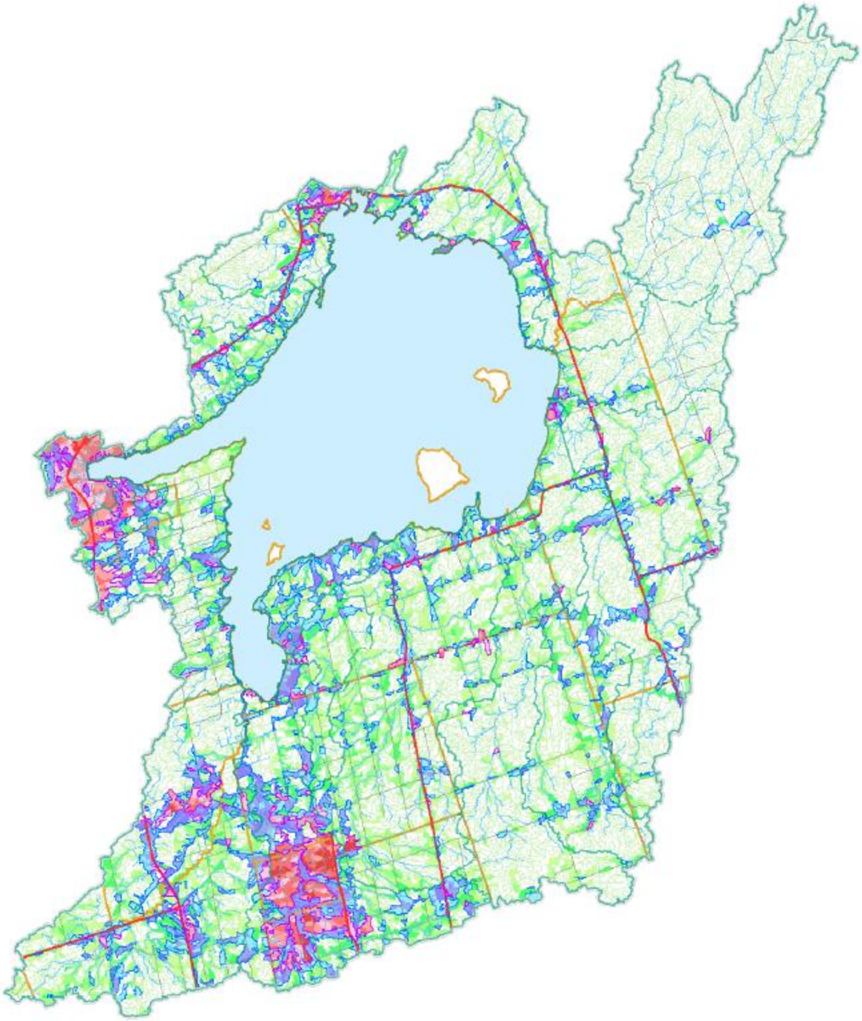
2015

The identification of Salt Vulnerable Areas in the Lake Simcoe watershed



Lake Simcoe Region
conservation authority

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Executive summary

Since water quality monitoring began in the Lake Simcoe watershed, the Ontario Ministry of the Environment and Climate Change and Lake Simcoe Region Conservation Authority (LSRCA) have recorded increasing chloride concentrations in Lake Simcoe and its tributaries. Currently, the majority of water quality samples collected from Tannery Creek, Lovers Creek, the East Holland River, North Schomberg River, and Hotchkiss Creek exceed the Canadian Council of Ministers of the Environment long-term guideline for the protection of aquatic life. The case of Lovers Creek in Barrie is particularly striking, as a consistent increase in chloride concentration at the mouth of the creek is evident, concurrent with an increase in development within its subwatershed.

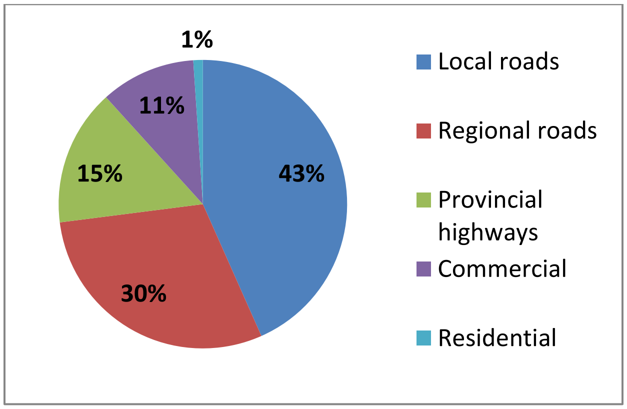
All municipalities within the Lake Simcoe watershed have adopted Environment Canada's Code of Practice for the Environmental Management of Road Salts, in an attempt to balance the environmental impacts of salt with its benefits to public safety. The Code makes two main recommendations: the development of salt management plans by all road management authorities, and the implementation of best management practices in the areas of salt application, salt storage, and snow disposal. One of the best management practices it recommends is the identification of areas that are particularly sensitive to road salts, for assessing additional salt management measures (i.e. "salt vulnerable areas"). Although rates of participation in the Code of Practice, including the development of salt management plan and investment in sophisticated technologies has been high, relatively few road management agencies across Canada have identified salt vulnerable areas. In an attempt to rectify this situation, Andrew Betts and Bahram Gharabaghi from the University of Guelph developed a model for identifying salt vulnerable areas, based on comparing modelled exposures to chloride in watercourses with published sensitivities of aquatic organisms.

In order to apply this model to the Lake Simcoe watershed, GIS-based analysis of various land use, operational, and hydrological data was necessary. Data on land use (i.e. location of roads and parking lots) was available in the LSRCA GIS database. Hydrological data such as normalized annual flow rates and base flow indices was available from the Source Water Protection Program. Other data on chloride levels in surface water was available from the LSRCA Environmental Monitoring program. The only other data necessary for the model was information on salt application rates, which was generously provided by watershed municipalities and the MTO.

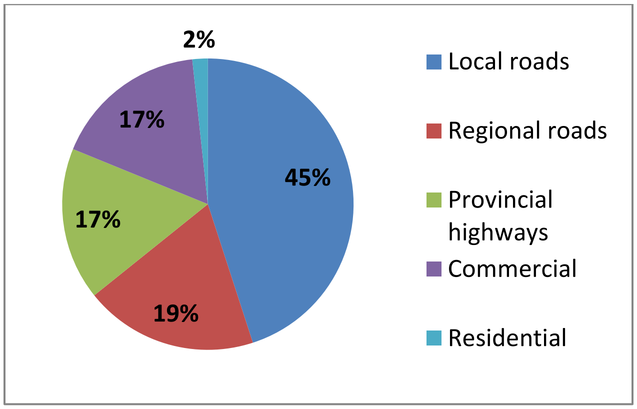
The total volume of chloride applied in the Lake Simcoe watershed in winter 2012/2013 is estimated to have been 60,613 Tonnes (or the equivalent of 90,467 Tonnes of salt). The greatest contribution was from local and single tier municipalities, and upper tier municipalities, with lesser contributions from provincial highways and commercial parking lots.

Based on the results of the model, average annual chloride concentration in catchments around Lake Simcoe range from 0 to over 24,000 mg/L. Within the Lake Simcoe watershed as a whole, 16% of the watershed is predicted to exceed the Canadian Water Quality Guideline for long-term exposure for the protection of aquatic life from chloride (120 mg/L) on an average annual basis. Over 4.5% of the watershed is predicted to exceed the short-term exposure guideline (640 mg/L) on an average annual basis. The modelling approach used in this study estimates that chloride concentrations are impacting aquatic biota in 64% of the Lake Simcoe watershed. Within those catchments, number of taxa potentially impacted range from 1 to 45 taxa (of a total of 47 included in analysis).

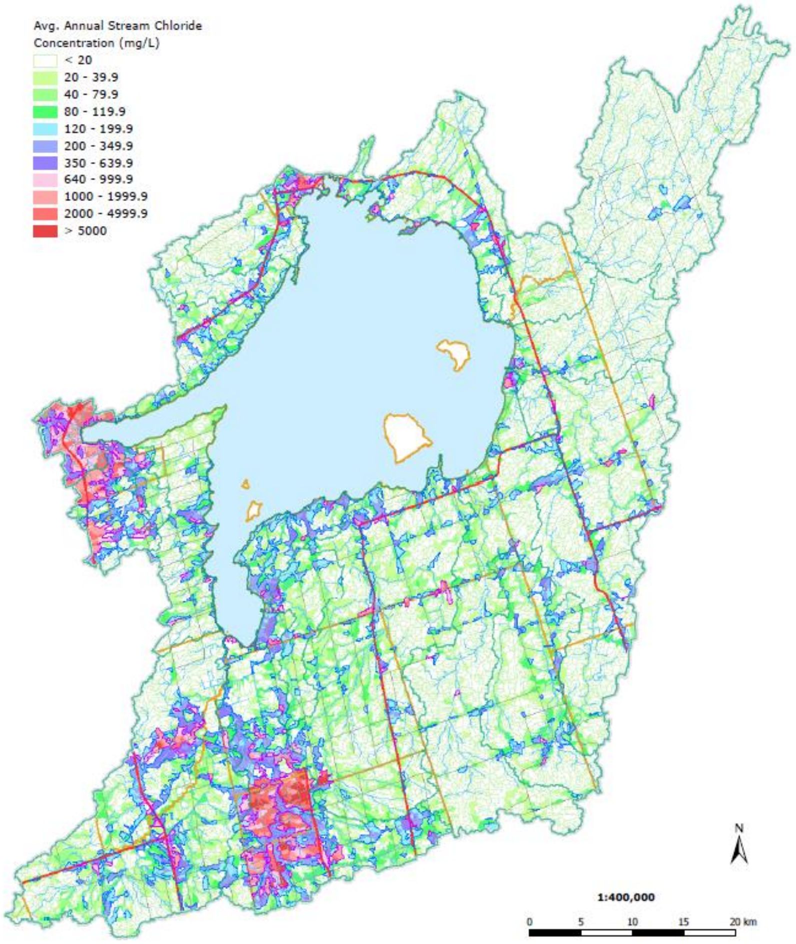
Salt vulnerable areas have been defined as those catchments where more than 5 taxa are impacted by the application of salt to roads or parking lots. As with hotspots of chloride concentration, these salt vulnerable areas tend to occur in more densely developed areas, and in localized areas along some of the major roads and highways in the watershed. Within those salt vulnerable areas, the management of local road networks have been predicted to play a signficant role in chloride levels in local watercourses.



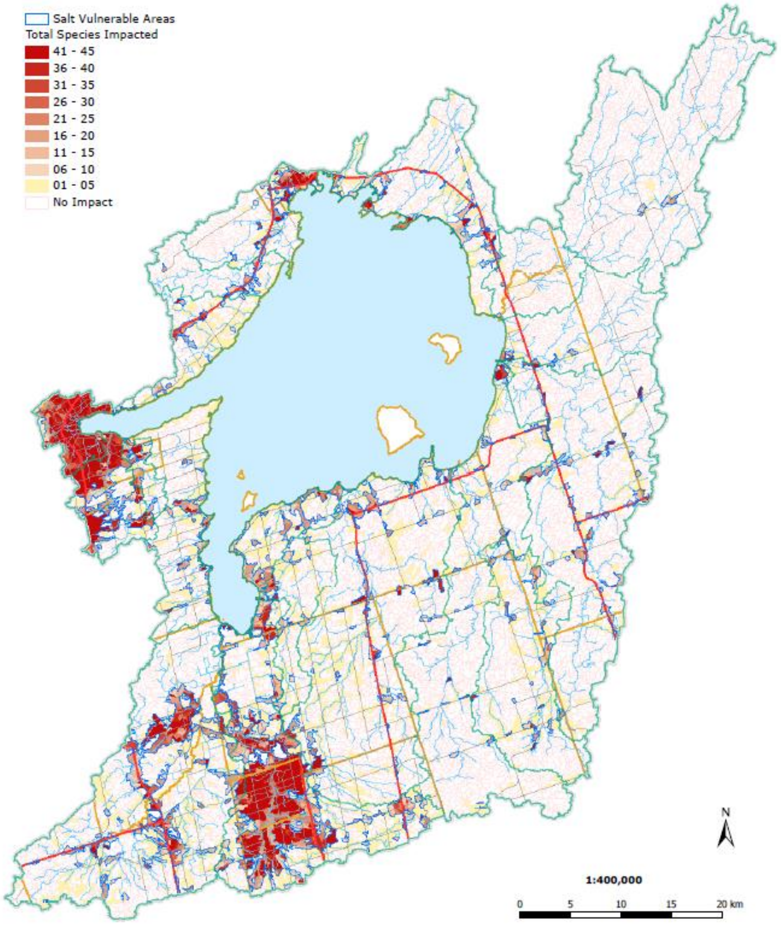
Relative contribution of chloride to the Lake Simcoe watershed, based on chloride application rates and total area managed



Relative contribution of chloride within salt vulnerable areas in the Lake Simcoe watershed, based on chloride application rates and total area managed



Predicted average annual chloride concentration (mg/L)



Predicted number of aquatic taxa impacted by chloride and designated 'salt vulnerable areas' in the Lake Simcoe watershed

Recommendations:

- That LSRCA develop workshops for municipalities managing salt vulnerable areas, sharing the results of this study and our ongoing monitoring program, providing suggestions for modifications to municipal operations,
- That LSRCA continue to partner with the Smart About Salt Council, to promote and provide the Smart About Salt Essentials training to contractors and facility managers active in the Lake Simcoe watershed,
- That all municipalities with salt vulnerable areas identified review their Salt Management Plan and operational practices to determine if there are additional best practices that can feasibly be implemented,
- That the LSRCA and watershed municipalities develop an education program to raise public awareness of the environmental impacts of winter salt use, with an intent of changing public expectations and behaviours,
- Municipalities which include catchments where the greatest anticipated gains have been identified should review their salt management plans, and challenge themselves to achieve a 25% reduction in salt application,
- Lake Simcoe Region Conservation Authority should focus the Smart About Salt training provided to contractors and facility managers to those catchments where the greatest potential gains are anticipated,
- That municipalities anticipating significant future growth, and where significant future impacts have been predicted, assess ways of reducing those impacts through land use planning, site design requirements, operational requirements, or education and outreach programs,
- That the Lake Simcoe Region Conservation Authority support its municipalities in developing such draft guidelines,
- That the Lake Simcoe Region Conservation Authority research the implications of LID on salt use (and vice versa), either through reviewing research on this topic done elsewhere, or by establishing studies in the Lake Simcoe watershed. Results of this research should be shared with municipal land use planners and stormwater engineers.

Acknowledgements

The salt vulnerable area mapping work summarized in this report is based on an approach piloted by Andrew Betts, while a graduate student in Bahram Gharabaghi's lab at the University of Guelph. My sincere thanks to Bahram for bringing Andrew's thesis to my attention and for providing enough information to replicate his work in the Lake Simcoe watershed. In fact, this study builds on a substantial body of work done by Bahram and his colleagues. Without the publications of their work on chloride in the City of Toronto, this work would have been much more difficult.

Data on salt application rates was generously provided by the Ministry of Transportation of Ontario, and 13 municipalities from the Lake Simcoe watershed. Additional data from the LSRCA monitoring program was provided by Eavan O'Connor, Lance Aspden, and Sara Rawski.

GIS analysis and mapping was done by Kelin Zhao. Report written by Bill Thompson. Project managed by Ben Longstaff.

This project has received funding support from the Government of Ontario. Such support does not indicate endorsement by the Government of Ontario of the contents of this material.

