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Stream Chloride Monitoring Program of City of Toronto: Implications of Road Salt Application

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In cold regions, winter road safety is a major challenge for municipalities and provincial highway transportation agencies. Road salt is widely used to improve winter road conditions, but concerns have been raised about the effects of road salts on the environment. This paper describes a water quality monitoring program designed to measure both background chloride concentrations and the effects of road salt application on stream water quality in four watersheds (Humber River, Don River, Highland Creek, and Morningside tributary of Rouge River) located within the City of Toronto boundary. The effect of road salts on stream water quality was evaluated based on chloride concentration because of its conservative nature. A bilinear correlation was developed to transform measured specific conductance levels in stream water to chloride concentrations. There are no Ontario aquatic fresh water quality guidelines for chloride, but chloride concentrations in almost all the monitored streams in Toronto periodically exceeded chronic and acute chloride threshold levels of the United States Environmental Protection Agency. The City of Toronto has been proactive in its efforts to implement management practices to reduce the impact of road salt application on the environment while maintaining safe driving conditions for its road users. Normalized salt application rates in Toronto have been on a gradual declining trend in the last decade from about 0.08 to 0.07 tonnes of salt applied per centimetre of snowfall per kilometre of lane. With public safety in mind, further reductions in salt application rates are being considered to reduce the adverse environmental effects to acceptable limits.

Key words: **road salt, water quality, stormwater, monitoring, management practices**

Introduction

Snow and ice conditions on the road system have a significant impact on public safety, roadway capacity, travel time, and economic costs (Keummel 1992). At present, control of snow and ice on road pavements and sidewalks is generally achieved by the application of de-icers and mechanical ploughing. Four common road salt de-icers (sodium chloride, calcium chloride, magnesium chloride, and potassium chloride, of which sodium chloride is the most predominant) have been used to minimize snow and ice dangers on road pavements and sidewalks. Salt lowers the freezing point of water and the melting action of the salt forms a brine at the ice–pavement interface. Brine prevents water from freezing and bonding to the pavement (Salt Institute 2007). Approximately 5 million tonnes of road salts are applied on roadways in Canada annually (Environment Canada 2004). The City of Toronto has 5,500 km of roads to maintain (City of Toronto 2005) and applies salt on roads and sidewalks during winter to improve transportation safety.

Chlorides from road salts enter streams primarily through surface runoff and groundwater discharge zones (D'Itri 1992; Ramakrishna and Viraraghvan 2005). Both aquatic and terrestrial ecosystems can be adversely affected by exposure to high chloride concentrations associated with the typical use of road salts (U.S. EPA 1988; Novotny et al. 1999; Williams et al. 2000; Environment Canada and Health Canada 2001). Benbow and Merritt (2004) conducted laboratory and field tests to determine the impact of chloride on macroinvertebrates. They concluded that some macroinvertebrates have a high tolerance to road salts but stated other toxic constituents found in road salts can affect tolerance thresholds. Chlorides alter partitioning between adsorbed and dissolved metals thus increasing the concentration of dissolved metals in snowmelt. Aquatic organisms in smaller ponds and streams with lower baseflow are more susceptible to toxicity due to road salts (Marsalek et al. 2000; Marsalek 2003). In 2004, these concerns prompted Environment Canada to issue a Code of Practice for the Environmental Management of Road Salts, designed to optimize salt application and to reduce chloride transfer to the environment. Currently there are no federal or provincial environmental water quality standards or guidelines for chloride levels for fresh water in Ontario. In the United States, toxicity thresholds have been developed for chloride and include a chronic freshwater quality criterion of 230 mg/L, and an acute freshwater quality criterion of 860 mg/L for small stream flow peaks resulting from snowmelt runoff (U.S. EPA 1988).

The persistence of chlorides in the environment does not allow easy treatment of contaminated water; therefore, the current management approach is to develop appropriate practices to optimize salt use under

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given winter snow and ice conditions, while ensuring the maintenance of roadway safety. These management options primarily focus on alternative de-icing chemicals and the way road salts are currently handled, stored, and used (TAC 2003). Although there have been some studies on the utility of alternative de-icing products, including calcium magnesium acetate, their relatively higher costs prevent widespread use (D'Itri 1992). Additional management options include improved storage and handling techniques at salt storage sites to minimize salt loss from storage facilities. In some locations drainage is collected and used in brine production. Road salt management practices such as prewetting and anti-icing have helped to reduce the amount of salts applied. Road weather information systems (RWIS) are increasingly being used to forecast road pavement conditions, thereby optimizing road salt application (Environment Canada 2004).

