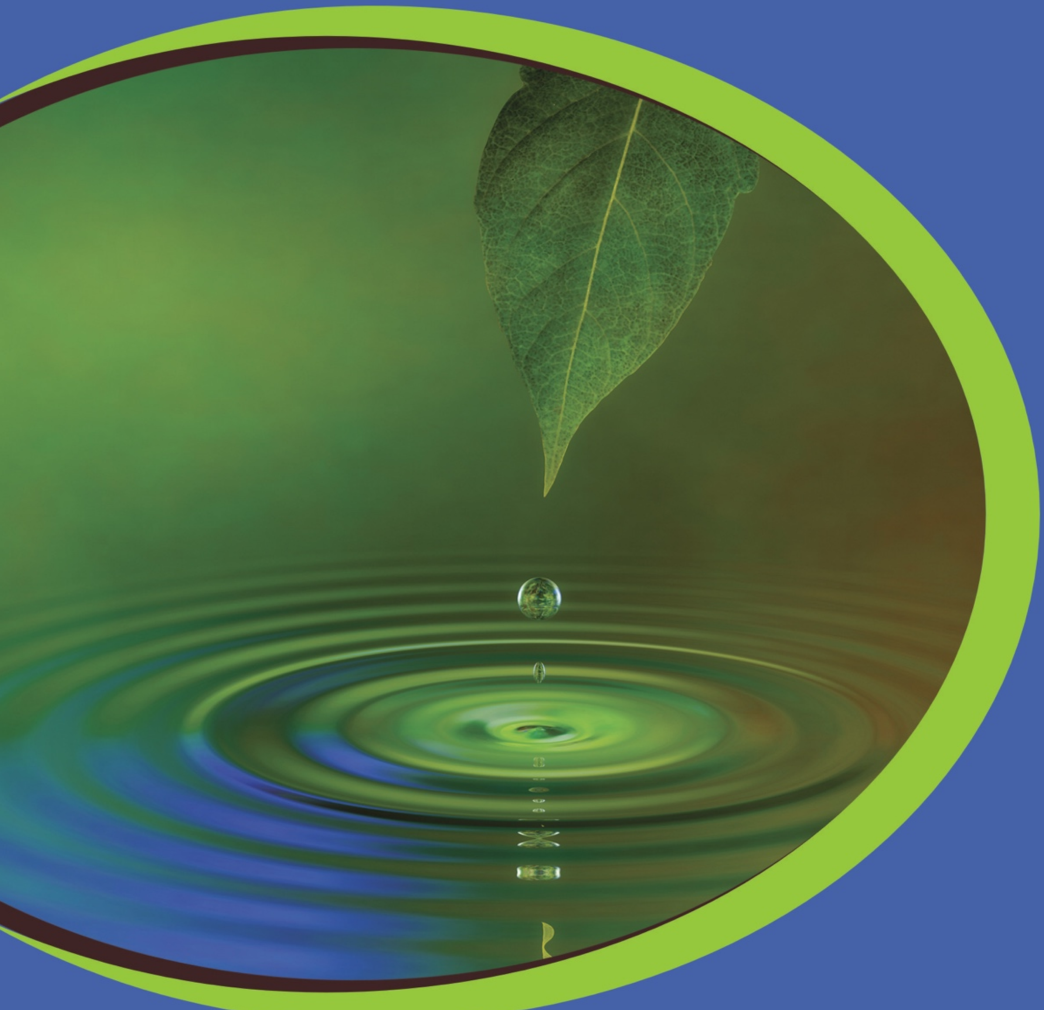
REPORT

CITIZEN SCIENCE INVESTIGATIONS OF ROAD SALT POLLUTION IN MUSKOKA: 2022 – 2024

FMW2025-02AR



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Friends of the Muskoka Watershed

The FMW Mission:

To identify environmental threats, develop practical science-based solutions, and connect with policy-makers to put these solutions in place. We also strive to cultivate an awareness of these threats and solutions through educational outreach within the Muskoka community.

We do this to ensure that those who live in, visit, and love the Muskoka watershed can continue enjoying this natural ecosystem forever.

Friends of the Muskoka Watershed

Science Driving Solutions

Citizen Science Investigations of Road Salt Pollution in Muskoka : 2022 – 2024

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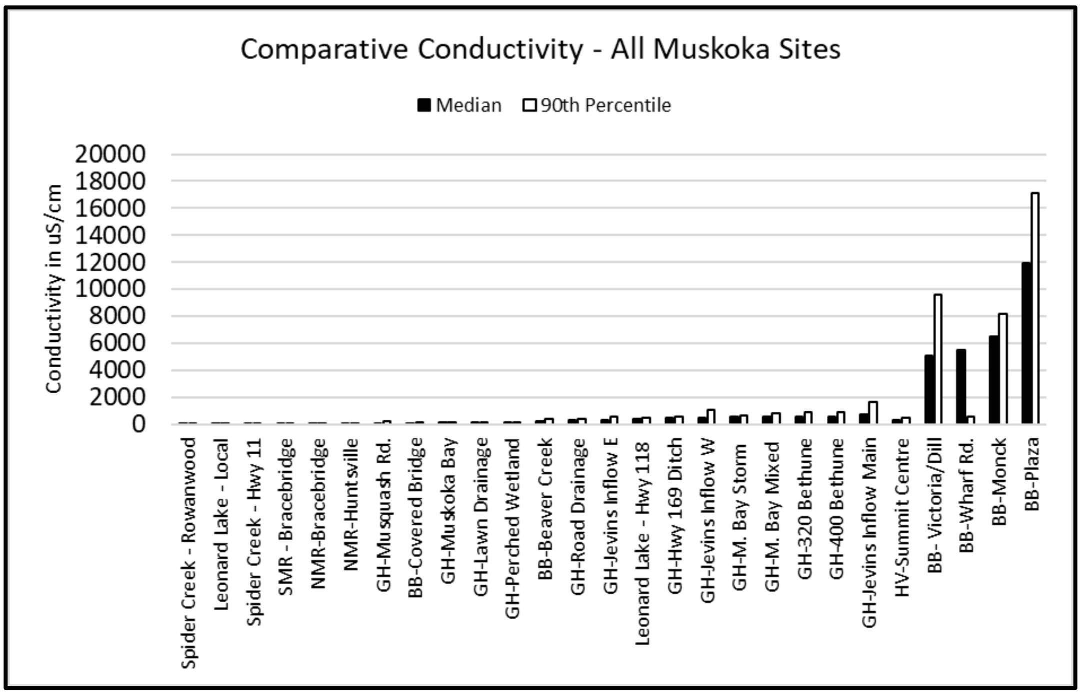
Executive Summary

Citizen Scientists and staff of the Friends of the Muskoka Watershed used measurements of conductivity (in μS/cm) as a surrogate of chloride concentration to document sources of road salt pollution to various water bodies in Muskoka. Conductivity measurements are a direct surrogate for chloride concentrations in the sampled waters and conductivity readings were converted to chloride concentrations using the formula:

Chloride (mg/L) = (0.248*Conductivity (μS/cm)) – 5.97

The reader is advised that, for simplicity, concentrations of the Cl ion in mg/L can be estimated by dividing the measurement of conductivity by 4.

These efforts included over 600 measurements made at 27 sites in Gravenhurst, Bracebridge and Huntsville from 2022 – 2024 and revealed a wide range in conductivity. The sites were categorized into 3 types of receiving waters: natural water bodies with minimal impact, urban receivers of storm water inputs and source areas of contaminant runoff.



Nine sites (Spider Creek – GH-Muskoka Bay (above)) represented natural water courses with minimal impact from urban runoff where median conductivity ranged from 22 to 90 μS/cm and 90th percentile values ranged from 28 to 178 μS/cm. Differences were likely related to soil thicknesses and small inputs of road salt but measurements in Muskoka Bay and the Muskoka River represented impacted waters.

Thirteen sites represented potential source areas where runoff from salting activities could flow to natural waters through urban drainage channels (GH-Lawn Drainage – GH Jevins Inflow Main, above). Median conductivity values ranged from 90 μS/cm for drainage from an urban lawn into Gull Lake to 687 μS/cm for the main inflow to Jevins Lake and 90th percentile values from 107 to 1613 μS/cm. The average median value for the 13 sites was 405 μS/cm and this represented an ~5-fold increase from the average median value of 54 μS/cm for the 9 natural receiving waters.

Five sites represented direct sampling of storm drains from known urban sources. The Huntsville Summit Centre runoff samples were taken in April and May, after winter activities and so are not representative of winter conditions. The four storm drains in Bracebridge, however, were sampled in winter and spring. Median conductivity values ranged from 334 to 6520 μS/cm and 90th percentiles from 470 to 8120 μS/cm. The average of the median measurements (7245 μS/cm) represents an enrichment of 125X over the median conductivity in the 9 natural water bodies.

Conductivity measurements therefore indicate substantial pollution of Muskoka's natural waters by road salt from residential, commercial and highway sources with potential for toxic effects to sensitive aquatic life. Continuous (automated) monitoring at hourly intervals is recommended in source areas (urban runoff) where concentrations may change quickly in response to storms and temperature changes.

The major concern with road salt in Muskoka waters is the potential for toxicity of the Cl ion to sensitive aquatic life. While the Canadian Water Quality Guideline for continuous, long-term exposure to Cl is 120 mg/L (CCME 2011) recent research highlights that this concentration is toxic in Muskoka's soft waters and safe exposure concentrations are <20 mg/L. The Citizen Science investigations indicate substantial pollution of Muskoka's natural waters by road salt from residential, commercial and highway sources with potential for toxic effects to sensitive aquatic life.

CCME (2011) advises that exposures of aquatic life to Cl concentrations exceeding 640 mg/L is lethal during short term ("acute") exposures, generally for 48 to 96 hours. Toxicity testing in soft waters found that 10% of four Daphnia species were immobilized at Cl concentrations ranging from 489 to 608 mg/L (average = 535 mg/L) in soft water (Ca < 2 mg/L).

- The average acute toxicity threshold of 535 mg/L Cl corresponds to a conductivity of 2180 μS/cm and so that value was adopted as a toxicity threshold for short term exposure in soft Muskoka waters.
- The safe exposure concentration threshold of 20 mg/L corresponds to a conductivity of 105 μS/cm.

The potential for chloride toxicity in the sampled waters was therefore assessed against:

- >105 μS/cm as potentially chronically toxic to sensitive aquatic life in soft water over long tern exposure
- >2180 μS/cm as potentially acutely toxic during short term exposure in soft Muskoka waters

None of the natural water bodies sampled had median values that exceeded 105 μS/cm (20 mg/L) and so Cl concentrations were not likely to threaten long or short term survival of sensitive aquatic life in these soft waters.

Median conductivity values exceeded the 105 μS/cm (20 mg/L Cl) threshold for long term exposure in 5 of the 12 Urban receivers. Of these, the main inflow to Jevins Lake represents potential aquatic habitat in which aquatic life would be threatened by Cl exposure.

Acutely lethal concentrations for soft water exposure (> 2180 μS/cm) were exceeded by median and 90th percentile concentrations in all four storm drains monitored in Bracebridge

In summary, although Cl in runoff in many of the sampling sites was high enough to be toxic, the natural receiving waters, with one exception, remained within safe levels for sensitive aquatic life. Management efforts must reduce the Cl in runoff to protect against further increases in receiving waters. Some studies show toxicity of Cl at concentrations below the 20 mg/L (105 μS/cm) threshold that was used to interpret the conductivity levels documented in our surveys. The research into the toxicity of Cl in soft waters should therefore be reviewed and summarized into a water quality objective, using formal procedures to protect the soft waters of Muskoka. Monitoring results could then be compared against a threshold of toxicity that was directly applicable to Muskoka waters.

Citizen scientists provided data that was valuable in terms of identification of multiple local sources from first hand knowledge and frequent sampling by virtue of the proximity of the volunteers to areas of concern. While frequent sampling during the winter season of road salt application (November to March) was valuable, summer sampling proved to be valuable as well, showing that enriched conductivity persisted into the summer season, even after salt applications ceased. Conductivity values dropped quickly in spring in urban drainages that were largely hardened but enriched values persisted in catchments where soils and vegetation retained chloride and released it slowly after the winter season. This pattern was shown most clearly in the Jevins Lake inflow but was evident at many sites.

This suggests that other factors besides seasonal chloride loadings, such as wetland hydrogeological dynamics, could influence chloride concentrations. There are three ways potential mechanisms for this and all are worthy of further investigation:

- First, that loadings from winter runoff are stored in wetlands and soils so that their migration into surface water is delayed and concentrations are less seasonally dependent.
- Second, that once winter loadings move into wetlands and soils, dry summer conditions concentrate chloride concentrations, such that they are higher than those measured in wetter seasons and
- Third, that other ions besides chloride that are mobilized by other wetland processes result in increased conductivity in surface waters.

Further investigation into year-round wetland dynamics and specific ion analyses would provide insights into the behaviour of road salt residues but would not alter the fact that Cl-enriched runoff is a concern year round, and that winter loadings persist into the summer.

The results presented here can help guide future efforts to reduce road salt pollution by identifying important sources of polluted runoff. Urban runoff from the storm drains that service large commercial properties, in particular, are important sources that were documented in Gravenhurst and Bracebridge. Continuous (automated) monitoring at hourly intervals is recommended in source areas (urban runoff) where concentrations may change quickly in response to storms and temperature changes.

Citizen scientist efforts should be focused on urban source terms and not on individual lakes. The spring sampling program of the District Municipality of Muskoka provides good coverage of long term trends on Cl concentration and spring sampling of chloride is providing good data on long term trends and which lakes are changing.

1.0 Introduction

In 2020, the Friends of the Muskoka Watershed (FMW) began investigations into the threats posed by the toxic chloride ion (Cl) in runoff from road salting activities on local highways. The toxicity of chloride to aquatic life and the role of road maintenance as a major contributor to road salt pollution was well established at that time. In 2001, investigations carried out by Environment Canada and Health Canada produced the "Priority Substances List Assessment Report – Road Salt" which concluded *that "Road salts that contain inorganic chloride salts .. should be considered "toxic" under CEPA*[1] *1999 because of tangible threats of serious or irreversible environmental damage"***.** As a result, the CCME[2] (2011) set a Canadian Water Quality Guideline (WQG) of 120 mg of Cl/L for the long-term protection of freshwater biota, based on a review of toxicity testing results of 28 plant and animal species. More recent research that is specific to the soft waters of Muskoka concludes that Cl concentrations should not exceed 10 mg/L of Cl for the long term protection of sensitive aquatic life (see Section 8.2).

The Environment Canada conclusions brought the threats from road salt use into scientific and public awareness. The FMW completed some initial investigations which produced a discussion paper summarizing our knowledge of the source and impacts of road salt and its relevance to Muskoka. These investigations were summarized in the form of "10 Questions About Road Salt" (Yan, 2020). The ten questions, and their answers, are presented in Appendix 1 and are not elaborated in this report. The reader is referred to the complete original document for further details[3].

Since 2020, much research has been completed and salinization of surface waters from road salt and other activities is now recognized as a global threat to biodiversity. The documented impacts of rising Cl concentrations on aquatic life, the observed increasing use of road salts and predicted increases in a changing climate, the lack of cost effective alternatives, the cost and difficulty of source treatment or freshwater remediation and the persistence of Cl as a pollutant in soils combine to encourage the need to reduce the use of road salt through adoption of Best Management Practices to maintain road safety (Hintz et. al., 2021).

A detailed assessment of the status and threat from road salt in Muskoka was first summarized in the Muskoka Watershed Council's (MWC[4]) 2023 "Muskoka Watershed Report Card" MWC, 2023). Lake monitoring data collected by the District Municipality of Muskoka and the Ontario Ministry of Environment Conservation and Parks (MECP) was used to assess the status of chloride in 274 of Muskoka's lakes. The 2023 Watershed Report Card concluded that

> *"Road salt use has generated substantial increases in the concentrations of chloride, a toxic pollutant, in Muskoka's lakes. Cl concentrations exceeded 1 mg/L and were therefore considered enriched in 193 of 274 (70%) lakes. Concentrations exceeded 10 mg/L and so*

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1 CEPA – Canadian Environmental Protection Act

2 CCME - Canadian Council of Ministers of the Environment, a joint federal and provincial body charged with, among other responsibilities, establishing safe levels for various pollutants in Canadian waters.

3 https://fotmw.org/fomw-publications/the-road-salt-threat-to-muskoka-lakes-answering-10-key-environmental-questions/

4 The Muskoka Watershed Council (MWC) is an advisory body of The District Municipality of Muskoka (DMM) and the Muskoka community that makes recommendations to municipal governments, decision-makers, managers and the general public on ways to protect and restore the resources of the area's watersheds.It is a organization separate from the Friends of the Muskoka Watershed but sharing similar goals https://www.muskokawatershed.org/about-us/

were considered potentially harmful in 68 lakes (25%). In 36 of these, chloride concentrations exceeded 20 mg/L. The average chloride concentrations measured in 81 (29%) lakes have increased in the past five years, exceed 70 mg/L in 3 lakes and exceed 115 mg/L in one lake (Jevins Lake in Gravenhurst).

Further investigation at a lake-specific level is required to determine the role of road density on chloride in Muskoka lakes."

They also found a significant ($p<0.015$) relationship between road density and the percentage of lakes in a quaternary watershed in which chloride had increased in 2018-2022 compared to historic data.

The report recommended that:

"MWC should therefore support existing initiatives to monitor and document road salt sources and work with provincial and municipal governments and the public to reduce and optimize road salt application in Muskoka by government, businesses, and individuals.

In 2022, The Friends of the Muskoka Watershed (FMW) began an investigation into the sources of chloride contamination in local water bodies. The investigations focused on sources to Jevins Lake and Muskoka Bay of Lake Muskoka in Gravenhurst as monitoring of both water bodies over the short term (2004 – 2022 for Jevins Lake, Figure 1) and long-term (1970 – 2022) for Gravenhurst Bay (Figure 2) showed steady increases in chloride from one year to the next.

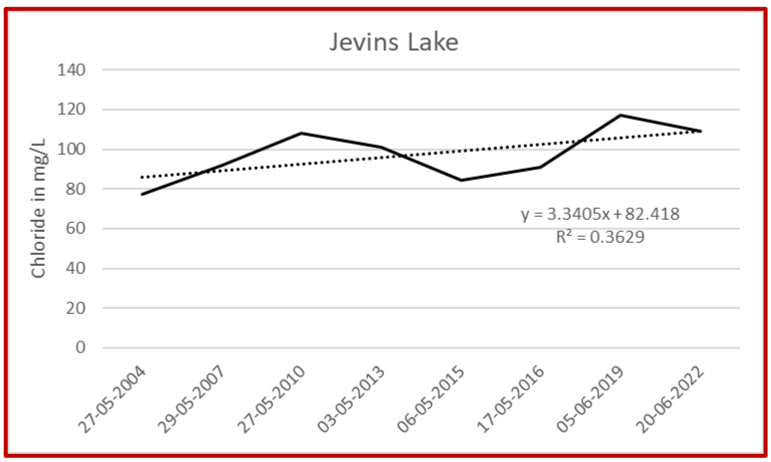

Figure 1. Increasing Cl in Jevins Lake 2004 - 2022. Data from District Municipality of

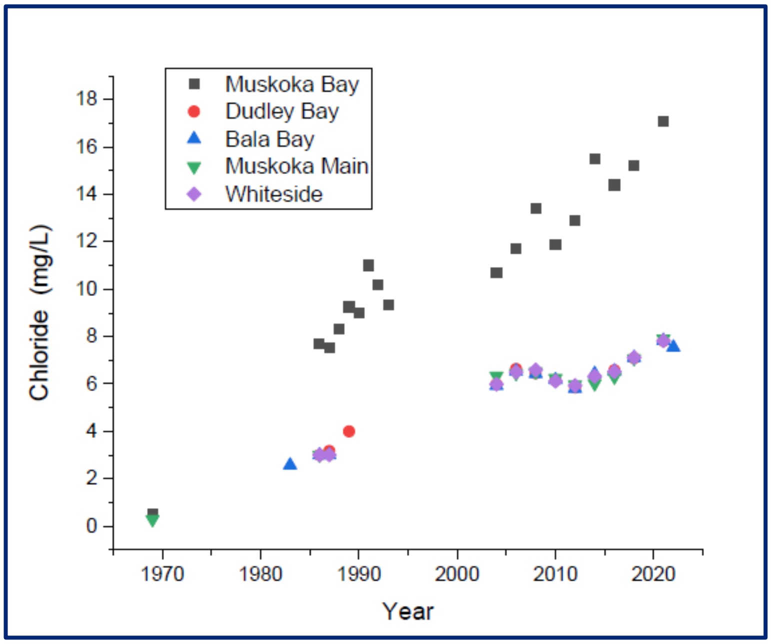

Figure 2. Increasing Cl in Muskoka Bay of Lake Muskoka 191969 - 2022.

Jevins Lake showed the highest Cl concentrations measured in Muskoka while Muskoka Bay represented an iconic Muskoka water body in which concentrations had risen by 35X over the period of record. Muskoka Bay data was taken from the records of the Ontario Ministry of the Environment (1970 – 1994) and the District Municipality of Muskoka (2004-2022).

In 2023 the Gull and Silver Lakes Residents Association joined the FMW in their efforts by a) engaging Gravenhurst Town Council to formally acknowledge the threat posed by road salt[5] and b) initiating their own monitoring program with the assistance of FMW (see Chapter 3). The Gull Lake watershed has substantial residential and road development and, as a result, recent measurements of Cl from the District Municipality of Muskoka averaged ~ 18 mg/L in Gull Lake.

5 In 2023 the Gull and Silver Lakes Residents Association and FMW presented a delegation on road salt to the Gravenhurst Municipal Council. As a result of their efforts, on Tuesday July 18 2023 Gravenhurst Council Passed the following resolution:

“Whereas, Environment and Climate Change Canada has declared road salt "toxic" under the Canadian Environmental Protection Act because of tangible threats of serious or irreversible environmental damage, the Town of Gravenhurst commits to the reduction of the use of road salt as much as possible while maintaining safety on roads and sidewalks.”

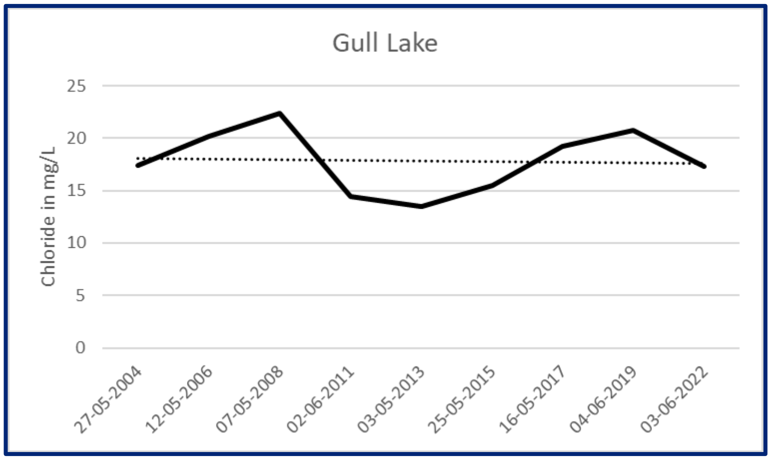

Figure 3. Cl concentrations in Gull Lake : 2004 - 2022.

Engaging “citizen scientists” was very useful to document the sources and magnitude of road salt runoff. Citizen Scientists were able to observe and document accessible sources of runoff in their neighbourhoods. Their measurements provided better spatial coverage and more frequent measurements than what the FMW could achieve on their own. Monitoring programs were carried out in 2023 and 2024 at a variety of sites in Gravenhurst. FMW staff monitored sites in Gravenhurst (Chapter 3), Bracebridge (Chapters 4 and 5) and Huntsville (Chapter 6) in 2023-2024 to build a record of runoff sources and their magnitude to inform future efforts to reduce road salt pollution. The Leonard Lake Stakeholders Association (Bracebridge) monitored chloride in road runoff in 2023 and 2024 as an independent investigation and provided their results to FMW for inclusion in this report (Chapter 7).

2.0 Methods

Direct measurements of chloride in water can be made by submitting samples of runoff to a commercial or government laboratory for analysis. Such laboratory analyses are either costly (commercial lab) or available only in limited quantities (government lab) to non-governmental organizations. Chloride can, however, be estimated with good accuracy by measuring conductivity of runoff in the field with a portable conductivity meter, using an established relationship between chloride and conductivity based on laboratory measurements. Laboratory measurements of chloride and conductivity data from the District Municipality of Muskoka's lake monitoring program were therefore used to develop the needed predictive relationship (Figure 4) for the use of citizen scientists.

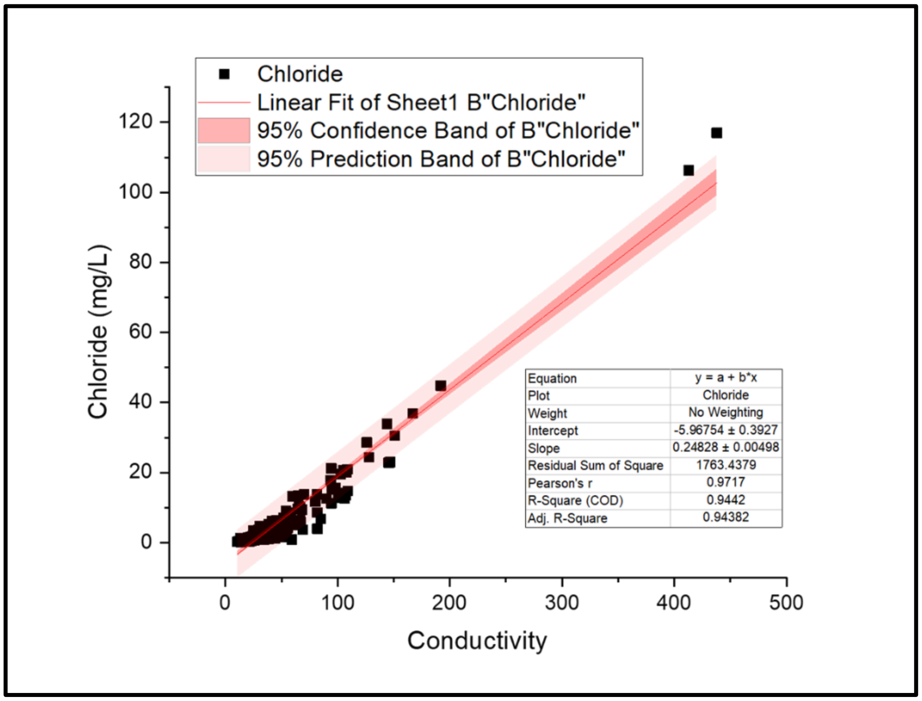

Figure 4. Conductivity/chloride relationship for soft-water lakes in Muskoka.