Introduction

Since lake water quality monitoring began in the 1970s, the Ontario Ministry of the Environment and Climate Change and the Lake Simcoe Region Conservation Authority (LSRCA) have recorded increasing chloride concentrations in Lake Simcoe. Winter et al (2011) summarized chloride concentration in the water at Atherley Narrows (representing water exiting the Lake Simcoe watershed) between 1971 and 2007, and documented a consistent increasing trend in chloride over time (Figure 1). At the end of that study, chloride concentrations in the Lake were approximately 39 mg/L, lower than the Federal guideline of 120 mg/L for long-term exposure for aquatic organisms. Estimates were however, that the Federal guideline would be reached in 110 years if current trends continue. Unfortunately, current trends are continuing; in 2014 average chloride concentration at Atherley Narrows was 46 mg/L, a result of a rate of increase slightly higher than the long term average of 0.7 mg/L/year (Winter et al, 2011).

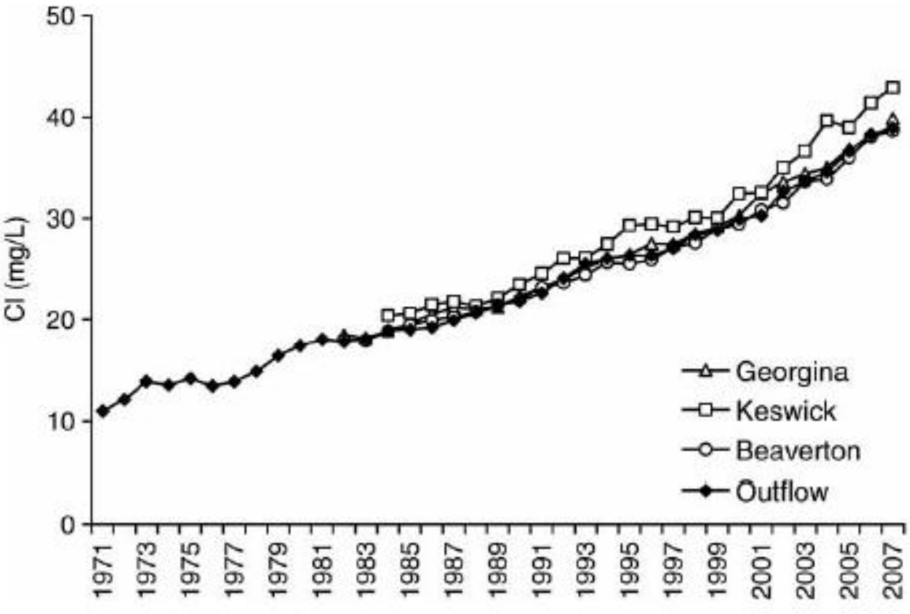
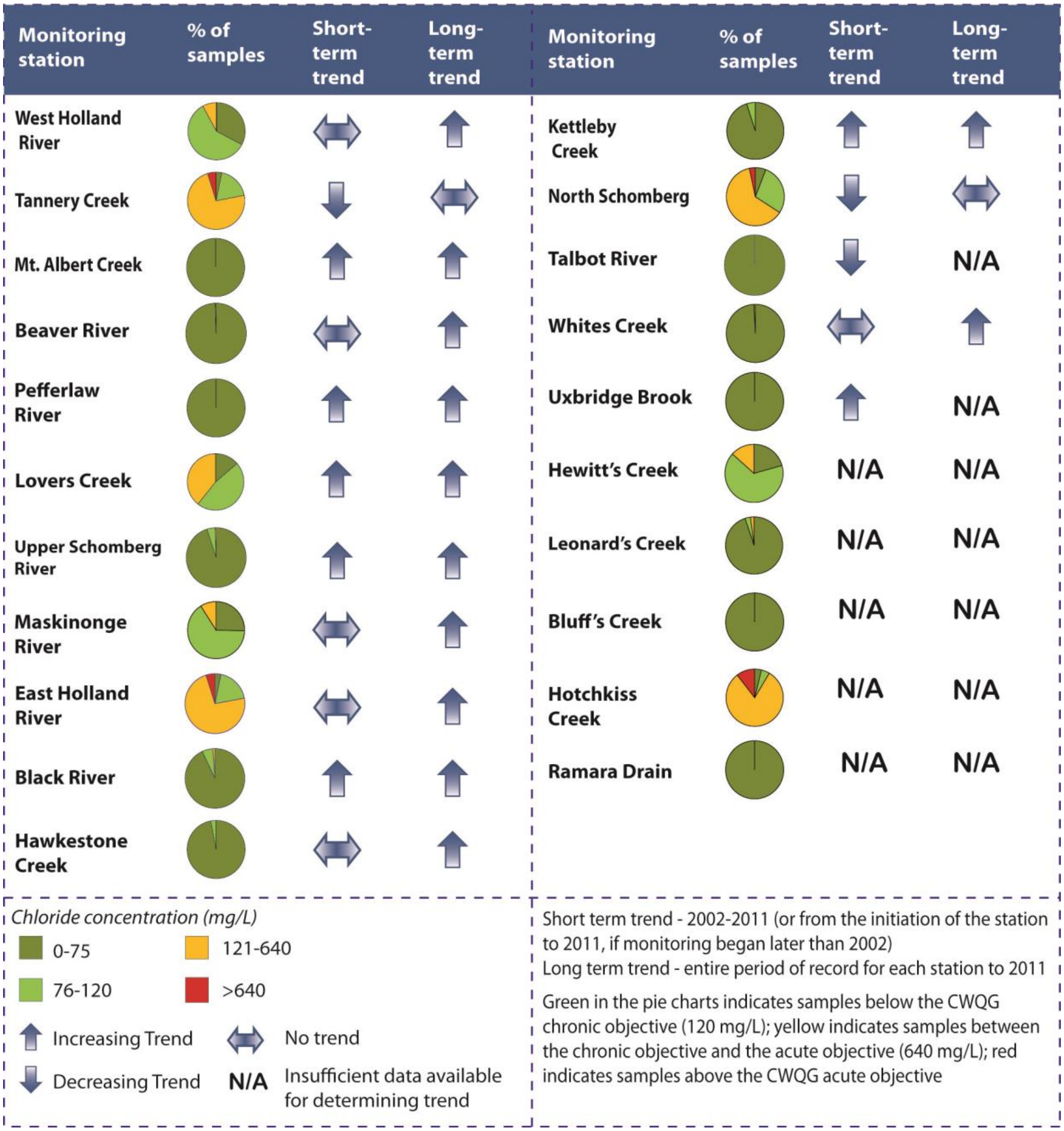


Figure 1. Average annual chloride concentration in Lake Simcoe, measured at Atherley Narrows and three municipal water treatment plants (Winter et al, 2011)

This increase in chloride concentration isn't limited to the lake itself however; chloride concentrations have increased in eight of the ten monitored watercourses in the Lake Simcoe watershed between 1993 and 2007 (Winter et al, 2007), to the point that the majority of samples collected from Tannery Creek, Lovers Creek, the East Holland River, North Schomberg River, and Hotchkiss Creek now exceed the Federal guideline of 120 mg/L for long-term exposure (Figure 2). In fact, Hotchkiss Creek, East Holland River, and North Schomberg River have all exceeded the Federal guideline of 640 mg/L for short-term exposure for aquatic organisms several times since 2007 (LSRCA, 2013). The case of Lovers Creek in Barrie is particularly striking, as a consistent increase in chloride concentration at the mouth of the creek is evident, concurrent with an increase in development within its subwatershed (Figure 3).



Monitoring station	% of samples	Short-term trend	Long-term trend
West Holland River		↔	↑
Tannery Creek		↓	↔
Mt. Albert Creek		↑	↑
Beaver River		↔	↑
Pefferlaw River		↑	↑
Lovers Creek		↑	↑
Upper Schomberg River		↑	↑
Maskinonge River		↔	↑
East Holland River		↔	↑
Black River		↑	↑
Hawkestone Creek		↔	↑
Kettleby Creek		↑	↑
North Schomberg		↓	↔
Talbot River		↓	N/A
Whites Creek		↔	↑
Uxbridge Brook		↑	N/A
Hewitt's Creek		N/A	N/A
Leonard's Creek		N/A	N/A
Bluff's Creek		N/A	N/A
Hotchkiss Creek		N/A	N/A
Ramara Drain		N/A	N/A

Chloride concentration (mg/L)

🟩 0-75

🟩 76-120

🟧 121-640

🟥 >640

↑ Increasing Trend

↓ Decreasing Trend

↔ No trend

N/A Insufficient data available for determining trend

Short term trend - 2002-2011 (or from the initiation of the station to 2011, if monitoring began later than 2002)

Long term trend - entire period of record for each station to 2011

Green in the pie charts indicates samples below the CWQG chronic objective (120 mg/L); yellow indicates samples between the chronic objective and the acute objective (640 mg/L); red indicates samples above the CWQG acute objective

Figure 2. Summary of chloride concentrations at Lake Simcoe water quality stations (taken from LSRCA, 2013)

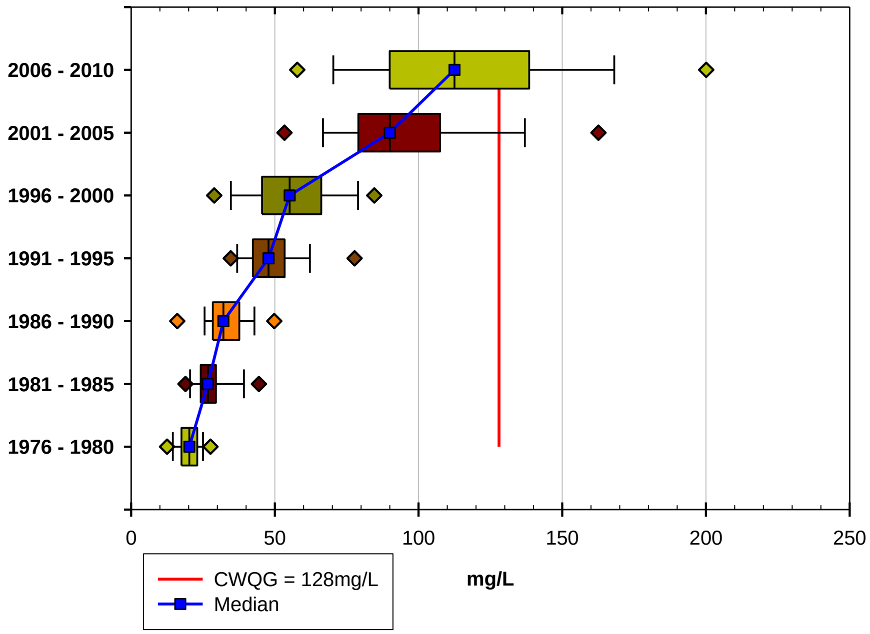


Figure 3. Lovers Creek chloride concentrations 1976 - 2010 (LSRCA, 2012)

The environmental and human health consequences of increasing chloride concentration can be significant. Road salt contaminates drinking water supplies, and is toxic to many species of plants, fish, and other aquatic organisms (Forman and Alexander, 1998). The increasing concentration of sodium in watercourses has negative impacts on fish and aquatic insects, by interfering with their respiratory processes. Gill-breathing animals rely on a higher solute concentration within their bodies than in the environment to allow the 'sodium pumps' in their gills to chemically attract oxygen from the water. A change to the solute concentration in the water requires these organisms to expend more energy to acquire oxygen from their surroundings (Findlay and Kelly, 2011). Increased levels of chloride ions can cause mortality, reduced weight and activity, decreased time to metamorphosis, and increased abnormalities in amphibians (Sanzo and Hecnar, 2006). Increasing chloride levels can also cause leaf injury to plants, alter soil pH and chemical composition, and increase the mobility of elements (such as heavy metals) in sediments (Forman and Alexander, 1998; Trombulak and Frissell, 2000). Increasing salt concentrations can also increase the density of water, affecting the duration of lake stratification (Findlay and Kelly, 2011). Because of these environmental concerns, Environment Canada reviewed published toxicity studies of the impacts of chloride on aquatic organisms, and set a guideline for long-term exposure of 120 mg/L, based on the 5th percentile of long-term (>7 day) LC_{50} rates reported, and a short-term exposure guideline of 640 mg/L, based on the 5th percentile of published short-term (24-96 hour) LC_{50} values (Figure 4; CCME, 2011).

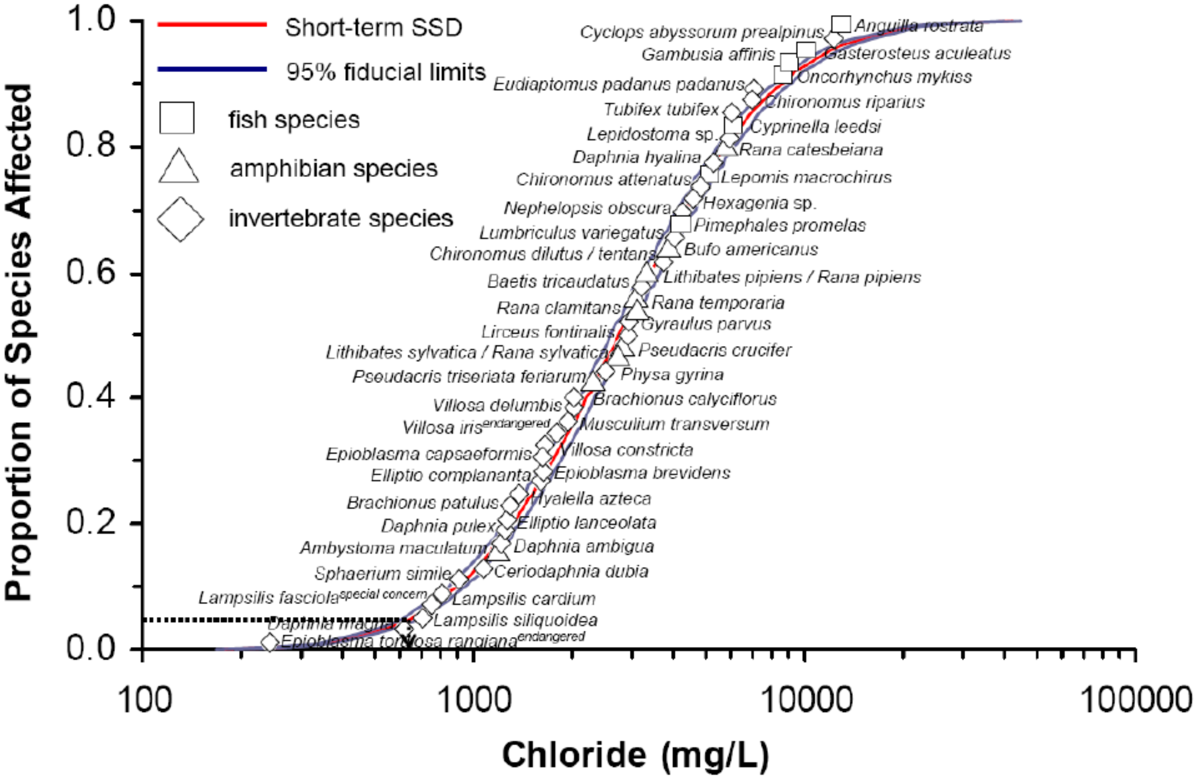


Figure 4. Short-term LC_{50} toxicity response of aquatic and semi-aquatic organisms (summarized in CCME, 2011)

Although there may be several sources of chloride in watersheds, including both natural (e.g. geologic deposits) and anthropogenic (e.g. salt applied to roads and parking lots, waste water effluent, water softeners, and dust suppressant applied to roads), the primary source of chloride in the Lake Simcoe watershed is associated with winter salt. The strong correlation seen in the Lake Simcoe watershed between road density and chloride concentration in nearby streams suggests that the source isn't natural, and the strong seasonality evident (with highest chloride concentrations found in winter and early spring), suggest that the management of snow and ice on roads, sidewalks, and parking lots is the primary source (Winter et al, 2011).

