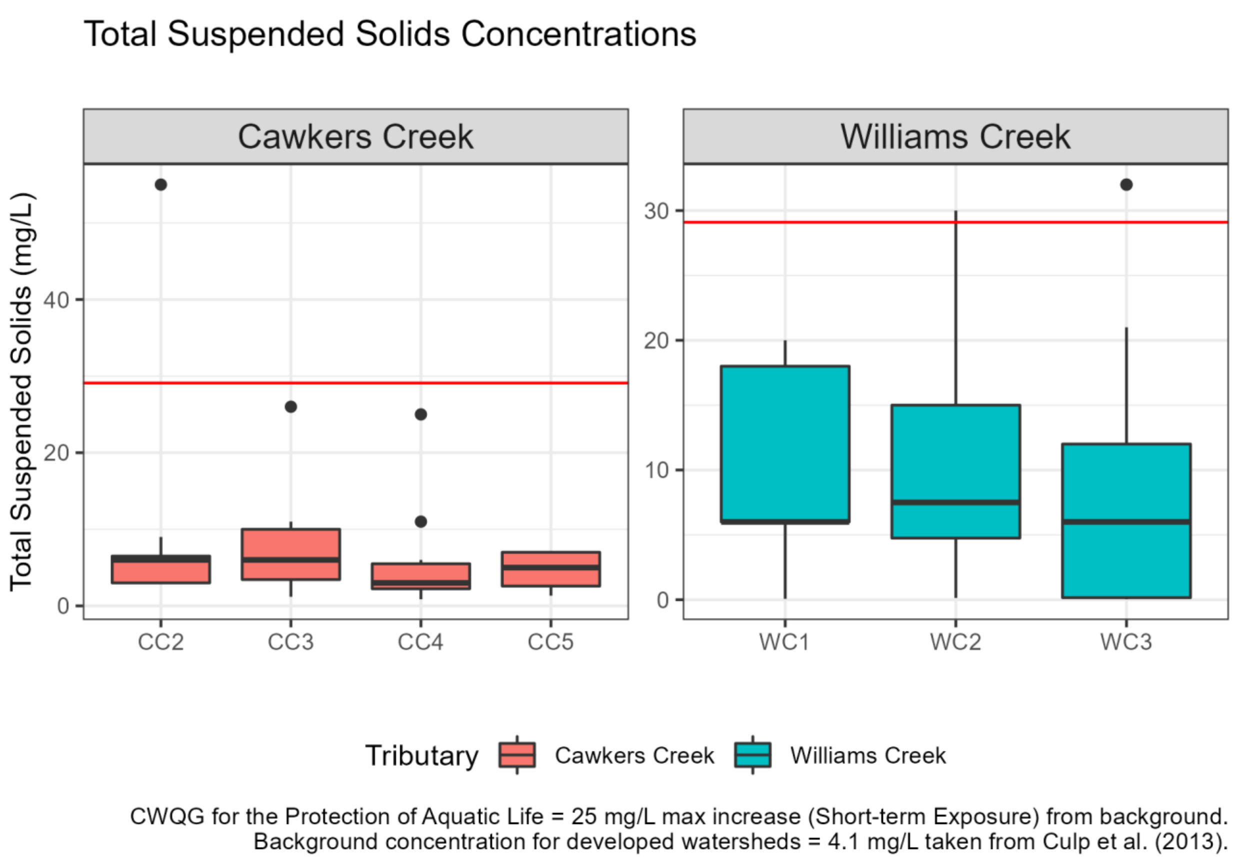



**Figure 7.** Total Suspended Solids (TSS) concentrations across seven sites.

In this study, we found that both creeks had higher average and median TSS concentrations than the proposed physical reference condition of 4.1 mg/L for southern Ontario (Culp *et al.*, 2013). Even more concerning, these levels were much higher than the Ecological Reference Condition (ERC) guideline of 3.5 mg/L which aims to protect the most sensitive of macroinvertebrates, i.e., *Mayflies (Ephemeroptera), Stoneflies (Plecoptera),* and *Caddisflies (Trichoptera)*. A reduction of the macroinvertebrate community will lead to further collapse of the biological community, especially fish.

When applying the CWQG for TSS (25 mg/L above background, i.e., the ERC; CCME, 2002), we have a threshold of 28.5 mg/L. At this threshold, we see only four exceedances, one found in CC2 and WC2, and two observations for WC3. Priority of sites should be **CC2** and **WC3**.

To better understand background TSS concentrations, a separate study should be conducted. It is recommended for this study to capture the variability of TSS concentrations in a natural catchment area with little influence from human activities.

### Loading

Loading is an important measure of how much of a specific compound is entering a stream within a given amount of time (Kilograms per Hectare per Year). Values calculated for WC3 were multiple times larger than the other sites (Table 3), which was mostly attributed to higher flow/discharge resulting in higher concentrations. For example, the average total phosphorus concentrations were similar between WC2 (0.064 mg/L) and WC3 (0.069 mg/L) and were even higher for WC1 (0.071 mg/L), but TP loadings were many times higher for WC3 (Table 2). This can also explain the higher loading values found for the other parameters, i.e., Cl, TN, and TSS for WC3.

