REDUCING ROAD SALT APPLICATION BY CONSIDERING WINTER MAINTENANCE NEEDS IN PARKING LOT DESIGN

David Lembcke[1], Bill Thompson[1], Kaitlyn Read[1], Andrew Betts[2], Dilan Singaraja[2]

INTRODUCTION

Winter snow and ice can have a significant impact on our mobility, whether on foot or by car. Alongside plowing, arguably the greatest tool in combating snow and ice is salt. The most commonly used salt for winter maintenance is Sodium Chloride (NaCl), the same salt used in food and water softeners, is applied to roads, sidewalks, and parking lots as it is an effective deicer when temperatures are between 0°C and –12°C. Studies have shown that deicing with salt reduces accidents by 88% and injuries by 85% (Salt Institute 2017). The effectiveness of road salt, as well as its relative affordability, means that as much as four million tonnes may be applied annually in Canada for deicing (Environment Canada 2012). However, while salt is relatively inexpensive to purchase, there are a number of external costs that are becoming increasingly apparent. These include corrosion of vehicles and infrastructure like concrete, bridges, and water mains; damage and staining to the interior and exterior of buildings; impacts to roadside vegetation and soils; and the contamination of fresh water. In fact, the environmental impacts are such that it prompted Environment Canada to propose that winter salt be considered a toxic substance primarily due to the quantity that is applied annually (Environment Canada 2001).

The Lake Simcoe watershed, approximately 3,400km^2 in size, is situated just 20km north of Toronto, Ontario, with the southern portion of the watershed being considered part of the Greater Toronto Area (GTA), the most populous metropolitan area in Canada. As part of the GTA, the Lake Simcoe watershed has experienced and continues to experience considerable growth, and with this growth comes an increase in the amount of impervious surfaces requiring winter salting. Indeed, chloride has been showing a strong increasing trend in the urban creeks and in Lake Simcoe itself over the last 30 years. Even rural creeks are showing an increasing trend, albeit not as severe, nor are the concentrations of chloride reaching the same levels (LSRCA 2015). The highest chloride level recorded in a Lake Simcoe tributary was 6,120mg/l in the winter of 2013. Chloride guidelines for the protection of aquatic ecosystems utilize a guideline of 120mg/L for chronic exposure and 640mg/L for acute exposure (CCME 2011). While the high value recorded in the Lake Simcoe tributary greatly exceeds these guidelines, it is still drastically lower than values being recorded in larger, intensively urbanized catchments such as Cooksville Creek in Mississauga, Ontario, which sees concentrations in excess of 20,000 mg/L, the concentration of

1. Lake Simcoe Region Conservation Authority, Newmarket, Ontario, Canada
2. GHD, Newmarket, Ontario, Canada

sea water, nearly every winter (Credit Valley Conservation personal comm). Similarly, in July of 2011 a small population of Atlantic blue crabs, a marine species, was found surviving in Mimico Creek in Toronto (Toronto Star: May 26, 2012). That a marine species was able to survive in this fresh water creek in summer demonstrates that the impacts of winter salt are not just limited to winter but are impacting shallow groundwater and thus summer baseflow, maintaining high chloride concentrations year round. The same is being seen in some urban creeks in the Lake Simcoe watershed, with summer baseflow concentrations exceeding the chronic guideline and trending upwards (LSRCA unpublished). While not yet as extreme as rivers in the more densely urbanized parts of the GTA, these examples foreshadow what is in store for Lake Simcoe rivers if current winter salt practices continue along with the projected urban growth.

During the winter of 2012 an estimated 99,300 tonnes of salt was applied in the Lake Simcoe watershed, an amount that equals nearly 250kg of salt per capita, or ~3 times the average person's body weight in salt. This estimate was generated through a survey of local road agencies along with the total area of commercial/institutional parking lots within the watershed. The exercise served to highlight a knowledge gap around application practices and rates in commercial/institutional parking lots. The majority of road agencies were found to record annual volumes, application dates and rates whereas literature values range from 10–40% of the salt applied in a catchment come from commercial/ institutional parking lots (Perera et al, 2009; Trowbridge et al, 2010; Lake Simcoe Region Conservation Authority, 2015), and a survey of winter maintenance contractors cite an average value of approximately 58g/m^2/application (Fu et al, 2013) (Figure 1).