Increasing trends in chloride in water bodies is not limited to the Lake Simcoe watershed. This issue is becoming common throughout urbanized northeastern North America (e.g. Mayer et al, 1999; Kausal et al, 2005). As a measure to help address this emerging issue, Environment Canada developed a Code of Practice for the Environmental Management of Road Salts (Environment Canada, 2004). The intent of the Code of Practice is to ensure environmental protection while maintaining roadway safety. The Code makes two main recommendations: the development of salt management plans by all road management authorities, and the implementation of best management practices in the areas of salt application, salt storage, and snow disposal. The Code also promotes annual reporting from municipalities to Environment Canada. One of the key recommendations of the Code is the identification of areas that are particularly sensitive to road salts, for assessing additional salt management measures (hereafter described as "salt vulnerable areas"). Although rates of participation in the Code of Practice, including the development of salt management plans and investment in sophisticated technologies has been high, relatively few road management agencies have identified salt vulnerable areas (Environment Canada, 2012).

In an attempt to rectify this barrier, Betts et al (2014) developed a model for identifying salt vulnerable areas, based on six watersheds in the City of Toronto. Their approach was a conceptually simple one; they modelled average annual chloride concentration in watercourses, based on watershed land use and salt application rates in the watershed, as well as factors related to watershed area and flow volume (Equation 1). They then identified relative vulnerability of watercourses based on the relative sensitivity of aquatic organisms. Based on a strong correlation (R^2=0.99) evident between average and standard deviation in chloride concentrations in study watercourses, Betts et al (2014) developed a lognormal cumulative distribution model to predict the probability that the chloride concentrations in each of their study watersheds would exceed these reported LC_{50} values (Equation 2). Relative sensitivity of each watercourse was based on the number of aquatic and semi-aquatic organisms which could be expected to be impacted by the use of winter salt within the respective watershed.

$$SCC = \frac{A*CAD*UAR*(1-BFI) + BFC*BFI*A*MAF}{A*MAF}$$

Where,

SCC = Mean annual stream chloride concentration (mg/L)

A = Watershed area (m^2)

CAD = Chloride application density

UAR = Unit chloride application rate (g/m^2)

BFI = Baseflow index

BFC = Baseflow chloride concentration (mg/L)

MAF = Normalized mean annual flow (m)

Equation 1. Estimating stream chloride concentration, based on flow variables and land use within a drainage area (Betts et al, 2014)

$$Probability\ of\ Occurrence = 1 - LOGNORM.DIST(X, mean, standard_{dev}, cummulative)$$

Equation 2. Probability of occurrence that chloride concentration of 'X' will be exceeded (Betts et al, 2014)

The purpose of this study is to identify and map geographic areas in the Lake Simcoe watershed that are vulnerable to water quality impairment caused by the application of salt for the purpose of winter maintenance of roads, parking lots, and sidewalks (i.e. ‘salt vulnerable areas’). The results of this study will be used to help focus education and outreach projects, and will be provided to watershed municipalities for use in road operations and strategic planning.

Salt application rates in the Lake Simcoe watershed

One of the key data inputs to the salt vulnerable area modelling of Betts et al (2014) is an estimation of salt application rates in the drainage area above the point being monitored ('unit chloride application rate' in Equation 1). The development and validation of the original model was conducted on smaller watersheds, which were almost entirely located in the City of Toronto. As such, they were able to rely on detailed salt application data from the City, and develop a generalized annual average application rate, which was used as a primary input to the analysis.

In the Lake Simcoe watershed however, there are 20 municipal and provincial agencies managing roads. The roads they manage range from multi-lane highways to rural gravel roads. As such, salt application rates may vary substantially amongst road management authorities. This aspect of the study compiles, analyses, and reports salt application rates used by the public and private sectors across the Lake Simcoe watershed.

Methods

Road salt application data was requested from all municipalities in the Lake Simcoe watershed via email. In total, 11 municipalities (as well as the Ministry of Transportation of Ontario) responded, and provided data with varying levels of detail. Some municipalities provided reports from multiple years, along with weather records, and lengths of roads managed. Others reported simply total volumes applied in winter 2012/2013 (the most recent winter, prior to request). Annual application rates across the watershed were calculated for winter 2012/2013 by dividing the total volume of salt reported by the total area of road managed by each road management agency.

To convert total application amounts to unit application rates, amounts reported by each road management authority were divided by the total area of roads they manage. Total area of roads managed by each road management authority was derived from the road layer in LSRCA's GIS database, with attributes reflecting the number of lanes and the responsible road management authority added to each line segment in that dataset. Provincial highways are already identified in the GIS layer; roads managed by upper tier municipalities were identified based on road maps provided by municipal staff or available on municipal websites. Any roads not maintained by the province or upper tier municipalities were assumed to be maintained by the local municipality. Any non-provincial roads located in single tier municipalities were assumed to be maintained by that municipality. The number of lanes of road associated with each line segment in the dataset was attributed based on air photo interpretation. The total 'lane-kilometers' of road managed by each authority in the Lake Simcoe watershed was then summed (Table 1).

Table 1. Total area of road managed by the Ministry of Transportation of Ontario and municipalities within the Lake Simcoe watershed

Road Authority	Lane - km
Aurora	396
Barrie	979
Bradford West Gwillimbury	394
Brock	658
Caledon	1
City of Kawartha Lakes	738
Durham (Scugog yard)	228
Durham (Sunderland yard)	172
East Gwillimbury	382
Georgina	803
Innisfil	628
King	331
MTO (Durham)	106
MTO (Kawartha Lakes)	2
MTO (Simcoe)	310
MTO (York)	259
New Tecumseth	45
Newmarket	500
Orillia	206
Oro-Medonte	430
Ramara	421
Scugog	72
Simcoe County	236
Springwater	1
Uxbridge	588
Whitchurch - Stouffville	218
York (central yard)	549
York (north yard)	596
Total	**10,246**

Total volume of salt applied by the MTO and watershed municipalities were converted to annual chloride application rates by dividing the total volume of material that each road management agency applies by the total road surface area they manage. However, as salt is applied in a variety of forms around the watershed (including both sodium chloride and magnesium chloride, applied both dry and in solution as a brine), total mass of material applied was converted to mass of chloride based on the relative atomic mass of sodium, magnesium and chloride (i.e. sodium chloride salt was assumed to be

66.7% chloride by mass, and magnesium chloride 75% chloride by mass), and ratios reported by each municipality for their sand-salt mixes. Based on advice provided by municipal roads maintenance staff, brine was assumed to be 25% NaCl by volume. In order to determine total road surface area, lanes were assumed to be 3m wide (O. Reg 239/02).

For municipalities which did not provide salt application reports (all of which were relatively rural municipalities), application rates were assumed to be equal to other rural municipalities within the same upper tier municipality where possible.

Betts et al (2014) noted that salt application by private sector contractors maintaining parking lots had a substantial impact on watersheds identified as being salt vulnerable areas. Unlike public agencies however, private sector contractors are not requested to report their salt application to Environment Canada, making their data more difficult to obtain. Fortunately, Fu et al (2013) recently undertook a survey of members of Landscape Ontario, to determine salt application practices, including typical per-event application rates. Over 100 contractors responded to their survey. The average reported ‘light’ application rate was 11.9 lbs/1000 ft^2, or 58.1 g/m^2. Although self-reporting mechanisms like this are somewhat vulnerable to under-reporting, monitoring of three parking lots in the Lake Simcoe watershed suggests that this value is representative of contractor operations. As such, this value was taken as an average per-event application rate for private contractors active in the Lake Simcoe watershed. It was assumed that salt was applied at this rate an average of 54 times in 2012 (based on the average number of events responded to by Newmarket, Whitchurch-Stouffville, and Uxbridge), resulting in a total annual application rate of 3137.4 g/m^2.

The amount of salt applied by private homeowners in the Lake Simcoe watershed is that much more difficult to estimate again. According to the Salt Institute (reported in Sander et al. 2007), 91-97% of de-icing salt sold in North America is sold as bulk salt; the remainder is sold as packaged salt, primarily purchased by private individuals. As such, it was estimated that 10% of the salt applied in the Lake Simcoe watershed is applied by private home owners. An annual salt application rate of 63 g/m^2 was derived as a pro-rated average, by dividing the total estimated application volume by the total estimated residential parking area.

Land cover maps maintained by LSRCA do not provide sufficient detail to identify parking areas. In order to estimate the extent of parking lots in each land use category, a subsample of each land use category of a range of property size classes were overlain on the most current air photos available, and the extent of parking areas within the lots was digitized. These values (Table 2) were used in analysis.

Table 2. Representative areas dedicated to parking in the Lake Simcoe watershed, classified by land use and property size

Land Cover Class	Area Class (m2)	Smallest parking area (m2)	Largest parking area (m2)
Urban	150	62	150
Urban	250	151	250
Urban	500	251	500
Urban	1000	501	1000
Urban	2000	501	2000
Urban	3000	2001	3000
Urban	5000	3001	5000
Urban	10000	5001	9999
Urban	> 10000	10005	794192
Rural	500	29	500
Rural	2000	501	2000
Rural	10000	2001	9998
Rural	40000	10009	39989
Rural	> 40000	40004	1014967
Estate Residential	500	24	473
Estate Residential	2000	618	1998
Estate Residential	10000	2008	9998
Estate Residential	40000	10010	39928
Estate Residential	> 40000	40012	373240
Institutional	500	36	489
Institutional	2000	501	1974
Institutional	10000	2009	9974
Institutional	40000	10064	39834
Institutional	> 40000	40231	728339
Commercial	500	24	500
Commercial	2000	501	2000
Commercial	10000	2003	9977
Commercial	40000	10031	39249
Commercial	> 40000	40121	347665
Industrial	500	25	498
Industrial	2000	508	1979
Industrial	10000	2011	9979
Industrial	40000	10001	39344
Industrial	> 40000	40021	372438

To identify underlying factors determining salt application practices on roads, multiple regression equations relating municipal application rates with total lane-kilometres of road managed by each road management authority and municipal population were developed.

Multiple year application data provided by four watershed municipalities also permits an assessment of the influence of varying weather conditions on salt application rates. Multiple regression equations were developed which tested the influence of municipality (as a categorical variable) and both total winter precipitation (defined as the amount of snow or rain received during days when minimum temperatures fell below 2° C), and total precipitation events (which meet the same characteristics). One municipality provided data from a particularly long period of record (1995-2012), which also included data on the length of roads managed. This longer period of record allowed an assessment of the interacting influence of weather and road network size on salt application rates. Stepwise multiple regression equations relating the total volume of salt applied to area of road network and both total winter precipitation and number of winter precipitation events were developed.

The total volume of chloride applied in the Lake Simcoe watershed in 2012 was estimated by multiplying the estimated chloride application rates by the total area of roads managed by each authority (or area of parking lot managed by contractors), and summed.

Results and discussion

Chloride application rates in the Lake Simcoe watershed ranged from less than 46 g/m^2 to 4711 g/m^2 (Figure 5). Generally speaking, there is a trend to greater chloride application in the northern half of the watershed (in the 'snowbelt') than in the south, and a greater use in urban areas than rural. Annual application rates in the City of Toronto range from 357 g/m^2 to 1308 g/m^2 over a 25 year period (Betts et al, 2014), roughly equivalent to that applied by more urbanized local municipalities in our watershed, but less than that applied by the MTO or upper tier municipalities, some of whom apply over three times as much salt as Toronto. Application rates in the Minneapolis/St Paul Metropolitan area however range from 1315 g/m^2 to 3006 g/m^2 (Sander et al, 2007), which is relatively similar to application rates in the Lake Simcoe watershed.

In order to derive the annual salt application estimates in Figure 5, several generalizations needed to be made. These included equal application rates per road in each municipality, and equal application rates by contractors to all parking lots across the watershed. The results of the salt vulnerability model will need to be validated against chloride concentrations recorded by LSRCA monitoring data to determine how critical these generalizations were.

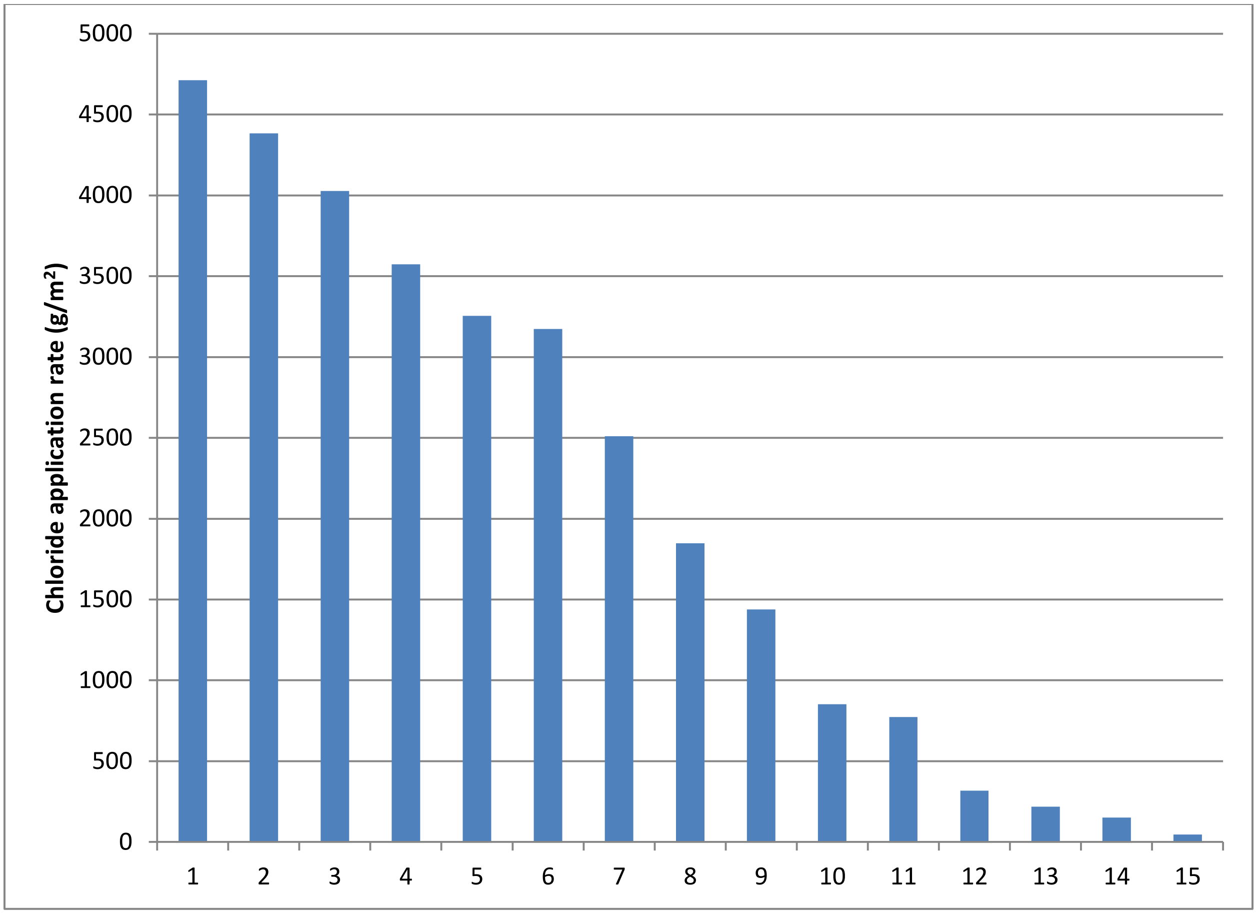


Figure 5. Chloride application rates (g/m^2) on roads in the Lake Simcoe watershed, applied by reporting road authorities. Names of road authorities have been removed.

