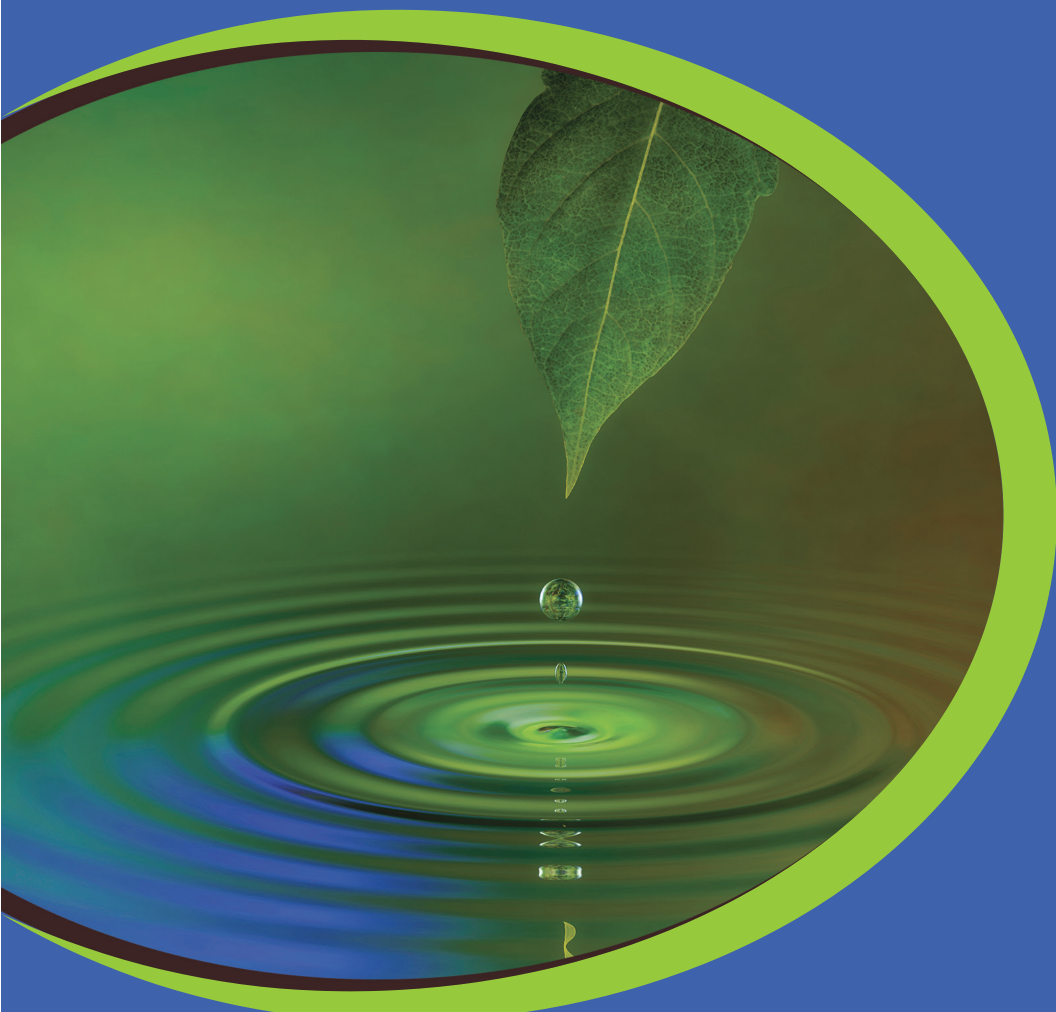
REPORT

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

FMW2020-09AR



Norman D. Yan, PhD, FRSC

Friends of the Muskoka Watershed

Document #: FMW2020-09AR

September 18, 2020

Friends of the Muskoka Watershed is an incorporated, member- and donor-supported non-profit organization whose vision is to ensure healthy Muskoka watersheds forever. To fulfil that vision, we collaborate with local and scientific communities to identify, develop and foster solutions to watershed stressors in Muskoka.

Please direct all questions, comments and inquiries to:

friends@fotmw.org

PO Box 416, Bracebridge, ON   P1L 1T7

Contents

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, 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, road side 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.

Introduction

Salinization is one of the most widespread current threats to life in freshwaters around the world (Reid et al. 2019). Agricultural irrigation, land clearing, and resource extraction can each increase freshwater salinity, and climate change does exacerbate the threat (Carnedo-Arguellas et al. 2019); however, in Canada, the most common cause of increasing salinity in lakes and rivers is the use of de-icing compounds on roads in the winter. The principal de-icing salt is sodium chloride, NaCl (Dugan et al. 2017).

North American road managers began using NaCl as a de-icer in 1938, and by the 1950s the practise was widespread (Kelly et al. 2010). In Canada, roughly seven million tonnes of salt are now used annually on our roads (Env. Canada 2012). In Muskoka we use roughly 60,000 tonnes of salt on our major roads and highways each winter (verbal report to Muskoka Salt Reduction Advisory Committee, 2019) roughly a tonne of salt per permanent resident.

Because NaCl is very soluble, it doesn't stay put. In consequence Cl levels in lakes and rivers in Ontario have risen rapidly - the greater the density of winter-maintained roads, the higher the Cl levels in local watercourses (Corsi et al. 2010; Todd and Kaltenecker 2012). Road salt is toxic to aquatic life at levels that are now fairly common in southern Ontario rivers; therefore, Cl toxicity is a growing water pollution problem in southern Ontario (Todd and Kaltenecker 2012). In fact, Cl levels are now so elevated in groundwaters in parts of the GTA that they constrain development plans that rely on potable ground water (Howard and Maier 2007), and so complex are the changes in lakes that salinization induces that Kaushal et al. (2019) coined the term Freshwater Salinization Syndrome (FSS).

But has the problem reached Muskoka? Sadly, it has.

Twenty years ago, Environment Canada deemed road salt toxic (PSL Assessment report 2001), and in 2011, based on lab toxicity studies of 28 plant and animal species, the CCME (2011) set a Canadian Water Quality Guideline (WQG) of 120 mg of Cl/L for the long-term protection of freshwater biota. However, the guideline came with two cautions. First, the report warned the guideline would not protect all species of aquatic life. A few particularly sensitive species, especially molluscs, would suffer damage at Cl levels below the WQG; and secondly, and more importantly for Muskoka, the report warned "because the guideline is not corrected for any toxicity modifying factors (eg. hardness), it is a generic value that does not take into account any site-specific factors (CCME 1999)". Brown and Yan (2018) were the first to raise alarms about a site-specific factor that might make Muskoka lakes particularly vulnerable to road salt. They found that both NaCl and calcium chloride (CaCl2) were much more toxic to the native water flea, Daphnia[1] , in waters with algal densities (algae are their food) as low as those typical of Muskoka lakes. Daphnia survived at the Canadian WQG concentration when food levels were raised to those of nutrient-rich lakes, but at the lower food levels typical of Muskoka's nutrient-poor lakes, half the test animals died at 40 mg of Cl/L, three times lower than the Canadian WQG. Food stress increased Cl sensitivity.