The relationship confirms that conductivity (measured in microSiemens/cm (μS/cm)) provides a good estimate of chloride and that chloride (in mg/L) can be reliably estimated by the equation:

Chloride = (0.248*Conductivity) – 5.97[6]

Citizen science projects measuring urban runoff in the City of Ottawa (Ottawa Riverkeeper 2020) also found a similar relationship between chloride and conductivity but at higher concentrations (Figure 5). Although neither regression equation nor statistical significance was given, Figure 5 shows that 4000 μS/cm corresponds to ~1000 mg/L of Cl and so a 4:1 ratio of conductivity (in (μS/cm) to Cl (in mg/L) appears to allow a useful approximation.

Samples were also taken from 13 Gravenhurst sites and submitted to the MECP laboratories to test the conductivity vs Cl relationship for specific source areas. Results are presented and discussed in Appendix 2.

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[6] Throughout this report, all estimates of Chloride concentrations were made by converting conductivity measurements using this equation.

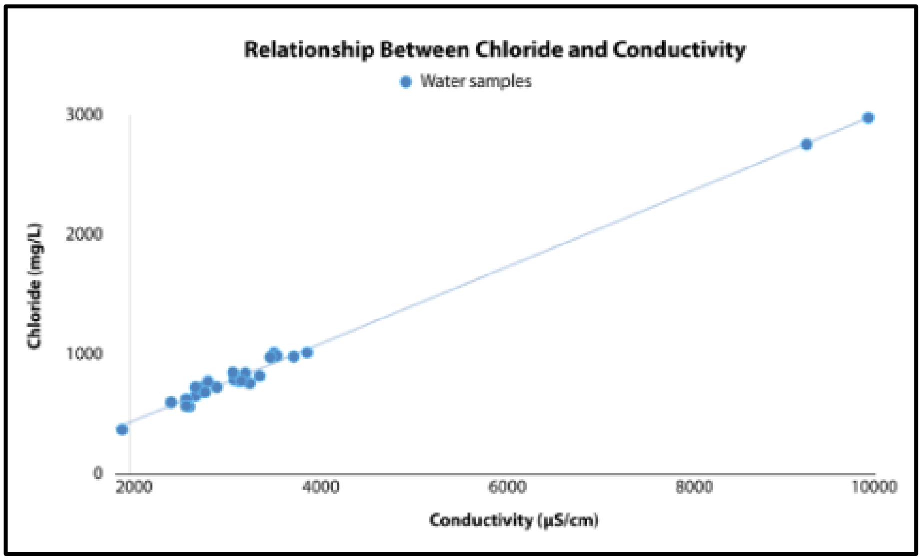

Figure 5. Conductivity : chloride relationship developed for urban runoff by Ottawa Riverkeeper (2020) project.

We also know that sodium chloride (road salt) is responsible for the elevation of Cl concentrations in Muskoka lakes, as provided by the following elaboration from FMW (2020).

> *There are no natural local marine salt deposits in Muskoka, and the lakes with elevated Cl levels all have major winter-maintained highways in their immediate catchments. Road salt is therefore the only logical salt source. The relationship of Na with Cl is almost perfect (Figure 6 left). The r² value of the regression of Na on Cl indicates that 99.5% of variability in Na levels among lakes is attributable to Cl, and the 0.983 value of the slope of this regression indicates a virtually 1:1 relationship. Thus, a unit increase in Cl is accompanied by a unit increase in Na. The intercept of the regression approaches 0 indicating that there is no missing cation needed to account for residual Cl. In contrast, the relationship between calcium (Ca) and Cl concentrations in Muskoka's lakes is very weak (Figure 6 right) Therefore, high Cl values in Muskoka lakes owe their high Cl to NaCl, not to CaCl2.*

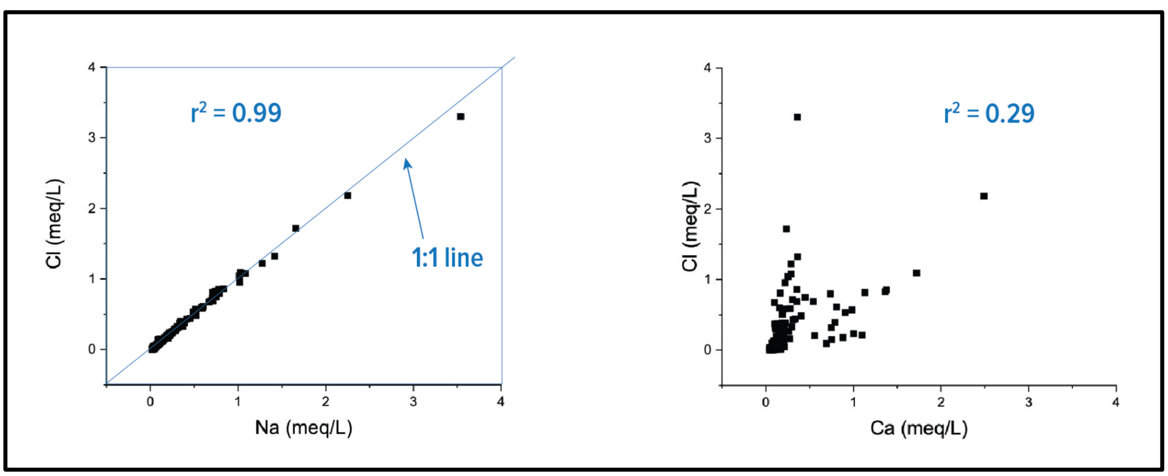

Figure 6. the strong relationship between Na and Cl (left), compared with that of Ca and Cl (right) confirms that road salt is the dominant source of Cl in Muskoka's lakes (FMW 2020).

Portable conductivity meters (Photo 1) were therefore used to measure conductivity in urban runoff by citizen scientists and FMW volunteers in Gravenhurst, Bracebridge and Huntsville in 2022, 2023 and 2024. Monitoring sites were selected by FMW and citizen scientists and the rationale for site selection is documented in each of chapters 3 to 6. In general, sites were selected to investigate specific potential sources of road salt runoff and which were safely accessible. Samples were collected in winter (November – March) and non-winter periods when open water was present. Volunteers were encouraged to sample a) during periods of runoff and after events such as snow or ice storms in which road salt applications would be expected and b) between events to assess difference in conductivity between event and non-event sampling.

Photo 1 Portable conductivity meter used for runoff measurements. Photo by Joanne Smith.

Monitoring efforts were focused on specific areas of concern in Gravenhurst and Bracebridge and on initial reconnaissance in Huntsville. Gravenhurst efforts addressed salt inputs to Jevins Lake, Muskoka Bay and Gull Lake (Ch. 3). In Bracebridge (Ch.4), efforts were focused on commercial runoff to Beaver Creek, a tributary of the Muskoka River, two sites on the Muskoka River and two sites draining residential areas. The Spider Creek catchment (Huntsville) was sampled at two locations (Ch. 5) and the Muskoka River and one institutional site were sampled in Huntsville (Ch.6).

	Site	Name	Catchment Characteristic	Monitoring Period	No. Observations
Gravenhurst Sites	S1	Jevins Lake Inflow-DS Hwy. 11	Commercial, Residential a	210824-221025	16
	S2	Jevins Lake Inflow-US Hwy. 11	Commercial and Resident	210824-221025	15
	S3	Urban Wetland Drainage	Commercial and Resident	210824-221025	16
	S4	Urban Perched Wetland	Urban Parkland Reference	210824-240904	49
	S5	Urban Drainage Ditch	Commercial Runoff	210824-240904	53
	S6	Muskoka Wharf Storm Drain	Residential Runoff	210824-221025	15
	S7	Muskoka Bay at Steamship Docks	Muskoka Bay Receiver	210824-221025	13
	S8	Runoff to Muskoka Bay	Residential Runoff	210824-221025	15
	S9	Reference Site - Musquash Road	Forest and Wetland Draina	210824-221025	16
	S10	West Gravenhurst Runoff	Highway, Residential and F	210824-221025	16
	S11	320 Bethune Drive	Commercial PLaza Runoff	230131-240331	53
	S12	400 Bethune Drive	Mixed Residential and Con	230131-240326	56
	S13	Phillip St. Residential Culvert	Residential Runoff	230207-240410	14
	S14	Phi;llip St. Shoreline	Residential Runoff	230414-240409	22
Bracebridge Sites	BB1	North Muskoka River at Wilsons Falls	Watershed Characteristics	230127-240131	18
	BB2	South Muskoka River at Confluence	Watershed Characteristics	230127-240131	17
	BB3	Victoria and Dill St. Urban Drainage	Residential Drainage	230127-240131	18
	BB4	Wharf Road Urban Drainage	Residential and Commerc	230127-240131	18
	BC1	Beaver Creek at Covered Bridge	Upstream Reference - Low	230127-240131	18
	BC2	Storm Drain from Commercial Area	Storm Runoff from Large P	230127-240131	18
	BC3	Storm Drain from Mixed Use	Storm Runoff from Road, C	230127-240131	18
	BC4	Beaver Creek at Gainsborough Road	Downstream Impact at Mu	230127-240924	68
Huntsville Sites	HV1	North Muskoka River at Center St.	Watershed Characteristics	230305-230320	8
	HV2	Summit Centre Drainage	Storm Runoff from Instituti	230321-230414	8
	SC1	Spider Creek - Upper Watershed	Watershed Characteristics	230413-230512	14
	SC2	Spider Creek - Lower Watershed	Storm Runoff from Instituti	230413-230512	14
		Total Observations			**606**

Table 1 Summary of sampling effort 2021-2024.

A total of 22 sites were sampled from 2021 to 2024 (Table 1). Details on site location and results are provided in each chapter and a summary of conclusions and recommendations for all sites is presented in Ch. 8.

3.0 Results – Gravenhurst Scoping Study

Sampling conducted by:

Friends of the Muskoka Watershed – Neil Hutchinson

Gull and Silver Lakes Residents Association – Joanne and Clarke Smith, Brian Ochab, Sandy Cairns

3.1 Background

Data from the District Municipality of Muskoka show high or increasing chloride concentrations in three Gravenhurst water bodies: Muskoka Bay of Lake Muskoka, Jevins Lake and Gull Lake (see Chapter 2). Between August 2021 and October 2022, Friends of the Muskoka Watershed (FMW) surveyed 13 sites in Gravenhurst to assess the range of runoff quality from different sources to Muskoka Bay and Jevins Lake and to select sites for more intensive monitoring by citizen scientists in the future. In the winter of 2023-2024 citizen science volunteers from the Gull and Silver Lakes Residents Association took over monitoring of several of the FMW sites and added several sites of their own to assess runoff quality into Gull Lake.

3.2 Site Description Overview

A total of 14 monitoring sites were identified and sampled between August of 2021 and April of 2023 to document road salt inputs into Jevins Lake, Muskoka Bay and Gull Lake (Table 2). These sites captured runoff from substantial portions of urbanized and non-urbanized catchments in Gravenhurst (Figure 7). Note that an additional site (SW6) was monitored by FMW staff but is not included in this summary as no useful additional information was obtained.

Site	Name	Catchment Characteristics	Monitoring Period	No. Observations
S1	Jevins Lake Inflow-DS Hwy. 11	Commercial, Residential and Highway Runoff	210824-221025	16
S2	Jevins Lake Inflow-US Hwy. 11	Commercial and Residential Runoff	210824-221025	15
S3	Urban Wetland Drainage	Commercial and Residential Runoff	210824-221025	16
S4	Urban Perched Wetland	Urban Parkland Reference	210824-240904	49
S5	Urban Drainage Ditch	Commercial Runoff	210824-240904	53
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S9	Reference Site - Musquash Road	Forest and Wetland Drainage	210824-221025	16
S10	West Gravenhurst Runoff	Highway, Residential and Forest Runoff	210824-221025	16
S11	320 Bethune Drive	Commercial PLaza Runoff	230131-240331	53
S12	400 Bethune Drive	Mixed Residential and Commercial Runoff	230131-240326	56
S13	Phillip St. Residential Culvert	Residential Runoff	230207-240410	14
S14	Phillip St. Shoreline	Residential Runoff	230414-240409	22

Table 2. List of Gravenhurst monitoring sites 2021-2024.

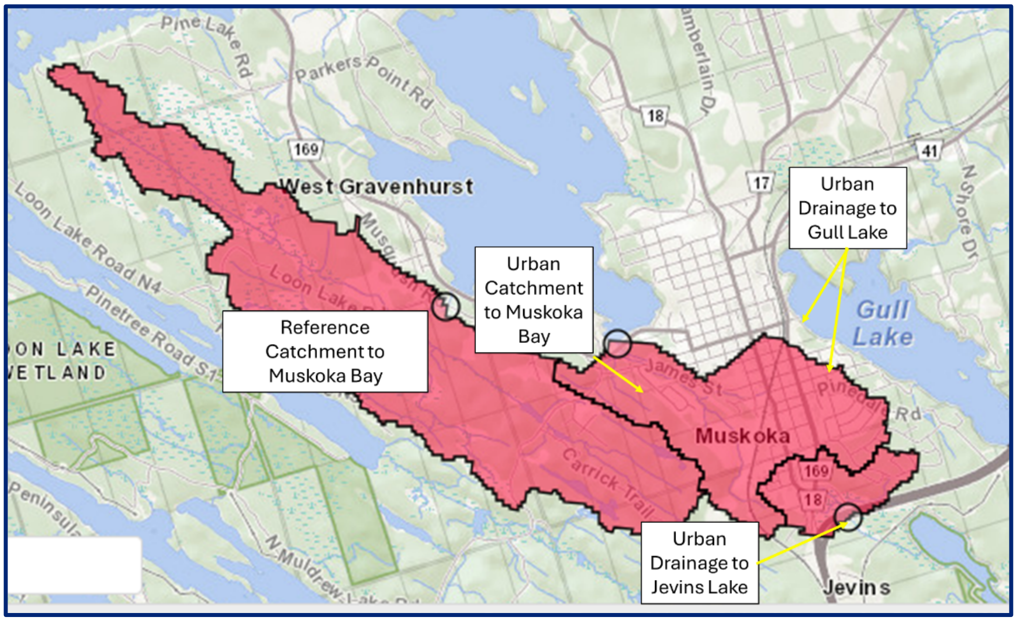

Figure 7. Monitored catchments to Muskoka Bay, Jevins Lake and Gull Lake in Gravenhurst.

3.2.1 Jevins Lake Sites

The inflow to Jevins Lake was a major focus as Jevins Lake has the highest chloride levels (~110 mg/L) measured in any of the 274 lakes monitored by the District Municipality of Muskoka and concentrations are trending upwards (Figure 1). The main inflow to Jevins Lake originates in the southern urban area of Gravenhurst which is dominated by commercial land use. Runoff from these areas flows through a large wetland, under Highway 11 and into Jevins Lake (Figure 8). Jevins Lake therefore receives runoff from commercial areas and a major highway. Runoff quality was monitored at five locations (Figure 9) to assess changes and concentrations:

SW1. Jevins Lake inflow, downstream of Hwy. 11
SW2. Jevins Lake inflow – wetland drainage upstream of Hwy 11
SW3. Wetland drainage at Hwy. 11 at southbound exit to Gravenhurst
SW4. Perched Wetland in Kinsman Park – Reference site with no direct runoff
SW5. Ditch alongside Muskoka Road 18 at Kinsman Park receiving Commercial Urban runoff

The total catchment area of 52.5 ha and land uses (Table 3) were determined using the Ontario Watershed Information Tool[7]. The eastern wetland catchment of 19.2 ha was made up of 39% forested areas and 59 % largely residential Community Infrastructure. The western wetland catchment of 33.3 ha was made up of 81% Community Infrastructure (mostly commercial use) and 19% undisturbed forest and wetland areas.

[7] https://www.lioapplications.lrc.gov.on.ca/OWIT/index.html?viewer=OWIT.OWIT&locale=en-CA

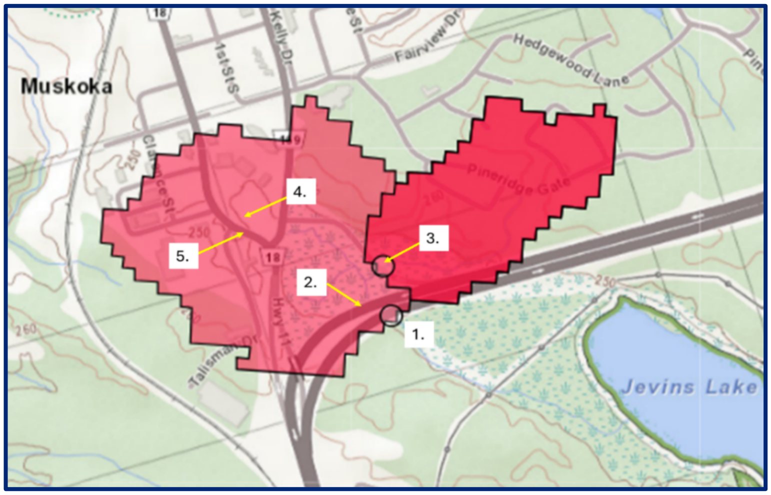

Figure 8. Jevins inflow subcatchments and sampling points. Western subcatchment is light red, eastern subcatchment is dark red.

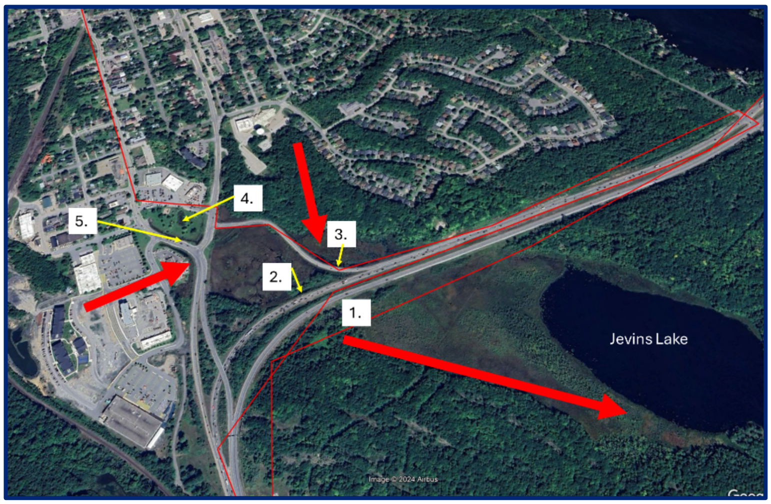

Figure 9. Jevins Lake catchment sampling points. Yellow arrows show sample points, red arrows show general flow path of runoff.

Jevins Inflow at Hwy 11	Jevins Total		Wetland East		Wetland West	
Land Cover Type	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**	**Area (ha)**	**Percent**
Clear Open Water	0.0	0.0%	0.0	0.0%	0.0	0.0%
Bog	0.0	0.0%	0.0	0.0%	0.0	0.0%
Sparse Treed	6.8	12.9%	2.0	10.4%	4.8	14.3%
Deciduous Treed	6.2	11.8%	5.4	28.1%	0.8	2.3%
Mixed Treed	1.2	2.4%	0.1	0.4%	1.2	3.5%
Coniferous Treed	0.0	0.0%	0.0	0.0%	0.0	0.0%
Bedrock	0.0	0.0%	0.0	0.0%	0.0	0.0%
Undisturbed Total	14.2	27.0%	7.5	38.9%	6.7	20.2%
Sand/Gravel/Mine Tailings/Extraction	0.0	0.0%	0.0	0.0%	0.0	0.0%
Community/Infrastructure	38.3	73.0%	11.4	59.3%	27.0	80.9%
Agriculture and Undifferentiated Rural Land Use	0.0	0.0%	0.0	0.0%	0.0	0.0%
Disturbed Total	38.3	73.0%	11.4	59.3%	27.0	80.9%
Total	52.5	100.0%	19.2	100.0%	33.3	100.0%

Table 3. Land use areas for Jevins Lake catchments.

The two urban sites in the south end of Gravenhurst were sampled as source terms to the wetlands and Jevins Lake (Photo 2). Site SW4 was a cattail wetland located in the Kinsman Park. It had no direct connection to surface water and was assumed to be fed only by precipitation and groundwater and so represented little influence of urban sources. The surrounding parking lots were paved and serviced by storm sewers and so road salts from those sources had no interaction with the wetland. Site SW5 was a ditch adjacent to Muskoka Road 18 and Kinsman Park. It received runoff from the large commercial areas, upstream on the other side of Muskoka Road 18. Both sites were initially sampled by FMW in 2021-2022 and then by citizen scientists Joanne and Clarke Smith in 2023-2024 (Table 2).

Photo 2. Urban source sites to Jevins Lake in south Gravenhurst.

3.2.2 Jevins Lake Results

Jevins Lake Inflow

The Jevins Lake inflow was monitored at three points (Figure 10). Conductivity results from the Upstream Exit Ramp (Site 3) represented drainage from mixed residential and wetland areas in the east catchment. This runoff was added to runoff from the west catchment (Site 2) that drained the large commercial areas and represented the “net” input of chloride from south Gravenhurst. Measurements made at Site 1 showed the combined influence of urban runoff and runoff from Hwy. 11 into Jevins Lake.

Conductivity measurements increased by ~40% as runoff from the mixed land use in the east catchment (Site 3, median = 334 μS/cm, Table 4) mixed with that from the commercial land uses (Site 2,median = 460 μS/cm) and by another ~50% when runoff from Hwy. 11 entered the Jevins Lake inflow at Site 1 (median = 687 μS/cm). Values representing the 75thand 90th percentiles and maximum values were approximately tripled between the east catchment and the main inflow to Jevins Lake. The 10th percentile value of conductivity in the Jevins Lake inflow (Site 1) corresponds to ~ 126 mg/L of chloride. This means that the Jevins inflow exceeded the Canadian Water Quality Guideline of 120 mg/L of chloride for continuous long-term exposure of aquatic life for 90% of the measurements and is not suitable for aquatic life.

	Jevins Lake Inflow		
	Upstream Exit Ramp Site 3	Upstream Hwy. 11 Site 2	Downstream Hwy. 11 Site 1
Minimum	217	289	441
10th Percentile	258	316	507
25th Percentile	281	344	585
Median	334	460	687
75th Percentile	393	581	1101
90th Percentile	507	1046	1613
Maximum	476	1275	3750
n =	15	15	16

Table 4. Conductivity summaries for Jevins Lake inflows.

Conductivity measurements remained high year round and the highest conductivity measurements, in fact, were recorded in summer and autumn at all three sites (Figure 10).

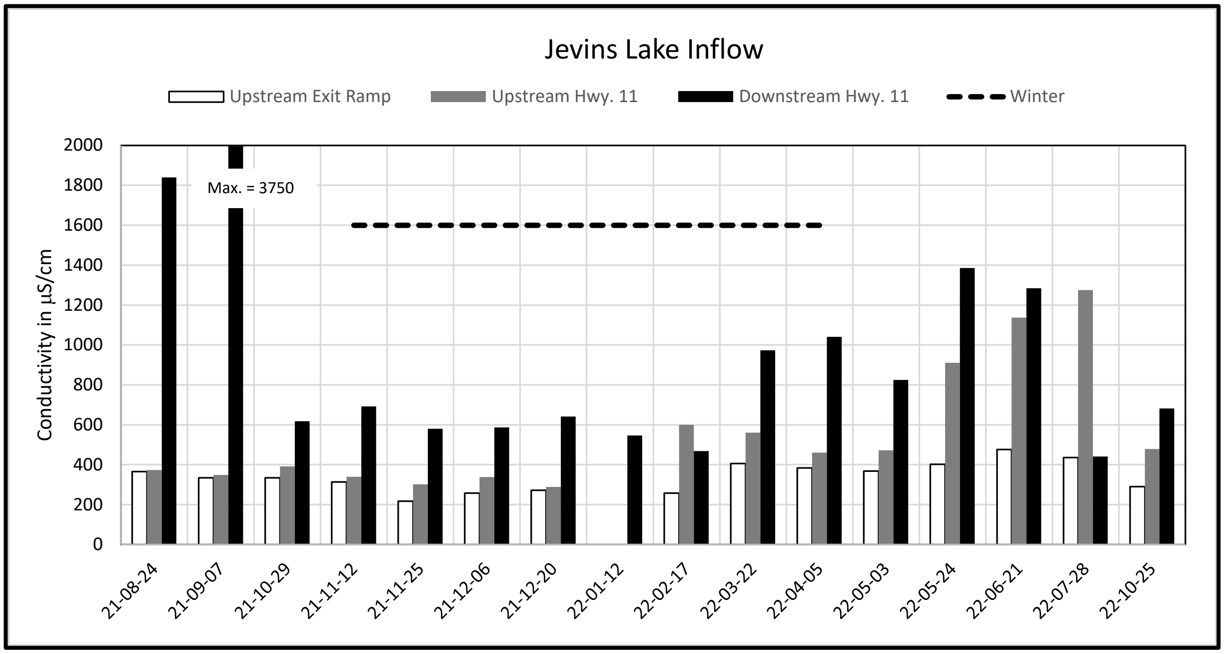

Figure 10. Conductivity record for Jevins Lake inflow.

This suggests that other factors besides seasonal chloride loadings, such as wetland hydrogeological dynamics, could influence chloride concentrations. There are three potential mechanisms for this and all are worthy of further investigation:

- First, that loadings from winter runoff are stored in wetlands and soils so that their migration into surface water is delayed and concentrations are less seasonally dependent. Dugan and Rock (2021) reported that chloride can be transported through soils in shallow groundwater systems such that transport and salinization proceed more slowly than predicted on the basis of assuming surface runoff only. In these cases chloride is stored in the soil, to be released more slowly to surface water in non-winter months, long after application.
- Second, that once winter loadings move into wetlands and soils, dry summer conditions concentrate chloride concentrations, such that they are higher than those measured in wetter seasons, and
- Third, that other ions besides chloride that are mobilized by other wetland processes (e.g. sulphate oxidation, DeVito and Hill 1998) result in increased conductivity in surface waters.

Nevertheless, it is clear that conductivity increases in response to inputs of urban and highway runoff into surface water and that chloride loadings should be considered on a year-round basis.

Cattail Wetland and Commercial Ditch Drainage

Conductivity values in the cattail wetland (Site 4) were consistently higher in summer (126 µS/cm) than in winter (90 µS/cm) with maximum values of 217 and 141 µS/cm respectively. This confirms that there was no hydrologic connection of the wetland to the surrounding parking lots and suggests that higher conductivity values were driven by drier summer conditions. (Figure 11, Table 5).