The total volume applied in the Lake Simcoe watershed in winter 2012/2013 is estimated to have been 60,613 tonnes of chloride (or the equivalent of 90,467 tonnes of salt). The greatest contribution was from local and single tier municipalities (43%), and upper tier municipalities (30%). Both provincial highways and commercial parking lots are relatively limited in the Lake Simcoe watershed, so have a lower overall contribution to chloride loading (Figure 6). This total application volume equates to an approximate per capita application rate of 150 kg of chloride (or 225 kg of salt) per person, per year, in the Lake Simcoe watershed.

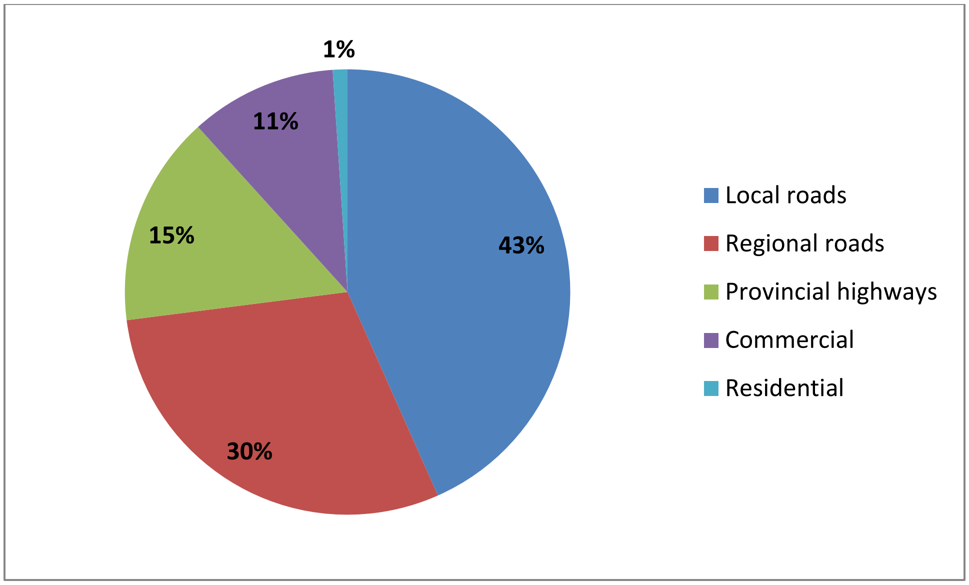


Figure 6. Relative contribution of chloride to the Lake Simcoe watershed, based on chloride application rates and total area managed

Amongst municipal and provincial road management agencies across the watershed, there was no significant relationship between salt application rates and either municipal population, or total area of roads managed ($p > 0.05$ in both cases). The multi-year data provided by one watershed municipality provides an opportunity to assess the impacts of these factors on the actions of individual municipalities. For this municipality, there was a significant ($p=0.01$) relationship between salt applied in a given year, and the total area of roads managed, indicating that as the road network in a municipality increases, their salt use will tend to increase as well (Figure 7).

In assessing the influence of winter severity on total volume of salt applied by watershed municipalities, neither the total amount of precipitation nor the number of precipitation events were significantly related ($p>0.05$) to the total volume of salt applied by reporting municipalities. The categorical 'municipality' variable was significantly related however ($p=0.007$), indicating that municipal operational decisions have a greater influence on application rates than do varying weather conditions. Within the longer period of record (1995 - 2012) however, both total precipitation and total number of events remained non-significant ($p>0.05$).

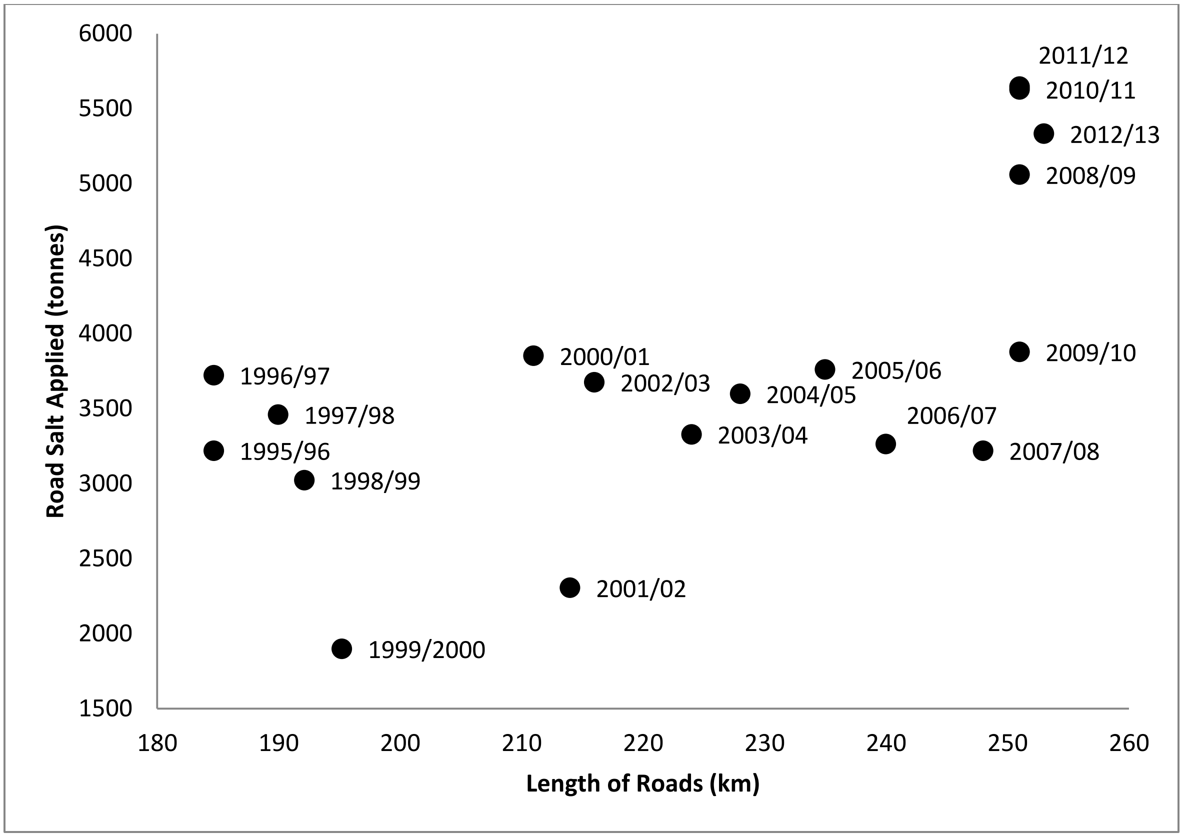


Figure 7. Relationship between road network extent and total salt applied within a single municipality in the Lake Simcoe watershed (1995- 2013)

The significant relationship seen between the extent of the road network managed and total salt applied makes the (perhaps obvious) point that, as road networks in the watershed expand to support projected population growth, that total salt application volumes will likely increase as well. In fact, Kilgour et al (2013) found that although adoption of the Code of Practice in Toronto led to a reduction in unit area salt application rates by 26%, an increase in road area in the City more than offset the gains achieved through best practices, leading to an increase in total salt applied by up to 80% since Toronto's adoption of the Code of Practice. As such, operational practices alone will not be sufficient to reduce future chloride loading to Lake Simcoe. Instead, consideration should be given to how the planning process can be used to reduce some of the potential impacts associated with future development.

The lack of clear relationship between precipitation patterns and volume of salt applied by road management agencies suggests that predicting the impacts of climate change on future chloride levels remains challenging. While Kilgour et al (2013) and Sander et al (2007) found relatively simple relationships between total snowfall and salt applications, Environment Canada (2012), in their review of salt application nationally, found it challenging to derive simple relationships between winter weather and salt application. A similar challenge was found in this study, perhaps reflective of the fact that salt application relates to intensity, duration, and frequency of storm events, number of freeze-thaw cycles, and number of frost events (as well as differing public expectations in different municipalities). Climate change projections for southern Ontario suggest that, overall, winters should become slightly warmer, and experience less frost, less snow, and fewer freeze-thaw cycles (Canadian Climate Change Scenarios Network, 2014), all of which should tend to reduce salt application. However, using the relationship between snowfall and salt application derived from the City of Toronto (Kilgour et al, 2013), projected decreases in winter snowfall in the Lake Simcoe watershed are expected to reduce salt application rates by only 2.5%.

Validating the model

The approach for identifying salt vulnerable areas developed by Betts et al (2014) in Toronto models average annual chloride concentration in watercourses based on watershed land use and salt application rates (Equation 1). Calculated actual chloride concentrations in the study watercourses were well predicted by the model (exhibiting a coefficient of determination (R^2) of 0.96).

The current study area is larger and more complex than the area where the approach was pioneered however. Unlike the study catchments of Betts et al (2014), catchments in the Lake Simcoe watershed are larger, have greater diversity in land use, and cross multiple municipal jurisdictions. In order to use the approach of Betts et al (2014) for identifying salt vulnerable areas in the Lake Simcoe watershed, it is necessary to confirm that the model accurately predicts stream chloride concentration in this more complex landscape.

Methods

Actual average chloride concentrations in Lake Simcoe tributaries over a five-year period (2008 - 2012) were compiled from 16 sites (Table 3). Other monitoring stations lacking land use data at the time of analysis (i.e. stations on the Talbot River) were excluded from analysis, as were sites which had other monitoring sites nested within their catchments (i.e. Atherley Narrows, West Holland River, Schomberg River) to avoid issues with pseudoreplication of non-statistically independent data (Hurlbert, 1984).

Predicted average annual chloride concentration at these monitoring stations was calculated by applying Equation 1 to the drainage area above the monitoring stations (Figure 8). The Ontario road network layer was clipped to the catchments above the monitoring stations, and total salt applied to roads within each catchment was estimated as the product of the total area of road managed by each road authority and their reported salt application rate (Figure 5). Total amount of salt applied to parking lots in each catchment was estimated by clipping the LSRCA land cover map to the drainage area boundaries, and then estimating the total area of parking lot in each catchment based on average parking lot percentages (Table 2), applied to the total area within each land use in each catchment. Total salt applied to parking lots was estimated as the product of that area and the most common 'light' application rate reported in the Landscape Ontario survey (58.1 g/m^2; Fu et al. 2013).

Mean annual flow values across each catchment and baseflow index values for their respective subwatersheds were provided by EarthFx (2010), and baseflow chloride concentration in urban and rural catchments was estimated by applying the methods of Perera et al. (2013) to chloride concentration data from the Holland Landing and Beaverton water quality monitoring stations between 2008 and 2012, respectively .

The predictive ability of the model of Betts et al (2014) was then tested by calculating the Pearson product-moment correlation between monitored and modelled average annual chloride concentrations at long-term monitoring stations.

Table 3. Average chloride concentration at selected water quality monitoring stations (2008-2012)

Monitoring station	Average annual chloride concentration (mg/L)
Beaver River	28.7
Black River	50.3
Bluffs Creek	11.7
Hawkestone Creek	26.4
Hewitts Creek	108.0
Holland Landing (East Holland River)	224.0
Hotchkiss Creek	409.9
Kettleby (West Holland River)	53.9
Leonards Creek	46.8
Lovers Creek	122.3
Maskinonge River	93.8
North Schomberg (West Holland River)	153.7
Pefferlaw River	29.7
Pumphouse (West Holland River)	113.4
Upper Schomberg (West Holland River)	55.9
Whites Creek	25.8

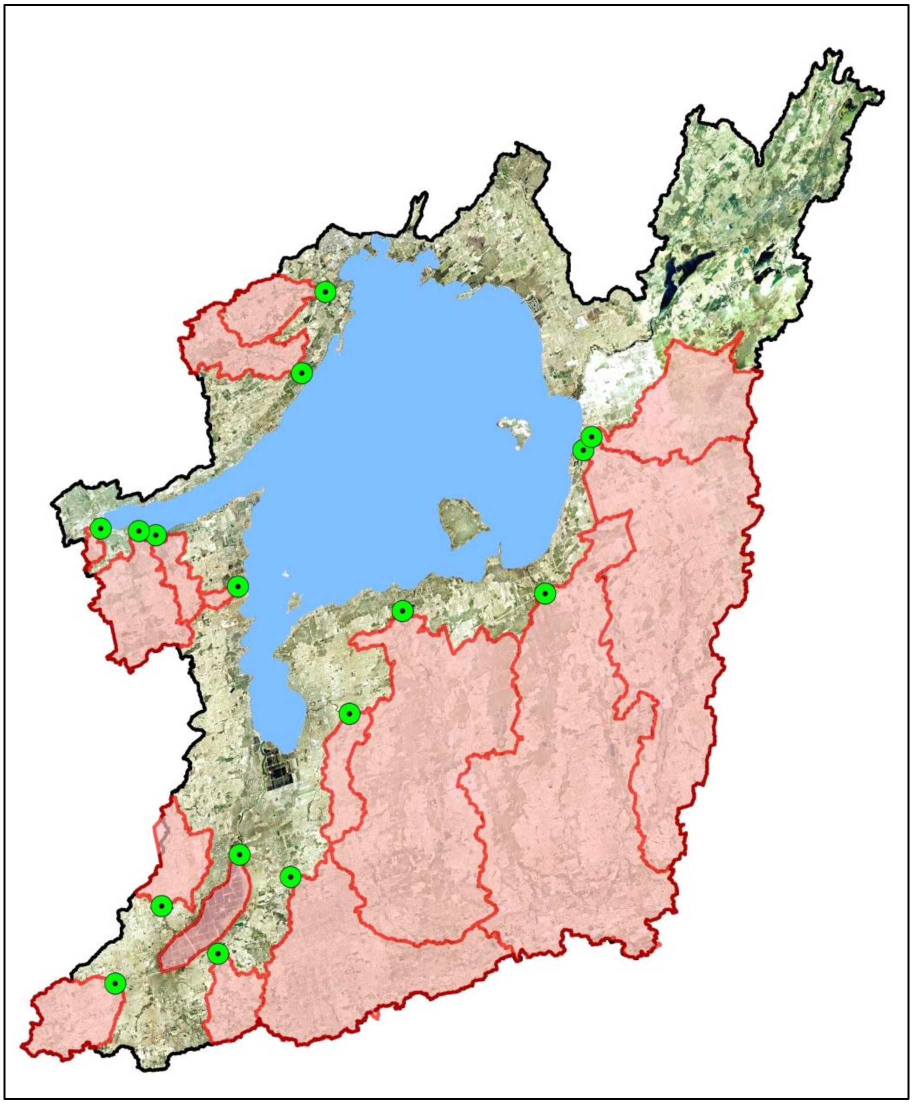


Figure 8. Monitoring stations, and associated catchments, used in validation of stream chloride concentration model

Results and discussion

The correlation between predicted and actual average annual chloride concentrations at LSRCA's long term water quality monitoring stations was high (Figure 9; $r = 0.95$; $p<0.001$). The model however tends to overestimate stream chloride concentration slightly (Figure 9; $\beta = 1.3$). This over-estimation may represent chloride that actually ends up in groundwater rather than surface water (e.g. Perera et al. 2010) or may relate to the implicit assumption in the model that all parking lots and all residential driveways are treated with salt. This model also ignores differential salt application rates on roads within a municipality, due to differing service levels, which may be contributing to a model which is slightly less precise than that developed by Betts et al (2014).

The greatest outlier to the curve, and the exception to the general trend of the model over-estimating chloride concentration at LSRCA monitoring stations, is the North Schomberg station. In that case, the levels of chloride found in the creek are higher than the model predicted. LSRCA monitoring staff consider the North Schomberg station an outlier in their data as well, and feel that the chloride levels they find in the creek at that station are higher than they would expect based on land use. The North Schomberg station is in close proximity to Highway 400, and receives direct highway run-off, which may tend to create a local chloride "hot spot" (Lance Aspden, LSRCA Hydrologist, pers. comm.)

