THINKING WATER

Community Environmental Monitoring in Greater Saint John

Thinking Water: Community Environmental Monitoring in Greater Saint John

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ACAP SAINT JOHN

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Table of Contents

Executive Summary

This report summarizes the results of ACAP Saint John's 2022 *Thinking Water* project. This project aims to assess the general water quality of streams within the Greater Saint John Area, including tributaries of the Wolastoq (St. John River) and the Saint John Harbour. The *Thinking Water* project remains significant in a city with a long history of human and industrial influences within waterways. ACAP Saint John has been conducting water quality monitoring in Saint John and its surrounding areas for over 30 years, providing a long-term dataset that can be used by managers and other organizations.

In 2022, ACAP Saint John continued to analyze the water quality of 27 sites in freshwater streams and estuaries within the Greater Saint John area. Water quality index (WQI) values were calculated from field and lab measurements including water temperature, dissolved oxygen (DO), pH, salinity, turbidity, ammonia (as NH_3), orthophosphate (as P), and *Escherichia coli* (*E. coli*) concentration, collected between May and October. No sites had "excellent" water quality in 2022, while only three sites had "good" water quality as determined by the Canadian Council of Ministers of the Environment (CCME) water quality index calculations. Of the remaining sites, ten were in "fair" condition, eight were in "marginal" condition, and six were in "poor" condition. The sites with the poorest water quality index include five out of seven Marsh Creek sites, Newman's Brook Downstream, and Hazen Creek Mouth. Mean phosphate concentrations exceeded the threshold limit at 21 of 27 sites (77.7%) while ammonia and *E. coli* concentrations exceeded the recreational limit at 11 of 27 sites (40.7%). These water quality issues are a persistent problem in these watersheds, indicating stormwater or sewage inputs and other sources of contamination still have considerable impact on the Saint John region.

ACAP Saint John also evaluated biotic communities across eight sites within the Saint John Harbour by quantifying the abundances of fish and invertebrates caught at these sites using beach seines and fyke nets in 2022. This work is part of a large monitoring program focused on developing an environmental baseline for the region. In 2022, a total of 6516 individuals representing 25 species were caught, with the majority of the catch comprised of sand shrimp (*Crangon septemspinosa*).

Introduction

The Wolastoq (St. John River) and its tributaries provide habitat for countless aquatic species and serves as a water source for many more terrestrial species. Three cities and numerous towns and villages in New Brunswick lie along the banks of the Wolastoq before its confluence with the Saint John Harbour on the Bay of Fundy. This expansive river is culturally, industrially, recreationally, and ecologically significant, and as it runs more than 600 kilometres inland it impacts both humans and wildlife. Modern uses of the river generally have deleterious effects, given the influence of humans along its entire length, and climate change and other environmental phenomena also have negative impacts. The Saint John Harbour at the mouth of the river hosts frequent shipping and dredging activities and receives various industrial (e.g., pulp and paper effluent, ballast water, and oil refinery effluent) and municipal discharges; these activities all have the potential to impact overall water quality.

Starting in the mid-1800s, the City of Saint John released raw sewage into Marsh Creek and the Saint John Harbour; this was a common practice for port cities for centuries. This practice has left rivers and watersheds polluted, creating unsuitable habitat for aquatic species. In 2014, the Harbour Cleanup project brought an end to the routine discharge of raw sewage, resulting in the return of migrating fish species and improved water quality. Continuous monitoring projects like ACAP Saint John's water quality monitoring programs help identify specific problem areas or recent changes in water quality that need to be addressed. This report provides analysis of the current state of water quality in the Greater Saint John area and provides recommendations for further action in the city's watersheds.

The purpose of this project is to continue the water quality and fish assemblage monitoring within the Marsh Creek watershed and neighbouring waterways to document system recovery after centuries of raw sewage disposal. *Thinking Water* is a continuation of the *Rebirth of Water* monitoring program which was originally meant to track improvement after the sewage ban. The project encompasses monitoring of the tributaries of the Wolastoq and other waterways found throughout the City of Saint John.

Methods

I. Water Quality Monitoring Sites

Water quality monitoring sites are located across 10 different sub-watersheds of the Wolastoq. ACAP Saint John has been monitoring sites within the Marsh Creek watershed for over 30 years. Additional sites were selected to represent a range of brackish and freshwater streams in the Greater Saint John Area. In total, 27 sites were monitored in 2022 (Figure 1). Below is a brief overview of the selected watersheds with the primary threats to water quality identified, further site descriptions and GPS coordinates can be found in Appendix A.

Marsh Creek (MC2, MC-DS, MC3, MC4, MC5, MC11, MC-US): An internationally recognized environmental concern due in large part to its receipt of untreated municipal wastewater and heavy creosote contamination in the sediments downstream.

Hazen Creek (HC-M, HC2): Flows through forested, residential, commercial, and industrial areas. As such, the watershed has suffered over the years from direct and indirect impacts of development.

Taylors Brook (TB-US, TB-DS): The main threat to this watershed is potential encroachment from development as East Saint John and the Town of Rothesay expand further into the watershed.

Newman's Brook (NB-US, NB-DS): The headwaters of Newman's Brook lie in an area that was once a landfill which has only been partially capped, resulting in the potential for leachate to move through the brook.

Caledonia Brook (CB-US, CB-DS): Development and encroachment have put pressure on sections of the watershed, potentially affecting the water quality.

Salmon Creek (SC-US, SC-DS): Many residences are located within this watershed and the watercourse may suffer from the effects of development, riparian area degradation, nutrient runoff, and natural flow regime changes.

Mill Creek (MIC): The watershed itself is mostly forested with some development (mostly housing) as it approaches the Wolastoq and the Saint John Marina, which is located at the outflow of the creek.

Spruce Lake Stream (SLS-US, SLS-M): A quarry within the watershed may impact the stream with sediment runoff.

Manawagonish Creek (Man-US, Man-DS): The watercourse flows through a stormwater pond and crosses Highway 1 twice before by-passing a wastewater treatment plant.

Crescent Lake (CL): This lake in Rockwood Park is a site for the aquatic driving range. It is adjacent to both Rockwood Park Golf course and the high traffic Sandy Point Road.

Additional sites include Fairweather Brook (FB), Dominion Park (DP), Kennebecasis Drive (KD), and Inner Harbour (IH).

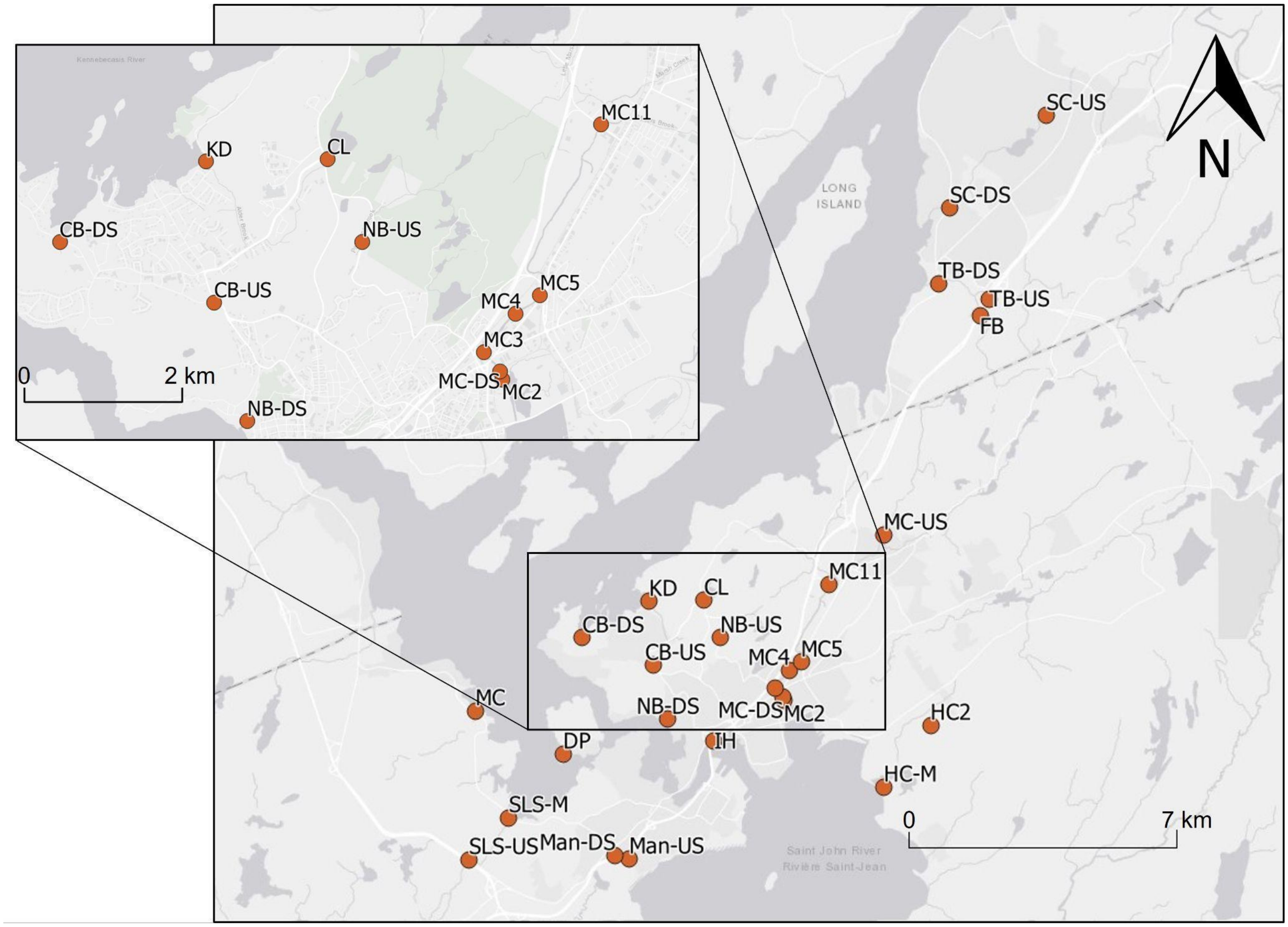

Figure 1. Locations of water quality sampling sites during the 2022 field season. Coordinates and site names can also be seen in Appendix 1. Figure was created using QGIS 3.16 (QGIS Development Team 2021). Light Gray Canvas base map from Esri, HERE, DeLorme, MapmyI.

II. Water Quality Analysis

Water quality data was collected in the field using a handheld YSI Professional Plus multimeter. Dissolved oxygen and pH probes were calibrated following the manufacturer's recommendations. Turbidity was also measured in the field using a handheld turbidity meter. Ammonia and orthophosphate were quantified using a DR900 colorimeter, and total coliform and *Escherichia coli* (*E. coli*) colonies were estimated using the IDEXX Colilert-18 system. All laboratory analyses were performed at the New Brunswick Community College (NBCC) Saint John campus or at ACAP Saint John. For each day on which laboratory analysis was conducted, either a blank or a duplicate sample was tested for each measure to ensure Quality Assurance/Quality Control (QAQC).

II. i. Ammonia

Ammonia was measured using the DR900 Nitrogen, Ammonia method (Code 8155). Ten mL of sample water was added to a clean test tube, and two chemical reagents were added to the sample with time between reagent additions. After allowing the sample to sit for 15 minutes, the colorimeter was calibrated using a blank sample (deionized [DI] water) and the sample was subsequently tested. The ammonia reading provided was in mg/L.

II. ii. Orthophosphate

Orthophosphate was measured using the DR900 Phosphorus, Reactive (Orthophosphate) method (Code 8048). Results are in mg/L as concentration of both Phosphate (PO_4^{3-}) and Phosphorous (P).

II. iii. Total coliforms and *E. coli*

Total coliforms and *E. coli* were measured using an IDEXX Colilert-18 system. The Colilert-18 reagent was added to 100 mL of sample and incubated in standardized trays at 35°C for 18 hours. The trays were removed from the incubator after eighteen hours. The number of yellow and fluorescing trays corresponded to the total coliform and *E. coli* concentrations, respectively, measured as the most probable number per 100 mL (MPN/100 mL). If a site exceeded 2 ppt salinity, the sample was analyzed in a 1:10 dilution so that the salinity would not interfere with bacterial growth, and results were multiplied by ten to achieve MPN/100 mL, rendering a detection limit of 24196 MPN/100 mL for diluted sites. Undiluted freshwater sites achieving *E. coli* counts at or above the detection limit (2419.6 MPN/100 mL) were assigned the detection limit as a value. The dilution and subsequent multiplication at higher salinity sites can result in *E. coli* counts over the detection limit, but undiluted sites cannot be given values higher than the detection limit; with that, the total *E. coli* levels at various sites may be far higher than 2419.6 MPN/100 mL. Total coliform counts are unreliable outside of freshwater sites; for this reason, total coliforms are not presented in this report, though they were observed.

II. iv. Guidelines

Water quality guidelines and thresholds taken from literature were used for various parameters in this report to interpret the environmental state at each site. Values above (and below when applicable) the selected thresholds were considered suboptimal conditions and contributed to a lower water quality. Temperatures below 23°C are considered optimal for juvenile salmonids (Breau et al. 2007); for this report, we selected an upper thermal limit of 23.5°C to allow some flexibility with temperatures that just exceed 23°C. Other thresholds and guidelines were taken from reports made by the Canadian Council of Ministers of the Environment (CCME). The threshold for dissolved oxygen was a lower limit of 6.5 mg/L (Canadian Council of Ministers of the Environment 1999c). For pH, the guidelines used were a lower limit of 6.5 and an upper limit of 9 (Canadian Council of Ministers of the Environment 1999b). The threshold used for *E. coli* in 2022 was a single exceedance of 400 MPN/100 mL or an average of 200 MPN/100 mL (Canadian Council of Ministers of the Environment 1999a). For ammonia, the upper limit was 0.1 mg/L total ammonia because natural concentrations are generally below this value (Canadian Council of Ministers of the Environment 2010). Orthophosphate has no guideline from the CCME, but thresholds should be based on historic values. In this report, the threshold used for orthophosphate (PO_4-P) was 0.04 mg/L. For turbidity, threshold should also be based on deviations from background levels as there are no set guidelines from CCME; we selected 55 NTU as an upper limit.

II. v. Water Quality Index

The CCME has created a Water Quality Index (WQI) that rates water quality based on a ratio of parameters that exceed thresholds (see methods for guidelines above) for the total number of parameters measured (minimum number of four parameters measured over four timepoints). This index has five rankings: poor (0-44), marginal (45-64), fair (65-79), good (80-94), and excellent (95-100); Canadian Council of Ministers of the Environment 2001).

III. Biotic Community Monitoring

In 2022, fishing occurred monthly (May – October) at 8 sites across the Saint John Harbour as part of ACAP Saint John's Harbour Baseline Monitoring Program (Table 1). Fishing was conducted using seine nets (one 3-minute tow per site each month) and fyke nets (one 24-hour deployment per site each month). All fish were identified, and total body lengths (mm) were measured for up to 30 individuals of each species before being returned to the water. If more than 30 individuals of a species were caught, the remaining individuals were counted but not measured before being released. This was done to reduce animal stress due to handling and time out of their environment. This is part of a larger monitoring program that is developing a baseline of fish communities within the Harbour near some of Saint John's most industrially or residentially impacted sites.

Table 1. Biotic community sampling sites in the Saint John Harbour area in 2022.

Site	Site ID	Latitude	Longitude
Courtenay Bay	CB	45.276202	-66.047032
Digby Ferry Terminal	DFT	45.253016	-66.062025
Hazen Creek Nearshore	HC-NS	45.257228	-66.022186
Inner Harbour	IH	45.272068	-66.073478
Little River	LR	45.272416	-66.022299
Marsh Creek 2	MC2	45.281834	-66.049478
Spar Cove	SC	45.276147	-66.090295
Tin Can Beach	TCB	45.262244	-66.054578

Results & Discussion

I. Rainfall Occurrence

In 2022, there was a substantial increase in ammonia, phosphate, and *E. coli* concentrations across most sites. Nutrient loading is often associated with rainfall events that can result in lift station overflows, combined sewer inputs, and runoff which enters streams and threatens overall water quality. Such overflows and inputs from combined stormwater and sewage lines can be caused by a 10 mm rainfall, with effects lasting up to five days after the rainfall event within the urban core of Saint John. Overall, at a large scope, monthly rain data was compared to the sampling period throughout 2019 to 2022 to determine if there was a substantial increase in rainfall (Figure 2). When compared with previous years, overall rainfall was not substantially higher across the entire sampling period.