All statistical summaries of conductivity in the ditch draining the commercial areas were 10X those for the adjacent wetland with median summer and winter values of 747 and 1089 µS/cm and maximum values of 2230 and 3140 µS/cm, respectively (Table 5).

Gravenhurst Kinsman Park				
	Commercial Drainage		Cattail Wetland	
	Winter Only (Nov-Apr)	Summer Only (Nov-Apr)	Winter Only (Nov-Apr)	Summer Only (Nov-Apr)
Minimum	119	221	30	62
10th Percentile	354	254	33	95
25th Percentile	581	395	58	116
Median	1089	747	90	126
75th Percentile	1617	1311	110	145
90th Percentile	2163	1831	117	157
Maximum	3140	2230	141	217
n =	28	25	25	23

Table 5. Conductivity summaries for Jevins Lake urban source areas in Gravenhurst.

The median conductivity values correspond to approximate Cl concentrations of 180 and 270 mg/L while maximum values were approximately 560 and 780 mg/L. The maximum value of 780 mg/L exceeds the Canadian Water Quality Guideline of 640 mg/L for short term exposure of aquatic life (CCME 2011) and is therefore considered acutely toxic.

The dominance of commercial land uses (parking lots) in the catchment suggests that the high conductivity values were a result of substantial loadings of chloride. Conductivity remained high in the summer, however, (Figure 12) suggesting that winter loadings persisted into the summer and/or shallow groundwater flowed to the ditches in the summer and was contaminated with chloride. Direct measurements of anions and cations in the ditch would help determine the reasons and any relationship with road salt applications

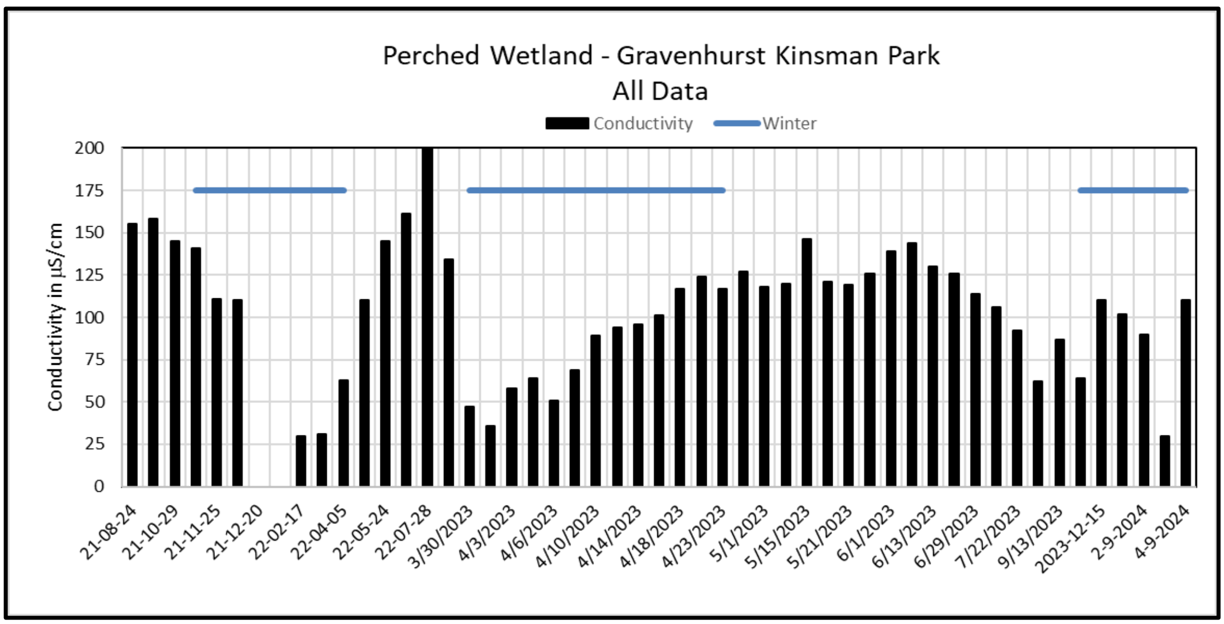

Figure 11. Seasonality of conductivity in commercial drainage ditch in Gravenhurst.

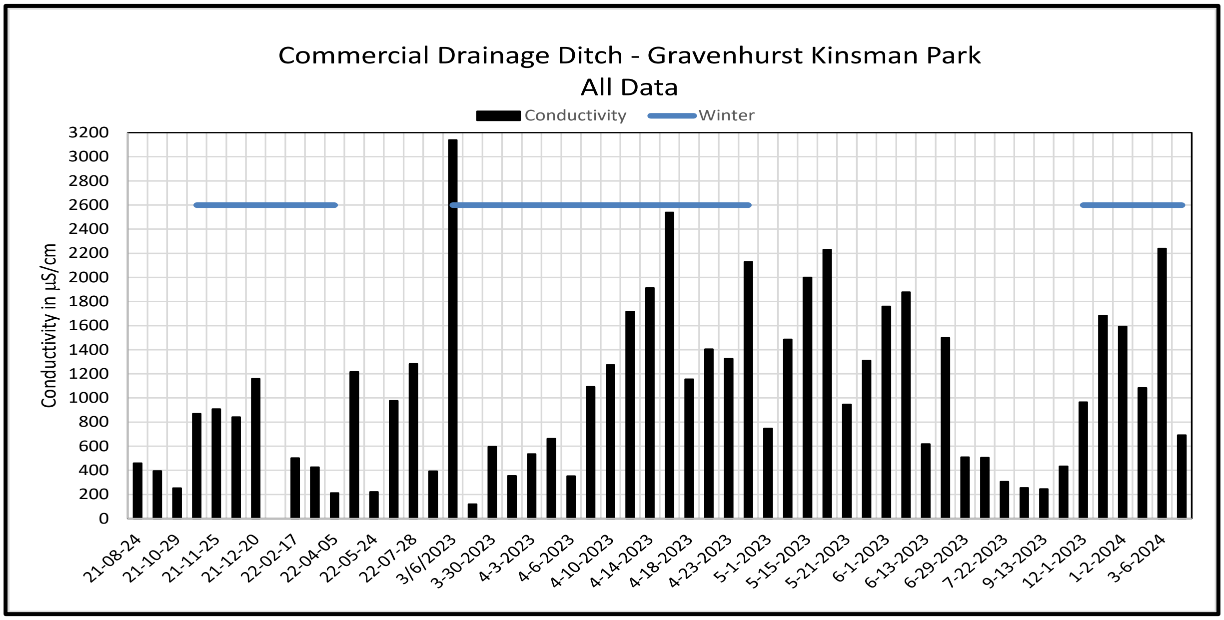

Figure 12. Seasonality of conductivity in perched cattail wetland in Gravenhurst.

3.3 Muskoka Bay Overview

Five sites (Figures 13 and 14) were selected to investigate chloride loading to Muskoka Bay:

Site 7. Storm water grate at Cherokee Lane/Muskoka Wharf – unknown catchment size.
Site 8. Muskoka Bay at Muskoka Wharf.
Site 9. Runoff to Muskoka Bay at Hwy. 169 from catchment of 201 ha.
Site 10. Reference site – Musquash Road catchment of 480 ha
Site 11. Runoff at Hwy 169 at West Gravenhurst tennis courts– unknown catchment size.

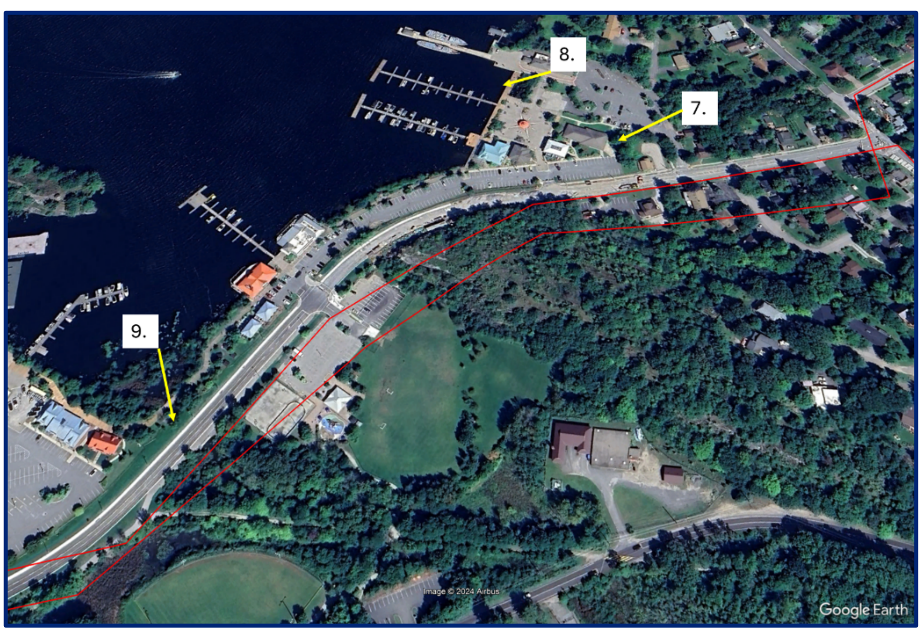

Figure 13. Sampling sites to Muskoka Bay: Sites 7, 8, 9.

Figure 14. Sampling sites to Muskoka Bay: Sites 10 and 11.

Site 7 was discharge from a municipal storm sewer that was accessed using a bilge pump inserted through the grate. Site 8 was Muskoka Bay at the steamship docks and could only be sampled when ice free. Site 9 was surface drainage to Muskoka Bay from 201 ha of urban Gravenhurst (Figure 15) sampled just downstream of Hwy. 169. Community infrastructure made up 53% of the catchment while 47% was sparsely vegetated (Table 6).

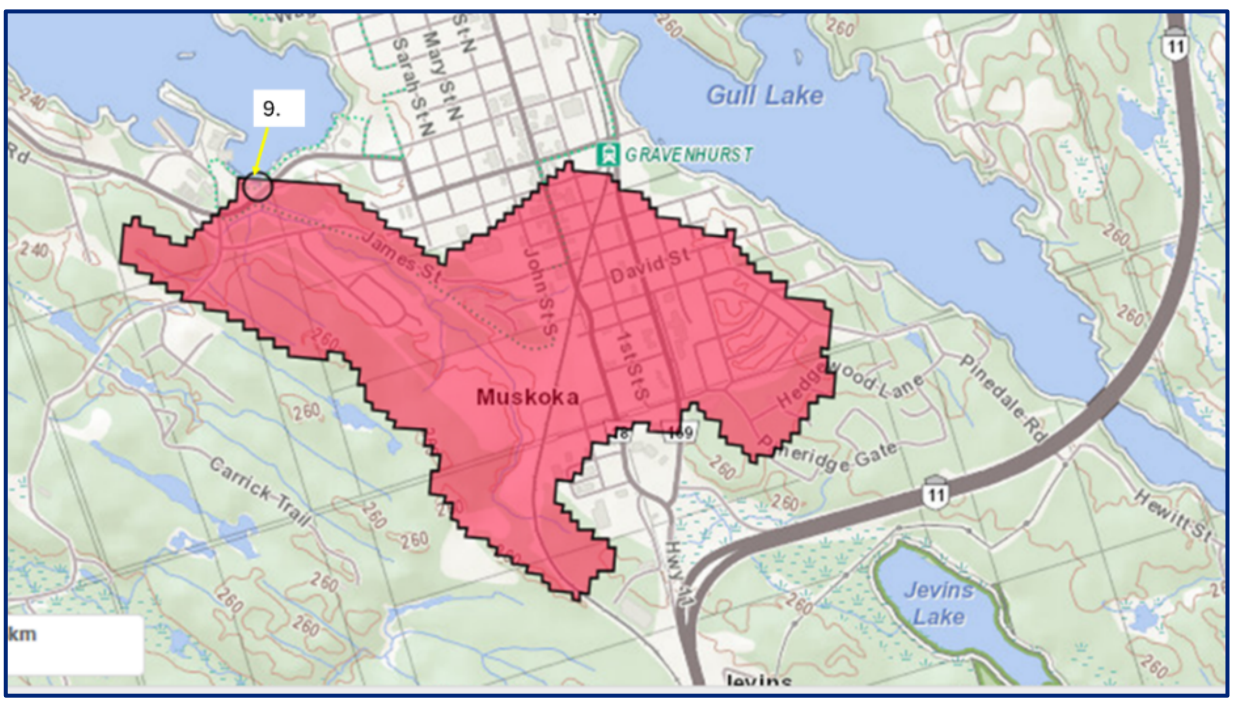

Figure 15. Catchment of urban runoff at Site 9.

Site 9 - Urban Drainage to Muskoka Bay		
Land Cover Type	Area (ha)	Percent
Sparse Treed	49	24%
Deciduous Treed	24	12%
Mixed Treed	15	7%
Coniferous Treed	0	0%
Bedrock	6.3	3%
Undisturbed Total	94.3	47%
Community/Infrastructure	107	53%
Disturbed Total	107	53%
Total	201	100%

Table 6. Land use areas for Gravenhurst urban drainage at Site 9.

Site 10 (Figures 14 and 16) was chosen as a site with minimal urban influence. It was sampled where a creek crossed Musquash Road and drained a large catchment of 480 ha which was 7% Community Infrastructure and 93% unaltered forest and wetland area. Site 11 (Figures 14 and 16) was ditch drainage adjacent to Hwy. 169 at the West Gravenhurst tennis courts. Neither land use nor catchment size could be determined.

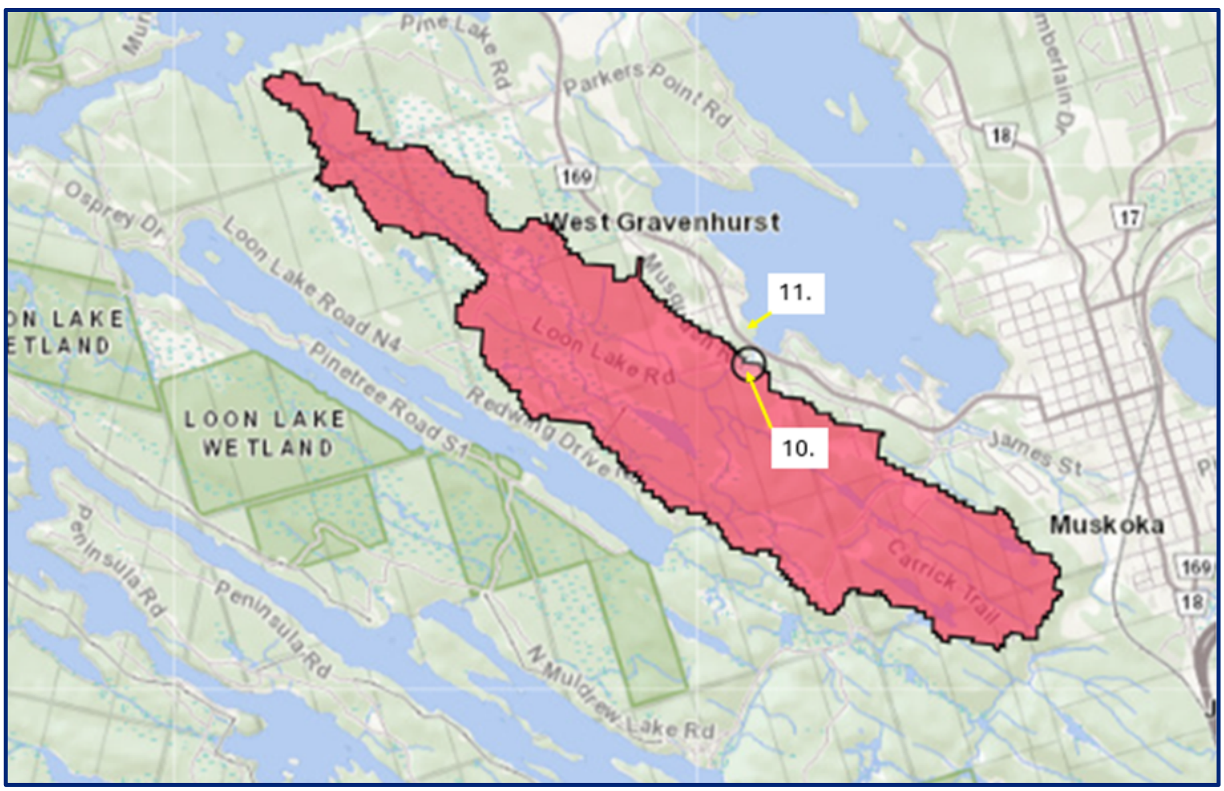

Figure 16. Musquash Road reference catchment and West Gravenhurst sampling site.

3.3.1 Results – Muskoka Bay

Storm Sewer Runoff at Muskoka Wharf – Site 7

A ditch flows to Muskoka Wharf and was sampled through a storm grate ~100m from Muskoka Bay and appears to drain residential land use south of Hwy. 169 in the western edge of Gravenhurst (Figure 13). Conductivity was high with a median value of 532 µS/cm and ranged from 142 to 659 µS/cm (Table 9, Figure 17). With the exception of the minimum value of 142 µS/cm measured in February, conductivity values showed little variance, with 80% of the measurements between 367 and 605 µS/cm (Table 9). The narrow range of elevated conductivity, coupled with the sub-surface location of the water, suggest that this site was influenced by shallow groundwater in which chloride would remain high year round. Direct measurements of anions and cations in the water are recommended to distinguish groundwater from road salt at this site.

Muskoka Wharf	
Drainage	
Minimum	142
10th Percentile	367
25th Percentile	454
Median	532
75th Percentile	563
90th Percentile	605
Maximum	659
n =	15

Table 6. Conductivity summary for storm drain to Muskoka Bay at Muskoka Wharf.

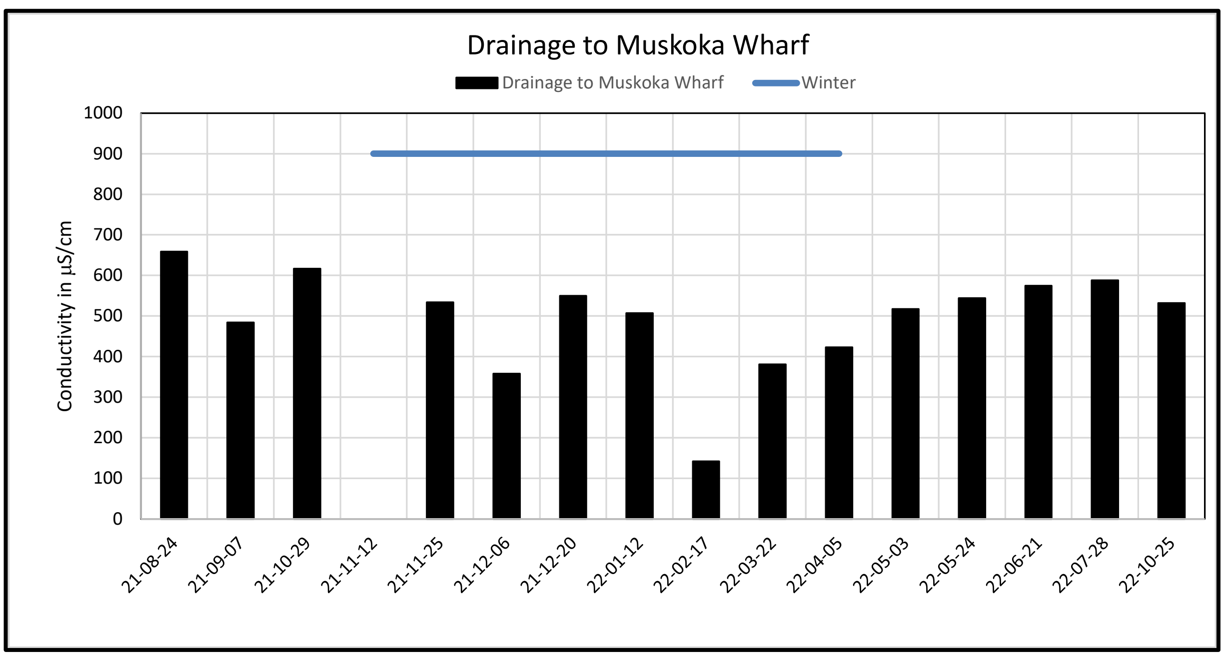

Figure 17. Conductivity measurements in storm drain to Muskoka Bay at Muskoka Wharf August 2021 – October 2023.

Muskoka Bay at Muskoka Wharf – Site 8

The most recent data from the District of Muskoka show that the Cl concentration in Muskoka Bay was 17.1 mg/L (Figure 2) and conductivity was 103 μS/cm on May 25, 2021. Conductivity measurements made from August 2021 until October 2023 ranged from 42 to 105 μS/cm (Figure 18) with a median value of 90 μS/cm (Table 7). While the DMM measurement falls within the range measured by FMW the DMM site is offshore at the deepest point of Muskoka Bay while the FMW measurements were made nearshore at Muskoka Wharf where water quality would be more variable in response to runoff events. The FMW equation for prediction of chloride from conductivity (Cl = (0.248*Cond)-5.96) provides a median Cl concentration of 16.4 mg/L for the FMW measurements and provides confidence in them. The low value of 42 μS/cm was measurement in early April and may reflect the influence of dilute snowmelt or rain in the nearshore.

Muskoka Wharf	
Lake Muskoka	
Minimum	42
10th Percentile	76
25th Percentile	78
Median	90
75th Percentile	94
90th Percentile	98
Maximum	105
n =	13

Table 7. Conductivity summary for Muskoka Bay at Muskoka Wharf.

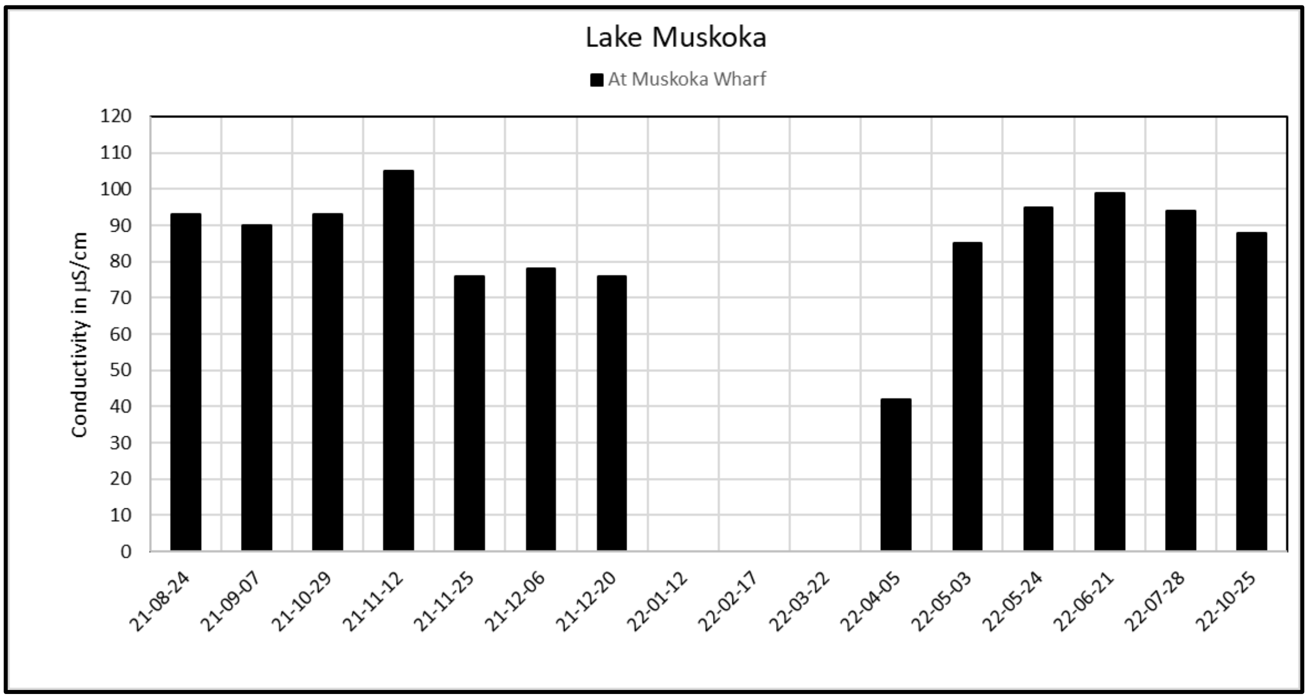

Figure 18. Conductivity measurements in Muskoka Bay at Muskoka Wharf – August 2021 – October 2023.

Residential Drainage to Muskoka Bay – Site 9

Monitoring of the inflow to Muskoka Bay at Site 9 captured runoff from a large (201 ha) catchment of western Gravenhurst that was 53% Urban Infrastructure (Table 6, Figure 19). The surface flow was sampled 5m downstream of Hwy. 169 (Site 9) and 50m upstream (Ste 9a) with the intent to see the influence of highway runoff.

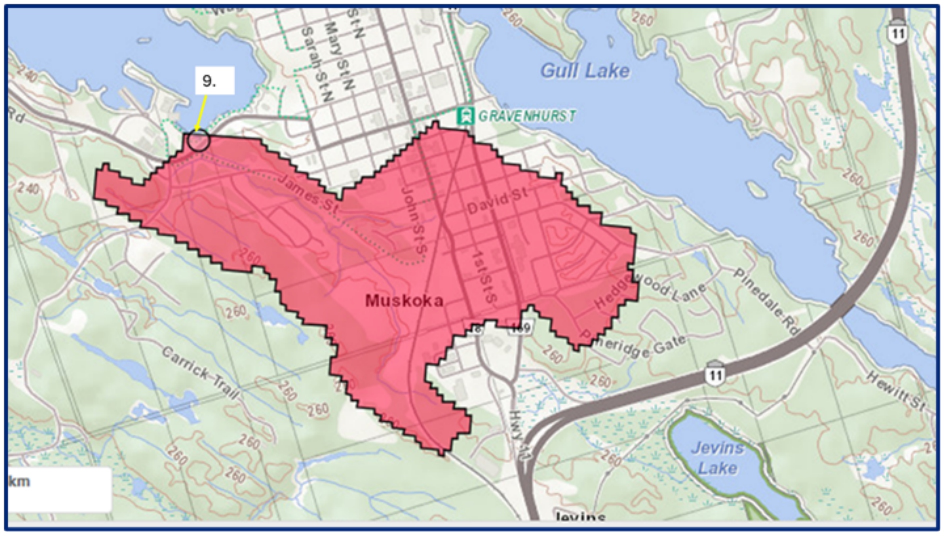

Figure 19. Mixed residential catchment sampled at Site 9, western Gravenhurst.