**Table 3.** Average loadings (kg/ha/yr) per parameter and site.

| | | Loading (kg/ha/yr) | | | |
|---|---|---|---|---|---|
| **Tributary** | **Site** | **Cl** | **TN** | **TP** | **TSS** |
| Cawkers Creek | CC2 | 3.09 | 0.12 | 0.002 | 0.35 |
| | CC3 | 4.75 | 0.13 | 0.004 | 0.27 |
| | CC4 | 4.59 | 0.18 | 0.004 | 0.58 |
| Williams Creek | WC1 | 4.87 | 0.04 | 0.01 | 0.19 |
| | WC2 | 10.46 | 0.09 | 0.003 | 0.31 |
| | WC3 | 1014.75 | 10.49 | 0.43 | 47.45 |

To achieve targets that would align with provincial objectives (PWQO) and with limits, the reduction targets in kilograms were calculated for chloride and phosphorus (Table 4). At these levels, excessive plant growth should be eliminated, and the long-term protection of aquatic life is ensured. As seen in Table 4, reduction targets for both chloride and phosphorus are greatest at **WC3**, where 534.4 kg of chloride would need to be reduced to mitigate negative impacts to aquatic life and 0.429 kg of phosphorus would need to be reduced to eliminate excessive growth of aquatic plants.

**Table 4.** Reduction targets (kg/yr) for chloride (Cl) and phosphorus (TP).

| **Tributary** | **Site** | **Cl** | **TP** |
|---|---|---|---|
| Cawkers Creek | CC2 | | 0.001 |
| | CC3 | 1.4 | 0.003 |
| | CC4 | | 0.003 |
| Williams Creek | WC1 | 2.4 | 0.010 |
| | WC2 | 6.7 | 0.002 |
| | WC3 | 534.4 | 0.429 |

# Recommendations

## Hot Spots

Throughout this study, a variety of chemical parameters have been assessed at multiple sites across Cawkers and Williams Creek. Sites with elevated levels have been found and are summarized in the following table:

| | Cawkers Creek | | | | Williams Creek | | |
|---|---|---|---|---|---|---|---|
| **Parameter** | **CC2** | **CC3** | **CC4** | **CC5** | **WC1** | **WC2** | **WC3** |
| Dissolved Oxygen | | | X | | X | | |
| Ammonia | | | X | | | | X |
| Nitrate | | | | X | | X | |
| Total Phosphorus | | X | | | | X | |
| Chloride | | | X | | | X | |
| Total Suspended Solids | X | | | | | | X |

Based on the table above, different sites have different sets of water quality concerns. The types of action required to reduce impacts are not discussed in this paper.

## Monitoring

Continued monitoring of each tributary should take place to assess trends. In addition, background concentrations of turbidity and TSS should be assessed to understand the baseline variation. Knowledge of baseline levels of turbidity and TSS can thus be used with existing guidelines when sites exceed guidelines. Remedial actions for TSS and turbidity will enhance local biotic habitat for fish and benthic species within these streams.

## References

Bash, J., Berman, C.H. and Bolton, S., 2001. Effects of turbidity and suspended solids on salmonids. University of Washington Water Center.

Bodo, B.A., 1989. Heavy metals in water and suspended particulates from an urban basin impacting Lake Ontario. Science of the total environment, 87, pp.329-344.

Buda, A.R. and DeWalle, D.R., 2009. Dynamics of stream nitrate sources and flow pathways during stormflows on urban, forest and agricultural watersheds in central Pennsylvania, USA. Hydrological Processes: An International Journal, 23(23), pp.3292-3305.

Canadian Council of Ministers of the Environment (CCME). 1999. Canadian water quality guidelines for the protection of aquatic life: Dissolved oxygen (freshwater). In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2002. Canadian water quality guidelines for the protection of aquatic life: Total particulate matter. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2010. Canadian water quality guidelines for the protection of aquatic life: Ammonia. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2011. Canadian water quality guidelines for the protection of aquatic life:Chloride. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Canadian Council of Ministers of the Environment (CCME). 2012. Canadian water quality guidelines for the protection of aquatic life: Nitrate. In: Canadian environmental quality guidelines, Canadian Council of Ministers of the Environment, Winnipeg.

Canchola, J.A., Tang, S., Hemyari, P., Paxinos, E. and Marins, E., 2017. Correct use of percent coefficient of variation (% CV) formula for log-transformed data. MOJ Proteomics Bioinform, 6(4), pp.316-7.

Cooper, C.A., Mayer, P.M. and Faulkner, B.R., 2014. Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream. Biogeochemistry, 121(1), pp.149-166.

Culp, J.M., Brua, R.B., Benoy, G.A. and Chambers, P.A., 2013. Development of reference conditions for suspended solids in streams. Canadian Water Resources Journal, 38(2), pp.85-98.

Divers, M.T., Elliott, E.M. and Bain, D.J., 2014. Quantification of nitrate sources to an urban stream using dual nitrate isotopes. Environmental science & technology, 48(18), pp.10580-10587.

Government of Ontario. 2015. Ontario Watershed Information Tool. Provincial Mapping Unit, Mapping and Information Resources Branch, Corporate Management and Information Division, Ministry of Natural Resources and Forestry, Peterborough, Ontario

Howell, E.T., Chomicki, K.M. and Kaltenecker, G., 2012. Patterns in water quality on Canadian shores of Lake Ontario: Correspondence with proximity to land and level of urbanization. Journal of Great Lakes Research, 38, pp.32-46.

https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E (accessed October 5, 2021).

Kawartha Conservation. 2010. Lake Scugog Environmental Management Plan. Kawartha Conservation, Lindsay, Ontario.

Kawartha Conservation. 2017. Coldwater Streams Water Temperature Monitoring Report (2011 – 2015). Kawartha Conservation, Lindsay, Ontario.