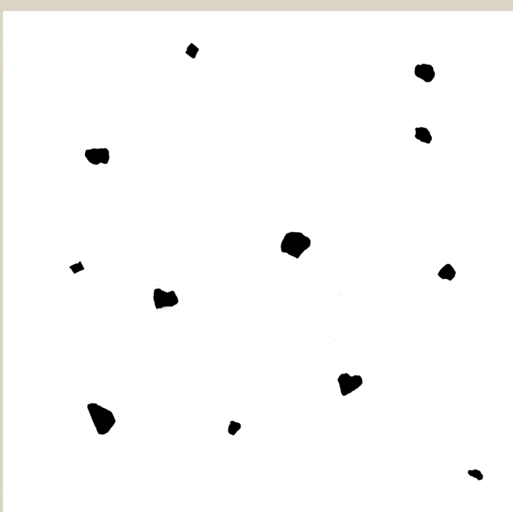


FIGURE 1. Representation of 58g of salt l in 1m^2.

While these values were used in the estimation as they were the best available, observational data suggested these may be on the conservative side (Figure 2).

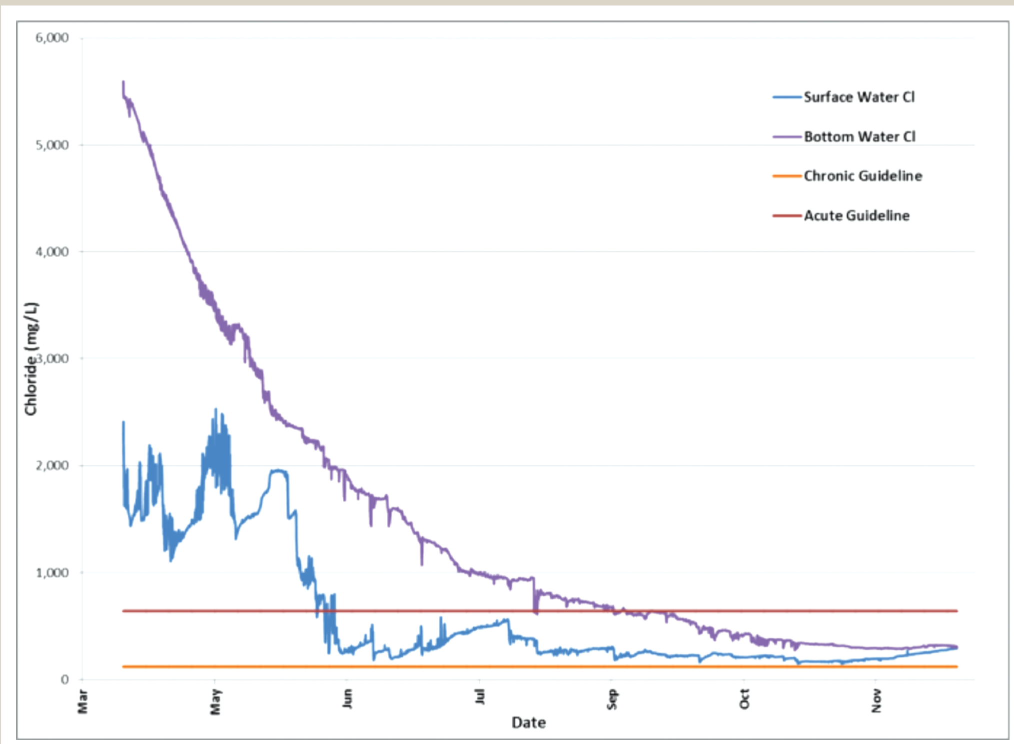
Therefore, monitoring of a 14 ha commercial lot was undertaken for the winters of 2014/15, 2015/16, and 2016/17 to better quantify the amount of salt coming from this type of land use. The winters of 2014/15 and 2016/17 saw similar applications of 1,067 and 1,010 tonnes applied respectively, while the mild winter of 2015/16 saw 556 tonnes applied. While the amounts varied somewhat each winter, the impacts downstream were consistent. Maximum concentrations recorded in the melt water reached 3.5 to 4 times the salt concentration of sea water every winter, equating to chloride concentrations of 70,000mg/L to 85,000mg/L; two orders of magnitude above the water quality guideline.

FIGURE 2. Example of excessive salt application in a commercial parking lot.