More recently, Arnott et al. (2020) tested the effects of low calcium (Ca) levels on the toxicity of Cl to native Daphnia. This was the modifying factor that worried the CCME. Arnott and colleagues found Cl was toxic to a few common species of Daphnia at 5 mg/L, and to all 6 tested taxa at 40 mg/L, when the calcium (Ca) levels were lowered to levels typical of Muskoka lakes, i.e. 2.5 mg of Ca/L.   An examination of Cl levels in hundreds of Ontario's recreational lakes suggested 23% of Ontario's recreational lakes currently receive enough road salt inputs to threaten native daphniid assemblages.   Arnott and colleagues also reported clear evidence of alterations of the entire animal plankton assemblage in Jevins lake, near Gravenhurst, a change that began with the onset of road salt applications to the neighbouring Highway 11. Perhaps this is no surprise, because Jevins lake has among the highest Cl levels of Muskoka Lakes at around 90 -120 mg/L depending on the year; but, Valleau et al. (n press) recently found that the animal plankton of 4 other Muskoka lakes with Cl levels above 30 mg/L suffered similar changes, while no change occurred in a control lake with a Cl level of 1 mg/L. In all these road-salt impacted lakes, the timing of the changes coinciding with the onset of road salting.

The studies led by Arnott and Valleau provide the first documented evidence of impacts of road salt on an entire open-water assemblage of animal plankton in lakes in Canada, and all five lakes are in the Muskoka region. They provide proof of a local road salt threat and suggest that much of Muskoka represents a "site-specific" case where the Canadian WQG of 120 mg of Cl/L does not protect aquatic life.

Time to think the road salt threat through. Here we answer 10 logical questions about the threat of road salt toxicity, in particular Cl toxicity, to Muskoka waters. We are uniquely fortunate in Muskoka to have excellent long-term data on a small number of lakes provided by the Ministry of Environment Conservation and Parks' (MECP) Dorset Environmental Science Centre (DESC; http://www.desc.ca, eg. Yan et al. 2008), and 15 years of data collected as part of the District Municipality of Muskoka's water quality monitoring program (http://www.muskokawaterweb.ca/). This program cycles through about 160 Muskoka lakes, including multiple sites on the bigger lakes, every few years.   We rely mainly on these two publicly funded data sets, and the published scientific literature, to answer the following questions:

1. What are the natural background levels of Cl in Muskoka lakes; are they stable, or has the natural base line changed?
2. What is the range of Cl levels in Muskoka lakes, and why is so large?
3. How do we know that road salt is responsible for the lakes with elevated Cl levels?
4. What are safe levels of Cl for aquatic biota in Muskoka?
5. How many Muskoka lakes currently have Cl concentrations that exceed safe levels?
6. Is road salt an issue in Lake Muskoka?
7. Might climate change or development worsen the Cl problem?
8. What else does road salt threaten, and can we estimate the overall cost?
9. How much salt is used as a de-icer in Muskoka?
10. What can be done about the road salt problem?

Answers to the 10 Questions About Road Salt

Q1: What are the natural background levels of chloride (Cl) in Muskoka lakes; are they stable or has the baseline changed?

A1: 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. Hence, current natural background levels of Cl in Muskoka lakes are well under 0.5 mg/L, typically averaging about 0.25 mg/L.

Chloride levels are naturally low in undeveloped Muskoka lakes for several reasons. There is no nearby ocean, so rain and snow are not influenced by marine aerosols as they are in maritime lakes. Muskoka soils are thin and have low levels of ions of all kinds, include salt ions. Muskoka has no large ancient marine salt beds, such as those near Goderich. And perhaps most importantly, inputs of precipitation are about double the sum of evaporation and transpiration in Muskoka, so water moves into, through, and out of the region, and virtually all Muskoka lakes have outflows. What comes into the lakes in solution, leaves the lakes in solution without the magnitude of evaporative concentration that makes saline lakes and oceans salty.

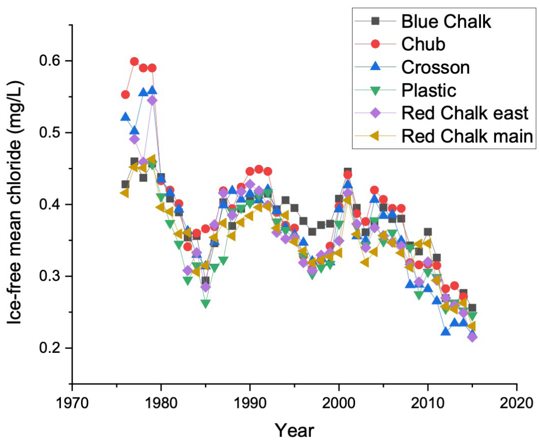


Figure 1: Chloride levels have fallen by 50% in remote Muskoka lakes

The best data sets to determine natural levels of Cl in Muskoka lakes are the long-term data sets from DESC's 6 sites (5 lakes including the two distinct basins of Red Chalk Lake) that are essentially undeveloped and lack winter-maintained roads in their watersheds. These lakes are Blue Chalk, Red Chalk, Crosson and Chub lakes in Muskoka, and Plastic Lake in Haliburton. Cl levels have been measured in top to bottom composite samples in these lakes monthly or fortnightly from May to November, and occasionally in the winter since the mid- to late 1970s. Cl levels averaged about 0.5 mg/L in the 1970s. They varied from year to year thereafter, but on balance levels have fallen to roughly 0.25 mg/L over the intervening 4 decades (Figure 1, and Yao et al. in press). The baseline Cl level in undeveloped Muskoka lakes has thus dropped by about 50%, an enormous change in relative terms in lakes without anthropogenic influence.

Importantly the Cl declines are very similar in all the lakes (Figure 1) suggesting a common underlying cause operating at a scale larger than individual lake watersheds. One logical explanation would be a regional decline in atmospheric Cl input, likely linked to successful national and international efforts to reduce levels of atmospheric pollution, leading to less-contaminated rain and snow. Indeed Cl deposition in precipitation has fallen substantially as discussed by Yao et al. (in press) over this time period, but considering this and other possible mechanisms to explain this interesting pattern is not our purpose. Rather our objective here is simply to determine the natural background Cl levels in Muskoka lakes, and its stability. That baseline level is now about 0.25 mg/L and it has fallen to that level over the last 40 years or so.

Q2: What is the range of Cl levels among Muskoka lakes, and why is it so large?

A2: Cl levels now range over 700-fold among the Muskoka lakes monitored by the District, from 0.16 to 116 mg/L. The range is large both because reductions in natural Cl inputs have lowered the 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.