Kawartha Conservation. 2019. An assessment of potential Walleye spawning habitat within certain tributaries of Lake Scugog and Scugog River. Kawartha Conservation, Lindsay, Ontario.

Kincaid, D.W. and Findlay, S.E., 2009. Sources of elevated chloride in local streams: groundwater and soils as potential reservoirs. Water, Air, and Soil Pollution, 203(1), pp.335-342.

Lawson, L. and Jackson, D.A., 2021. Salty summertime streams—road salt contaminated watersheds and estimates of the proportion of impacted species. FACETS, 6(1), pp.317-333.

Lopaka Lee. 2020. NADA: Nondetects and Data Analysis for Environmental Data. R package version 1.6-1.1. https://CRAN.R-project.org/package=NADA

Lorenz, A.W. and Feld, C.K., 2013. Upstream river morphology and riparian land use overrule local restoration effects on ecological status assessment. Hydrobiologia, 704(1), pp.489-501.

Martin, C., Aquilina, L., Gascuel-Odoux, C., Molénat, J., Faucheux, M. and Ruiz, L., 2004. Seasonal and interannual variations of nitrate and chloride in stream waters related to spatial and temporal patterns of groundwater concentrations in agricultural catchments. Hydrological Processes, 18(7), pp.1237-1254.

McNeely, R.N., Neimanis, V.P., Dwlyer, L. 1979. Water Quality Sourcebook: A Guide to Water Quality Parameter. Inland waters Directorate, Water Quality Branch, Environment Canada, Ottawa, Canada.

Ontario Ministry Environment and Energy (OMOEE). 1994. Policies Guidelines and Provincial Water Quality Objectives of the Ministry of Environment and Energy. Queen's Printer for Ontario, Toronto. June 1994

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Schindler, D.W., Dillon, P.J. and Schreier, H., 2006. A review of anthropogenic sources of nitrogen and their effects on Canadian aquatic ecosystems. Nitrogen Cycling in the Americas: Natural and Anthropogenic Influences and Controls, pp.25-44.

Sorichetti, R.J., Raby, M., Holeton, C., Benoit, N., Carson, L., DeSellas, A., Diep, N., Edwards, B.A., Howell, T., Kaltenecker, G. and McConnell, C., 2022. Chloride trends in Ontario's surface and groundwaters. Journal of Great Lakes Research, 48(2), pp.512-525.

Stammler, K.L., Taylor, W.D. and Mohamed, M.N., 2017. Long-term decline in stream total phosphorus concentrations: A pervasive pattern in all watershed types in Ontario. Journal of Great Lakes Research, 43(5), pp.930-937.

Statistics Canada. 2017. Port Perry [Population centre], Ontario and Ontario [Province] (table). Census Profile. 2016 Census. Statistics Canada Catalogue no. 98-316-X2016001. Ottawa. Released November 29, 2017.

Tuttle-Raycraft, S. and Ackerman, J.D., 2019. Living the high turbidity life: The effects of total suspended solids, flow, and gill morphology on mussel feeding. Limnology and Oceanography, 64(6), pp.2526-2537.

Upper Midwest Water Science Center.2019. Evaluating chloride trends due to road-salt use and its impacts on water quality and aquatic organisms. Upper Midwest Water Science Center, United States Geological Survey.

Yang, Y.Y. and Toor, G.S., 2017. Sources and mechanisms of nitrate and orthophosphate transport in urban stormwater runoff from residential catchments. Water research, 112, pp.176-184.