As with most parking lots constructed in the last two decades, the runoff from this parking lot is captured in a stormwater pond prior to entering the receiving watercourse. Interestingly, the winter salt also caused persistent chemical stratification in the permanent pool of the pond. The pond was monitored with continuous monitors for the ice free period of 2015 and 2016 (April to December) during which the bottom water chloride concentration remained distinct from the surface chloride concentration, indicating stratification (Figure 3). This has two significant implications; first of which is that this pond, and therefore many other ponds like it, may not be functioning as designed which is leading to diminished performance (McEnroe 2012, Marsalek 2003). Second is that ponds are acting as salt reservoirs, slowly releasing salt year round and contributing to river chloride concentrations that continually exceed the chronic exposure guideline and thereby exposing aquatic life to harmful concentrations during sensitive life cycle stages.

To determine the extent to which the catchment land use type impacts stormwater ponds, chemical profiles were measured on three ponds in February 2017. The catchments included the 24.6 ha commercial catchment with 14 ha of salt application surface, an institutional catchment (14.3 ha) with 6 ha of salt application area that includes parking lots and roads, and a 16.4 ha residential catchment with 3 ha of salt application area comprised of tertiary municipal roads. Interestingly, all three ponds showed chemical stratification, with the severity of the stratification and highest chloride concentrations relating to the amount of salt application area in the catchment. The residential pond yielded a maximum chloride concentration of 3,115mg/L in the bottom waters, the institutional yielded 16,144mg/L, and the commercial yielded 25,530 mg/L with chloride concentrations in the bottom 0.5m of the pond exceeding that of sea water. The maximum chloride concentration recorded in the receiving watercourse downstream of the commercial lot was measured at 5,406 mg/L, well in excess of the acute guideline of 640 mg/L. These results highlight that commercial parking lots are not only receiving a significant volume of salt but are also having the most dramatic impacts on receiving stormwater infrastructure and watercourses.

FIGURE 3. Persistent chemical stratification (April through December) in the permanent pool of a commercial parking lot stormwater management pond.



KEYWORDS:

salt, winter maintenance, chloride concentrations, water quality, parking lot design, Lake Simcoe watershed

CONSIDERING WINTER MAINTENANCE IN PARKING LOT AND SITE DESIGN

As compared to the literature value of 58g/m^2/application (Fu et al, 2013), results of our monitoring yielded average annual application rates that ranged from a low of ~65.3 g/m^2 for the 2015/16 winter to a high of ~117.4 g/m^2 for the 2014/15 winter. However, what also became clear from the monitoring was that salt is not applied uniformly across different parking lot features. Application rates were measured following a single application event and found parking stall rates of 24 g/m^2 to 656 g/m^2 adjacent to melting snow piles, and walkway values that varied from 60g/m^2 to 488g/m^2 to an extreme of 4,536g/m^2 (Figure 4). This variation was all within the same parking lot and in response to the same event.

FIGURE 4. Application rate of 4,536 g/m^2 on sidewalk.

What this further highlighted was that while application rates for the majority of the parking lot are generally consistent with the 58g/m^2 value reported by Fu et al (2013), walkways, store entrances and trouble spots are generally receiving far in excess of this application rate and are largely responsible for driving up the overall amount of salt applied annually. Walkways and store entrances are typically treated differently from parking stalls or driving areas with application being conducted with different equipment, which may be calibrated differently or not calibrated at all, or application may simply be applied by shovel with no consideration of applicable application rates. The result is that these areas see a much higher rate of salt application. As the general expectation is that all walkways remain passable year round, commercial lots with a greater proportion of walkways could expect greater annual salt volumes to be applied.

Monitoring of the parking lot also identified a number of persistent trouble spots. These were typically areas of the parking lot that required much more frequent salt application, with some seeing daily application regardless of precipitation. Examples included areas where melt water from snow piles travels across active drive areas or parking stalls, and low spots or depressions where water pools and freezes. Both these examples may see daily salting when day to night melting and refreezing occurs. Depressions may also see early salting in October or November as well as salting well into April if night temperatures drop below freezing. Steep driveways may see multiple salt applications during a single storm event as the applied salt is washed off by melt water or continued precipitation. Roof drainage or design may lead to melt water, with the potential to refreeze, crossing walkways or drive areas and requiring additional salting. As with walkways, the greater the number of trouble spots in a parking lot the greater the volume of salt that will need to be applied throughout the winter.

The recognition that walkways and trouble spots are typically receiving greater application rates prompted the idea that it may be possible to avoid excessive salt application if parking lots were designed differently and considered the needs of winter maintenance. In order to better understand the relationship between site design and salt application, a series of interviews were conducted with stormwater engineers, academics, contractors, and regulators to gauge what factors tended to support good winter maintenance practices, and to gain additional insight from their years of experience. Those discussions identified six key design features or operational practices which could provide relatively cost-effective approaches to reducing winter maintenance needs, and which could easily be incorporated into the design and maintenance of new parking lots. These included proper site grading, snow storage location, stormwater management, landscaping features, sidewalk design and pedestrian flow, and seasonally closed parking areas.

