Sustainable Technologies
EVALUATION PROGRAM

Review of Snow and Ice Control Practices on Parking Lots and Walkways

Prepared by:

Toronto and Region Conservation Authority

Prepared for:

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

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EXECUTIVE SUMMARY

Winter salts and abrasives are essential tools for maintaining winter road safety and mobility, but their use also poses significant risks on the environment and built infrastructure. Recognition of the adverse consequences of winter salts has prompted a wealth of international research on practices and the development of guidelines aimed at optimizing salt use to avoid over-application and minimize damage to the environment. Most of this research and best practice guidance have focused on roadways, particularly highways, with relatively few studies on appropriate practices and materials for parking lots, sidewalks and walkways.

The lack of attention to salt use on private property represents a significant gap in the literature. While parking lots and walkways cover much smaller areas than roads, they account for about 20 to 40% of the salt used for winter maintenance in cities, with the potential for even higher levels in some densely urbanized areas. The disproportionate impact of private winter maintenance practices on streams is a consequence of higher salt application rates on parking lots and walkways, which in turn is driven in part by the unique conditions of parking lots and the capacity of the industry to respond to operational challenges. These unique conditions include differences in traffic conditions (pedestrian and vehicle), client demands for high levels of service, low contractor and property owner tolerance for litigation risk, and various operational constraints that affect the timing and application of salts.

The purpose of this review was to summarize the literature on snow and ice management practices for parking lots and walkways as a first step towards prioritizing and selecting practices that will contribute to improvements in environmental outcomes without compromising pedestrian or driver safety. To that end, the review (i) characterizes the state of practice as revealed through on-line and in-person surveys of contractors, municipalities, and property owners responsible for undertaking or procuring services for winter maintenance, and (ii) synthesizes key findings from research and guidelines on application rates and snow and ice best management practices, with a specific focus on parking lots and walkways. Special consideration is given to practices that help mitigate business risk and address the key winter maintenance challenges of parking lots and walkways, both of which have been identified as important drivers of excess salting.

Industry Surveys

Surveys of organizations responsible for snow and ice maintenance on parking lots and walkways were reviewed to help identify current practices and the motivations and drivers behind winter snow and ice maintenance methods and application rates.

Three formal surveys conducted between 2012 and 2016 were reviewed and summarized:

- ***Winter maintenance contractors***: Survey conducted in 2012; included 100 survey responses to 30 questions from winter maintenance contractors in Ontario (Fu et al., 2013).
- ***Parking lot and sidewalk winter maintenance practitioners***: Survey conducted in 2013 and 2014; included responses to 10 questions from 58 cold climate municipalities and states in Canada and the US, of which 9 were from Ontario (Hossain, et al., 2015a).
- ***Commercial property owners/managers, institutional property managers and winter maintenance contracting companies***. Open ended Interviews conducted in 2016 by Freeman

and Associates with 26 businesses and followed up with key informant interviews of winter maintenance industry associations in Ontario (Landscape Ontario) and the US (Snow and Ice Management Association) (LSRCA, 2016).

The 2012 survey of Ontario winter maintenance contractors portrayed an industry strongly influenced by slip and fall litigation risk with limited uptake of advanced technologies. Among the respondents, 85% used dry salt (45% of which was treated salt) and 31% occasionally or regularly used a sand/salt mix. Liquids were used by only 15% of survey respondents. When asked about application rates, 25 percent of respondents provided no response and another 12 percent said they did not calculate rates. The remaining contractors provided a wide range of rates, with the average reported rate (77 g /m^2) higher than that determined from the literature (55 g/m^2; median value as per the sources referenced in the review). Some contractors used more advanced technologies such as automated ground speed control spreaders (28%), infrared thermometers for pavement temperature monitoring (38%) and location tracking with GPS/AVL (40%). When asked how much salt would be used if litigation was not a concern, 75% indicated a savings of greater than 10%, of which 29% thought application rates could be cut back by 30% or more.

The 2013/14 survey of municipal parking lot and sidewalk winter maintenance practitioners was much shorter than the previous survey and included different questions. When asked when they initiated plowing, 60% of respondents said they did so after 1 – 5 cm of snow accumulation (which is considered reasonable), 24% plowed after snow accumulation greater than 6 cm and the remainder did not provide an answer. Only 5% used liquids as an anti-icer. Sodium chloride was the most common material (65%), followed by sand/salt (16%) and magnesium chloride (13%). Pre-wetting of rock salt was relatively common at 36%, and no one indicated the use of organic products such as beet juice. When asked about application rates after plowing, 45% said they did not calculate rates, while 35% said they applied at rates less than 49 g/m^2, with the remainder applying at a rate between 49 and 146 g/m^2.

The 2016 open ended interviews of businesses and institutional property owners/managers indicated that most were not aware that salt was an important environmental concern, and a minority of respondents also did not make the link between excess application has a detrimental effect on property assets such as paved surfaces, metals, vehicles, landscaping or entrance ways. The key concern was the safety of outdoor spaces and owners/managers had little specific knowledge of the practices being employed on the properties. However, there was a general willingness to learn more and consider alternative salt management practices as a means of better protecting the environment.

For contractors, legal liability was a key driver behind their selection of winter maintenance practices as lawsuits pose a significant financial burden that can have long lasting effects on insurance premiums. Contractors also identified the lack of standards and regulations were also a key driver of excess salt use.

Best Practice Guidelines

There are relatively few snow and ice management best practice guides targeted specifically at parking lots and walkways in Canada. Environment Canada produced a short document in 2004 that describes some of the core salt management best practices for private roads, parking lots and sidewalks, and provides an overview of the principles of salt use to help guide decisions on materials and methods (Environment Canada, 2004). A similar but updated and expanded document on the same topic was prepared by the Transportation Association of Canada (TAC) in 2013 as part of their *Synthesis of Best Practices for Road Salt Management* series (TAC, 2013a).

In 2018, the Canadian Landscape and Nurseries Association (CNLA) and Landscape Ontario (LO) commissioned Marsh Canada to prepare a best practices document entitled *Snow and Ice Operations Risk Management Guidelines*. While the guidelines are not focused specifically on salt management, they provide good process summaries of common salt management best practices along with other useful information on contracts, site inspections, incident reporting, staff management and other topics that are critical to the management and mitigation of winter maintenance operation risks.

In Ontario, Lake Simcoe Region Conservation Authority commissioned a report in 2017 entitled *Parking Lot Design Guidelines to Promote Salt Reduction*. The report highlights design features and measures that can be undertaken during the design of parking lots and walkways to facilitate winter maintenance and ultimately reduce salt use.

In the United States, best practices manuals targeted specifically at winter parking lot and sidewalk maintenance contractors included:

- *Winter Parking Lot and Sidewalk Maintenance Manual,* prepared in 2006 and updated in 2008 and 2015 by the Minnesota Pollution Control Agency;
- *Smart Salting for Property Management*, prepared in late 2020 by the Minnesota Pollution Control Agency and Fortin Consulting Inc.;
- *Snow and Ice Control Handbook for Parking Lots and Sidewalks,* prepared in 2010 by McHenry County in Illinois
- *Best Practice Guidelines for Sustainable Salt Use*, prepared by the Snow and Ice Management Association in 2015

Other best practice guides directed at winter maintenance of roads and highways were also reviewed for information relevant to understanding how salt use could be better optimized on parking lots and walkways.

Salt Application Rates

Typical application rates of sodium chloride on parking lots were derived from the University of Waterloo field research, the SIMA best practice guides, the New Hampshire Training Program recommendations and a SIMA initiative that determined rates from GPS enabled tracking equipment installed in 200 vehicles across 25 companies in 10 states and 2 provinces (Sexton, 2017). The University of Waterloo field trials showed a wide range of application rates for pavement temperatures between 0 and -9°C. These rates were between 15 and 88 g/m^2 based on a 2 hour bare pavement regain time (BPRT) and between 5 and 29 g/m^2 for a 6 hour BPRT. The rates are likely conservative given that most of the testing was done when vehicles were not present. Research trials by the same researchers showed that even low levels of traffic required rates less than half those of no traffic areas, particularly when pavements are cold.

The other three sources for salt application rates referenced above fell within a range of 22 to 66 g/m^2. The median rate for the four sources was 55 g/m^2 (using the 2 hour BPRT value from UW) which is over 3 times higher than average rates reported by municipal agencies and highway road authorities (17 g/m^2). As an aspirational target, it may be reasonable to apply salt under most conditions at rates between 15 and 40 g/m^2 (TAC, 2013a), combined with careful monitoring of performance and adaptive management at lower temperatures (below -7 C) when NaCl becomes less effective and when there is less agreement on the 'right' rates.

The wide range of reported rates was expected as research and monitoring have shown that there are several factors that influence decisions about how much salt is enough. These include pavement temperature, level of service (as measured by bare pavement regain time), snow depth and type, traffic density, pavement materials and salt type (treated, pre-wetted, effective temperature range, etc). The sensitivity of application rates to the materials used, site conditions and weather highlights the importance of training and experience as a pre-requisite to the selection of appropriate maintenance approaches for optimizing performance and salt use.

Salt Management Practices

A large number of materials and practices have been developed to improve winter maintenance outcomes and reduce impacts to the environment and built infrastructure. Performance of these practices were reviewed based on academic research and pilot programs delivered through public sector winter maintenance departments. Research specific to parking lots and walkways was highlighted whenever possible.

Table 1 presents a summary of findings for the more common practices and their relevance to parking lots. Expected salt reductions are derived primarily from parking lot studies cited in this review, supplemented by studies on roads where sufficient information from parking lots was not available. Most of the research specific to parking lots was sourced from the suite of studies undertaken by the research team at the University of Waterloo between 2013 and 2015.

Table 1: Selected salt management practices and expected benefits

Practice	Description	Expected salt reduction benefit[1]	Considerations for application on parking lots & walkways
Alternative Materials	Various low chloride ice melting products are available	>30% for alternative liquids. Less than 5% for rock salt treated with chloride free products	High price of alternatives relative to conventional salts has been a barrier to uptake. Nutrient and potassium content of some organic products may pose environmental concerns in some contexts.
Pre-treated salt	Salt pre-treated with a chemical such as $MgCl_2$ to improve effectiveness at low temperatures and prevent bounce and blow off.	10 – 15%	Expected 10-15% salt reduction benefits rely on operators applying at lower rates when using pre-treated salt, which is not always done.
Pre-wetted salt	Similar benefits to pre-treated salt but higher moisture content promotes better performance	20%	As with pre-treated salt, application rates must be reduced to realize benefits. Loss reductions from wind may be less on parking lots where vehicles are moving slowly
Direct liquid application (DLA) on parking lot and walkways	Involves applying brine before, during or after snow events to prevent ice formation on pavement and walkways. Anti-icing is the application of a brine or treated rock salt before snow events.	39 – 46% for use of brines as anti-icers. If liquids are used before and after winter events, the benefits may be higher than indicated.	Liquids require specialized equipment. Anti-icing with treated rock salt will have lower salt reduction benefit than indicated but is well suited to low traffic parking lot conditions and walkways. DLA benefits on walkways expected to be significant given frequent reports of excess salt application on walkways.
Ground speed controllers	Salt spreaders are equipped with controllers that automatically dispense salt based on truck speed.	49%[2]	Particularly relevant for parking lots where salt trucks are frequently required to vary speeds and stop/start.
Equipment calibration	Salt spreading equipment is calibrated to ensure it is functioning and applying salt at the calibrated rates.	Reductions vary based on equipment condition. Benefits widely regarded as significant.	Requires calibration method tailored for parking lots as these surfaces do not have a fixed lane width. Private contractors rarely calibrate equipment.
Plowing before salting	Avoids the use of salt to melt snow. Snow dilutes salt and significantly reduces effectiveness.	Research indicates that applying salt on 2 cm of snow instead of plowing requires over 6 times more salt to meet the same LOS.	Property owners or managers should set snow plowing requirements to avoid excess salt use. It is often cheaper for contractors to use salt to melt snow than to plow at low snow depths.
Segmented or 'live edge' plow blades	These blades better conform to the pavement surface and therefore remove more snow than traditional blades.	Test results show them to be effective in removing more snow than conventional blades, which the previous point indicates would reduce salt use.	Especially relevant for parking lots that may have more variable surface elevations than roads and often require higher surface levels (*i.e.* shorter bare surface regain times).
Decision support tools	May include use of RWIS, pavement temperature and residual salt monitoring, on-site cameras and decision support software/systems.	Reductions will vary based on equipment and range of decisions informed by use of the tools.	Low use of decision support tools among parking lot contractors highlights potential benefits. Patrolling sites before and during storms to collect relevant information is often used as a substitute for automated decision support systems.
Staff training	Regular training of winter maintenance staff each year, preferably through a certification program.	Training is a pre-requisite to reductions associated with many BMP types. Magnitude of reduction will vary based on staff knowledge and expertise prior to training	Especially relevant to contractors for parking lots and walkways due to the complexity of decision making required for the diverse site conditions encountered. Certification designations should require an auditing process to ensure knowledge imparted through training is being operationalized.
Site Condition Assessment and Plan	Identifies the various factors that may influence winter maintenance operations; provides a plan for site preparation and winter operations. Plan may include areas to be plowed, site drainage patterns, snow storage areas, problem areas, etc.	Reductions will vary based on site layout, age, space constraints, existing drainage and other factors	This practice helps to provide clarity on requirements, procedures and site conditions that can significantly improve operational efficiencies and avoid contractor – client disputes.

1. Values shown are from studies on parking lots except as indicated. Study results from research on roads are also summarized in the review.
2. Tested on a road. Results are for closed loop ground speed controller performance relative to a manual spreader.

Review findings showed that many of the same practices that help optimize salt use on roads apply to parking lots as well. However, the degree of effectiveness will vary according to the baseline against which performance is being compared. Surveys of parking lot contractors indicate that many salt management practices commonly used on roads are less common on parking lots. Examples include ground speed controllers, equipment calibration, anti-icing and the use of decision support tools. Therefore, the shift to the use of better practices on parking lots would result in much greater salt savings than on roads because the gap between what is currently being done and the new practice is much greater.

The unique conditions of parking lots also influence the effectiveness of practices. For instance, slower traffic on parking lots may mean less loss of material from wind generated by moving vehicles, but vehicle mixing of salt and snow and heat generated by friction between tires and the pavement means that areas with little traffic, such as parking stalls and walkways, will require higher salt application rates than roads to achieve the same ice-free level of service. Since blow off and bounce is less of an issue on parking lots, prewetting and treated salts may not have the same level of performance as on roads. Plowing may also be important on parking lots as melting depends more on the salt applied in parking stalls or shaded areas that do not benefit from heating from the sun or friction from tires.

Land developers, property owners and property managers also play a critical role in helping to facilitate good winter maintenance practices. Land developers can ensure parking lots and walkways are well designed for winter maintenance. Several of the important design innovations are highlighted in the aforementioned parking lot design guide (LSRCA, 2017). Interventions related to drainage, heated walkways or pavement overlays to improve friction are more cost effective to implement during the initial development of sites than as a retrofit.

Likewise, property owners and managers can improve salt management through their procurement of winter maintenance services and their intimate knowledge of their sites. Tailoring salt management practices to site conditions, designating areas for snow piles, preparing site specific salt management plans and including best practice requirements in procurement documents is critical to optimize salt use without compromising safety.

Finally, a series of case studies demonstrating the use and effectiveness of alternative materials and best practices are briefly summarized in Appendix B. These provide results from real world applications of salt management practices implemented within a southern Ontario climate.

1.0 INTRODUCTION

Winter salts and abrasives are of critical importance for winter road safety and mobility, but their use also poses significant risk to the environment and built infrastructure. To help mitigate the impact of winter salts on the environment, the Government of Canada published a document entitled *Code of Practice for the Environmental Management of Road Salts* (Environment Canada, 2004) under the *Canadian Environmental Protection Act* (1999). The document and associated best practices (TAC, 2003; updated in 2013) were directed primarily at public road authorities and municipalities using more than 500 tonnes of salt per year. Winter salt uses on parking lots or private properties were not addressed in the *Code of Practice*, although Environment Canada subsequently released a best practice brief in 2004 addressing salt use on private roads, parking lots and sidewalks (Environment Canada, 2004). This brief was used as the basis for a new Transportation Association of Canada (TAC) best practice document released in 2013 as part of its Synthesis of Best Practices series (TAC, 2013a).

While parking lots and walkways cover much smaller urban areas than roads, they account for about 20 to 40% of the salt used in winter maintenance (Environment Canada, 2012), with the potential for even higher levels in some densely urbanized areas (Sparachino et al., 2021). In New Hampshire, for instance, research conducted to examine the impacts of highway expansion in the Porcupine watershed indicated that more than 50% of salt spread within the watershed originated from only 7 parking lots and private roads (Burack et al., 2008). In the Region of Waterloo, analysis of chloride concentrations in urban drinking wells revealed that as much as 40% of salt loading could be attributed to salt application on private roads, parking lots and sidewalks. (Novotny, Murphy & Stefan, 2007). Research on Highland Creek in Toronto showed that approximately 38% of salt loading to the Creek was from private operators (Perera et al., 2010). Several snow and ice contractors in Ontario apply more than 500 tonnes of salt per year, and should, arguably, be subject to requirements like those imposed on road authorities through the *Code of Practice*.