The City of Toronto has been proactive in its efforts to protect the environment and human health while maintaining safe transportation routes. Since 2001, the City has developed programs to optimize its salt application rates and to implement various best management practices in the storage, handling, and application of road salt. All of the City road salt storage locations are covered. The City of Toronto has employed prewetting since 2003 and uses anti-icing at problematic locations such as bridge decks and steep slopes. The City salt trucks—equipped with electronic spreader controls that are regulated to ground speed—are used to ensure that a consistent amount of salt is applied on pavements and to provide data that permits salt use to be tracked. The City developed a chloride monitoring program with the objective of gathering data to better understand spatial and temporal distribution of chlorides in response to road salt application. Another objective of the monitoring program is to evaluate the effect of recent road salt management practices on reducing chloride transfer to the environment.

The purpose of this paper is to describe the City of Toronto stream chloride monitoring program and to discuss the effect of road salt application on stream water quality. Chloride concentrations among and within streams are compared on an aggregate basis using probability of exceedance graphs. Seasonal and annual comparisons of stream chloride concentrations are also made. The paper also presents results of the statistical analysis of stream chloride concentrations on an event basis. The chloride monitoring data is discussed in the context of current de-icing operations using chloride loads in the streams and road salt application records for the drainage area.

Materials and Methods

Study Area

The City of Toronto stream chloride monitoring program includes four watersheds within the City limits: namely, the Humber River, the Don River, Highland Creek, and the Morningside tributary of the Rouge River. Most of the Highland Creek watershed is located within the City boundary, while the other streams have their headwaters located north of the City outside its boundary. For example, approximately 50% of the Don River watershed and 75% of the Humber River watershed are located outside the City boundary and consist of mainly agricultural areas. Most of the areas located within the City boundary are highly urbanized with a high density of road networks, except for the Rouge River watershed. The proportion of the watershed located within the City and its land use is important to understand the relative contribution of water quality on streams. Main contributors of road salt within the City are the City of Toronto Transportation Services and the Ontario Ministry of Transportation which is responsible for Highway 401. The typical road salt application rate is 0.07 tonnes per lane kilometre (City of Toronto 2005). There is a minor contribution from businesses and residents due to salt application on parking lots and driveways. The monitoring station locations were selected to cover as much of the City as logistically feasible, and to estimate chloride contributions from sources outside the City's control. Locations of the monitoring stations are shown in Fig. 1.

Monitoring Program

The monitoring program was developed to collect continuous chloride data. Granato and Smith (1999) indicated that discrete or composite samples of highway runoff do not adequately represent in-storm water quality fluctuations because continuous records of water stage, specific conductance, pH, and temperature of the runoff show that these properties fluctuate substantially during a storm. The City of Toronto stream chloride monitoring program uses specific conductance, or electrical conductivity (EC), as a surrogate for chloride (Cl^-) concentration, similar to Howard and Haynes (1993) and Granato and Smith (1999). EC was measured hourly using conductivity sensors (Hach model no. 5798A with

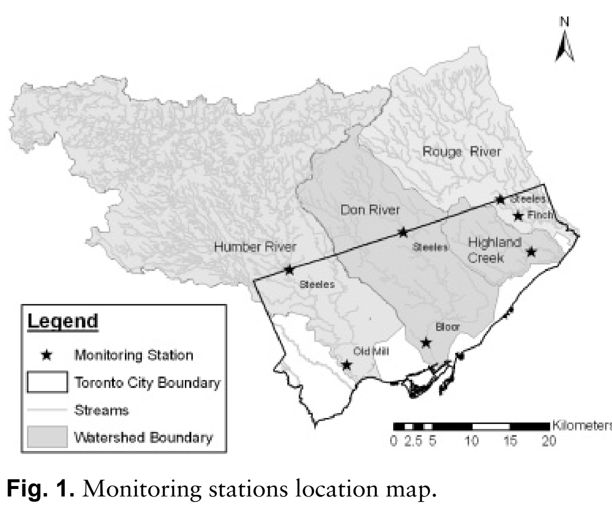

Fig. 1. Monitoring stations location map.

a sensitivity of 0.01 mS/cm) attached to Hach Sigma 900 Max autosamplers.

In addition to the continuous EC measurements, grab sampling was conducted on a regular basis (every 2 to 3 weeks). These samples were analyzed for EC, pH, major ions (sodium, calcium, magnesium, potassium, chloride, sulphate, bromide), nutrients, and metals by the Toronto Water Laboratory. During these site visits, sensors were checked for their performance, and sensor cleaning and recalibration were performed as required.