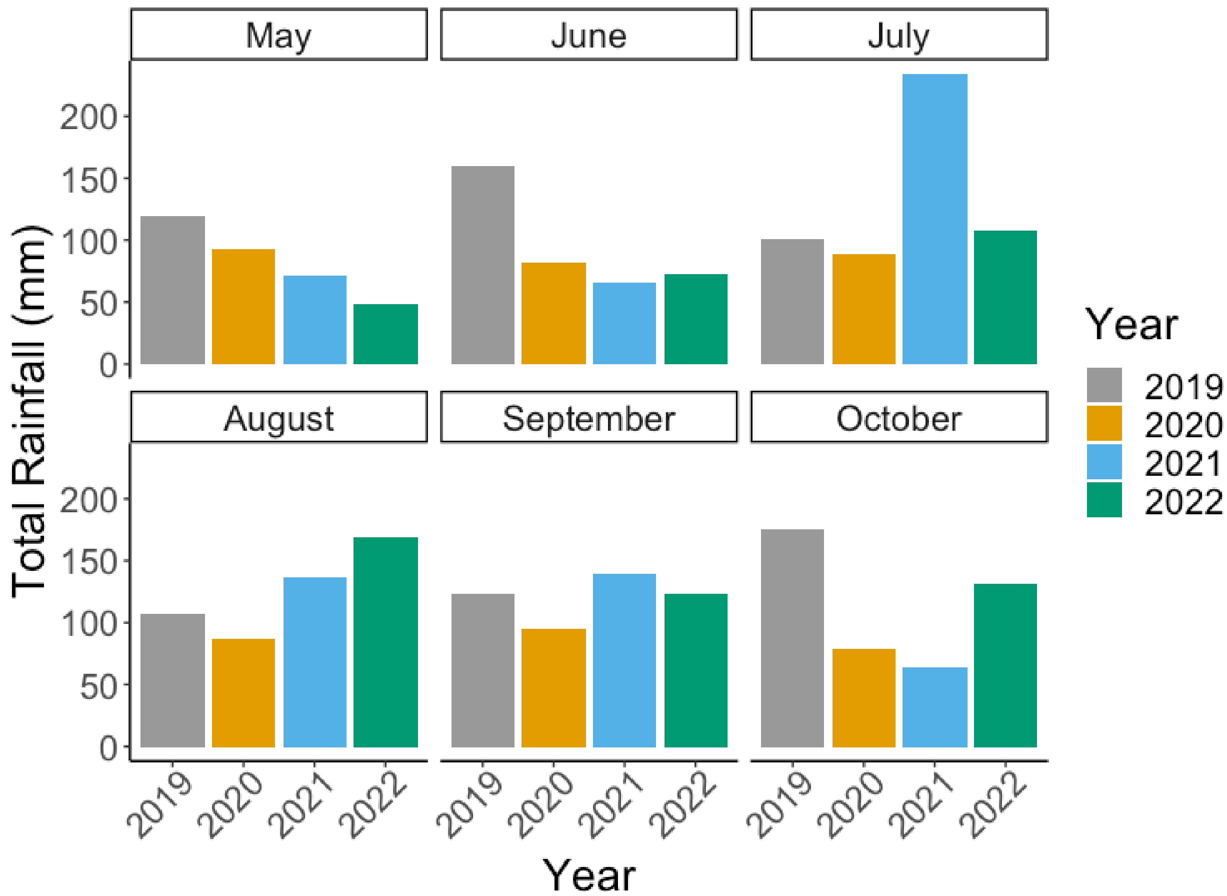

Figure 2. Rainfall per sampling month from 2019 to 2022.

To further investigate whether increased rainfall impacted the nutrient and *E. coli* concentrations, specific rainfall events were compared with sampling occurrences. Through this, it was determined that many sampling dates (specifically within the Marsh Creek watershed) took place during or shortly after rainfall events, which likely could have contributed to the overall increase in nutrient and *E. coli* concentrations. Table 2 below depicts the number of sampling occurrences per year that were influenced by rainfall events. A sampling event was determined to have rainfall influence if >7 mm fell within 48 hours of sampling, and if >15 mm within five days of sample collection. The number of days with rainfall influence were divided by the total number of sampling events per year to determine the percentage of days impacted by rainfall. Although 2022 had higher nutrient levels than previous years, only 19 (47.5%) sampling events were impacted by rainfall compared to 25 events (55.6%) in 2021, and 38 events (64.4%) in 2019 (Table 2). This data suggests that watersheds may be incurring nutrients through various inputs, or there may have been testing errors when processing ammonia and phosphate samples. Further monitoring is recommended to determine if these results were caused by year-to-year variation or overall degradation of water quality.

Table 2. Sampling events with rainfall influence by year. The number of rain days were determined by examining historical rain data and determining if >7 mm fell within 48 hours of sampling, and if >15 mm within five days of sample collection.

Year	Days with Rain Influence	Percent Total (%)
2019	38 of 59	64.4
2020	11 of 24	45.8
2021	25 of 45	55.6
2022	19 of 40	47.5

II. Marsh Creek Water Quality

The Marsh Creek watershed is the subject of ACAP Saint John's longest running water quality monitoring program due to its historical contamination. The 2020 *Thinking Water* report provided an overview of the water quality changes in Marsh Creek over time, dating back to initial monitoring in 1993 (Reinhart and MacKinnon, 2021). In this report, comparisons are made between data from 2019, 2020, 2021 and 2022, with comments on the continued changes since 1993.

In 2022, Marsh Creek exhibited a decrease in water quality at all seven locations, where two sites achieved a marginal water quality index score (Marsh Creek Upstream and Marsh Creek 11) and the remaining sites had poor water quality (Figure 3). Overall decrease in water quality was observed at most sites, specifically within Marsh Creek as sampling dates coincided with heavy rainfall events, resulting in nutrient loading and elevated *E. coli* concentrations. The greatest contributor to poor water quality within the Marsh Creek watershed was phosphate concentrations, though every site except Marsh Creek Upstream also exceeded the threshold values for ammonia, *E. coli*, and dissolved oxygen.

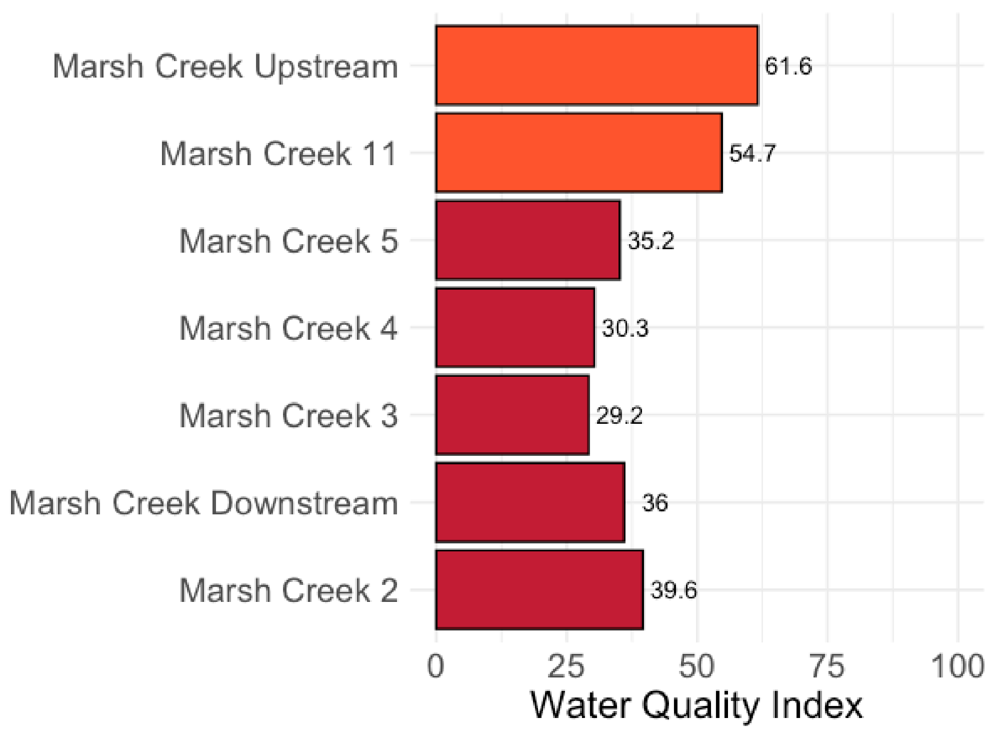

Figure 3. Water quality index (WQI) from Marsh Creek sampling locations. WQI scores are calculated from raw water quality data collected in 2022 according to CCME procedure.

Total coliforms met or exceeded the detection limit (2419.6/100mL) for most samples excluding the Marsh Creek Upstream (MCUS) site which only exceeded the detection limit on one occasion (Figure 4). Each site exceeded the *E. coli* concentration threshold chosen for this report (400 PN/100 mL) at least once, if not most times, while Marsh Creek Upstream did not exceed this threshold on four occasions. *E. coli* concentrations below an average of 200 MPN/100 mL are recommended for recreational activities, and concentrations above this limit may pose health risks (Health Canada, 2012). In many cases, *E. coli* concentrations were greater than the detection limit (2419.6 MPN/100 mL); this is typically true for the farthest downstream sites such as Marsh Creek 2 and Marsh Creek Downstream (MCDS), however; in 2022, Marsh Creek 4 and Marsh Creek 5 exceeded the detection limit on the most occasions. Fecal contamination in Marsh Creek is the result of lift stations overflows and combined sewer inputs that persist during heavy rainfall events when the system receives too much stormwater. As mentioned, many of the sampling dates within Marsh Creek coincided with such heavy rainfall events, contributing to the high levels of total coliforms and *E. coli* outlined by this report. The effects of a rainfall of just 10 mm can cause the system to overflow, with contamination lasting up to five days after. Regardless of a rainfall event, Marsh Creek continues to experience elevated levels of fecal contamination, indicating that this remains a consistent issue within the Marsh Creek watershed nine years after the Harbour Cleanup and the cessation of raw sewage inputs.

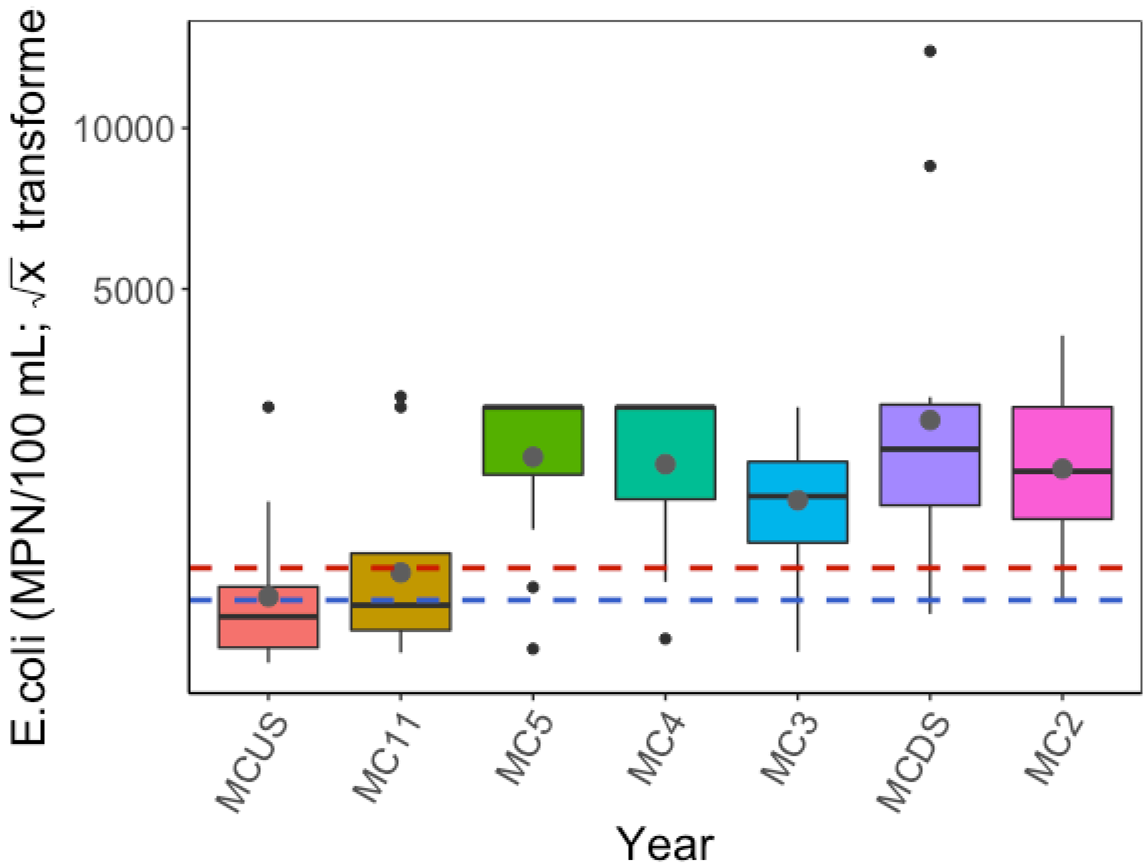

Figure 4. E. coli concentrations (MPN/100 mL) across sites within the Marsh Creek watershed in 2022. The mean values for each site are represented in grey dots, while outliers are represented by black dots, the threshold value (geometric mean concentration of 200 MPN/100 mL; minimum 5 samples) is represented by the blue dotted line, while the single-sample maximum concentration (400 MPN/100 mL) is represented by the red dotted line.

Ammonia concentrations were also elevated throughout the watershed with mean concentrations exceeding the threshold (0.1 mg/L) at all sites except Marsh Creek Upstream and Marsh Creek 11 which did not exceed the limit on one occasion (Figure 5). Similarly, orthophosphate concentrations exceeded the threshold (0.04 mg/L) at all sites including Marsh Creek Upstream, although this location only exceeded the limit on some occasions (Figure 5). In 2022, both ammonia and orthophosphate were elevated considerably from previous years. High nutrient levels and *E. coli* concentrations are often associated with sewage inputs, run-off, and stormwater carrying nutrients into the watercourse. In addition to the heavy rainfall events occurring near/during sampling, the areas around Marsh Creek are highly industrialized, particularly at the downstream locations, and poor riparian cover allows nutrients and other contaminants to easily enter the stream without filtration or mitigation.

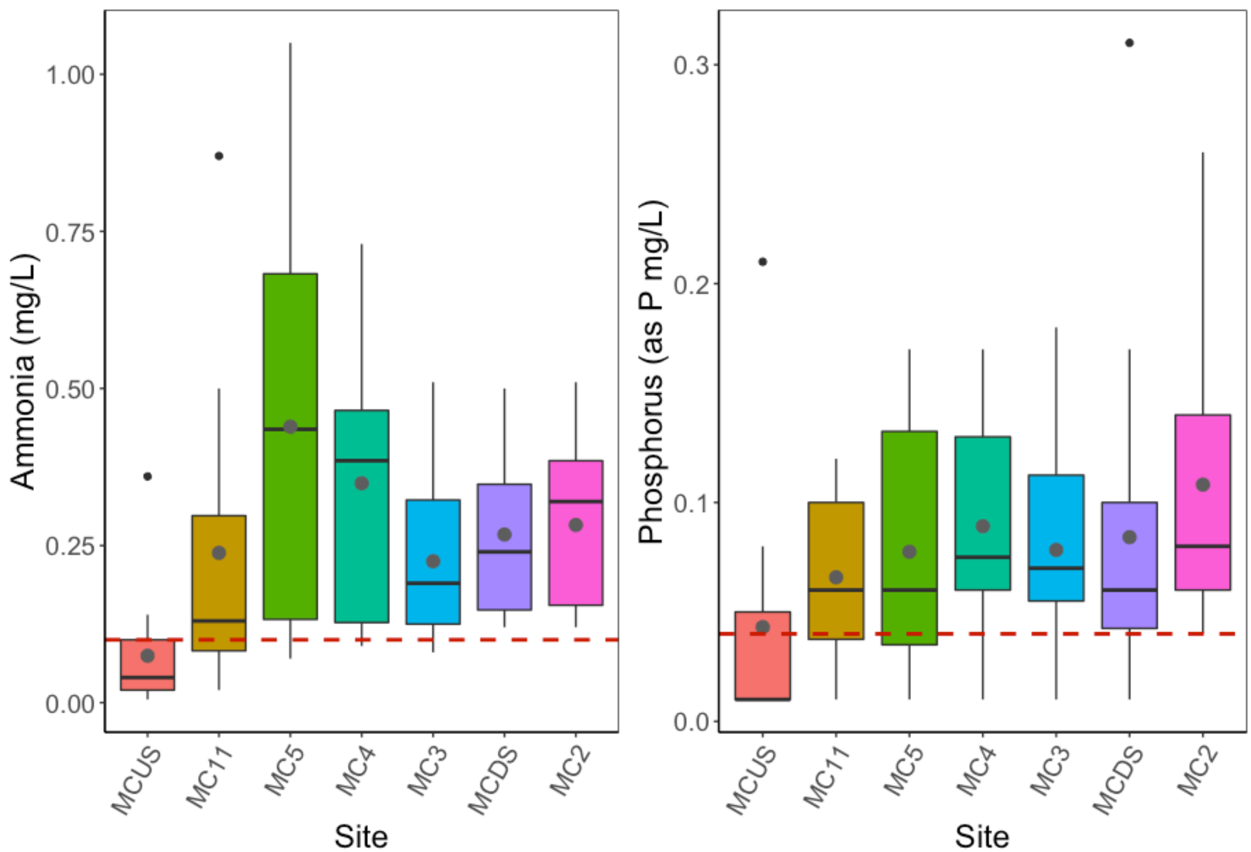

Figure 5. Left - ammonia concentrations (mg/L) across sites in the Marsh Creek watershed in 2022. The mean values for each site are represented in grey dots, while outliers are represented by black dots, and the threshold value (0.1 mg/L) is represented by the dotted line. Right – 2022 Orthophosphate concentration (mg/L) as P across sites in the Marsh Creek watershed. The mean values for each site are represented in grey dots, whole the outliers are represented by black dots, and the threshold value (0.04 mg/L) is represented by the dotted line.

Lower dissolved oxygen (DO) concentrations were measured in 2022, with most sites falling below the threshold value of 6.5 mg/L on multiple occasions. Mean DO concentrations hovered around the threshold at all sites except the most upstream (Marsh Creek Upstream, Marsh Creek 11), which had DO levels well above the threshold limit (Figure 6). Nutrient inputs (such as what Marsh Creek exhibited in 2022) can drive algal growth that lowers DO concentrations, where decreases in dissolved oxygen can be detrimental to aquatic organisms.