The disproportionate salinization impact of parking lots and walkways on urban rivers in part relates to higher application rates relative to roads (see section 3.2 below). High salt application rates on parking lots and walkways may be explained, in part, by various factors that influence the methods, materials and practices used for winter maintenance (Hossain, 2014). These factors include but are not limited to the following:

- *Vehicle traffic*: traffic volumes and speeds are lower on parking lots compared to roads, and some areas such as parking stalls are subject to infrequent traffic;
- *Pedestrian traffic*: foot traffic may occur on any part of a parking lot as well as walkways, stairs and ramps around the building. By contrast, walkways on municipal roads are mostly limited to sidewalks and intersections;
- *Level of service*: property owners and managers of parking lots often require (and demand) that bare pavement conditions following snow events be achieved more quickly on parking lots than roads, particularly during periods of high parking lot use;
- *Surface types*: parking lots often have a greater diversity of surface materials (e.g. concrete, segmented pavers, asphalt) and surface types (ramps, walkways, stairs, loading areas)

- *Shading*: parking lots are often subject to less snow and ice melting from solar radiation than roads due to shading from parked cars, adjacent buildings, garbage areas and other obstructions;
- *Operational constraints*: snow plows and salters on parking lots are required to navigate irregular shaped surfaces and barriers while also negotiating accessibility during times when parked cars are present;
- *Drainage conditions*: parking lots are often not optimally designed for winter drainage resulting in some areas that experience frequent re-freezing of melted snow.
- *Risk tolerance*: property owners and winter maintenance contractors often have a much lower risk tolerance than road maintenance crews in part because the areas maintained are subject to greater scrutiny and the financial and health related impacts of accidents have a more direct effect on profit margins.

Each of these conditions require an approach to winter maintenance that is tailored to the property. This approach will vary based on the capacity and experience of the contractor hired to perform the services as well as the knowledge, experience and direction provided by property owners or managers that procure the services and perform site assessments. In an industry that is largely unregulated and driven by the need to avoid costly liability claims, it is not surprising that the default response in terms of salt use would be to over-apply. For practices to be successful on parking lots and walkways, they need to address the root causes driving excess salting practices.

The purpose of this review is to summarize the literature on snow and ice management practices on parking lots and walkways as a first step towards prioritizing and selecting practices that will contribute to improvements in environmental outcomes without compromising safety. The first section summarizes the state of practice as revealed through on-line and in-person surveys of contractors, municipalities, and property owners responsible for undertaking or procuring services for winter maintenance. The second section synthesizes key findings from research and guidelines on application rates and snow and ice best management practices, with a specific focus on parking lots and walkways. Since there were few research studies focusing specifically on parking lots and walkways, the review places heavy reliance on research and surveys conducted through the *Snow and Ice Control on Parking Lots, Platforms and Sidewalks* (SICOPS) group at the University of Waterloo between 2012 and 2015.

Case Studies of salt management best practices applied to parking lots and walkways in locations across southern Ontario are briefly summarized in Appendix A to provide real world examples of the feasibility and effectiveness of different practices and approaches.

2.0 SURVEYS OF WINTER MAINTENANCE CONTRACTORS, MUNICIPALITIES AND PROPERTY OWNERS

Surveys of organizations responsible for snow and ice maintenance on parking lots and walkways help identify current practices and areas for improvement within the industry. They also help to highlight the motivations, thought processes and drivers behind the selection of winter snow and ice maintenance methods and application rates. The following sections provide survey summaries of private winter maintenance contractors, municipal winter maintenance personnel responsible for parking lots, property owners/managers and industry associations.

2.1 Snow and Ice Management Contractors

A survey of snow and ice management professionals in Ontario was conducted by Fu et al (2013) at the end of the 2012 winter season. A series of 30 closed and open-ended questions was sent to 600 members of Landscape Ontario (an association representing landscaping and winter maintenance professionals), of which approximately 100 members sent back a complete set of responses. About 85% of responses were received from professionals working in areas with mild winters, while the remaining 15% respondents were working in colder areas of Ontario. Over 72% of survey respondents maintained small and large commercial properties, 11% served residential clients and the remainder served clients in other categories not identified in the study report.

<u>Contract type.</u> The method of renumeration for services in contracts influences the amount of salt applied. Hence the survey asked what type of contract was preferred and what type of contract is most common. The three standard contract types are 'salt extra' where the price for services is denominated based on salt use, 'salt inclusive' where contractors are paid by event or season, and 'mixed' where a set amount of salt is included and extra is charged on top of the set amount. At the time of the survey, 61% preferred salt extra payment, 24% favoured salt inclusive contracts and 15% preferred a mix type contract. Respondents indicated that 51% of contracts are salt extra, although industry association promotion of contracts other than 'salt extra' has made these contracts less common in recent years.

<u>Level of service demands</u>. The level of service demanded by clients to some extent dictates the amount of salt applied and level of effort needed to maintain properties. Three general categories were identified in order of difficulty: bare pavement 24/7, bare pavement before the day starts, and service on demand. Not surprisingly, the highest level of 24/7 service was more often required by large commercial clients (35%). Over 70% of small commercial clients required 'before day starts' service, while residential clients most often preferred on-demand services (45%). Most contractors (80%) patrolled sites to determine when services were required. A significant portion of respondents (40%) said that on-line video cameras would be very useful, but cost was a concern.

<u>Maintenance methods</u>. Most respondents plowed (97%) and used dry salt (85%). About 31% of contractors had sometimes used sand/salt mix. Only 25% indicated frequent or occasional use of pre-wetted salt, and only 15% indicated the use of direct liquid application (DLA). Among the contractors surveyed, only 32% and 28% owned equipment for pre-wetting and DLA, respectively.

Materials. While dry salt was most commonly used, 45% of respondents used treated salt comprised of dry salt with other additives to improve melting effectiveness and/or increase retention on the pavement surface. Magnesium chloride was another popular choice (25%). Less than 15% thought that the use of organic products such as corn syrup or beet juice could reduce maintenance costs, with several respondents commented that there was not enough information on the effectiveness of these products to warrant use.

Application rates. The survey asked what would constitute a light, medium and heavy salt application rate on parking lots. This question was answered by only 75% of respondents, probably because contractors that didn't respond were either unsure or did not measure application rates. The most common application rate for the light, medium and heavy categories were 24 to 49 g/m2 (53%), 49 to 98 g/m2 (33%) and 98 to 146 g/m2 (22%), respectively. However, the methods of application rate varied considerably, with the most common involving counting the number of trucks or hopper loads used for each site (or more commonly, several sites). Twelve percent said they did not calculate rates.

Technology. Automated salt rate controllers, which includes ground speed controllers were used at least occasionally by 28% of respondents. This number may have increased since that time as the technology has become more cost effective. Only 37% used infrared thermometers despite their low cost and proven effectiveness. A larger number of respondents (40%) used and recommended GPS technologies.

Insurance concerns. Fear of litigation has been well documented as an important driver of oversalting (e.g. TAC, 2013a). Therefore, respondents were asked to indicate how much salt could be saved if litigation and insurance were not a concern. Over 75% thought that more than 10% of the salt could be saved, and 29% felt that salt rates could be cut back by over 30%. This points to litigation as a primary driver of excess salting if it can be assumed that lower rates would provide an adequate safeguard against accidents and slip and falls, which everyone would want to avoid regardless of litigation risks.

2.2 Municipalities

Researchers from the University of Waterloo in Ontario conducted another on-line survey targeting parking lot and sidewalk winter maintenance practitioners from 58 cold climate municipalities and states in Canada and the US at the end of the 2012-2013 and 2013-2014 winter seasons, of which 9 were from Ontario (Hossain, et al., 2015a). The survey consisted of 10 closed end questions with opportunities to provide open ended responses.

Maintenance Methods. Sixty percent of respondents indicated that they plowed after 1 to 5 cm of snow accumulation and approximately 24% indicated that they would do so only after 6 to 10 cm of snow had accumulated. The remainder did not identify a specific threshold. Also, 24% of respondents indicated that they did not plow and instead used salt only after snow events with accumulations of 1 to 5 cm. Only 5% of respondents indicated that they used a liquid brine in advance of snow events (referred to as anti-icing), even though this practice has been shown to reduce the amount of salt required to meet the same level of service.

Materials. Of the respondents, 65% indicated they use sodium chloride, while the remainder used magnesium chloride (13%), sand/salt mix (16%), calcium chloride (3%) or other products (3%).

Interestingly, 36% respondents used pre-wetted salt, which is a higher percentage than the 25% of respondents in the private industry survey conducted in Ontario (Fu et al, 2013). Pre wetting products used included NaCl brine (60%), $MgCl_2$ (30%), $CaCl_2$ (5%) and other products (5%). No one indicated that they used organic products such as beet juice on parking lots.

Salt application rates. Survey participants were asked to identify the salt application rates after snow plowing, when there was very little snow on the ground. Among the respondents, 45% indicated that they did not record the amounts applied, while 35% said they applied a low rate of less than 49 g/m^2, and the remaining 20% indicated that they applied between 49 to 146 g/m^2. Several respondents indicated that they used similar application rates on parking lots as on roads despite differing functional characteristics and environmental conditions (and despite most guidelines indicating that much lower rates are required on busy public roads).

2.3 Property Owners and Industry Associations

A survey of commercial property owners/managers, institutional property managers and winter maintenance contracts was undertaken in 2016 to help develop a market-based strategy for improved uptake of sustainable salt use practices in the Lake Simcoe Watershed in Ontario (LSRCA, 2016). The interviews conducted as part of this research included 26 businesses. Several themes were explored and elaborated on through in-person interviews with commercial property owners, major tenants/property owners, and a smaller number of school boards and property maintenance contracting companies (specific numbers for each group were not provided). Interviews were also conducted with well-informed staff from associations representing the snow and ice management contractors in Canada (Landscape Ontario) and the United States (Snow and Ice Management Association).

The interviews highlighted the importance of slip-and-fall litigation as a key driver of high salt use on parking lots. Commercial and institutional property owners and managers were often not aware that salt was an important environmental concern, and a minority of respondents also did not make the link between excess application and detrimental effects on property assets such as paved surfaces, metals, vehicles, landscaping or entrance ways. The key concern was the safety of outdoor spaces and owners/managers had little specific knowledge of the practices being employed on the properties. Sustainability efforts were often more focused on energy efficiency in response to the climate emergency in part because these investments often have an attractive payback. Institutional managers were particularly sensitive to the potential higher cost of employing improved salt management practices.

While awareness of excess salt application as an issue was generally low, there was a general willingness to learn more and consider alternative salt management practices. These actions were generally regarded as consistent with corporate and institutional sustainability policies directed at better protecting the environment.

Not surprisingly, legal liability was also a key driver behind their selection of winter maintenance practices as lawsuits pose a significant financial burden that can have long lasting effects on insurance premiums. Contractors often felt they have little choice in improving their equipment and methods as proposals are often selected based on low bid, and the payback doesn't justify the higher costs.

Moreover, property owners and managers often demand a high level of service that requires that more salt be applied to keep the surfaces clear and ice free following snow events. Contractors also identified that the lack of standards and regulations were also a key driver of excess salt use. While training helps, it is mostly the larger and more progressive contractors that complete the training. Progress is being made in improving practices and upgrading equipment, but mostly by larger operators.

2.4 Summary

The available surveys of snow and ice management professionals highlight a relatively low level of adoption of salt management best practices in part due to the perception that investment in the infrastructure to improve practices would not generate a significant payback. This suggests that the industry does not see the adoption of better practices translating into significant salt savings, operation efficiency gains or reduced long term insurance premiums by increasing the effectiveness of due diligence defense, despite evidence to the contrary (see below).

There was evidence from the contractor and municipal surveys that salt application rates on parking lots are likely elevated since 65% of practitioners in both surveys either did not record or calculate rates or indicated that they regularly applied at rates above 49 g/m^2, which is considered to be on the high side.

Property owners surveyed had a low level of awareness of salt as a problem, both for the environment and built infrastructure, and were sensitive to cost and legal liability associated with winter maintenance. On a positive note, however, there was an interest in improving awareness and considering improved practices as part of meeting corporate social and environmental responsibility goals.

3.0 PARKING LOT AND WALKWAY SALT MANAGEMENT GUIDELINES, APPLICATION RATES AND BEST PRACTICES

This section reviews available parking lot best practice guideline documents and specific practices that are either commonly applied to parking lots and walkways or may be considered under certain circumstances. Where necessary, selected reports and guides from the literature on road and highway snow and ice management are used to supplement and enhance the parking lot and walkway specific literature, particularly for newer practices that may show promise for this land use type.

3.1 Guidelines

There are relatively few snow and ice management best practice guides in Canada that are targeted specifically at parking lots and walkways. Environment Canada produced a short document in 2004 that describes some of the core salt management best practices for private roads, parking lots and sidewalks, and provides an overview of the principles of salt use to help guide decisions on materials and methods (Environment Canada, 2004). This document is also available from the Canadian Parking Association as a 'Technical Bulletin' (CPA, 2005).

The Transportation Association of Canada (TAC) prepared a series of 10 best practices documents covering different salt management topics in 2013. This series was updated from an earlier version developed as part of the 2004 *Environment Canada Code of Practice for the Environmental Management of Road Salts* including one additional document that addresses salt management on private driveways, parking lots and walkways (TAC, 2013a). This short guideline provides an updated and expanded description of best practices described in the earlier Environment Canada document.

In 2018, Landscape Ontario (LO) and the Canadian Landscape and Nurseries Association (CNLA) commissioned Marsh Risk Consulting to prepare a best practices document entitled *Snow and Ice Operations Risk Management Guidelines* (Marsh Canada, 2018). The document draws upon information from other best practices guidelines to 'facilitate a consistent approach for the management of risks for common snow and ice maintenance operations." While the guidelines are not focused specifically on salt management, they provide good process summaries of common salt management best practices along with other information on contracts, site inspections, incident reporting, staff management and other topics that are critical to good business and client management.

In the United States, a manual targeted specifically at winter parking lot and sidewalk maintenance contractors was prepared in 2006 by a consortium of organizations and revised in 2008 and again in 2015 by the Minnesota Pollution Control Agency (MPCA, 2015). The manual was developed based on an earlier *Minnesota Snow and Ice Control Field Handbook for Snowplow Operators* and the MPCA's parking lot winter maintenance training program. A separate manual directed at property owners was developed in late 2020 that contains more information on best management practices and actions property managers and owners can undertake to reduce salt use (MPCA and Fortin Consulting, 2020).

McHenry County in Illinois also produced a Snow and Ice Control Handbook for Parking Lots and Sidewalks (McHenry County, 2010) specifically directed at snowplow operators. This is a simple tool for operators with charts and guidance on calculations that shares much of the same guidance provided in the Minnesota Field Handbook for Snowplow Operators referenced above, along with advances in anti-icing from the *Utah Local Technical Assistance Program*.

The Association for snow and ice management professionals in the United States released a series of best practice recommendations in 2015 oriented towards optimizing salt use (SIMA, 2015). The short document includes a list of processes, policies and activities that can be used by any site, contractor or organization to apply salt more efficiently. It includes sections on purchasing, storage and transport, and operational considerations, with recommendations on documentation requirements.

Often sites are not well designed for winter maintenance. Lake Simcoe Region Conservation Authority commissioned a report that addresses this issue entitled *Parking Lot Design Guidelines to Promote Salt Reduction* (LSRCA, 2017). The report provides useful tips on measures that can be taken during the design of parking lots to facilitate winter maintenance activities, and ultimately reduce salt use.

Literature supporting or lending credibility to the best practices recommended in these guidelines are reviewed in section 3.3 below.

3.2 Application Rates

Contractor surveys cited above and salt tracking equipment mounted on trucks indicate that winter salt application rates are often higher on parking lots and walkways than on municipal roads and highways. These differences can be attributed in part to various factors identified earlier, including the unique conditions of parking lots and walkways and client and liability insurance pressures that promote high level of service expectations.

Evidence of these higher application rates are reflected in research and guidelines for parking lots, as summarized by Sexton (2017). Figure 1 shows the range of recommended or measured sodium chloride (NaCl) application rates on parking lots and public roads at pavement temperatures between 0 and -9°C. This comparison shows median application rates for parking lots are approximately 3x higher than for roads/highways, with some variation among literature sources.

The University of Waterloo application rate reference is the only value based on controlled research trials on parking surfaces (Hossain and Fu, 2015). Data were collected during approximately 100 events during three winter seasons from 2011/12 to 2013/14. Detailed application rates from this study by pavement temperature, level of service and traffic conditions are provided in Appendix A. The range shown in Figure 1 is for a plowed surface and 2 hour bare pavement regain time (BPRT), which was suggested as a common service level for parking lots (Sexton, 2017).