Data Quality Assurance and Control

Several quality assurance/quality control measures were followed to maintain the accuracy of the data. Sensors fouled without routine maintenance causing lower sensitivity, and as a result, frequent site visits (every 2 to 3 weeks) were required to clean the sensors. Continuous EC data were compared with field EC measurements using a portable EC meter (YSI 30), and with the laboratory results of the grab samples. Compatibility of readings with stream flow, precipitation, temperature, and road salt application data were also checked to identify any anomalies.

Table 1 summarizes the monitoring data availability and drainage area associated with each station. It is noted that there were extended periods without monitoring data from some monitoring stations. This is because the initial interest was mainly on the winter period when road salt application occurs, and then the monitoring program was expanded to collect data year-round to capture all the processes associated with chlorides in the streams. These no-data periods were excluded from the statistical analysis. However, seasonal chloride loads in the streams were estimated only for the periods when continuous data were available.

EC to Cl^- Concentration Correlation

Results from instream grab samples were used to examine the relationship between EC and Cl^- concentration for each stream. There is an overall good linear relationship between EC values and Cl^- concentrations, indicating a dominant effect of Cl^- ions on EC, similar to the Howard and Haynes (1993) and Granato and Smith (1999) results. However, accuracy at lower EC values was poor, as the conversion generated under-estimates of Cl^- concentrations, and occasionally negative values. Impact of other ions (calcium, magnesium, potassium, sulphate) on EC at low Cl^- concentrations was significant, making a simple linear relationship inaccurate. Higher order polynomial equations did not improve the relationship. Accordingly, bilinear equations were developed for all the streams.

A bilinear correlation improved the performance of transformation by removing negative chloride concentrations caused by a single linear relationship. Although low Cl^- concentration values are not critical in assessing the environmental impacts of road salts, they can affect chloride load or annual mass balance calculations. Further refinement of the transformation equation could be achieved by considering the contribution of other ions on EC at low chloride concentrations. Figure 2 presents the bilinear correlation for Highland Creek using analytical results.

Selection of a deflection point of the bilinear graph was determined using a successive approximation approach. The first approximation of the value differentiating high and low values was used to plot the trend lines. The resultant intersection point was used as the next approximation of the deflection point. Successive approximations were carried out until the difference between two successive iterations was not significantly different.

TABLE 1. Monitoring data availability and drainage area by station

Watercourse and station location	*Drainage area (km^2)*	*Data period (data points)*		
Humber River at Steeles	567.4	Dec. 24, 2001	– Sep. 18, 2003	(14,208)
		Dec. 4, 2003	– Sep. 30, 2004	(6,960)
Humber River at Old Mill	877.6	Dec. 24, 2001	– Jun. 17, 2002	(4,195)
		Nov. 6 , 2002	– Jul. 17, 2003	(5,880)
		Oct. 8, 2004	– Jan. 25, 2005	(2,617)
Don River at Steeles	59.5	Oct. 1, 2003	– May 2, 2005	(13,887)
Don River at Bloor	300.6	Jan. 23, 2002	– Jun. 18, 2002	(3,522)
		Nov. 27, 2002	– Aug. 25, 2003	(6,498)
		Oct. 27, 2004	– Apr. 1, 2005	(3,739)
Highland Creek at Morningside Ave.	79.2	Nov. 17, 2004	– Sep. 30, 2007	(25,137)
Morningside tributary at Steeles	8.6	Nov. 27, 2003	– Aug. 22, 2006	(16,604)
Morningside tributary at Finch	14.6	Dec. 2, 2003	– Apr. 11 , 2005	(11,888)
		Aug. 26, 2005	– Nov. 4, 2005	(1,680)
		Jan. 9, 2006	– Sep. 15, 2006	(5,589)

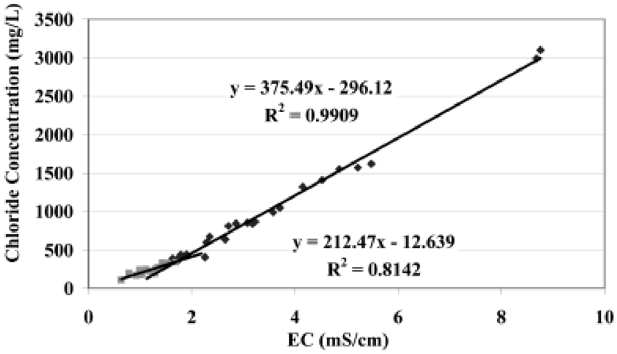

Fig. 2. Correlation between EC and Cl^- concentration—Highland Creek.