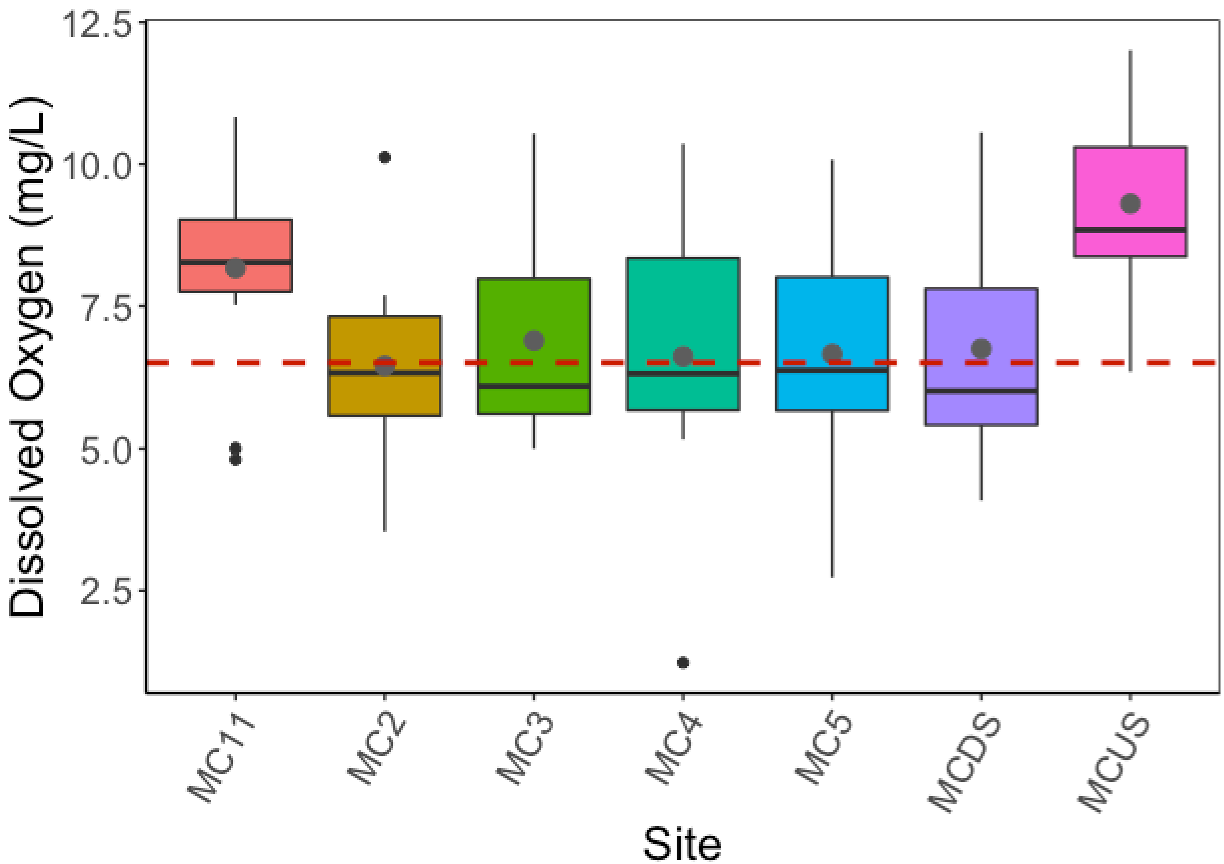

Figure 6. Dissolved oxygen concentrations (mg/L) measured across sites in the Marsh Creek watershed in 2022. The mean values for each site are represented by grey dots, while outliers are represented by black dots, and the threshold value (6.5 mg/L) is represented by the dotted line.

Additional water quality measurements, namely temperature, pH, and turbidity, did not contribute to the poor water quality observed in Marsh Creek in 2022. The highest temperatures were measured in early August with only two sites (Marsh Creek 4 and Marsh Creek 5) exceeding the threshold value of 23.5°C and a mean average temperature of 22.4°C across sites. The pH values generally remained within the guidelines (6.5 to 9), not once falling below the threshold but on a few occasions, rising above; with that, the average pH was 8.03. Turbidity exceeded 40 NTU on one occasion but generally remained low.

In 2022, water quality was poor at all sites except Marsh Creek Upstream and Marsh Creek 11 which had a marginal water quality index score. Water quality decreased at all seven sites between 2021 and 2022, including Marsh Creek Upstream which diminished from fair to marginal, while the remaining sites decreased from marginal to poor (Figure 7). Elevated concentrations of *E. coli*, ammonia, and orthophosphate caused by increased rainfall all contributed to the significant decrease in water quality exhibited at Marsh Creek in 2022. These changes may be the result of year-to-year variation more than considerable degradation in water quality in 2022.

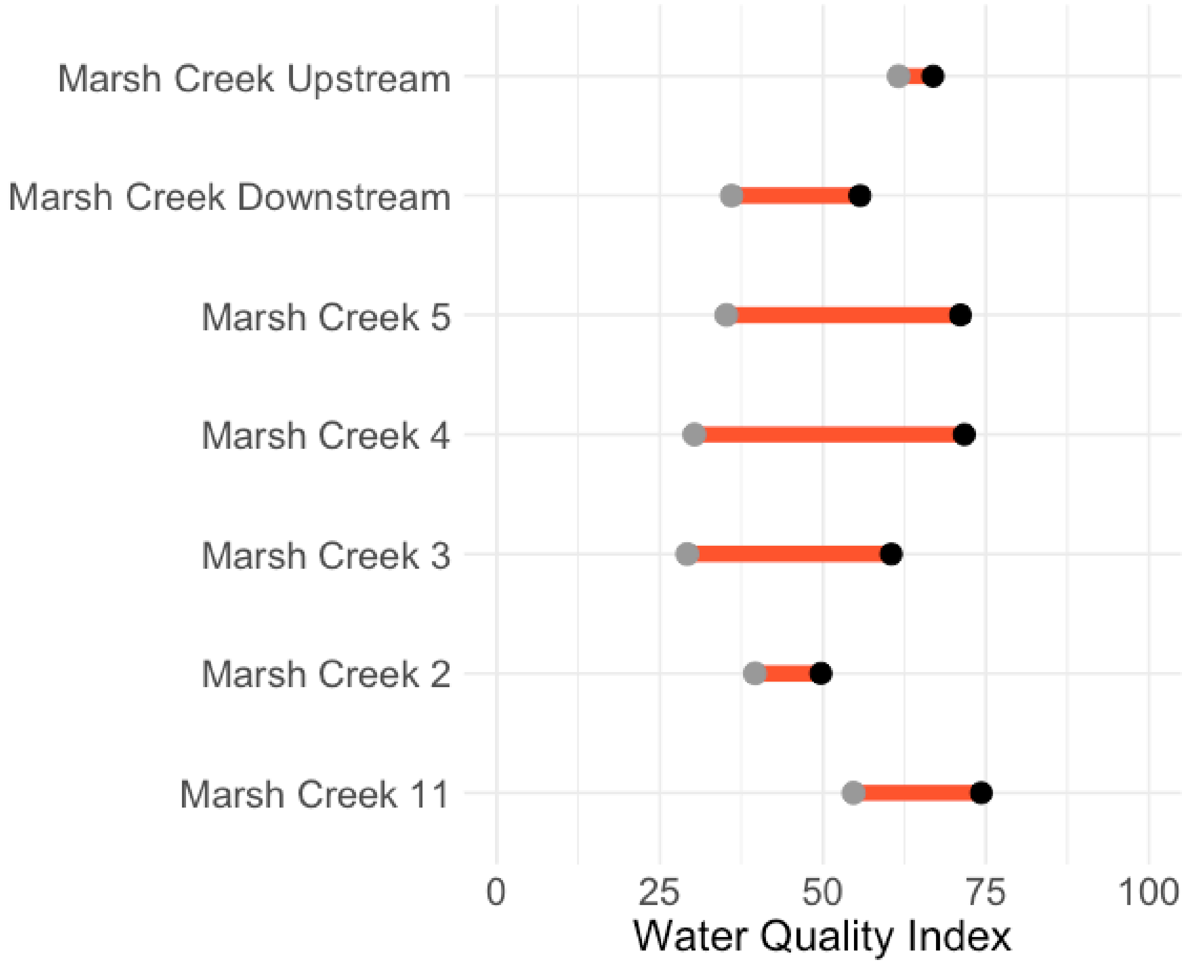

Figure 7. Change in water quality between 2021 (black circles) and 2022 (grey circles) at sites within the Marsh Creek watershed, with colours indicating whether the water quality index has improved (green) or declined (red) from 2021 to 2022.

II.i. Marsh Creek Water Quality Comparative Analysis

The following subsection compares water quality data collected within the Marsh Creek watershed throughout 2019 to 2022. Parameters including ammonia, phosphate, and *E. coli* are presented graphically to exhibit year-to-year trends, allowing for any amelioration or deterioration to be identified. In 2022, the Marsh Creek watershed experienced an increase in phosphate, ammonia, and *E. coli* concentrations; this nutrient loading and increased *E. coli* concentration can be attributed to sampling that coincided with heavy rainfall events, leading to runoff and sewage overflows adding pollutants into Marsh Creek. In addition to the rainfall events of 2022, it is possible that testing errors occurred when processing ammonia and phosphate samples; it is less likely, but possible, that *E. coli* samples were contaminated. With its history of contamination, lack of riparian cover, and heavily urbanized/industrialized reaches, the Marsh Creek watershed typically exhibits high nutrient and *E. coli* concentrations.

Ammonia concentrations in 2022 were the highest recorded in four years at all sites except Marsh Creek Upstream, where it decreased slightly (Figure 8). All sites (excluding Marsh Creek

Upstream) exhibited a mean concentration above the threshold (0.1 mg/L). Ammonia levels have spiked several times over the past three decades, including after the cessation of raw sewage dumping in 2014. Such an increase in ammonia concentrations between 2019 and 2022 may indicate the continued influence of these pollution sources and the need for further management.

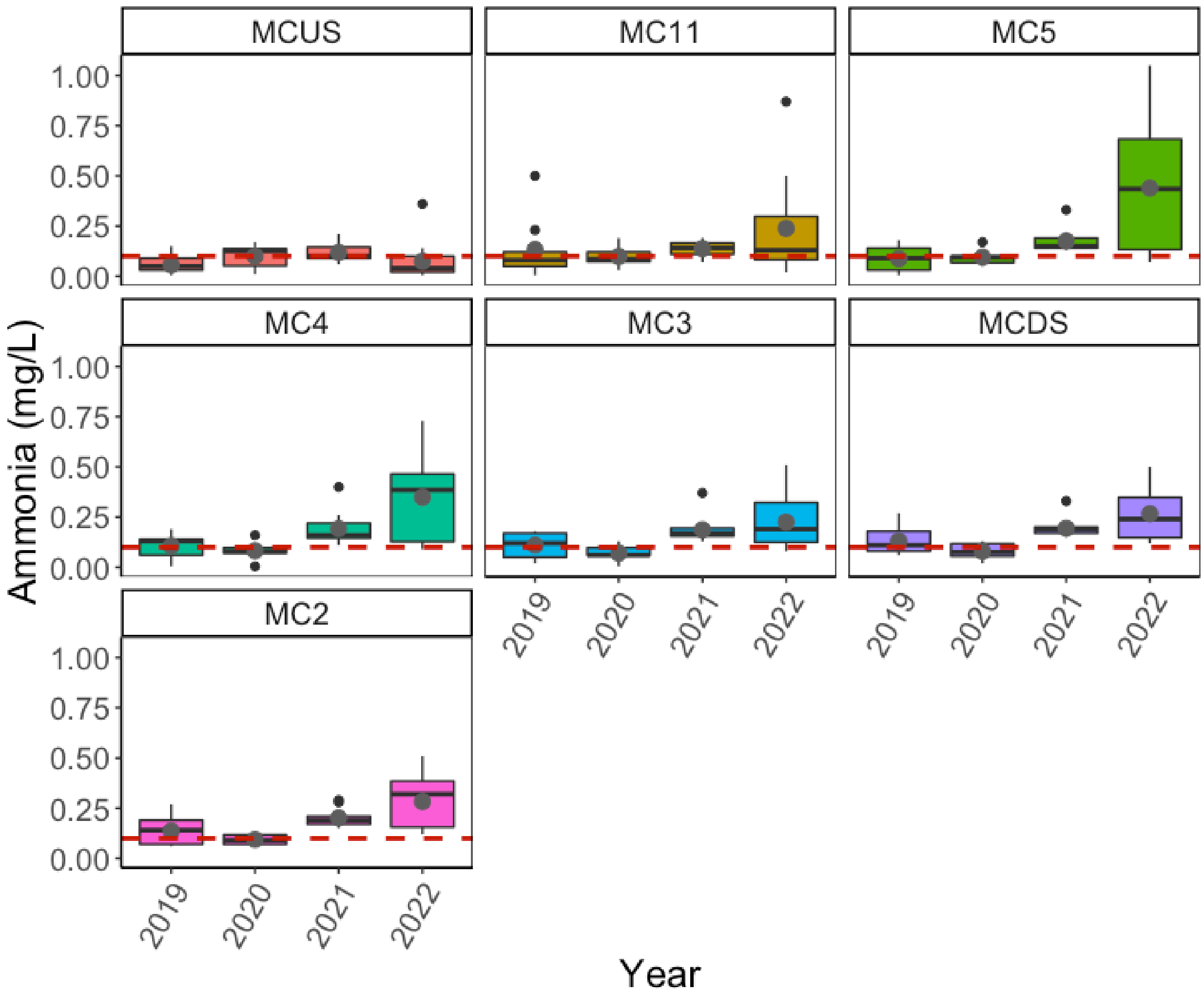

Figure 8. Ammonia concentrations (mg/L) within the Marsh Creek watershed throughout 2019 to 2022 with mean values represented by grey dots, outliers represented with black dots, and the threshold value (0.1 mg/L) indicated by the dotted line.

Phosphate concentrations met or exceeded the chosen threshold at all sites except for Marsh Creek Upstream in 2022; these measurements were the highest observed over the last three years (Figure 9). As with ammonia, phosphate levels have periodically been elevated within the Marsh Creek watershed over the last decade, and the sources of phosphate entering the watercourse can vary.

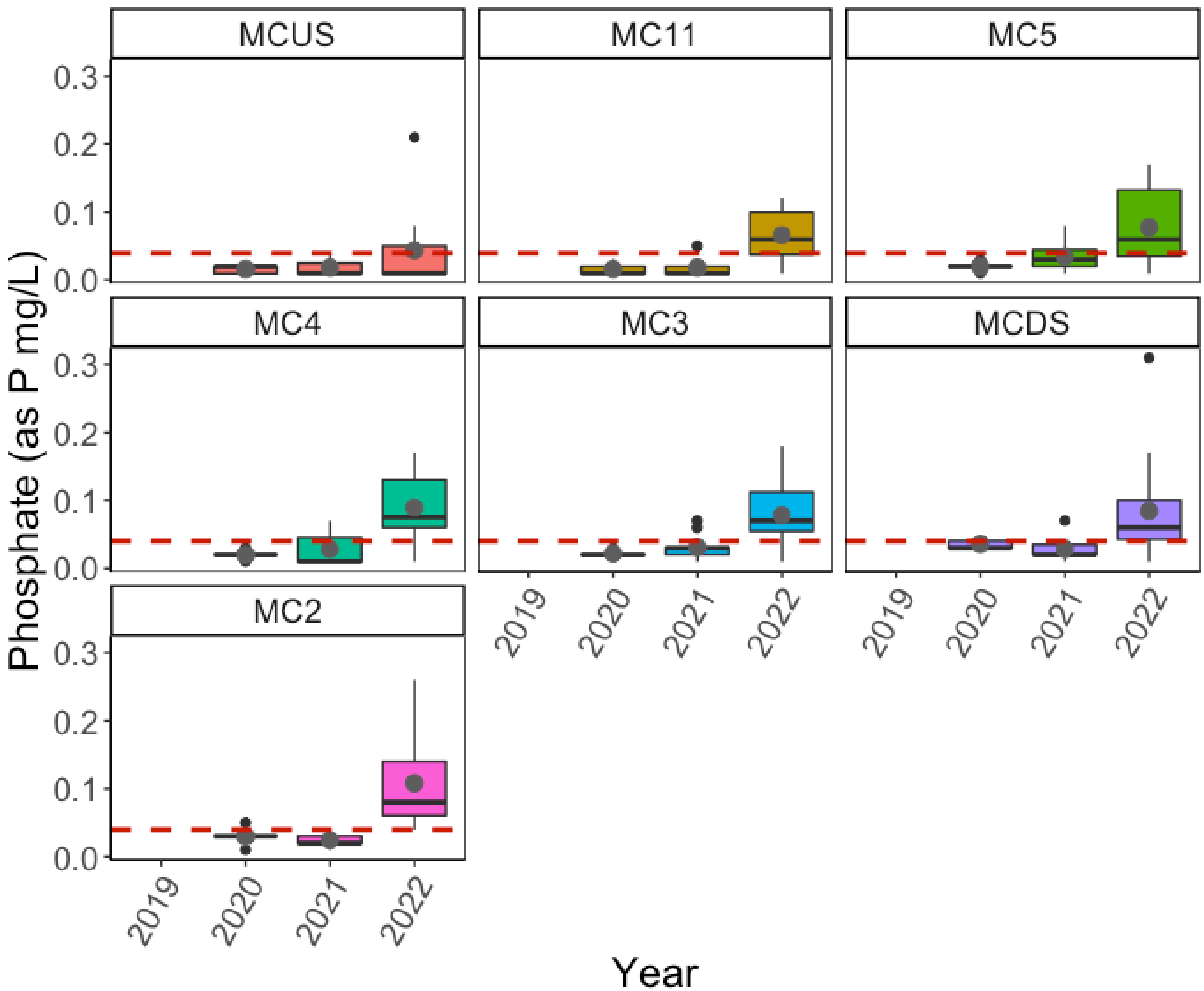

Figure 9. Orthophosphate concentrations as Phosphorus (mg/L) within the Marsh Creek watershed throughout 2019 to 2022 with mean values represented by grey dots, outliers represented with black dots, and the threshold value (0.04 mg/L) indicated by the dotted line.