## Appendix A – Raw Data

**Table A1.** Water quality and water quantity results.

| Site ID | Date Collected | °C Temp. | mg/L DO | µS/cm Cond | pH | NTU Turb | mg/L Cl | mg/L $NO_2$-N | mg/L $NO_3$-N | mg/L $NH_3$-N | mg/L TKN | mg/L TP | mg/L TSS | $m^3/s$ Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC1 | 2021-05-25 | 21 | 14.37 | 2135 | 8.18 | 2.67 | 514 | 1.55 | 0.46 | 0.06 | 0.9 | 0.043 | 6 | 0.0052 |
| WC2 | 2021-05-25 | 18.7 | 10.47 | 2037 | 7.94 | 3 | 514 | 1.7 | 0.44 | 0.08 | 0.9 | 0.044 | 10 | 0.0003 |
| WC3 | 2021-05-26 | 20.3 | 10.1 | 1717 | 7.95 | 3.45 | 385 | 2.03 | 1.01 | 0.15 | 1.1 | 0.041 | 4 | 0.0008 |
| CC2 | 2021-05-26 | 19.1 | 7.13 | 1337 | 7.79 | 1.68 | 256 | 0.25 | 0.28 | 0.19 | 0.9 | 0.046 | 3 | 0.009 |
| CC3 | 2021-05-26 | 19.4 | 8.41 | 1364 | 7.83 | 1.68 | 297 | 0.27 | 0.27 | 0.07 | 0.8 | 0.04 | < 3 | 0.01709 |
| CC4 | 2021-05-26 | 17.9 | 8.77 | 961 | 7.81 | 0.95 | 155 | 0.64 | 0.19 | 0.04 | 0.8 | 0.042 | < 3 | 0.007 |
| CC5 | 2021-05-26 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2021-06-23 | 17.8 | 10.33 | 1862 | 7.99 | 4.75 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.0027 |
| WC2 | 2021-06-23 | 16 | 8.95 | 1768 | 7.89 | 2.66 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.0017 |
| WC3 | 2021-06-23 | 17.7 | 8.82 | 1365 | 7.81 | 2.16 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.0024 |
| CC2 | 2021-06-23 | 13.5 | 7.82 | 1468 | 7.77 | 6.07 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.0028 |
| CC3 | 2021-06-23 | 14.6 | 8.67 | 1629 | 7.69 | 4.14 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.008014 |
| CC4 | 2021-06-23 | 12.7 | 7 | 2038 | 7.43 | 3.1 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.0024 |
| CC5 | 2021-06-23 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2021-07-27 | 19.6 | 7.62 | 719 | 7.62 | 14.99 | 140 | 0.88 | < 0.05 | 0.41 | 1.2 | 0.115 | 6 | 0.0137 |
| WC2 | 2021-07-27 | 19.4 | 7.68 | 921 | 7.58 | 13.57 | 186 | 0.96 | < 0.05 | 0.25 | 1.1 | 0.102 | 8 | 0.0072 |
| WC3 | 2021-07-27 | 20.1 | 8.13 | 1099 | 7.75 | 4.58 | 219 | 0.74 | < 0.05 | 0.06 | 0.8 | 0.065 | 6 | 0.0059 |
| CC2 | 2021-07-27 | 18.1 | 7.36 | 1236 | 7.65 | 5.45 | 208 | 0.17 | < 0.05 | 0.08 | 0.7 | 0.056 | 6 | 0.0226 |
| CC3 | 2021-07-27 | 17.8 | 8 | 1507 | 7.75 | 5.47 | 302 | 0.17 | < 0.05 | 0.51 | 4.5 | 0.154 | 6 | 0.148 |
| CC4 | 2021-07-27 | 17.5 | 8.36 | 948 | 7.7 | 9.77 | 141 | 0.84 | < 0.05 | 0.07 | 0.6 | 0.07 | 11 | -0.003 |
| CC5 | 2021-07-27 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2021-08-18 | 20.8 | 9.78 | 2100 | 8.03 | 2.87 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | -0.017 |
| WC2 | 2021-08-18 | 20.2 | 9.05 | 1898 | 8.04 | 3.27 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.001 |
| WC3 | 2021-08-18 | 20.6 | 9.23 | 5343 | 7.42 | 3.04 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.002 |
| CC2 | 2021-08-18 | 19.5 | 7.12 | 1452 | 7.75 | 3.46 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0 |
| CC3 | 2021-08-18 | 19.8 | 6.68 | 1508 | 7.67 | 3.4 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.002934 |

| Site ID | Date Collected | °C Temp. | mg/L DO | µS/cm Cond | pH | NTU Turb | mg/L Cl | mg/L $NO_2$-N | mg/L $NO_3$-N | mg/L $NH_3$-N | mg/L TKN | mg/L TP | mg/L TSS | $m^3/s$ Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CC4 | 2021-08-18 | 18.1 | 6.62 | 1321 | 7.6 | 4.95 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0 |
| CC5 | 2021-08-18 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2021-09-21 | 19.69 | 8.66 | 1969 | 7.91 | 1.1 | 455 | 1.1 | < 0.05 | 0.04 | 0.4 | 0.04 | 6 | n/a |
| WC2 | 2021-09-21 | 18.88 | 8.52 | 1778 | 7.84 | 0.9 | 369 | 1 | < 0.05 | 0.05 | 0.5 | 0.051 | < 3 | n/a |
| WC3 | 2021-09-21 | 19.71 | 8.49 | 1340 | 7.82 | 4.4 | 249 | 0.83 | < 0.05 | 0.02 | 0.5 | 0.023 | < 3 | n/a |
| CC2 | 2021-09-21 | 16.78 | 7.52 | 1285 | 7.87 | 2.8 | 197 | < 0.05 | < 0.05 | 0.04 | 0.9 | 0.039 | 3 | n/a |
| CC3 | 2021-09-21 | 16.7 | 6.77 | 1328 | 7.64 | 3.6 | 213 | 0.26 | < 0.05 | 0.07 | 1.2 | 0.04 | 4 | 0 |
| CC4 | 2021-09-21 | 16.52 | 7.72 | 1239 | 7.54 | 1.9 | 186 | 0.78 | < 0.05 | 0.03 | 0.5 | 0.072 | 3 | n/a |
| CC5 | 2021-09-21 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2021-10-13 | 17.93 | 8.57 | 2145 | 8.12 | 1.1 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.003 |
| WC2 | 2021-10-13 | 17.41 | 7.73 | 1948 | 8.06 | 1.3 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.003 |
| WC3 | 2021-10-13 | 17.78 | 7.65 | 1588 | 7.96 | 0.4 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.003 |
| CC2 | 2021-10-13 | 16.83 | 7.74 | 1027 | 7.68 | 2.7 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.037 |
| CC3 | 2021-10-13 | 16.91 | 8.25 | 1033 | 8.14 | 2.8 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.073372 |
| CC4 | 2021-10-13 | 17.18 | 7.77 | 888 | 7.94 | 1 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.03 |
| CC5 | 2021-10-13 | 14.41 | 7.92 | 670 | 7.46 | 1 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0 |
| CC2 | 2018-04-23 | 5.0 | 12.23 | 711.0 | 9.39 | 8.00 | 68.9 | 0.009 | 5.65 | 0.04 | 0.47 | 0.039 | 7 | 0.5790 |
| CC3 | 2018-04-23 | 5.6 | 12.59 | 717.0 | 8.80 | 5.40 | 66.1 | 0.01 | 5.86 | 0.04 | 0.49 | 0.038 | 11 | 0.3567 |
| CC4 | 2018-04-23 | 5.9 | 12.21 | 661.0 | 8.51 | 3.40 | 47.2 | 0.01 | 6.6 | 0.04 | 0.46 | 0.033 | <2 | 0.4682 |
| CC5 | 2018-04-23 | 4.3 | 11.09 | 615.0 | 8.65 | 1.00 | 17.4 | 0.005 | 10.5 | 0.01 | 0.25 | 0.005 | <2 | 0.0258 |
| WC1 | 2018-04-23 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 0.015504 |
| WC2 | 2018-04-23 | 8.7 | 12.37 | 1909.0 | 8.24 | 4.80 | 417 | 0.008 | 3.8 | 0.04 | 0.45 | 0.03 | <2 | 0.0311 |
| WC3 | 2018-04-23 | 9.2 | 12.72 | 1759.0 | 8.01 | 2.20 | 355 | 0.007 | 4 | 0.02 | 0.42 | 0.024 | <2 | 0.0296 |
| WCN1 | 2018-04-23 | 9.2 | 12.73 | 3332.0 | 8.29 | 3.40 | 883 | 0.009 | 2.65 | 0.06 | 0.33 | 0.016 | 8 | n/a |
| WCN2 | 2018-04-23 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2018-05-14 | 12.6 | 11.54 | 1065.0 | 8.31 | n/a | 173 | 0.016 | 1.85 | 0.04 | 0.43 | 0.018 | 6 | 0.0401 |
| CC3 | 2018-05-14 | 13.9 | 12.60 | 1067.0 | 8.51 | n/a | 175 | 0.020 | 1.94 | 0.05 | 0.43 | 0.015 | <2 | 0.0325 |
| CC4 | 2018-05-14 | 12.9 | 11.40 | 860.0 | 8.51 | n/a | 105 | 0.047 | 2.72 | 0.05 | 0.52 | 0.019 | <2 | 0.0244 |
| CC5 | 2018-05-14 | 10.4 | 14.94 | 634.1 | 8.32 | n/a | 9 | 0.006 | 2.90 | 0.04 | 0.33 | 0.015 | 7 | 0.0001 |