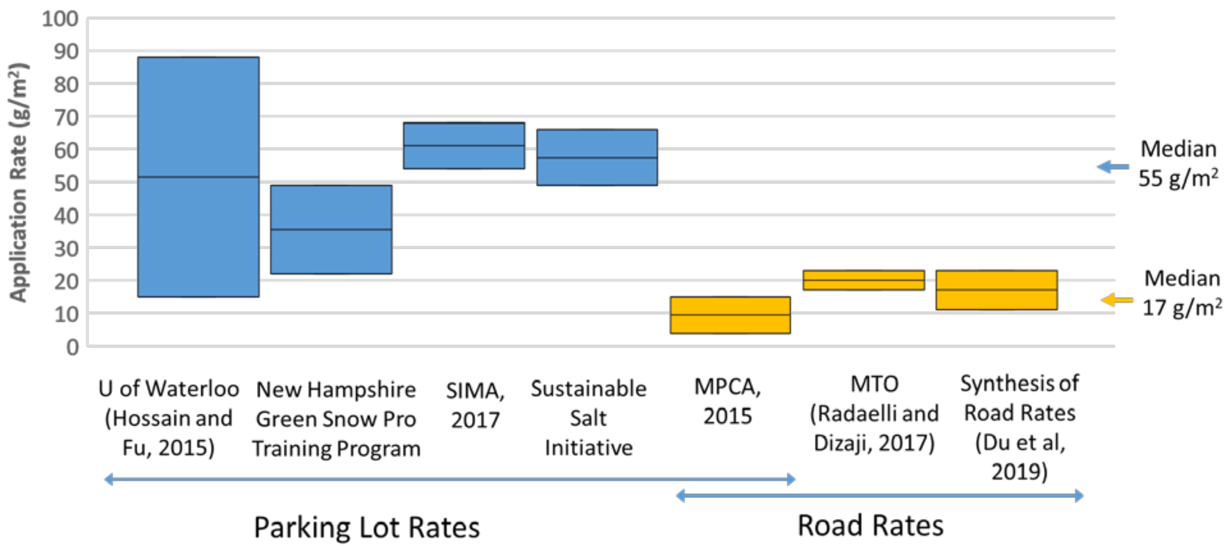

Figure 1: Published NaCl application rate ranges for plowed parking lots and roads (0 to -9°C). The application rates published in the MPCA winter parking lot and sidewalk maintenance manual (2015) are derived from road rates and are therefore considered to be representative of road rates for the purpose of calculating the median value. The University of Waterloo research is for a 2 hour BPRT on a plowed parking stall surface.

The New Hampshire, Snow and Ice Management Association (SIMA) and Minnesota values (MPCA, 2015) are from parking lot guidelines or training programs targeted at private contractors, with no indication of how these relate to BPRT. The Sustainable Salt Institute reference is from GPS enabled tracking equipment installed in 200 vehicles across 25 companies collectively serving 1500 properties in 10 states and 2 provinces (Sexton, 2017). The MPCA winter Parking Lot and Sidewalk Maintenance Manual (2015) rates are derived from road rates for that state.

The DuPage River Salt Creek workgroup in Illinois also suggests a relatively low rate for parking lots on their website of between 15 and 34 g/m^2 for a specified temperature range of 0 to -9°C (www.drscw.org). According to the University of Waterloo research on application rates, the peak rate of the DRSC range aligns with that of a 5 hour BPRT rates for parking stalls and a 2 hour BPRT for drive lanes with low levels of traffic (see Appendix A). By contrast, estimated application rates for two different contractors providing winter maintenance on a large commercial parking lot (including walkways) in Newmarket, Ontario averaged 65 g/m^2 (3 seasons) and 81 g/m^2 (4 seasons) (see case study #5 in Appendix B).

The road application rates shown in Figure 1 are from the Ontario Ministry of Transportation (*e.g.* Radaelli and Dizaji, 2017) and a synthesis of guidelines and practices used by several US Departments of Transportation (Du et al., 2019). Typical bare pavement regain times for freeways and urban highways in Ontario is eight hours, and for major highways bare pavement is to be regained within 16 hours after a winter storm (Radaelli and Dizaji, 2017). Road application rates are typically expressed as kg/lane km, which has been converted to g/m^2 in this figure based on a 12 foot (3.66 m) lane width.

Unfortunately, there were few studies that addressed application rates on sidewalks, ramps and walkways. The LSRCA found that rates were sometimes in excess of 100 times typical parking lot rates (LSRCA, 2020) and it is well established that oversalting of walkways is a common practice. Reasons may include the coarse method of manual application used (often spreading by hand), fears associated with pedestrian/visitor slip and falls, and the tendency for building operations staff to repeat applications over the course of the day . When walkways are included, the actually amount of salt applied at commercial and institutional sites may be considerably higher than those indicated in Figure 1.

3.2.1 Key Factors Influencing Application Rates on Parking Lots

The research at the University of Waterloo identified several key factors that influence the rate of application on parking lots. These include pavement temperature, level of service, snow depth and type, traffic density, pavement type and salt characteristics. The importance of these factors on application rates is discussed in the following sections.

Pavement temperature is one of the most important variables. For plowed surfaces salted with NaCl rock salt after an event, the UW research found that an application rate for a pavement temperature between -1 to -3°C is almost 6 times lower than that required rate at pavement temperatures between -7 and -9 °C. This was true at all levels of service tested (BPRTs between 1 and 6 hours)(Hossain and Fu, 2015). Subsequent research on the field application of the UW research reported a 1 hour decrease in BPRT with every 3 degree drop in temperature (Usman et al., 2018).

Level of service is another key factor in determining the amount of salt applied on parking lots. The UW research used Bare Pavement Regain Time as an indicator to assess service levels, as shown in Figure 2. The data showed that median application rates of rock salt were almost 6 times greater at a BPRT of 1 hour (100 g/m^2) versus 6 hours (17 g/m^2). The data also showed that the application rates increased more quickly as the BPRT decreased below 4 hours, indicating that more aggressive LOS requirements can result in disproportionately higher salt use (Hossain and Fu, 2015).

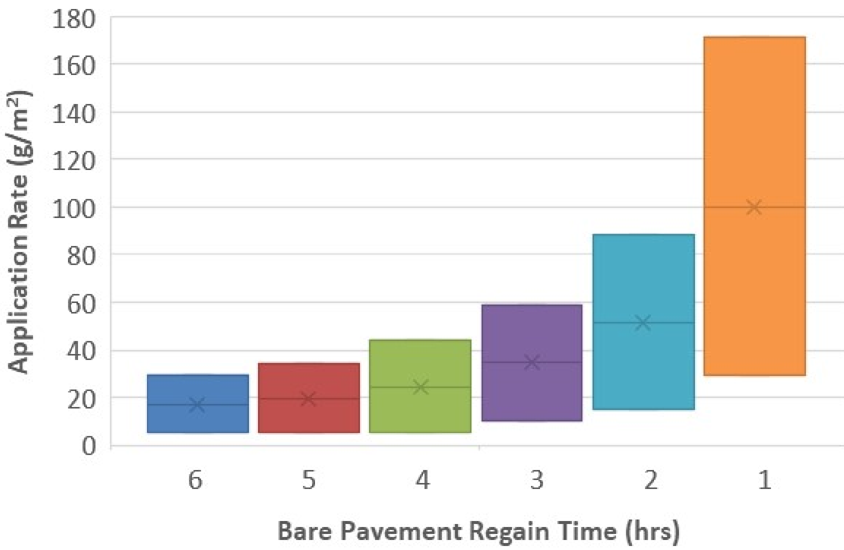

Figure 2: Rock salt (NaCl) application rates required to meet different levels of service (i.e. bare pavement regain times) on plowed parking stalls (0.1 to 0.5 cm snow cover) at the University of Waterloo. The bottom and top of each box represents application rate values for pavement temperatures ranging from -1 to-3 °C and -7 to -9 °C, respectively (based on data from Hossain and Fu, 2015).

Snow depth and type affect application rates in different ways. Salting on top of snow dilutes the melting power of salt and therefore the more residual snow on the pavement, the higher the application rate needed to meet LOS requirements. Controlled trials in parking stalls at UW showed that, on average, over 6 times more salt was needed to meet a two hour BPRT target when snow depths were between 0.1 and 0.5 cm vs snow depths of 2.0 to 2.5 cm (Hossain and Fu, 2015). Snow cover has a range of densities. Fresh snow typically has a density of 100 kg/m^3. If the snow is loose (75 kg/m^3), the amount of salt required is 0.75 times that of fresh snow, while denser snow would require proportionately higher rates. Freezing rain and ice are very dense (approx. 800 kg/m^3) and would therefore require a rate 8 times higher than fresh snow (Hossain and Fu, 2015).

Traffic density. Vehicle traffic generates heat through friction and accelerates the melting process by crushing and dispersing the salt crystals. In parking lots, the drive lanes would experience higher traffic volume and speeds than the stalls, but traffic speeds would be much lower than roads. There may also be traffic variations across the parking, with areas closer to the front doors experiencing higher volumes. Hossain and Fu (2015) examined the difference in application rates on parking stalls and on drive lanes with low, medium and high traffic frequency. The results for the 2 hour and 6 hour bare pavement regain times shown in Figure 3 indicate that drive lane application rates are relatively similar regardless of traffic, but parking stalls with little to no traffic and shading from cars require considerably higher application rates. As expected, median salt application rates at the 2 hour BPRT are much higher than those required at the longer 6 hour BPRT.

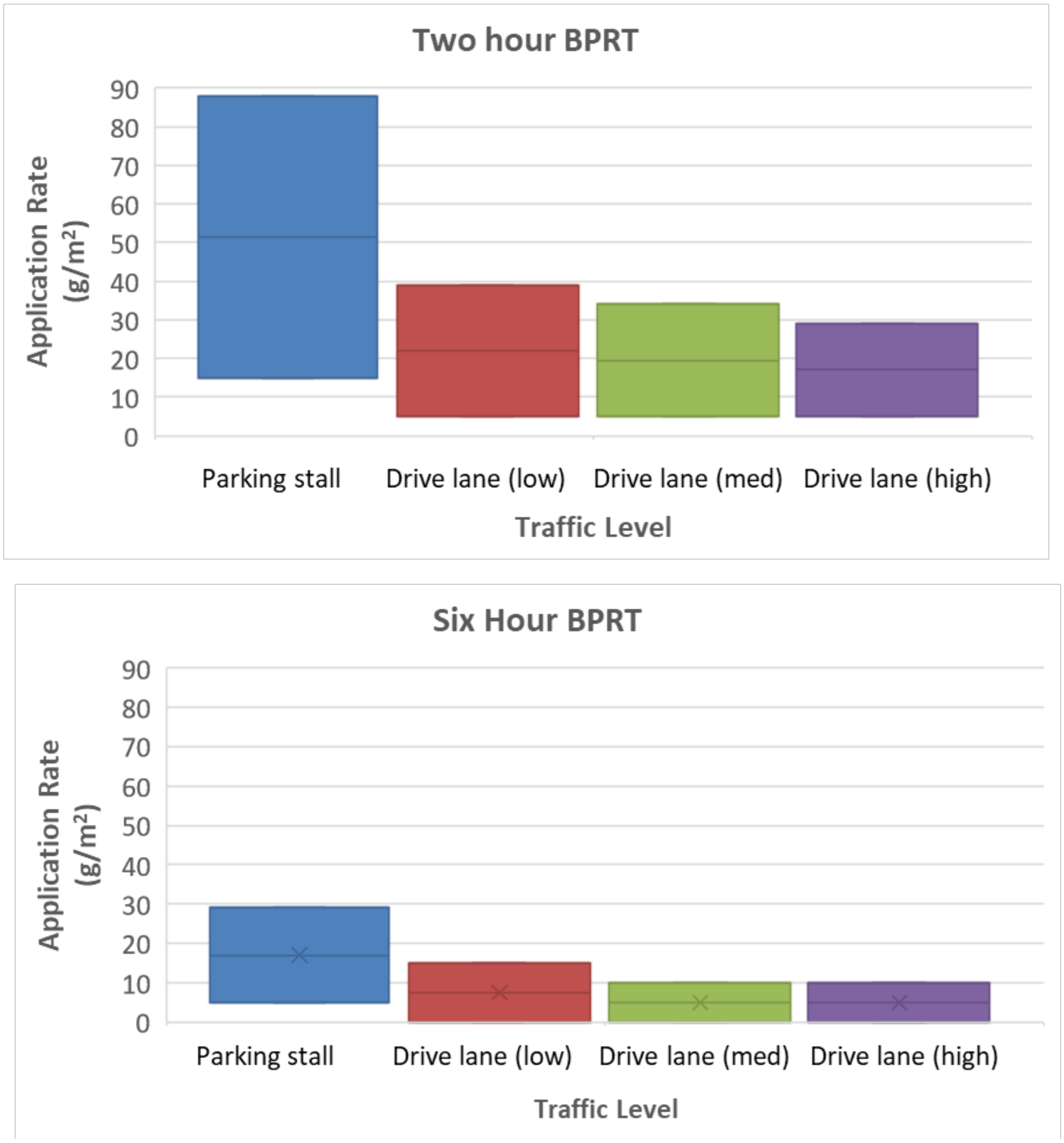

Figure 3: Change in rock salt (NaCl) application rates required on plowed parking lot surfaces (0.1 to 0.5 cm snow cover) with varying traffic levels for 2 hour (top) and 6 hour (bottom) bare pavement regain times. The bottom and top of each box represents application rate values for pavement temperatures of -1 to-3 °C and -7 to -9 °C, respectively (based on data from Hossain and Fu, 2015).

<u>Pavement type</u> has a more minor effect on application rates. The UW research examined asphalt, concrete and interlocking concrete pavements. The research showed that snow was found to melt 10% per hour more quickly on asphalt pavements than concrete pavements. Interlocking concrete pavers melted snow at the same rate as concrete pavements, although the former may have greater bare surface friction coefficients (Hossain et al, 2016). When translated to application rates, the researchers suggested that the two concrete pavements would require approximately 20% higher application rates than asphalt (Hossain et al, 2016).

Prewetting with chemicals that reduce the effective temperature of salt can mitigate against increased application rates at temperatures below -9°C. In general, dry salts will require higher application rates than pre-treated salt which in turn will require higher application rates than pre-wetted salt (MTO, 2018, Raedelli and Roshanak, 2017). On parking lots, even within the effectiveness range of NaCl, Hossain et al (2015d) found that pre-wetting salt melted snow and ice more quickly than dry salt. This was particularly evident when the snow was dry. The benefits of pre-wetting were greater at higher application rates. This topic is discussed further in section 3.3.2.

Salt type. The effect of salt type on application rates is discussed in more detail in the 'best practices' section below. The material type may affect application rates by working more effectively at low temperatures (< - 7°C), adhering better to the road surface, and initiating the melt process more quickly. Liquids also have the potential to reduce salt for reasons discussed in the anti-icing section.

3.3 Winter Maintenance Best Practices

3.3.1 Winter Maintenance Materials

The choice of materials for winter maintenance of parking lots and walkways is based primarily on the product's ice melting performance, cost and temperature effectiveness range. Corrosion, pavement degradation and environmental considerations are often secondary considerations (Levelton Consultants, 2007). Solid and liquid forms of salt are employed with a range of different strategies including de-icing, anti-icing, pre-wetting, and salt mixing with abrasives.

3.3.1.1 Conventional Salts

Table 1 shows the characteristics of the most common chemicals and products used by municipalities, businesses and contractors. The least expensive and most common material used is sodium chloride (NaCl) rock salt, with an effectiveness range down to –7°C. During colder temperatures, NaCl rock salt is often treated with concentrated de-icing liquids, such as magnesium chloride ($MgCl_2$) or calcium chloride ($CaCl_2$), to lower the effective temperature range of rock salt. This may be done by combining the salt and liquid prior to application (called pre-wetting if on-board equipment is used, and pre-treating if liquid is added to stockpiles), or by using proprietary products that have already been pre-treated with these chemicals.

The content of chloride varies according to the product. By molecular weight, sodium chloride, magnesium chloride and calcium chloride are comprised of 61, 74 and 64% chloride, respectively (Levelton Consultants, 2007). Conventional chloride-based salts have similarly adverse effects on aquatic life, groundwater, soils and vegetation (Fay and Shi, 2012).

Chloride based snow and ice chemicals are the most corrosive to metals, particularly the hygroscopic chemicals of Mg and Ca because of the longer duration of wetness. Corrosion inhibiters are sometimes added to slow the rate of corrosion but can behave differently on different metals, which can result in a decrease in corrosion on one type of metal while accelerating corrosion of another (Levelton Consultants, 2007).

Chloride-based de-icers can damage concrete pavements in two ways. The winter salts can accelerate corrosion of re-bar within the concrete, which poses a problem for bridges, parking lots above underground garages or other contexts where the concrete contains metals. The salts may also react with the cement paste causing deterioration of the cement matrix in poured and pre-cast concrete pavers. Magnesium is particularly reactive in this regard, resulting in a decrease in concrete compressive strength. The quality of the concrete influences the susceptibility of surfaces to damage (Levelton Consultants, 2007). Both $CaCl_2$ and $MgCl_2$ can also cause cracking and spalling of concrete, as well as increased permeability (Du et al, 2019).