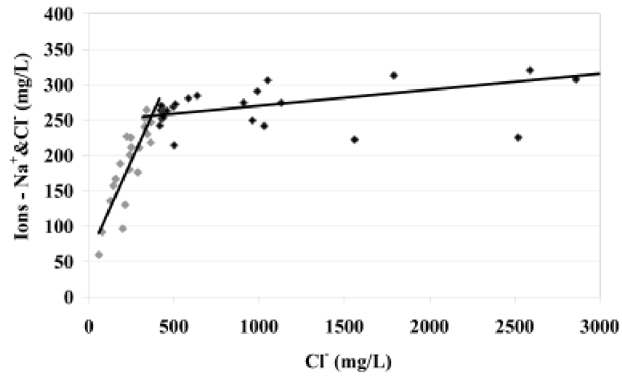

Fig. 3. Comparison between Cl^- concentration and total ions (minus sodium and chloride)—Highland Creek.

Table 2 summarizes the bilinear equations developed to transform EC to Cl^- concentration. It is noted that the deflection point differs from one stream to another and its magnitude is related to the Cl^- concentration values monitored at the stream. The deflection point for Highland Creek is approximately 375 mg/L, and the Morningside tributary has the lowest deflection point of 150 mg/L. Highland Creek, the Don River, and the Humber River had decreasing values in the same trend of background chloride concentrations.

The suitability of the bilinear relationship was tested considering the other major ions in water, except for sodium and chloride. Comparison of chloride ions with other ions except, for sodium and chloride (main constituents of road salts), indicated a very similar deflection point as shown by the EC versus Cl^- relationship. Figure 3 presents the graph of total ions (minus sodium and chloride) versus chloride for grab samples collected from Highland Creek.

Results and Discussion

Hourly EC monitoring data provided a better understanding of spatial and temporal variation of stream chloride concentrations. Calculated chloride concentrations from City of Toronto stream chloride monitoring stations were used for the analyses presented. Although data from all the monitoring stations are presented, data from the Highland Creek station has been given more consideration because the data are uninterrupted and spans for few years. Figure 4 presents a box and whisker plot for aggregate winter (November to March) chloride concentrations in the streams.

The data show that chloride concentrations were highly variable, but the values are similar to those previously reported in the literature (Howard and Haynes 1993; Granato and Smith 1999; Mayer et al. 1999; Novotny et al. 1999). Chloride concentrations ranging from 350 to 3,050 mg/L were measured by Novotny et al. (1999) from a creek in Milwaukee, Wisconsin. They also reported chloride concentrations as high as 17,200 mg/L from a storm sewer in Syracuse, New York. Granato and Smith (1999) reported highway runoff chloride concentrations, which ranged from 10 to 20,000 mg/L in southeastern Massachusetts. Mayer et al. (1999) summarized chloride concentrations reported from Canadian surface waters, and values reported from Ontario and Quebec show similarity to the results from this study.

According to Fig. 4, within the same stream, downstream stations showed higher chloride concentrations when compared with upstream stations, indicating the cumulative impact of increased salt loading due to higher urbanization within the City of Toronto. Highly urbanized drainage areas such as the Highland Creek and Don River watersheds have higher chloride concentrations when compared with less developed areas, such as Morningside Creek.

TABLE 2. Bilinear Equations developed for the streams to transform EC to Cl^-concentration

Watercourse and station location	*Chloride [a] (mg/L)*	*Equation above and below the deflection point (Coefficient of Determination)*
Humber River	200	323.07x – 144.31 (0.9929) 222.76x – 60.286 (0.8178)
Don River	300	345.58x – 205.98 (0.9932) 213.89x – 51.389 (0.8003)
Highland Creek	375	375.49x – 296.12 (0.9909) 212.47x – 12.639 (0.8142)
Morningside tributary	150	307.81x – 144.31 (0.9929) 228.09x – 61.92 (0.8751)

[a] Chloride concentration at deflection point.

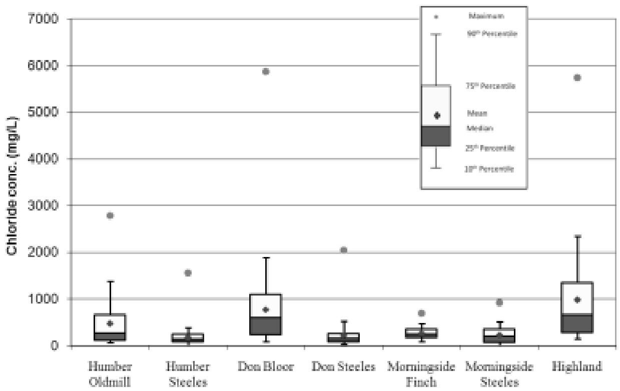

Fig. 4. Statistical summary of chloride concentrations (November to March).