| Site ID | Date Collected | °C Temp. | mg/L DO | µS/cm Cond | pH | NTU Turb | mg/L Cl | mg/L $NO_2$-N | mg/L $NO_3$-N | mg/L $NH_3$-N | mg/L TKN | mg/L TP | mg/L TSS | $m^3/s$ Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC1 | 2018-05-14 | 17.9 | 15.32 | 2411.0 | 8.40 | n/a | 577 | 0.027 | 1.93 | 0.13 | 0.56 | 0.027 | 8 | n/a |
| WC2 | 2018-05-14 | 13.6 | 11.81 | 2071.0 | 8.32 | n/a | 515 | 0.031 | 2.46 | 0.05 | 0.5 | 0.025 | 7 | 0.0079 |
| WC3 | 2018-05-14 | 14.7 | 13.43 | 1984.0 | 8.39 | n/a | 439 | 0.046 | 2.41 | 0.08 | 0.59 | 0.031 | 8 | 0.0074 |
| WCN1 | 2018-05-14 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2018-05-14 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2018-08-08 | 20.5 | 7.08 | 1124.0 | 7.74 | 11.71 | 254 | 0.008 | 0.46 | 0.06 | 0.70 | 0.068 | 4 | 0.0308 |
| CC3 | 2018-08-08 | 20.9 | 6.50 | 1249.0 | 7.63 | 13.10 | 293 | 0.009 | 0.47 | 0.09 | 0.70 | 0.070 | 10 | 0.0168 |
| CC4 | 2018-08-08 | 22.0 | 5.47 | 1391.0 | 7.52 | 6.59 | 315 | 0.008 | 0.69 | 0.10 | 0.80 | 0.130 | 4 | 0.0065 |
| CC5 | 2018-08-08 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2018-08-08 | 22.4 | 5.68 | 1191.0 | 7.42 | 20.40 | 240 | 0.033 | 0.82 | 0.16 | 1.20 | 0.095 | 18 | n/a |
| WC2 | 2018-08-08 | 21.6 | 7.38 | 1064.0 | 7.76 | 15.40 | 229 | 0.008 | 0.84 | 0.10 | 1.30 | 0.090 | 18 | 0.0061 |
| WC3 | 2018-08-08 | 22.2 | 7.69 | 986.0 | 7.73 | 9.29 | 204 | 0.007 | 0.45 | 0.08 | 2.20 | 0.140 | 32 | 0.0069 |
| WCN1 | 2018-08-08 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2018-08-08 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC3 | 2018-08-08 | 20.9 | 6.53 | 1148.8 | 7.65 | 13.42 | 293 | 0.009 | 0.47 | 0.09 | 0.7 | 0.07 | 10 | 0.030816 |
| WC1 | 2018-08-08 | 22.6 | 6.08 | 1117.7 | 7.51 | 25.58 | 240 | 0.033 | 0.82 | 0.16 | 1.2 | 0.095 | 18 | 0.006865 |
| WC2 | 2018-08-08 | 21.6 | 7.39 | 995.2 | 7.77 | 15.8 | 229 | 0.008 | 0.84 | 0.1 | 1.3 | 0.09 | 18 | 0.006141 |
| WC3 | 2018-08-08 | 22.2 | 7.7 | 933.1 | 7.75 | 9.63 | 204 | 0.007 | 0.45 | 0.08 | 2.2 | 0.14 | 32 | 0.016813 |
| CC2 | 2018-10-31 | 6.2 | 10.52 | 630.0 | 8.10 | 36.02 | 195 | 0.004 | 0.44 | 0.08 | 0.70 | 0.157 | 55 | 0.1314 |
| CC3 | 2018-10-31 | 6.5 | 10.43 | 952.0 | 8.02 | 14.07 | 175 | 0.002 | 0.77 | 0.06 | 0.70 | 0.113 | 26 | n/a |
| CC4 | 2018-10-31 | 7.4 | 10.14 | 755.0 | 7.86 | 17.23 | 140 | 0.004 | 0.91 | 0.05 | 0.60 | 0.134 | 25 | 0.5870 |
| CC5 | 2018-10-31 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2018-10-31 | 9.4 | 9.39 | 626.0 | 7.88 | 29.96 | 117 | 0.004 | 0.55 | 0.08 | 0.60 | 0.122 | 20 | 0.0116 |
| WC2 | 2018-10-31 | 9.3 | 10.36 | 540.0 | 7.87 | 35.06 | 94.8 | 0.004 | 0.68 | 0.09 | 0.60 | 0.132 | 30 | 0.0191 |
| WC3 | 2018-10-31 | 9.3 | 10.45 | 550.0 | 7.79 | 22.49 | 94.2 | 0.004 | 0.65 | 0.10 | 0.70 | 0.127 | 21 | 0.0272 |
| WCN1 | 2018-10-31 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2018-10-31 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2019-05-21 | 12.1 | 13.24 | 885.0 | 8.08 | 1.84 | 135 | 0.040 | 3.58 | 0.06 | 0.60 | 0.031 | 3 | 0.0676 |
| CC3 | 2019-05-21 | 11.8 | 13.85 | 905.0 | 8.11 | 1.82 | 134 | 0.041 | 3.76 | 0.22 | 0.60 | 0.031 | 6 | n/a |