While there is very little variability in Cl levels among DESC's undeveloped remote Muskoka lakes, there is an enormous range in lake Cl concentration across Muskoka, based on the 2017 to 2019 data set representing one full cycle of samples in the 191 lakes and lake basins in the District's Water Quality Monitoring Program. Levels range from a minimum of under 0.2 mg/L in South Nelson, Camp and Moot lakes to over 100 mg/L in Jevins Lake (Figure 2). The distribution is not bell-shaped, i.e. not "normal". Fully 25% of the lakes have very low levels under 0.8 mg/L, the 1st quartile, while 25% have more than 10 mg/L, the 3rd quartile. The median Cl level is just over 3 mg/L. But because there are quite a few high Cl outliers, well above the upper quartile (Figure 2), the average Cl concentration approaches 10 mg/L, 3 times the median (Figure 2). There is a long right tail in this distribution; a relatively small number of lakes have very high Cl levels.

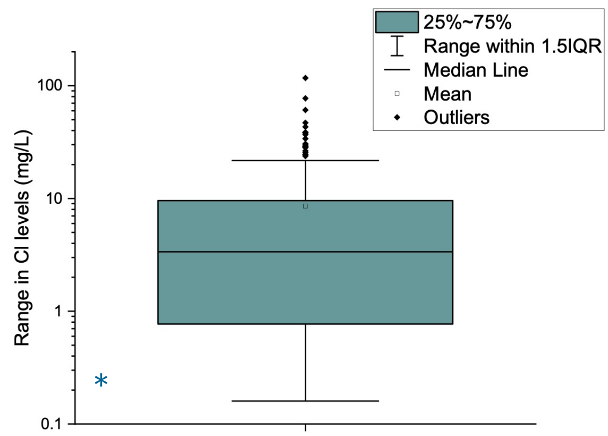


Figure 2: Chloride range is 700-fold among Muskoka lakes

The very low minimum Cl of 0.16 mg/L in the District's data set, is even lower than the average found in the undeveloped DESC lakes (Figure 1 vs. Figure 2). These low levels reflect the absence of road salt use in the watersheds of these lakes, and, probably, the regional reduction of Cl input in precipitation over the last 4 decades. The high outliers are almost certainly attributable to additional inputs of Cl, likely in the form of a salt of anthropogenic origin. After all, natural inputs have declined (Figure 1), so anthropogenic inputs must have increased at an even higher rate than the natural decline to account for the high levels.

Q3: How do we know that road salt is responsible for lakes with elevated Cl levels?

A3: 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.

Sodium chloride is responsible for the elevation of Cl concentrations in Muskoka lakes. The proof is that the relationship between Ca and Cl concentrations is very weak on an equivalent weight[2] basis among Muskoka lakes, but the relationship of Na with Cl is almost perfect (Figure 3). The r^2 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, a unit increase in Cl is accompanied by a unit increase in Na. Further the intercept of the regression approaches 0 indicates there is no missing cation needed to account for residual Cl. Therefore, all of high Cl outliers in Muskoka lakes (Figure 2), owe their high Cl to NaCl, not $CaCl_2$. Because there are no natural surficial marine sea-salt deposits in Muskoka, the source of the NaCl is anthropogenic.

The location of the outlier lakes indicates winter de-icing is the anthropogenic source. For example, Baxter, Loon, Tooke, Penfold, Ada, Sparrow, Webster, Barrons, Six Mile, Cornall and Jevins lakes are the 11 lakes that are the highest Cl outliers in Figure 2, all with >30 mg/L of Cl. All but one of these have major multi-lane, winter-maintained highways in their immediate catchments (Figure 4). The exception is Sparrow Lake, south of Gravenhurst, but its main inflow comes from Lake Simcoe and Lake Couchiching which also have very elevated levels of Cl mainly from road salt use in their catchments. In contrast, none of the lakes with the lowest Cl levels have winter-maintained roads in their immediate watersheds (Figure 4). By Muskoka standards these low Cl lakes are all quite remote.

Panel A

Panel B

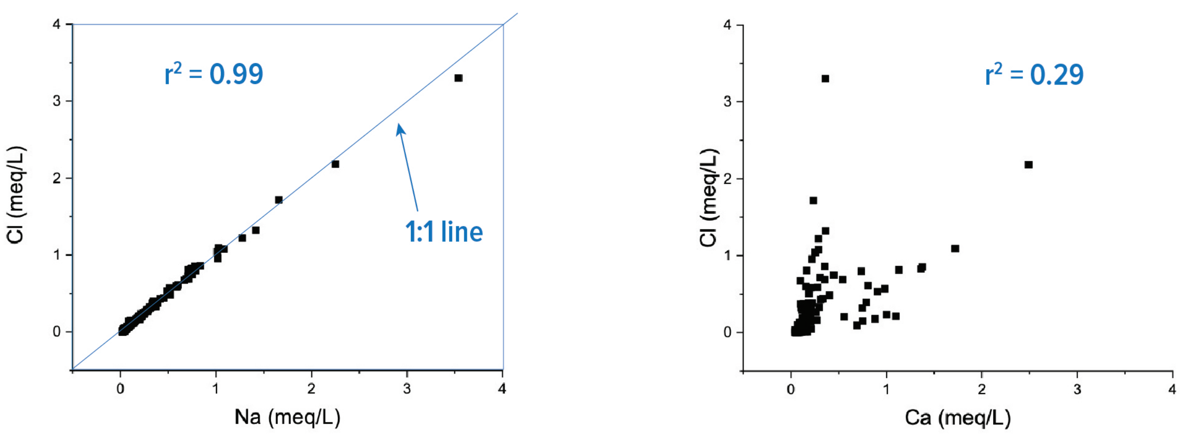


Figure 3: Chloride varies with sodium, not calcium, so the chloride source is road salt