Probability of Exceedance

Probability of exceedance curves were developed for each monitoring station to evaluate the proportion of time stream chloride concentration was above any concentration value. Probability of exceedance for a particular chloride concentration was calculated by dividing the number of hours with a higher value than the chloride concentration by the total number of hours for which data was available.

The probability of exceedance analysis was categorized according to season: November to March, April to June, and July to October. The November to March period includes winter and early spring to account for salt application and spring snow melt. The July to October season predictably showed the least impact from road salt application, and the April to June period was an intermediate season. Figure 5 presents seasonal probability of exceedance of chloride concentrations at the Highland Creek monitoring station.

The contrast in chloride concentrations between the winter period (November to March) and rest of the year is evident from the graph and is similar for all stations. During this period, the chloride concentration at Highland Creek is likely to exceed the United States Environmental Protection Agency (U.S. EPA) criteria of 230 mg/L (chronic threshold) approximately 80% of the time, and the acute threshold is likely to be exceeded 35% of the time. Downstream locations in the Don River also indicate similar exceedances. The Humber River downstream location exceeded the chronic threshold only 35% of the time due to the effect of its less urbanized headwater areas. The Morningside tributary and Humber River upstream stations recorded lowest exceedance probabilities. Most of the literature on urban winter stream water quality (Howard and Haynes 1993; Novotny et al. 1999; Marsalek et al. 2000; Marsalek et al. 2003) indicates frequent exceedance of U.S. EPA criteria for chloride, but there are no recorded quantitative estimates.

Variation in concentrations between upstream and downstream locations of a stream is demonstrated in Fig. 6 by showing winter chloride probability of exceedance values for the Don River monitoring stations. It is noted that the Bloor station is located approximately 20 km downstream of the Steeles station. The higher chloride concentrations in downstream locations could be attributed to higher road density within the City of Toronto.

Year to year variation in probability of exceedance in chloride concentration at a monitoring station provides an indication of the effectiveness of road salt management practices because a reduction in salt use should be accompanied with a decrease in chloride concentrations in the stream. However, it is important to consider theses results in light of any year-to-year change in climatic factors, such as total snowfall and average winter temperature. Available chloride data sets do not span to cover before and after implementation of the City's salt management plan best practices to undertake this analysis. Yearly variation for the Highland Creek November to March chloride concentration is presented in Fig. 7. Year 2004/2005 winter recorded higher stream chloride concentrations compared with other years, mostly due to the relatively high snowfall quantity in that year. Chloride values for winter 2005/2006 and 2006/2007 show similar probabilities of exceedance, but 2006/2007 recorded slightly lower probabilities, especially above 230 mg/L.

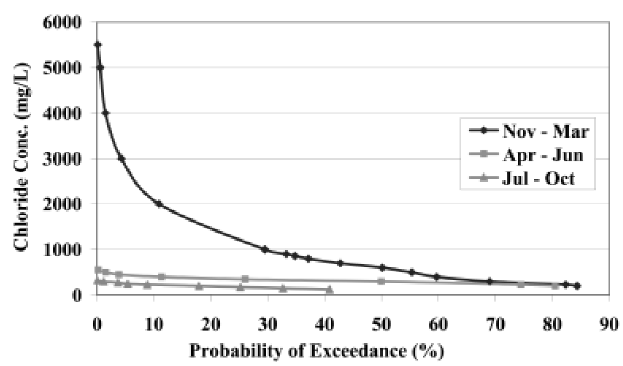

Fig. 5. Seasonal probability of exceedance of chloride for Highland Creek.

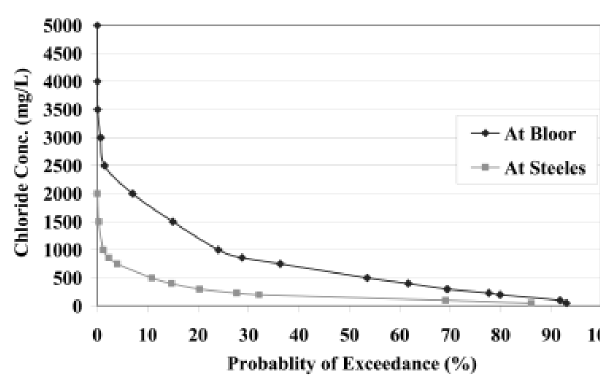

Fig. 6. Probability of exceedance of chloride—Don River (November to March).