The decrease in water quality observed in 2022 is in part caused by an increase in *E. coli* concentrations. ACAP Saint John has previously found that recent fecal coliform counts are generally lower than they were prior to 2015 (ACAP Saint John, 2021). Until 2020, fecal coliform concentrations (including, but not limited, to *E. coli*) were measured rather than *E. coli* concentrations, with that, 2019 data was not included in Figure 10 below. Fecal coliform counts at Marsh Creek Downstream were historically much higher than those at the upstream site, with extremely high concentrations measured between 2000 and 2015. Following the cessation of raw sewage inputs in 2014, fecal coliform counts declined, which have for the most part continued in 2022, although an increased mean concentration was measured at three sites (MC4, MC5, and MC11). Again, these elevated levels are largely due to lift station overflow and runoff caused by heavy rain near or during the sampling events, and likely represent a yearly change rather than overall decrease in water quality. As indicated by Figure 10 below, all sites measured at or above the recommended guideline (400 MPN/100mL) on every occasion except for Marsh Creek Upstream and Marsh Creek 11. The sites measured above the guideline were often far higher than 400 MPN/100mL and in many cases, above the detection limit (24196 MPN/100mL). Sewage overflows after heavy rainfalls still occur, and there may be other sources of contamination that exist as well, particularly at Marsh Creek 4 and Marsh Creek 5. With that, there remains opportunity for further remediation within Marsh Creek to reduce sewage outfalls and other sources of pollution.

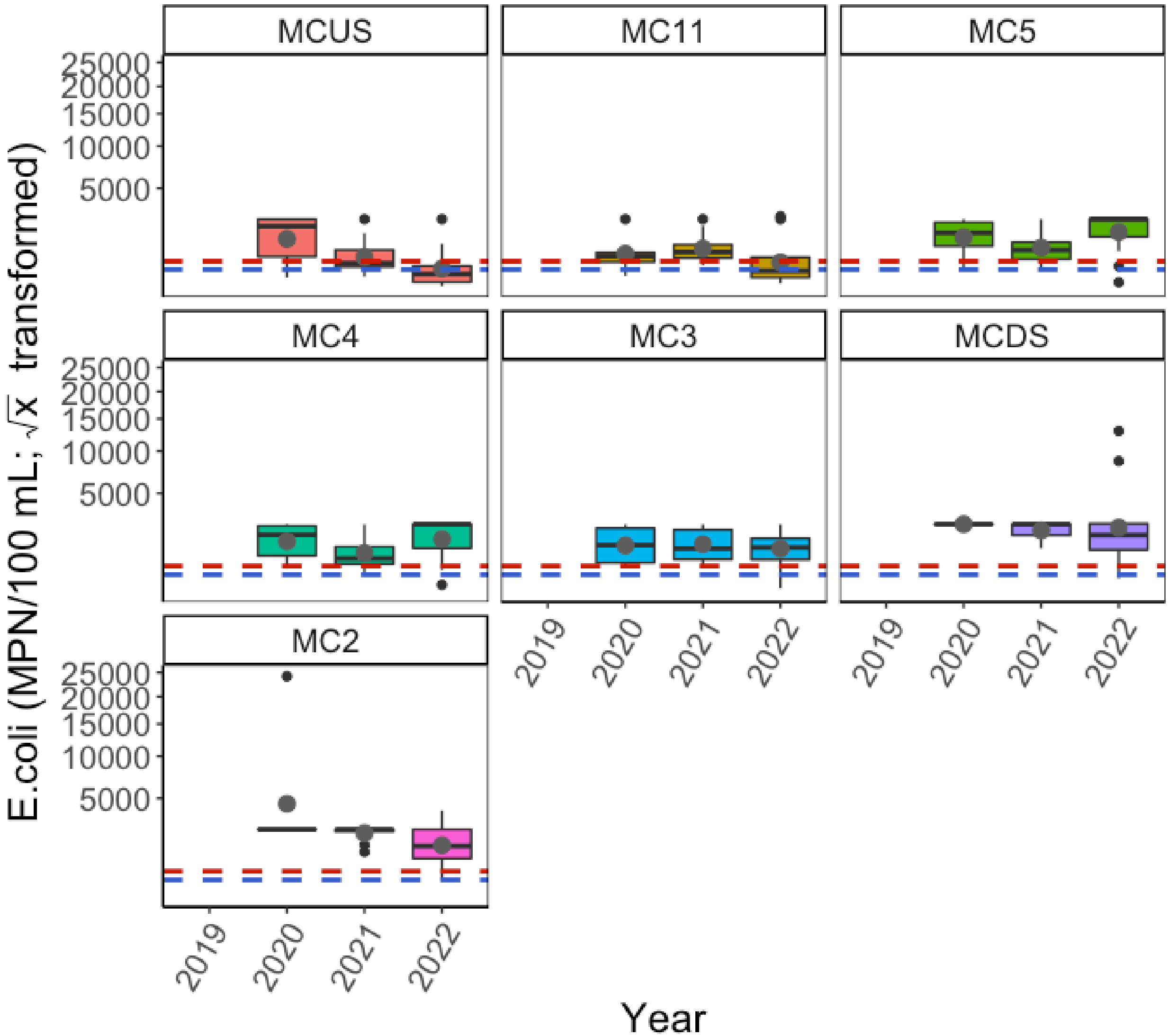

Figure 10. E. coli concentrations (MPN/100mL) within the Marsh Creek watershed over 2020 to 2022 with the mean values (grey dots), outliers (black dots), the threshold value (geometric mean concentration of 200 MPN/100 mL; minimum 5 samples) is represented by the blue dotted line, while the single-sample maximum concentration (400 MPN/100 mL) is represented by the red dotted line.

Dissolved oxygen concentrations decreased compared to previous years, with sites having a concentration of 6.5 mg/L or lower more often than in 2021. A mean concentration across sites was measured at 7.3 mg/L; in 2021, mean concentrations for most sites was at or below 8 mg/L. This holds true for historical data as well, with occasional drops in DO levels at downstream sites in particular.

As in previous years, the primary contributors to poor water quality in the Marsh Creek watershed were phosphate, ammonia, and *E. coli*. These parameters have been historically high in this watershed, and continued to remain elevated across sites in 2022, which is likely attributed to nutrient loading caused by rainfall events before or during sampling at Marsh Creek. Although not indicated by the water quality scores of 2022, Marsh Creek is capable of supporting animal populations, with waterfowl and schools of fish frequently observed at various sites. Despite this, the watershed remains polluted with high nutrient levels and *E. coli* concentrations that often exceed recreational limits. Marsh Creek remains Saint John's most polluted watershed, and further remediation efforts would benefit this system.

III. Water Quality in the Greater Saint John Area

In this section, the water quality monitoring completed in the Greater Saint John area outside of Marsh Creek is presented. Due to the large volume of data collected in the Marsh Creek watershed since 1993 it was reported in an isolated chapter above. The Water Quality Index (WQI) has five rankings: poor (0-44), marginal (45-64), fair (65-79), good (80-94), and excellent (95-100) (Canadian Council of Ministers of the Environment, 2001). These WQI calculations were based on temperature, dissolved oxygen, pH, salinity, ammonia, phosphate (measured as P), and *E. coli* concentrations.

Like 2021, no sites achieved an excellent water quality index score in 2022. Of the sites, only 3 exhibited good water quality, the majority (10) had fair water quality, 6 were marginal, and 1 achieved a poor water quality index score (Figure 11). These scores indicate that all sites had at least one parameter measure below the guidelines and thresholds described above. The lowest water quality analyzed was at Newman's Brook Downstream (WQI of 42.7) and Hazen Creek Mouth (WQI of 52.8) while the best water quality was measured at Mill Creek (WQI of 85) and Spruce Lake Stream Upstream (WQI of 83.6). As with the Marsh Creek sites, the greatest contributing factor to poor water quality in the rest of the Greater Saint John area in 2022 was phosphate; however, several sites did not meet the guidelines for ammonia, dissolved oxygen, and *E. coli*.

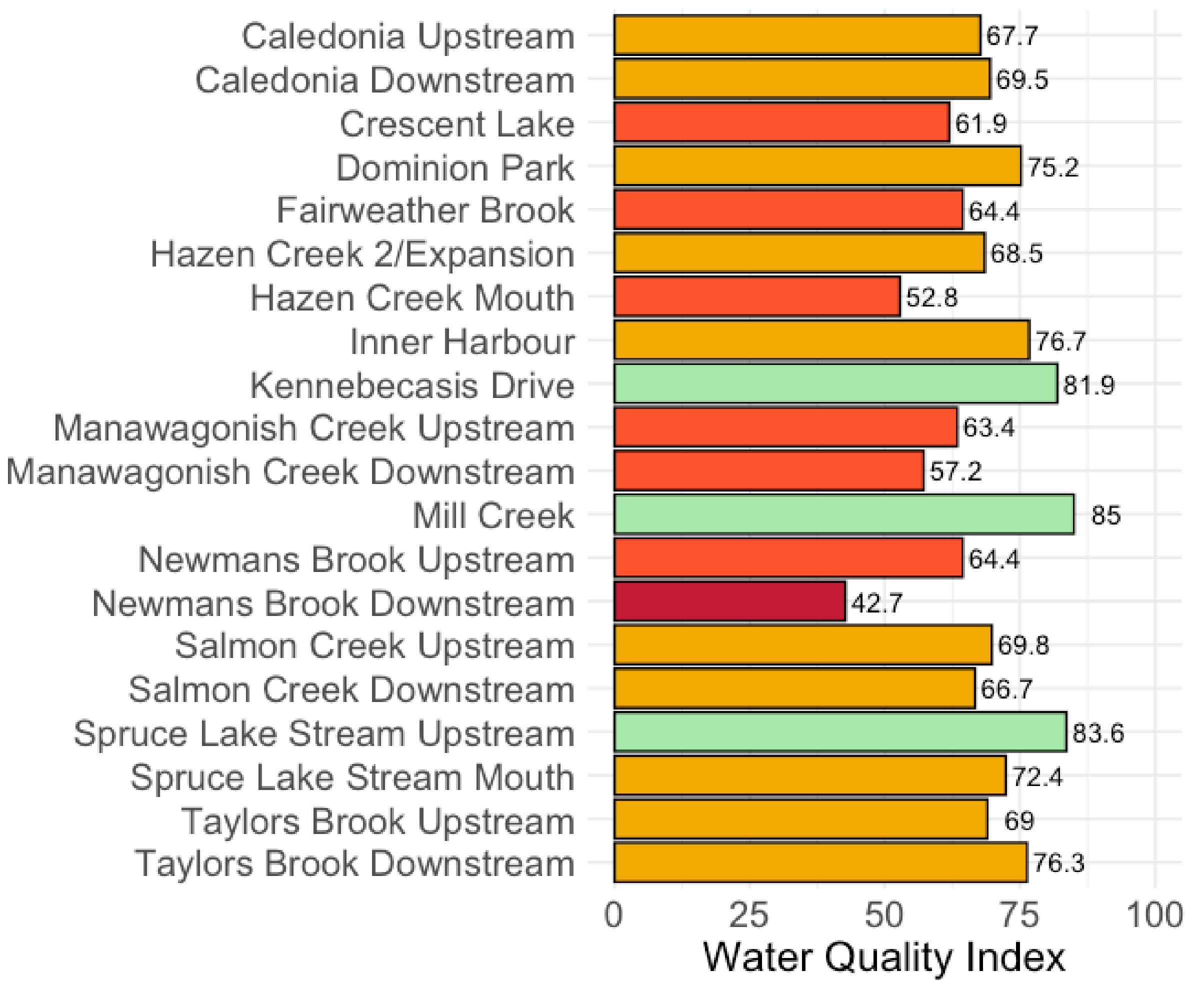

Figure 11. Water quality index values for mentioned sites in the Greater Saint John area in 2022.

The highest mean *E. coli* concentrations were measured at Caledonia Downstream (DS) and Manawagonish Creek Downstream, rendering a total of 5 out of 20 sites (25%) with a mean concentration above the recommended recreational limit (200 MPN/100 mL) (Figure 12). Caledonia Downstream and Manawagonish Creek Downstream likely experienced considerable sewage inflows or run-off at some points in 2022, resulting in a broad range of *E. coli* concentrations and high mean concentrations. Eight sites (Crescent Lake, Dominion Park, Hazen Creek 2/Expansion, Hazen Creek Mouth, Newman's Brook Upstream (US), Salmon Creek (US), Taylor Brook Downstream, and Taylor Brook Upstream) had mean concentrations below the threshold but exceeded the limit once, while two sites (Salmon Creek Downstream and Spruce Lake Mouth) had values approaching the threshold. These one-time measurements are likely associated with heavy rainfall events resulting in sewage inputs, or less likely, but possible, the contamination of samples collected. Occasional exceedances of the recreational limit (400 MPN/100 mL) are concerning for locations like Dominion Park, which is a popular swimming spot.

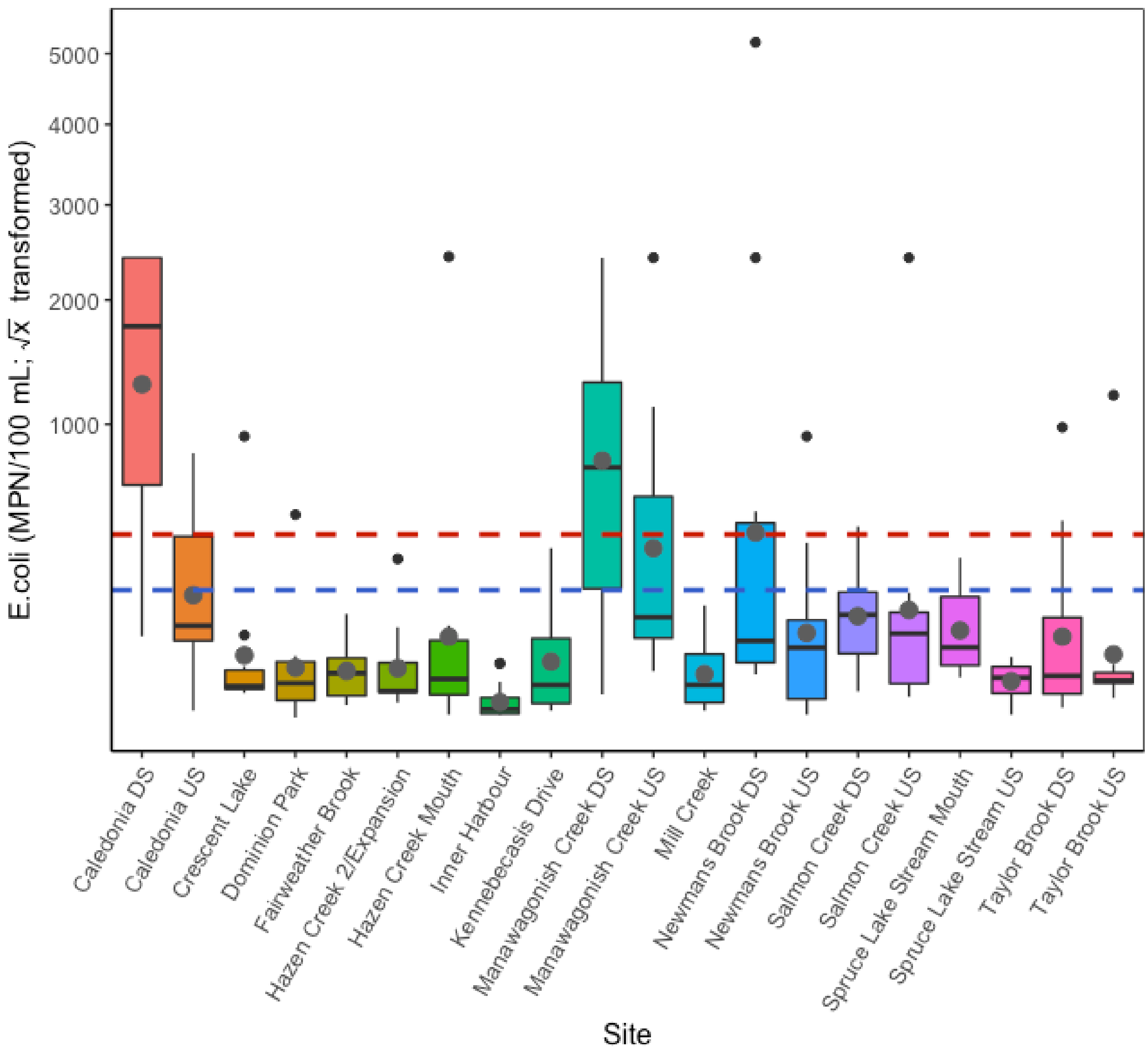

Figure 12. E. coli concentrations (MPN/100mL) across sites in the Greater Saint John area in 2022. The mean values for each site are represented by grey dots, the black dots represent outliers, the threshold value (geometric mean concentration of 200 MPN/100 mL; minimum 5 samples) is represented by the blue dotted line, while thee single-sample maximum concentration (400 MPN/100 mL) is represented by the red dotted line.