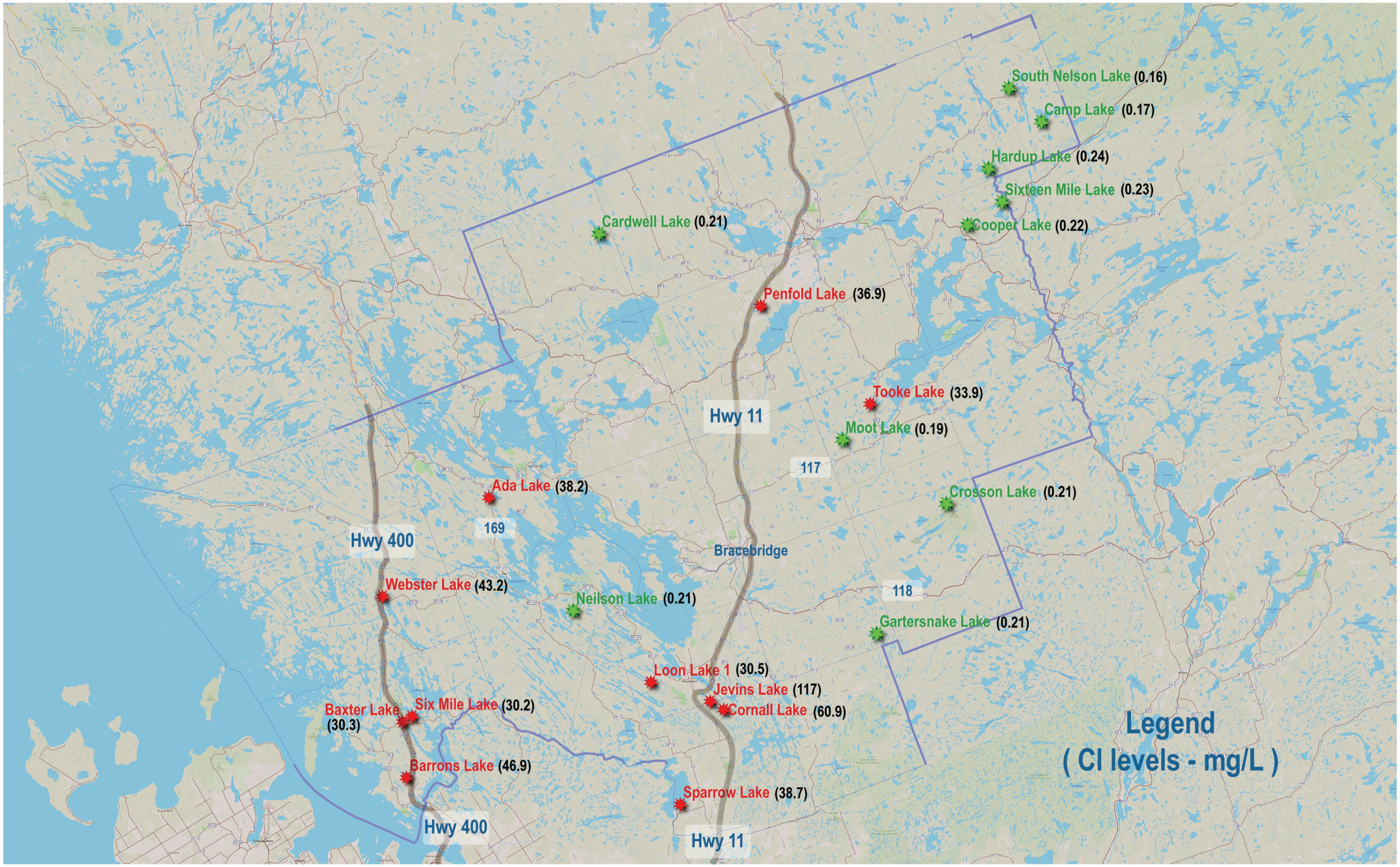


Figure 4: Chloride is high in lakes near winter-maintained highways

Q4: What are safe levels of Cl for aquatic biota in Muskoka?

A4: 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 species of daphniid water fleas, and because the choice involves a value judgement. How protective do we wish to be? Such a 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.

The current Canadian WQG of 120 mg of Cl/L was set to protect 95% of aquatic species from long-term Cl exposure, without consideration of site-specific modifiers of toxicity. Brown and Yan (2018) proved that lake nutrient status is a key modifier, because in Muskoka's typically low-nutrient waters, algal food densities are low enough that 50% of their test daphniids died in lab experiments at 40 mg of Cl/L, 3 times below the Canadian WQG. Food stress increased Cl sensitivity. Arnott et al (2020) proved that water hardness also modifies Cl toxicity. When reared and tested in waters with Ca levels typical of Muskoka lakes, their 6 native Daphnia species all suffered reproductive impairment at 40 mg of Cl/L, while some of the species, such as the ubiquitous Daphnia mendotae, suffered at levels as low as 5 mg of Cl/L (Figure 5). We don't yet know if a combination of low food and low Ca would further amplify Cl sensitivity, although this is certainly possible, and Ca and nutrient levels are typically both low in Muskoka lakes.

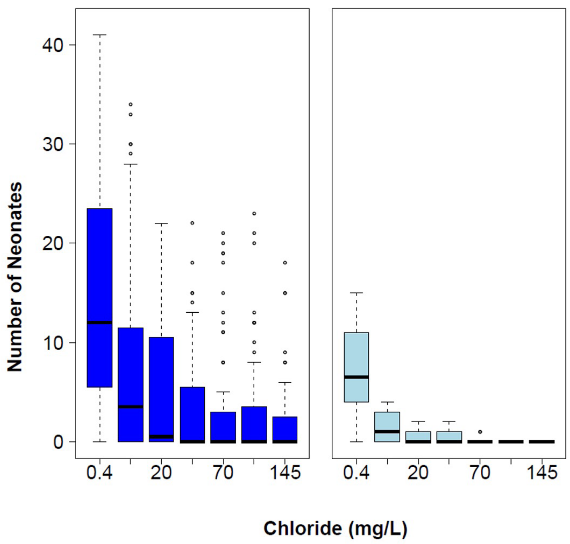


Figure 5: Water flea egg production falls at levels well below the federal salt guideline

Would a Muskoka-specific WQG set using daphniid data protect the majority of aquatic life in Muskoka lakes? We don't currently know, because the research that Elphick et al. (2011) and Arnott et al. (2020) have done to prove water hardness alters Cl toxicity for daphniids has not been repeated for other plant and animal taxa. What we do know is that daphniids are quite sensitive to Cl, more sensitive than all the aquatic plants and animals examined by the CCME with the exception of a few mollusc species. The three species of Daphnia they included all fell low on the Cl species sensitivity curve (Figure 6). Hence, setting a Muskoka specific WQG based on the sensitivity of 6 native daphniids to Cl would likely go a long way to protecting the majority of aquatic species. Setting a target range of 5 to 40 mg/L of Cl (see Figure 6) reflects a range over which damage to aquatic biota in Muskoka may be anticipated, and dropping the guideline from 120 to between 5 and 40 mg/L would also likely protect the majority of mollusc species which appear to be even more sensitive to Cl than daphniids.

We do not believe it is defensible to choose a single number for a Muskoka

WQG for Cl within the 5 to 40 mg/L range without more research on Cl toxicity to plant and other animal species at the low food and hardness values that are typical of Muskoka lakes. However, setting a guideline even at 40 mg of Cl would be an improvement over using the current Canadian WQG, even though damage to Muskoka animal plankton communities should be anticipated at 40 mg Cl /L, given Arnott's lab and Valleau's field observations.