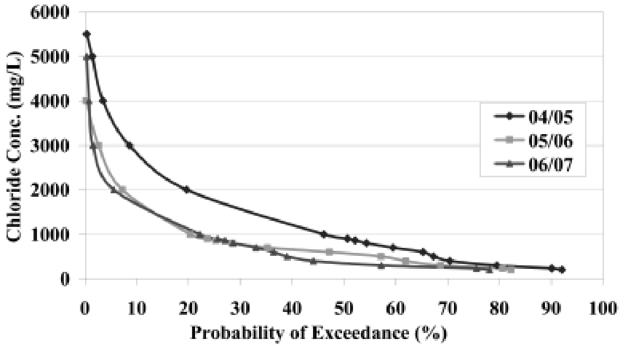

Fig. 7. Annual probablity of exceedance—Highland Creek (November to March).

Chloride Event Statistics

An analysis of the chloride events (based on pollutograph time series) was also undertaken to study the impact of each salt application or precipitation event on chloride concentration in the streams. The chloride events were based on thresholds of 230 and 860 mg/L (representing the chronic and acute chloride levels specified by the U.S. EPA) and an additional threshold, 1,500 mg/L. Figure 8 indicates how the chloride events were defined. Duration and peak chloride concentration were derived from each event.

Subsequent analyses were mainly based on Highland Creek monitoring data. This station was selected mainly because of the availability of continuous data for at least three years. This watershed is also located almost entirely within the City of Toronto, minimizing impacts due to different road salt application and management practices implemented by other jurisdictions. It is noted that the majority of roads in this watershed are maintained by the City of Toronto, except for Highway 401 which is maintained by The Ministry of Transportation, Ontario (MTO).

Table 3 presents the summary of chloride event statistics for the monitoring station at Highland Creek. Any 230 mg/L event less than 3 hours in duration was removed from the analysis to prevent a bias of statistics

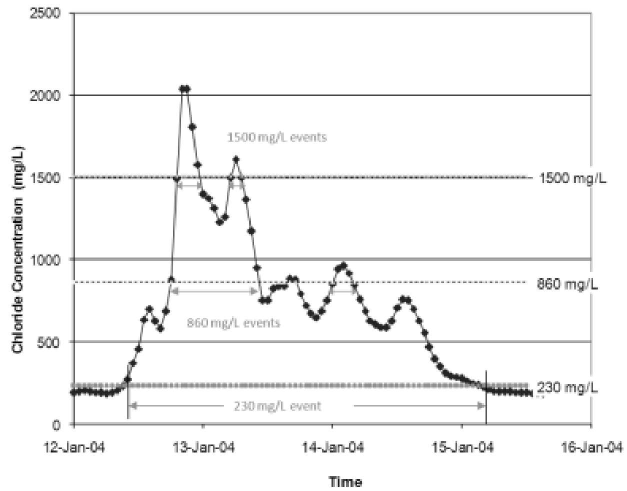

Fig. 8. Determination of chloride events.

towards lower peaks and mean event durations. It was observed that the difference between the peak value and 230 mg/L for these very low-duration events was within the accuracy of the EC sensor.

The results in Table 3 confirm the trends in Fig. 7. Winter period 2004/2005 recorded a higher number of events, total duration of exceedance, and mean event maximum chloride concentration, confirming the fact that winter 2004/2005 was severe with a comparatively high snowfall. Winters 2005/2006 and 2006/2007 have similar characteristics, but 2006/2007 indicated longer mean event durations and fewer events. Standard deviations for both event duration and event maximum concentration showed high variability.

Normalized Road Salt Application Rates

It is important to understand the relationship between stream chloride concentrations and actual road salt application rates. Total amount of road salt applied per year provides a comparative measure to evaluate effectiveness of road salt management practices. The limitation of this method lies in the fact that it does not consider yearly variation in snowfall and other meteorological factors.

TABLE 3. Chloride event statistics for Highland Creek monitoring station

Winter period	*Chloride threshold (mg/L)*	*No. of events*	*Total duration of exceedance (h)*	*Mean event duration (h)*	*Standard deviation (h)*	*Mean event max. conc. (mg/L)*	*Standard deviation (mg/L)*
2004/05	230	33	5,253	164	±257	974	±1,640
	860	19	1,682	88	±113	2,500	±1,689
	1,500	22	1,025	47	±58	2,674	±1,429
2005/06	230	32	4,522	141	±203	815	±1,254
	860	23	915	40	±60	1,834	±1,180
	1,500	12	427	36	±33	2,638	±1,154
2006/07	230	20	3,796	190	±165	820	±1,226
	860	9	754	84	±59	2,148	±1,253
	1,500	8	348	44	±44	2,433	±1,173

Normalizing the road salt application rate by cumulative snowfall and total length of roadway lanes provides a better comparative tool for the purpose of evaluating road salt related best management practices. The normalized application rate accounts for the main factor affecting road salt application, cumulative snowfall, and also allows comparison between different areas or jurisdictions because it considers the total length of road network.