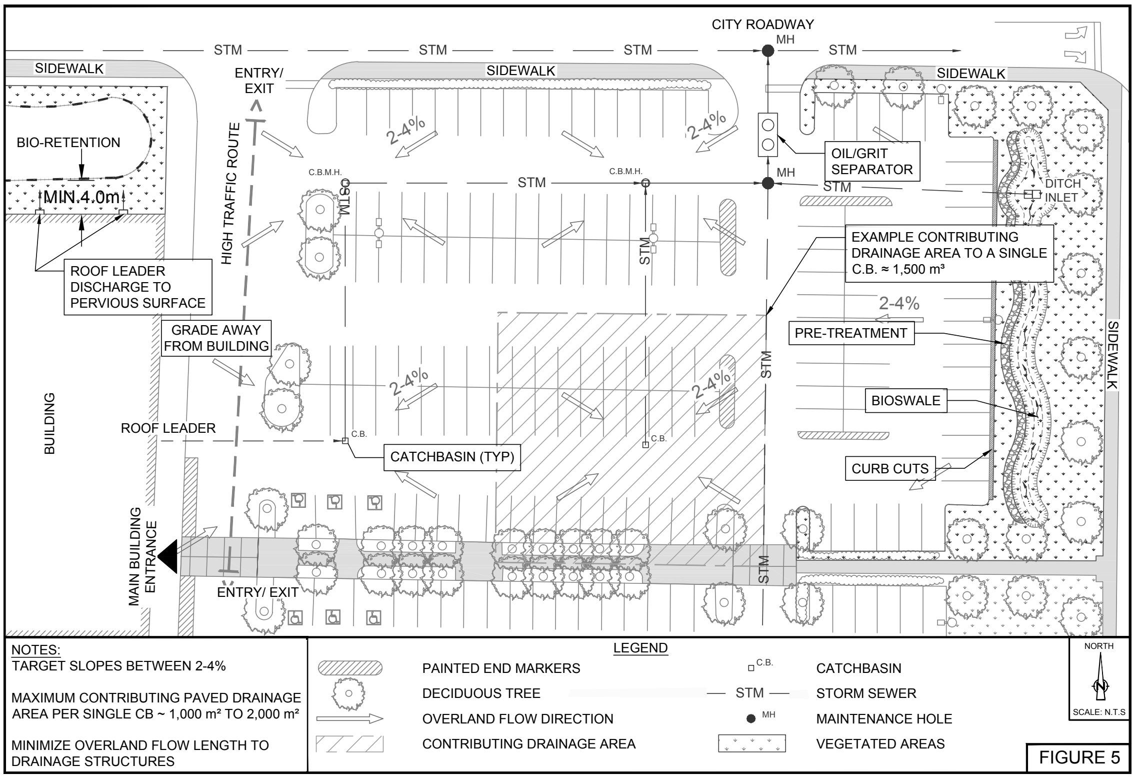
1. Proper Site Grading

While salt is most commonly used to clear and de-ice a parking lot after a winter storm, it is also often required between storm events to deal with melt water as it has the potential to refreeze. This additional salt use could be minimized with proper site grading.

When parking surfaces are graded at slopes less than 2%, there is an increased risk of depressions forming that can result in the pooling of water and ultimately to ice formation. Ensuring that parking lots have slopes between 2 and 4 percent can minimize this potential, however proper geotechnical design must be completed to ensure that grades can be maintained over the long-term. Parking lot design should also ensure that the underlying gravel base is drained effectively enough to minimize the potential of frost heave during winter months.

Proper site grading requires that melt water be directed towards strategically placed stormwater collection infrastructure. The key to effective stormwater collection during winter runoff is to ensure that melt water from high traffic areas or snow piles does not have to travel great distances to a collection point, and that the exposure of pedestrians or drivers to this melt water upon refreeze is minimized. Factors to consider include grading parking lots away from building entrances and in such a way that major drainage pathways do not cross heavily used areas of the parking lot, and draining to catch basins in the middle of the drive paths which would allow for traffic to break up the snow and ice. In addition, catch basins should be installed near to or directly downgradient from the snow storage pile locations (Figure 5 and Figure 6).

FIGURE 5. Guidelines for site grading and drainage to support reduced winter salt application.