| Site ID | Date Collected | °C Temp. | mg/L DO | µS/cm Cond | pH | NTU Turb | mg/L Cl | mg/L $NO_2$-N | mg/L $NO_3$-N | mg/L $NH_3$-N | mg/L TKN | mg/L TP | mg/L TSS | $m^3/s$ Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CC4 | 2019-05-21 | 11.2 | 12.76 | 787.0 | 8.04 | 1.04 | 86 | 0.050 | 5.01 | 0.08 | 0.60 | 0.039 | 3 | 0.0400 |
| CC5 | 2019-05-21 | 9.1 | 12.32 | n/a | 8.16 | 1.49 | 11.6 | 0.007 | 12.10 | 0.05 | 0.40 | 0.019 | 3 | n/a |
| WC1 | 2019-05-21 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC2 | 2019-05-21 | 11.7 | 11.31 | 1013.0 | 7.72 | 1.09 | 487 | 0.013 | 3.41 | 0.05 | 0.50 | 0.041 | 14 | 0.0085 |
| WC3 | 2019-05-21 | 12.5 | 12.35 | 1646.0 | 7.60 | 1.07 | 441 | 0.016 | 3.30 | 0.06 | 0.60 | 0.040 | 9 | n/a |
| WCN1 | 2019-05-21 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2019-05-21 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2019-07-08 | 18.2 | 8.48 | 887.0 | n/a | n/a | 114 | 0.075 | 5.76 | 0.10 | 0.80 | 0.068 | 6 | 0.0273 |
| CC3 | 2019-07-08 | 18.4 | 8.28 | 897.0 | n/a | n/a | 117 | 0.080 | 5.86 | 0.10 | 0.80 | 0.066 | 8 | n/a |
| CC4 | 2019-07-08 | 18.3 | 8.00 | 739.0 | n/a | n/a | 86.4 | 0.169 | 6.94 | 0.10 | 0.90 | 0.064 | 6 | 0.0508 |
| CC5 | 2019-07-08 | 15.1 | 7.17 | 617.0 | n/a | n/a | 12.6 | 0.005 | 8.99 | 0.05 | 0.30 | 0.009 | 7 | n/a |
| WC1 | 2019-07-08 | 26.2 | 5.53 | 638.0 | n/a | n/a | 152 | 0.007 | 0.11 | 0.10 | 0.90 | 0.041 | <3 | n/a |
| WC2 | 2019-07-08 | 19.4 | 8.34 | 1782.0 | n/a | n/a | 407 | 0.019 | 1.94 | 0.10 | 0.60 | 0.058 | 4 | 0.0028 |
| WC3 | 2019-07-08 | 18.6 | 8.38 | 1449.0 | n/a | n/a | 315 | 0.023 | 1.49 | 0.09 | 0.50 | 0.053 | <3 | n/a |
| WCN1 | 2019-07-08 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2019-07-08 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2019-08-13 | 20.1 | 12.72 | 1665.0 | n/a | n/a | 410 | 0.008 | 0.15 | 0.06 | 0.50 | 0.094 | 9 | 0.0044 |
| CC3 | 2019-08-13 | 19.1 | 8.77 | 1625.0 | n/a | n/a | 388 | 0.007 | 0.26 | 0.08 | 0.50 | 0.081 | 4 | 0.0420 |
| CC4 | 2019-08-13 | 17.7 | 7.33 | 3195.0 | n/a | n/a | 964 | 0.017 | 0.66 | 0.13 | 0.70 | 0.061 | 5 | 0.0012 |
| CC5 | 2019-08-13 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC1 | 2019-08-13 | 25.1 | 12 | 815.0 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WC2 | 2019-08-13 | 20.0 | 8.06 | 1499.0 | n/a | n/a | 375 | 0.014 | 0.99 | 0.09 | 0.50 | 0.044 | *6* | 0.0017 |
| WC3 | 2019-08-13 | 18.9 | 9.97 | 1243.0 | n/a | n/a | 295 | 0.008 | 0.85 | 0.08 | 0.60 | 0.062 | <3 | 0.0005 |
| WCN1 | 2019-08-13 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2019-08-13 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| CC2 | 2020-09-30 | 11.8 | 8.17 | 147.8 | 7.83 | 2.29 | 338 | 0.006 | <0.5 | 0.1 | 1.1 | 0.062 | 3 | 0.0033 |
| CC3 | 2020-09-30 | 12.7 | 7.41 | 1531 | 7.58 | 1.74 | 409 | 0.008 | <0.5 | 0.09 | 0.9 | 0.113 | <3 | 0.0036 |
| CC4 | 2020-09-30 | 12.7 | 6.89 | 2183 | 7.66 | 2.67 | 556 | 0.017 | 0.48 | 0.11 | 0.6 | 0.06 | 3 | n/a |
| CC5 | 2020-09-30 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