Table 4 presents calculated normalized road salt application rates used by the City of Toronto. Road salt used by MTO, City residents, and businesses are not included. The nearby Environment Canada weather station in North York was used to obtain snowfall accumulation data. Although there is considerable variation, these values are consistent with the specified road salt application rates in North America (City of Toronto 2005; Salt Institute 2007) for road safety. The variability indicates that there are other factors, other than total annual snowfall, that affect road salt application rates. It also indicates that there is a potential to optimize the application rates to minimize adverse environmental effects. Figure 9 graphically presents the normalized road salt application rates shown in Table 4 for better visualization.

Normalized road salt application rates based on snowfall and total lane kilometres show some year-to-year variation, but with a declining trend over the last 10 to 12 years. On average, the normalized salt application rate for the City of Toronto has been reduced from 0.08 tonnes per cm of snowfall per lane kilometre to 0.07 tonnes per cm of snowfall per lane kilometre during this period.

Additionally, the normalized road salt application rates were determined for the Highland Creek watershed considering both City and MTO application data. Table 5 presents calculated normalized road salt application rates used in the Highland Creek watershed by the City and the MTO. These data show that very similar application rates were used within the last five years; however, it was difficult to come to any conclusion regarding the

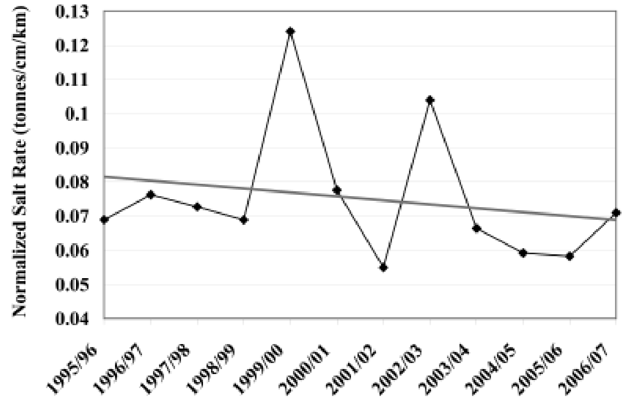

Fig. 9. Normalized salt application rates for the City of Toronto.

effectiveness of salt management practices implemented by the City by only considering normalized application rates. A closer look at the methodology indicates that this method does not account for all the factors that affect road salt application. For example, the amount of salt required to melt the same amount of snow varies with temperature, with low temperatures requiring more road salt (TAC 2003). Snow clearing policies also have an impact on the amount of salt applied. For example, if a large amount of snow fell within a short time period, the majority of it would be ploughed and possibly removed resulting in a lower amount of road salt being applied. However, if an equivalent amount of snowfall was received over a prolonged single storm, or a series of successive smaller storms, road salt would be applied several times resulting in a higher application ratio. Also, if very small quantities of snow were to fall during above-zero temperature conditions, then the snow would likely melt and may require little to no road salt. Possible spatial variation of snowfall within the watershed would also introduce errors. Another factor affecting road salt application rate is the form of precipitation. For example, during freezing rain events, the only effective control measure is the application of de-icing chemicals;

TABLE 4. Normalized road salt application rates — City of Toronto

Winter period	*Total amount of road salt applied (tonnes)*	*Cumulative snowfall (cm)*	*Length of roadway lanes (km)*	*Normalized road salt Application (tonnes/cm/km)*
1995/06	127,977	150.4	12,343	0.069
1996/97	157,585	166.6	12,415	0.076
1997/98	101,939	112.2	12,493	0.073
1998/99	140,410	124.0	12,493	0.069
1999/00	142,869	88.4	13,846	0.124
2000/01	176,595	181.2	13,800	0.078
2001/02	56,893	77.4	13,800	0.055
2002/03	208,230	145.2	13,800	0.104
2003/04	108,152	108.2	15,052	0.066
2004/05	147,433	165.5	15,052	0.059
2005/06	94,673	108.1	15,052	0.058
2006/07	89,112	83.4	15,052	0.071

TABLE 5. Normalized road salt application rates—Highland Creek

Winter period	*Total amount of road salt applied (tonnes)*	*Cumulative annual snowfall (cm)*	*Length of roadway lanes (km)*	*Normalized road salt Application (tonnes/cm/km)*
2002/03	22,019	145.2	1,263	0.12
2003/04	14,783	108.2	1,377	0.099
2004/05	20,673	165.5	1,377	0.091
2005/06	14,628	108.1	1,377	0.098
2006/07	12,654	83.4	1,377	0.11

therefore, normalizing salt application by total snowfall is not always a correct indicator, although it provides a comparative tool. Table 6 summarizes the parameters affecting road salt application for the period of 2001 to 2007, which can be used to further analyze application rates. The meteorological data was obtained from the North York Environment Canada weather station.