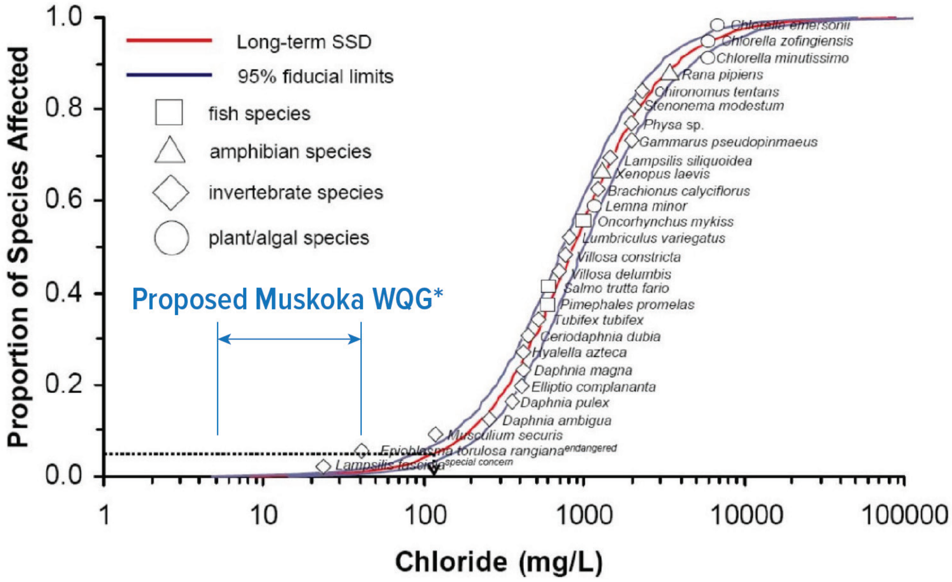


Figure 6: Muskoka lakes are more sensitive to salt than most lab-based studies suggest.

Q5: How many Muskoka lakes currently have Cl concentrations that exceed safe levels?

A5: 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.

Based on a sample of over 800 Ontario lakes, Arnott et al. (2020) estimated that 23% of Ontario's recreational lakes currently have Cl levels between 5 and 40 mg/L, levels that she and her colleagues considered problematic for animal plankton assemblages. In the District's latest complete sampling cycle of 191 lakes and lake-sites, 56% of lakes had <5 mg/L of Cl, leaving 44% with more than 5 mg/L of Cl. Only 2% of lakes had more than 40 mg/L of Cl, so the choice of a safe Cl level for Muskoka produces a large range in the estimated number of sites threatened by Cl toxicity.

Rather than using the lab-based toxicity data of Arnott and colleagues, an alternative approach is to use the field-based evidence from Valleau and colleagues (in press), i.e. the Cl level at which animal plankton communities in nature have actually been altered by road salt. That threshold would be 30 mg/L of Cl at the moment, and would suggest 6% of Muskoka's monitored lakes have problematic Cl concentrations. However there has not been an attempt to document Cl toxicity in the field beyond the 5 lakes that Valleau and colleagues studied, and all of her study lakes were impacted. Hence, her 30 mg/L should be considered a conservative impact threshold.

This is early days in our understanding of the extent to which Cl toxicity is affecting Muskoka Lakes. If we wish to be very protective and choose 5 mg/L, this would suggest 44% of the District's monitored lakes are impacted. If that seems alarmist, recall that the current natural background in Muskoka is 0.25 mg/L, so 5 mg/L represents a 20-fold (2000%) level of salt contamination compared to the current natural baseline. If we wished to be conservative and choose 30 mg/L, then 6% of the District's monitored lakes would be considered damaged. What we cannot recommend is using the Canadian WQG of 120 mg/L, because it will not protect typical Muskoka lakes given that we now have clear evidence of Muskoka-specific modification of Cl toxicity by low food and Ca levels, just the sort of site-specific toxicity modifier the CCME (1999) warned should be considered.

It is important to remember that the District samples just over 10% of the lakes in the Muskoka watershed, so the true number of lakes damaged by road salt is not currently known.

Q6. Is road salt an issue in Lake Muskoka, our most iconic lake?

A6: Yes. Lake Muskoka is holding at least 12000 tonnes of road salt in its waters, and concentrations in Muskoka Bay have risen to levels that likely threaten aquatic life.

Lake Muskoka is the iconic lake that many celebrate as an exemplar of the "good life" in Muskoka – a large, beautiful, island-dotted, clear-water lake that provides enormous recreational value to thousands of seasonal and permanent residents and supports the local economy. But is it "healthy"? Might there be a threat from road salt?

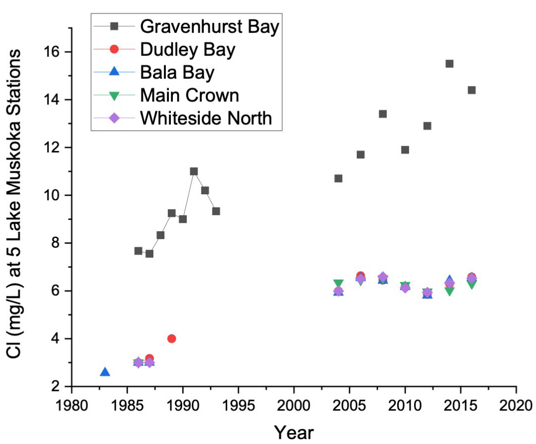


Figure 7: Chloride levels have risen in Lake Muskoka, especially in Gravenhurst Bay

The earliest reliable measurements of Cl we have found from Lake Muskoka were taken from the outflow below the Bala Falls[3] on a monthly basis in the summer of 1983 (Yao et al. 2018). Average Cl levels at that time were 2.57 mg/L (Figure 7), and given they were outflow samples they likely reflected average conditions in at least Bala Bay if not in much of the lake. What were then called the MOE and MNR ran a joint sampling program on Lake Muskoka starting in 1986 and running for about a decade. In their records, Cl levels increased to about 4 mg/L in the main lake but were quite a bit higher in Gravenhurst (Muskoka) Bay, at 8 to 11 mg/L. The District began sampling the lake in 2003. Cl levels in the open waters of the lake had increased to about 6 mg/L at all stations and appeared to be at steady state, but levels rose steadily in Gravenhurst Bay from about 11 to 15 mg/L (Figure 7). Depending on what is considered to be a safe level of Cl, 5 vs. 30 or 40 mg/L, there may not yet be a lake-wide threat from Cl toxicity (unless 5 mg/L is chosen), but there does appear to be a real threat in Gravenhurst Bay, and that threat appears to be worsening over time. While Cl levels appear to have reached a new steady state of about 6 mg/L in the open waters of the lake, a level reflecting average upstream road salt inputs of the last few decades, levels are still rising in Gravenhurst Bay.

Given road salt doesn't stay where we put it, but dissolves and heads downstream, how much road salt is dissolved in the waters of Lake Muskoka now, compared to 40 years ago? The answer is a big number – at least 12,000 tonnes. Assuming all the Cl is associated with Na (a safe assumption, Figure 3), there were about 7750 tonnes of NaCl in the lake in 1983, and that rose to about 19330 tonnes in 2016, a difference of about 12,000 tonnes. But we were already salting the watershed in 1983, so much of that initial 7750 tonnes was likely also road salt. Thus, the true mass of road salt that Lake Muskoka is now holding is between 12,000 and somewhat under 19,000 tonnes. Given a typical salt truck carries 10 tonnes of salt, picture a line of 1200 to 1900 trucks dumping all their loads into the lake. That's what it has taken to raise the levels of salt to its current level in Lake Muskoka.