| Site ID | Date Collected | °C Temp. | mg/L DO | µS/cm Cond | pH | NTU Turb | mg/L Cl | mg/L $NO_2$-N | mg/L $NO_3$-N | mg/L $NH_3$-N | mg/L TKN | mg/L TP | mg/L TSS | $m^3/s$ Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC1 | 2020-09-30 | 16.3 | 9.32 | 1381.0 | 8.04 | 2.22 | 316 | 0.016 | <0.5 | 0.23 | 1.9 | 0.064 | 5 | n/a |
| WC2 | 2020-09-30 | 15.4 | 9.06 | 925.0 | 8 | 3.21 | 186 | 0.011 | 0.18 | 0.24 | 1.1 | 0.065 | 5 | 0.0162 |
| WC3 | 2020-09-30 | 15.8 | 8.56 | 888.0 | 7.86 | 3.44 | 185 | 0.016 | 0.1 | 0.21 | 1.1 | 0.083 | 6 | 0.0153 |
| WCN1 | 2020-09-30 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| WCN2 | 2020-09-30 | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

# Appendix B – Additional Figures

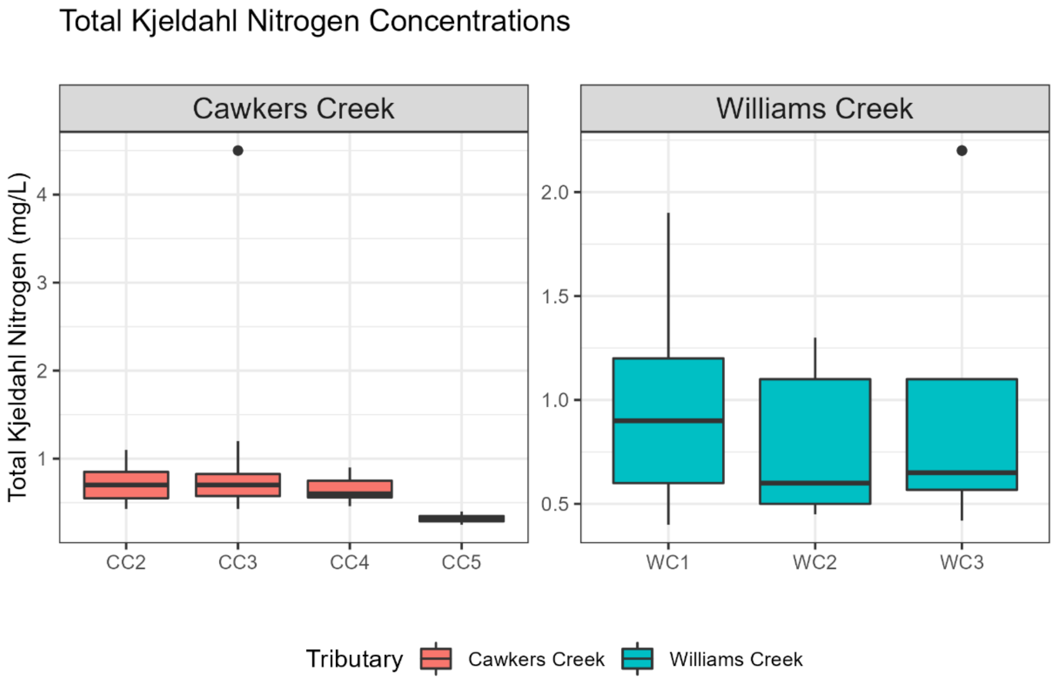



**Figure B1.** Total Kjeldahl Nitrogen (TKN) concentrations (box plot) among all seven (7) sites across the monitored years (2018-2021).