Information in Table 6 provides a better picture of the factors affecting road salt application. For example, in 2001/2002 it was a relatively warmer winter and this resulted in a lesser amount of road salt applied (refer to Fig. 9). The data also indicate that although 2006/2007 had less total snowfall and fewer number of days with snow, lower mean temperatures required more road salt application when compared with 2005/2006.

Instream Chloride Loads

Chloride load (mass) within the streams can also be used to determine effectiveness of management practices employed by the City since it indicates how much road salt is applied in the drainage area. Monitoring chloride concentration and the corresponding stream flow rate provides a means of achieving this quantity. Hourly data at a minimum is required for accuracy of the chloride load estimates since chloride concentrations can vary significantly within several hours. The Highland Creek monitoring data (which is the most complete data set), however, do not permit comparison of chloride load prior to and after implementation of best management practices, since data acquisition started in 2004.

Chloride load is calculated by multiplying chloride concentration by the flow rate. Contribution of chloride mass due to baseflow should be accounted for accurate estimates of chloride load due to road salt application. Considering the daily stream flow values (Water Survey Canada flow data), baseflows were determined using the digital filter developed by Arnold and Allen (1999). Chloride concentration under baseflow conditions were determined to be approximately 200 mg/L based on stream chloride concentrations during dry periods in the summer.

Figure 10 presents the instream chloride load resulting from road de-icing operations within the Highland Creek watershed. The instream chloride mass indicates an increase of salt in the stream within the winter period, and a drastic drop in the summer, with the lowest levels occurring in the fall. This pattern was previously identified by Howard and Haynes (1993). It is apparent that there was a continued reduction in chloride mass in Highland Creek during winters ranging from 2004 to 2007. The reduction in chloride mass is partly due to lower amounts of snowfall and could also indicate the effect of best management practices.

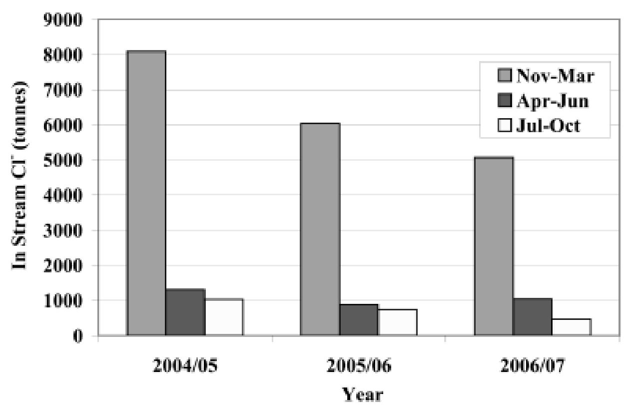

Fig. 10. Variation of seasonal instream chloride load in Highland Creek.

TABLE 6. Meteorological parameters affecting road salt application

Winter period	*Days >2 cm of snowfall*	*Days <0 °C after precipitation*	*Days >10 cm of snowfall*	*Mean winter daily max temp (°C)*	*Winter daily mean temp (°C)*
2001/02	13	5	3	3.1	-0.6
2002/03	19	18	4	0.3	-3.8
2003/04	17	15	0	0.7	-3.3
2004/05	23	15	3	0.7	-3.5
2005/06	16	7	1	1.72	-1.8
2006/07	9	9	1	0.9	-2.8

Conclusions

The analysis of chloride concentration data from eight monitoring stations in four Toronto streams (Humber River, Don River, Highland Creek, and Morningside tributary in the Rouge River) indicated elevated chloride concentrations during winter months. The Highland Creek monitoring station exceeded the U.S. EPA chronic chloride limit about 80% of the time during the winter, and the acute limit was likely exceeded approximately 35% of the time during the monitoring period. The effect of relative urbanization of each watershed was also noticeable; the Humber River with a relatively large nonurbanized drainage area exceeded the chronic limit approximately 25% of the time.

It was also found that the majority of road salt applied runs off to the streams in a watershed during winter and early spring, with a smaller quantity continuing to discharge during the rest of the year. Stream chloride concentration and load depend on several factors, including total amount of snowfall and type of precipitation, average winter temperature, and also road salt application rate and the management practices implemented. However, available monitoring data is insufficient to make a concrete conclusion on the effectiveness of road salt management practices implemented by the City of Toronto due to the limited span of data.

Normalized salt application rates in Toronto have been on a gradual declining trend in the last decade, from about 0.08 to 0.07 tonnes of salt applied per centimetre of snowfall per lane kilometre. Further reductions in salt application rates should be explored in order to reduce adverse environmental effects to acceptable limits.

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