Table 1: Characteristics and impacts of common chloride-based freeze point depressants and abrasives

Chemical	Effective/ Eutectic temp.(°C)[1]	Typical Form	Optimal Conc. in Liquid Form	Concrete (chemical degradation)[2]	Steel Corrosion	Environmental Impact (soil/water)	Cost
Sodium Chloride (NaCl)	-9/-21	Solid, liquid	23%	Low	High	Increases salinity; Toxic to aquatic life; pollutes groundwater	$
Magnesium Chloride ($MgCl_2$)	-23/-33	Mostly liquid, some solid flakes	27-30%	High	Moderate to High	Increases salinity; Toxic to aquatic life; pollutes groundwater	$$
Calcium Chloride ($CaCl_2$)	-29/-51	Mostly liquid, some flakes or pellets	22-30%	Moderate	High	Increases salinity; Toxic to aquatic life; pollutes groundwater	$$$
Abrasives	Does not melt snow or ice	Solid	Often treated with Cl based brines to melt ice	none	none	Air quality impacts; sedimentation of streams, wetlands	$

1. Effective melting temperature is the lowest pavement temperature at which the product could be practically useful to melt ice. Eutectic temperature is the lowest possible melting temperature.
2. All products that melt snow and ice will increase the number of freeze-thaw cycles, which can accelerate the deterioration of concrete surfaces. However, the effect of freeze-thaw cycles on concrete deterioration may be worse for chloride-based chemicals that react with cement mixes.

3.3.1.2 Abrasives

Abrasives include material such as sand, gravel, ash, cinders, volcanic rock or sawdust. They do not melt snow and ice but can improve traction on paved surfaces by increasing friction, even at very cold temperatures. Some products are wetted with salt brine to help melt ice and they are always used in combination with plowing.

Abrasives are often applied at higher rates than chloride-based de-icers (Levelton Consultants, 2007), resulting in more frequent return trips to depots to refill trucks. Since abrasives do not dissolve, the materials build-up and require significant sweeping and cleaning of drainage infrastructure at the end of season. Abrasives can also be transported to waterways where they could have adverse effects on aquatic habitat and water quality. In a cost benefit evaluation of winter maintenance activities, Fay et al (2015) found positive cost benefit ratios for all winter maintenance practices examined, with the exception of abrasives which was negative due to high clean up and environmental costs.

Abrasives are not used extensively on urban parking lots due to their inability to melt snow and ice and meet level of service requirements. Clean up costs and other operational issues associated with abrasives, along with potential liability risk concerns, often persuade contractors and property owners to favour chloride-based salt products. In the industry surveys cited above, 31% of contractors and 16% of municipalities reported occasionally using a salt/sand mix or sand only for traction.

3.3.1.3 Salt Alternatives

Alternatives to salt may be used to reduce the environmental and infrastructure impacts associated with the use of chloride-based salts. These alternatives include acetates, formates, glycols, succinates, and agricultural byproducts. The agricultural byproducts, such as beet juice or corn-based products, are often applied with conventional winter salt to improve its effectiveness by reducing loss from wind and bounce and increasing the effective temperature range. Each of these products has advantages and disadvantages under different conditions and there are several on-going studies documenting their effectiveness and environmental impacts (Fay and Shi, 2012; Fay and Shi, 2011). Their effective temperature ranges and other characteristics are summarized in Table 2.

More expensive salt alternatives, such as acetates, formates, glycols and succinates, are rarely used on parking lots due to their high costs. Airports use them more frequently due to their low corrosion potential. They are also used by some municipalities on bridge decks and other areas where chloride-based de-icers are not recommended.

Agricultural byproducts are less expensive, but still rarely used on parking lots. Environmental concerns around chloride-based de-icers are one of the primary reasons supporting the use of alternative products, although more recent research has shown that many of these alternatives are not as environmentally benign as originally thought (e.g. Gillis et al, 2021; Fay and Shi, 2012). Agro-products may be used either alone, as a liquid mixed with salt brine (NaCl or other), or as a liquid pre-treatment of conventional rock salt. The high viscosity of some agricultural products such as beet juice is a frequent concern raised by contractors as the products can complicate operations by clogging salt spreading and spraying equipment.

Table 2: Characteristics and impacts of alternative salts

Chemical	Lowest Effective Pavement Temp. (°C)	Typical Form	Optimal Conc. in Liquid Form	Concrete (chemical degradation)	Steel Corrosion	Environmental Impact (soil/water)	Cost
Calcium Magnesium Acetate	-9	Solid	32%	Moderate	Low	Improves soil structure, moderate BOD increase	$$$$
Potassium Acetate	-27	Liquid	50%	Low to Moderate	Moderate to High (galvanized steel)	Improves soil structure, moderate BOD increase	$$$$
Products derived from beet juice	Usually blended with chloride products; generally -17 to -23	Liquid, may be used to treat rock salt	As liquid, usually blended 30/70 beet juice/NaCl brine	Low	Non-corrosive	Nutrient source, depletes oxygen	$$$$
Other organic materials	Usually blended with Cl based products	Liquid, may be used to treat rock salt	Usually blended with Cl based products	Low	Non-corrosive	Nutrient source, depletes oxygen	Varies
Glycol/ glycerines	-17 to -29	Liquid	n/a	Low	Low	High BOD increase and toxicity	$$$$$
Formates	-17 to -29 (NaFm, KFm)	Liquid and solid	n/a	Low to Moderate	Galvanized steel	moderate BOD increase and toxicity	$$$$
Succinates	-29 (KSu)	Liquid	n/a	Low	Low	Moderate toxicity and BOD	$$$

Sources: Fortin Consulting Inc., 2014; Western Transportation Institute, 2017.

3.3.1.4 Research on Treated Salts and Brines in Ontario

In Ontario, Hossain et al (2015b) compared the performance of conventional NaCl rock salt to various treated salts available on the market. The trials were conducted at the University of Waterloo parking lot during 21 snow events over 33 days with 10 to 15 test sections for a total of 300 test sections over the duration of the project. Tests included plowed and unplowed sections. The products tested and test results are presented in Table 3

Table 3: Treated and alternative de-icers tested at U of Waterloo. Results are presented as Bare Pavement Regain Times (BPRT) for plowed and unplowed sections (Hossain et al., 2015b; 2014b)

Product name	Contents	Approx. Cost ($/ton)	BPRT (hrs) difference between proprietary products and rock salt	
			Plowed	Unplowed
Rock Salt	NaCl	80	n/a	n/a
Blue Salt	Treated with $MgCl_2$ (quantity unknown)	100	0.5	0.3
Slicer	78% NaCl, 9.4% $MgCl_2$, 2-3% proprietary products	358	0.9	0.5
Green Salt	Sodium Formate treated with GEN3 runway deicing fluid - a combination of polyols, organic salts and bio-based additives (proportions not known)	950	1.2	1.3
Jet Blue	NaCl treated with proprietary polyol (proportion not known)	495	1.4	0.7

Results showed that all treated salts had shorter bare pavement regain times than regular rock salt. On plowed sections, which is arguably the most common scenario, Jet Blue performed best, followed by Slicer, Green and Blue salt. Improvements in BPRTs relative to rock salt ranged from 0.5 to 1.4 hours on plowed sections. On unplowed sections, Slicer performed slightly better than Jet Blue, followed by Green and Blue Salt.

Through the lens of cost, Green Salt is least affordable and was not among the top performers on either plowed or unplowed surfaces. This product is mostly used in airports to reduce corrosion of aviation equipment, which likely justifies the higher cost. Blue salt was the least expensive by far, costing only 20% more than regular rock salt. The performance advantage however was mostly at application rates above the normal range of 43 to 73 g/m^2 and therefore is probably only justified for its ability to extend the effectiveness of salt at lower temperatures. Slicer had the highest chloride content of the alternatives tested, which may partly explain why it also performed relatively well in the tests, but it was also reported to have a cost over 4 times that of rock salt. Most of the performance benefit associated with this product may disappear if rock salt application rates had been adjusted based on chloride content. Jet Blue was also considerably more expensive than rock salt (over 6 times) but can boast the advantage of reducing chloride inputs to the environment and possibly some reductions in infrastructure damage (Hossain et al, 2015b).

A second study conducted by researchers at the University Waterloo parking lot with TRCA compared liquid NaCl brine to organic and semi-organic alternative liquids (fusion 2350, snow melt and Caliber 1000) (Hosseini et al., 2014; Hosseini et al., 2017). The products were applied as anti-icers prior to snow fall and tested for differences in pavement friction. The low chloride alternatives (fusion 2350, snow melt) performed as well as the two products with higher chloride content (NaCl, Caliber1000), and both organic products were more effective at temperatures below -7 to -10 C. The optimal application rate for all anti-icing products was found to be 3.2L/100 m^2 (equivalent to a dry salt application rate of 8.6g/m^2).

Chemical tests of various blends by TRCA indicated relatively high concentrations of nutrients and other organic components. Even after correcting for dilution resulting from snow melt, the concentrations of phosphorus were at levels that may cause algae growth and oxygen depletion in sensitive water bodies (STEP, 2015; summarized as a case study in Appendix B). Potassium in the snow melt and beet juice products were also elevated, which emerging research in Ontario suggests may be harmful to sensitive aquatic species if delivered to streams at elevated concentrations (Gillis et al, 2021).

On an expressway in Ontario, Fu et al. (2012) compared the performance of NaCl brine to a blend of beet juice (Fusion) mixed at a ratio of 30 parts beet juice to 70 parts NaCl brine. The products were applied in separate tests as direct liquid applications and as a pre-wet treatment of rock salt. Friction measurements from highway areas treated with the two products were compared. Results showed similar friction performance between the brine and the beet juice mixture when used as pre-wetting liquids. However, the beet juice mixture performed better than the brine when applied alone as a direct liquid on roadways.

3.3.1.5 Standards for Rock Salt and Brine (freeze point depressants)

In Ontario, NaCl rock salts and brines used for snow and ice control should meet Ontario Provincial Standard Specifications (OPSS 2502, OPSS Mun 2502) for moisture content, texture, and chemistry to ensure optimal performance.

For rock salt, utilizing a consistent salt texture is especially important as spreading equipment is calibrated to salt in a specific range, and texture can negatively impact performance. Fine graded salt, for instance, is prone to rapid dilution and blow off, while coarse graded salt (3 to 5 mm range) will take longer to activate and is prone to bounce during spreading operations (Hashemian et al., 2020). Conventional NaCl brines are mixed at 23.3% salt to 76.7% water for optimal effectiveness.

3.3.2 Pre-wetting

The term pre-wetting refers to the practice of applying concentrated de-icing liquids to rock salt by using on-board pre-wetting equipment where brine is applied to rock salt at the auger or spinner immediately before salt is applied to the surface. Sometimes the term is also used when applying and mixing brine into the salt pile prior to loading, although this application is also called pre-treating salt.

A pre-wet ratio of 5 to 10% of liquid to solid salt mass is generally used, with most studies suggesting that ratios higher than 10% do not significantly increase performance (Usman et al, 2017; Alger and Hasse, 2006).

Brines used for prewetting are typically comprised of NaCl, $MgCl_2$ or $CaCl_2$. The latter two are used if a lower effective temperature is desired. Organic brines can also be used to reduce chloride content and extend the effectiveness range of NaCl. In Ontario, Fu et al (2006) found that pre-wetting dry salt with $CaCl_2$, performed better and generally resulted in a higher level of service than prewetting with NaCl, $MgCl_2$ and pure water.

Pre-wetting salt is widely regarded as an effective technique for improving the deicing capability of salt by providing the initial moisture needed to accelerate the start of the melting process while also reducing losses from bounce/scatter as the material is released from the spinner or blowing caused by wind and/or moving vehicles (Du et al, 2019). The Utah Snow and Ice manual states that at traffic speeds of 60 km/h only 15% of a dry salt will remain on the road versus 80% for pre-wetted salt (Evans, 2008). The Wisconsin Transportation department suggests that pre-wetting salt results in a more conservative 30% reduction in losses versus dry salt (WTB, 2005). Similar results have been found in early studies by the Michigan Department of Transportation at speeds of 50 km/h (Nixon and DeVries, 2015). The accelerated melting and reduced wind loss benefits of pre-wetting can translate into significantly lower application rates (Table 4), with typical reductions of between 25 and 30% commonly reported (Burtwell 2004; Maine DOT 2003, MTO, 2018; O'Keefe and Shi, 2005).

Table 4: Reductions in salt use associated with the practice of pre-wetting

Study/Report	Location	Salt reduction benefits
Ministry of Transportation, 2018	Ontario	30%
Fu et al, 2006	Ontario	Pre-wetting with $CaCl_2$ improved LOS by an average of 14% over dry salt
Illinois, 1998	Illinois	30 to 50% improvement in performance
Kahl, 2004	Michigan	28-38%
MPCA, 2008	Minnesota	27-33% reduction based on recommend rates chart
O'Keefe and Shi, 2005	Washington State	26% improvement in material retention on road surface
Hossain et al, 2015d	Ontario, Parking Lot	Approximately 20% reduction for parking lots

3.3.2.1 Pre-wetting on Parking Lots

Pre-wetting is still not commonly undertaken by most contractors responsible for winter maintenance of parking lots. Only 25% of respondents in the Ontario 2012 survey of snow and ice management professionals indicated that they regularly or occasionally practiced pre-wetting (Fu et al, 2013). Instead, most use pretreated proprietary products (Fu et al, 2013) which have similar effective temperature and adhesion benefits, but do not require specialized salt application equipment or the added labour required to manually spray salt piles. Since treated salts have lower moisture content (1-3% vs 5% or greater for prewetted salts), they do not activate as quickly, or adhere to the surface as well as pre-wetted salts. Tests by the Ontario Ministry of Transportation suggests that pre-wetting can result in application rate reductions of 30% relative to conventional NaCl, versus only 15% for treated salt (MTO, 2018; Radael and Dizaji, 2017).

There is evidence to suggest, however, that the performance advantages of pre-wetting for roads may not translate well to parking lots, where wind loss from slow moving vehicles is likely much lower than roads. At the University of Waterloo, researchers compared the BPRT of dry salt to pre-wetted salt at the same application rates on plowed parking surfaces (Hossain et al., 2015d). Since the application rates were determined by mass, the pre-wetted salt had a 20% lower salt content on average compared to the dry salt. The test conditions implicitly limited potential losses from wind and therefore observed differences in effectiveness were primarily related to melting differences caused by moisture availability.

Results from over 77 observations showed that the average BPRT for the prewetted salt was slightly longer (3.2 hours) than for dry salt (3.0 hours), and that the difference in mean values was statistically significant. This surprising result was attributed in part to differences in the chloride content of tested salts, but the lower loss associated with drive-by traffic may also explain why the benefits were less evident in this test than on roads. The researchers nevertheless recommended that that 20% less salt (by volume) can be used if pre-wetting is practiced (Hossain et al., 2015d). This value is 5 to 10% lower than the salt reduction typically associated with pre-wetting on highways (see table 4 above).

3.3.3 Anti-icing

Anti-icing is the practice of applying a liquid or solid freeze point depressant material to the pavement prior to a snow event to prevent snow and ice from bonding to the pavement. This practice saves salt compared to conventional post storm de-icing because less material is required to prevent formation of an ice bond than to melt snow and ice after a bond has formed. Also, as discussed earlier, rock salt is prone to loss from bounce or blow off with vehicular traffic and wind, whereas the liquid adheres to the surface on which it has been applied, often leaving a residual even after the pavement has been cleared.

Anti-icing has become a common practice on highways and, to a lesser extent, municipal roads but is still relatively uncommon on parking lots, in part because additional investments in equipment and storage are needed to facilitate use of liquids. In the 2013 survey of private snow and ice maintenance contractors in Ontario, only 15% of respondents owned equipment needed to apply liquids (Fu et al., 2013), even though these practices have been shown to significantly reduce salt application rates. Anecdotal evidence from industry consultations conducted by the author suggest that contractor adoption of liquids for winter maintenance may have increased since that survey was conducted. On roads, a survey of US states showed that anti-icing was practiced by 78% of respondents, and that this practice was one of the 10 most common practices implemented by agencies (Fay et al., 2014).

Estimates of how much salt can be saved through anti-icing varies. Table 5 shows typical estimates for roads and parking lots/walkways, with a range of salt savings between 25 and 75%. Clear Roads research also suggests that anti-icing on roads can reduce crashes by up to 85% and reduce salt use by up to 75% when compared to conventional de-icing (Nixon and DeVries, 2015). The Salt Institute's Snowfighters Handbook (2007) states that anti-icing uses from one third to one quarter the amount of salt used in deicing, making it one of the most cost effective practices for improving winter traffic safety.

A Clear Roads study examined the use of solid chemicals for anti-icing in the United States and their effectiveness (CTC and Associates Ltd, 2018). The survey represented 33 states with 40 respondents. All of the respondents indicated that they used liquids for anti-icing but 36% of respondents said they also used pre-wetted solids and about 8% indicated they sometimes used dry solids for anti-icing. Effectiveness in terms of performance or cost were not the primary reason for using solids for anti-icing, suggesting that the practice was part of a tool box of options rather than a preferred method.