Conductivity was consistently higher downstream of Hwy.169 with the exception of one measurement in October of 2021 which may have been influenced by interaction with the mass of water in Muskoka Bay (Figure 24). Median values were 356 and 568 μS/cm and maximum values were 687 and 836 μS/cm upstream and downstream of Hwy 169 respectively (Table 8), suggesting that high conductivity in water from the residential area was further increased by runoff from the highway. Conductivity measurements showed no clear differences between winter and summer (Figure 20).

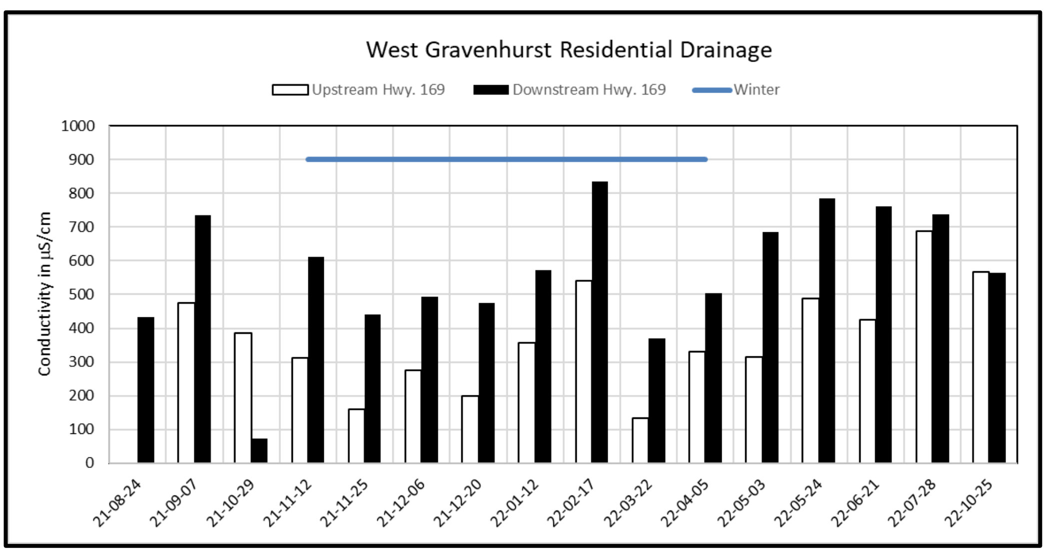

Figure 20. Conductivity measurements for mixed residential drainage to Muskoka Bay 50m upstream and downstream of Hwy. 169.

	West Gravenhurst Residential Area	
	Upstream Hwy. 169	Downstream Hwy. 169
Minimum	134	73
10th Percentile	177	402
25th Percentile	294	466
Median	356	568
75th Percentile	482	736
90th Percentile	556	772
Maximum	687	836
n =	15	16

Table 8. Conductivity summary for mixed residential drainage to Muskoka Bay in West Gravenhurst.

Further monitoring, however, showed additional sources of conductivity upstream of the highway. Table 9 shows that conductivity was increased substantially between Site 9 (50m upstream of the highway) and Site 9b, located ~10m downstream of Site 9a and 40 m upstream of Hwy. 169. Conductivity increased further between Site 9b and the upstream side of Hwy. 169 (Site 9c) such that the values recorded at Site 9 (downstream of the highway) were enriched not by highway runoff but by unknown sources upstream of the highway. Therefore, the conductivity increase measured at Site 9, downstream of the highway was not a direct result of road salt applied to Hwy. 169.

		May 3, 2022	May 24 2022	June 21, 2022	October 25, 2022
S9a	Upstream of usual site	314	487	424	518
S9b	Downstream of footpath	384		648	539
S9c	Upstream of Hwy 169	662	789	774	566
S9	Downstream usual site	684	784	760	565

Table 9. Detailed monitoring results at Site 9.

Further investigation, including more detailed water quality assessment and investigations of land use history, are warranted to determine the source of the increased conductivity. Air photography (Photo 3) from the District of Muskoka GeoHub[8] site, for example, shows that the former Gravenhurst WWTP was located upstream of Site9a in 1977 (prior to its closure) and may have discharged to Muskoka Bay by way of this watercourse.

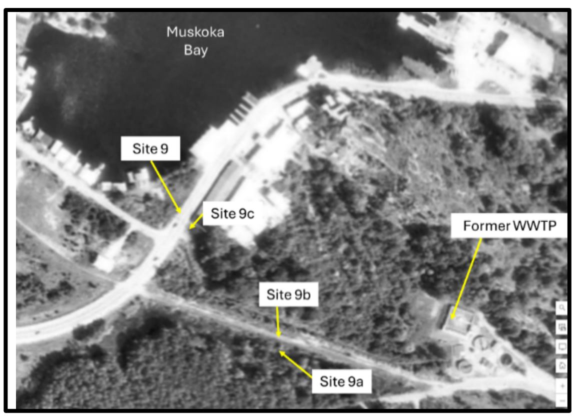

Photo 3. Site 9 catchment air photo – DMM 1977.

8 https://www.arcgis.com/apps/mapviewer/index.html?panel=gallery&layers=154408746edc41c6bb38fb2786e00f7c

Musquash Road Reference - Site 10

The median conductivity value of 62 μS/cm at the Musquash Road site (Table 10) provides a median Cl concentration of 9.4 mg/L using the FMW equation for prediction of chloride from conductivity (Cl = (0.248*Cond)-5.96). The catchment is 93% unaltered and so the high concentration of Cl was unexpected and higher than that in ~80% of Muskoka's Lakes (Figure 21 from Muskoka Watershed Council (MWC 2023)). The FMW predictive equation was developed for lakes, however, and may not accurately reflect the relations between Cl and conductivity in this stream and source drainage.

	Reference Creek
	Musquash Road
Minimum	32
10th Percentile	33
25th Percentile	39
Median	62
75th Percentile	104
90th Percentile	178
Maximum	447
n =	16

Table 10. Conductivity summary for reference watershed drainage to Muskoka Bay at Musquash Road.

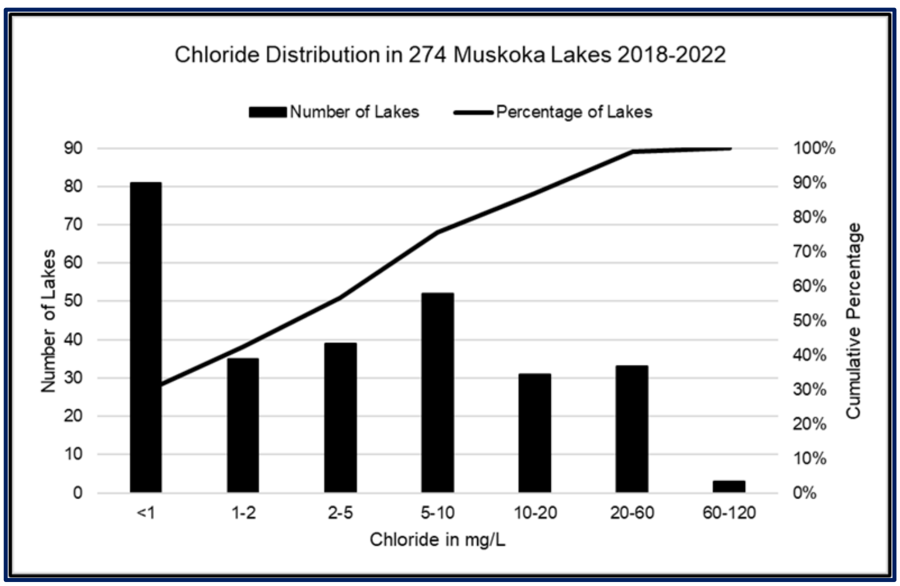

Figure 21. Chloride concentration in 274 Muskoka Lakes. From MWC (2023).

Conductivity values were lowest in winter at this site (Figure 22) showing that watershed dynamics (i.e drought) determined seasonality and not road salt application.

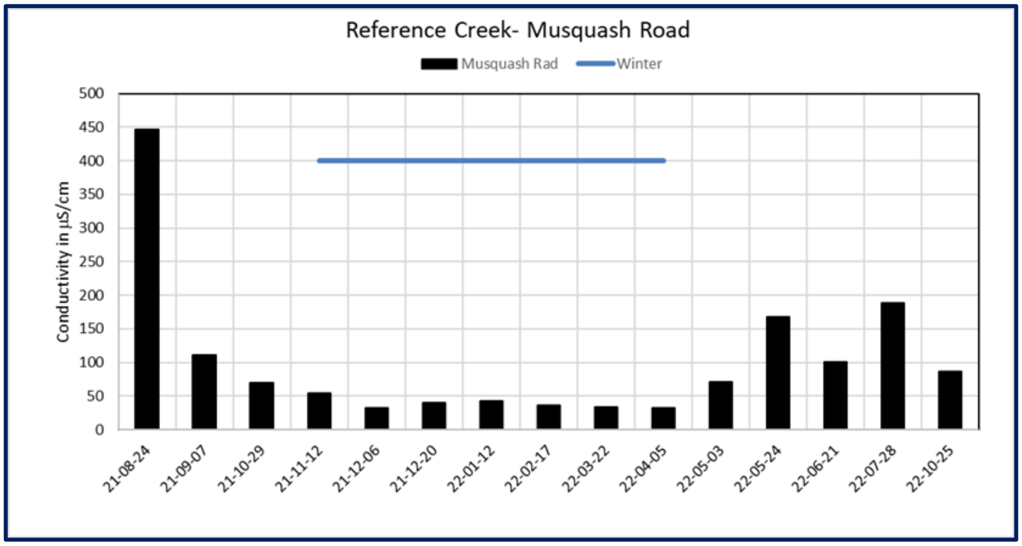

Figure 22. Conductivity measurements at Musquash Road reference site.

West Gravenhurst Roadside Ditch - Site 11

Samples taken from the roadside ditch at the West Gravenhurst tennis courts were high in conductivity with median and 90th percentile values of 434 and 567 mS/cm (Table 11). Although road salt is a likely source, the site was also characterized by permanent flow, no clear seasonality in measurements (Figure 23) and growth of watercress, indicative of groundwater flow. Further investigations should include direct measurements of ions to determine sources.

	Roadside Ditch West Gravenhurst
Minimum	113
10th Percentile	327
25th Percentile	358
Median	434
75th Percentile	494
90th Percentile	567
Maximum	602
n =	16

Table 11. Conductivity summaries at Hwy. 169 ditch in West Gravenhurst

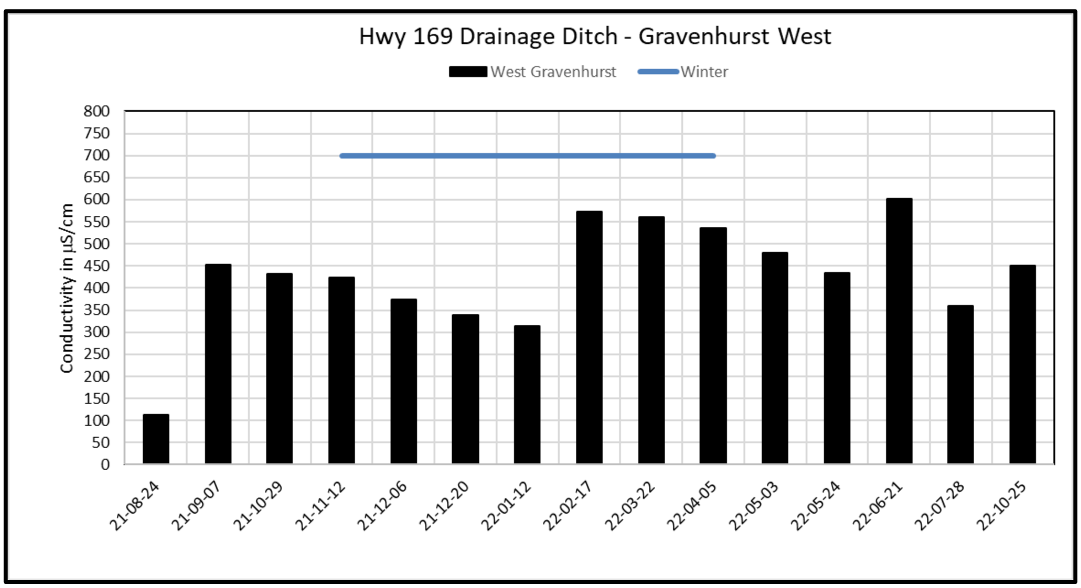

Figure 23. Conductivity measurements in Hwy. 169 ditch in West Gravenhurst.

3.4 Gravenhurst – Gull Lake Drainage

Sampling was conducted by citizen scientists from Gull and Silver Lakes Residents Association:

Joanne and Clarke Smith
Sandy Cairns
Brian Ochab

Six sites within the Gravenhurst Urban Area were monitored in 2023 and 2024. These included the two FMW sites presented in Section 3.2:

Site 4. Perched Cattail Wetland in Kinsman Park – Reference site with no direct runoff
Site 5. Ditch alongside Muskoka Road 18 at Kinsman Park receiving Commercial Urban runoff

Four additional sites (Fig. 24) represented potential sources of salt polluted runoff into Gull Lake that were identified by citizen scientists working with the FMW.

Site 12. Culvert at 320 Bethune Drive which drained commercial areas (Your Independent Grocer Plaza) of Gravenhurst.
Site 13. Drainage culvert at 400 Bethune Drive which drained mixed residential and commercial land uses.
Site 14. Residential storm drainage into Gull Lake from culvert at Phillip St E.
Site 15. Shoreline runoff to Gull Lake from Upper Phillip St. residential area.

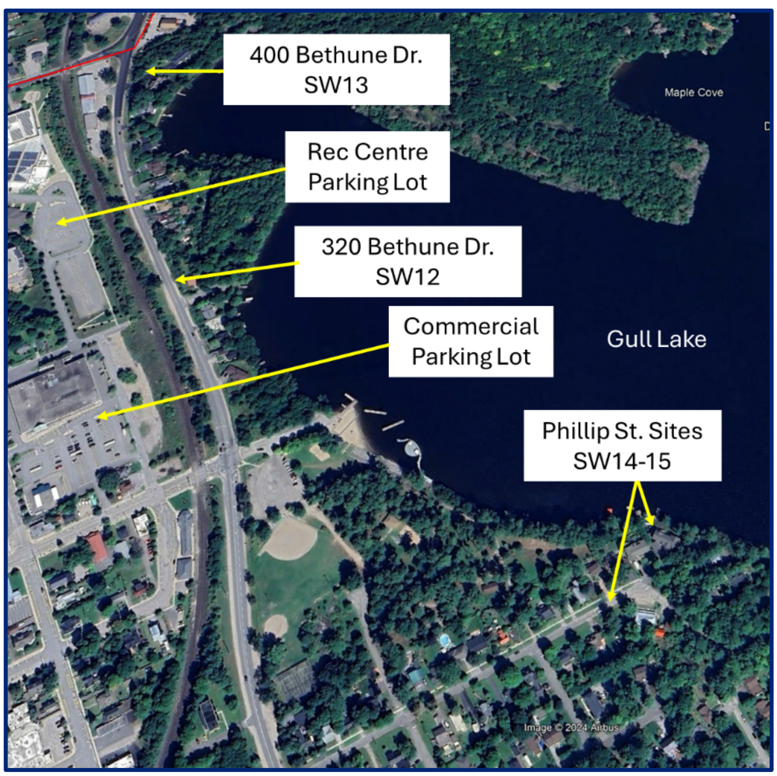

Figure 24. Gravenhurst 2023-2024 Gull Lake sites.

3.5.1 Results - Gull Lake Drainage

Commercial Runoff at 320 Bethune Drive – Site 12

Citizen Scientist Brian Ochab from the Gull and Silver Lakes Residents Association sampled runoff from commercial sites (Gravenhurst Independent Grocer and Recreational Centre parking lots) 53 times from January 31, 2023 to March 31 2024. The dominance of hardened surfaces and the absence of vegetation in the catchment provided for strong seasonality in conductivity measurements (Figure 25) with rapid increases at the onset of winter and a rapid decline as salt applications ceased in the late winter. Median conductivity increased from 1615 µS in summer months to 6550 µS/cm in winter months (Table 13) with a maximum value of 9230 µS/cm recorded on March 28, 2023. Ninety percent of all measurements exceeded 726 µS/cm.

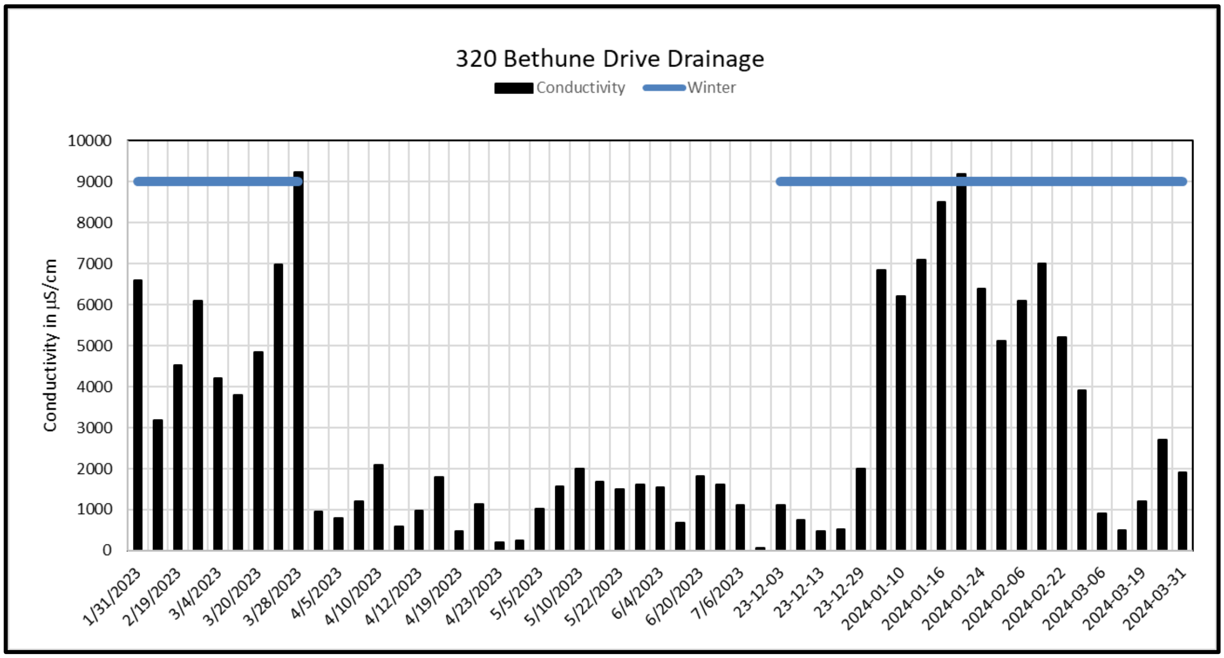

Figure 25. Conductivity measurements in surface runoff at 320 Bethune Dr. in Gravenhurst.

	320 Bethune Drive Commercial Drainage	
	Winter Only (Nov-Mar)	Summer Only (April - Oct)
Minimum	480	60
10th Percentile	726	296
25th Percentile	1925	740
Median	4685	1130
75th Percentile	6550	1615
90th Percentile	7240	1808
Maximum	9230	2100
n =	30	23

Table 12. Conductivity summaries from 320 Bethune Drive.

Mixed Runoff at 400 Bethune Drive – Site 13

Citizen Scientist Brian Ochab from the Gull and Silver Lakes Residents Association sampled runoff from mixed residential and commercial sites at 400 Bethune Drive 56 times from January 31, 2023 to March 31 2024. There was little difference between winter and summer measurements with median values of 560 and 576 µS/cm, respectively (Table 14). Conductivity measurements did indicate substantial enrichment from road salt runoff but the clear distinction between winter and summer and the sudden drop to summer values seen at 320 Bethune Drive were not apparent (Figure 26). Residential areas would contain more soil and vegetation which would retain and delay runoff and diminish seasonal differences in contrast to the high seasonality seen in pavement-dominated catchments.

	400 Bethune Drive	
	Mixed Storm Drainage	
	Winter Only (Nov-Mar)	Summer Only (April - Oct)
Minimum	250	185
10th Percentile	323	340
25th Percentile	393	411
Median	560	576
75th Percentile	713	740
90th Percentile	876	841
Maximum	945	876
n =	31	25

Table 13. Conductivity summaries from 400 Bethune Drive

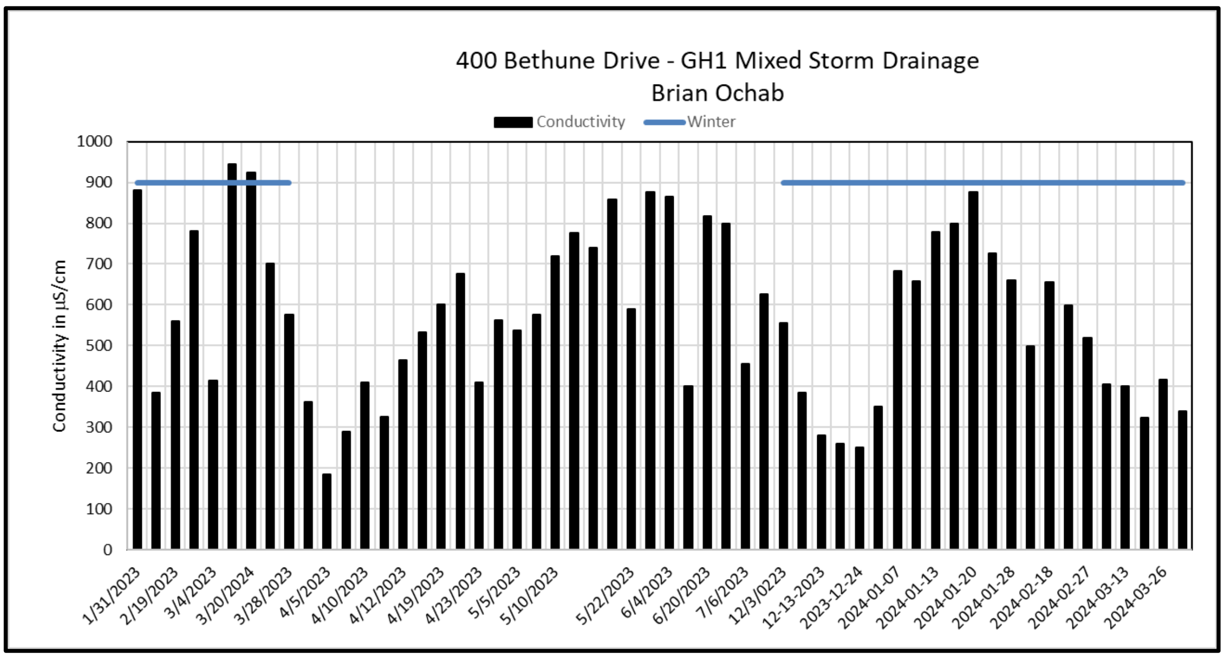

Figure 26. Conductivity measurements at 400 Bethune Drive.

Residential Runoff Phillip St.- Sites 14 and 15

Two distinct patterns were seen in the conductivity records collected for two sites on Phillip St. by Citizen Scientists Joanne and Clarke Smith and Sandra Cairns. Conductivity was stable (Figure 27), with little variance between samples taken from the drainage to the Gull Lake shoreline from the Smith property with a median value of 102 µS/cm and maximum of 117 µS/cm (Table 15, right).

Phillip St. E -Cairns	
Residential Drainage	
Minimum	121
10th Percentile	144
25th Percentile	197
Median	286
75th Percentile	330
90th Percentile	413
Maximum	564
n =	14

Upper Phillip St. - Smith	
Residential Drainage	
Minimum	95
10th Percentile	100
25th Percentile	101
Median	102
75th Percentile	104
90th Percentile	107
Maximum	117
n =	22

Table 14. Conductivity summaries from two residential sites on Phillip St.

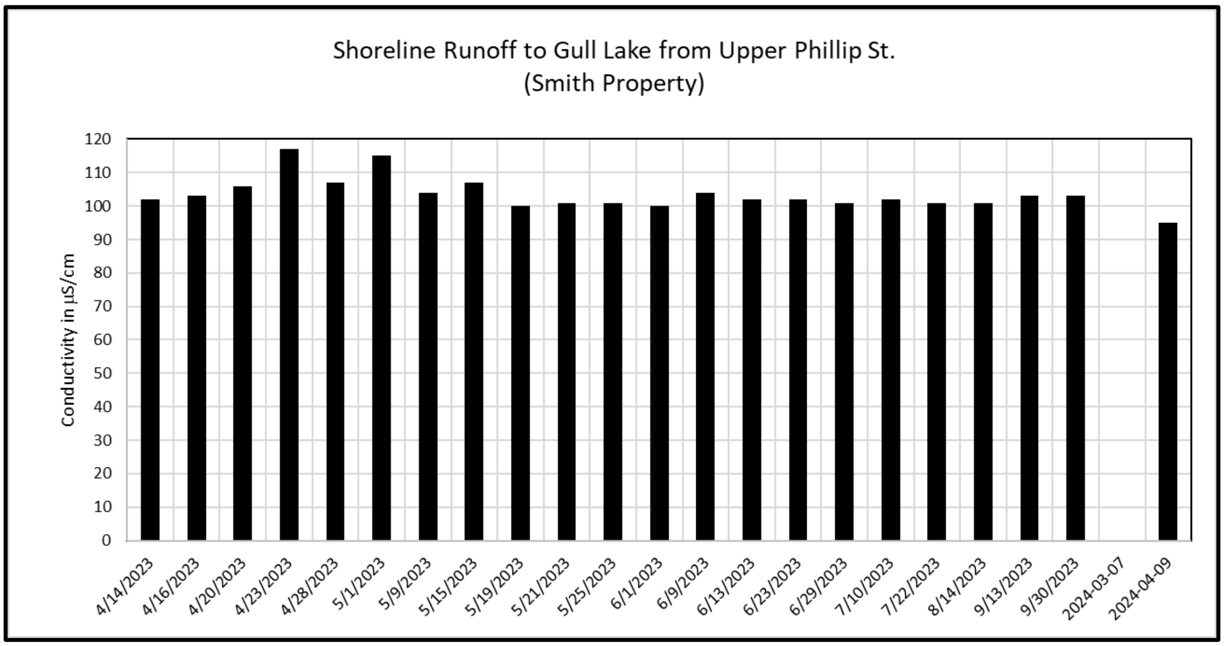

Figure 27. Conductivity measurements in drainage to Gull Lake shoreline. (Missing point was a date where ice cover prevented sampling).