Nitrite-N

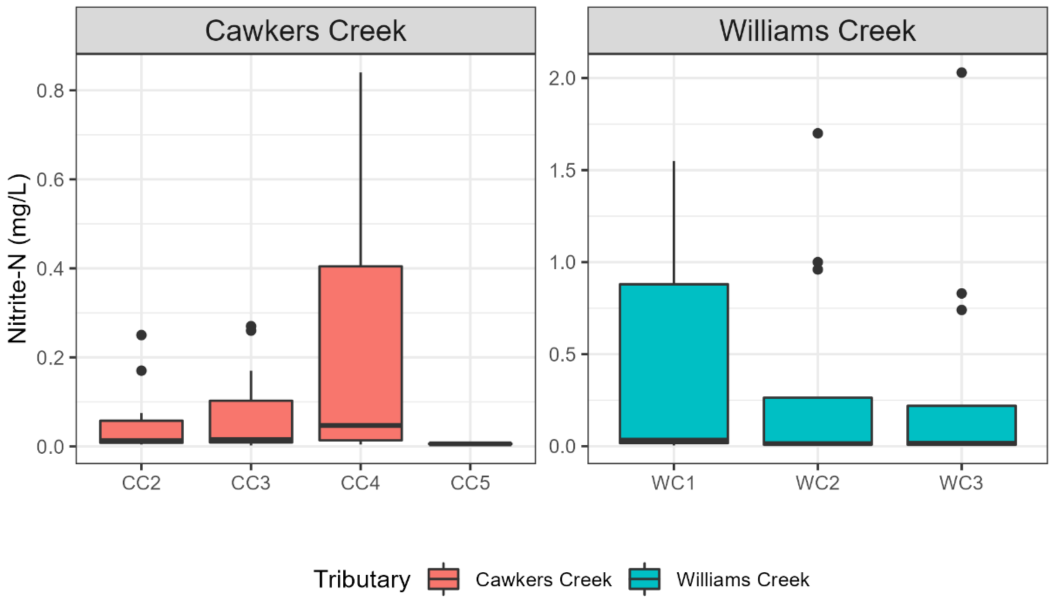



**Figure B2.** Nitrite-N concentrations (box plot) among all seven (7) sites across the monitored years.

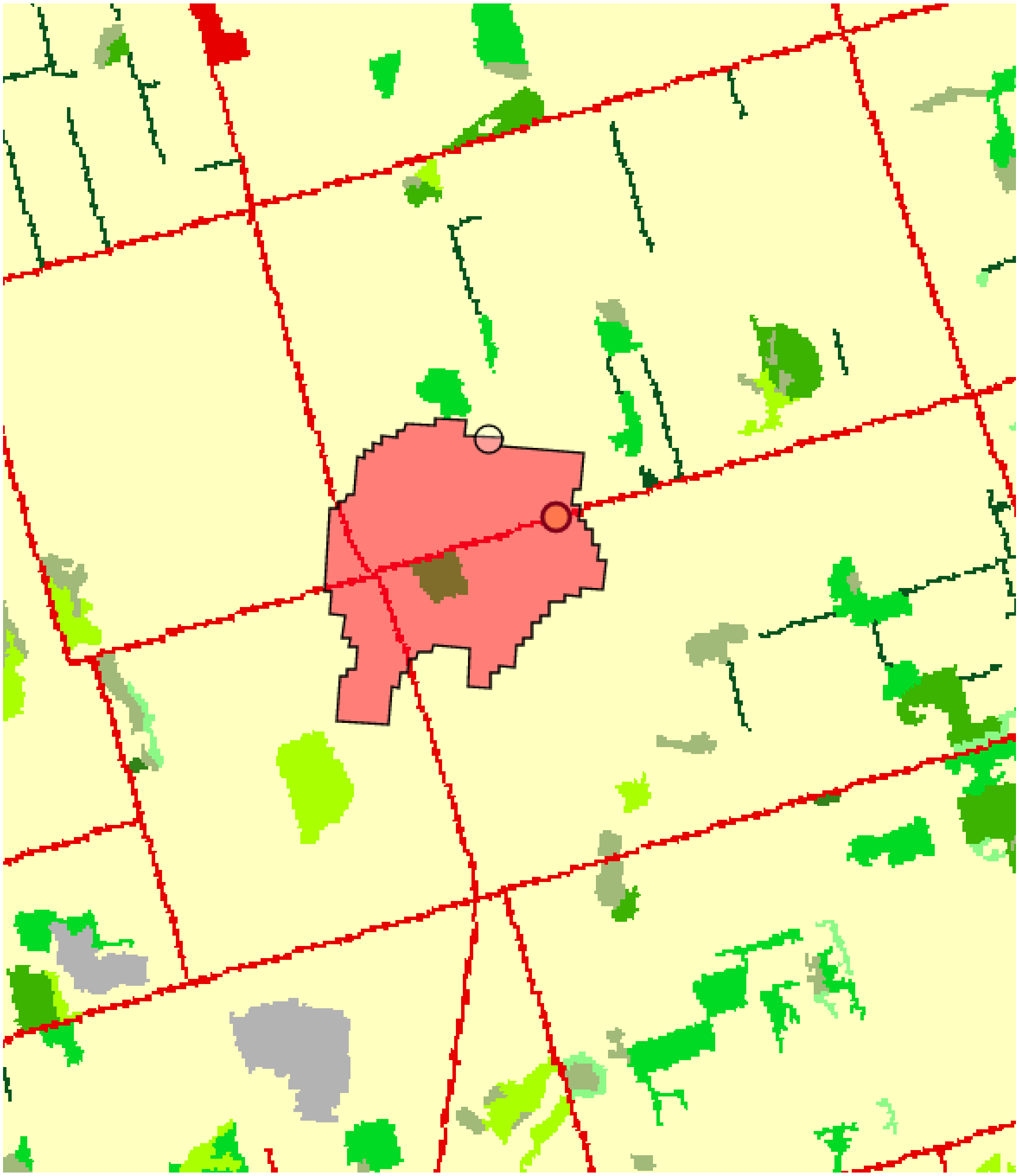


**Figure B3.** Land cover of the surrounding area of site CC5 (orange circle). Source: Government of Ontario (2015). Yellow = agricultural, red = roadways, and green = natural land cover (forest, hedges, wetlands).