Table 5. Salt reduction through Anti-icing

Reference	Location	Salt reduction	Comments
Haake and Knouft, 2019	St Louis County, Missouri	45% reduction in salt conveyed to watercourses	Comparison of rock salt and liquid in different cities.
Maine DOT, 2003	Maine, highways	25-30%	Combination of anti-icing and de-icing
Nixon and DeVries, 2015	Synthesis of US jurisdictions	50 to 75%	50% reduction in solid salt use through liquids. 75% reduction to prevent ice bond with liquids rather than melting ice-bonded pavement with solids
Kahl, 2004	Michigan	28% reduction	Pilot test program including anti-icing and de-icing during most storm events (1999-2000 season)
Breen, 2001	Idaho, highways	83% reduction in abrasives	Anti-icing also reduced labour hours be 62% and crashes by 83%
Hossain, 2014c	University of Waterloo. Parking lot	39% reduction	Based on the quantity of NaCl brine and rock salt needed to achieve the same level of service.
Oswald et al, 2021	Ryerson University walkways	40% reduction	Liquids used after plowing to melt snow and ice on pedestrian throughways on a University campus.
Murison, 2021	Commercial Parking lots in Southern Ontario	46% reduction (preliminary data)	Compares anti-icing with NaCl brine to anti-icing with rock salt followed by rock salt treatments. See Appendix B for case study.

Some instances when solids may be preferred over liquids for anti-icing include during prolonged snowfall or freezing rain (Blackburn et al, 1994). When rain is expected to occur before a snowfall, prewet solids are seen as a better option than liquids. Prewet solids are also recommended when pavement temperatures are less than – 7°C. Anti-icing with hygroscopic chemicals such as $MgCl_2$ and $CaCl_2$ that attract moisture can create slippery conditions in the early season when humidity may be higher or at higher application rates. Liquids can also cause blowing snow to stick to the road and therefore should be avoided when these conditions can occur (Du et al., 2019; Washington State University, 2019).

Liquid application rates for anti-icing are typically much lower than for de-icing. The median NaCl de-icing rate for roads cited above was approximately 17 g/m^2. In an early review of anti-icing strategies in Europe and North America, Blackburn et al (1994) reported an application rate of 7.7g/m^2 (28 kg/lane km) during non-severe storms at pavement temperatures above -5°C. In Finland, a brine application rate for moist pavements of 5 to 15 g/m^2 is suggested for pavement temperatures between -0.5 and -7 C (Raukola and Terhela, 2001). In Minnesota, the recommended NaCl brine application rate is 1.0 to 1.6 L/100 m^2, which is equivalent to a solid application rate of 3.2 to 4.3 g/m^2 (MPCA, 2008).

3.3.3.1 Anti-icing on Parking Lots

There have been very few studies of anti-icing on parking lots. Blackburn et al., (2004) suggested that parking lots may provide a unique opportunity for anti-icing with solid chemicals after work hours when a storm is predicted overnight because there would be no cars to displace the material from the surface. Parking lots also often meet the traffic conditions under which solid material anti-icing could be effective, which includes vehicle speeds less than 45 km/h and less than 100 vehicles per hour (Blackburn et al., 2004).

It should be noted however that while pre-wetted solids may be used as an alternative to liquids for anti-icing under some conditions, the former requires a higher application rate. Study results on parking lots showed that brine could be applied at a rate of 3.2 L/m^2 (equivalent to a solids application rate of about 8.6 g/m^2) whereas the recommended application rate for solids was 24 g/m^2 to achieve the same level of service (Hossain and Fu, 2015). In examining the residual of brine and solids on roads in Denmark, Fonnesbech (2001) found that 90% of brine remains on the road, while only 60 to 65% of the pre-wetted solid did the same.

A detailed parking lot field study of anti-icers in Waterloo, Ontario was conducted during the 2012/13 winter, covering 50 discrete events (Hossain, 2015; Hosseini et al., 2017). The study compared different treatments and products. Key findings included the following:

(i) Post plowing pavement friction coefficients for pre-event applications of NaCl rock salt and NaCl brine were significantly greater than a 'do nothing' control for all but two low temperature (<-10 C) events, which were larger and longer in duration than others;

(ii) Comparison of a 23% NaCl brine to two alternative anti-icing liquids (Caliber 1000 - 27% $MgCl_2$ and 7% Carbohydrate- and Snow Melter 2 comprised of Glycerin, Polyether Polymer and other non-chloride based materials) showed no statistically significant difference among products, which confirms that low chloride alternatives can be equally as effective as chloride based products; and

(iii) Application of NaCl rock salt at 24 g/m^2 and NaCl brine at a liquid rate equivalent to 14.6 g/m^2 before a snow event showed similar performance, indicating a salt reduction of 39%. Increasing the application rate of the brine from a rock salt equivalent of 14.6 g/m^2 to 43.8 g/m^2 did not improve friction performance.

These results indicate a strong salt reduction benefit to anti-icing on parking lots. A similar 40% reduction in salt application was also reported by researchers at Ryerson University in a pilot of liquids used to melt snow and ice on portions of the Toronto downtown campus (Oswald, 2021). In that study, liquids were also found to be very effective when applied to stairs, ramps and other surfaces outside of the main pedestrian routes between the buildings.

The recommended liquid anti-icing rate in the University of Waterloo study based on field trials was 8.6 g/m^2 (3.2 L/100 m^2) (Hossain and Fu, 2015). This rate is similar to rates cited by Blackburn et al., (1994) and Raukola and Terhela (2001), but roughly double that of the MPCA recommended rate (MPCA, 2008). Overall, the data suggests that, on average, liquid application rates are more similar on roads and parking lots than is the case for de-icers, where earlier analysis in section 3.2 above showed that parking lot application rates of conventional solid de-icers were approximately 3 times higher than for roads.

There were no studies specifically documenting the benefits or application rates of liquids used to maintain walkways and sidewalks. Oswald (2021) found that operations staff that used a hose and spray gun to apply liquids on walkways, stairs and ramps at a university campus found this method of ice melting to be preferable to rock salt both in terms of time saving and salt use reductions. Since walkways are commonly subject to much higher application rates than roads (e.g. LSRCA, 2020), there is merit to further exploring this approach as an alternative to use of rock salt on pedestrian walkways.

Some barriers to the use of brines by contractors were reported by Sparacino et al. (2018). These challenges included the additional costs associated with application and storage equipment and the extra time required to manage different materials. Testing may be required to ensure that purchased brine is mixed at the recommended salt to water ratio and that the concentration is not altered through evaporation. There have also been reports of brines being especially corrosive to vehicles and freezing in spreading equipment (Sparacino et al., 2018).

3.3.4 Equipment and Calibration

There have been significant advances in winter maintenance equipment in recent years. Many of these innovations are aimed at improving winter maintenance operations by facilitating snow removal and increasing the accuracy and efficiency of material delivery to the roadway. These advances include decision support systems (RWIS, weather tracking), improved sensors, ground speed controllers, spreading and plowing equipment and hydraulic equipment (Du et al, 2019).

3.3.4.1 Controllers

Accurate delivery of salt to the roadway in the right amount and at the right time requires the use of automated material delivery systems that adjust the amount of material applied according to the speed of the vehicle. There are two general types of controllers: open loop controllers that monitor the truck speed, and closed loop controllers that monitor both the truck speed and the spreader discharge rates (CTC and Associates, 2008). Both require that the operator only set an application rate, avoiding the need for manual adjustments based on speed. Some controllers and salt spreader systems also allow for automatic adjustment of application rates based on pavement temperature (Minge et al., 2020).

These technologies are of particular relevance to parking lots because winter maintenance vehicles are required to frequently change speeds as they navigate around the parking lot. The 2013 survey of contractors indicated that only 28% of contractors regularly or occasionally used automated controllers (Fu et al, 2013).

Research on roads showed that closed loop ground speed controllers can reduce salt by up to 47% when compared to manual spreaders. Further, closed loop systems were able to deliver material to the roadway at a much more accurate rate than open loop systems because the former adjusts spread rates based on more information from the vehicles spreading system, thereby reducing the possibility for systemic errors in delivery rates (Blackburn et al, 2008). These results are expected to be replicable on parking lots given the challenges of effectively operating driver controlled spreaders on parking lots where speeds frequently vary.

Some problems encountered with electronic controllers include inadequate minimum hydraulic system capacity, too many wires and connectors, and corrosion of wiring connections (Conger 2005). Vendor support to equipment users is critical in the initial start-up phase to work through potential technical problems.

3.3.4.2 Salt Spreaders

Application of solid and liquid freeze point depressant materials requires close interaction of the storage unit (box, bed, hopper, and/or liquid tanks) spinners or nozzles and application rate controls. The term spreader refers to the storage unit and spinner or both (Conger, 2005) There are a wide range of different spreader types which can work well but it is critical to ensure that the system is regularly inspected and calibrated (see calibration section below). In general, broadcast spreaders should be used on parking lots to allow rapid coverage. All spreaders should either have automatic or manual controls to change the amount of material being applied based on vehicle speed and conditions (Environment Canada, 2004).

Liquid sprayers should use pencil or streamer nozzles of holes in the bar that spray in lines (rather than spray nozzles). Spacing of nozzles should be between 20 and 38 cm to ensure even application and loss of material from misting or wind.

Walkways, stairs and other vehicles are often maintained using shovels and manual spreaders or liquid sprayers. The method and equipment used to salt is spread on these very visible areas is particularly important because they are often subject to much higher application rates than other parts of the parking lot. Some factors driving higher salt rates on walkways included higher potential for slip and falls, high level of service demands, and the rudimentary methods used to apply salt in these areas. Drop spreaders rather than broadcast spreaders are recommended for walkways to improve the accuracy of material delivery and avoid salt damage to landscaped areas (Environment Canada, 2004; TAC, 2013a).

Education of building operations personnel is critical to addressing what may be unreasonable expectations of salt coverage. Improved equipment that helps ensure an even and accurate spread of material on the surface is also important. Manual shakers and speed-controlled spreaders, for instance, would be preferred over hand spreading. Anti-icing with liquids has also been shown to be an effective means of ice control in these areas that can significantly reduce salt use (Oswald, 2021).

3.3.4.3 Snow Plowing

Effective plowing of snow and ice can reduce the need for de-icers, particularly if the plows remove snow and ice before it has bonded to the pavement. At very cold temperatures, when conventional de-icers are less effective, and there are no signs of ice bonding to the pavement, plowing may be the most suitable pavement treatment option with limited need of de-icers (Atkin et al., 2013; Blackburn et al, 2004). Case studies have shown that plowing best practices can reduce costs, operation hours, fuel usage and the amount of salt used (Environment Canada, 2000).

On paved surfaces, the trigger snow depth for plowing has an important impact on the amount of salt used because when salt is applied on top of snow, it is diluted during the snow melting process, requiring a significant increase in the amount of salt applied in order to meet level of service targets. The UW salt application research on parking lots showed that on average, over 6 times more salt was needed to meet a two hour bare pavement regain time target when snow depths were between 0.1 and 0.5 cm vs snow depths of 1.5 to 2.5 cm (Hossain and Fu, 2015) (Figure 4). The SIMA best practices guide (2015) and Environment Canada guide (2004) specifically recommends against using salt to 'burn off' snow (sometimes referred to as chemical plowing).

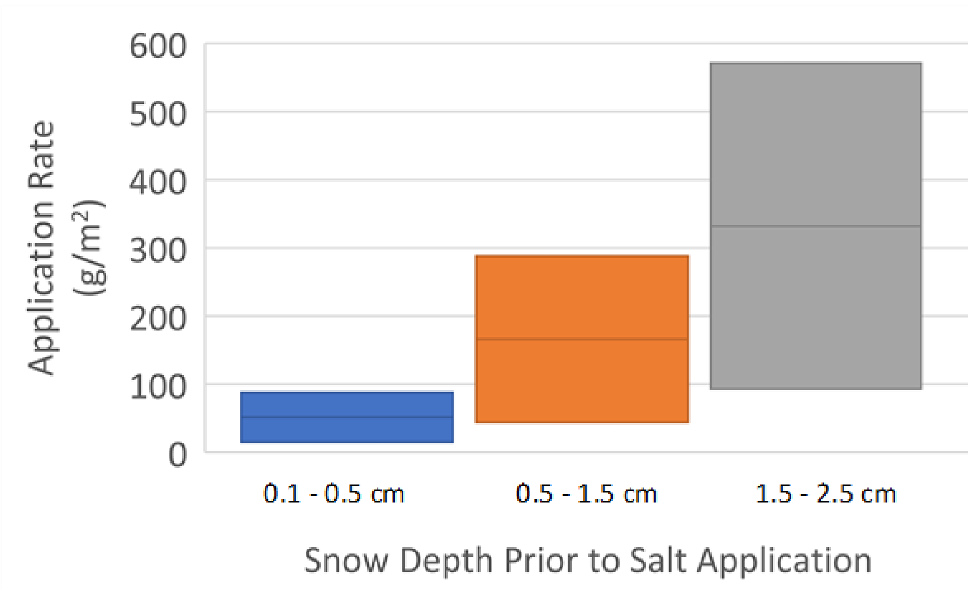

Figure 4: Influence of snow depth on NaCl dry salt application rates for a 2 hour BPRT level of service. The range of values for each snow depth represents temperatures from 0 to -7 C. Adapted from Hossain and Fu, 2015.

Various types of plow blades are available. Straight edge steel plows are commonly used on parking lots to ensure access to all areas. Live edge plow blades, also referred to as articulated blades or segmented blades, can be more efficient than conventional straight blades at removing snow and reducing salt application rates by better conforming to the contours of the pavement surface. In 2019, segmented plow blades were tested in 4 Minnesota neighbourhoods to evaluate effectiveness in removing snow and reducing salt use. They were found to be effective in removing snow and had the added benefit of being quieter than traditional blades, prompting the agency to replace more of their plow blades with the segmented product (Fay and Clouser, 2020).

Experimentation with a flexible edge blade with one foot sections and a squeegee blade in Iowa found that the blade was quieter and conformed to the surface producing a more even wear on the pavement surface. The squeegee blade is typically made of plastic or rubber and is often used in combination with a steel segmented or non-segmented blade. The squeegee provides additional snow removal and is effective at removing slush from pavement surfaces, which can further reduce salt application rates. Some squeegee blades behind standard steel blades are attached to hydraulics that allow the blade to be lowered only when needed (Fay and Clouser, 2020). The durability and longevity of alternative plow blades relative to conventional ones was not mentioned, likely due to the relatively recent introduction of these blades into truck fleets.

Brooms and sweepers have traditionally been used at airports but are now being used more and more on trails, sidewalks and roadways. They are effective at snow depths between 2.5 and 15 cm, with the maximum depth depending on snow density and moisture content. Staff in Montana report that 7 foot brooms have been more effective than plows in removing snow, resulting in faster bare pavement regain times and less or no use of salt following sweeping operations. They also suggest that they help increase pavement longevity by reducing the number of freeze thaw events (Fay and Clouser, 2020)

3.3.4.4 Tracking Equipment

In the past 10 years there has been a gradual shift towards increased use of Global Positioning System (GPS) and Advanced Vehicle Location (AVL) technologies that track the location of equipment and provide operational data from the vehicle controllers. These systems can be configured to provide real time information on application rates, pavement temperatures, locations, plow positions and road surface conditions. The information can be used to improve material application efficiencies, adjust plow routes based on surface conditions, increase operator accountability, recommend treatment options and reduce costs (Du et al., 2019).

Material and operational tracking is particularly useful on parking lots as the data and records help provide evidence needed to respond effectively to accident claims (Kennaley, 2004). While court cases can be expensive, successful defense of lawsuits can prevent escalation of insurance premiums and deter others from bringing cases against companies with a proven track record in the court system, especially if prior lawsuits have been successfully won. Tracking and record keeping also helps with budgeting, resource requests and efforts directed towards improving operational efficiencies.

Advances in the integration of automated material spreading systems with AVL tracking, onboard sensors, and friction measurements have also shown promise (Erdogan et al., 2010). These systems adjust spread rates based on real time data on pavement friction from vehicle on-board sensors. By improving salt spreading efficiencies, these technologies have been estimated to reduce salt use by approximately 10% (Shi and Fu, 2018).

While AVL tracking has been widely implemented on roads, it remains less common on parking lots. In the 2013 Ontario contractor survey, up to 37% of respondents either did not answer the question about application rates or said they did not track rates (Fu et al., 2013). Most of the remaining 63% of respondents indicated that they tracked material use by counting the number of truck loads needed to de-ice a certain number of parking lots. This provides an average application rate for a large area but does not provide the measurements needed to identify rates used on individual parking lots. Therefore, this bulk measurement may be of limited use as a proof of due diligence in slip and fall suits.

A robust tracking method on parking lots is to set material dispensing equipment equipped with controllers to automatically record the material applied in real time with GPS location tracking. Cameras in parking lots can further corroborate tracking data by showing snow removal and salting practices, particularly for walkways and stairs where rates may not be digitally tracked.

Measuring the application rates and procedures allows for post hoc assessments of effectiveness, which ensures that deficiencies are identified and rectified quickly. These assessments can also show whether operators are applying consistently across the designated service areas and identify opportunities for individual operator improvements. Although recognizing the difficulty of quantifying the benefits of salt application measurement practices, Nixon and DeVries (2015) indicate that previous management studies show that learning from past experiences and managing based on these lessons can reduce material use by 10 to 30%.