In contrast, samples collected from the storm drain on Phillip St. were higher and more variable, being slightly higher in winter than in summer (Figure 28). The median value was 286 µS/cm and individual samples ranged from 121 to 564 µS/cm (Table 15, left). The difference between the two sites could be explained by direct runoff from the salted surface of Phillip St. to the storm drain compared to seepage from areas of lower salt application into soils of the lawn adjacent to the shoreline of Gull Lake.

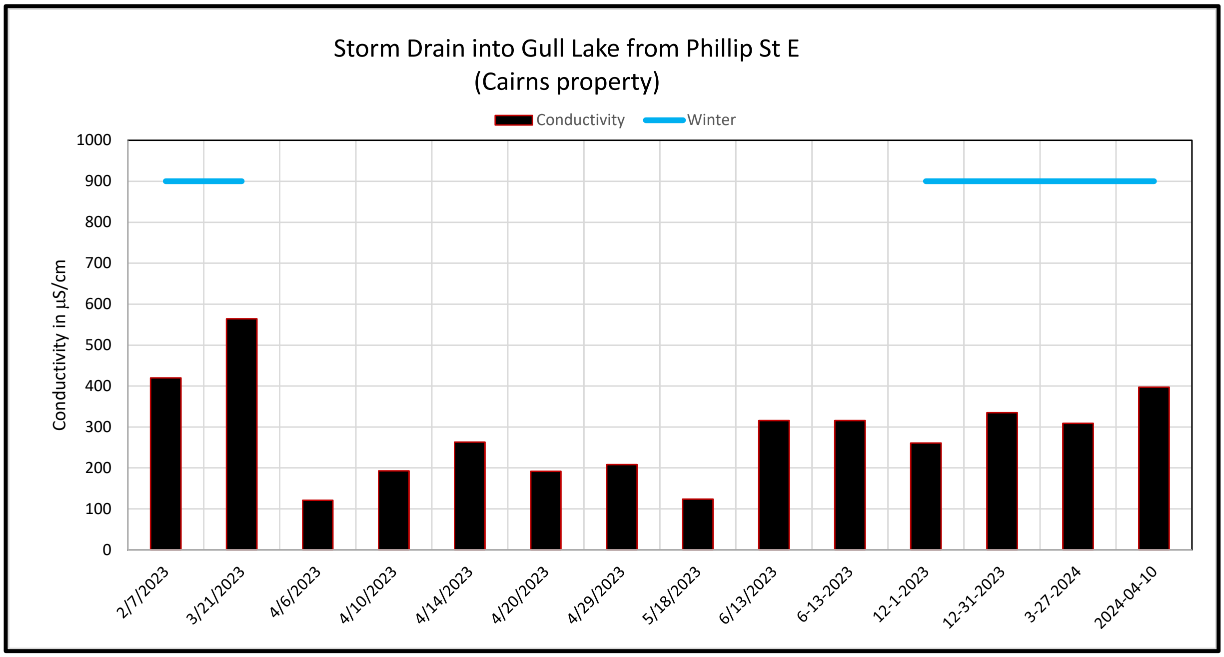

Figure 28. Conductivity measurements at Phillip St. storm drain.

4. Citizen Science Results – Bracebridge

The Beaver Creek watershed, two residential storm drains and sites on the North and South Muskoka Rivers were identified for sampling in the winter of 2023 - 2024.

4.1 Beaver Creek Catchment

Sampling was undertaken at four sites in the Beaver Creek watershed in the winter of 2023-2024 by the citizen scientists and FMW staff.

Citizen Science Volunteers: Judi Brouse and Jan Simmons
Friends of the Muskoka Watershed: Spencer Macpherson

4.1.1 Site Description

Beaver Creek is a tributary of the North Muskoka River and drains the western areas of the Town of Bracebridge (Figure 29). The upper catchment is dominated by forested areas with some agriculture land use with some residential land use (Covered Bridge subdivision). The lower portion of the catchment receives urban runoff from commercial, residential and institutional land uses, all of which contain substantial areas of hardened pavement and which are known to be treated with road salt. Some salt is stored for future use in a commercial plaza area and is poorly covered such that much can run off even before it is spread. Other commercial areas in the catchment show overuse and accumulations that are present after all snow has melted (Photo 4). Drainage from these sites, as well as other sources in the catchment, drain to Beaver Creek via storm drains but the contributions of individual sources could not be isolated.

This catchment was monitored to a) observe any changes in conductivity as Beaver Creek received runoff from developed areas and b) to observe the relative inputs of conductivity from two urban storm drains, one draining a largely commercial area (“Plaza Storm Drain”) and one draining a mixture of commercial, residential and institutional runoff (“Monck Storm Drain”.

Photo 4. Salt storage and over-use in commercial areas of Bracebridge.

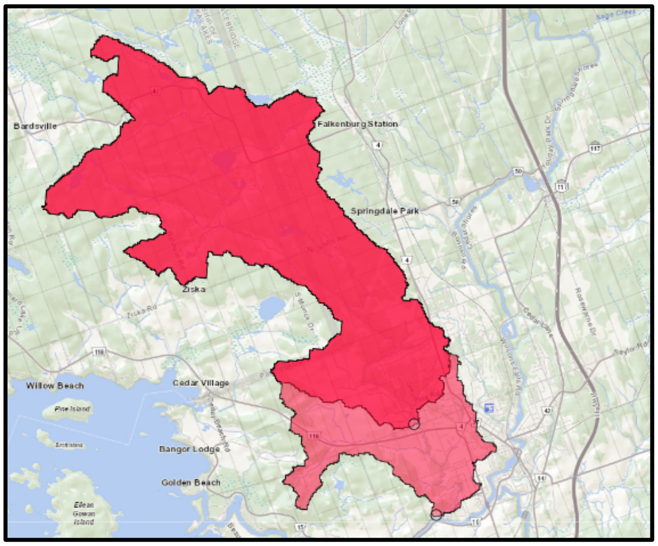

Figure 29. Beaver Creek watershed showing upper (red) and lower (pink) delineations.

The total area of the Beaver Creek catchment is 30.79 km2 (3079 ha). Monitoring efforts were focussed on the lower catchment of 604 ha, below the Covered Bridge subdivision. Land uses and watershed areas were derived using the Ontario Watershed Information Tool. In the upper watershed of 2475 ha, 85.2% of land uses were classified as forested or wetland ("Undisturbed") and unlikely to include areas of salt application while 4.3% ware classified as "community infrastructure" and 10.3% as agricultural/rural and therefore potential areas of road salt application (Table 16.) By contrast, the lower watershed areas were dominated by community infrastructure (27.8%) in which road salt applications would occur and rural/agricultural land uses (35.9%) in which some road salt application could be expected.

Land Cover Type	Upper Watershed		Total Watershed		Lower Watershed	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Clear Open Water	60	2.4%	60	1.9%	0	0.0%
Bog	90	3.6%	91	3.0%	1	0.2%
Sparse Treed	144	5.8%	162	5.3%	18	3.0%
Deciduous Treed	1014	41.0%	1116	36.2%	102	16.9%
Mixed Treed	753	30.4%	850	27.6%	97	16.1%
Coniferous Treed	48	1.9%	49	1.6%	1	0.2%
Undisturbed	2109	85.2%	2328	75.6%	219	36.3%
Community /Infrastructure	107	4.3%	275	8.9%	168	27.8%
Agriculture and Undifferentiated Rural Land Use	254	10.3%	471	15.3%	217	35.9%
Disturbed	361	14.6%	746	24.2%	385	63.7%
Other	5	0.2%	5	0.2%	0	0.0%
Total	2475	100%	3079	100%	604	100%

Table 15. Land uses and areas in Beaver Creek Catchment

Four sites were monitored in the Beaver Creek catchment (Figure 30):

- BC1 - The top of the lower watershed was monitored at the Covered Bridge on Covered Bridge Trail, where Beaver Creek was easily and safely accessed. This site included ~80% of the catchment and was intended to capture inputs from natural and minor residential sources before the creek was influenced by commercial area runoff.

- BC2 - The “Plaza Storm Drain” was monitored as a source of road salt from the large commercial area on the south side of Hwy. 118 (“Balls Flats”) which includes the Independent Grocer, Canadian Tire, banking, fast food and other smaller retail stores.
- BC3 - The “Monck Storm Drain” was monitored as a source of road salt at Salmon Avenue. It discharges runoff from an area of mixed land use (school, road, commercial, residential) along Wellington St and eventually enters Beaver Creek.
- BC4 - Beaver Creek was monitored at Gainsborough Road, ~500m upstream of its confluence with the Muskoka River.

A summary of sites and sampling effort is given in Table 17.

	Site	Purpose	Period Sampled	No. Samples
BC1	Beaver Creek at Covered Bridge	Upstream Reference - Low Residential Agricultural Use	230127-240131	18
BC2	Storm Drain from Commercial Area	Storm Runoff from Large Plaza	230127-240131	18
BC3	Storm Drain from Mixed Use	Storm Runoff from Road, Commercial and School Uses	230127-240131	18
BC4	Beaver Creek at Gainsborough Road	Downstream Impact at Muskoka River Confluence	230127-240924	68

Table 16. Sampling sites and effort in Beaver Creek catchment

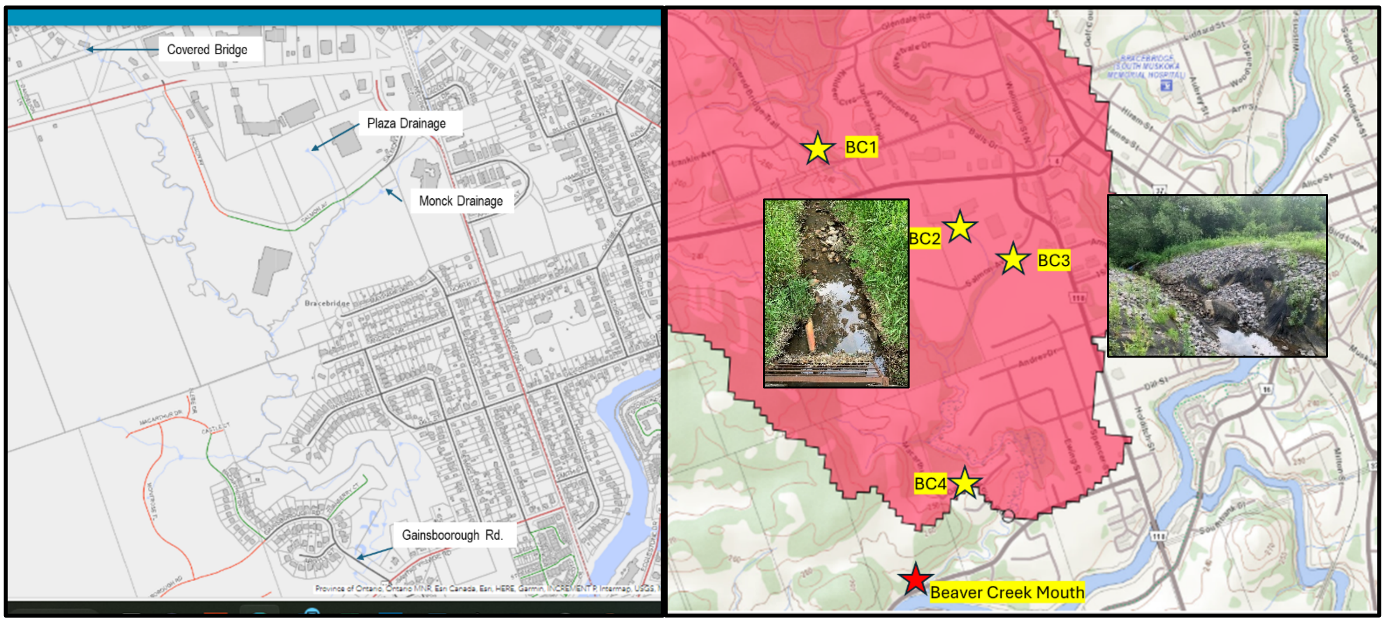

Figure 30. Beaver Creek sampling locations.

4.1.2 Results – Beaver Creek

Beaver Creek at Gainsborough Road was sampled 68 times between March 2023 and September 2024 by citizen science volunteers Judi Brouse and Jan Simmons while the other sites were sampled 17 or 18 times between February 2023 and January 2024 by Friends of the Muskoka Watershed Staff Spencer Macpherson. Median conductivity values doubled from 81 to 177 μs/cm between Covered Bridge and Gainsborough Road (Table 17) while statistics for more extreme values (75th ,90th percentiles and maximum values) increased by 3 to 5 fold (Table 18). These increases were driven by the urban runoff inputs which had median values of 11,905 and 6520 μS/cm and 90th percentiles of 17,155 and 8120 μS/cm for the plaza drainage and Monck drainage respectively. Seawater, by comparison, has a conductivity of 50,000 μS/cm. We note that Beaver Creek also receives urban runoff (which was not monitored) from large residential areas between the storm drains and the Gainsborough Road site.

	Beaver Creek at Covered Bridge	Beaver Creek at Gainsborough Bridge	Plaza Drainage	Monck Drainage
Minimum	60	16	1070	820
10th Percentile	74	68	1654	1594
25th Percentile	78	116	5433	4433
Median	81	177	11905	6520
75th Percentile	105	288	17155	7195
90th Percentile	108	389	17155	8120
Maximum	111	540	19490	8180
n=	17	68	18	18

Table 17. Summary statistics for the Beaver Creek catchment.

Chloride concentrations can be estimated from conductivity measurements by the equation:

Chloride = 0.25(Conductivity) – 5.97

This conversion shows that median chloride concentrations in Beaver Creek increased from ~14 mg/L at Covered Bridge to 38 mg/L at Gainsborough Road and are potentially toxic to sensitive invertebrate life during chronic exposures (Arnott et al. 2020). The median values of conductivity in the runoff from the commercial plaza and Monck drainage sites to Beaver Creek correspond to Cl concentrations of ~3000 and 1600 mg/L, respectively and thus would be considered toxic to aquatic life[9]. (CCME 2011).

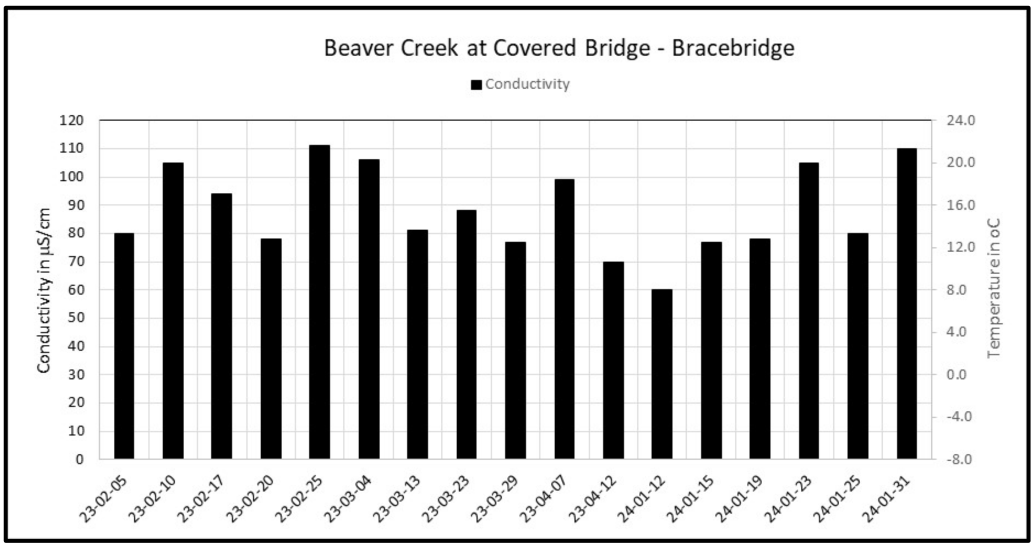

Figure 31. Winter records of conductivity measurements at Covered Bridge site.

Conductivity at the Covered Bridge site, upstream of the storm drains was only measured in winter (January – April), was low and showed little variance, ranging from 60 to 110 µs/cm (Figure 31). Upstream land uses included residential and rural lands and so these values while low, would still be potentially influenced by road salt applications upstream.

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[9] *The Canadian Water Quality Guideline for acute (short term safe exposure) of Cl is 640 mg/L (CCME 2011).This equates to ~2560 υS/cm conductivity.*

Although conductivity at the Gainsborough site declined in late March and April as winter salt application ceased, it rose again over the summer and remained high. The lowest values occurred in March and April and the highest values measured in summer months matched values measured during winter (Figure 32). The summer increases would be a result of Cl inputs from soils and shallow groundwater and/or drought conditions concentrating Cl concentrations in the water.

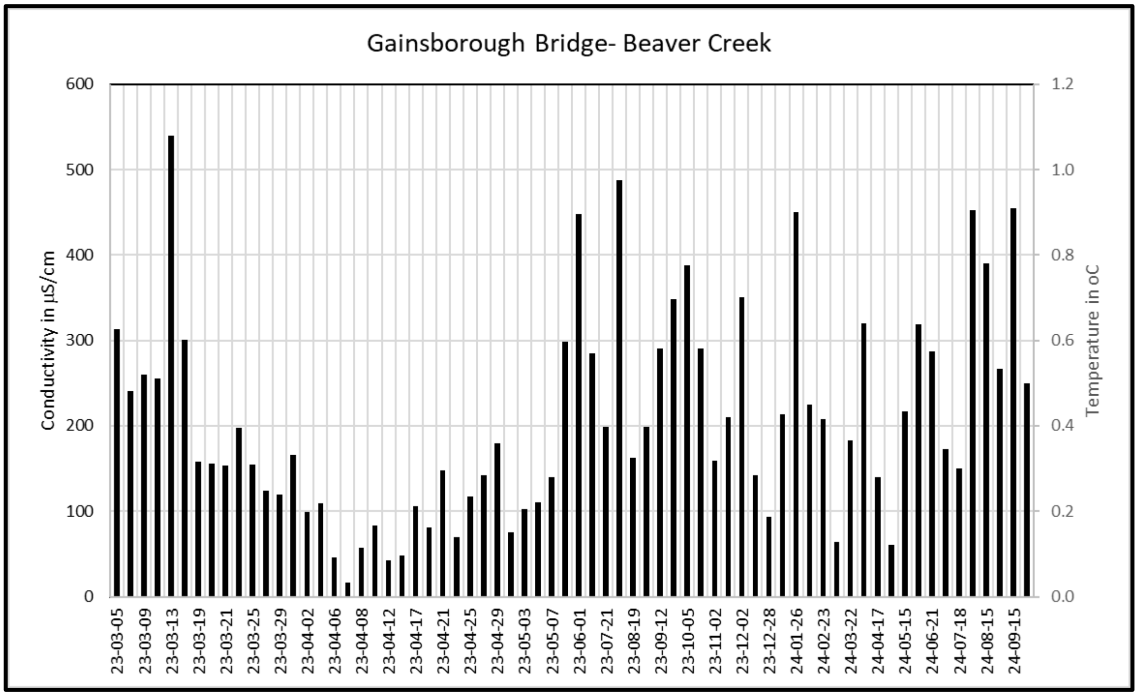

Figure 32. Seasonality of conductivity in Beaver Creek at Gainsborough Rd.

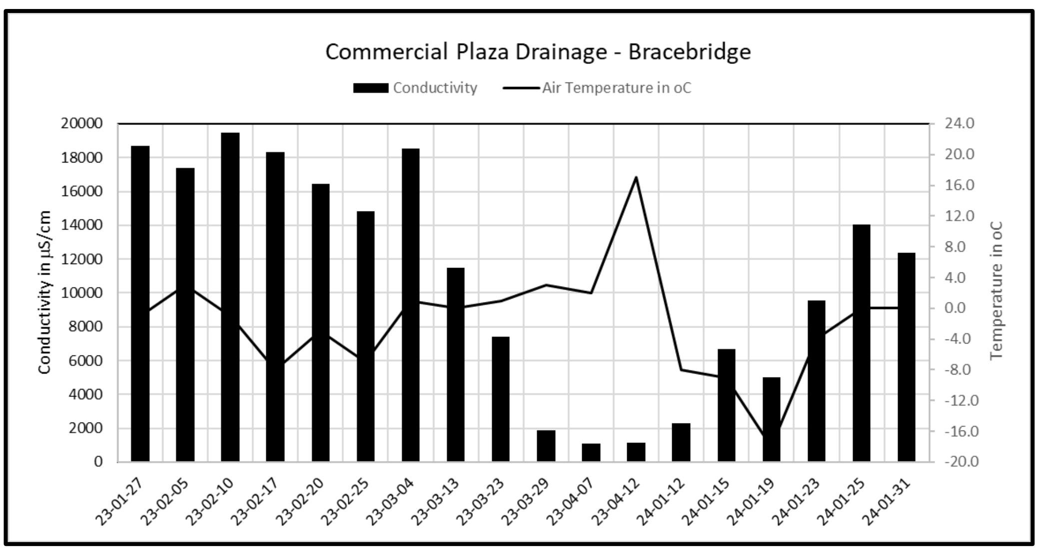

Figure 33. Winter trends in conductivity of storm drainage from commercial sites in Bracebridge.

Conductivity in storm drain runoff from the commercial plazas was only measured in winter (January – April), but values were high, exceeding 8000 µS/cm until air temperatures rose in March. Rapid snowmelt is suggested by large drops in conductivity as water and air temperatures rose from mid-

March onward. (Figure 33) although conductivity still exceeded 1000 μS/cm in mid April when measurements ceased.

Conductivity in storm drain runoff from the Monck mixed-use drainage commercial plazas was only measured in winter (January – April). Measured values were approximately half of those in the plaza drainage (Table 18) but showed the same trends (Figure 34). Values exceeded 4000 μS/cm until air temperatures rose in mid-March. Rapid snowmelt is suggested by large drops in conductivity as air temperatures rose from mid-March onward. (Figure 34) although conductivity still exceeded 8000 μS/cm in mid April when measurements ceased.

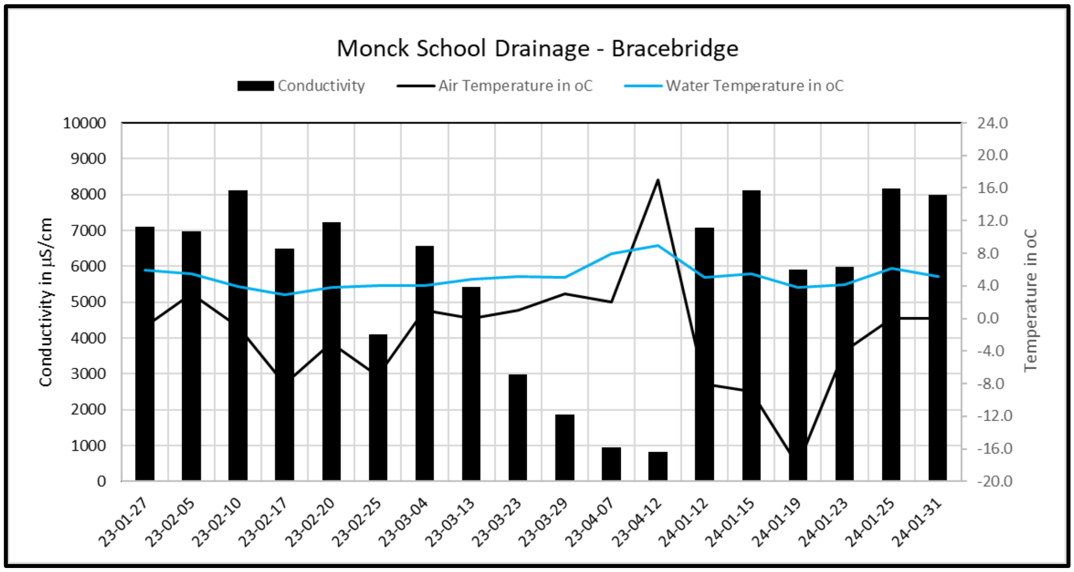

Figure 34. Winter trends in conductivity of storm drainage from Monck mixed use area in Bracebridge.

4.1.3 Summary

Overall, monitoring of the Beaver Creek catchment showed that conductivity in runoff from developed areas where road salt is applied was 100 to 200 times higher than at the upstream (Covered Bridge) site on Beaver Creek. These high conductivity inputs doubled the conductivity in Beaver Creek between the Covered Bridge and Gainsborough Road sites. Estimation of chloride concentrations from the measured conductivity values showed that median concentrations in Beaver Creek could be toxic to sensitive invertebrates in long term (chronic) exposures while median levels in the runoff itself could be lethal to sensitive fish and invertebrates during short-term (acute) exposures. Future monitoring efforts should include measurements made year-round at all sites. Continuous (automated) monitoring at hourly intervals is recommended in source areas (urban runoff) where concentrations may change quickly in response to storms and temperature changes.

4.2 Drainage to Muskoka River

Four sites in Bracebridge were monitored by FMW staff Spencer MacPherson from February 2023 to February 2024 (Figure 35).

- The North Muskoka River at Wilsons Falls, upstream of Bracebridge urban areas – BB1
- The South Muskoka River at its confluence with the North Branch in Bracebridge – BB2
- Runoff from the urban areas of Dill and Victoria streets to a storm drain – BB3
- Runoff from urban and commercial areas to a storm drain on Wharf Road – BB4

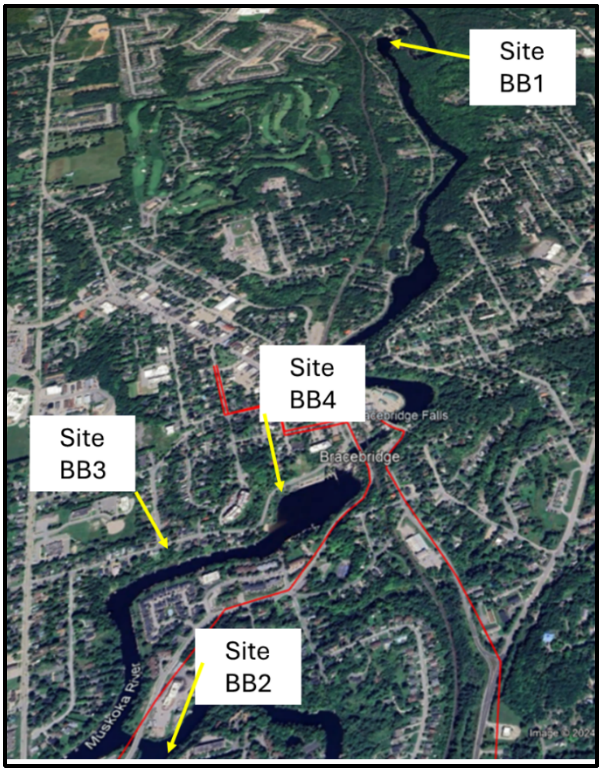

Figure 35. Sampling sites in Muskoka River drainage – Bracebridge.