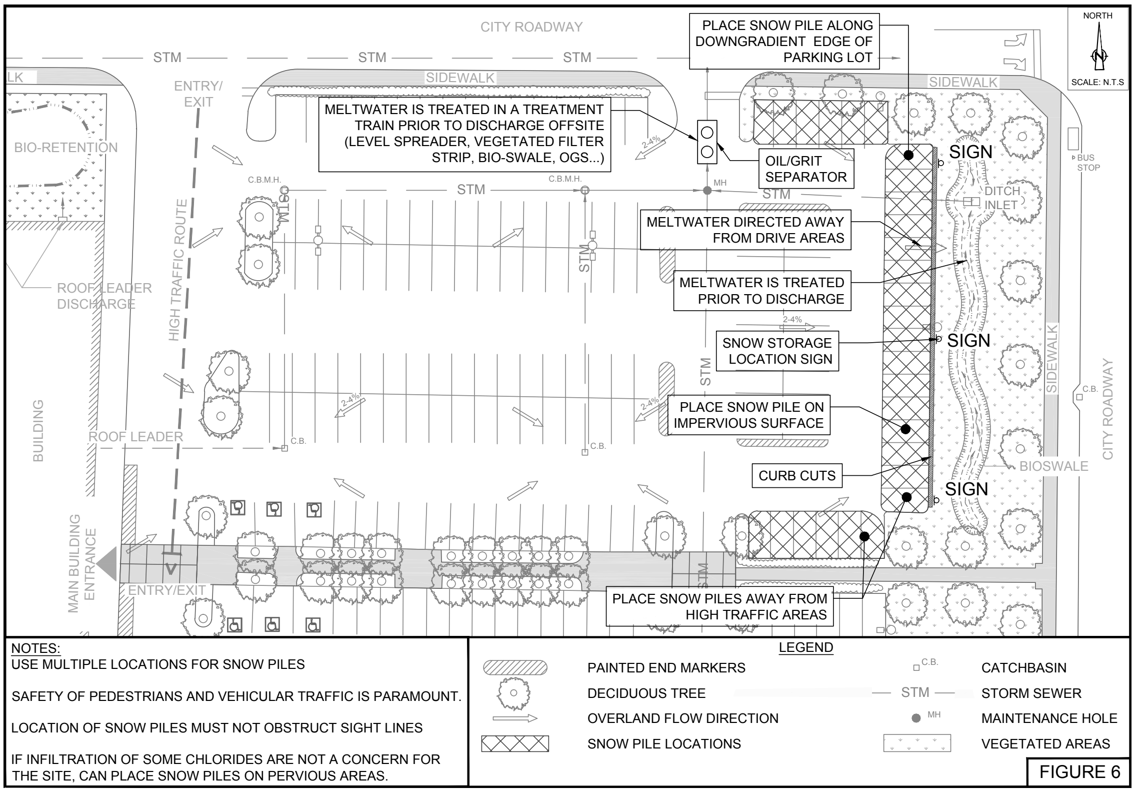


Roof runoff, or runoff from canopies which only cover part of walkways, can be another source of ice accumulation when it discharges onto paved surfaces. Roof leaders should be directed to pervious areas where possible or to infiltration/storm systems. Where infiltration is not feasible or desired, roof drains should be connected to a stormwater collection system, rather than discharging onto paved surfaces.

2. Snow Storage Location

The proper siting of snow storage piles is an important part of reducing liability and decreasing the amount of winter salt applied in parking lots. Strategically locating snow storage piles in low traffic areas, along the outer edges of parking lots and downgradient from high traffic areas, can help minimize the risk of melt water draining to high traffic areas and refreezing (Figure 6). It is also important to locate snow storage piles to prevent visual obstructions for drivers and pedestrians and reduce snow drifts across parking lot surfaces. Therefore, it is important to understand the wind patterns of the parking lot and locate the snow pile in a location that is least likely to cause snow drifts. Placing snow piles in locations that do not result in long plow routes will reduce the tendency for snow to become compacted by plows, which enhances the bond between snow and ice. If possible, the main snow pile should be placed at the lowest point of the parking lot where it will also receive high sun exposure to promote quicker melting.

FIGURE 6. Proper location of snow storage is important in reducing winter salt application.