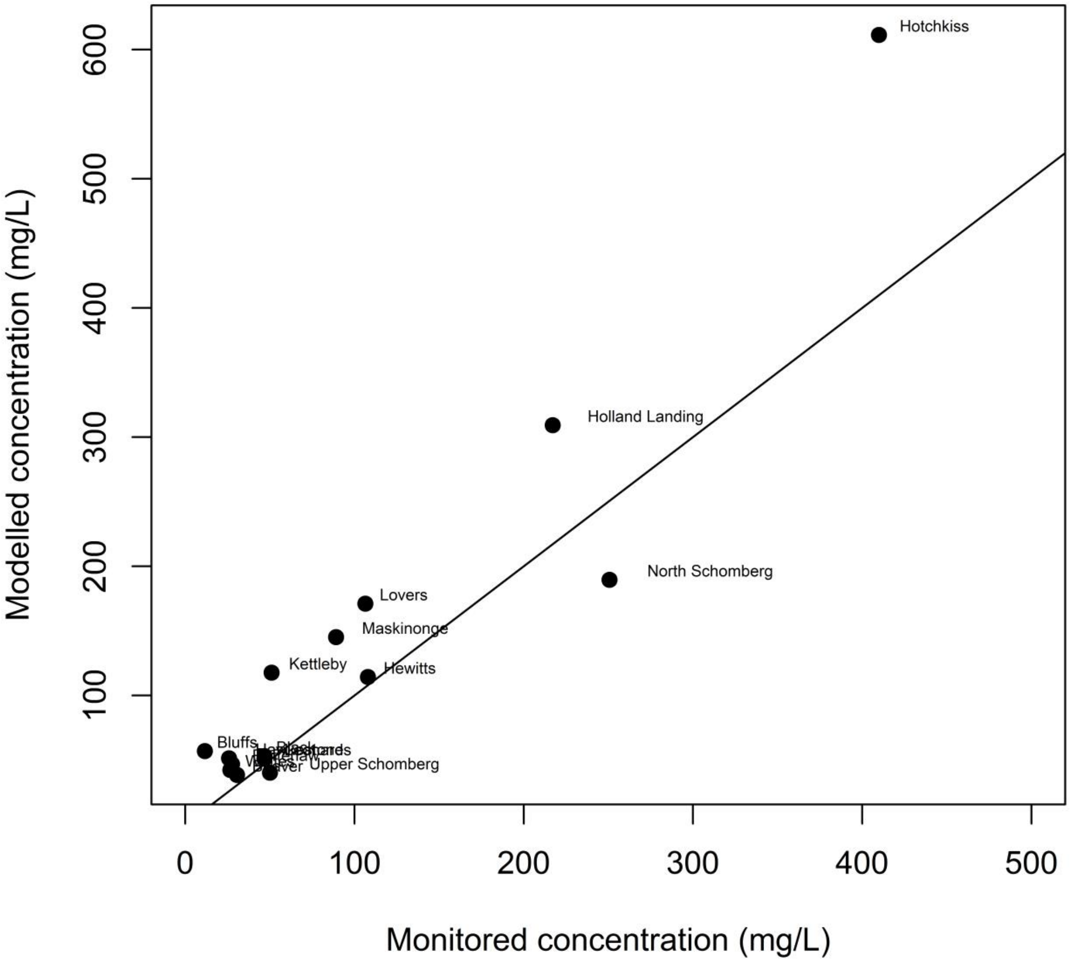


Figure 9. Relationship between actual and predicted stream chloride concentrations at LSRCA water quality monitoring stations. Asymptote represents the line where model perfectly predicts stream chloride concentration

As can be seen from Figure 9, the model Betts et al (2014) developed to predict average stream chloride concentration in Toronto works quite well for the Lake Simcoe watershed. In the original derivation of the model, Betts et al (2014) included a factor (called ‘chloride application density’) to account for relative intensities of salt application by private contractors on land uses of different types. As a result that of factor, their model provided a more precise estimate of chloride concentration (β=0.92). In the Lake Simcoe watershed, where parking lots have a lower contribution to overall chloride loading (Figure 6), a 30% over-estimate was considered preferable to including another assumption in the model that hasn’t been tested locally.

One significant limitation in the approach of Betts et al (2014) is that it assesses stream chloride concentration based on salt application rates within the study watershed. That works well at the scale with which it has been validated, however estimating chloride concentrations at this scale (Figure 8) is neither new information for the conservation authority, nor useful for roads managers. In order to be an effective planning tool for municipal or provincial roads managers, this model will need to identify salt vulnerable areas on a much more local scale, while accounting for cumulative impacts of salt application and run-off across larger catchments. The next section will describe a modification to the approach piloted by Betts and his colleagues to account for these cumulative impacts.

Mapping salt vulnerable areas

Given the ability of this simple modelling approach to predict average annual chloride concentrations at LSRCA's long-term water quality monitoring stations, it appears to be an appropriate approach for generating estimates of chloride concentration elsewhere in the Lake Simcoe watershed.

The final stage of this project is to apply the approach of Betts' et al (2014) to a more local scale within the Lake Simcoe watershed, to identify catchments which can be classified as being 'salt vulnerable areas', and to use this information to inform municipal road management activities, and to assist LSRCA in developing a program to reduce chloride levels in the lake and its tributaries.

Methods

The identification of salt vulnerable areas within the Lake Simcoe watershed was a GIS analysis, completed in ArcMap 10.0 with the Spatial Analyst extension.

Primary data sources for this analysis included shapefiles depicting municipal boundaries, the Ontario road network, the Lake Simcoe watershed boundary, and the '10 ha catchment' shapefile which represents the smallest scale catchments which have been delineated in the Lake Simcoe watershed (mean area=18 ha; range = 0.0025 ha to 160 ha). Additional data, in raster format, that was used includes a digital elevation model for the watershed, and estimates of mean annual flow developed by EarthFx for the source water protection program (EarthFx, 2010).

A modified catchment boundary layer was created, by unioning the 10ha delineated catchments with lower-tier municipal boundaries. This was necessary to ensure that both catchment-specific hydrologic variables and municipality-specific salt application variables were accurately represented in the analysis.

As the mean annual flow raster layer had 100m spatial resolution, and the digital elevation model raster had 5m spatial resolution, the mean annual flow raster was resampled, using bilinear resampling, to interpolate data to 5m resolution. Initial tests indicated that bilinear sampling, which interpolates using a weighted distance average of the 4 nearest cells, provided the greatest resolution resampling, without artificially increasing pixel values.

Baseflow index values were derived from the Quaternary geology layer developed by the Ontario Geologic Survey, using values developed by Piggot and Sharpe (2007). Area-weighted baseflow index values were then calculated for each modified catchment, based on the proportional area of each geologic unit in each catchment.

Baseflow chloride concentration values were calculated for the East Holland River and Beaver River subwatersheds, using chloride concentrations estimated from biweekly conductivity values measured at the LSRCA Holland Landing and Beaverton monitoring stations, respectively. Baseflow chloride concentration was defined as the median chloride concentration observed in the streams during dry-weather, non-winter (i.e. May - Sept) conditions between 2003 and 2012, following the methods of Perera et al. (2013). The baseflow chloride concentration at the Holland Landing station was applied to all primarily urban catchments in the watershed, and the baseflow chloride concentration from the Beaverton station was applied to all primarily rural catchments.

A raster layer of salt application was generated by combining salt application rates on roads and salt application rates on parking lots. Attributes were added to the Ontario road network shapefile, indicating road management agency, and per-area salt application rates for each agency. Maps of parking lots were derived from the most current LSRCA land cover layer (completed in 2014, using images from 2008 and 2009), and filtering out land use types which included parking lots (i.e. urban, rural, estate residential, institutional, commercial, and industrial). Parking area within each resultant land use polygon was estimated based on estimates of average parking lot size in properties of different size and land use types (Table 2). Total salt applied was then estimated as the product of this area and average reported application rate by contractors (for non-residential parking lots; Fu et al, 2013), or the estimated application rate of 63 g/m^2 (for residential parking lots) derived from Sander et al (2007). These two layers were then combined into one grid layer of total salt applied, with 5m resolution.

A second raster layer of salt application was derived from this layer, to permit a scenario of gains possible through the adoption of best practices. All salt application values in the original raster were reduced by 25%, as reductions of that magnitude have been achieved elsewhere in Ontario (e.g. Stone et al, 2010; Kilgour et al, 2013; Bob Hodgins, Smart About Salt Council, pers. comm.).

Areas of future development within the Lake Simcoe watershed were mapped based on designated settlement areas in the most recently available municipal Official Plans. Settlement area designations were overlain on the LSRCA land cover map to exclude any areas which have already been developed. Identified natural heritage systems, or lands classified as ‘Open Space’ or ‘Greenlands’ in municipal Official Plans were also excluded, as development will tend to be highly restricted in these areas. A grid layer of salt application changes resulting from future development was generated, using a process similar to that described above, based on this map of projected future growth areas, and additional data on projected new roads, where available.

Average annual chloride concentration in each ‘modified’ catchment was calculated using a modification to the approach of Betts’ et al (2014) (Equation 3). In this modified equation, assumptions about ‘chloride application density’ have been excluded, and the total estimated amount of salt applied (per 5m pixel in the raster layer) used instead. In order to account for the accumulation of both salt and overland flow of water from headwater systems to the mouths of Lake Simcoe’s tributaries, the accumulation of both salt and surface water runoff was calculated using the ‘weighted flow accumulation’ tool in ArcMap’s Spatial Analyst extension.

$$SCC = \frac{CA*(1-BFI) + BFC*BFI*A*MAF}{A*MAF}$$

Where,

SCC = Mean annual stream chloride concentration (mg/L)

CA = Chloride applied (mg)

BFI = Baseflow index

BFC = Baseflow chloride concentration (mg/L)

MAF = Normalized mean annual flow (m)

Equation 3. Modified approach for estimating stream chloride concentration, based on flow variables and land use within a drainage area.

Prior to analysis, values of both the mean annual flow grid and salt application grid were averaged over the 'modified' catchments using the zonal statistics tool in Spatial Analyst. This step was necessary to ensure that there were no elements within the analysis area with a value of zero in the denominator in Equation 3, and to 'smooth' any outlying values in the numerator. The 'modified' catchments thus became the basic spatial unit over which the analysis occurred, and on which results are reported.

Modelled average annual chloride concentration in the 'modified' catchments ('SCC' in Equation 3) were then exported into an Excel file to estimate the number of aquatic organisms which may be impacted by salt application within each catchment. The Canadian Council of Ministers of the Environment (2011) reviewed and summarized a range of laboratory studies on the sensitivity of aquatic organisms to chloride exposure, and developed LC_{50} relationships for both long-term (> 7 day) and short-term (24 – 96 hr) exposures. A subset of this list was created for analysis, by excluding any taxa whose native range does not include the Lake Simcoe watershed (Table 4). The probability that chloride concentrations in each 'modified' catchment would exceed the published LC_{50} values for either the short-term or long-term period was calculated using Equation 2. The total number of taxa which could experience exceedances of either of their short-term or long-term LC_{50} values was then calculated for each 'modified' catchment.

Table 4. Sensitivities of aquatic biota native to the Lake Simcoe watershed to the chloride ion (CCME, 2010)

Response to short-term (24 – 96 hours) exposure		
Scientific name	**Common name**	**LC_{50} (mg/L)**
Sphaerium simile	A peaclam	902
Ambystoma maculatum	Spotted salamander	1178
Tubifex tubifex	Sludge worm	1204
Daphnia ambigua	A water flea	1213
Ceriodaphnia dubia	A water flea	1284
Daphnia pulex	A water flea	1295
Brachionus patulus	A rotifer	1298
Elliptio complanata	Eastern elliptio	1353
Hyalella azteca	An amphipod	1450
Epioblasma brevidens	Cumberlandian combshell	1626
Gyraulus circumstriatus	A freshwater snail	1941
Brachionus calyciflorus	A rotifer	1945
Rana sylvatica	Wood frog	2309
Pseudacris triseriata	Western chorus frog	2320
Physa gyrina	A freshwater snail	2540
Diaptomus spp.	A copepod	2571
Pseudacris crucifer	Spring peeper	2830
Daphnia magna	A water flea	3073
Rana clamitans	Green frog	3109
Baetis tricaudatus	A mayfly	3130

Response to short-term (24 – 96 hours) exposure		
Cricotopus trifascia	A midge	3774
Bufo americanus	American toad	3926
Hydroptila angusta	A caddisfly	4016
Lumbriculus variegatus	Blackworm	4094
Nephelopsis obscura	A leech	4310
Erpobdella punctata	A leech	4550
Pimephales promelas	Fathead minnow	4700
Chironomus attenatus	A midge	4850
Hydropsyche spp.	A caddisfly	5459
Rana catesbeiana	Bullfrog	5846
Chironomus dilutus	A midge	5867
Lepomis macrochirus	Bluegill	6026
Culex spp.	A mosquito	6187
Lepomis cyanellus	Green sunfish	6499
Oncorhynchus mykiss	Rainbow trout	7951
Libellulidae spp.	A dragonfly	9671
Cambarus spp.	A crayfish	10557
Anguilla rostrata	American eel	10846
Argia spp.	A damselfly	14252
Response to long-term (> 7 day) exposure		
Scientific name	**Common name**	**LC$_{50}$ (mg/L)**
Musculium securis	Pond fingernail clam	121
Daphnia pulex	A water flea	368
Daphnia magna	A water flea	421
Hyalella azteca	An amphipod	421
Tubifex tubifex	Sludge worm	519
Pimephales promelas	Fathead minnow	598
Lumbriculus variegatus	Blackworm	825
Gammarus pseudopinmaeus	An amphipod	2000
Physa spp.	A freshwater snail	2000
Chironomus tentans	A midge	2316
Rana pipiens	Northern leopard frog	3431
Chlorella minutissima	An algae	6066
Chlorella zofingiensis	An algae	6066

Estimates of average annual chloride concentration, and total aquatic taxa impacted, were calculated three times: once for the current scenario (based on application rates shown in Figure 5), once for a scenario of increased adoption of best practices (with 25% reductions in all salt application) at current levels of development, and once for a 'full build-out' scenario representing potential future development (without the application of best practices).

Results and discussion

Average annual chloride concentration in catchments around Lake Simcoe range from 0 to over 24,000 mg/L (Figure 10). The upper values in this range occur rarely across the watershed, and thus may be outliers in the model, however they are also consistent with concentrations observed directly running off parking lots (David Lembcke, LSRCA Manager of Environmental Science and Monitoring, pers. comm; Amanjot Singh, Credit Valley Conservation Water Quality Engineer, pers. comm.). Perhaps not surprisingly, hotspots for chloride tend to occur within urban areas and along major roads (Figure 10). At this scale, the fairly self-evident result is that areas with high densities of asphalt tend to have high concentrations of chloride. Variation exists within those urban areas however. For example, in the case of the Town of Newmarket, chloride concentration tends to remain below the CCME short-term exposure guideline of 640 mg/L around the margins of the Town, but chloride tends to become concentrated towards the centre of the Town, causing tributaries to exceed that guideline. Higher water volumes within the main branch of the East Holland cause subsequent dilution, bringing average annual chloride concentration down between the chronic and acute guidelines (Figure 11).