A summary of sites and sampling effort is given in Table 19.

Site		Purpose	Period Sampled	No. Samples
BB1	North Muskoka River at Wilsons Falls	Watershed Characteristics -Some Urbanization	230127-240131	18
BB2	South Muskoka River at Confluence	Watershed Characteristics -Low Urbanization	230127-240131	17
BB3	Victoria and Dill St. Urban Drainage	Residential Drainage	230127-240131	18
BB4	Wharf Road Urban Drainage	Residential and Commercial Drainage	230127-240131	18

Table 18. Sampling sites and effort for Muskoka River and Bracebridge urban area.

4.2.1 North Muskoka River at Wilsons Falls – BB1

Conductivity was low and stable at Wilsons Falls (Figure 36), with a median value of 59 μS/cm and a range of 44 to 68 μS/cm (Table 20). The North Branch watershed is largely undeveloped upstream of Bracebridge but does include the towns of Port Sydney and Huntsville, and receives drainage from Hwy. 11 such that 4.8% of the watershed of 1581 km^2 is altered by urban or agricultural infrastructure. The median conductivity value of 59 μS/cm is therefore enriched and corresponds to 8.7 mg/L of Cl, using the FMW relationship of Cl to conductivity developed for lakes (Cl = (0.248*conductivity) – 5.96).

North Muskoka River at Wilsons Falls Bracebridge	
Minimum	44
10th Percentile	48
25th Percentile	52
Median	59
75th Percentile	61
90th Percentile	67
Maximum	68
n=	18

Table 19. Conductivity summary for North Muskoka River at Wilsons Falls.

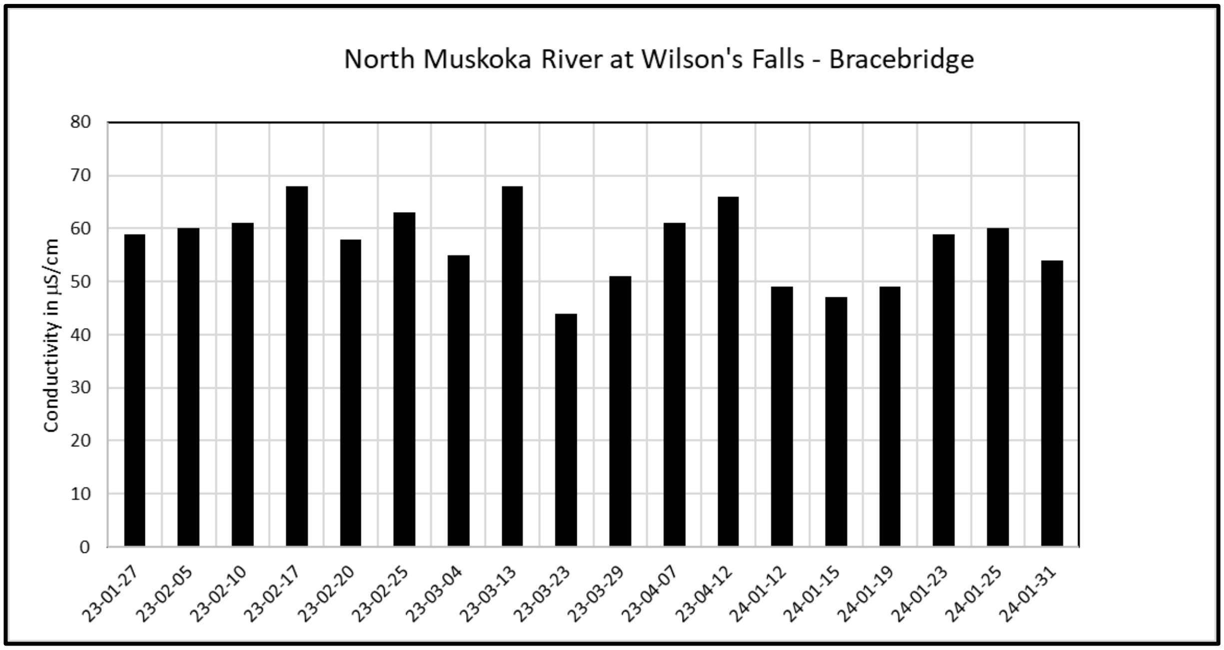

Figure 36. Conductivity measured at North Muskoka River at Wilsons Falls.

4.2.2 South Muskoka River at Confluence – BB2

Conductivity was low and stable in the South Muskoka River at its confluence with the North Branch in Bracebridge (Figure 37), with a median value of 44 µS/cm and a range of 34 to 52 µS/cm (Table 21). The South Branch watershed is relatively pristine and includes the towns of Baysville and Dwight upstream, and receives drainage from Hwy. 117 and Hwy 118 such that only 1.7% of the watershed of 1774 km^2 is altered by urban or agricultural infrastructure. The median conductivity value is therefore lower than that of the North Branch and is only slightly enriched, corresponding to 5.0 mg/L of Cl, using the FMW relationship of Cl to conductivity developed for lakes (Cl = (0.248*conductivity) – 5.96).

South Muskoka River at Confluence Bracebridge	
Minimum	34
10th Percentile	38
25th Percentile	40
Median	44
75th Percentile	49
90th Percentile	50
Maximum	52
n=	17

Table 20. Conductivity summary for South Branch of Muskoka River.

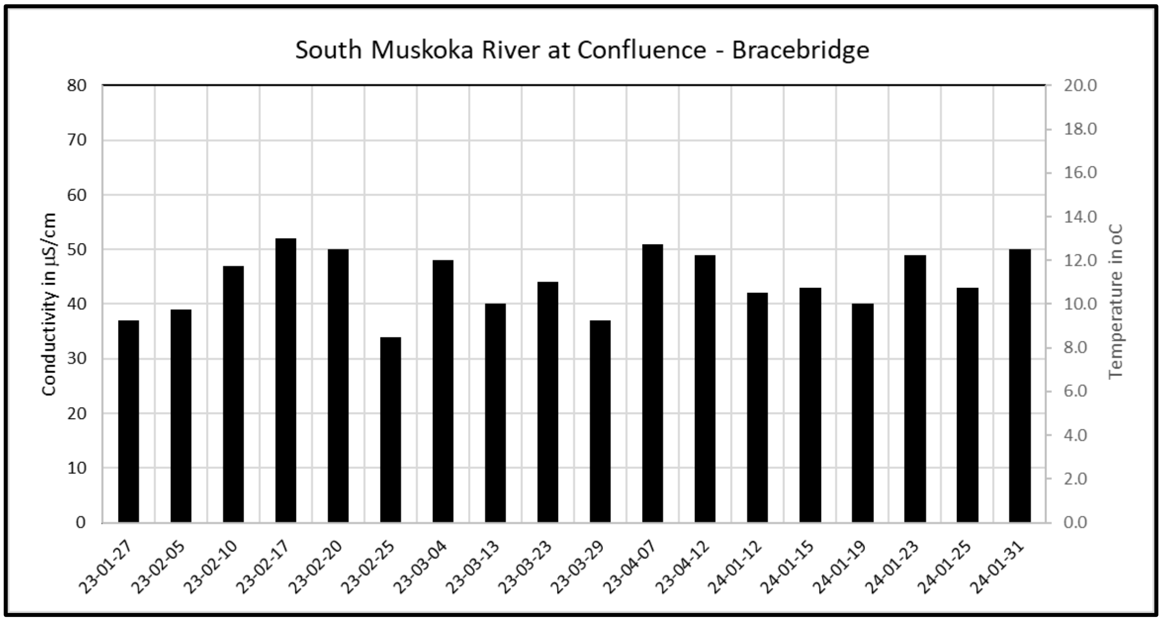

Figure 37. Conductivity measured at South Muskoka River at Bracebridge confluence.

4.2.3 Victoria Street Runoff to Storm Drain – BB3

Conductivity was high and variable for the residential drainage at Victoria and Dill St (Figure 38), with a median value of 5060 µS/cm and a range of 3460 to 1090 µS/cm (Table 22). All samples were collected over the winter (January to April) periods of 2023 and 2024 and so represent responses to different winter events and not seasonality.

Victoria and Dill St Drainage - Bracebridge	
Minimum	3460
10th Percentile	3864
25th Percentile	4108
Median	5060
75th Percentile	7753
90th Percentile	9597
Maximum	10900
n=	18

Table 21. Conductivity summary for Victoria and Dill St. residential drainage.

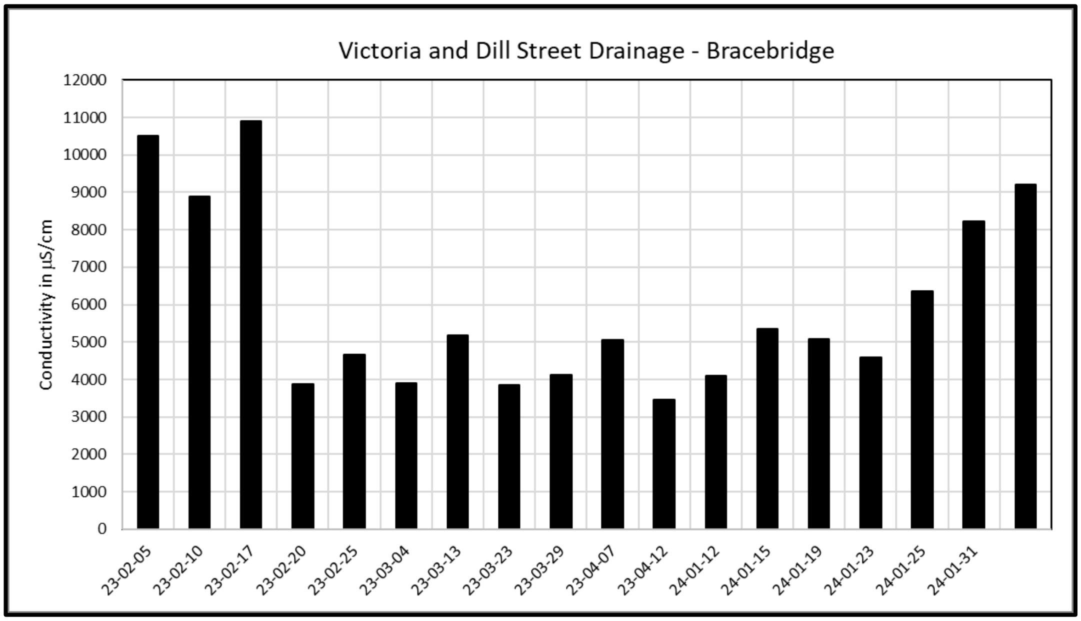

Figure 38. Conductivity measured at Victoria and Dill St. residential drainage.

4.2.4 Runoff to Wharf Road Storm Drain – BB4

Conductivity was high and highly variable for the urban drainage to the storm drain at Wharf Road (Figure 39), with a median value of 5495 µS/cm but a range of 1920 to 34,800 µS/cm (Table 23) with three samples measuring over 25,000 µS/cm. All samples were collected over the winter (January to April) periods of 2023 and 2024 and so represent responses to different winter events and not seasonality.

Wharf Road Drainage - Bracebridge	
Minimum	1920
10th Percentile	2962
25th Percentile	3705
Median	5495
75th Percentile	9825
90th Percentile	26114
Maximum	34800
n=	18

Table 22. Conductivity summary for Wharf Road storm drain – Bracebridge.

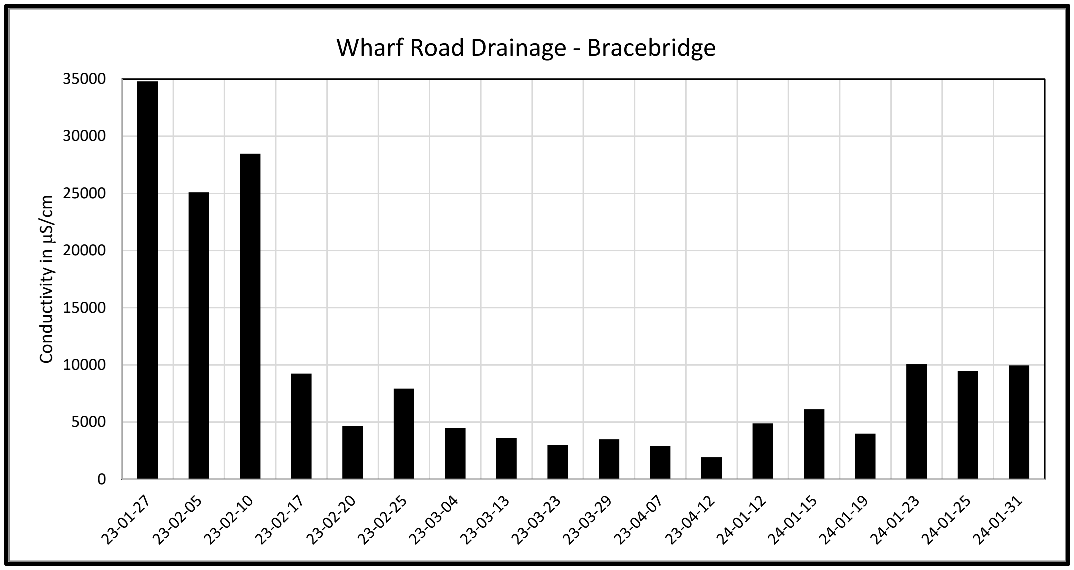

Figure 39. Conductivity measured at Wharf Road – Bracebridge.

5. Citizen Science Results – Spider Creek at Highway 11

Friends of the Muskoka Watershed: Spencer Macpherson

This catchment was originally selected to observe any changes in conductivity in Spider Creek above and below Hwy. 11. The creek was sampled at Hwy. 11 and at the Rowanwood Bridge just upstream of Mary Lake. Later review showed, however, that measurements at the Rowanwood bridge site downstream were more representative of drainage from a large and sparsely occupied catchment with little influence from the highway.

5.1 Site Description

Spider Creek drains an area of rural Muskoka to the west of Hwy. 11. The total area of the Spider Creek watershed is 7629 ha. There are two subcatchments. Runoff from the upper catchment of 2044 ha flows under the highway to Spider Lake and ultimately to the North Muskoka River by way of Mary Lake. (Figure 40). The lower subcatchment drains an area of 5585 ha to the southwest of the upper catchment and downstream from Highway 11 to Mary Lake.

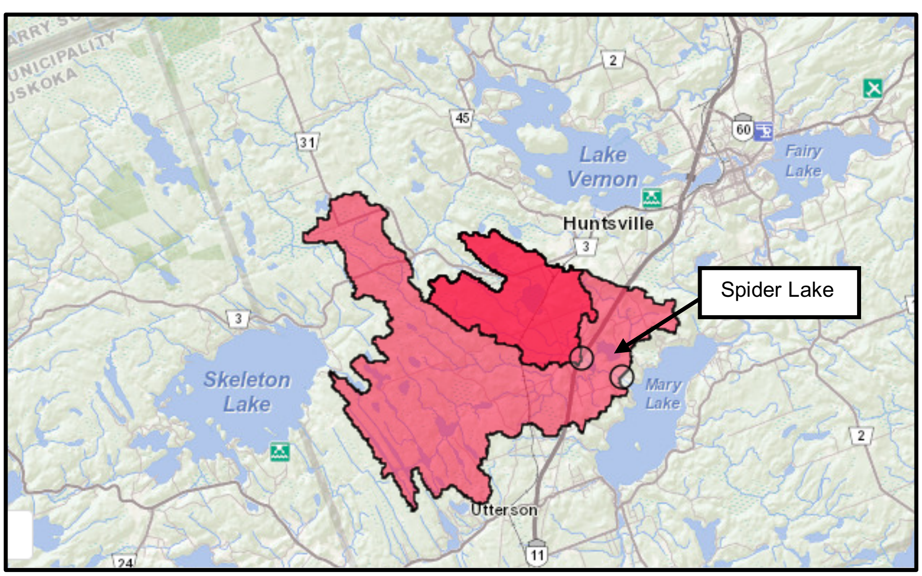

Figure 40. Spider Creek watershed. Upper watershed (red) drains to Hwy. 11 site and lower watershed (pink) drains to

Land uses and watershed areas for Spider Creek were derived using the Ontario Watershed Information Tool[10]. In the upper watershed of 2044 ha, 77.1% of land uses were classified as forested or wetland ("Undisturbed") and unlikely to include areas of salt application while 22.9% was classified as "community infrastructure" and therefore included potential areas of road salt application (Table 24.) By contrast, the lower watershed area of 5585 ha was dominated by undisturbed lands (95%) and road salt applications would be expected in only the 4% of lands classified as "community/infrastructure".

Land Cover Type	Upper Watershed		Total Watershed		Lower Watershed	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Clear Open Water	88	4.3%	415	5%	327	6%
Bog	59	2.9%	247	3%	188	3%
Sparse Treed	188	9.2%	678	9%	490	9%
Deciduous Treed	535	26.2%	2399	31%	1864	33%
Mixed Treed	551	27.0%	2659	35%	2108	38%
Coniferous Treed	133	6.5%	450	6%	317	6%
Bedrock	22	1.1%	50	1%	28	1%
Undisturbed	1576	77.1%	6898	90%	5322	95%
Community /Infrastructure	184	9.0%	412	5%	228	4%
Agriculture and Undifferentiated Rural Land Use	284	13.9%	283	4%	0	0%
Disturbed	468	22.9%	695	9%	228	4%
Other	0	0.0%	36	0.5%	36	1%
Total	2044	100%	7629	100%	5585	100%

Table 23. Land uses and areas in the Spider Creek watershed.

5.2 Results

Spider Creek was sampled 14 times between April 13 and May 12, 2023 (Fig. 41). Sampling notes show that air temperature ranged from -1 ^oC to 22 ^oC and that no snow fell during the sampling period. These measurements therefore represent late spring when road salt applications had ceased, instead of winter conditions. Median conductivity values decreased from 38 to 22 μS/cm between Highway 11 and the Rowanwood Bridge (Table 25) and statistics for more extreme values (75th 90th percentiles and maximum values) also decreased by half. These decreases were driven by the large volumes of water from the lower watershed in which 95% of the land was undisturbed in which little road salt application would be expected. The median value of 22 μs/cm measured at the Rowanwood Bridge therefore represents a near-background/unaltered state. Conductivity was only measured during spring and so no seasonal comparisons were possible.

	Spider Creek at	
	Hwy. 11	Rowanwood
Minimum	12	12
10th Percentile	15	17
25th Percentile	21	19
Median	38	22
75th Percentile	53	23
90th Percentile	55	28
Maximum	66	35
n=	14	14

Table 24. Summary statistics for conductivity in the Spider Creek watershed. All values are in μS/cm.

[10] https://www.lioapplications.lrc.gov.on.ca/OWIT/index.html?viewer=OWIT.OWIT&locale=en-CA

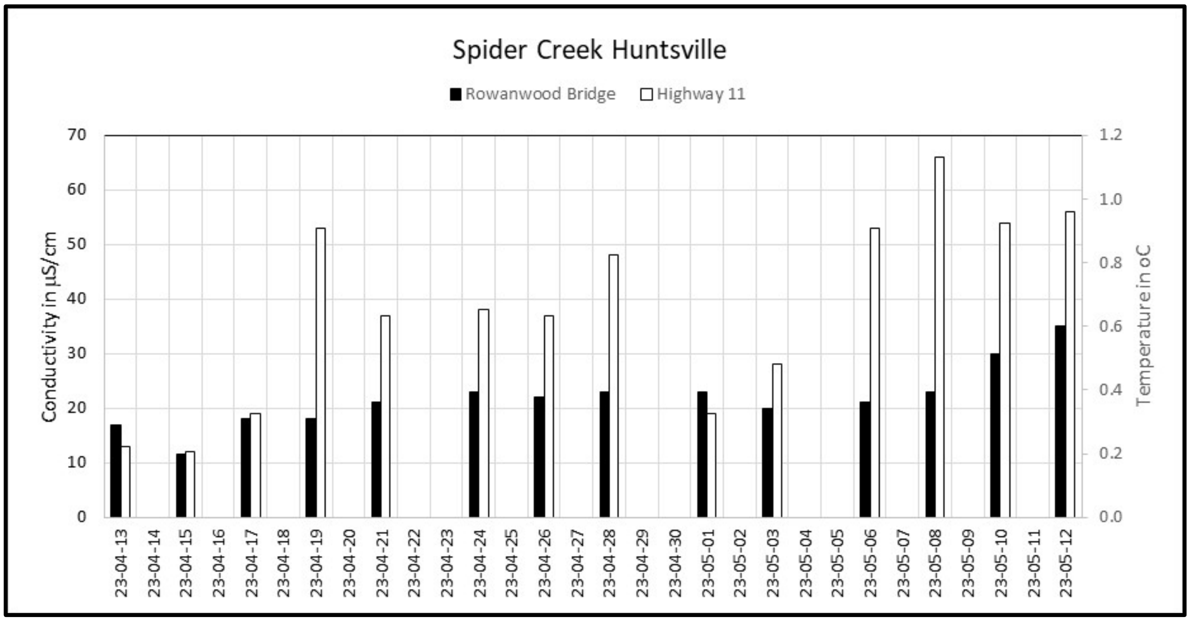

Figure 41. Spring patterns of conductivity in Spider Creek.

5.3 Summary

Overall, monitoring of the Spider Creek catchment showed very low conductivity and the late spring sampling represented flushing of winter conditions by runoff in which road salt indicators were low or non-existent. The lower watershed diluted conductivity measured for the upper watershed near Highway 11 with runoff from the lower watershed little influenced by human activities. Future monitoring efforts should focus on direct comparisons upstream and immediately downstream of Highway 11, as well as at the Rowanwood Bridge to assess any road salt effects and any recovery downstream. Sampling should include winter conditions and continue into the spring.

6. Citizen Science Results – Huntsville Summit Centre

Friends of the Muskoka Watershed: Spencer Macpherson

6.1 Site Description

Two sites were monitored at the Huntsville Summit Centre:

- The North Branch of the Muskoka River (Figure 42) was monitored at Centre Street in Huntsville on 8 occasions between March 21 and April 14. The watershed extends into western Algonquin Park with a total area of 1110 km^2
- Drainage from the Summit Centre property was also monitored on 8 occasions between March 21 and April 14 as an example of urban runoff

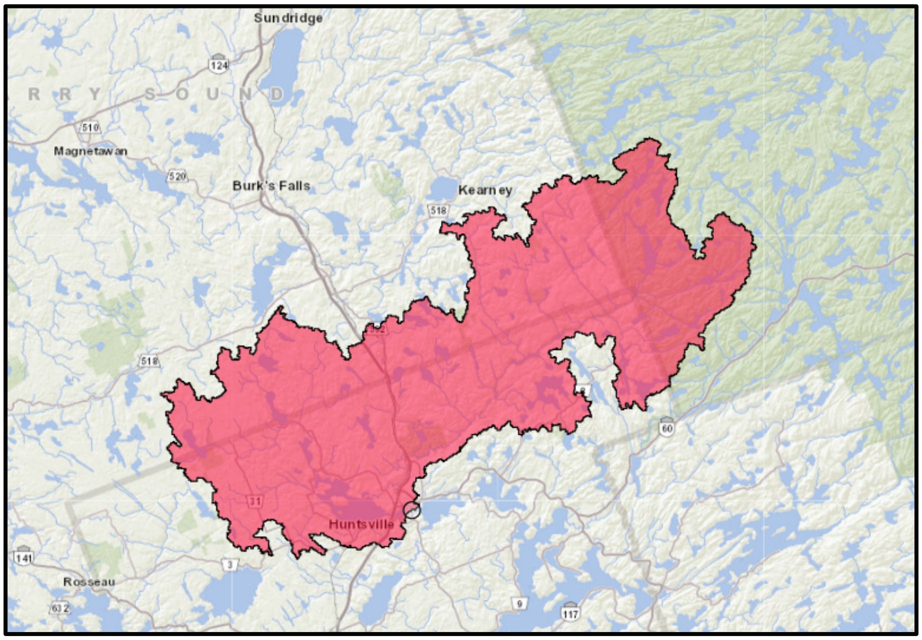

Figure 42. North Muskoka River watershed at Huntsville.

Land Cover Type	Area (Sq. Km.)	Percent
Clear Open Water	104	9.4%
Bog	25	2.2%
Sparse Treed	48	4.3%
Deciduous Treed	476	42.9%
Mixed Treed	338	30.4%
Coniferous Treed	84	7.6%
Bedrock	1	0.1%
Undisturbed	1077	97%
Sand/Gravel/Mine Tailings/Extraction	1	0.1%
Community/Infrastructure	13	1.21%
Agriculture and Undifferentiated Rural Land Use	19	1.72%
Disturbed	33	3%
Total	1110	100%

Table 25. Land uses and areas for the North Muskoka River watershed at Centre St., Huntsville.

Land uses and areas for the North Muskoka River were derived using the Ontario Watershed Information Tool. At Centre St. in downtown Huntsville, 97% of the total watershed area of 1110 km^2 was undisturbed and 85% of the watershed was forested (Table 26). Agricultural land uses accounted for 19 km^2 (1.7%) of the land use while the Town of Huntsville (Community Infrastructure) represented 13 km^2 (1.2%) of the watershed. At the mouth of the North Muskoka River at Fairy Lake, an additional 1.2 km^2 of urban land use is added. Drainage area at the Summit Centre was unknown but represents parking lots and sidewalks.

6.2 Results

Both sites were sampled only 8 times between March 21 and April 14 (Table 27, Fig. 43). Results from the North Muskoka River showed little influence of road salt use, as the watershed was 97% unaltered land use. Sampling notes show that air temperature ranged from 1 ^{o}C to 26 ^{o}C and that no snow fell during the sampling period. These measurements therefore represent late spring when road salt applications had ceased instead of winter conditions. The median conductivity value was 69 $\mu s/cm$ and individual samples ranged from 33 to 83 $\mu s/cm$, decreasing from March into April.

Conductivity was ~5X greater in runoff from the Summit Centre areas showing the influence of residual runoff from salting of parking areas and sidewalks in the late winter

	North Muskoka River	Summit Centre
Minimum	33	160
10th Percentile	38	203
25th Percentile	57	256
Median	69	334
75th Percentile	75	427
90th Percentile	80	470
Maximum	83	502
n =	8	8

Table 26. Summary statistics for conductivity at Huntsville Sites. All values are in µS/cm.