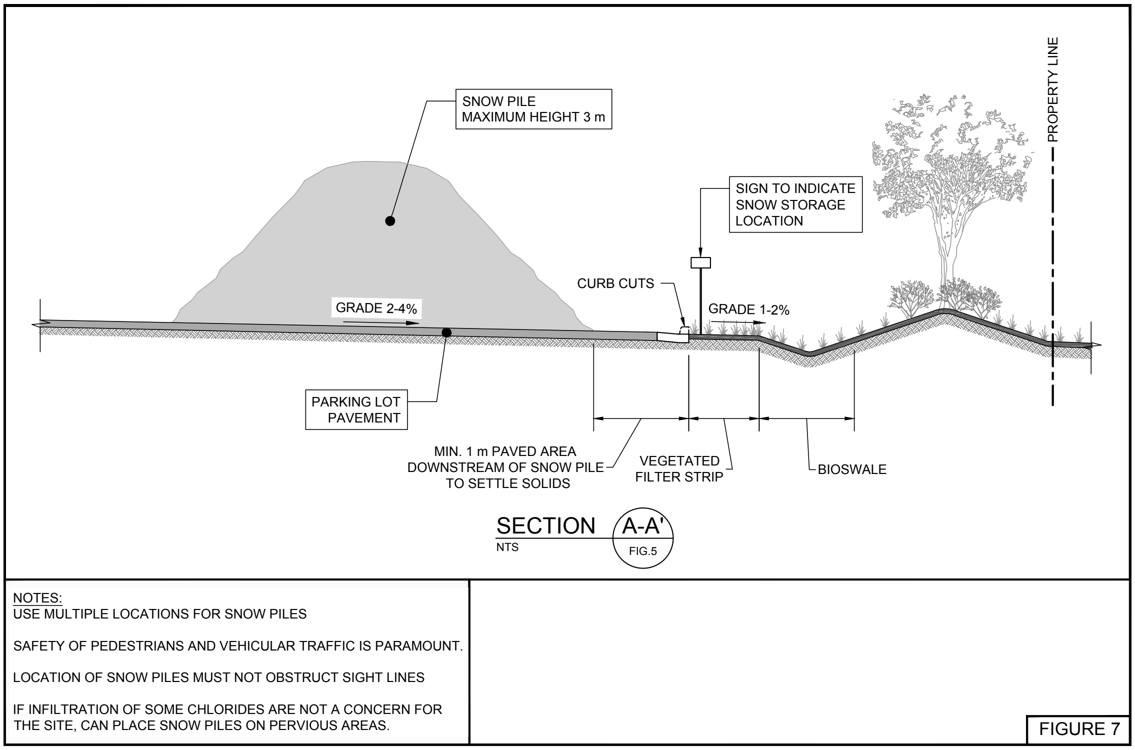


Snow piles can be located in such a way to promote melt water draining away from high traffic areas towards nearby catch basins. Locating catch basins near snow disposal sites will ensure that melt water is quickly collected within the vicinity of the pile and not provided the opportunity to refreeze. In some cases, this may require the construction of additional catch basins. Snow storage and disposal piles should not be placed directly on top of catch basins. Alternatively, snow piles can be placed up-gradient of vegetated swales in areas where groundwater chlorides are not a concern, allowing it to infiltrate before it has the potential for discharge. If groundwater quality is of major concern, such as in the vicinity of municipal drinking water sources, then the snow storage locations can be designed to minimize infiltration through the use of clay underlining of vegetated areas, or ensuring that they are placed on impervious features such as asphalt or concrete pads (Figure 7).

As the location of snow storage sites is typically negotiated between contractors and property managers at the beginning of each season, clearly marking them with signage and/or pavement painting will assist in ensuring that these design considerations are not lost during operational decisions and changes in maintenance staff.

As a general rule, a minimum of 500 to 1500 m^3 of snow pile storage per hectare of parking lot should be used. For a maximum snow pile height of 3 m, this will result in approximately 8 to 16 percent of the snow removal area being required as designated snow storage

FIGURE 7. Snow pile location, with its associated stormwater management facilities.



3. Stormwater Management

In addition to the placement of catch basins, winter maintenance needs and chloride contamination can also be taken into account in stormwater management design. In all cases, parking lots should be graded to drain away from natural surface water features and other environmentally sensitive areas, and directed instead to a stormwater management facility.

Designated snow storage areas can also be designed to promote sheet flow across shallow sloped vegetated surfaces, as an example, to promote water quality improvements. Vegetated swales, bioretention or landscaped islands with curb cut inlets can be used to collect and retain melt water runoff, reducing melt water ponding and refreezing. As with other sites, bioswales should be installed in well-drained soils, or should include underdrain systems when installed in poorly drained soils. Oil grit separators, vegetated filter strips and grassed swales may be included downstream from snow disposal areas to attenuate runoff and reduce suspended solids, metals, and petroleum hydrocarbon loads in parking lot runoff.