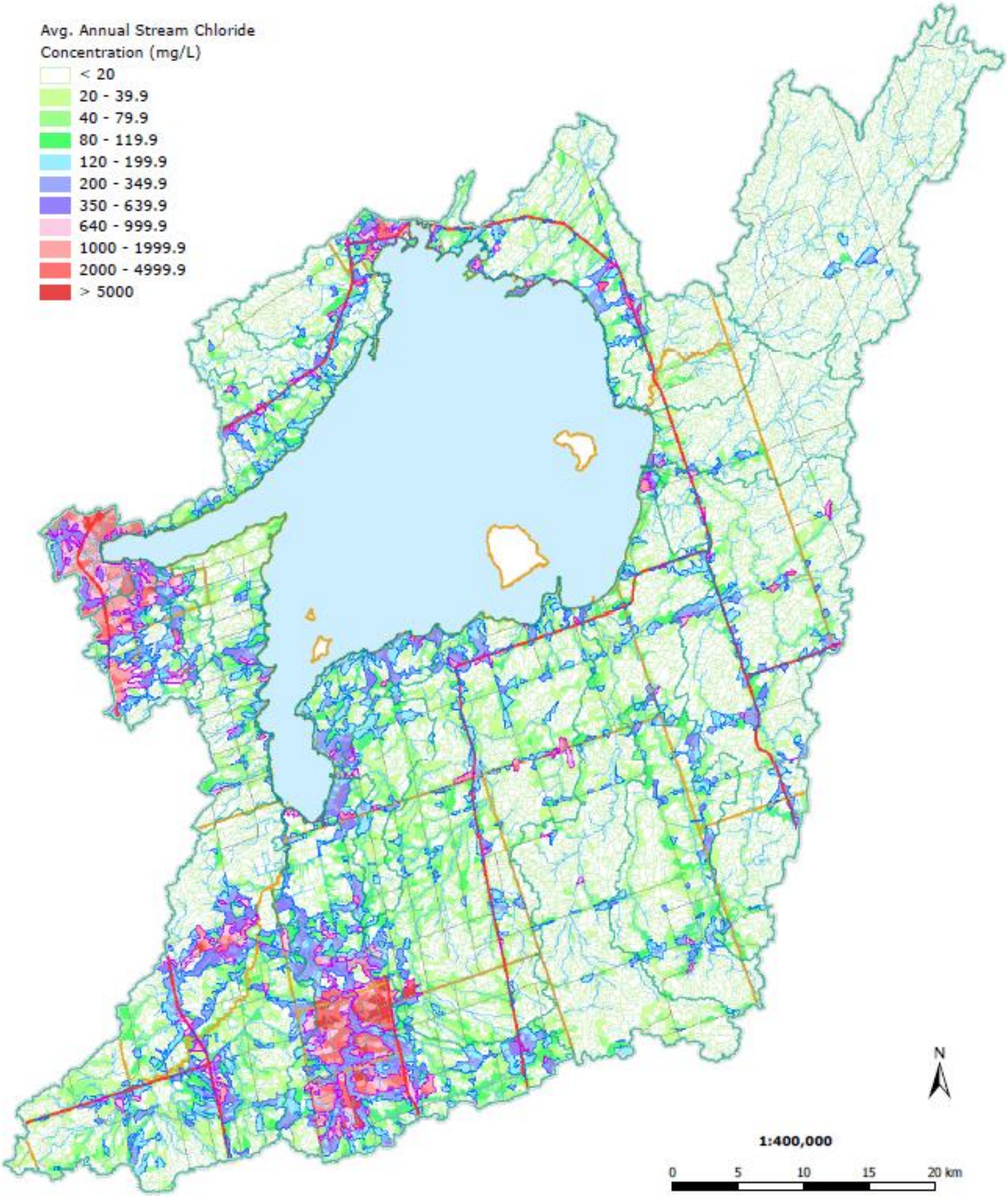


Figure 10. Predicted average annual chloride concentration (mg/L)

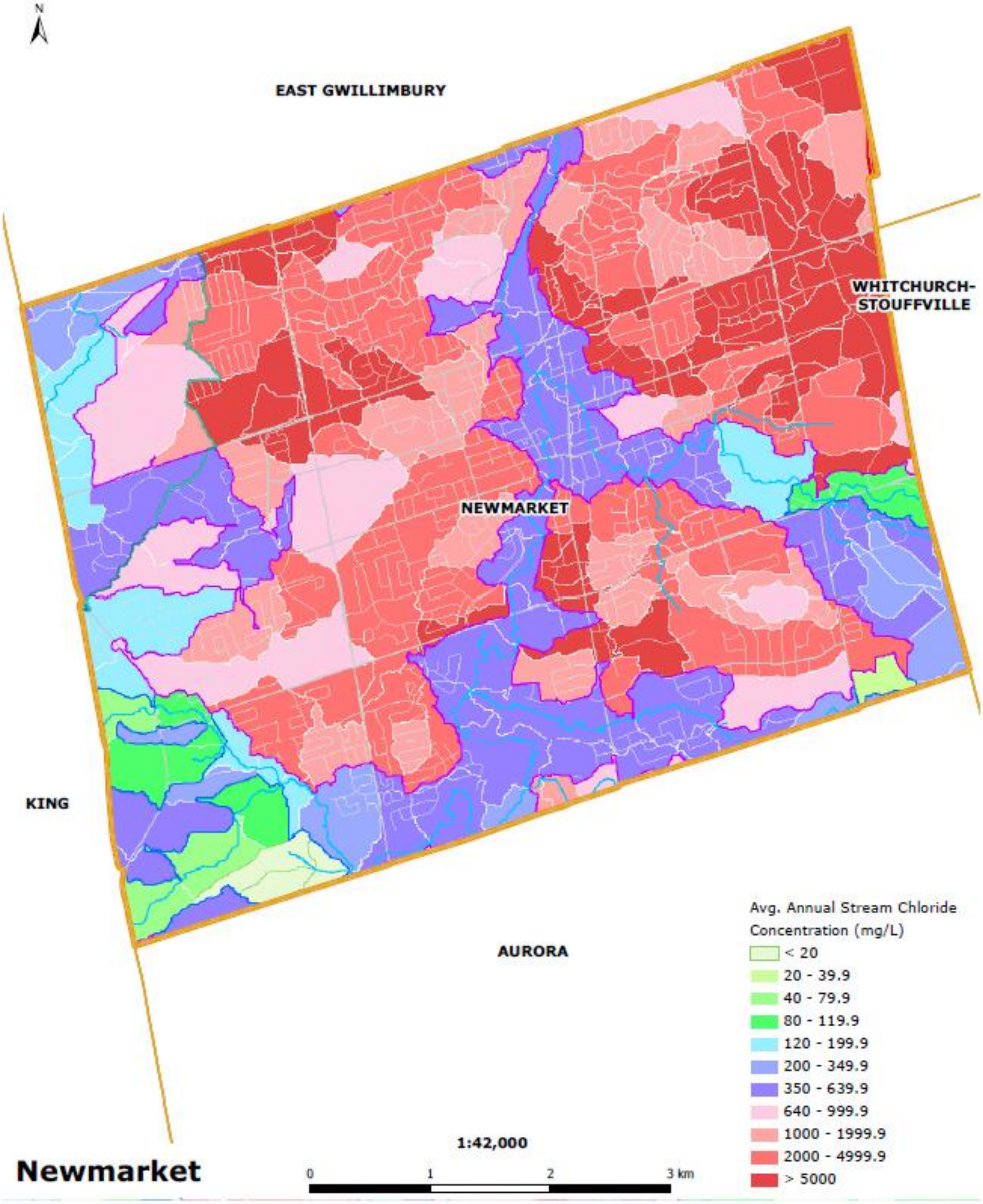


Figure 11. Predicted average annual chloride concentration (mg/L) in the Town of Newmarket

Within the Lake Simcoe watershed as a whole, 16% of the watershed is predicted to exceed the Canadian Water Quality Guideline for long-term exposure for the protection of aquatic life from chloride (120 mg/L) on an average annual basis (Figure 10). Over 4.5% of the watershed is predicted to exceed the short-term exposure guideline (640 mg/L) on an average annual basis. However, it is the severity and extent of extreme events, rather than annual averages, which determine how many aquatic species are impacted by chloride. The modelling approach used in this study estimates that such events are impacting aquatic biota in 64% of the Lake Simcoe watershed. Within those catchments, number of taxa impacted is estimated to range from 1 to 45 (of a total of 47 included in analysis) (Figure 13).

The approach to defining salt vulnerable areas developed by Betts et al. (2014) is a relative one (i.e. vulnerable areas are those where the impacts of salt on biota are the greatest). Based on Figure 12, one could define salt vulnerable areas as those catchments where more than five taxa are potentially impacted by the application of salt to roads or parking lots. As with hotspots of chloride concentration, these salt vulnerable areas tend to occur in more densely developed areas, and in localized areas along some of the major roads and highways in the watershed (Figure 13).

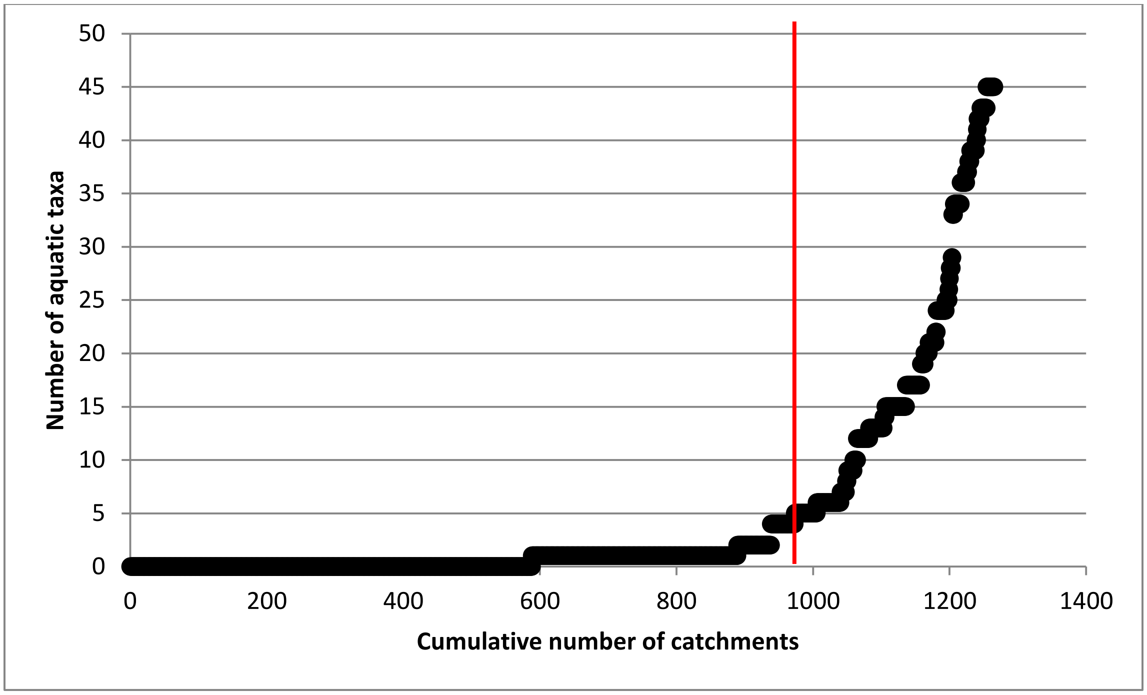


Figure 12. Range of numbers of aquatic taxa predicted to be impacted by chloride in Lake Simcoe's tributaries. Red vertical line represents divide between salt vulnerable areas and non-salt vulnerable areas (>5 species impacted)

The raster layer of combined salt application used in Equation 3 can be used to estimate the relative contribution of salt from each sector (i.e. road management agency, private contractors, or home owners) in the identified salt vulnerable areas. While this estimate is based on several estimates and generalizing assumptions, it does suggest that, within salt vulnerable areas, the influence of the management of commercial, industrial, or institutional parking areas is greater than it is across the Lake Simcoe watershed as a whole (Figures 6, 14). Similarly, the influence of local road networks is slightly greater, and regional road networks slightly lesser, than in the watershed as a whole (Figures 6, 14). This is reflective of the fact that identified salt vulnerable areas tend to occur in urban areas (Figure 13) where both local roads and parking lots exist in greater density. While Provincial highways are relatively rare in the Lake Simcoe watershed, they make a relatively large contribution to total salt applied in salt vulnerable areas (Figure 14).

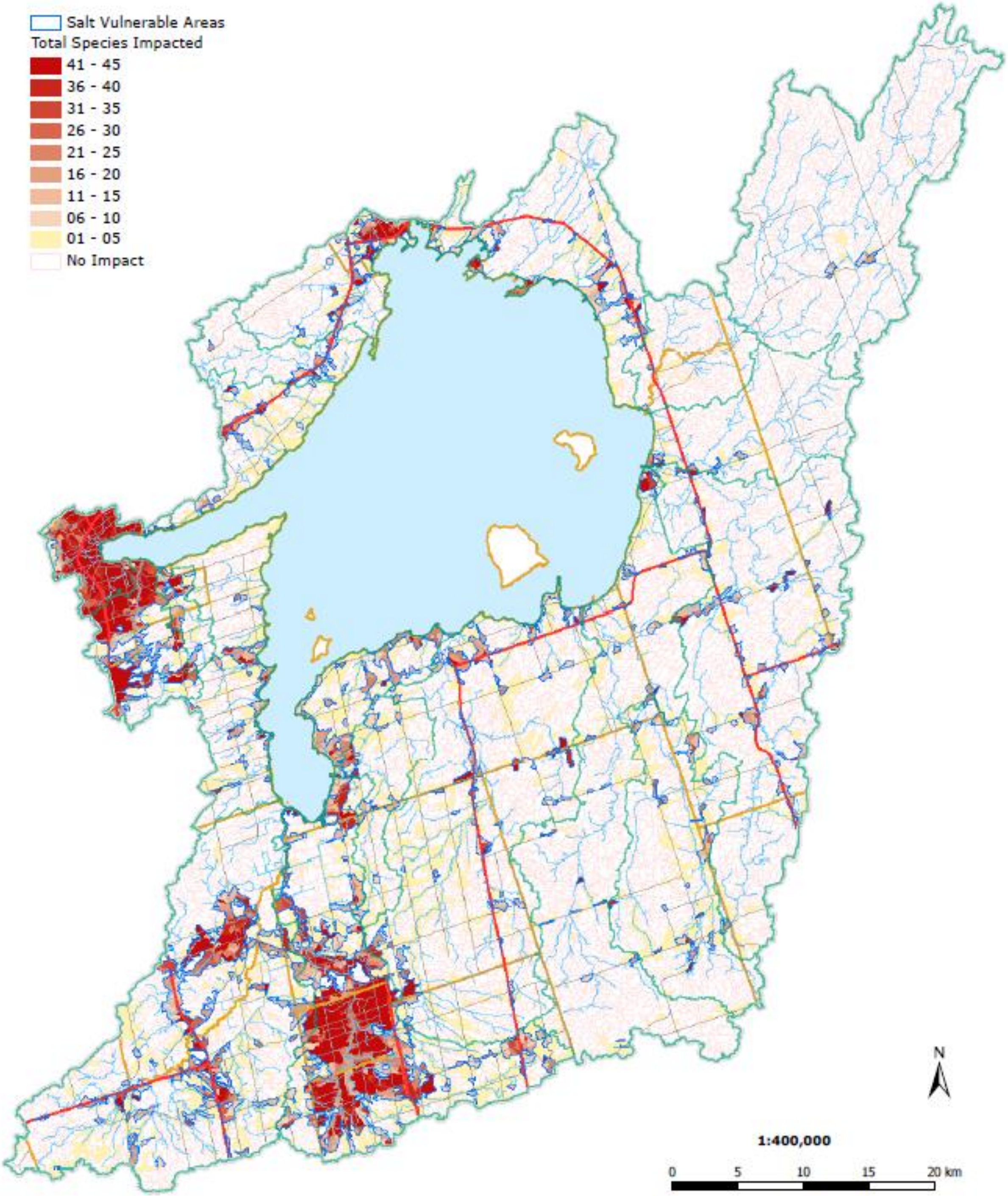


Figure 13. Predicted number of aquatic taxa impacted by chloride and designated 'salt vulnerable areas' in the Lake Simcoe watershed