Five sites (Crescent Lake, Manawagonish Creek Upstream, Manawagonish Creek Downstream, Hazen Creek Mouth, and Newman's Brook Downstream) had mean ammonia concentrations above the threshold (0.01 mg/L) in 2022 (Figure 13). Newman's Brook had the highest mean concentration in 2022 and has had historically high ammonia concentrations; Newman's Brook is known to receive municipal outputs and runoff from roads, creating a persistent issue with high nutrient concentrations. This site also had one of the highest mean concentrations of phosphate, just slightly below that of Caledonia Brook Downstream; although in 2022, each site had a mean concentration of phosphate at or above the threshold of 0.04 mg/L (Figure 14). High nutrient concentrations can be detrimental to aquatic life, particularly when these high levels are sustained over long periods of time. The elevated levels of both phosphate and ammonia in 2022 were likely in part due to sampling concurrent with rainfall events; these changes may also be due to a testing error.

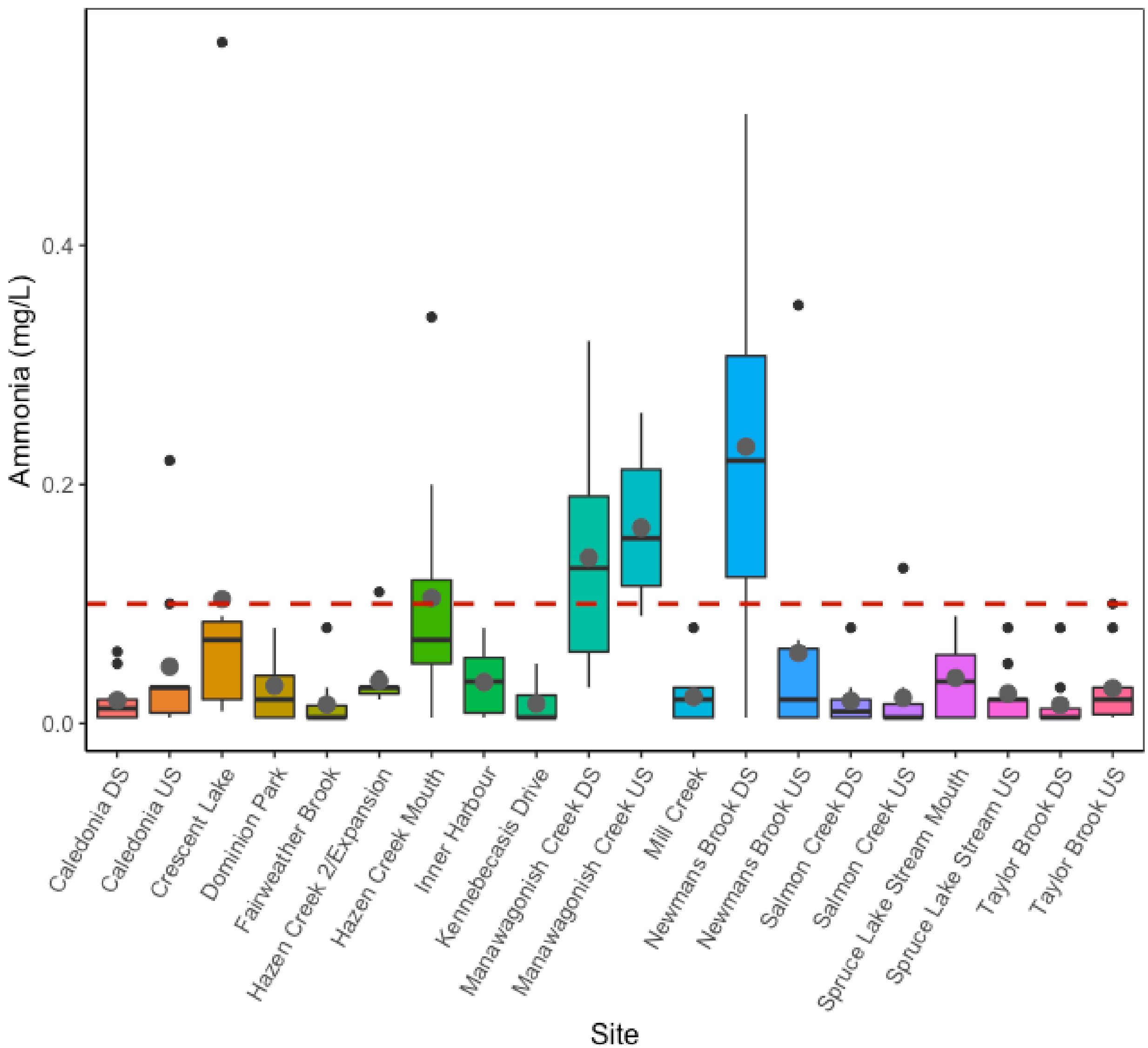

Figure 13. Ammonia concentrations (mg/L) across sites in the Greater Saint John area in 2022. The mean values for each site are represented by grey dots, the outliers are represented by black dots, and the threshold value (0.1 mg/L) is represented by the dotted line.

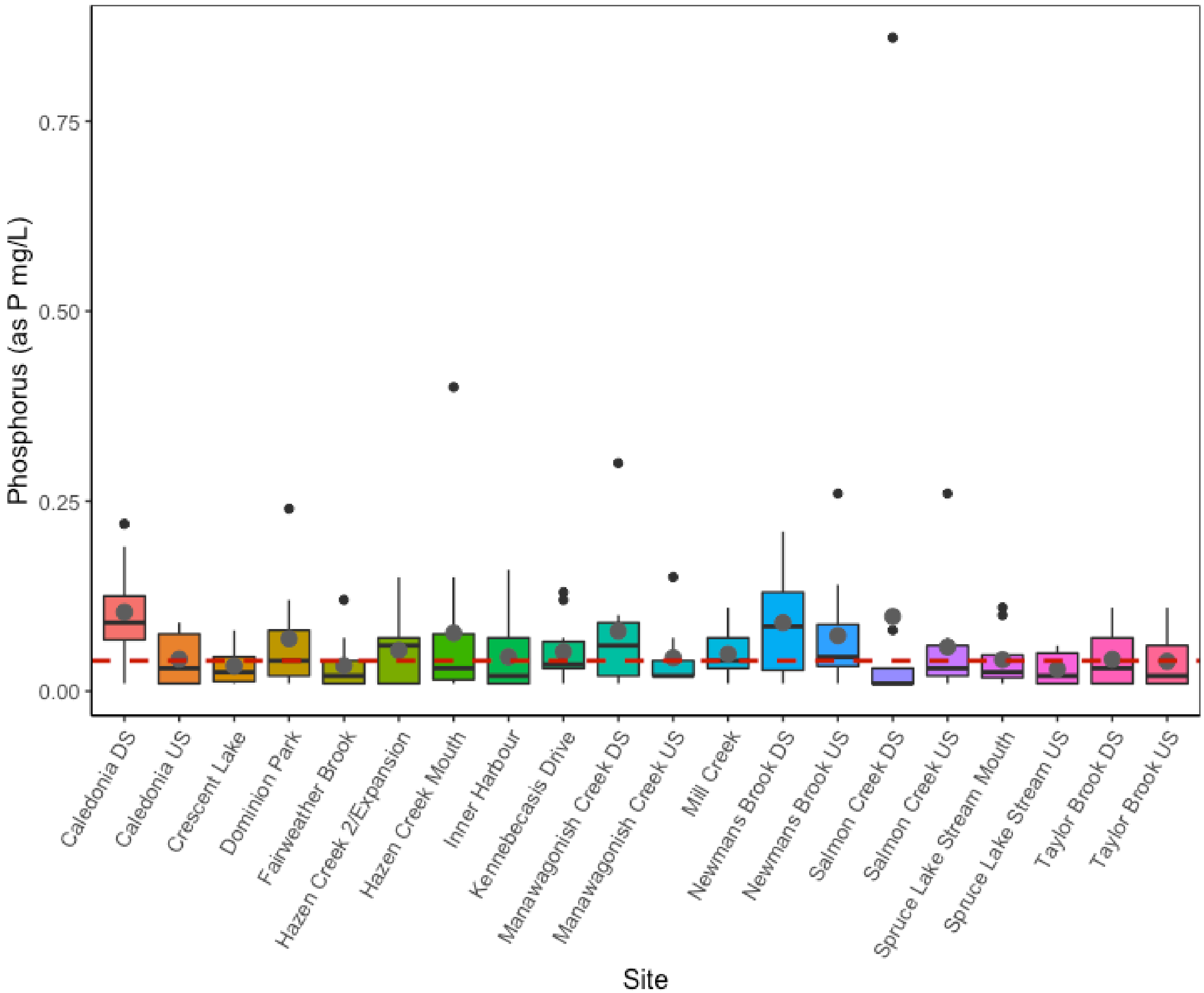

Figure 14. Orthophosphate concentrations (mg/L) as P across sites in the Greater Saint John area in 2022. The mean values for each site are represented by grey dots, the outliers are represented by black dots, and the chosen threshold value (0.04 mg/L) is represented by the dotted line.

Very few dissolved oxygen measurements fell below the threshold (6.5 mg/L) outside of Newman's Brook Downstream, with only the occasional drop at Crescent Lake, Hazen Creek Mouth, and Manawagonish Creek Downstream, which all had mean concentrations above the recommended limit. The high nutrient levels exhibited at Newman's Brook Downstream could have caused increased productivity and more oxygen depletion than at other sites. Additionally, Crescent Lake is the only site sampled in this program that may have relatively low dissolved oxygen levels because of slow-moving water and algal or macrophyte growth. Overall, most sites sampled within the Greater Saint John area have sufficient oxygen levels to support aquatic life (Figure 15).

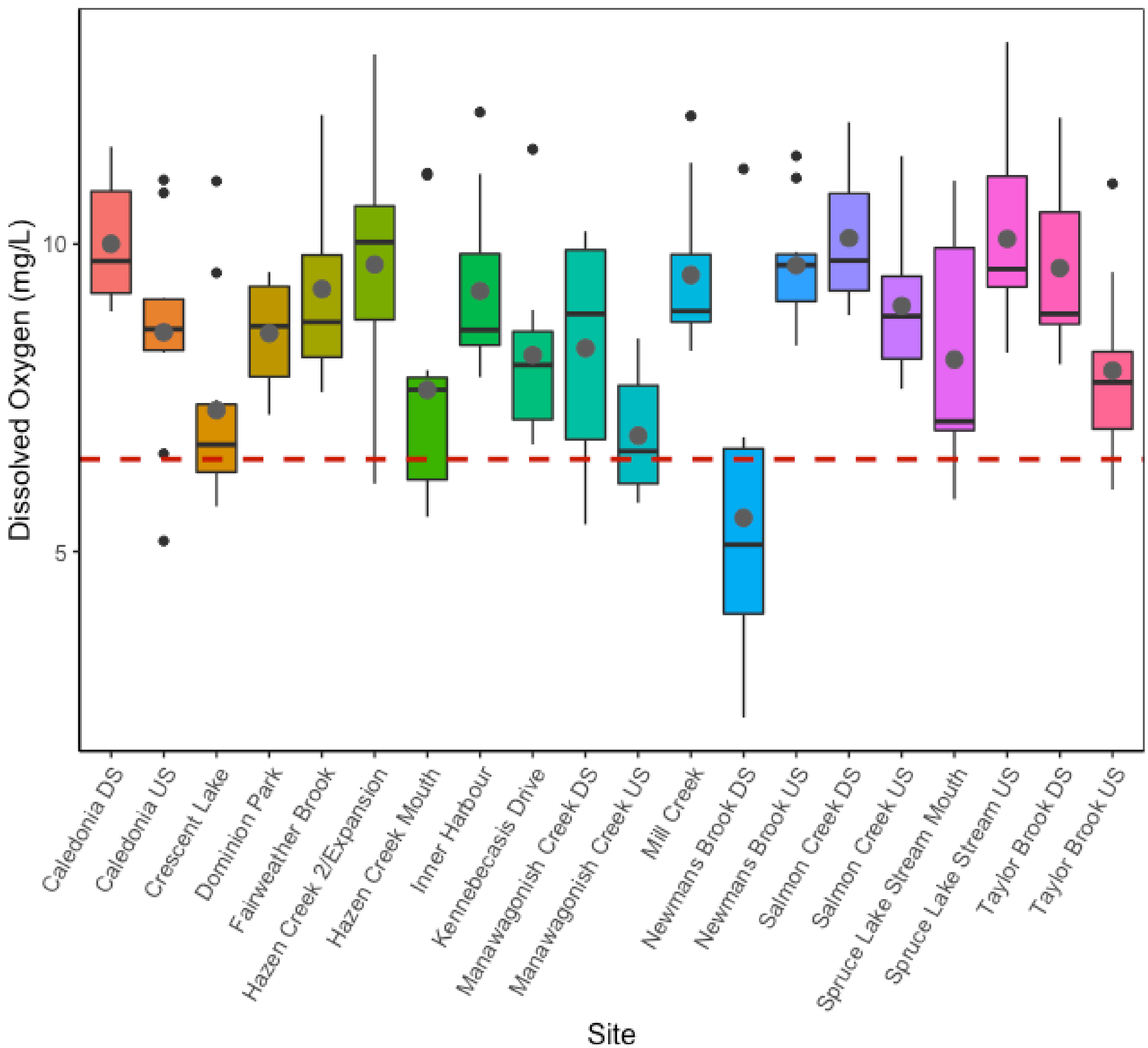

Figure 15. Dissolved oxygen concentrations (mg/L) across sites in the Greater Saint John area in 2022. The mean values for each site are represented by grey dots, the outliers by black dots, and the threshold value (6.5 mg/L) is represented by the dotted line.

In 2022, no sites within the Greater Saint John area exceeded the selected temperature threshold (23.5°C) during sampling events and mean temperatures measured were just above 15°C (Figure 16). The data spans a broad range of temperatures as measurements are taken between late spring and early fall. Sites such as Crescent Lake, Dominion Park, Kennebecasis Drive, and Mill Creek often exhibited higher water temperatures as they lack canopy cover that would provide shade and thermal refuge. Cooler waters are beneficial for aquatic life in the watersheds, particularly salmonids, which cannot tolerate high temperatures for extended periods of time (Breau, 2012). The pH values of the Greater Saint John area sites never fell below 6 and generally ranged between 7 to 9, although some sites exceeded the chosen threshold of 9. Sites reached or exceeded the upper threshold in August, which had the highest mean pH values of all sampling periods.

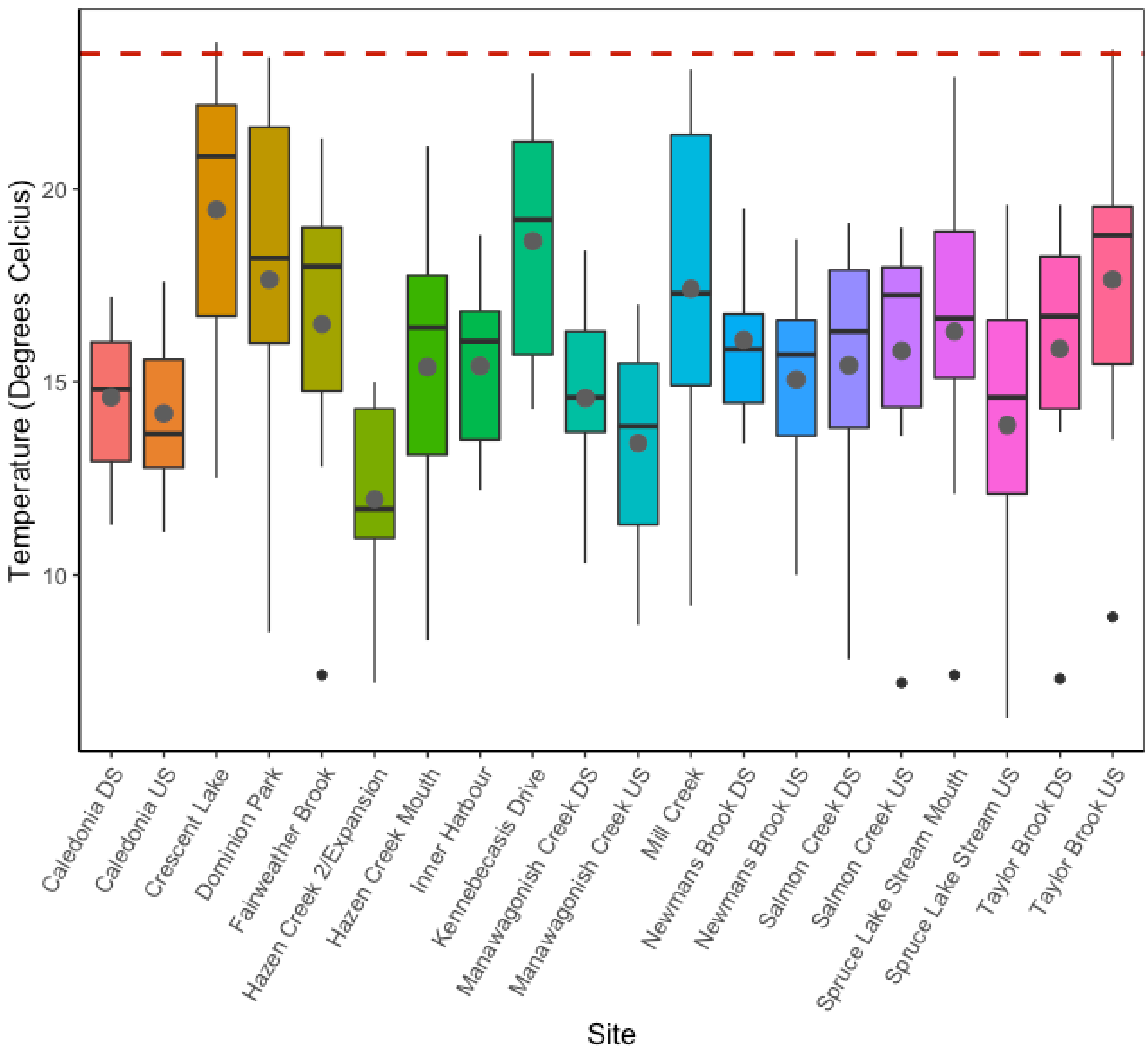

Figure 16. Temperature (°C) across all sites in 2022, with mean temperature represented by grey dots, outliers represented with black dots, and the threshold value (23.5 °C) represented by the dotted line.