Permeable pavers may also be an option to reduce the need for road salt application; a study in New Hampshire found that permeable pavements used up to 77% less salt to achieve bare pavement than did conventional pavement (Roseen et al, 2013). Permeable pavers similarly improve drainage and thereby prevent melt water from ponding and refreezing. Additionally, the highly porous joint and sub base materials that surround and underlie permeable pavers absorb and retain heat, further increasing the efficiency of snow and ice melting from parking lot surfaces. However, contractors interviewed as part of this study had concerns about the use of permeable pavers, citing that the immediate infiltration of salt brine into the cracks between pavers would reduce the efficiency of the salt applied, and if not correctly installed the potential for frost heave over time, which may cause the stones to become displaced and damaged by plows.

If stormwater runoff is managed with a stormwater management pond, the design of the pond and timing of its release of chloride-rich runoff should consider the protection of the most vulnerable species in receiving waterbodies.

4. Landscaping Features

Landscaping in parking lots is an important component of Low Impact Development (Denich and Zaghal, 2014) and can also help manage urban heat island effect. Furthermore, landscaping features such as vegetated swales or landscaped islands can lead to a reduced requirement for salt application by providing locations to direct snowmelt runoff and reducing the area requiring salting. However, vegetated islands can be difficult for contractors to maneuver around, and have the potential to cause accumulations of snow and ice. Instead, parking lot layouts should be conducive to mechanical snow removal by snow plows. This involves minimizing the number of tight turns and obstacles that snow plows encounter by allowing them to plow in straight lines as much as possible. As such, landscaped islands should be kept to the ends of parking aisles. If trees are included in the landscaping areas, consideration should be given to deciduous trees with high canopies to promote cooling of parking lots in summer months and maximize solar energy to melt snow and ice in winter months.

The vegetation used in vegetated swales and landscaped islands, should be salt tolerant (see, for example, Dirr 1976, Delahaut and Hasseklus 1996) and should be suited to each site's soil, climate and moisture conditions.

5. Sidewalk Design and Pedestrian Flow

While it is critical to provide and maintain pedestrian access to buildings, the difficulty in applying calibrated amounts of salt to walkways means that they can become salt application 'hotspots' in the winter. If walkways aren't providing a function for pedestrians, their salting would represent unnecessary costs and environmental impact. The design process should consider that pedestrians typically follow the path of least resistance and not necessarily the designed walkways. Often, this leads to pedestrians walking along the vehicle routes, especially in large parking lots. By re-thinking the pedestrian walkways and designing them with consideration given to pedestrian traffic flow to and from buildings, transportation corridors (such as bus stops), and connectivity to main pedestrian thoroughfares, walkway networks will be more direct and user friendly, and the total footprint of walkways can be reduced, thus reducing the total amount of salt used in winter maintenance. While the total area of walkways in the commercial parking lot monitored as part of this study was only about 7% of the total salt application area, walkways accounted for approximately 15% to 25% of the total volume of salt applied, due to application rates being significantly higher than that in parking stalls. Priority areas to establish and maintain walkways include areas designed to support the needs of those with mobility challenges, families with small children, or the elderly. Prevailing wind direction should be considered when selecting sidewalk location. When sidewalks are constructed on only one side of a roadway, consideration should be given to placing the sidewalk on either the north or west side. For mobility concerns, sidewalk plowing and salting near transit stops and along accessible walkways should be a priority.

By raising and properly grading pedestrian walkways slightly above grade, designers can ensure that upstream areas do not drain across them, and that ponding is minimized. Depressions that may form on sidewalks/walkways must be repaired to minimize retention of water and potential safety hazards. As with parking stalls, snow storage locations for walkway shoveling should be located at the most downgradient location possible. The use of rougher material to enhance traction may also prove beneficial in reducing the need to apply salt.

Pedestrian sidewalks constructed with a minimum width of 1.5 m can be maintained by snowplows, thus easing the use of calibrated equipment to apply salt. Drop spreaders rather than broadcast spreaders should be used on walkways to increase the amount of material retained on the walkway. This also helps to limit salt damage to vegetated areas and buildings.

6. Seasonally Closed Parking Areas

Parking lot users typically choose stalls that are as close as possible to building entrances. Except for the peak shopping period, such as around Christmas, there is the potential for closing some of the less used parking lot areas and not performing any winter maintenance in these sections. These areas may be suitable for snow disposal, and in some situations may be ideal locations for the installation of permeable pavements and other low impact development features.