3.3.4.5 Equipment Calibration

Calibration of equipment is critical to ensuring that the spreaders and controllers are functioning as designed and delivering salt to roadways evenly and at the target rate and spread width (Nixon and DeVries, 2015; Fay et al, 2015). In general, equipment should undergo detailed calibration once a year prior to the winter season and spot checked throughout the winter. Calibration should also be repeated when salt stockpiles are replenished, after a significant repair or maintenance event, and when material calculations do not line up with expectations. Separate calibrations should be conducted for each type of material – sand, liquid, rock salt, etc (Du et al, 2019; CTC and Associates, 2018). Equipment may also be set up with mechanical restrictions that prevent applications greater than a maximum approved rate (Fay et al., 2013). Equipment may also be set up with mechanical restrictions that prevent applications greater than a maximum approved rate (Fay et al., 2013).

On roads, the spread width is fixed, but on parking lots, the area to which material is being applied may be of variable widths, and therefore the equipment needs to be adjustable and calibrated to account for different truck speeds and spread widths. Normally cab charts and comprehensive training are needed to ensure the operator is selecting the right setting for the desired application rate and material being applied (e.g. treated vs regular rock salt).

The TRCA developed a detailed calibration procedure for de-icers that describes the process and includes spreadsheets and a cab chart to aid in the process. These resources are available at *www.sustainabletechnologies.ca* under the SAVE (Salt Application Verified Equipment) program. The Salt Institute's, Snow Fighters Handbook, also provides details on the calibration process (Salt Institute, 2007).

The specific benefits of calibration in reducing salt are highly variable. However, evidence from practitioners suggests that malfunctioning spreaders are common, and calibration can generate salt savings of up to 50% (Nixon and DeVries, 2015). A survey of road agencies by Grit and Horn (2010) indicated a more modest 8 – 14% savings from equipment calibration (as cited in Du et al, 2019).

3.3.5 Decision Making Tools

Access to good information on weather and site conditions is critical to good decision making. The three site conditions critical in informing materials, methods and timing of applications are pavement temperature, the amount of snow/ice remaining on the surface after plowing and the presence/absence of an ice pavement bond (Blackburn et al., 2004).

3.3.5.1 Road Weather Information Systems (RWIS)

A road weather information system (RWIS) is a combination of advanced technologies which collect, process, and disseminate road weather and pavement condition information. This information is used by winter maintenance staff to make decisions that improve safety and mobility during snow and ice events. Road weather information systems are widely used by municipalities and road authorities throughout the United States and Canada (Conger, 2005; Fay et al., 2015), but are less commonly used by private contractors. RWIS provide information on snow type and amount, relative humidity, temperature, wind speed and direction, and forecasting. Detailed, local weather information can significantly improve operational efficiencies by better aligning maintenance services, schedules and selected practices with weather conditions and forecasts, while avoiding unnecessary travel and repeat applications (see case study #5 in Appendix B).

3.3.5.2 Site Condition Measurements

RWIS stations are often supplemented with Environmental Sensing Stations (ESS) consisting of embedded sensors that monitor the pavement surface and subsurface temperature, pavement moisture conditions and, in some cases, residual salt on the roadways (ODOT, 2011). These measurements help to refine the selection of materials and methods to match observed conditions and avoid over application of salt.

Pavement temperatures can be measured using embedded sensors or mobile truck mounted sensors (Minge et al., 2019). Truck mounted temperature sensors supply information to operators in real time allowing them to find efficiencies by adjusting methods and application rates to meet observed conditions. Infrared sensors may be used to measure pavement temperature during patrols and at the time of plowing. Trends in pavement temperature and dew point measurements will determine whether frost conditions may exist (Environment Canada, 2004).

The 2013 survey of contractors in Ontario found that only 37% were using mobile temperature sensors (Fu et al, 2013). Most contractors patrolled sites to determine site conditions. It was not clear to what extent residual salt measurements were also used to set application rates. On-line video camera viewing was regarded as being helpful but there was concern about the cost. Case study #5 summarized in Appendix A show how careful site assessments of parking lot conditions can significantly reduce the quantity of salt applied while reducing overall operational costs.

3.3.5.3 Maintenance Decision Support Systems (MDSS)

A maintenance decision support system enhances an RWIS and ESS by building in event and post-event analysis and recommendations for making decisions based on real time and post storm information supplied to the system (Fay et al., 2015). Data inputs may include RWIS, on-vehicle sensors, stationary in-pavement sensors, crowdsourced traffic data, weather data and other sources (Minge et al., 2020). The analysis component evaluates materials used, assesses application rates and timing of applications, and makes recommendations on products and treatment practices (Fay et al., 2015). These systems are sometimes used by municipalities and more commonly by road authorities (Minge et al, 2020). Private contractors typically rely on patrolling and less automated methods to make winter maintenance decisions.

3.3.6 Salt Storage and Handling

Proper storage and handling of salt and snow is a key component of a good winter maintenance plan. Effective storage ensures that salt is not lost to the environment by wind and rain, thereby preventing negative impacts on groundwater, surface water, soil and plants. The practices are well documented in the Transportation Association of Canada's best practice guide for that practice (TAC, 2013) and some good tips for parking lot contractors are provided in the associated parking lot and walkway guide (TAC, 2013a), as well as the CNLA/LO guidance document (Marsh Canada, 2018).

The primary best practices include (i) ensuring good coverage of salt piles with permanent structures; (ii) collection systems and procedures on site that prevent discharge of spilled materials into the environment, and (iii) special considerations for liquid storage such as protection from UV exposure and damage from vehicles, and secondary containment tanks around the storage tank (Environment Canada, 2004). Material loading, mixing areas and storage areas should all be protected with appropriate containment systems underlain with impervious pads (TAC, 2013a; Faye et al., 2015). Spreaders should only be cleaned in areas where the washwater is properly managed (TAC, 2013a; Environment Canada, 2004). Temporary storage of salt on parking lot surfaces, which has been observed in rare cases, is unacceptable and should never be practiced.

3.3.7 Training Programs

Professional Training of staff is critical as the success of snow and ice management strategies relies heavily on judgements and decisions made by knowledgeable and experienced staff. Training should be delivered by experienced and well-respected experts with written manuals and other supports provided as reference materials. As much as possible, training programs should incorporate participatory, hands on methods to provide more direct experience with the subject material. Separate tailored training should be delivered to operations managers, forepersons, and operators/drivers (Fay et al., 2015). Details on training program recommendations for drivers and operators, as well as safety training for all employees are provided in the CNLA/LO guidelines (Marsh Canada, 2018).

Since parking lots, walkways and private drives require a number of special considerations that differ from roads and expressways, it is important to ensure that training is specific to this land use type. Training is rarely sufficient in and of itself to ensure the use of best practices; it is also critical to include an auditing or verification component to training that ensures certified professionals are effectively utilizing the practices on which they are trained. In Ontario, the primary contractor snow and ice training program is offered by the Smart about Salt Council (www.smartaboutsalt.com). A verification component of this program would involve random on-site audits of certified companies along with requirements to maintain and submit documentation of procedures for equipment calibration, record keeping and other practices.

Knowledge and skill development is a key benefit of training, but many contractors also see training as a marketing tool. Many private and public winter maintenance contracts for parking lots in Ontario include training as a requirement of tenders, which helps incentivize training. In New Hampshire, contractors that have been trained through a certified training program are offered limited liability protection by the state as long as best practices have been followed and operational records are maintained. This program has been considered especially effective because it addresses legal liability issues that have been identified repeatedly by property owners and contractors as a key driver of excess salting (Barber, 2021).

3.3.8 Salt Reduction Practices for Property Owners and Site Developers

3.3.8.1 Developing a Winter Maintenance Policy

A first step for owners and managers of ICI sector properties interested in responsible management of salt is the establishment of a winter maintenance policy. The policy outlines the strategy to be undertaken, specifies how it will be communicated to relevant parties and staff, outlines documentation requirements and a schedule for regular updates. The policy may also be used in the event of accidents or lawsuits to demonstrate how the organization has endeavored to provide a reasonable level of care (MPCA and Fortin consulting, 2020). To help with the development of a winter maintenance strategy, the Smart about Salt Council offers training and certification to property managers and owners on the process of developing a plan or policy and the various steps required to prepare properties for winter operations.

3.3.8.2 Property Assessments, Winter Maintenance Plans and On-site Equipment

The winter maintenance policy should also include a detailed plan that describes how the property should be evaluated to identify various factors that may influence winter maintenance operations, as well as those that could be improved to reduce the expense and effort associated with winter maintenance activities. The plan should include areas to be plowed, a map of catch basins and downspouts, snow storage areas in relation to grades and drainage infrastructure, proximity of snow and materials storage to sensitive receivers, evidence of damage from salt or snow plows, vehicle impact hazards and other considerations (MPCA and Fortin Consulting, 2020; TAC, 2013; Marsh Canada, 2018). Problem areas such as downspouts directed to walkways or grading that directs precipitation onto pavements or causes puddling should be corrected prior to the winter season (TAC, 2013). The plan and associated site map should be updated annually based on observations from experiences in previous years.

To facilitate winter operations, salt boxes, and spreading devices (e.g. shakers, walk behind spreaders) for walkways should be provided, along with tools such as mobile or in-pavement temperature and salt residue sensors to support salting and plowing decisions. If liquids are preferred for winter maintenance, similar storage containers and spray equipment should be made available for walkways unless the contractor(s) prefer using their own equipment. One benefit of on-site equipment is its availability to building management staff for periodic or spot treatments when the contractor is not available, which can prevent requests for contactors to return to the site to apply more salt.

In addition to on site-equipment, property maintenance staff should also implement processes to track site conditions and winter maintenance operations using on-site cameras and/or other tracking tools or logs. This information can help resolve potential conflicts between property management and contractors, contribute to learning through trial and error, ensure the winter maintenance plan is being followed and provide due diligence evidence in the event of slip and fall lawsuits.

3.3.8.3 Sustainable Procurement of Snow and Ice Services

Contracts for snow and ice management on parking lots are typically oriented towards ensuring that plowing and salting promotes safe conditions throughout the winter, and that interruptions to regular business operations are kept to a minimum. These are important goals, but it is also critical to ensure that contracts are oriented towards minimizing the harmful effects of salt on freshwater ecosystems, drinking water, soils, vegetation and wildlife. Applying more salt than is necessary not only harms the environment but also shortens the life of pavements and accelerates corrosion of building and transportation infrastructure. Winter salting is necessary, but using too much salt carries a heavy price tag, both for our environment and built infrastructure.

Property owners, businesses and contractors have control over how much salt is applied through their snow and ice management contracts, and the diligence with which they manage and oversee these contracts. There are several clauses and conditions that can be included in contracts to promote the responsible use of winter salts, such as requirements for certified professionals and ensuring payment is based on a fixed price per season or event, rather than on the amount of salt that is used (TAC, 2013).

Examples of the types of best practices that may be considered when preparing contracts are provided in a report prepared by TRCA (2019), along with estimates of the impact on salt use, and the potential influence these may have on contract costs. The document also provides details and sample clauses that may be used in snow and ice management contracts to provide direction on what is expected from contractors.

In addition to requiring the use of certain practices like liquids or less harmful materials, contracts should also clearly indicate the areas to be maintained, salt use tracking requirements, salt use targets, response times and level of service expectations, and avoid inclusion of over-reaching ‘hold harmless’ clauses that place undue legal burdens on contractors (TAC, 2013a). The snow and ice risk management guidelines produced by the Canadian Nurseries and Landscape Association and Landscape Ontario provide a number of useful suggestions on how contracts can be written to manage client relations, confirm responsibilities and outline record keeping and site assessment requirements (Marsh Canada, 2018).

3.3.8.4 Minimizing the Area Requiring Winter Maintenance

Often parking lots are designed to accommodate a high volume of cars for occasional large events, leaving portions of the parking lot underused. When peak use occurs only during the summer, there may be opportunities for building managers and owners to close off part of the parking lot to traffic, thereby reducing the cost and effort of salting and plowing these areas. There may also be opportunities to close off certain stairways and entrances in the winter to facilitate maintenance activities. Closing certain areas during heavy winter storms to reduce risk and salt use has also been suggested (Environment Canada, 2004). The Region of Waterloo piloted a ‘closed parking lot program in 2019 and 2020 by providing signage to interested property owners (see case study in Appendix B). The program was well received by participating organizations and reported savings in winter maintenance and salt costs were in-line with the size of area that was closed during the winter.

An alternative to closing portions of parking lots and walkways for the whole winter would be to close them for only a portion of the winter when use is limited, or to designate a different level of service for certain areas, such as overflow parking lots. For instance, these less used areas may require longer bare pavement regain times, or they could be permitted to have compacted snow only with a traction material applied, rather than salt.

3.3.8.5 Heated Pavements

Different technologies are available to heat pavements in order to prevent ice buildup and promote anti-icing. These involve heating with hydronic systems, such as geothermal, electrical resistance heating and/or using conductive carbon or other materials to improve heat transfer in pavements. It is also possible to heat the pavement from above with infrared or microwave sources (Xu et al., 2021). A number of full scale studies have been conducted on these technologies with some success, although in all cases the installation and operating costs were high and some technologies showed reduced longevity relative to traditional concrete or asphalt pavements (Xu et al., 2021).

It is unlikely that pavement heating technologies would be applied broadly in parking lots, however there may be scenarios where it makes sense on a smaller scale for walkways, which do not undergo the same stresses as drive lanes and stalls. For example, a senior's residence in the Greater Toronto Area used excess heat from a geothermal heating and cooling system to eliminate the need for salting and reduce snow plowing activities. The owners also cited savings from reduced corrosion and damage to building infrastructure from salt. In cooling dominant buildings such as this one, surplus heat must be used to balance the heat extracted from and rejected into the ground, allowing the system to operate without the extra cost of generating heat (Meanwell, et al., 2015).

3.3.8.6 Pavement Overlays and Asphalt Additives

High Friction anti-icing polymer overlays for pavements have been promoted as a technique to reduce icy or slippery conditions on surfaces. In one product, an epoxy is applied to the paved surface on which an aggregate is broadcast. The aggregate acts like a sponge that slowly releases liquid deicers effectively offering residual anti-icing benefits between applications. Experimental trials against a standard NaCl deicer and granite aggregate showed reduced snow and ice accumulation, lower application rates to achieve the same level of service and better snow removal when plowed. Although, these same results were less impressive in the second year of testing and trials at temperatures below – 9°C showed poor performance relative to a control (Xu et al., 2021). High friction pavements were also found in trials to lose their friction and angularity over short time periods due to normal wear and plow activities, thereby limiting their service life. Research on new materials and mixes is currently underway to address durability and effectiveness concerns (Xu et al., 2021).

Another promising approach is to mix anti-icing additives into the asphalt binders. This process has been shown to delay ice formation, accelerate the melting process and reduce adhesion between the ice and pavement at temperatures above – 7°C. Anti-icing additives have been used since the 1970s in Europe, Japan and North America. Improvements in the technology over time have improved the balance between asphalt durability and de-icing effectiveness (Xu et al., 2021).

Although overlays and asphalt additives show promise, they cost much more than conventional asphalt. On parking lots, the high traffic walkways and areas near the entrance of the building that commonly receive very high applications of salt may be good candidates for applying these technologies.

3.3.8.7 Improved Parking Lot Design

Traditional parking lots are often not designed with winter maintenance in mind. A variety of design features can be incorporated to facility winter maintenance and reduce the amount of salt that needs to be applied to maintain the desired level of service. These may be done as part of the design for new parking lots, or as part of the re-design process for older ones (MPCA and Fortin Consulting, 2020).

Typical design features for reducing salt use include (i) better grading to ensure melt water does not drain far to a stormwater collection point; (ii) avoiding shallow grades that may eventually form isolated depressions were water can pond on the surface; (iii) directing downspouts away from paved surfaces; (iv) locating snow storage areas close to collection points; (v) minimize unused walkways; (vi) cover, heat or add overlays to sidewalks to reduce the need for salt; (vi) incorporate wind breaks with evergreen trees to prevent snow accumulation on paved surfaces; and (vii) utilize low impact development systems such as swales and bioretention to provide effective drainage. For details see the report commissioned by LSRCA on the topic (LSRCA, 2017). Additional tips are available in the Smart Salting for Property Management Manual (MPCA and Fortin Consulting, 2020).

3.4 Summary

The review of literature found a number best practice guidance documents for winter maintenance of parking lots and walkways in Canada and the United States. Most of these are directed at snow and ice management professionals, but a minority also provide guidance on actions appropriate for property owners and managers. The guides for winter maintenance professionals are generally consistent in promoting better materials, application methods, record keeping, equipment calibration, salt storage and handling, staff training, and the use of a variety of decision support tools to reduce apply only as much salt is needed to promote safe walkways and parking lots.

An important finding from the research on salt application rates was that even very small differences in parking lot factors such as traffic conditions, level of service requirements (e.g. BPRT times), residual snow prior to salting and pavement temperature can have dramatic effects on the amount of salt needed to ensure surfaces are safe. This finding highlights the critical role that operator knowledge and diligence plays in decisions about how much salt is 'enough' in any given circumstance. Without regular and sustained training, quality control programs and field experience, it is all too easy for snow and ice professionals to default to applying salt indiscriminately as a strategy for liability avoidance. This over application of salt is likely occurring most often at temperatures at or just below freezing when research indicates that very little salt is needed to create ice free surfaces.