Turbidity ranged from 0 to 30 NTU for most sites, and typically did not exceed 20 NTU. Turbidity values measured above the threshold (55 NTU) occurred once at Inner Harbour (69 NTU) and Hazen Creek Mouth (110 NTU). The elevated turbidity exhibited at Inner Harbour occurred in early August, during a heavy rainfall event in combination with a high low tide, at this time, *E. coli* levels were low, ammonia concentrations were only slightly elevated, however, phosphate was very high (0.22 mg/L). The increase concentrations at Hazen Creek Mouth occurred in early October and were not caused by any rainfall but may have incurred tidal influence. During this event, *E. coli* levels remained low, while ammonia and phosphate were high, measuring at 0.34 mg/L and 0.13 mg/L, respectively. Outside of these occurrences, Inner Harbour exhibited fair water quality, while Hazen Creek Mouth scored marginal water quality; this raises questions about the input sources into this stream and the impacts on water quality.

The water quality in 2022 was generally much lower than 2021, which had four sites with good water quality, only four with marginal water quality, and no sites with poor water quality. Eighteen locations (comprising 90% of sites) declined in water quality between 2021 and 2022, and two sites with historically low water quality (Newman's Brook Downstream and Crescent Lake) and in 2021 marginally improved in 2022. The declines in water quality in 2022 may be the result of more threshold exceedances across a few parameters at most sites in addition to potential testing errors amongst ammonia, phosphate, and *E. coli*. On average, water quality declined from the higher end of fair (74.3) to the lower end of fair (68.5) between 2021 and 2022 (Figure 17).

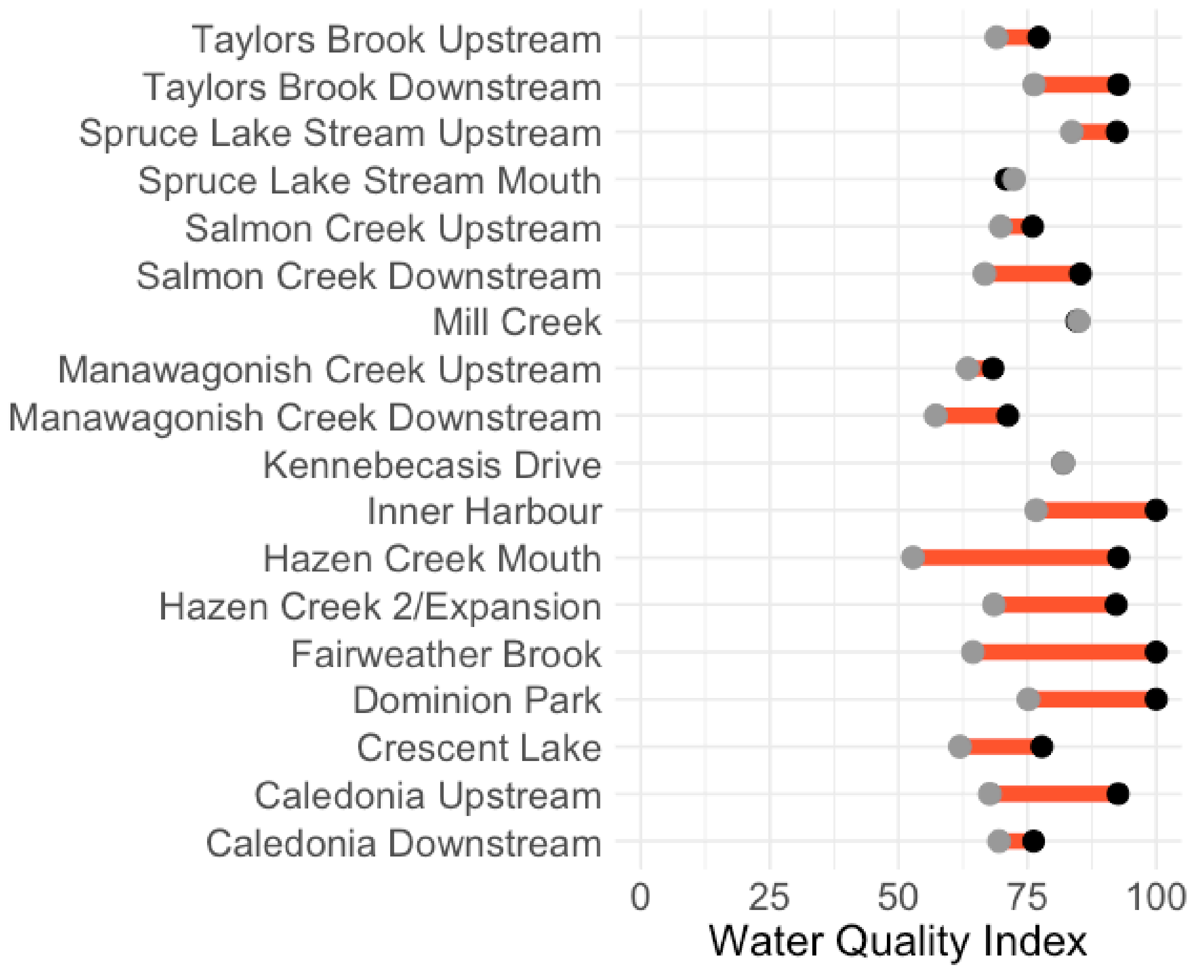

Figure 17. Change in water quality index scores between 2021 (black circles) and 2022 (grey circles) at sites within the Greater Saint John area, with colours indicating whether the WQI has improved (green) or declined (red) from 2021 to 2022.

III.i. Water Quality in the Greater Saint John Area Comparative Analysis

The following subsection compares water quality data collected within the watersheds throughout the Greater Saint John Area between 2019 to 2022. Nutrient and *E. coli* concentrations are presented graphically to exhibit year-to-year trends, allowing for any degradation or improvements to be identified. In 2022, the monitored watersheds across Saint John experienced an increase in phosphate, ammonia, and *E. coli* concentrations; this nutrient loading and increase in *E. coli* can somewhat be attributed to sampling that coincided with heavy rainfall events, leading to runoff and sewage overflows adding pollutants into waterways. In addition to the rainfall events of 2022, it is possible that testing errors occurred when processing ammonia and phosphate samples; it is less likely, but possible, that *E. coli* samples were contaminated.

Overall ammonia concentrations were found to be lower in 2022, realigning more with the past levels of 2019 and 2020, prior to the spike in 2021. Most sites in 2022 exhibited greater variance in ammonia concentrations yet only three sites exhibited an increased mean concentration (Manawagonish Creek Downstream, Manawagonish Creek Upstream, Newman's Brook Downstream) (Figure 18). With that, most sites had means below the threshold (0.1mg/L) while five exceeded. In contrast, mean phosphate concentrations in 2022 were generally the highest across sites compared to the past three years, and typically exhibited greater variance as well. In 2019 and 2020, most sites had mean phosphate concentrations below the threshold (0.04mg/L) with few sites meeting or exceeding this limit occasionally (excluding Newman's Brook Downstream) (Figure 19). This sitewide increase may be the result of a year-to-year variance, inputs from rain events coinciding with sampling, or testing errors.

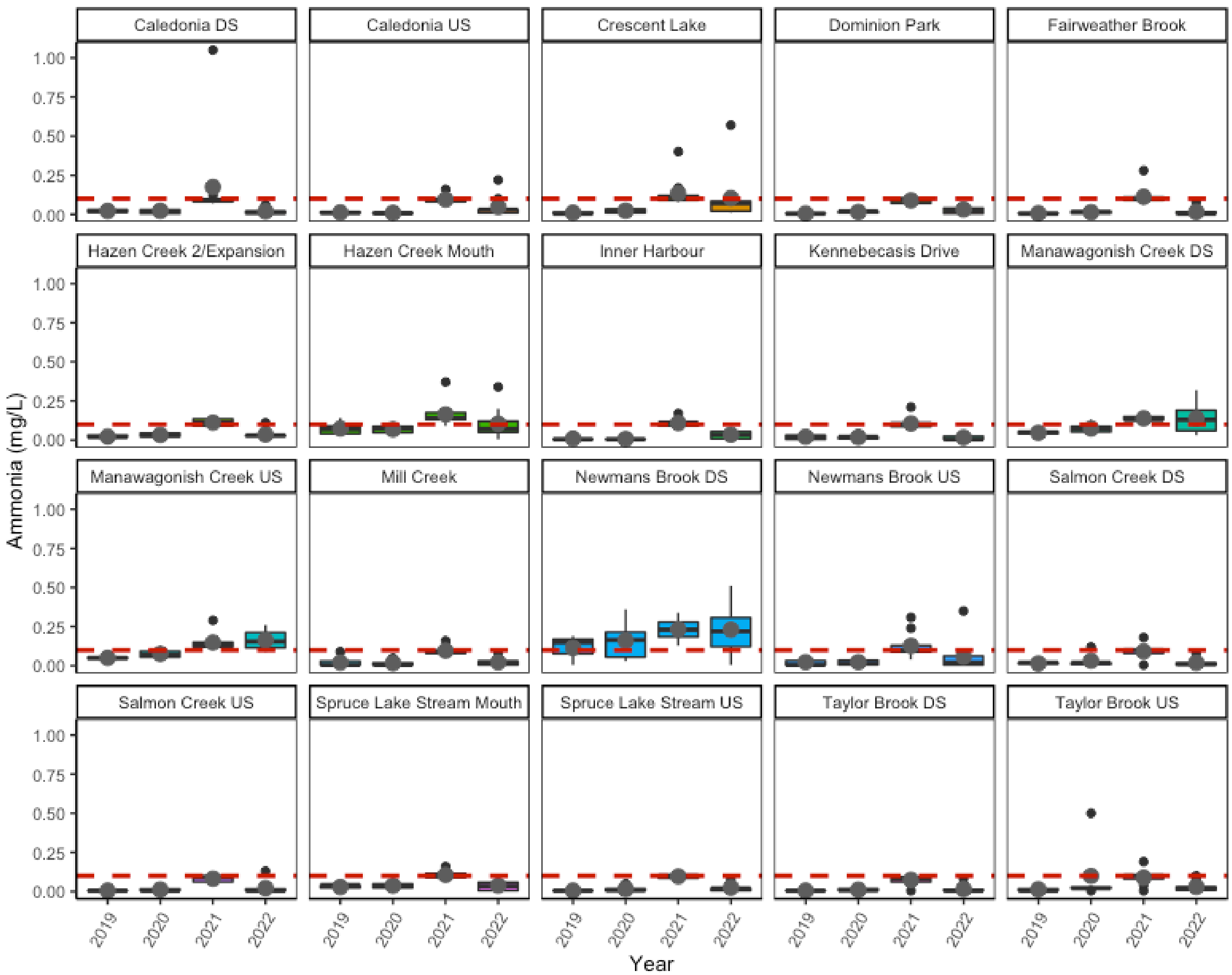

Figure 18. Ammonia concentrations (mg/L) across sites in the Greater Saint John area between 2019 and 2022, the mean values for each site are represented by grey dots, the outliers are represented by black dots, and the chosen threshold value (0.1mg/L) is represented by the dotted line.

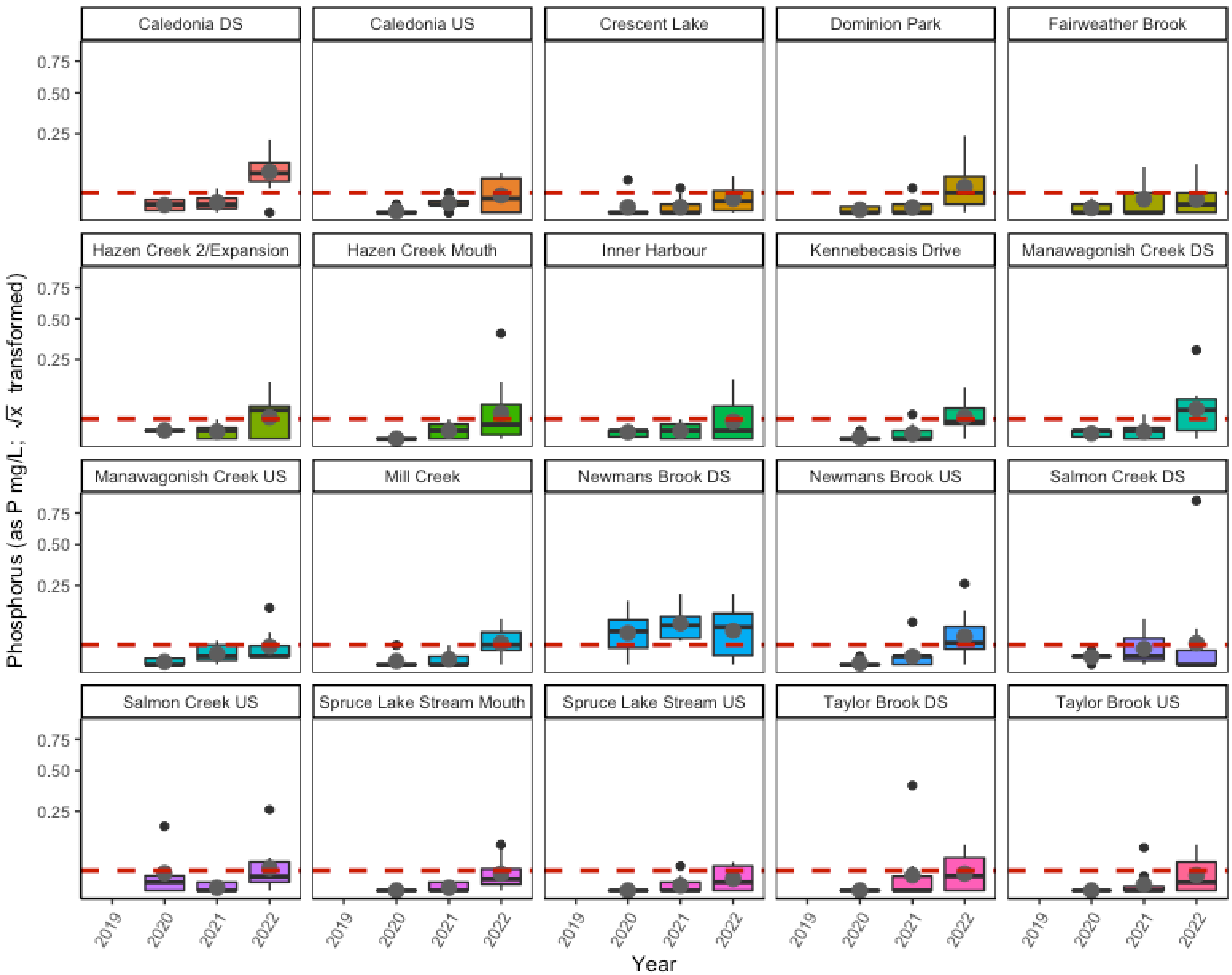

Figure 19. Orthophosphate concentrations (mg/L) as P across sites in the Greater Saint John area between 2019 and 2022. The mean values for each site are represented by grey dots, the outliers are represented by black dots, and the chosen threshold value (0.04 mg/L) is represented by the dotted line.

In 2022, *E. coli* concentrations seemed to either increase in variability, or increase in mean concentration compared to 2021, which had overall lower concentrations than in 2020 (Figure 20). This year, nine sites had an increased mean concentration overall in comparison to 2021. Single measurements of high *E. coli* concentrations may be the result of abnormally heavy rainfall events or other uncommon events, while higher temperatures and elevated nutrient inputs can allow for increased bacterial growth; these sites should be monitored closely in the following years for further instances of elevated *E. coli* concentrations.