CONCLUSION

As a means of keeping roads and parking lots safe and passible through winter, salt is still the most cost effective means of deicing and as such is not likely to be replaced. Increasingly, however, we are seeing the external costs associated with the large quantities of salt being applied, through impacts to the environment and the degradation of buildings and infrastructure. As such, where relatively simple solutions exist, it is imperative that they be implemented. With so many of these solutions available for commercial parking lots there is a real opportunity to reduce the amount of winter salt being applied. Adopting the simple design features or operating practices outlined here into municipal planning processes will help mitigate some of the impact of future development. Indeed many of these practices can be adopted even in existing parking lots and would help to address existing impacts.

In addition to the environmental benefits of reducing salt through the adoption of these practices, there would also be a direct savings to the property owner as they would need to purchase less salt. Arguably there would be an even greater indirect savings in extending the life of the parking lot infrastructure by reducing the damage caused by salt, as well as reducing the damage and staining to building facades, wear and staining of carpets or floors and corrosion of vestibules.

While adoption of these practices would assist in reducing salt on commercial parking lots, there is still an unsustainable volume of salt being applied in the GTA on an annual basis. In large part this is due to society's expectation that we can still maintain unimpeded mobility throughout winter and thus winter maintenance practices have come to reflect this with bare pavement standards as the norm. Until society changes these expectations and we change our behavior around winter mobility, we place the winter maintenance operators in a position where their only recourse is to use too much salt.

ACKNOWLEDGEMENTS

Funding for this work was provided by the Ontario Ministry of Environment and Climate Change. The authors would like to thank Tim Krsul for his continued support of the project; Chandler Eves, Lance Aspden, Lauren Grzywniak, Ray Bolton, Sara Rawski and Drake Columbe for collecting field data under cold and challenging conditions; Hailey Ashworth and Beverly Saunders for assistance during the design workshop; Pamela Strong for her typically excellent editorial review; and the assistance of Laura Spiteri. Thanks also goes to all those who participated in our surveys and workshops, providing their invaluable insight and experience into this complex issue.

REFERENCES

Canadian Council of Ministers of the Environment. 2011. Canadian water quality guidelines for the protection of aquatic life: Chloride. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Delahaut, K.A., and Hasselkus, E.R. 1996. Salt Injury to Landscape Plants. University of Wisconsin Extension Service Publication, A2970

Denich, C and Zaghal, A. 2014. Designing for environmental and infrastructure sustainability: Ontario case studies for retrofits and new developments. Journal of Green Building 9.1: 40–59

Dirr, M.A. 1976. Selection of trees for tolerance to salt injury. Journal of Arboriculture 2:209–216

Environment Canada. 2001. Canadian Environmental Protection Act, 1999; Priority Substances List Assessment Report; Road Salts

Environment Canada. 2012. Fiver-year Review of Progress: Code of Practice for the Environmental Management of Road Salts

Fu, L., Omer, R., and Liaqat, Z. 2013. A survey of current state of practice for winter maintenance of parking lots and sidewalks. Paper submitted for presentation at 2013 annual Transportation Research Board meeting.

Lake Simcoe Region Conservation Authority. 2015. The identification of salt vulnerable areas in the Lake Simcoe watershed.

McEnroe, N.A., Buttle, J.M., Marsalek, J., Pick, F.R., Xenopoulos, M.A., Frost, P.C. 2012. Thermal and chemical stratification of urban ponds: Are they "completely mixed reactors"? Urban Ecosystems. 16:327-339

Markalek, J. 2003. Road salts in urban stormwater: an emerging issue in stormwater management in cold climates. Water Science Technology. 48(9) pg 61–70

Perera, N., Gharabaghi, B., & Noehammer, P. (2009). Stream chloride monitoring program of City of Toronto: Implications of road salt application. *Water Quality Research Journal of Canada (Canadian Association on Water Quality), 44*(2).

Roseen, R. M., Ballestero, T. P., Houle, K. M., Heath, D., & Houle, J. J. (2013). Assessment of winter maintenance of porous asphalt and its function for chloride source control. Journal of Transportation Engineering, 140(2), 04013007.

Salt Institute http://www.saltinstitute.org/road/overview/ accessed March 3 2017

Trowbridge, P. R., Kahl, J. S., Sassan, D. A., Heath, D. L., & Walsh, E. M. (2010). Relating road salt to exceedances of the water quality standard for chloride in New Hampshire streams. *Environmental science & technology, 44*(13), 4903–4909.