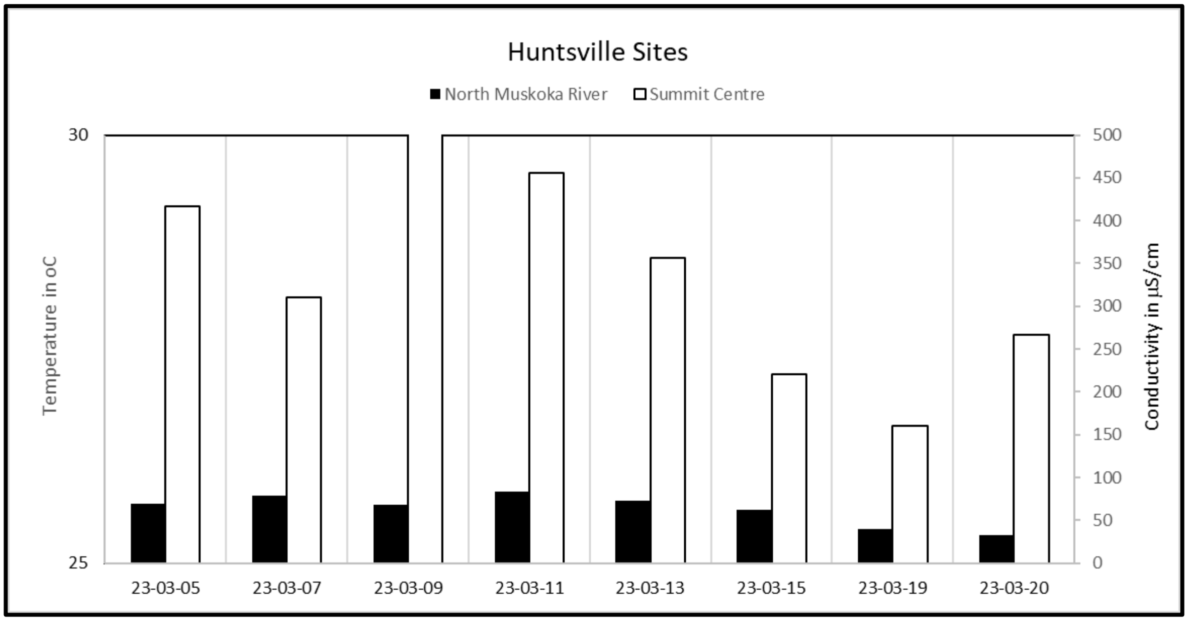

Figure 43. Spring patterns in conductivity at Huntsville sites.

6.3 Summary

Overall, monitoring of the Huntsville sites showed very low conductivity in the river and elevated conductivity coincident with the flushing of runoff from the Summit Centre sites in the spring. Future monitoring efforts should include sites in the river located upstream and downstream of the Town of Huntsville, should include winter conditions, continue into the spring and should include more urban runoff sources.

7. Leonard Lake

Leonard Lake Stakeholders Association

Esther Giesbrecht

Ken Riley

Leonard Lake is one of the few lakes in Muskoka in which there appears to be a declining trend in Cl concentrations (Figure 44). Results from the DMM's Lake System Health program show decreasing Cl concentrations over the past 15 years although the decline is slight and between-year variance is greater. The mean of the last 5 years was 4.85 mg/L.

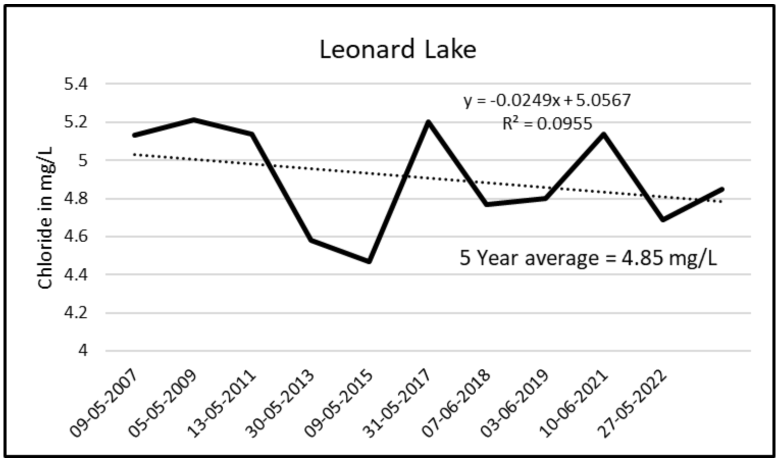

Figure 44. Chloride concentrations in Leonard Lake : 2007 –2022.

The Leonard Lake Stakeholders Association take an active role in the stewardship of Leonard Lake and began sampling for chloride in the lake and in runoff to the lake at 13 locations in 2023. Sites were sampled on April 20 and November 23, 2023 and on March 10 2024. Sampling locations are shown in Figure 45. Samples were filtered to remove any particulate matter and sent to a commercial laboratory for direct analysis of Cl, in contrast to the FMW program which estimated Cl on the basis of conductivity. Direct measurements of conductivity were made on March 10, 2024.

Two shoreline sites on Leonard Lake were sampled in early spring on April 20,2023. Chloride concentrations of 4.4 mg/L were slightly lower than the 2017-2022 average spring value of 4.85 mg/L measured by the District Municipality of Muskoka.(Table 28). Overall, Cl levels in Leonard Lake are enriched but are well below thresholds for protection of aquatic life (See Ch. 8).

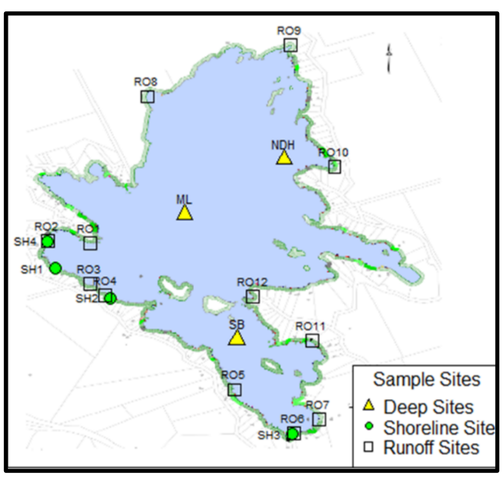

Figure 45. Sampling locations at Leonard Lake : 2007 –2022.

	Cl in mg/L			Conductivity	
	20-04-2023	23-11-2023	10-03-2024		Average
RO 1A	0.14		4	146	2.07
RO 2	2.4		3.2	76	1.87
RO 3	0.72	1.1	0.78	18	0.87
RO 5	6.8	9.3	4.5	28	6.87
RO 6	74.3		81.8	436	52.0
RO 7	81.8	94.7	40.7	183	72.4
RO 8A	0.15	0.3	0.21	12	0.22
RO 8B	0.13	4.7	0.18	9	1.67
RO 9	0.83	1.2	1.2	14	1.08
RO 10	0.39	2.3	0.41	16	1.03
RO 11	3.6	2.9	2.3	37	2.93
RO 12	2.5	2.9	2.7	55	2.7
RO 13			107.4	414	107
SH 4	4.41				4.4
SH 2	4.4				
DMM					4.9
Average RO<Lake					2.07
Average RO > Lake					43.8

Table 27. Chloride and conductivity measurements at Leonard Lake (2023-2024).

Chloride concentrations at 9 of the 13 runoff sites ranged from 0.13 to 2.9 mg/L and the average was 2.1 mg/L, well below current in-lake values (Table 27). Chloride at four sites was elevated, ranging from 4.5 to 107 mg/L , consistent with salt-contaminated runoff. Sites RO 6,7 and 13 were highly enriched, with average Cl concentrations of 52, 72.4 and 107 mg/L (overall average of 43.8 mg/L). They were situated in close proximity to Highway 118. RO 6 and RO 7 were located near the boat launch which is very near Highway 118. RO 13 (not shown on Figure 45) was at a culvert draining a large area near Highway 118 which emptied into a swamp and into the lake. RO 5 was only slightly enriched and drained a swampy area adjacent to the highway. Leonard Lake results are compared with those for the rest of Muskoka in Chapter 8.

The Cl sampling on March 10, 2024 was supplemented with in-field measurements of conductivity using a portable conductivity meter. The result showed a strong relationship between the two (Figure 46), such that future measurements of conductivity would provide reliable estimates of Cl using the equation:

$$\text{Cl (mg/L)} = 0.2277 * \text{Conductivity (in } \mu\text{S/cm)} - 6.14$$

The relationship is nearly identical to that derived by Friends of the Muskoka Watershed using DMM data (Ch. 3), providing confidence in the FMW robust predictive relationship:

$$\text{Cl (mg/L)} = 0.248 * \text{Conductivity (in } \mu\text{S/cm)} - 5.97$$

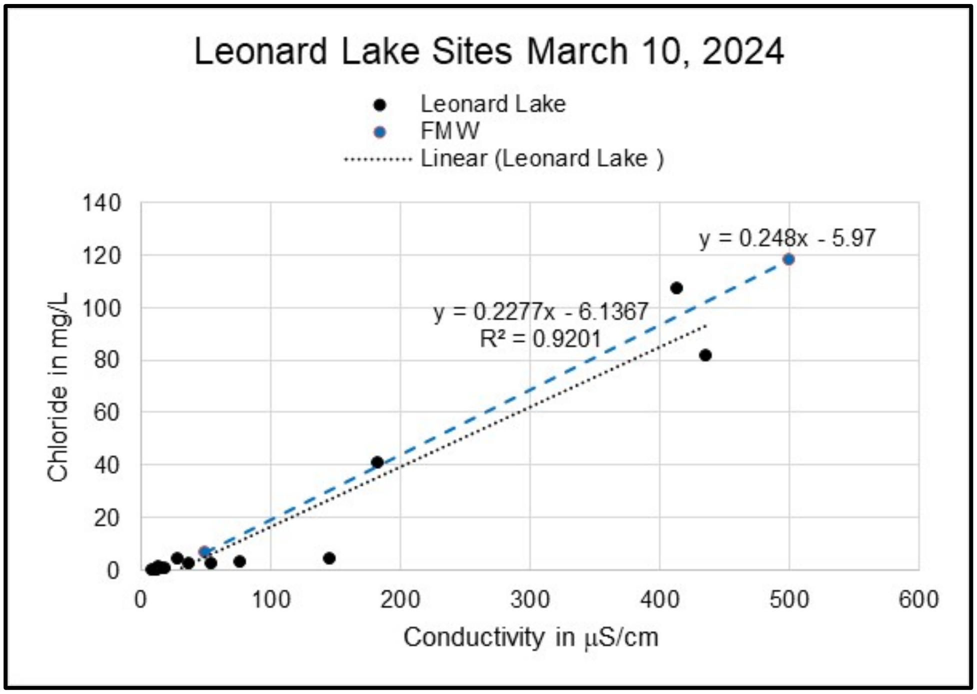

Figure 46. Conductivity vs chloride relationship for Leonard Lake samples (2023-2024).

8. Discussion and Conclusions

Citizen Science monitoring efforts revealed a wide range in conductivity over the 27 sites sampled from 2022 to2024 (Figure 47). The 27 sites were categorized into 3 types of receiving waters: natural water bodies, urban receivers and source areas (Section 8.1).

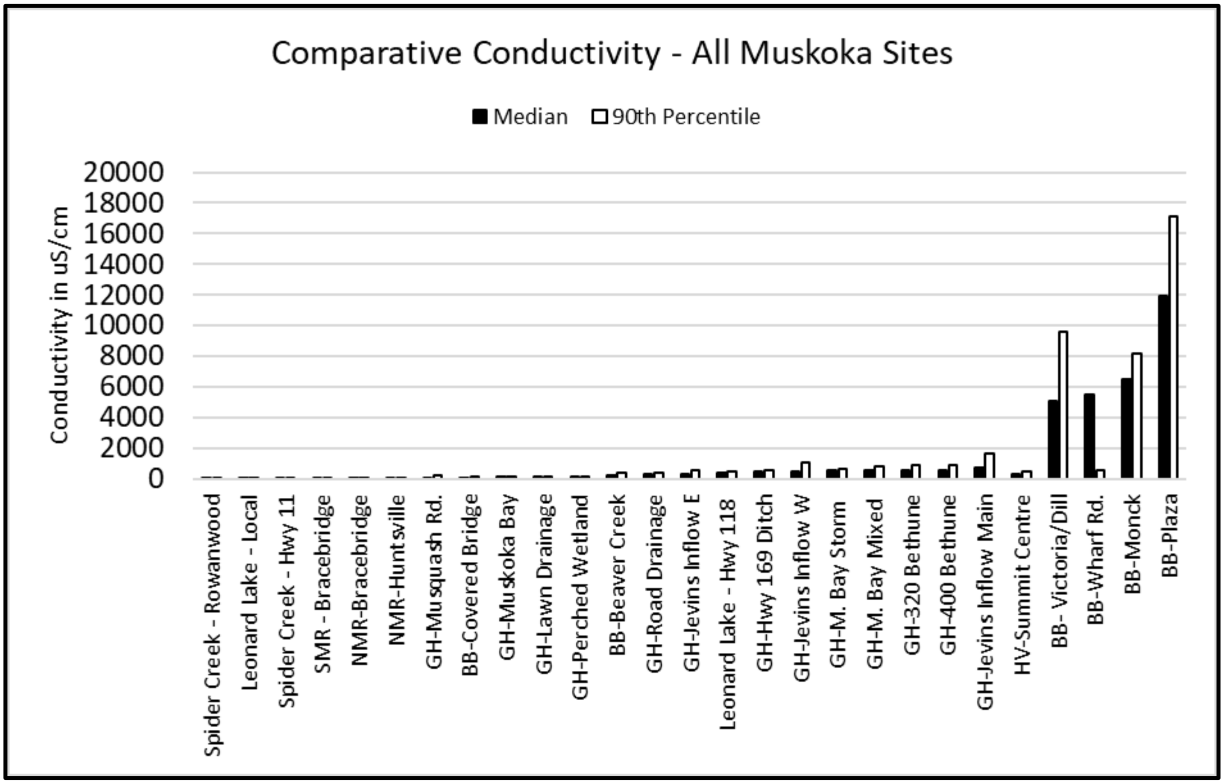

Figure 47. Median and 90th percentile conductivity across 27 Muskoka sites.

8.1 Receiving Water Summaries

8.1.1 Natural Watercourses

Nine sites represented natural water courses with minimal impact from urban runoff (Figure 48) where median conductivity ranged from 22 to 90 μS/cm and 90th percentile values ranged from 28 to 178 μS/cm. Of these eight sites, however, only the Spider Creek at Rowanwood site represented very little (10%) urbanization. The Spider Creek sites may not be representative, however, as they were sampled after winter, from mid-April to mid-May. Three sites at Leonard Lake, sampled March 10, 2024, had median and 90th percentile conductivities of 22 and 83 μS/cm and are more representative of winter conditions. The Musquash Road site in Gravenhurst was 7% altered yet had median and 90th percentile values of 62 and 178 μS/cm. These higher values with little watershed alteration may reflect differences in geology or soil thickness compared to Spider Creek. Sites on the North and South Muskoka rivers and Muskoka Bay are natural water bodies in which measured increases in Cl concentration have been measured but were included in this category as they are natural receiving water and not source areas.

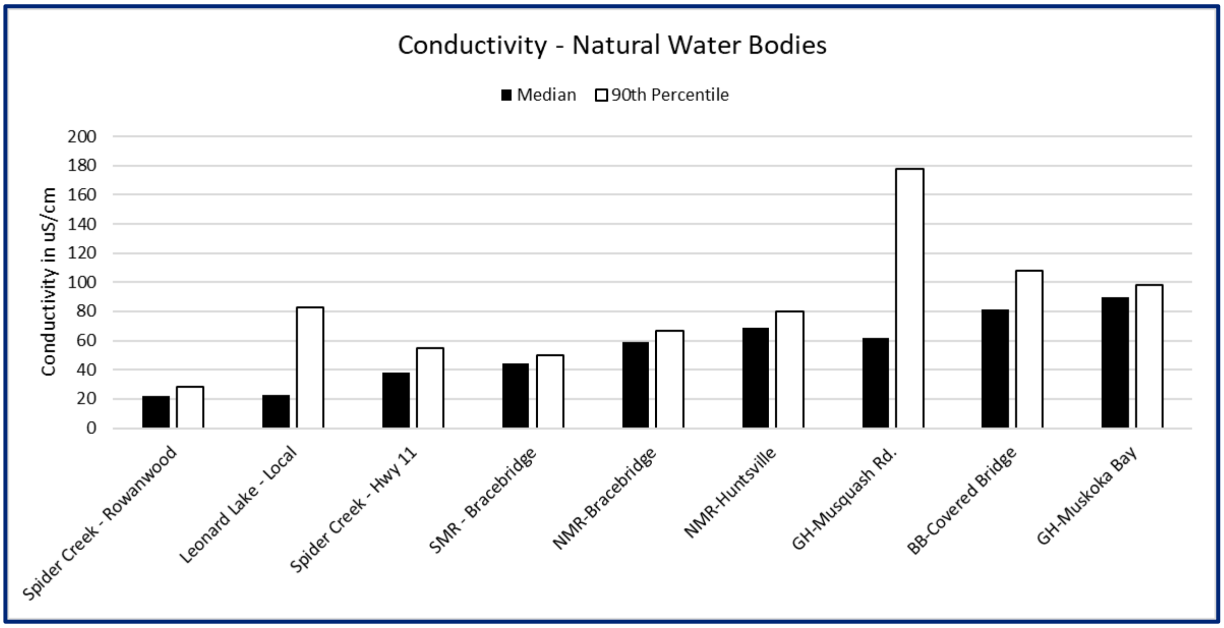

Figure 48. Range of median and 90th percentile conductivity across 9 natural water bodies in Muskoka.

8.1.2 Runoff Source Areas

Thirteen sites represented potential source areas where runoff from salting activities could flow to natural waters through urban drainage channels (Figure 49). Median conductivity values ranged from 90 μS/cm for drainage from an urban lawn into Gull Lake to 687 μS/cm for the main inflow to Jevins Lake and 90th percentile values from 107 to 1613 μS/cm. The average median value for the 13 sites was 405 μS/cm and this represented an ~5-fold increase from the average median value of 54 μS/cm for the 9 natural receiving waters.

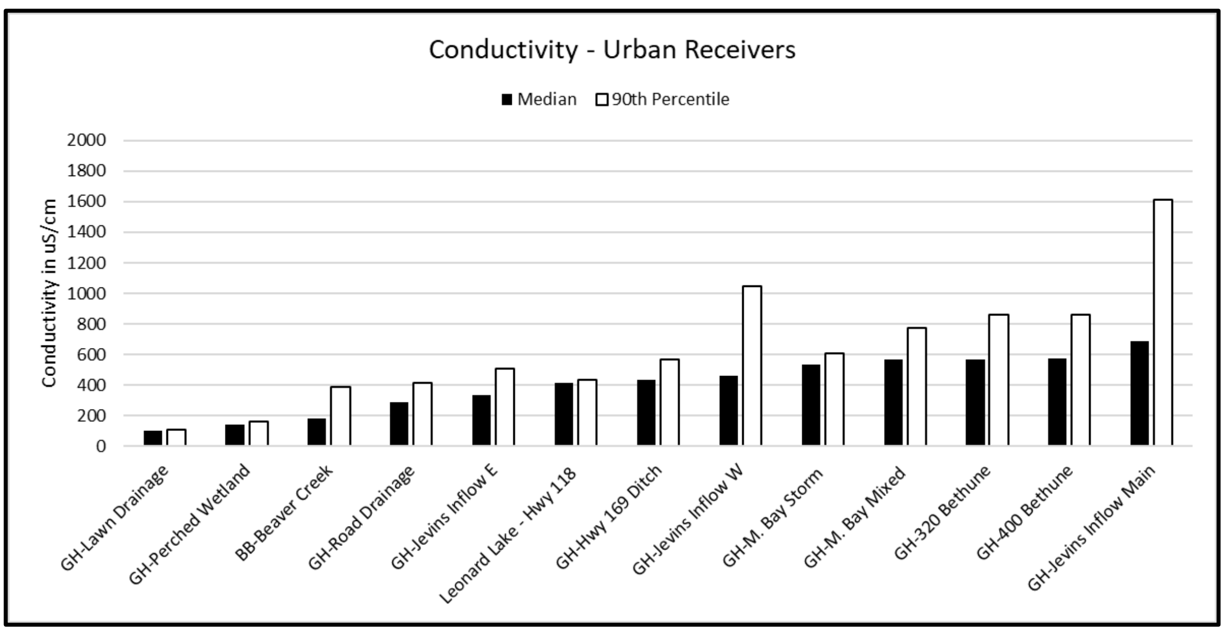

Figure 49. Median and 90th percentile conductivity across 13 Muskoka urban receiver sites.

8.1.3 Storm Drain Sources

Five sites represented direct sampling of storm drains from known urban sources (Figure 50).

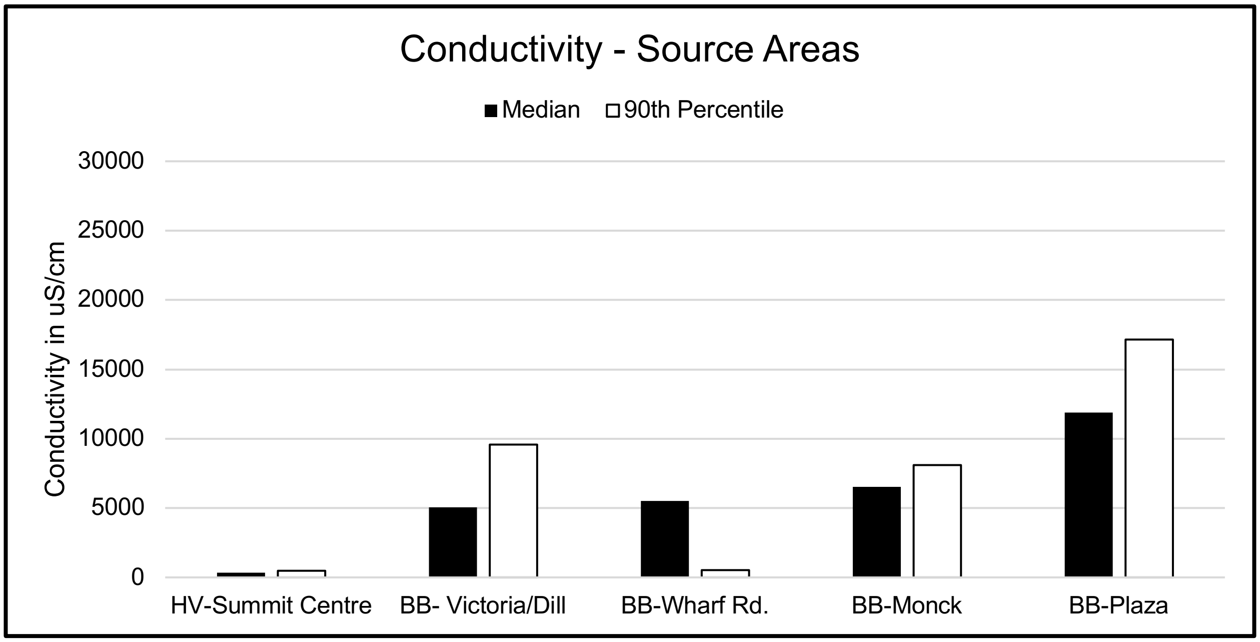

Figure 50. Median and 90th percentile conductivity in 5 Muskoka storm drains.

The Huntsville Summit Centre runoff samples were taken in April and May, after winter activities and so are not representative of winter conditions. The four storm drains in Bracebridge, however, were sampled in winter and spring. Median conductivity values ranged from 334 to 6520 μS/cm and 90th percentiles from 470 to 8120 μS/cm. The average of the median measurements (7245 μS/cm) represents an enrichment of 125X over the median conductivity in the 8 natural water bodies. Continuous (automated) monitoring at hourly intervals is recommended in source areas (urban runoff) where concentrations may change quickly in response to storms and temperature changes.

Conductivity measurements therefore indicate substantial pollution of Muskoka's natural waters by road salt from residential, commercial and highway sources with potential for toxic effects to sensitive aquatic life.

8.2 Toxicity of Runoff

A major concern with road salt in Muskoka waters is the potential for toxicity to sensitive aquatic life. While the Canadian Water Quality Guideline for continuous, long-term exposure to Cl is 120 mg/L (CCME 2011) recent research highlights that this concentration is toxic in Muskoka's soft waters and safe exposure concentrations are <20 mg/L (Arnott et al. 2020, Valleau et al. 2020, Yan, 2020).

CCME (2011) advises that exposures of aquatic life to Cl concentrations exceeding 640 mg/L is lethal during short term ("acute") exposures, generally for 48 to 96 hours. Buren and Arnott (2024) found that 10% of four Daphnia species were immobilized at Cl concentrations ranging from 489 to 608 mg/L (average = 535 mg/L) in soft water (Ca < 2 mg/L). The average toxicity threshold of 535 mg/L Cl corresponds to a conductivity of 2180 μS/cm and so that value was adopted as a toxicity threshold for short term exposure in soft Muskoka waters.

The FMW equation (Yan 2020) relates conductivity to Cl by : Chloride = (0.248*Conductivity)-5.97. A conductivity of 105 μS/cm thus corresponds to a Cl concentration of ~20 mg/L. The potential for toxicity of the conductivity results was therefore assessed against:

- >105 μS/cm as potentially chronically toxic to sensitive aquatic life in soft water over long tern exposure
- >2180 μS/cm as potentially acutely toxic during short term exposure in soft Muskoka waters
- >510 μS/cm as potentially chronically toxic during long term exposure according to CCME (2011)
- >2605 μS/cm as potentially acutely toxic during short term exposure according to CCME (2011)

Continuous monitoring results were not available by which to assess exposure duration and so:

- median conductivity values were used to assess chronic (long term) toxicity as concentrations would exceed median values at least half the time (long term).
- 90th percentile values used to assess acute (short term) exposure as concentrations greater than the 90th percentile would occur for short periods (<10% of the time).

Data from the 27 sampling sites (Figure 47) were compared to the long term exposure guidelines as these water bodies represent habitat for aquatic life. In practice, effluent discharges to surface waters in Canada are permitted with the objective that the receiving waters remain safe for long-term exposure.

Storm drains and urban runoff sources do not represent aquatic habitat but discharges to surface waters in Canada must not be acutely lethal under Canada's Wastewater Systems Effluent Regulations (WWER) as part of the Canada Fisheries Act[11]. Therefore, 90th percentile values data from the 12 Urban Receivers (Figure 49) and 5 Source Areas (Figure 50) were compared to the CCME guideline of 640 mg/L (2605 μS/cm) and the Muskoka soft water guideline of 2180 μS/cm.