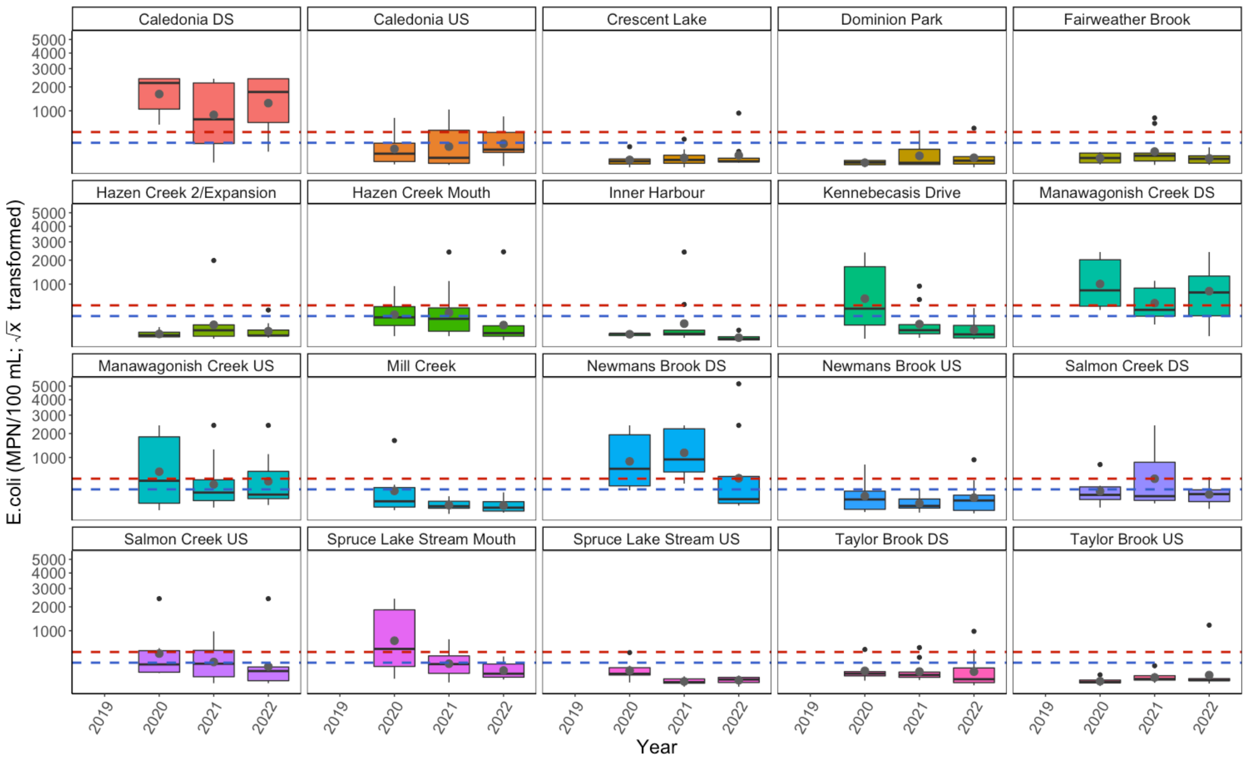

Figure 20. E. coli concentrations (MPN/100mL) across sites in the Greater Saint John area between 2020 and 2022. The mean values for each site are represented by grey dots, the black dots represent outliers, the threshold value (geometric mean concentration of 200 MPN/100 mL; minimum 5 samples) is represented by the blue dotted line, while the single-sample maximum concentration (400 MPN/100 mL) is represented by the red dotted line.

Dissolved oxygen concentrations did not vary greatly across most sites between 2019 and 2022, apart from Hazen Creek Mouth which exhibited a notable decrease in 2022 compared to previous years. Despite this, most sites (excluding Newman's Brook Downstream) continued to maintain an average dissolved oxygen concentration above the threshold (6.5 mg/L). Newman's Brook continued its historical trend with the lowest dissolved oxygen levels of all sites (Figure 21).

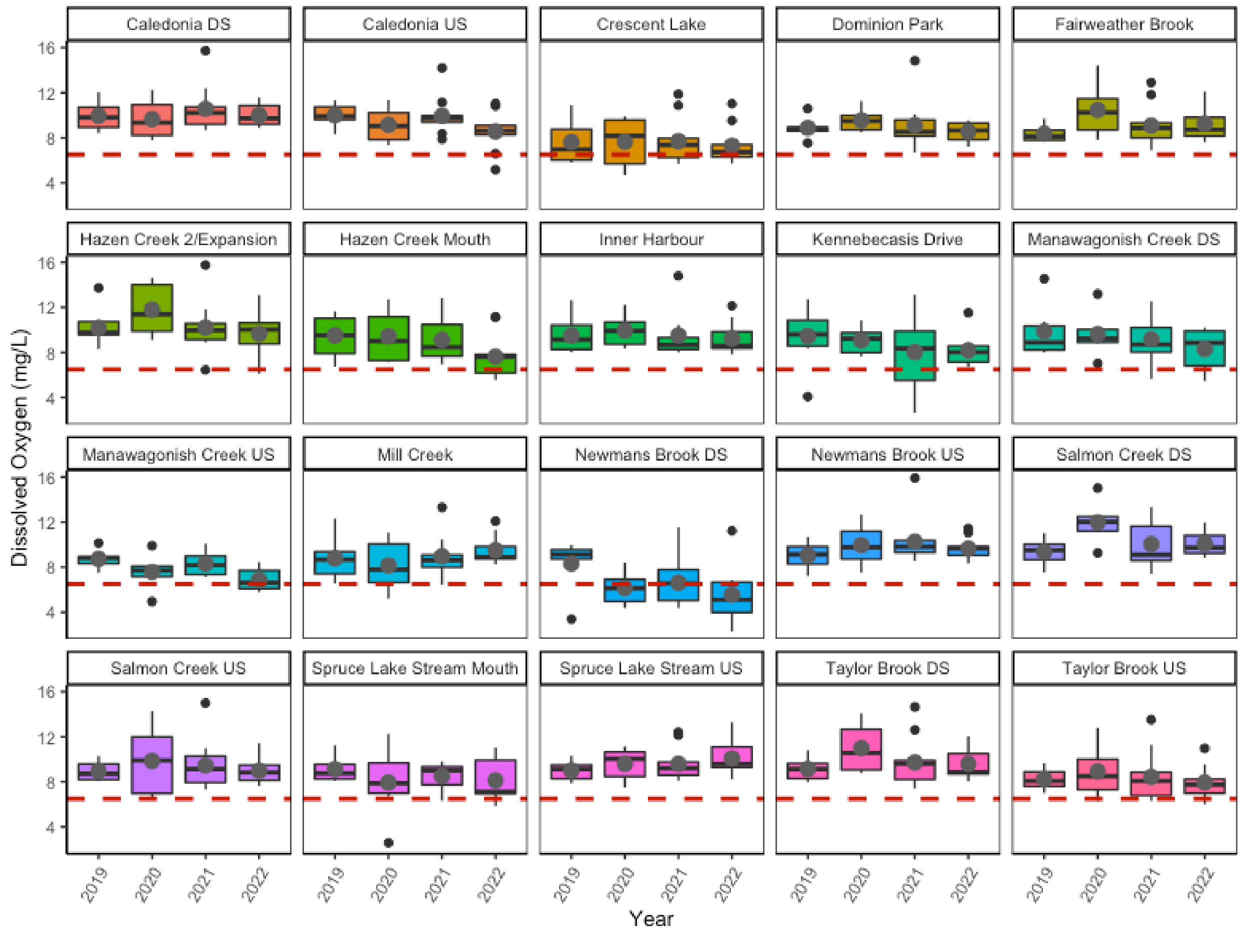

Figure 21. Dissolved oxygen (mg/L) across sites in the Greater Saint John area between 2019 to 2022, with mean concentrations represented by grey dots, outliers represented by black dots, and the chosen threshold value (6.5 mg/L) represented by the dotted line.

Water temperatures did not differ considerably between years for most sites, though overall temperatures were slightly cooler in 2022. Given the time frame of sampling (May to October/November), the temperatures measured throughout the season can vary greatly. Inner Harbour appears to be the least variable, which is likely due to its position within the Wolastoq, by far the largest watercourse sampled for this project. Sheltered areas within rivers, such as Dominion Park and Kennebecasis Drive, are among the warmest sites on average (Figure 22).

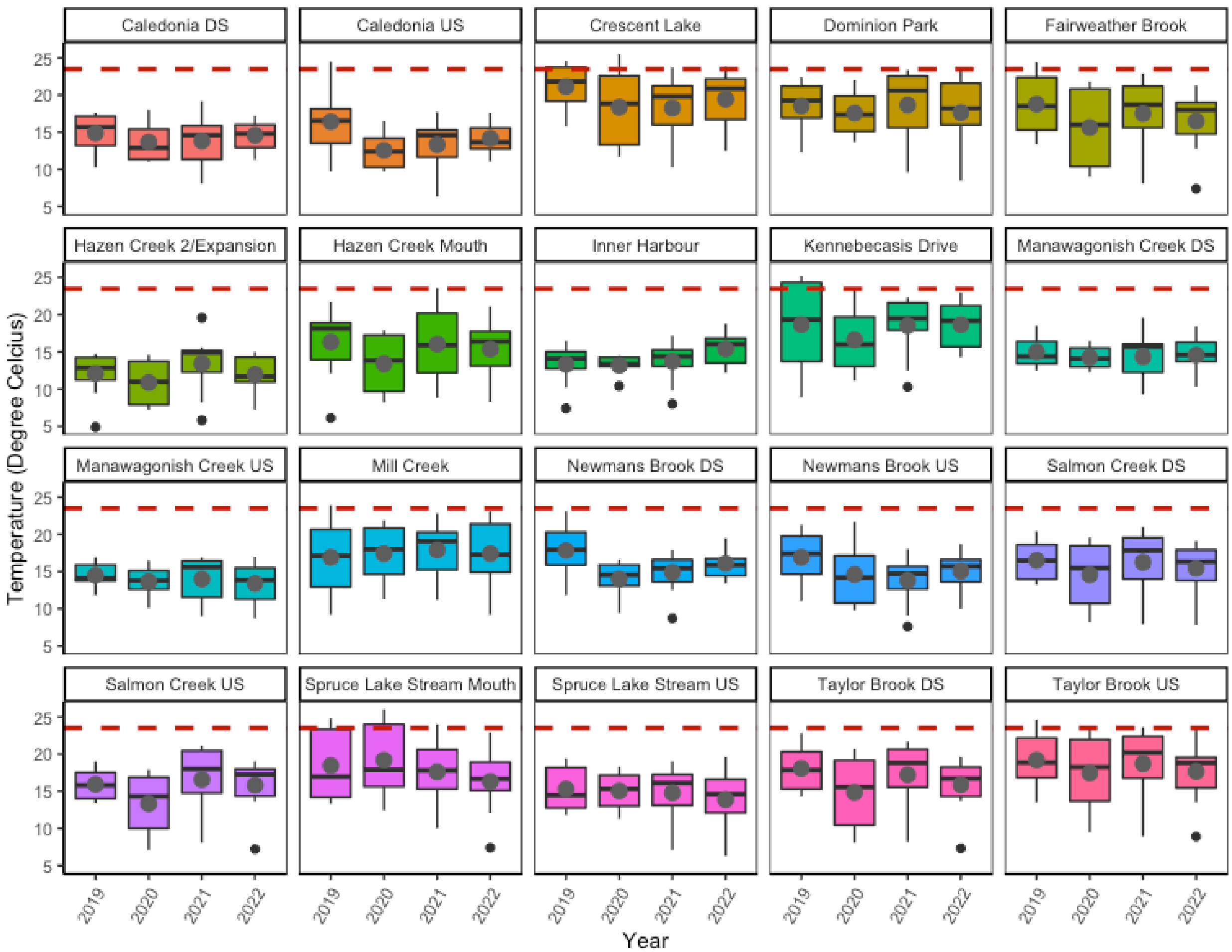

Figure 22. Water temperatures (°C) across sites in the Greater Saint John area between 2019 and 2022. The mean values for each site are represented by grey dots, with outliers presented as black dots, and the threshold value (23.5°C) is depicted by the dotted line.

IIII. Biotic Communities

In 2022, a total of 6516 individuals representing twenty-five species were caught using fyke and seine nets across eight harbour monitoring sites. Hazen Creek Nearshore had the greatest abundance in catch, followed by Spar Cove, while Little River represented the smallest proportion of the total catch (Figure 23). A breakdown of total catch by seine and total catch by fyke are presented in the following sections below.

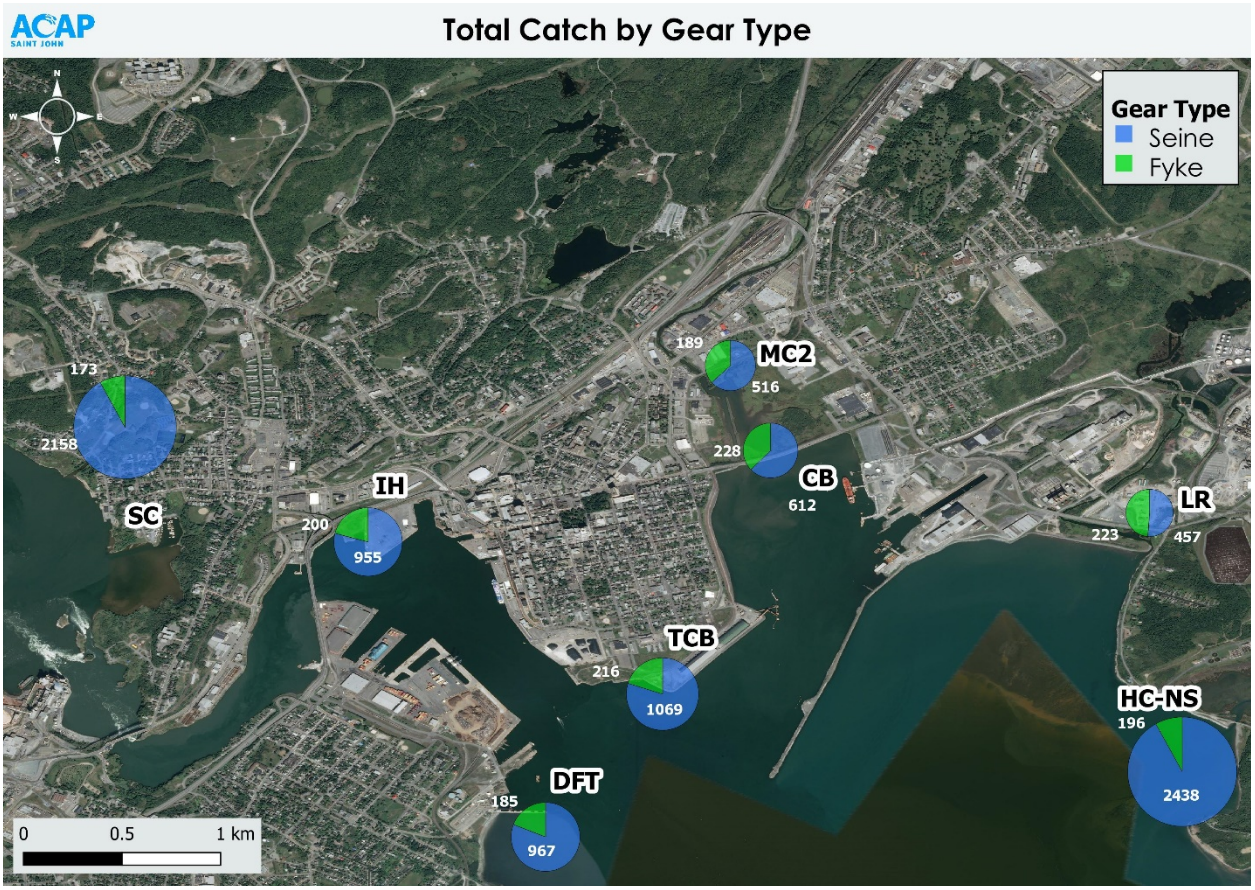

Figure 23. Total catch by gear type across the eight fishing sites in 2022.

IIII.i. Seine net method

In total, 6238 individuals across 17 species were captured with seine nets in 2022 across our 8 harbour fishing sites (Table 3). Like 2021, the most abundant species caught was the sand shrimp (*Crangon septemspinosa*; 47.4% of total catch), followed by Atlantic silverside (*Menidia menidia*; 32.8% of total catch) and Threespine stickleback (*Gasterosteus aculeatus*; 11.5% of total catch). Fewer individuals were caught in seine nets throughout 2022 (6238 individuals) in comparison to 2021 (8085 individuals); however, species abundance remained similar with 17 species represented in 2022, and 20 species within 2021.

The top two species of 2021 and 2022 (sand shrimp and Atlantic silverside) remained the same during both years. The sand shrimp population fluctuated noticeably, representing 2956 individuals (47.4% of total catch) in 2022 compared to 5239 individuals (65% of total catch) in 2021. In contrast, the Atlantic silverside increased to 2046 individuals (32.8% of total catch) in 2022 compared to 1460 individuals (18% of total catch) in 2021.

Table 3. Total number of individuals collected using seine nets in the Harbour Monitoring program between May and October 2022.

Total Seine Catch 2022	
Common Name	**Count**
Alosa sp.	24
Atlantic herring	3
Atlantic silverside	2046
Atlantic tomcod	196
Blackspotted stickleback	158
Common shiner	13
Fourspine stickleback	33
Grubby	1
Mummichog	11
Ninespine stickleback	2
Northern pipefish	2
Rainbow smelt	4
Sand shrimp	2956
Smooth flounder	11
Stickleback sp.	1
Threespine stickleback	714
Winter flounder	63
Total	6238

Hazen Creek represented the greatest proportion of the catch (33.1%), followed by Spar Cove (29% of total catch). As in previous years, Little River accounted for the smallest proportion of the catch at 1.08% of fish and invertebrates caught at this site in 2022; despite this, Little River saw an increase in abundance from 2021 (0.2% of total catch).