Q7: Might climate change or development worsen the Cl problem?

A7: 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.

We can't confidently answer the question about climate change at this time, as there are conflicting climate drivers that may move salt use either up or down. There will likely be more freeze-thaw cycles, as winter temperatures warm, producing more frequent need for salt application; however, less salt is needed to melt ice as temperature warms from freezing to thawing temperatures, complicating the calculation. The amount of snow fall also matters, and locally the largest change may be in lake-effect snowfall, but it is uncertain what will happen to lake-effect snow accumulation in the future. Muskoka receives more snow than most regions of Ontario, because of its location downwind of Lake Huron. Suriano and Leathers (2017) noted lake effect snow worsened east of Lakes Ontario and Erie over the last 50 years, but more recently it appears to be in decline. Notaro et al. (2015) modelled this risk and also predicted less lake-effect snow downwind of the Great Lakes in the future as more winter precipitation will fall as rain as the climate warms. We don't know if road salt applications will be more affected by increased numbers of freeze/thaw cycles or less lake-effect snow. We will have to wait and see.

On the other hand without careful management, additional development may certainly lead to more use of road salt if there are more parking lots, driveways, sidewalks and paved roads to maintain in the winter as the population swells (Todd and Keltenecker 2012). How much more will be up to us, and our governments' policies.

Q8 What else does road salt threaten, and can we estimate the overall costs?

A8: Road salt threatens aquatic plants and animals, our pets, road side vegetation, ground and drinking water, 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.

Road salt doesn't just directly threaten sensitive biota in our lake waters. It has more widespread effects on our waters, on the riparian and terrestrial environment, on our economy, and perhaps even on our air quality (Kelly et. al. 2010). In lakes it can slow recovery from acidification (Jensen et al. 2014), damage algae (MacDougall et al. 2017), alter mixing and oxygen regimes and fish habitat (Dupuis et al 2019, Wiltse et. al. 2019), and change the influx of cations, metals and nutrients (Kaushal et al. 2018). Road salt can even be aerosolized and contribute to fine particulate air pollution in the winter (Kolesar et. al. 2018).

At the moment, we can't estimate the economic cost of using road salt in Muskoka, but it is certainly large. Dindorf and Fortin (2014) estimated the damage to infrastructure, automobiles, vegetation, water supplies, human health and the environment from road salt use in Minnesota's Twin Cities ranged from $800 to $3300 (US) per ton of salt. Converting this to Canadian equivalent, and assuming we add about 60,000 tonnes of salt to Muskoka roads (likely an underestimate) suggests the damage done in Muskoka from road salt ranges from $60,000,000 to $250,000,000, a number of the same order of magnitude as Muskoka's annual budget! And the damage from the 7 million tonnes of salt we add to the environment in Canada runs into the billions of dollars[4] .

These damage estimates may seem far fetched, but consider simply the cost of road salt damage to our cars. The life expectancy of the author's family car was halved by road salt corrosion; hence, the Yan family has purchased two more cars than it otherwise would have at a cost of roughly $60,000. Road salt costs contractors perhaps roughly $200 a tonne to purchase, but the cost to society is much higher. These costs should be weighed against the increased safety benefits, but rarely if ever are.

Q9: How much salt is used as a de-icer in Muskoka?

A9: We don't currently know but it must be tens of thousands of tonnes.

The District's Road Salt Reduction committee has not estimated the total amount of salt added to roads and other paved surfaces in Muskoka. It will take collaboration from all levels of government, plus input from local commercial and residential property owners to determine this number. We do know it must be tens of thousands of tonnes, as there is that much extra road salt in our lakes. The District salt management plans must follow national standards, and currently call for 130 kg of salt /km-double lane, and 570 kg of sand-salt mix/km-double lane, but we don't know exactly how well these plans are followed, what the mix of the two strategies is, nor the frequency of salt spreading. There are about 1500 km of paved

District roads, 100s of km of provincial highways, town roads, plus commercial and government parking lots and sidewalks, It will be more difficult to gather salt loading data for the private property, but other jurisdictions have done it. We have work to do, as step one in aiming to reduce the damage from road salt is to know how much and where we use it. This may appear to be an academic question (It must be the roads, right), but ask yourself do we really know why Cl levels are rising in Muskoka Bay (Figure 7). Is it salting the neighbouring highway, Gravenhurst town roads or the large parking lots at the Wharf? Without knowing how much salt is used in the watershed of Muskoka Bay by the town, the province and commercial property owners in the watershed, we don't really know.

Q10: What can be done about the road salt problem?

A10: Lots.

Many things can be done to begin to address the problems of road salt in Muskoka. Here's a first list of suggestions with four goals: to review and adopt best practices from other jurisdictions, to assess the environmental threat of salt on an ongoing basis, to encourage public understanding of the issue, thereby building the will for action, and finally, to take action.

1. Review plans designed to reduce the use of salt while maintaining public safety that have been developed elsewhere, adopting or adapting those ideas that may be most promising for Muskoka, e.g.
    - Continue to measure to what extent the District and each municipality in Muskoka is following best practices for the storage and spreading of road salt as laid out by Environment Canada
    - Determine to what extent winter road managers and private salt contractors are following practices laid out by the Smart about Salt initiative.
    - Review the road salt reduction plans developed in neighbouring municipalities, eg. In Barrie (Anon. 2016. Salt Optimization Strategy, City of Barrie) and more broadly for Lake Simcoe (The Lake Simcoe Conservation Authority 2017).
2. Assess the ongoing threat of past and current use of road salt to Muskoka's waters
    - As all of Muskoka has been recognized as vulnerable to road salt given its widespread water resources (GHD 2018, section 3.5.7,) determine what the implications of this vulnerability are for salt use.
    - Quantify the magnitudes of salt used, alone and in combination with sand, on provincial, District and town roads in the watershed and how these quantities have changed over time.
    - Identify "hot-spots" of road salt input into important lakes and explore

methods to re-engineer these hot spots to retain more of the incoming salt (eg. Guesdon et. al. 2016) or reduce salt input using brines (Haake and Knouft 2019).

- Identify all lakes that have winter-maintained roads in their immediate catchments, and add these lakes to the District's Water Quality monitoring program, if they are not already included. Ensure that some minimally-impacted lakes are also included to track changes in natural inputs.
- Assemble all Cl and associated cation data from wetlands, rivers and lakes in Muskoka that have been gathered over the years by local and provincial agencies. Evaluate trends in the data and identify sites in need of additional or more frequent investigation.
- Track the evolving literature on the site-specificity of chloride toxicity to aquatic biota.
- Examine Na, Ca and Cl data at all sites used as raw water drinking sources to help anticipate and prevent future threats to the drinking water supply from salt.
- Measure Cl levels in ground water in Muskoka.
- Determine to what extent waste management facilities in the District might contribute salt to surface and ground waters.