The research on salt management best practices indicated that many of the same practices used on roads are also applicable to parking lots, although not necessarily with the same level of effectiveness. Many of these practices can reduce the amount of salt applied by 20 to 50%, or even more. Some of the key advances include the use of liquids, improved decision support systems, efficiency gains through ground speed controllers and the importance of calibration and record keeping. Like any change in behaviour, adopting new approaches as standard practice will take time and effort, and a keen appreciation of the potential rewards both from a business and social/environmental responsibility perspectives.

As the client, property owners and managers play a very important role in setting the stage for the increased use of best practices. Improving their knowledge of winter maintenance practices, investing in site improvements to optimize salt use and improve safety outcomes, and working closely with contractors to implement best practices helps send the signal to service providers that more salt is not necessarily better. Developing a winter maintenance policy and carefully stipulating the use of best practices and trained professionals in their procurement contracts are important first steps towards reducing salt use. There are also a number of opportunities in new development or redevelopment scenarios for owners to select materials and design parking lots and walkways to better facilitate winter maintenance activities, which includes limiting the need for salt.

4.0 CONCLUSION

This review summarized the literature on snow and ice management practices on parking lots and walkways as a first step towards prioritizing and selecting practices that will contribute to improvements in environmental outcomes without compromising pedestrian or driver safety.

Findings from surveys of winter maintenance personnel responsible for parking lots and walkways portrayed an industry strongly influenced by slip and fall litigation risk with limited uptake of advanced salt management technologies. Businesses and institutional property owners/managers indicated a low level of awareness of salt management impacts on the environment and building infrastructure. However, most were open to learning more and considering practices that would better protect the environment. Contractors identified the lack of standards and regulations as a key driver of excess salt use.

There were some snow and ice management best practice guides targeted specifically at parking lots and walkways. In Canada, the key guides were prepared by the Transportation Association of Canada in 2013 (based on an earlier Environment Canada guide) and the Canadian Landscape and Nurseries and Landscape Ontario associations, with the latter guide focused primarily on best practices for the mitigation of risk (Marsh Canada, 2018). In the United States, the association representing private contractors (SIMA) prepared a short guide on sustainable salt use in 2015. A more detailed guide for parking lots and walkways was prepared by the Minnesota Pollution Control Agency in 2015 and has undergone two updates. The same agency also prepared salt management best practices for property management in 2020.

Typical application rates of sodium chloride on parking lots were derived from the University of Waterloo field research, the SIMA best practice guides, the New Hampshire Training Program recommendations and a SIMA initiative that determined rates from GPS enabled tracking equipment installed in 200 vehicles across 25 companies in 10 states and 2 provinces (Sexton, 2017). The University of Waterloo field trials showed a wide range of application rates for pavement temperatures between 0 and -9°C. These rates were between 15 and 88 g/m^2 based on a 2 hour bare pavement regain time (BPRT) and between 5 and 29 g/m^2 for a 6 hour BPRT. The rates are likely conservative given that most of the testing was done when vehicles were not present. Research trials by the same researchers showed that even low levels of traffic required rates less than half those of no traffic areas, particularly when pavements are cold.

The three other sources for application rates fell within a range of 22 to 66 g/m^2 for unspecified BPRT targets. The median rate for the four sources was 55 g/m^2, which was over 3 times higher than average rates reported by municipal agencies and highway road authorities (17 g/m^2). As an aspirational target, it may be reasonable to apply salt at rates between 15 to 39 m^2 (TAC, 2013a), combined with careful monitoring of performance and adaptive management at lower temperatures (below -7 C) when NaCl becomes less effective and where there is less agreement on the ‘right’ rates.

The wide range of reported rates was expected as research and monitoring have shown that there are several factors that influence decisions about how much salt to apply. These include pavement temperature, level of service (as measured by bare pavement regain time), snow depth and type, traffic density, pavement materials and salt type (treated, pre-wetted, effective temperature range, etc). The sensitivity of application rates to the materials used, site conditions and weather highlights the importance of knowledge and training as a pre-requisite to the selection of appropriate maintenance approaches for optimizing performance and salt use.

Best Practices

A diverse number of materials and practices have been developed to improve winter maintenance outcomes and reduce impacts to the environment and built infrastructure. Performance of these practices were reviewed based on academic research and pilot programs delivered through public sector winter maintenance departments. Research specific to parking lots and walkways was highlighted whenever possible.

Table 1 presents a summary of findings for the more common practices and their relevance to parking lots. While many of these have been implemented and tested on roads, similar pilot testing programs and research on parking lots are less common. Therefore, most of the empirical data specific to parking lots was sourced from the suite of studies undertaken by the research team at the University of Waterloo between 2013 and 2015.

Review findings showed that many of the same practices that help optimize salt use on roads apply to parking lots as well. However, the degree of effectiveness will vary according to the baseline against which performance is being compared. Since parking lot contractors have not adopted best practices to the same extent as road winter maintenance professionals, shifts to greater use of these practices would result in more significant reductions in salt use within their service areas.

Land developers, property owners and property managers also play a critical role in helping to facilitate good winter maintenance practices. Land developers can ensure parking lots and walkways are well designed for winter maintenance. Several of the important design innovations are highlighted in the aforementioned parking lot design guide (LSRCA, 2017). Interventions related to drainage, heated walkways or pavement overlays to improve friction are more cost effective to implement during the initial development of sites than as a retrofit.

Likewise, property owners and managers can improve salt management through their procurement of winter maintenance services and their intimate knowledge of their sites. Tailoring salt management practices to site conditions, designating areas for snow piles, preparing site specific salt management plans and including best practice requirements in procurement documents is critical to optimize salt use without compromising safety.

Table 6: Selected salt management practices and expected benefits

Practice	Description	Expected salt reduction benefit[1]	Considerations for application on parking lots & walkways
Alternative Materials	Various low chloride ice melting products are available	>30% for alternative liquids. Less than 5% for rock salt treated with chloride free products.	High price of alternatives relative to conventional salts has been a barrier to uptake. Nutrient and potassium content of some organic products may pose environmental concerns in some contexts.
Pre-treated salt	Salt pre-treated with a chemical such as $MgCl_2$ to improve effectiveness at low temperatures and prevent bounce and blow off.	10 – 15%	Expected 10-15% salt reduction benefits rely on operators applying at lower rates when using pre-treated salt, which is not always done.
Pre-wetted salt	Similar benefits to pre-treated salt but higher moisture content promotes better performance	20%	As with pre-treated salt, application rates must be reduced to realize benefits. Loss reductions from wind may be less on parking lots where vehicles are moving slowly
Direct liquid application (DLA)	Involves applying brine before, during or after snow events to prevent ice formation on pavement and walkways. Anti-icing is the application of a brine or treated rock salt before snow events.	39-46% for use of brines as anti-icers. If liquids are used before and after winter events, the benefits may be higher than indicated.	Requires additional equipment for liquids application. Anti-icing with treated rock salt will result in a lower salt reduction benefit than indicated but is well suited to low traffic parking lot conditions and walkways. DLA benefits on walkways expected to be significant given frequent reports of excess salt application on walkways.
Ground speed controllers	Salt spreaders are equipped with controllers that automatically dispense salt based on truck speed.	49%[2]	Particularly relevant for parking lots where salt trucks are frequently required to vary speeds and stop/start.
Equipment calibration	Salt spreading equipment is calibrated to ensure it is functioning and applying salt at the calibrated rates.	Reductions vary based on equipment condition. Benefits widely regarded as significant.	Requires calibration method tailored for parking lots as these surfaces do not have a fixed lane width. Private contractors rarely calibrate equipment.
Plowing before salting	Avoids the use of salt to melt snow. Snow dilutes salt and significantly reduces effectiveness.	Research indicates that applying salt on 2 cm of snow instead of plowing requires >6 times more salt to meet the same LOS.	Property owners or managers should set snow plowing requirements to avoid excess salt use. It is often cheaper for contractors to use salt to melt snow than to plow at low snow depths.
Segmented or 'live edge' plow blades	These blades better conform to the pavement surface and remove more snow than traditional blades.	Test results show them to be effective in removing more snow than conventional blades, which the previous point indicates would reduce salt use.	Especially relevant for parking lots that may have more variable surface elevations than roads and often require higher surface levels (*i.e.* shorter bare surface regain times).
Decision support tools	May include use of RWIS, pavement temperature and residual salt monitoring, on-site cameras and decision support software/systems.	Varies based on equipment and range of decisions informed by use of the tools.	Low use of decision support tools among parking lot contractors highlights potential benefits. Patrolling sites before and during storms to collect information is often used instead of automated decision support tools.
Staff training	Regular training of winter maintenance staff each year, preferably through a certification program.	Training is a pre-requisite to reductions associated with many BMP types. Magnitude of reduction will vary based on staff knowledge and expertise before training.	Especially relevant to contractors for parking lots and walkways due to the complexity of decision making required for the diverse site conditions encountered. Certification designations should require an auditing process to ensure knowledge imparted through training is operationalized.
Site Condition Assessment and Plan	Identifies the various factors that influence winter maintenance operations; provides a plan for site preparation and winter operations. Plan includes areas to be plowed, site drainage patterns, snow storage areas, problem areas, sensitive receivers, etc.	Reductions will vary based on site layout, age, space constraints, existing drainage and other factors.	Helps to provide clarity on requirements, procedures and site conditions that can significantly improve operational efficiencies and avoid contractor – client disputes.

(1) Values shown are from studies on parking lots except as indicated. Study results from research on roads are also summarized in the review. (2) Tested on a road. Results are for closed loop ground speed controller performance relative to a manual spreader.

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APPENDIX A: PARKING LOT APPLICATION RATES (FU AND HOSSAIN, 2015)

Table A-1: Application Rates for Stall Areas lbs/1000 sqft (g/m²)

Stall		Application Rate for Desired LOS in BPRT (hr)					
Snow depth cm (in.)	Avg Tp °C (°F)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	6 (29)	3 (15)	2 (10)	1 (5)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	17 (83)	9 (44)	6 (29)	4 (20)	3 (15)	3 (15)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	35 (171)	18 (88)	12 (59)	9 (44)	7 (34)	6 (29)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	19 (93)	9 (44)	6 (29)	5 (24)	4 (20)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	58 (283)	29 (142)	19 (93)	14 (68)	12 (59)	10 (49)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	117 (571)	59 (288)	39 (190)	29 (142)	23 (112)	20 (98)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	38 (186)	19 (93)	13 (64)	9 (44)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	115 (562)	58 (283)	38 (186)	29 (142)	23 (112)	19 (93)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	235 (1147)	117 (571)	78 (381)	59 (288)	47 (230)	39 (190)

Table A-2: Application Rate for Driveways (Low Traffic-Parking Lot) lbs/1000 sqft (g/m²)

Driveway (Low)		Application Rate for Desired LOS in BPRT (hr)					
Snow depth cm (in.)	Avg Tp °C (°F)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	3 (15)	1 (5)	1 (5)	1 (5)	1 (5)	0 (0)

0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	8 (39)	4 (20)	3 (15)	2 (10)	2 (10)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	16 (78)	8 (39)	5 (24)	4 (20)	3 (15)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	8 (39)	4 (20)	3 (15)	2 (10)	2 (10)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	26 (127)	13 (64)	9 (44)	6 (29)	5 (24)	4 (20)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	52 (254)	26 (127)	17 (83)	13 (64)	10 (49)	9 (44)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	17 (83)	8 (39)	6 (29)	4 (20)	3 (15)	3 (15)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	51 (249)	26 (127)	17 (83)	13 (64)	10 (49)	9 (44)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	104 (508)	52 (254)	35 (171)	26 (127)	21 (103)	17 (83)

Table A-3: Application Rate for Driveways (Medium Traffic-Parking Lot) lbs/1000 sqft (g/m²)

Driveway (Medium)		Application Rate for Desired LOS in BPRT (hr)					
Snow depth cm (in.)	Avg Tp °C (°F)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	2 (10)	1 (5)	1 (5)	1 (5)	0 (0)	0 (0)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	7 (34)	3 (15)	2 (10)	2 (10)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	13 (64)	7 (34)	4 (20)	3 (15)	3 (15)	2 (10)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	7 (34)	4 (20)	2 (10)	2 (10)	1 (5)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	22 (107)	11 (54)	7 (34)	5 (24)	4 (20)	4 (20)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	45 (220)	22 (107)	15 (73)	11 (54)	9 (44)	7 (34)

1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	14 (68)	7 (34)	5 (24)	4 (20)	3 (15)	2 (10)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	44 (215)	22 (107)	15 (73)	11 (54)	9 (44)	7 (34)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	89 (235)	45 (220)	30 (147)	22 (107)	18 (88)	15 (73)

Table A-4: Application Rate for Driveways (High Traffic-Parking Lot) lbs/1000 sqft (g/m²)

Driveway (High)		Application Rate for Desired LOS in BPRT (hr)					
Snow depth cm (in.)	Avg Tp °C (°F)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	2 (10)	1 (5)	1 (5)	0 (0)	0 (0)	0 (0)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	6 (29)	3 (15)	2 (10)	1 (5)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	12 (59)	6 (29)	4 (20)	3 (15)	2 (10)	2 (10)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	6 (29)	3 (15)	2 (10)	2 (10)	1 (5)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	19 (93)	10 (49)	6 (29)	5 (24)	4 (20)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	39 (190)	19 (93)	13 (64)	10 (49)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	12 (59)	6 (29)	4 (20)	3 (15)	2 (10)	2 (10)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	38 (186)	19 (93)	13 (64)	10 (49)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	78 (381)	39 (191)	26 (127)	19 (93)	16 (78)	13 (64)

APPENDIX B: ONTARIO CASE STUDIES

This section provides a synopsis of results from various salt management case studies in Ontario, some of which are on-going.

Case Study #1: Using Direct Liquid Application to Reduce Winter Salt Use on Ryerson Campus.

Collaborators: Campus Facilities: Dan Batko; Academic Leads: Claire Oswald and Kevin Duffin (Urban Water Research Centre and the campus Sustainability Office).

References: Oswald, 2021. Road salt reduction on Ryerson University campus. Information Sheet. Presentation by C. Oswald at the Ottawa Riverkeeper salt management forum in April 2021.

Project Goal: To evaluate the feasibility and environmental benefits (specifically, the reduction of chloride (Cl) entering the environment) of using direct liquid application (i.e., NaCl brine) on Ryerson campus for both anti-icing and de-icing.

Key Finding: Switching from rock salt to brine for winter maintenance of the University campus walkways resulted in chloride reductions of between 38 and 40% and estimated annual material cost savings of almost $5000 if liquids were used for winter maintenance across the entire campus.

Methods

Four areas of the campus totaling 8200 m^2 were identified for the pilot. These included pedestrian-only roadways, walkways, sidewalks, accessibility ramps and staircases. A NaCl brine was used in these areas as an anti-icer prior to events and a de-icer after plowing. Ten events with less than 3 cm snow accumulation and no rain forecasted were selected for testing. Five of the events were maintained with rock salt, and five were maintained with brine with additional rock salt required.

The mass of chloride applied set of 5 events were compared to determine the effect of the two winter maintenance approaches on chloride inputs to the environment. Operational advantages and disadvantages were also tracked, along with any negative user feedback. Snow fall, precipitation, duration of snow and temperature were also recorded.

The brine was made with a Rittenhouse brine-making system, which included a 1700 L brine maker and a 375 L electric powered de-icing applicator with spray bar option installed on the back of a Bobcat Toolcat 5600. The brine was a 23.3% NaCl blend of rock salt and tap water.

Findings

Based on detailed monitoring of 10 events, it was estimated that between 2589-2899 kg of Cl was diverted from Ryerson campus through the use of brine. This corresponds to a 37.5 to 40% Cl reduction (compared to 'business-as-usual' rock salt use), and material cost savings of $1100-1237 (based on a rock salt price of $5.18/20 kg bag). There was no change in the number of slip and fall reports during the project compared to previous years. An extrapolation of these results to the entire campus (31,771 m^2) would result in approximately 11,120 kg of Cl being diverted from the environment and approximately $4,746 of material savings. The positive results, combined with reduced staff time for winter maintenance, prompted facilities staff to start using brine across the entire campus when appropriate.

Extrapolation of these results to Green P parking facilities in Toronto showed even greater savings. It was estimated that Green P facilities cover 815,118 m^2. Assuming similar salt savings, it was estimated that 285,293 kg Cl would be diverted through DLA practices, saving approximately $121,767 per year. Staff at Green P also noted that salt caused measurable damage to vegetation in the parking lots, which could also be mitigated to some extent through salt application reductions prompted through DLA.

Case Study #2: Using Liquids to Reduce Winter salt Use on Commercial Parking Lots

<u>Collaborators</u>: Academic Leads: Lorna Murison, Claire Oswald. Contractor: Daniel Schissler team, ILI landscaping. Facilities Co-ordinator: Eleanor Gillion, Peel Region.

<u>References</u>: Lorna Murison – personal communication. Study is on-going

<u>Project Goal</u>: To evaluate the feasibility and environmental benefits (specifically, the reduction of chloride (Cl) entering the environment) of using liquid anti-icing with NaCl brine (with and without beet juice additive) on commercial parking lots.