IIII.ii. Fyke net method

In 2022, 278 individuals representing 16 species were collected using fyke nets (Table 4). Fewer individuals were caught in 2022 compared to 2021 (393 individuals), 2020 (360 individuals) and 2019 (530 individuals). Like previous years, the Atlantic tomcod represented the largest proportion of the species caught (58.6% of the total catch) followed by the sand shrimp (8.6% of the total catch) in 2022. The site with the greatest abundance was Courtenay Bay (22% of total catch), followed by Little River (20.2% of total catch). The majority of the Atlantic tomcod were caught at Courtenay Bay, where most of the sand shrimp were caught at Marsh Creek 2 and all White suckers (*Catostomus commersonii*) captured this year were caught at Little River.

Table 4. Total number of individuals collected using fyke nets in the Harbour Monitoring program between May and October 2022.

Total Fyke Catch 2022	
Common Name	**Count**
Alosa sp.	12

American eel	3
Atlantic herring	1
Atlantic rock crab	1
Atlantic tomcod	163
Fourspine stickleback	6
Golden shiner	17
Pollock	1
Rainbow smelt	9
Sand shrimp	24
Striped bass	1
Threespine stickleback	4
White hake	2
White perch	3
White sucker	17
Winter flounder	14
Total	278

IIII.iii. Biotic community analysis

In 2022, a total of 6516 individuals representing twenty-five species were caught using fyke and seine nets across the eight harbour monitoring sites. Species richness ranged from seven (Inner Harbour) to thirteen species (Spar Cove), with the majority of sites representing ten species (Marsh Creek 2, Little River, Digby Ferry Terminal, and Tin Can Beach). Hazen Creek Nearshore had the greatest abundance followed by Spar Cove, in contrast, Little River had the lowest abundance (Figure 24). Sand shrimp were the most abundant species and dominated the proportion of catch across five sites. Similarly, Atlantic silverside represented the largest proportion of the catch at Spar Cove and were the second most abundant species in 2022. Historically, Little River has had significant industrial inputs which have likely contributed to it having the lowest species abundance of all eight sites; it is also the only site where White suckers, Common shiners, and Golden shiners were captured in 2022.

This year, fewer individuals were captured, but more species were represented across sites in comparison to previous years. Decreased abundance and low species richness may indicate that sites were not able to support the same diversity of aquatic life. These may represent year-to-year changes rather than degradation of overall habitat. New species were captured in 2022 that were not captured in previous years such as the Striped bass (*Morone saxatilis*), and the Atlantic herring (*Clupea harengus*), while the Rock gunnel (*Pholis gunnellus*) and *Peprilus sp*. Which were caught in previous years were not captured this season. The Saint John Harbour underwent significant construction this season, with annual dredging, the reconstruction of the seawall, the installation of a new breakwater and boat ramp, increased traffic throughout the port, along with sewar and stormwater system upgrades, all of which impact aquatic life at our harbour monitoring sites. Continued monitoring is recommended to determine migration and breeding patterns of aquatic life along with industrial impacts within the Saint John Harbour.

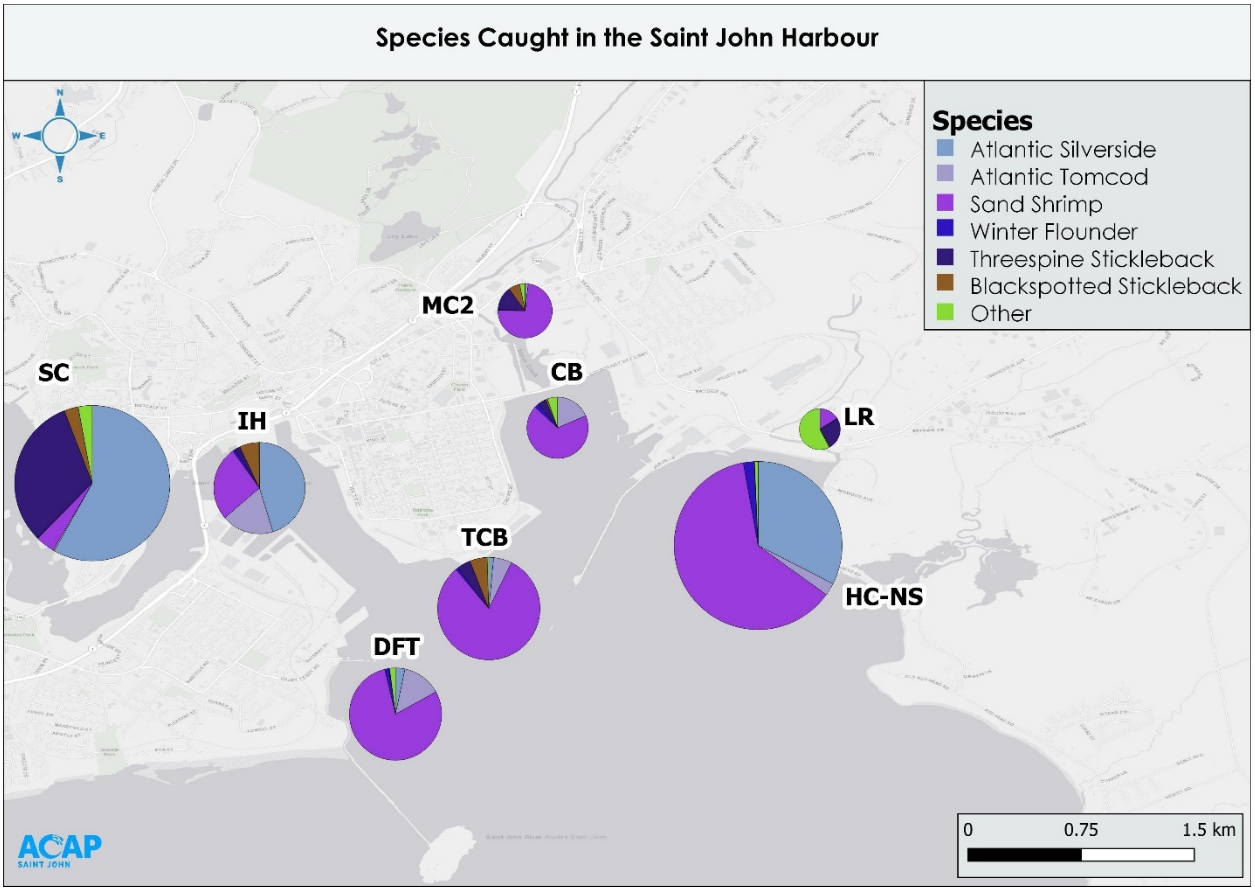

Figure 24. Top six species caught using both fyke and seine nets across all eight fishing sites in 2022. Atlantic silverside and Sand shrimp were the overall most abundant species caught.

Conclusion

Water quality monitoring was successfully conducted at 27 sites over ten watersheds within the Greater Saint John area in 2022. Given their locations in urban settings, many of these watercourses are subject to riparian degradation, stormwater inputs, and modifications to natural flow that can impact water quality. The 2022 data suggests that the majority of monitored sites had fair or marginal water quality, indicating that most sites examined have water quality that is frequently, or always threatened. No sites achieved excellent water quality and 24 of the 27 sites showed a decline in water quality. *E. coli* and nutrient concentrations were substantially higher in 2022 compared to 2021; the increased concentrations of these parameters are likely due to runoff and stormwater inputs from rainfall events during or prior to sampling occurrences, as well as potential phosphate and ammonia testing errors, or less likely, a contamination of *E. coli* samples. The issue of sewer and municipal inputs across the Greater Saint John area has been documented consistently in the past by ACAP Saint John; these issues are to be addressed in the near future as the City of Saint John prepares to modernize infrastructure. Despite the urban nature of these watercourses, the sites monitored within the Saint John and surrounding area are likely able to support healthy aquatic life given their low average temperatures, typically high dissolved oxygen, and acceptable pH and turbidity observed across most sites. Increased efforts to reduce nutrients and fecal contamination is recommended including riparian restoration/enhancement, stormwater storage, and infiltration structures to help further improve water quality.

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Appendix 1: Sampling Sites

Table 5. Characteristics of all water quality sampling sites of the project area sampled in 2021.

Site Name	Site Code	Latitude	Longitude	Site Description
Marsh Creek Upstream	MC-US	45.321517	-66.015117	Located on the downstream side of the small bridge on Glen Road near MacKay Street.
Marsh Creek Downstream	MC-DS	45.282400	-66.04946	Located immediately downstream of the access road/rail crossing containing three metal culverts just beyond the Universal Truck and Trailer parking lot.
Marsh Creek 2	MC2	45.281560	-66.048694	Located approximately 500 m upstream from Site 1, just upstream of where Dutchman's Creek enters Marsh Creek.
Marsh Creek 3	MC3	45.284844	-66.052393	Located 500 m upstream from Site 2 immediately (2 m) upstream of the former raw sewage outfall adjacent to the Universal Truck and Trailer parking lot.
Marsh Creek 4	MC4	45.288143	-66.048764	Located 500 m upstream from Site 3, immediately upstream of the former raw sewage outfall.
Marsh Creek 5	MC5	45.290998	-66.043606	Located upstream of the raw sewage outfalls, approximately 2 km from the outlet of Marsh Creek at the tide gates (Site 1). This sampling station can be found beneath the train bridge adjacent to Rothesay Avenue.
Marsh Creek 11	MC11	45.30963	-66.03402	Located approximately 2.2 km upstream of Site 5, on Ashburn Lake road, directly across from Strescon.
Hazen Creek Mouth	HC-M	45.220990	-66.015505	Located upstream of the bridge crossing along Red Head Road at the outflow of Hazen Creek into the Saint John Harbour.

Hazen Creek 2	HC2	45.275878	-65.998910	Located upstream of the culvert on Dedication Street within the industrial park.
Fairweather Brook	FB	45.378423	-65.978840	Located upstream of the McKay Highway (Highway 1) crossing next to the Dolan Road Irving gas station.
Taylors Brook Upstream	TB-US	45.374322	-65.982063	Located at the outflow of Carpenter's Lake, upstream of the McKay Highway culvert crossing on the other side of the Dolan Road Irving gas station.
Taylors Brook Downstream	TB-DS	45.382143	-65.996388	Located under the bridge crossing on Rothesay Road by Rothesay Netherwood School.
Newman's Brook Upstream	NB-US	45.296902	-66.071298	Located along Sandy Point Road, roughly 300 m above Hazen White-St. Francis School, in the above ground section of Newman's Brook.
Newman's Brook Downstream	NB-DS	45.277345	-66.089187	Located at the furthest inland point in Spar Cove, just downstream of the stormwater/Newman's Brook outflow.
Inner Harbour	IH	45.27182	-66.07439	Located underneath the Harbour Bridge just off the Harbour Passage boardwalk.
Caledonia Brook Upstream	CB-US	45.29025	-66.09449	Located just downstream of the culvert crossing Millidge Avenue, next to the Saint John Energy substation.
Caledonia Brook Downstream	CB-DS	45.29687	-66.11867	Located just upstream of the culvert crossing at 159 Ragged Point Road.
Salmon Creek Upstream	SC-US	45.42371	-65.95859	Located upstream of the culvert crossing at 7 Rafferty Court.
Salmon Creek Downstream	SC-DS	45.40077	-65.9918	Located within Salmon Creek off of Salmon Crescent where it meets Clark Road.

Spruce Lake Stream Mouth	SLS-M	45.25356	-66.14397	Located on the left-hand side of the street (Westfield Road) heading West; head down the embankment and sampling occurred near the culvert.
Spruce Lake Stream Upstream	SLS-US	45.24347	-66.15765	Located on the right-hand side of Highway 7 heading West; head down the embankment and sampling occurred near the culvert.
Crescent Lake	CL	45.30596	-66.07681	Located near the outflow of Crescent Lake found in Rockwood Park.
Manawagonish Creek Downstream	Man-DS	45.24445	-66.10737	Located off of Fairville Boulevard near the Comfort Inn parking, turn into the MelMart parking lot and park towards the end. Head down the embankment until the creek is reached.
Manawagonish Creek Upstream	Man-US	45.24355	-66.10259	Located off of Honeysuckle Drive, a weir is located on the outside of the street. Water was sampled 100 m upstream of the weir.
Dominion Park	DP	45.26889	-66.1253	Located at the Dominion Beach park.
Kennebecasis Drive	DP	45.305689	-66.095746	Located on the main stem of the Wolastoq off Kennebecasis drive. Tidal area near the outflow of Alder Brook.
Mill Creek	MIC	45.27860	-66.15567	Located off the Westfield Road across the street from the Saint John Marina.

Appendix: Average and Standard Errors of 2022 Water Quality Data

Table 6. Average and standard errors for water quality parameters collected from 27 sites across the 2022 field season.

Site ID	NH3 (mg/L)		PO4 as P (mg/L)		E. coli (MPN/100 mL)		pH		DO (mg/L)		Temp (°C)		SPC (µS/cm)		Turbidity (NTU)	
	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE	x	SE
CB-DS	0.021	0.023	0.10	0.06	1409.04	1018.17	8.31	0.31	10.0	0.98	14.60	2.06	714.90	266.77	3.42	2.98
CL	0.104	0.167	0.03	0.03	114.91	284.14	8.16	0.28	7.3	1.69	19.46	3.90	439.66	55.52	2.01	2.34
CB-US	0.058	0.072	0.04	0.04	248.30	268.79	8.01	0.51	8.56	1.75	14.18	2.23	533.81	137.38	9.25	8.04
DP	0.034	0.032	0.07	0.08	23.46	18.70	7.91	0.22	8.55	0.93	17.64	4.69	6959.13	6837.63	9.05	7.80
FB	0.018	0.028	0.03	0.04	41.26	44.71	8.19	0.52	9.27	1.46	16.49	3.99	177.07	35.57	0.90	1.06
HC2	0.035	0.025	0.05	0.05	52.87	88.12	8.14	0.53	9.67	1.95	11.95	2.76	282.16	66.05	0.96	1.09
HC-M	0.105	0.095	0.07	0.12	254.41	722.46	8.13	0.50	7.63	1.92	15.38	3.65	14992.18	9495.22	16.16	31.18
IH	0.037	0.027	0.04	0.05	8.41	12.92	7.92	0.29	843.5	2637.87	15.41	2.13	24807.30	12380.31	22.55	22.71
KD	0.019	0.024	0.05	0.04	74.71	113.77	8.22	0.44	8.19	1.40	18.65	3.30	8158.59	5607.24	7.59	8.68
MC11	0.215	0.240	0.07	0.04	426.06	747.92	8.03	0.53	8.17	1.85	15.83	4.31	404.12	82.99	15.86	25.02
MC2	0.283	0.143	0.11	0.07	1569.22	1168.66	7.96	0.46	6.44	1.71	16.77	3.92	7109.20	10279.67	10.87	4.25
MC3	0.225	0.131	0.08	0.05	947.30	567.33	7.95	0.51	6.89	1.75	16.88	4.81	854.35	747.32	7.99	3.54
MC4	0.349	0.228	0.09	0.05	1001.28	844.81	7.90	0.52	6.61	2.31	16.84	4.93	469.06	141.42	10.79	4.65
MC5	0.434	0.340	0.08	0.06	1014.70	994.36	7.92	0.53	6.65	2.04	16.19	4.45	459.23	108.73	10.12	5.26
MC-DS	0.268	0.139	0.08	0.08	3130.74	4254.34	7.90	0.56	6.75	1.97	16.36	4.21	4441.47	7399.38	8.91	3.14
MC-US	0.080	0.099	0.04	0.06	211.98	301.26	8.17	0.63	9.3	1.57	14.88	3.72	199.32	126.24	5.82	5.55
Man-DS	0.139	0.093	0.08	0.09	601.10	531.77	7.89	0.38	8.3	1.78	14.58	2.51	2015.96	3886.08	8.35	6.10
Man-US	0.164	0.061	0.04	0.05	284.09	392.99	8.25	0.25	6.88	0.99	13.41	2.81	903.28	348.74	6.04	6.92
MIC	0.023	0.027	0.05	0.03	40.80	51.07	8.06	0.25	9.50	1.34	17.41	4.62	4710.83	6877.67	2.57	1.74
NB-DS	0.257	0.142	0.09	0.07	870.02	1680.00	7.32	0.53	44.85	123.76	16.08	2.09	11992.05	9745.62	8.58	6.97
NB-US	0.063	0.111	0.07	0.08	167.43	286.00	8.13	0.30	9.65	0.99	15.06	2.49	346.22	66.49	0.72	0.83
SC-DS	0.021	0.024	0.09	0.25	158.45	144.76	8.33	0.49	10.1	1.16	15.43	3.34	677.68	107.31	1.36	1.18
SC-US	0.030	0.051	0.06	0.07	312.07	743.17	8.28	0.50	8.99	1.17	15.80	3.54	862.73	264.84	1.67	2.31

SLS-M	0.041	0.035	0.04	0.04	118.46	108.90	7.81	0.45	8.12	1.91	16.30	4.79	10631.91	22639.64	6.79	6.37
SLS-US	0.026	0.027	0.02	0.03	24.94	18.65	8.72	0.30	10.08	1.56	13.88	4.29	228.62	126.95	1.15	1.12
TB-DS	0.019	0.030	0.04	0.04	164.64	302.56	8.20	0.49	9.61	1.31	15.85	3.49	247.12	41.20	1.23	1.40
TB-US	0.034	0.033	0.04	0.04	129.71	356.19	7.97	0.48	7.94	1.38	17.65	4.14	298.57	49.07	5.13	6.14