- None of the natural water bodies sampled had median values that exceeded 105 μS/cm and so Cl concentrations were not likely to threaten long or short term survival of sensitive aquatic life in these soft waters.
- Acutely lethal concentrations for soft water exposure (> 2180 μS/cm) were exceeded by median and 90th percentile concentrations in all four storm drains monitored in Bracebridge (Figure 50).
- Median conductivity values exceeded the CCME (2011) guideline of 510 μS/cm for long term exposure in 5 of the 12 Urban receivers (Figure 49). Of these, the main inflow to Jevins Lake represents potential aquatic habitat in which aquatic life would be threatened by Cl exposure.

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[11] This interpretation Is not strictly accurate as the WWER were written to apply to specific water quality parameters that are not to exceed lethal levels. *For the purpose of the definition "deleterious substance" in subsection 34(1) of the Act, the following substances or classes of substances are prescribed as deleterious substances:(a) carbonaceous biochemical oxygen demanding matter;(b) suspended solids;(c) total residual chlorine; and (d) un-ionized ammonia.*

In practice, however, whole effluent discharges, regardless of the specific contaminants they contain, must not be acutely lethal.

In summary, although Cl in runoff in many of the sampling sites was high enough to be toxic, the natural receiving waters, with one exception, remained within safe levels for sensitive aquatic life.

Management efforts must reduce the Cl in runoff to protect against further increases in receiving waters.

Some studies (Arnott et a. 2020, Valleau et al. 2020) show toxicity of Cl at concentrations below the 20 mg/L (105 µS/cm) threshold that was used to interpret the conductivity levels documented in our surveys. The research into the toxicity of Cl in soft waters should therefore be reviewed and summarized into a water quality objective, using formal procedures (CCME 2003) that protect the soft waters of Muskoka. Monitoring results could then be compared against a threshold of toxicity that was directly applicable to Muskoka waters.

8.3 Conclusions and Recommendations

The Citizen Science investigations indicate substantial pollution of Muskoka's natural waters by road salt from residential, commercial and highway sources with potential for toxic effects to sensitive aquatic life. Urban runoff from the storm drains that service large commercial properties in Gravenhurst and Bracebridge had conductivity values that would be rapidly lethal to sensitive aquatic life (Section 8.2) and which would contribute to the observed increases in conductivity and chloride in Jevins Lake and Beaver Creek (Section 3.2, 3.2, 3.4, 4.1) and resultant chronic toxicity in those water bodies (Section 8.2).

Citizen scientists provided data that was valuable in terms of identification of multiple local sources from first hand knowledge and frequent sampling by virtue of the proximity of the volunteers to areas of concern. While frequent sampling during the winter season of road salt application (November to March) was very valuable, summer sampling proved to be valuable as well, showing that enriched conductivity persisted into the summer season, even after salt applications ceased. Conductivity values dropped quickly in spring in drainages that were largely hardened (Fig. 25, 26, 33, 34) but enriched values persisted in catchments where soils and vegetation retained chloride and released it slowly after the winter season. This pattern was shown most clearly in the Jevins Lake inflow but was evident at many sites.

This suggests that other factors besides seasonal chloride loadings, such as wetland hydrogeological dynamics, could influence chloride concentrations. There are three ways potential mechanisms for this and all are worthy of further investigation:

- First, that loadings from winter runoff are stored in wetlands and soils so that their migration into surface water is delayed and concentrations are less seasonally dependent. Dugan and Rock (2021) reported that chloride can be transported through soils in shallow groundwater systems such that transport and salinization proceed more slowly than predicted on the basis of assuming surface runoff only. In these cases chloride is stored in the soil, to be released more slowly to surface water in non-winter months, long after application.
- Second, that once winter loadings move into wetlands and soils, dry summer conditions concentrate chloride concentrations, such that they are higher than those measured in wetter seasons and
- Third, that other ions besides chloride that are mobilized by other wetland processes (e.g. sulphate oxidation, DeVito and Hill 1998) result in increased conductivity in surface waters.

Further investigation into year-round wetland dynamics and specific ion analyses would provide insights into the behaviour of road salt residues but would not alter the fact that Cl-enriched runoff is a concern year round, and that winter loadings persist into the summer.

Monitoring at Site 9 in Gravenhurst (Section 3.3.1., Tables 8 and 9) initially suggested that runoff from Hwy. 169 was enriching conductivity in an inflow to Muskoka Bay from mixed residential land uses. Further investigations, however, revealed that the enrichment occurred in a wetland area upstream of Hwy. 169 and may have been a result of historic land use – the former Gravenhurst WWTP. Further investigation and laboratory analyses for specific ions and other potential contaminants is warranted to a) determine the source of the observed enrichment and b) determine of there are other contaminants besides chloride in the runoff that may be entering Muskoka Bay.

The results presented here can help guide future efforts to reduce road salt pollution by identifying important sources of polluted runoff. Urban runoff from the storm drains that service large commercial properties, in particular, are important sources that were documented in Gravenhurst and Bracebridge. Continuous (automated) monitoring at hourly intervals is recommended in source areas (urban runoff) where concentrations may change quickly in response to storms and temperature changes. Sites in Huntsville should be identified and sampled, as sampling there was limited in spatial extent and sites were only sampled in April.

Citizen scientist efforts should be focused on urban source terms and not on individual lakes. The spring sampling program of the District Municipality of Muskoka provides good coverage of long term trends on Cl concentration and spring sampling of chloride is providing good data on long term trends and which lakes are changing.

Conductivity vs chloride relationships presented for Muskoka's lakes (Fig.4), Ottawa source areas (Fig. 5) and runoff to Leonard Lake (Fig. 46) all showed similar patterns in that the numeric value of conductivity measurements in μS/cm were ~ 4X the corresponding chloride concentration in mg/L. This relationship held true over a large range of measurements. Chloride concentrations can therefore be usefully approximated by dividing a measured conductivity value (μS/cm) by 4. For the Gravenhurst sites, two widely differing relationships between conductivity and Cl were obtained differing and both were different again from the FMW lakes, Leonard Lake and Ottawa relationships. Further detailed investigations of the ionic makeup of Gravenhurst runoff sites is warranted.

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Appendix 1 The Road Salt Threat to Muskoka Lakes: Answering 10 Key Environmental Questions.

FMW2020-09AR
Yan, N.D. 2020.
https://fotmw.org/fomw-publications/the-road-salt-threat-to-muskoka-lakes-answering-10-key-environmental-questions/

Summary

Road salt represents a threat to the long-term health of Muskoka watersheds. Because Friends of the Muskoka Watershed's vision is "*to protect Muskoka Watersheds Forever*", road salt requires FMW's attention. In this Muskoka-focused review, we answer 10 questions about the threat of road salt to local waters.

1. **What are the natural background levels of chloride (Cl) in Muskoka lakes; are they stable, or has the base line changed?** Levels of Cl are very low in Muskoka lakes with no winter-maintained roads in their catchments. Levels averaged about 0.5 mg/L four decades ago, and have since fallen by about 50% to about 0.25 mg/L.

2. **What is the current range of Cl levels among Muskoka lakes; why is it so large?** Cl levels now range over 700-fold (0.16 to 116 mg/L) among the Muskoka lakes monitored by the District Municipality of Muskoka. The range is large both because reductions in natural Cl inputs have lowered the current minimum observed Cl levels in undeveloped lakes, while levels in some developed lakes near winter-maintained highways have increased and now approach or in one case, exceed 100 mg/L.

3. **How do we know that road salt is responsible for the elevated Cl levels?** The almost perfect 1:1 correspondence of Cl with sodium (Na) concentrations across the 700-fold range in Cl establishes that the Cl salt source is NaCl. As there are no natural local marine salt deposits in Muskoka, and the lakes with elevated Cl levels all have major winter-maintained highways in their immediate catchments, road salt is the only logical salt source.

4. **What Cl levels are safe for aquatic biota in Muskoka?** A Muskoka-specific Water Quality Guideline (WQG) for Cl should be well below the Canadian WQG of 120 mg/L, but choosing a specific protective threshold is difficult, both because the modifying effects of water hardness and food levels have been assessed only for 6 water flea species, and because the choice involves a value judgement. How protective do we wish to be? A Muskoka-specific protective guideline should likely fall between 5 and 40 mg of Cl/L, i.e. between 20 and 160 times, respectively, the current Muskoka background level of 0.25 mg/L.

5. **How many Muskoka lakes currently have Cl concentrations that exceed safe levels for aquatic biota?** Depending on the safe level selected, 6 to 44% of the lakes in the District's monitoring program have been damaged by road salt, but the true number is not currently known because Cl levels have been measured in only about 10% of the lakes in the watershed.

6. **Is road salt an issue in Lake Muskoka, our most iconic lake?** Yes. Lake Muskoka is holding at least 12000 tonnes of road salt in its waters[12], and concentrations in Muskoka Bay have risen to levels that likely threaten its aquatic life.

7. **Might climate change or development worsen the Cl problem?** At the moment we simply don't know if climate change will worsen the road salt threat over the long term, but without changes in behaviour and policies, major population development will certainly worsen the problem.

8. **What else does road salt threaten, and can we estimate the overall cost?** Road salt threatens aquatic plants and animals, pets, roadside vegetation, ground and drinking water supplies, infrastructure, and vehicles. We can't yet estimate the total cost but it may well be in the millions of dollars for Muskoka, and the billions of dollars for Canada. These costs of road salt should be considered along with its benefits for road safety.

9. **How much salt is used as a de-icer in Muskoka?** We don't currently know but it certainly is tens of thousands of tonnes.

10. **What can be done about the road salt problem?** Lots, if we put our minds to it.

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[12] A more recent analysis suggests 30,000 tonnes is a more likely estimate.

Appendix 2 Site – Specific Conductivity : Chloride Relationships

Samples from the Gravenhurst FWM sites were submitted to the analytical lab of the Dorset Environmental Science Centre (MECP) in November of 2021 and in February and April of 2022 for comparison of measured chloride concentrations against the conductivity:chloride relationship developed by the FMW (Ch.2). A total of 33 samples were analysed for a range of major ions (chloride (Cl), sodium (Na), magnesium (Mg), calcium (CA), sulphate (SO4) and potassium (K)). Conductivity was measured at the time of sample collection with a portable conductivity probe.

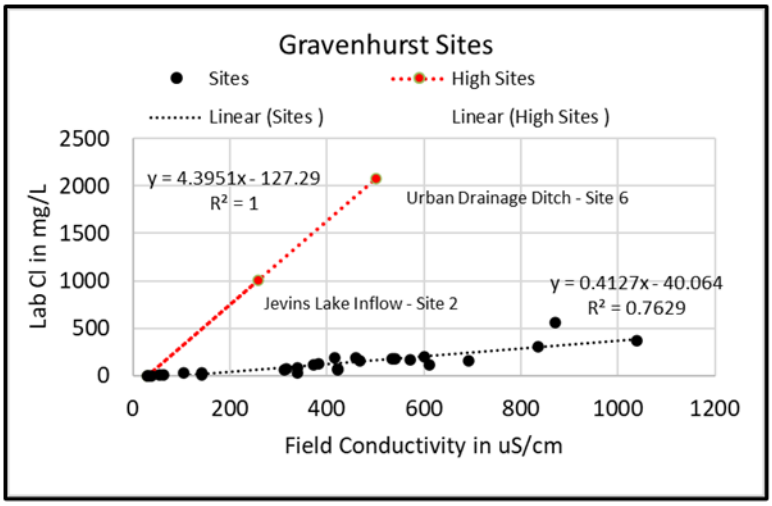


Figure 51. Conductivity:chloride relationship for Gravenhurst sites.

Two separate relationships were documented (Figure 51). Most sites fell into a relationship where : Chloride = (Conductivity * 0.41) – 40.1) but three apparent outliers ("High Sites") formed a perfect fit described as Chloride = (Conductivity * 4.4) – 127.3. Both lines fell well outside of the FMW relationship for Muskoka's Lakes and there is no immediate explanation for the difference. The two highest Cl values were recorded at the Urban drainage Ditch (Site 6) and the Jevins Lake inflow downstream (Site 2). The tight relationship between sodium (Na) and chloride (Cl) observed (Fig. 52) confirms that road salt is the major source of enrichment.

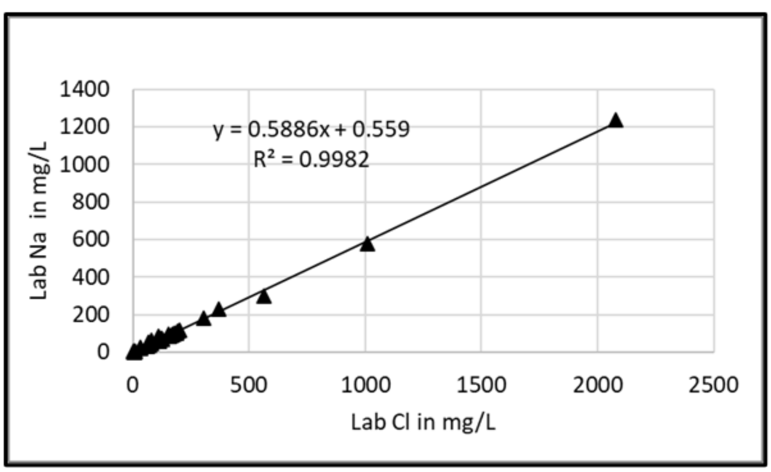


Figure 52. Sodium vs chloride relationship for Gravenhurst sites.

Comparison of the sum of all ions (Cl+Na+Ca+K+Mg+SO4) with conductivity (Figure 53) shows the same general relationship as with Cl only (Figure 53), with the same two outlier sites. There is no clear explanation for these results and further research focussing on all ions and groundwater is warranted.

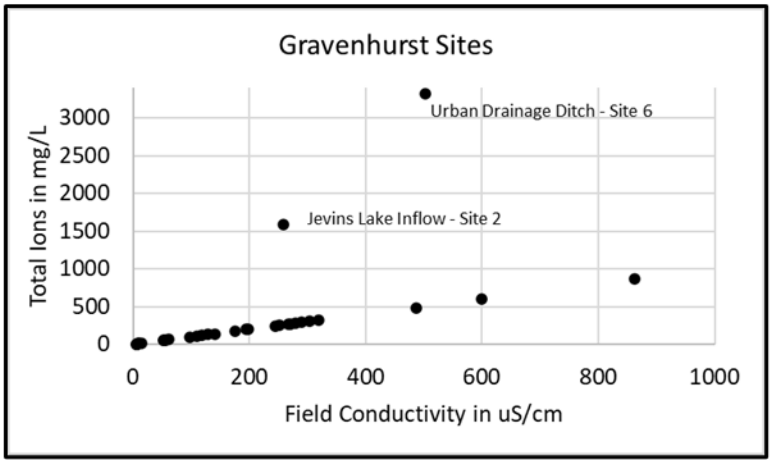


Figure 53. Relationship of conductivity to total ion concentration for Gravenhurst sites.

Appendix 3. Sources of Chloride Pollution - A Tale of Two Lakes

Neil Hutchinson, Ph.D. Friends of Muskoka Watershed

I live on a small lake, Halfway Lake, outside of Bracebridge. Halfway Lake has a surface area of 14 ha and a watershed area of 471.4 ha (Figure 54). There are 7 permanent residences in the catchment which is bisected by Hwy, 117, and a year-round road is maintained along the entire north shore of the lake (Figure 54). The catchment is 94% forest and wetland and only 6% is considered altered as "Community Infrastructure"[13]. In spite of the rural character and low development intensity, spring monitoring by the District Municipality of Muskoka shows that chloride concentrations are high (average of most recent 2 measurements = 15.7 mg/L) and increasing (Figure 55) in Halfway Lake. These results are nearly identical to those seen in the highly urbanized Muskoka Bay in the Town of Gravenhurst (average of most recent 2 measurements = 16.1 mg/L).

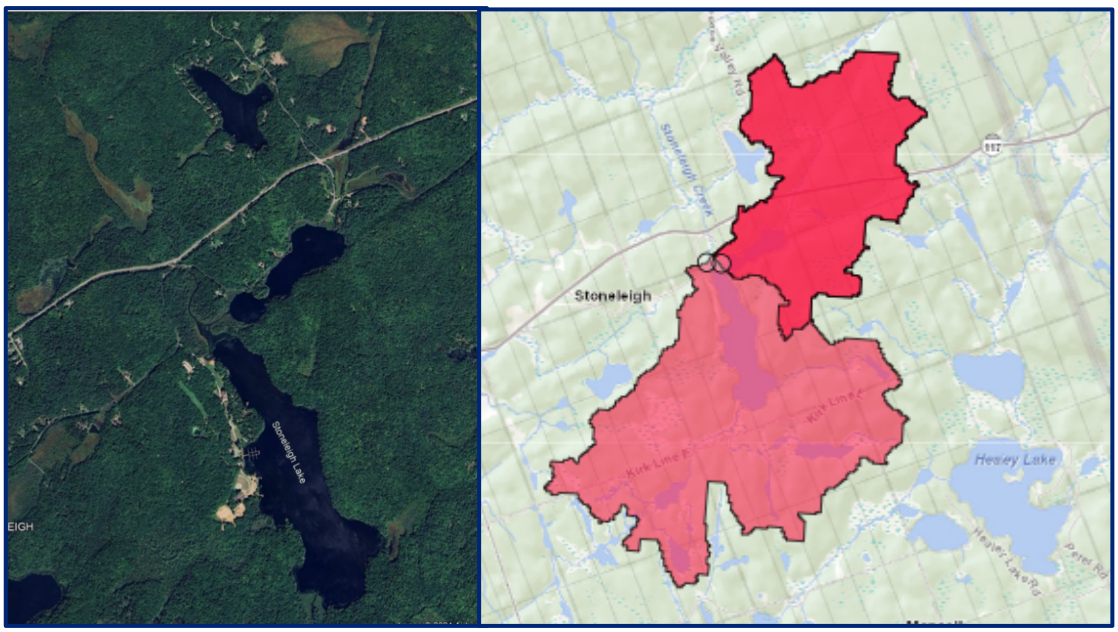


Figure 54. Halfway Lake and Stoneleigh Lake locations (left) and watersheds (right), Town of Bracebridge.

[13] Ontario Watershed Information Tool.

https://www.lioapplications.lrc.gov.on.ca/OWIT/index.html?viewer=OWIT.OWIT&locale=en-CA

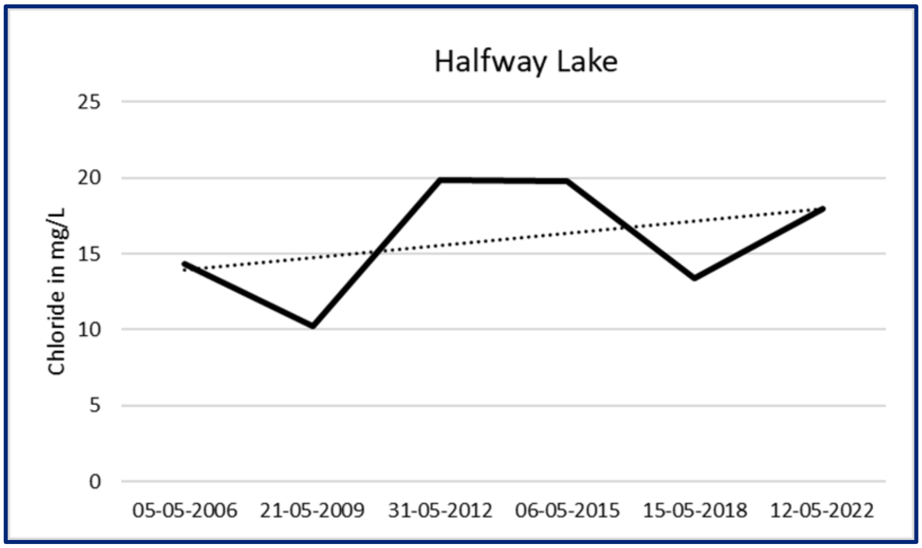


Figure 55. Increasing chloride concentrations in Halfway Lake : 2006 -2022.

Halfway Lake flows into the outflow of Stoneleigh Lake, approximately 500m downstream (Figure 54). Stoneleigh Lake has a surface area of 50 ha and a local watershed area of 837 ha. Runoff from Hwy. 117 flows away from the lake and the only urban feature is a summer camp and a road, which is not salted in winter. The absence of maintained roads and year-round residences results in very low Cl concentrations and no increasing trend (Fig. 56). The long term average Cl concentration is 0.51 mg/L which is considered the background or original concentration in Muskoka's lakes (Yan, 2020).

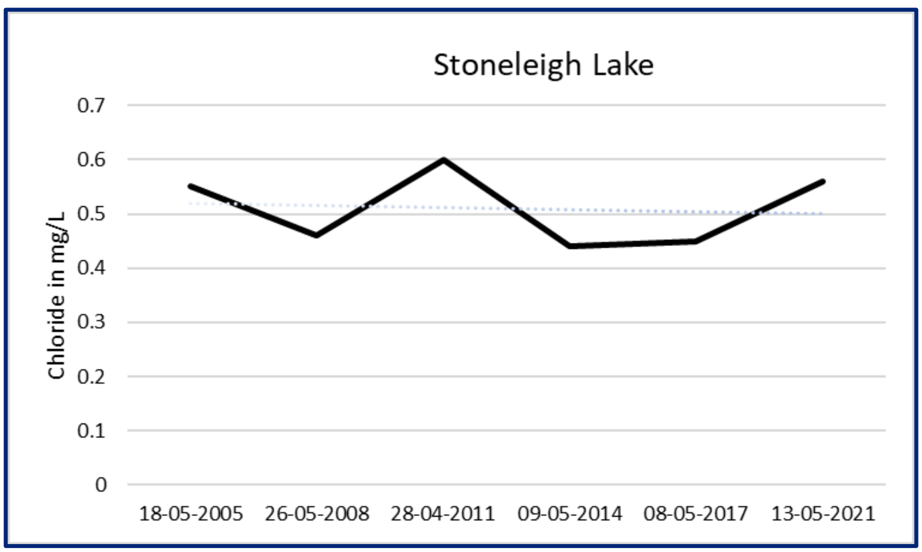


Figure 56. Chloride concentrations in Stoneleigh Lake: 2005 -2021.

These two lakes are located in the same geological setting and are adjacent to teach other and differ only in a) the presence of a year round access road, a highway and residences on Halfway Lake and b) resultant increased chloride concentration in Halfway Lake.

Appendix 4 Chloride Stratification in Muskoka Bay – March 2, 2023

Neil Hutchinson, Ph.D. Friends of Muskoka Watershed

The immediate focus of our road salt investigations was concern over the potential for toxicity of the chloride ion to sensitive aquatic life in the soft waters of Muskoka (see Ch. 1). Salinization, however also has physical impacts on lakes through increased density of salt enriched waters and the potential for interference with the dynamics of lake stratification and overturn (Dupuis et al. 2019, Ladwig et al. 2021). Lake stratification and overturn are responses to temperature-dependent changes in water density. Salinization increases the density of fresh waters such that the seasonal responses of lakes to temperature changes may be altered as salinity increases. Detailed investigations by Ladwig et al. (2021) documented delayed spring overturn in responses to increased salinity from road runoff and resultant increased density in Lake Mendota and Lake Monona in Wisconsin.

Muskoka Bay in Gravenhurst receives direct inputs of saline urban runoff from its catchment (Section 3.3) such that chloride concentrations have risen from ~ 0.5 mg/L to ~ 17 mg/L (Fig. 2, Section 1). The Friends of the Muskoka Watershed therefore completed a profile of conductivity in Muskoka Bay on March 1, 2023 to determine the status of conductivity and whether it increased with depth.

A Van Dorn bottle[14] was used to collect discrete samples of water at 1m intervals for the surface to the bottom (~15m) of Muskoka Bay at the District of Muskoka deep water sampling site (Sample Point: 44.9259 -79.3979). Water samples were brought to the surface where temperature and conductivity were measured with a portable conductivity probe (Photo 5).

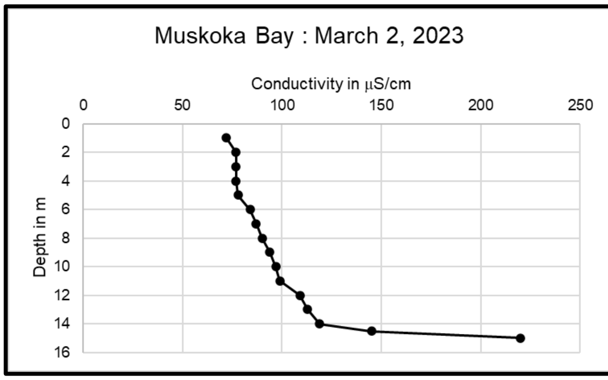
Photo 5. Spencer MacPherson and Dr. Neil Hutchinson of FMW sample Gravenhurst Bay on March 2, 2023. Photo : Sandy Lockhart, FMW.

The density of water is highest at 4 °C such that water which is warmer or colder will “float” on top of the denser water below. This was observed in Muskoka Bay where water temperature declined from 0.6 °C at the surface to 2.9 °C at the 15m depth (Figure 57, right). Conductivity also increased gradually with depth and showed a sharp increase at the bottom, suggesting that a layer of cold, salty

[14] We thank Hutchinson Environmental Sciences Ltd. and Michalski – Nielsen Associates Ltd. for equipment loan.

water was present. Chloride was estimated using the FMW equation as increasing from 12 mg/L at the surface to 49 mg/l at the bottom.

Urban runoff into Muskoka Bay has therefore a) increased the overall salinity of the bay and b) produced a denser layer of salty water at the bottom of the bay. Additional monitoring is needed to determine the duration of the salinity and stratification and whether it changes from one year to the next.



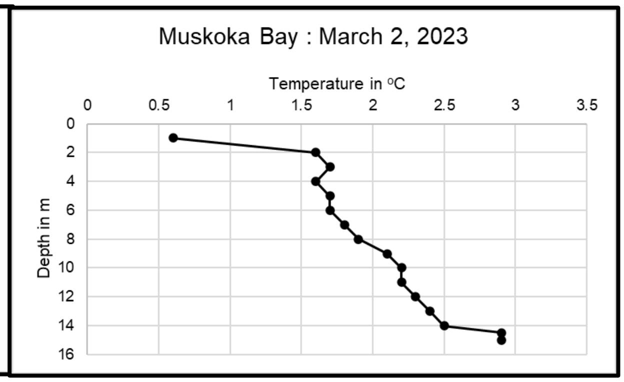


Figure 57. Profiles of conductivity, left, and temperature (right) in Muskoka Bay. March 2, 2023.