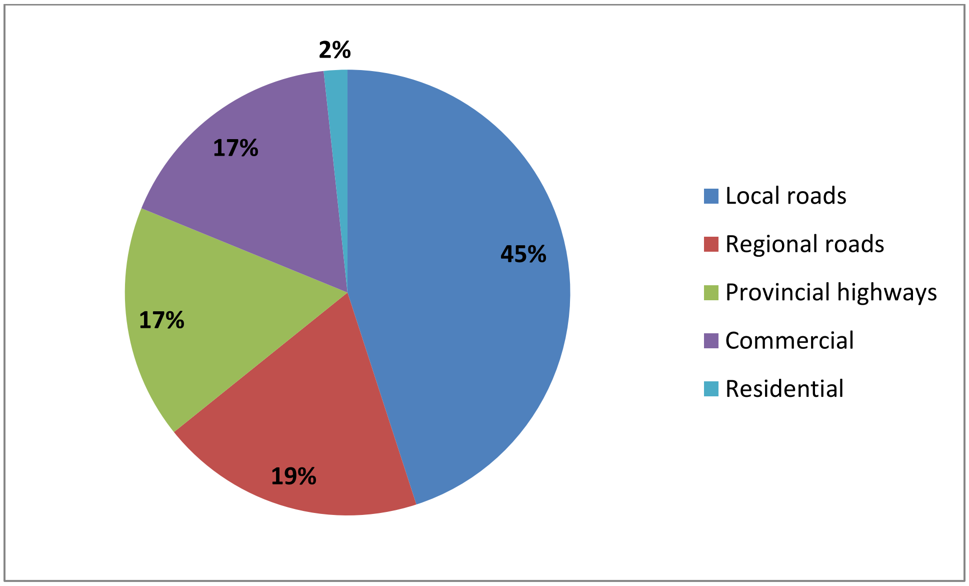


Figure 14. Relative contribution of chloride within salt vulnerable areas in the Lake Simcoe watershed, based on chloride application rates and total area managed

Despite high chloride concentrations in Lake Simcoe's tributaries, and associated high levels of potential impacts to native aquatic biota, significant gains can be achieved through the implementation of best practices (Figure 15). A 25% reduction in salt applied to roads and parking lots could lead to a reduction in the number of taxa impacted by chloride by up to 13 (or a third of the total species assessed). Because the relationship between chloride concentration and the number of species which are sensitive is a non-linear one (Figure 4), the greatest benefits to the environment can actually be achieved in areas with moderate levels of impact. In the Lake Simcoe watershed, these include areas such as Holland Landing, Keswick, and parts of Innisfil (Figure 15). Similarly, areas of moderate impact within densely developed urban areas could benefit to the point of being delisted as 'vulnerable' (Figure 16). However, chloride reductions would propagate through the main branch of the East Holland River, to the extent that up to 11 species (or 23% of those studied) could be gained in this river (Figure 16).

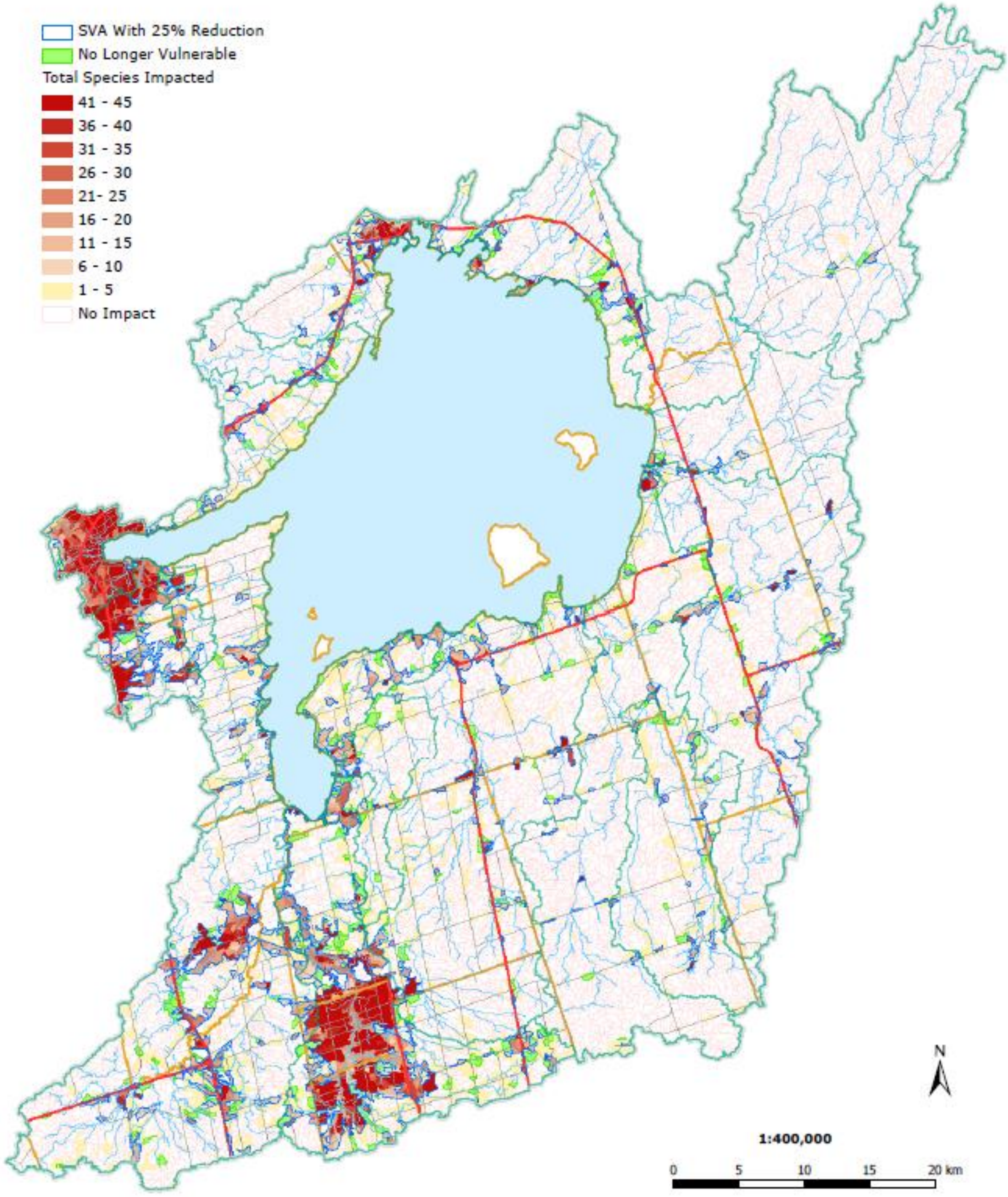


Figure 15. Predicted average annual chloride concentration, and reductions to impacts possible with 25% reduction in salt application rates

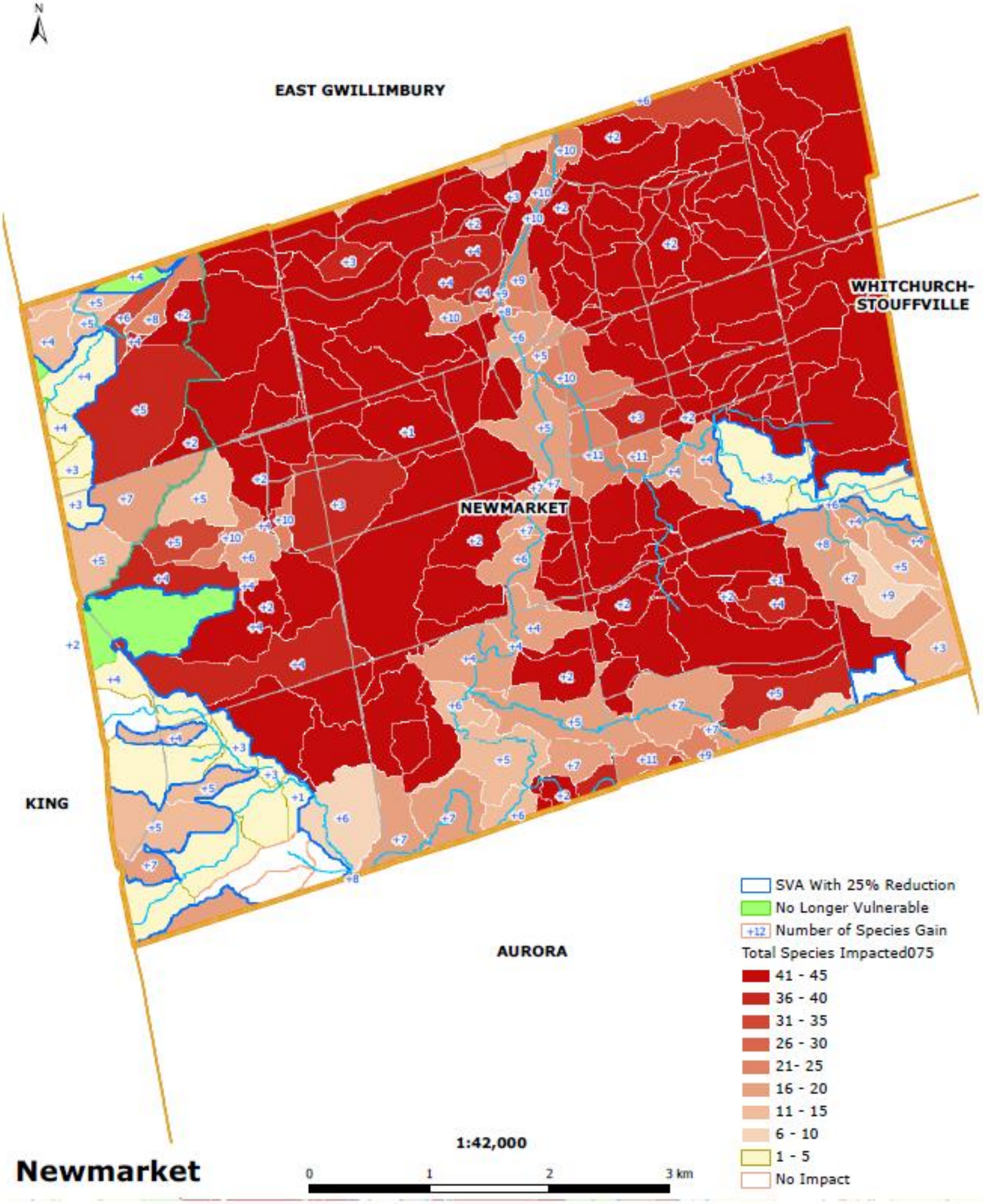


Figure 16. Predicted average annual chloride concentration in Newmarket, and reductions to impacts possible with 25% reduction in salt application rates. Numbers represent number of aquatic taxa expected to be gained in each catchment

However, concurrent with any promotion of the adoption of best practices, development will continue to occur in the Lake Simcoe watershed. Estimates suggest that urban areas within the watershed may increase by over 12,000 ha (or a 52% increase) by 2013 (XCG Consultants Ltd, 2014; Figure 17). Estimates of changes to average annual stream chloride concentration as a result of this increased density of roads and parking lots suggest that chloride concentrations in some catchments may increase from essentially zero to over 24,000 mg/L (i.e. to the maximum value calculated by the model) (Figure 18). Areas where the greatest increases have been predicted include the south end of Cook's Bay in East Gwillimbury, particularly around Queensville (Figure 19). In addition to being a focal area for growth in the Lake Simcoe watershed, the Queensville area is primarily in the headwaters of the Maskinonge River, which has characteristically low flows and limited groundwater discharge. As such, relatively little surface water runoff will be available to dilute salt applied to roads and parking lots in this area. Increases in chloride concentration in this area are predicted to be as high as 6000 mg/L (or roughly equivalent to chloride levels currently observed in Hotchkiss Creek in Barrie; LSRCA, 2012), resulting in a potential of increasing impacts to 45 aquatic species (of a total of 47 included in analysis) (Figure 19). Similar increases may be expected to occur within areas slated for development at the south end of Barrie; however, maps of areas designated for development in the Hewitt's and Salem Secondary Plans were not made available at the time of analysis.

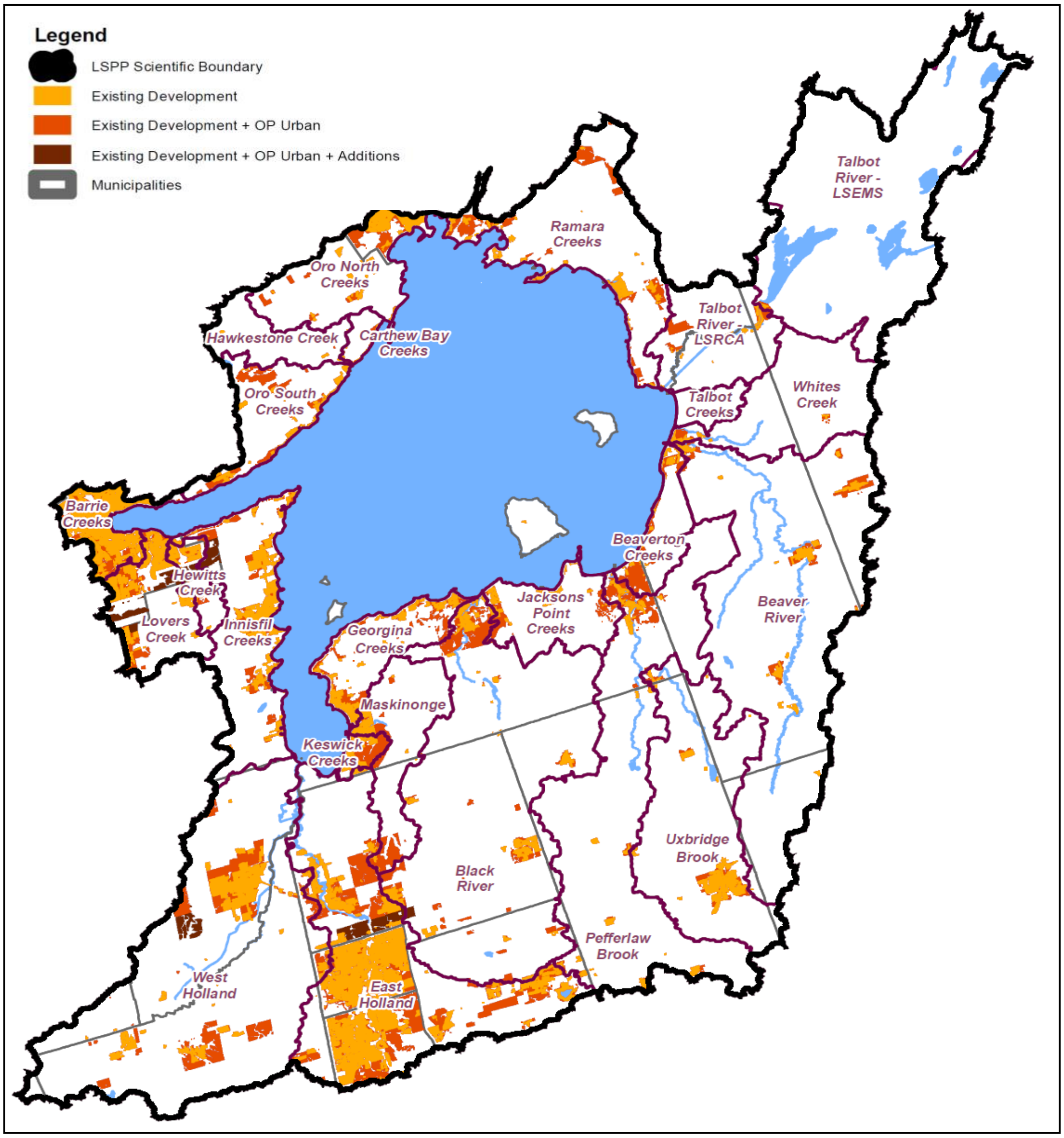


Figure 17. Projected urban growth centres in the Lake Simcoe watershed (XCG Consultants, 2014)