3. Encourage public understanding about road salt as an environmental issue, to foster the will for action
    - Conduct a broad survey of Muskoka residents to quantify their understanding of the costs and benefits of winter road maintenance using salt, and their willingness to consider reductions in their own use of salt, and by other residential and commercial property owners in Muskoka.
    - Communicate with the public via print and social media to encourage reduction in salt use, once the barriers to reduction in salt use have been identified.
    - Work with the schools, youth groups and the Muskoka Steamship Discovery Centre to develop curricula to communicate the road salt issue to the public.
4. Take appropriate action to reduce salt use while maintaining public safety.
    - Examine and where applicable implement Kelly and colleagues' (2010) recommendations to improve road salt application efficiency that are currently not practised in Muskoka.
    - Supplement current estimates of the costs of road salt management plans with estimates of environmental and social costs and benefits of

road salt.

- Evaluate the methods in use to minimize the use of salt on paved surfaces in cities, including parking lots and sidewalks to see if additional reductions are possible without jeopardizing safety, for example with the use of brines.
- Evaluate planning protocols for new parking lot construction to determine if mechanisms to minimize salt drainage into receiving waters can be adopted.
- Require all private salt contractors to be “Smart About Salt” certified, and encourage commercial property owners that award winter maintenance contracts to insist their contractors have Smart about Salt certification.
- Encourage commercial property owners to include the cost of salt in their winter maintenance contracts. Not doing this encourages more salt use.
- Encourage the provincial government to make legislative changes making winter tires mandatory in Northern Ontario, including Muskoka, and reducing statute of limitations times over which ‘slip and fall’ law suits can be filed against property owners.

References

Anon. 2016. Salt Optimization Strategy for City of Barrie. 19 pp.

Arnott, S.E., M. P. Celis-Salgado, R.E. Valleau, A.M. DeSellas, A.M. Paterson, N.D. Yan, J.P. Smol and J.A. Rusak. 2020. Road salt impacts freshwater zooplankton at concentrations below current water quality guidelines. Env. Sci. Technol. In press.

Brown, A.H. and N.D Yan. 2018. Food quantity affects the sensitivity of Daphnia to road salt. Env. Sci. Technol. 49: 4673-4680

Canedo-Arguelles, M., B. Kefford and R. Schafer. 2019. Salt in freshwaters: causes, effects and prospects – introduction to the theme issue. Phil. Trans. R. Soc. B 374: 2018002.

CCME (Canadian Council of Ministers of the Environment). 2011. Canadian Water Quality Guideline for the Protection of Aquatic Life: Chloride. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. 16 pp.

Corsi, S.R., D.J. Graczyk, S.W. Geis, N.L. Booth and K.D. Richards. 2010. A fresh look at road salt: aquatic toxicity and water-quality impacts on local, regional and national scales. Env. Sci. Technol. 44: 7376-7382.

Dindorf, C. and C. Fortin. 2014. The real cost of salt use for winter maintenance in the twin cities metropolitan area. Report to the MN Poll. Contr. Ag. 21 pp.

Dugan, H. A., S. L. Bartlett, S. M. Burke, J. P. Doubek, F. E. Krivak-Tetley, N. K. Skaff, J. C. Summers, K. J. Farrell, I. M. McCullough, A. M. Morales-Williams, D. C. Roberts, Z. Ouyang, F. Scordo, P. C. Hanson, and K. C. Weathers. 2017. Salting our freshwater lakes. Proc. Nat. Acad. Sci. 114:4453–4458.

Dupuis, D., E. Sprague, K.M. Docherty and C.M Koretsky. 2019. The influence of road salt on seasonal mixing, redox stratification and methane concentrations in urban kettle lakes. Sci.Tot. Environ. 661: 514-521.

Elphick, J. R. F., K. D. Bergh, and H. C. Bailey. 2011. Chronic toxicity of chloride to freshwater species: Effects of hardness and implications for water quality guidelines. Environ Toxicol. Chem. 30:239–246.

Env. Can. 2012. Five-year review of progress: code of practice for the environmental management of road salts. ISBN: 978-1-100-19682-4 95 pp.

GHE 2018. Salt Management Plan update to the District of Muskoka engineering and public works Department. 135 pp.

Guesdon, G., A. de Santiago-Martin, S. Raymond, H. Messaoud, A. Michaux, S. Roy and R. Galvez. 2016. Impacts of salinity on Saint-Augustin Lake, Canada: remediation measures at watershed scale. Water. 8: 285.

Haake, D.M. and J.H. Knouft. 2019. Comparison of contribution to chloride in urban stormwater from winter brine and rock salt application. Env. Sci. Technol. 53: 11888-11895.

Howard, K.W.F. and H. Maier. 2007. Road de-icing salt as a potential constraint on urban growth in the Great Toronto Area, Canada. J. Contaminant Hydrol. 91: 146-170.

Jensen, T.C., S. Meland, A.K. Schartau and B. Walseng. 2014. Does road salting confound the recovery of the microcrustacean community in an acidified lake? Sci. Tot. Environ. 478: 36-47.

Kaushal, S.S., G.E. Likens, M.L. Pace, S. Haq, K. L. Wood, J.G. Galella, C. Morel, T.R. Doody, B. Wessel, P. Kortelainen, A. Raike, V. Skinner, R. Utz and N. Jarowski. 2019. Novel 'chemical cocktails' in inland waters are a consequence of the freshwater salinization syndrome. Phil. Trans. R. Soc. B. 374: 20180017.

Kelly, V. R., S. E. G. Findlay, W. H. Schlesinger, K. Menking, and A. M. Chatrchyan. 2010. Road salt: moving toward the solution. The Cary Institute of Ecosystem Studies. (Available from http://www.caryinstitute.org/research/reports/road_salt_2010.pdf)

Kolesar, K.R., C.N. Mattson, P.K. Peterson, N.W. May, R.K. Prendergast and K.A. Pratt. 2018. Increases in wintertime PM2.5 sodium and chloride linked to snowfall and road salt application. Atmos. Environ. 177: 195-202.

Lake Simcoe Region Conservation Authority 2017. Lake Simcoe Watershed Salt Reduction Strategy. 30 pp. (https://www.lsrca.on.ca/watershed-health/salt)

MacDougall, M.J., A.M. Paterson, J.G. Winter, F.C Jones, L.A. Knopf and R.I Hall. 2017. Response of periphytic diatom communities to multiple stressors influence lakes in the Muskoka River Watershed, Ontario, Canada. Freshwater Sci. 36: 77-89.