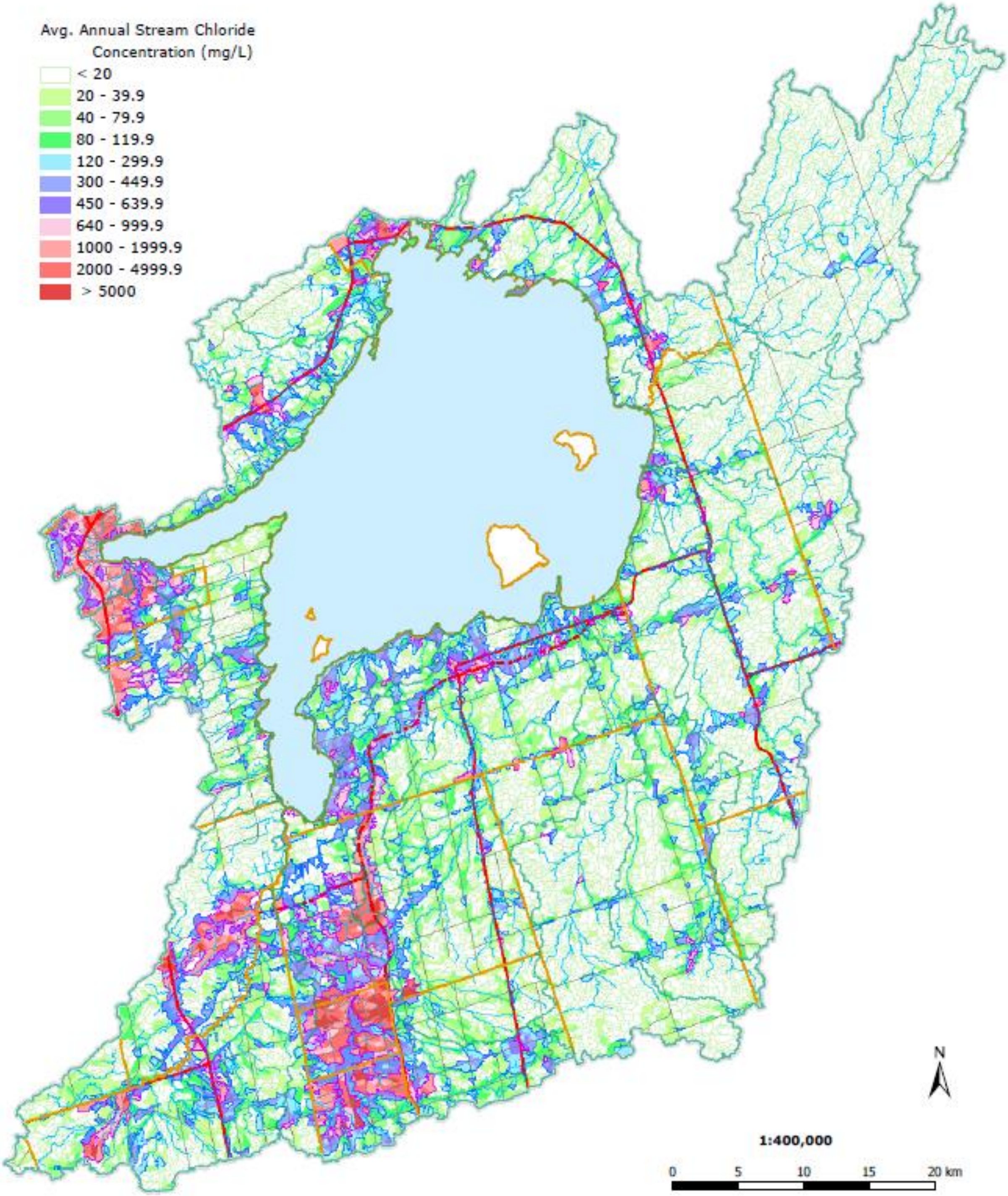


Figure 18. Predicted average annual chloride concentration at the time of "full build-out"

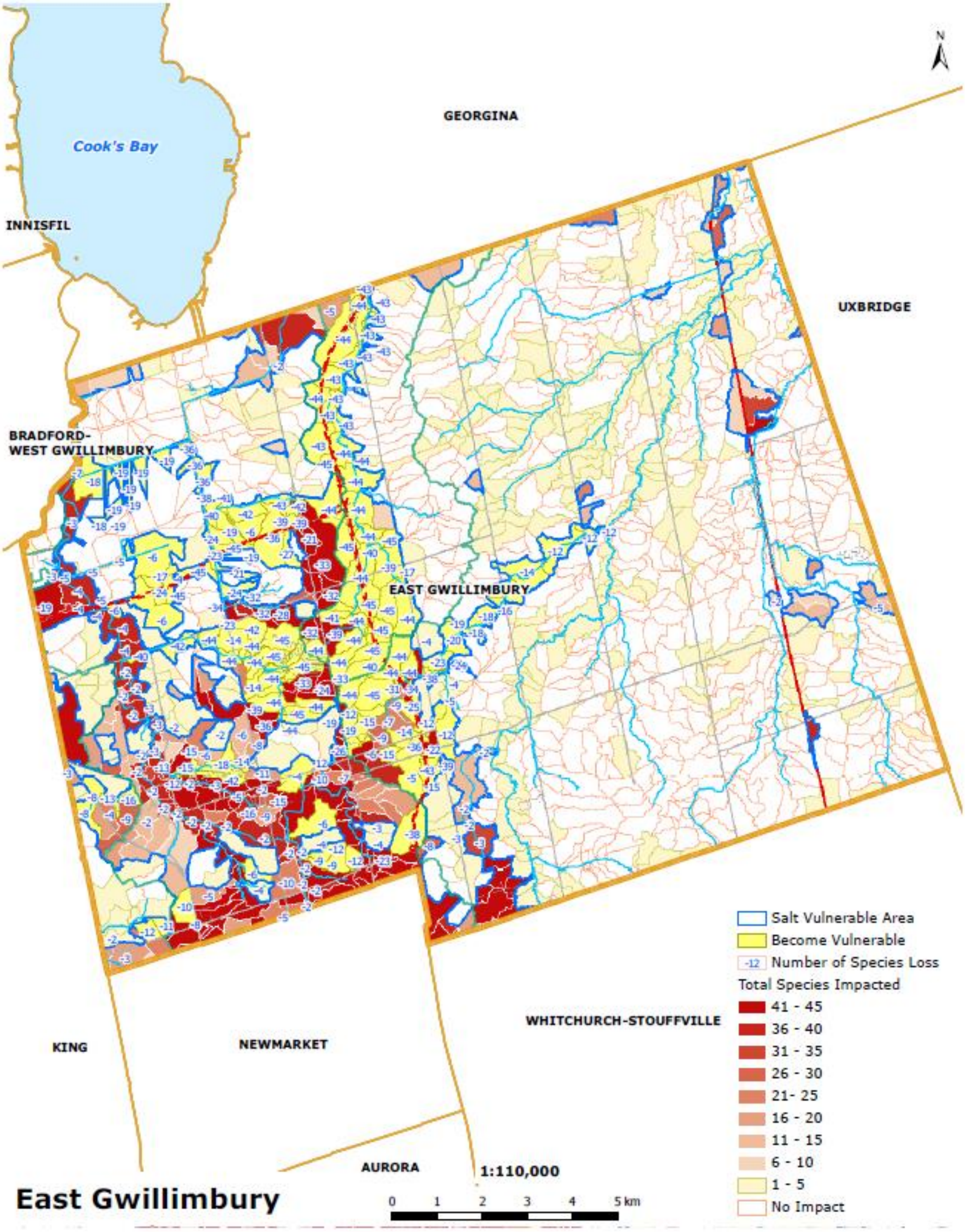


Figure 19. Predicted average annual chloride concentration and number of species impacted in East Gwillimbury at the time of "full build-out". Numbers represent number of aquatic taxa expected to be lost from each catchment.

Recommendations

Salt vulnerable areas (Figure 13) have been identified in most of the larger settlement areas in the Lake Simcoe watershed, including Aurora, Newmarket, Keswick, Bradford, Barrie, and Orillia. Although it is a relatively small community, much of Beaverton has been identified as being a salt vulnerable area as well. Localized salt vulnerable areas can also be found along provincial highways in our watershed, as well as some Regional roads. Interestingly, communities located on the Oak Ridges Moraine, including Uxbridge and the south end of Aurora have relatively low impacts on aquatic biota associated with winter salt, likely because these communities tend to be in headwaters of watersheds (and thus, chloride has had little time to accumulate), and perhaps because high rates of clean groundwater discharge tends to dilute what chloride is in the system.

Although some municipalities have been identified as salt vulnerable areas in their entirety, chloride concentration within watercourses in these communities varies as well (Figure 10). Opportunities may still exist within these communities for road managers to focus salt reduction efforts in those areas most impacted. One of the advantages of the approach to identifying salt vulnerable areas developed by Betts et al (2014) is that 'vulnerability' is a relative term. As no scientifically-defensible threshold has been proposed as to what constitutes an acceptable number of species impacted, salt vulnerable areas have been defined as those which are most impacted within a study area. In the Lake Simcoe watershed, a threshold of more than five aquatic taxa potentially impacted has been selected to fit the definition of salt vulnerable area, based on an assessment of the range of results observed across the watershed (Figure 12). Some road managers may wish to refine the analysis within their municipality if this proposed threshold does not identify the areas of greatest vulnerability within their watershed, by doing a similar histogram for catchments within their municipality only.

Recommendations:

- That LSRCA develop workshops for municipalities managing salt vulnerable areas, sharing the results of this study and our ongoing monitoring program, providing suggestions for modifications to municipal operations.

On a sectoral basis, commercial parking lots have a relatively high chloride contribution to salt vulnerable areas (Figure 14). The Region of Waterloo has developed the Smart About Salt training and certification program, in partnership with Landscape Ontario and the Ontario Good Roads Association, to address this sector. This training and certification program is aimed at both contractors and the facilities they manage, and introduces the topics of how salt works (i.e. the eutectic point), and best practices in salt storage, transport, and application. Experience from that program indicates that many contractors active in snow and ice management have not been offered training of this sort before, and that when they adopt the best practices advocated in the Smart About Salt course, that they can reduce applications by 25-35% (Bob Hodgins, Smart About Salt Council, pers. comm.).

Recommendation:

- That LSRCA continue to partner with the Smart About Salt Council, to promote and provide the Smart About Salt Essentials training to contractors and facility managers active in the Lake Simcoe watershed.

A number of best practices for snow and ice removal within municipal operations have been proposed by the Transportation Association of Canada, including tracking salt application rates and periodic equipment calibration, use of pre-wetted material, taking advantage of weather forecasts, including data on pavement temperature, and the proper location and design of snow disposal sites (Transportation Association of Canada, 2013). A study on the effectiveness of these operational best practices in the Region of Waterloo found that their implementation led to a reduction of chloride loading to groundwater of an average of 60% (although up to 90% in some cases) (Stone et al, 2010).

Recommendation:

- That all municipalities with salt vulnerable areas identified (Figure 13) review their Salt Management Plan and operational practices to determine if there are additional best practices that can feasibly be implemented.

Despite the best intentions of municipal road managers, changing demographics and public expectations tend to play a significant role in determining how much salt municipalities apply. For example, aging demographics and an increasing interest in 'active transportation' tends to create pressure on municipal staff to increase the extent of trails and sidewalks which are treated with salt in the winter.

Recommendation:

- That the LSRCA and watershed municipalities develop an education program to raise public awareness of the environmental impacts of winter salt use, with an intent of changing public expectations and behaviours.

Evidence from other jurisdictions suggests that achieving a 25% reduction in salt application through the implementation of these best practices is possible (Stone et al, 2010; Kilgour et al, 2013). Similar reductions are possible in the private sector with sufficient training and awareness (Bob Hodgins, Smart About Salt Council, pers. comm.). A scenario has been developed in this study (Figure 16) to determine which areas in the watershed support aquatic communities that could benefit the most from reductions of this magnitude. Given the non-linear relationship between chloride concentration in watercourses, and the number of species potentially impacted (Figure 4), areas where the greatest gains could be achieved tend to be those with moderate levels of impact. Areas where the greatest gains could be achieved as a result of improved operations include Holland Landing, Keswick, Bradford West Gwillimbury, the south end of Barrie, Lagoon City, and along Provincial highways (Figure 15).

Recommendations:

- Municipalities which include catchments where the greatest anticipated gains have been identified should review their salt management plans, and challenge themselves to achieve a 25% reduction in salt application.
- Lake Simcoe Region Conservation Authority should focus the Smart About Salt training provided to contractors and facility managers to those catchments where the greatest potential gains are anticipated.

Future growth projections for the Lake Simcoe watershed project an increase of 12,235 ha of settlement lands in the watershed (representing an approximate 50% increase from current levels of development) by 2031 (XCG Consultants Ltd, 2014). The projected increase in population and employment this represents will be associated with an increase in the number of parking lots and length of roads in the watershed. The increase in paved area will no doubt also lead to an increase in the amount of salt applied within the Lake Simcoe watershed. As with the reduction of any environmental impact, it may be most cost effective to deal with the potential environmental impacts associated with future salt application before they occur. To support decision-making on this point, a scenario was developed to estimate the chloride concentration in Lake Simcoe's tributaries and potential impacts on aquatic taxa (Figure 18) in 2031, assuming full build-out. Areas where the greatest changes are anticipated are those where the greatest growth is anticipated, including Queensville, Schomberg, Bradford, the annexed lands in Barrie, and Orillia. Depending on the stage these communities are at in their planning process, a number of different tools may be available for use in reducing salt application. For those which have not yet completed Secondary Plans, land use designations which give preference to residential development in high risk catchments would tend to reduce the total salt application as compared with commercial land uses. Similarly, residential areas may support roads with lower service levels (i.e. those that support lower traffic volumes and lower speeds), and fewer arterial roads, thus reducing the need for road salt application. For communities where land use designations have already been established, the site plan approval process may assist in ensuring that facilities are designed in a way that reduces the need for salt application.

Recommendations:

- That municipalities anticipating significant future growth, and where significant future impacts have been predicted, assess ways of reducing those impacts through land use planning, site design requirements, operational requirements, or education and outreach programs.
- That the Lake Simcoe Region Conservation Authority support its municipalities in developing such draft guidelines.

Concurrent with this new focus on winter salt, Lake Simcoe Region Conservation Authority is also currently advocating for the use of Low Impact Development (LID) techniques, such as permeable pavement systems, as stormwater management tools. While the infiltration of stormwater through LID will play an important role in balancing provincial targets of growth and phosphorus reduction, it may also lead to a greater increase in the rate of infiltration of chloride to groundwater. The relationship between stormwater management and salt management will continue to be one which needs to be explored in the Lake Simcoe watershed.

Recommendation:

- That the Lake Simcoe Region Conservation Authority research the implications of LID on salt use (and vice versa), either through reviewing research on this topic done elsewhere, or by establishing studies in the Lake Simcoe watershed. Results of this research should be shared with municipal land use planners and stormwater engineers.

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