Notaro, M., C. Bennington and S. Vavrus. 2015. Dynamically downscaled projections of lake-effect snow in the Great Lakes Basin. J. Climate 28: 1661-1684.

Priority Substances List (PSL) Assessment Report - Road Salts. 2001. Canadian Environmental Protection Act 1999. 181 pp.

Reid, A.J., A.K. Carlson, I. F. Creed, E.J. Eliason, P.A. Gell, P.T.J. Johnson, K.A. Kidd, T.J. MacCormack, J.D. Olden, S.J. Ormerod, J.P. Smol, W.W. Taylor, K. Tockner, J.C. Vermaire, D. Dudgeon and S.J. Cooke. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. 94: 849-873.

Suriano, Z.J. and D.J. Leathers. 2017. Synoptically classified lake-effect snowfall trends to the lee of Lakes Erie and Ontario. Climate Research 71: 1-13. doi.org/103554/cr01480

Todd, A.K. and M.G. Kaltenecker. 2012. Warm season chloride concentrations in stream habitats of freshwater mussel species at risk. Env. Pollut. 171: 199-206.

Valleau, R.E., A.M. Paterson and J.P. Smol. 2020. Effects of road salt application on Cladoceran assemblages in shallow Precambrian Shield lakes in south-central Ontario, Canada. J. Paleolimnol. In press.

Wiltse, B., E.C. Yerger and C.L. Laxson. 20019. A reduction in spring mixing due to road salt runoff entering Mirror Lake (Lake Placid, NY). Lake and Reservoir Manag. Doi: 10.1080/10402381.2019.1675826

Yan, N.D., A.M. Paterson, K.M. Somers and W.A Scheider. 2008. An introduction to the Dorset special issue: transforming understanding of factors that regulate aquatic ecosystems on the southern Canadian Shield. Can. J. Fish. Aquat Sci. 65: 781-785.

Yao, H, C. McConnell, T. Field and A. L James. 2018. Spatial-temporal changes of nutrients in Muskoka River, an example of an undeveloped area. Presentation at the Intern. Assoc. Great Lakes Res. Conference, Toronto, 18 June 22.

Yao, H. A.M. Paterson, A.L James, C. McConnell, T. Field, R. Ingram, D. Zhang, S. Arnott and S.N. Higgins. 2020. Contrasting long term trends of chloride in remote and human-disturbed lakes in south-central Ontario, Canada. Lake Reservoir Manag. (in press).

List and Explanation of Figures

1. Record of change in chloride (Cl) concentrations (ice-free season averages in mg/L) from 5 Muskoka-area lakes sampled by staff of MECP's Dorset Environmental Science Centre. These five lakes have little if any development other than a very few cottages, and no winter-maintained roads in their catchments. Samples have been collected monthly (Crosson, Chub, Blue Chalk and Red Chalk lakes) or fortnightly (Plastic Lake) since the late 1970s, as composites of the entire water column with aliquots from each depth weighted for the relative contribution of that depth stratum to the overall lake volume. Data source: MECP DESC. For details on causes of the decline in Cl levels, see Yao et al. (in press)

2. Box plot of the distribution of chloride levels in 191 sampling sites (mainly individual lakes, with a few of the largest lakes with multiple sites) in the last complete sampling cycle (2017 to 2019) of the District Municipality of Muskoka's (DMM) Water Quality Monitoring Program. The "box" in the plot spans the 1st to the 3rd quartiles. The median and mean are indicated by the horizontal line and small open symbol within the box. The whiskers are set at 1.5 times the range of the quartiles, and encompass values that are relatively common, beyond which are outliers found only on the high Cl side. Data source (DMM's water quality monitoring program). Note the log-scale on y-axis, necessary given the 700-fold range in Cl levels. The asterisk indicates the average Cl values in DESC undeveloped lakes, from Figure 1. Raw data provided by Rebecca Williston from the DMM.

3. Relationship of sodium (Na, panel A) and calcium (Ca, panel B) with chloride (Cl) in the DMM's Water Quality Monitoring Program data from 191 sites and lakes from the last complete lake sampling cycle, 2017 to 1019. Levels are plotted in meq/L so that the cation (Na or Ca) associated with the Cl can be identified. Note that Cl levels are very strongly associated with Na, not with Ca. Na explains 99% of the inter-lake differences in Cl. The relationship is virtually 1:1, i.e. the slope of the relationship is 0.98, and the intercept approaches 0 (0.004) suggesting there is no missing cation associated with residual chloride. Data provided by Rebecca Williston of the DMM.

4. Map of Muskoka with highways. Lakes from the DMM's Water Quality Monitoring Program with <0.25 and >30 mg of Cl/L are indicated with blue and red symbols, respectively.

5. A figure reproduced from Arnott et al. (2020) of the number of offspring (neonates) released by 6 species of Daphnia vs. concentration of Cl in 21-day experiments run at 2.5 mg/L of Ca, i.e. in soft water typical of Muskoka lakes. The left panel is the merged data from all 6 of the species, while the right panel is for Daphnia mendotae, the most common daphniid in Muskoka. Experiments were run at 0.4 (control), 5, 20, 45, 70, 95 and 145 mg of Cl/L. the Canadian Water Quality Guideline is 120 mg of Cl/L. For additional details see Arnott et al. (2020).

6. A figure reproduced from the CCME of the species sensitivity distribution to Cl in long-term assays in hard water for 28 plant and animal species used to develop the Canadian WQG for Cl. The proposed range that corrects for the site-specific sensitivity of Muskoka lakes (5 to 40 mg/L) is indicated.
7. Trends in Cl levels measured at 5 stations in Lake Muskoka from 1983 to 2017 (Data from 1980s and 1990s from Ministry Environment Conservation and Parks and thereafter from the DMM).

Endnotes

1 Daphnia are small animal plankton that are common in Muskoka lakes. They feed on algae and provide food for fish. Animal plankton filter the algae from entire volume of our lakes several times a summer and thus are important in maintaining water quality. They are also very important laboratory test species, the “white rats” of aquatic toxicology.

2 Concentrations of ions in the water can be reported in different ways. The most common format is units of mass, e. g. mg/L or ppm. However, if we wish to know what chloride salt is responsible for elevated Cl levels, mass units are not useful. Rather we must express concentration in what chemists call units of equivalent weight, which corrects for the both the ion’s atomic weight and its charge, or valence. For example, dissolved ionic calcium (Ca^{2+}) has a valence of +2, and its chloride salt has two chloride ions ($CaCl_2$) while dissolved ionic sodium has a valence of +1 and its salt, NaCl, has only a single Cl ion. Ca makes twice the equivalent contribution to its salt, given its charge. To convert mass to equivalent concentrations, we divide the mass concentration by the atomic weight and multiply by the valence.

3 Subsequent comparisons indicate Cl levels taken below the Bala Falls do reflect levels in Bala Bay above the falls

4 https://nationalpost.com/news/canada/how-canadas-addiction-to-road-salt-is-ruining-everything