<u>Key Finding</u>: Anti-icing with an NaCl brine resulted in a 46% reduction in salt use on commercial parking lots compared to a control with occasional anti-icing with granular rock salt and rock salt applied post plowing. Use of 30/70 Beet juice brine further reduced chloride inputs to the environment by 33% relative to standard NaCl brine.

<u>Methods</u>

The pilot study was comprised of a control and two treatments, applied to groups of 3 different parking lots over 3 winter seasons. The control used occasional anti-icing with granular rock salt and rock salt applied post plowing for all monitored events. The two treated areas included: (i) NaCl brine applications prior to the event followed by application of rock salt as needed after plowing, and (ii) NaCl brine with beet juice additive (30% beet juice, 70% NaCl brine) applied prior to the event, followed by rock salt as needed after plowing. In all cases, the rock salt was pre-treated with the same beet juice brine product used in anti-icing.

The contractor recorded the amount of salt applied during each visit to each parking lot using calibrated equipment on-board the salting and brining trucks. Brine amounts are reported in litres and rock salt amounts are reported in tonnes. Material application amounts were converted their respective chloride content in grams.

<u>Preliminary Findings</u>

Preliminary data from the winters of 2019/2020 and 2020/2021 indicate that on average, events using liquid anti-icing (either with or without beet juice additive) required a chloride application rate of 10.4

g/m^2, whereas rock salt alone required a rate of 19.4 g/m^2.[1] Liquid anti-icing, therefore, results in a 46 % reduction in chloride input to the environment compared to using rock salt alone.

The average chloride application rate for events using NaCl with beet juice additive was 8.5 g/m^2 compared to an average rate of 12.7 g/m^2 using NaCl without the beet juice additive. A beet juice additive, therefore, results in a 33 % reduction in chloride compared to NaCl brine alone. The savings resulting from the use of the beet brine reflect the fact that the beet brine itself contains 30 % less chloride than the NaCl brine alone. Liquid anti-icing with beet brine at the same rate as NaCl brine would result in 30 % less chloride being used.

It should be noted that there may be environmental impacts associated with the use of beet juice and other organic de-icer additives, depending on the level of dilution and oxygenation in receiving waters. Nutrients such as phosphorus, nitrogen and potassium have been raised as potential concerns (see case study #6). Therefore, it cannot be assumed that replacing 30% of the chloride with beet juice will be the most "environmentally friendly" option in all cases. However, using liquid anti-icing regardless of the product should be encouraged.

<u>Study Limitations</u>

Each season, a group of 3 parking lots were assigned to each treatment type. In some instances, however, the contractor was not able to use the assigned treatment (e.g. beet brine may have been used rather than NaCl brine because of its lower working temperature). In most cases this is due to weather conditions. The influence of weather (temperature in particular) will need to be considered in the final analysis.

Currently, the chloride content of rock salt is assumed to be 60 % of the total mass. This does not account for the fact that the rock salt is treated with beet brine. These estimates will need to be updated in the final analysis and may slightly reduce the estimates of chloride savings.

Finally, it is possible that contractors will apply at different rates depending on their independent assessments of requirements and directions provided by property owners/managers. Therefore, the documented rates for the different winter maintenance approaches may vary from those found in this study.

Case Study #3: Closing Areas to Reduce Salt Use and Winter Maintenance Costs

<u>Collaborators</u>: Region of Waterloo staff; various facilities

<u>Reference</u>: Dan Meagher – personal communication. Presentation to STEP salt working group

<u>Project Goal</u>: To explore the feasibility and interest in reducing salt use and maintenance costs by closing portions of ICI sector properties that receive little use during the winter.

[1] Note that these application rates are for chloride alone. Since NaCl rock salts are roughly comprised of 60% chloride and 40% sodium, the application rate for rock salt treated parking lots would be 32.3 g/m^2. This rate is well below the median rate for contractors of 55 g/m^2 determined from the literature and supported by contractor salt use tracking programs (see section 3.2 above and case study #5).

Key Finding: Outreach and support programs that encourage property owners and managers to close under-used areas of their properties during the winter can be a very successful means to reduce salt use, while providing significant savings on winter maintenance costs.

Project Design

There are large areas of properties that are underused during the winter and that could be closed to save money by reducing salt use and winter maintenance operations. An outreach program was developed to achieve buy-in from property managers. Prior to implementing the program, the Region consulted with legal experts to determine how the signs should be designed and where they should be placed to address liability concerns. Sign templates were developed through this process and procedures were developed to guide property managers interested in implementation of a closed area. The program was marketed to businesses and municipal property managers as a means of saving winter maintenance costs and improving site sustainability goals.

Project Outcomes

Twenty four property managers implemented in the program in 2018/19 and another 8 orders for signs and services were received in 2020. Areas closed included a part of parking lots, alternate entry ways to buildings and underused walkways. The program was very well received among property managers/owners who participated. Facilities staff appreciated the reduction in effort needed to maintain their properties during the winter. Signs were re-used after the initial year by almost all participants without prompting from Region staff, indicating that once closed area programs have been initiated, they stand a high chance of becoming self-sustaining.

After the initial marketing push, the Region decided to step aside and let other interested property managers implement their own programs based on experiences shared by the early adopters, and template signage. This decision was made to save time and resources. Up to 30% of a municipal staff member's time was spent co-ordinating the requests, and the signs and base cost about $150 each. While it was recognized that active marketing and assistance would likely have attracted more participants, the number of participants continued expand slowly even without these efforts. Some slowdown in participation was expected regardless because the less motivated second tier is harder to reach.

The savings in winter maintenance costs and salt use were not tracked, but these would have been directly proportional to the size of areas closed on the properties relative to the total area. It was estimated based on reports and areas closed that savings would have been around 10 to 20% both for salt and winter maintenance costs.

Case Study #4: Pavement Friction Testing to Assess Required Application Rates Associated with Different Practices

Collaborators: LSRCA, MECP

Reference: Technical Bulletin, Vol 3, September 2020. Friction and Parking Lots. LSRCA

Study Goal: To investigate how friction varies at different salt application rates and for different winter maintenance practices

Key Finding: Overapplication of salt during the winter can reduce surface friction and may not achieve intended safety benefits.

Methods

A friction tester was acquired in 2017. Friction was tested and compared on pavements under varying conditions. These conditions included concrete surfaces with various salt application rates from none to light to heavy and light snow cover vs no snow cover.

Findings

The results of the friction testing are presented in Table A1. The unit of measurement was designated as μ, with values ranging from 0 to 1.0. The safer a surface, the higher the μ value, although it was noted that friction is not the only measure of safety, as polished stone floors are not prone to slippage when dry, but have a μ value of between 0.3 – 0.4.

Table A1: Friction values (μ) under different conditions

Surface type	**μ value**
Clear and dry concrete	0.9
Concrete with a light salt application	0.63
Concrete surface with light covering of snow (with residual salt)	0.11
Plowed concrete surface with heavy salt application	0.26
Plowed interlocking concrete pavement with no salt	0.20 – 0.24
Plowed interlocking concrete pavement with heavy salt application	0.20 – 0.24

The tests showed that a light and loose covering of snow had the lowest friction values (0.11), while pavements with heavy salt applications had considerably lower friction values (0.26) than those with light applications (0.63). Also heavy salt applications on interlocking concrete pavers were found to have similar friction levels (0.2 to 0.24) to the same surface that was plowed but not salted. These data indicate that over-application of salt does not translate into improved pavement friction, and should be avoided to improve safety, reduce negative environmental consequences and reduce the costs of winter maintenance.

Case Study #5. Comparison of Winter Maintenance Approaches on a Commercial Parking Lot

Collaborators: LSRCA, MECP

<u>Reference</u>: Final case study, Comparison of two approaches for winter maintenance of a large commercial property, LSRCA.

<u>Project Goal</u>: To demonstrate the different approaches taken by two contractors over the course of the study, and document associated effects on site safety and the amount of salt applied.

Key Finding: Simple and low cost approaches to winter maintenance can result in significant reductions in salt use and contractor savings.

<u>Methods</u>:

The study compares practices implemented by two contractors on the same parking lot in Newmarket, Ontario. The first contractor (Contractor A) provided winter maintenance services for the property over the 2012/13 to 2017/2018 period, and the second contractor ("Contractor B) maintained the property for the period from the 2018/2019 to 2020/21 seasons. Continuous monitoring of weather conditions and chloride loads exiting the site have been monitored by LSRCA since the 2014/2015 season to determine application rates. A conductivity meter was used to measure salinity levels and a rating curve developed from empirical measurements of chloride and conductivity was used to convert conductivity to chloride. The high correlation between conductivity and chloride help reduce errors associated with not measuring chloride directly. This site was ideally suited for the study because all flows exited through a single pipe, which was used as the measurement point.

<u>Findings</u>

Contractor A, who worked on the site from 2012 to 2018 took a more traditional approach to snow and ice management by applying salt frequently at the same, relatively heavy rate. This is a common approach among contractors because of the real or perceived demands of clients (i.e. property managers) and the desire to avoid legal liability that can significantly increase contractor insurance premiums. Contractor B was certified through Smart about Salt and used this training to apply only what was necessary for safety given the weather and pavement conditions at the site.

Based on monitored data, the LSRCA calculated the amount of salt used by event, the average application rate per season and the frequency of salt applications per season. A summary of results for the two periods are provided in Table A2.

Table A2: Amount, rate and frequency of salt applied by Contractors A (4 seasons) and B (3 seasons)

Metric	**Contractor A**			**Contractor B**		
	Average	**Min**	**Max**	**Average**	**Min**	**Max**
Salt applied per event (tonnes)	12	9	17	9	8	11
Application rate (g/m^2)	81	65	117	65	53	75
Number of applications (#)	66	60	99	43	36	52

The results indicate that Contractor B applied less salt on average, applied at lower rates per event, and applied salt less frequently. The lower application rate and frequency of applications may be attributed to differences in approach. Contractor A indicated that they used the same salt application rate regardless of pavement conditions or weather, while Contractor B tailored rates according to the amount of snow, duration of snowfall, type of snow and other factors to help optimize performance both from a salt use and performance perspective. Contractor B also ensured he had local weather and condition data from the site to help reduce unnecessary applications associated with improper information. The largest difference between contractors was in the number of applications.

Weather conditions and salt availability were identified as possible factors influencing the application rates and frequency. Further investigation of these factors showed a particularly a mild winter in 2015/16 and a salt shortage in 2017/18 indicated, both of which decreased the volume of salt used by Contractor A relative to more normal conditions. Had these factors not been present, the difference in salt use by the two contractors would likely have been more pronounced.

Despite the different winter maintenance approaches, neither contractor received customer or client complaints about their services, and there were no claims. The parking lot was just as safe even with lower salt use and fewer applications. In addition to achieving performance targets, Contractor B saved fuel by sending plows and salters out less often, encountered less wear and tear on vehicles, and saved on labour costs through less time spent at the site. It was calculated that Contractor B also saved approximately $40,000 per year on material costs compared to Contractor A.

Case Study #6: Evaluation of the Effectiveness of Organic and Semi-organic Liquids for Anti-icing of Parking Lots

Collaborators: University of Waterloo Researchers, TRCA/STEP

Reference: STEP, 2015. Evaluation of Organic Anti-icing Materials for Winter Maintenance, Technical Brief. Hosseini, F., Hossain, S. M. K., & Fu, L. (2017). Bio-based materials for improving winter pavement friction. *Canadian Journal of Civil Engineering*, *44*, 99–105. https://doi.org/10.1139/cjce-2016-0460

Study Goal: To evaluate and compare the capacity of three organic and semi-organic anti-icing liquids and sodium chloride brine to improve pavement friction relative to an untreated control. The study also presents independent analysis of the chemical composition of the tested products and assesses the influence of external factors on product performance.

Key Finding: Organic anti-icing products were found to be as effective as traditional NaCl brine, despite having much lower chloride concentrations. A brine rate as low as 3.2L/100m^2 was found to provide similar friction performance to the same brine products applied at higher application rates.

Methods:

Anti-icing products were selected based on the percentage of organics in the product, performance of the product at low temperatures, product availability, and price. The following products were selected for field tests: Fusion 2350, Snowmelt, and Caliber M1000. Performance of products was compared to that of a standard sodium chloride (NaCl) brine and a control without any product applied (Table A3).

Snowmelt was the only product formulated from 100% organics. Its semi-organic form (30:70 Snowmelt to NaCl brine) referred to as Diluted Snowmelt was also tested.

Table A3: Products selected for field tests

Trade name	**Composition***	**Effective temperature**	**Cost ($/L)****
Brine	23% NaCl, 77% water	-7°C	0.15
Fusion 2350	12% NaCl, 50% degraded beet juice, 38% P/U*	-27°C	0.3
Snowmelt	15-20% Glycerine, 10-20% Polyether polymer, 3-8% Lactic acid, 2-4% Sorbitol, 1-3% Acetic acid, 1-2% 1,2 – Butanediol (balanced with water)	-20 to - 40°C	0.29
Caliber M1000	27%$MgCl_2$, 6% Carbohydrate, 67% water and P/U***	-29°C	0.4

*Compositions listed are as reported by supplier or in literature/material information sheet

**Unit prices are general quotes from supplier

***P/U: Proprietary/ Unknown

Separate plots were used for anti-icing and control (no product applied) treatments. All products were applied in liquid form with a sprayer prior to snowfall based on weather forecasts. Once the products were applied and snowfall had ended, the snow was removed from both control and anti-icing sites with either a plow truck or a shovel (depending on snowfall depth) and the friction of the sites was evaluated using a T2GO friction tester. This instrument calculates the Coefficient of Friction (CoF), a physical measure of the resistance between the road surface and vehicle tires or shoes. Anti-icing solutions should have weakened the bond between the snow pack and the pavement making snow removal more effective and improving friction over the control sites.

Field tests were conducted in a manner that simulated real world parking lot maintenance procedures. Tests were generally started at or before 7 AM and three different standard application rates of 3, 6, and 9 L/1000L ft^2 (3.2, 6.4 and 9.7 L/100m^2) were tested for each product. The most common application rate used by parking lot contractors is 4L/ 1000 ft^2 (4.3 L/100m^2). In addition to application rates, the following variables were measured at fixed time intervals after application: precipitation depth, air temperature, pavement temperature, snow type and snow depth. A multiple linear regression was conducted to determine which of these variables significantly affect the CoF.

<u>Findings</u>

The 2013-2014 winter season had 20 light snow events (less than 2 cm), 10 medium events (2 to 5 cm) and 5 heavy events (more than 5 cm). Anti-icing tests were conducted on 15 of these events. The pavement surface temperatures ranged between -15 to 1°C and average event based air temperatures ranged between -22 and -2°C.

Sites where anti-icers were applied at a rate of 3L/1000 ft^2 (3.2L/100m^2) had up to 40% higher CoFs than the control sites. Differences between the control and anti-icing sites were significantly different ($p < 0.05$). There were rare instances when anti-icing treatments had lower CoFs than the control, which was attributed to a specific range of conditions causing melt, dilution and refreeze of the melted water.

Differences between standard NaCl brine and the organic or semi-organic products was not statistically significant despite lower levels of chloride in the organic products. Further, there was no statistically significant improvement in friction performance at higher application rates of 6 and 9 L/1000 ft^2 (6.4 and 9.7 L/100m^2), suggesting that the 3L/1000 ft^2 (3.2L/100m^2) rate is appropriate for parking lots. Diluting the snowmelt (30/70 snowmelt:NaCl) product also did not improve performance over the undiluted version, despite the latter having no chloride.

The Toronto and Region Conservation Authority also submitted samples of products used in field testing to a certified laboratory for chemical analysis to quantify differences in product chemistry, particularly for nutrients such as potassium, phosphorus and nitrogen. These nutrients are often identified as having adverse effects on aquatic life in receiving waters or water bodies that are not well oxygenated or have naturally high levels of such nutrients. Pottasium in particular was recently identified as having important eco-toxicological effects on aquatic life (Gillis et al., 2021).

Since chemical constituents in snow melting products would be diluted to varying degrees in runoff, depending on the specific context, the study also showed what the chemical concentrations would have been when diluted by snow melt, either from the surface directly or in plowed piles. The hypothetical runoff concentration was determined based on drainage with 5 cm of snow, recognizing that if the runoff drains to ditches or melts with snow piles, the dilution levels may be very different. It is worth noting that in most cases, further dilution would occur in the receiving water itself.

Results showed that the products with NaCl or $MgCl_2$ brine contained the highest chloride levels while organic products contained the highest levels of nutrients, including phosphorus and potassium. Even with 5 mm snow dilution, concentrations in runoff from products were found to exceed receiving water guidelines for phosphorus or chloride, depending on the product composition. It should be noted, however, that nutrients are not as mobile in soil and groundwater as chloride as the former are more readily adsorbed by soil particles and taken up by plants. Therefore the year-round persistence of chloride in streams due to high concentrations in groundwater discharge may not be as pronounced with nutrients and other organic byproducts.

Table A4: Concentration of selected water quality variables in product samples. Average concentrations in stormwater runoff are simulated based on a winter melt event with 5 cm of snow accumulation and no plowing.

Water Quality Variable	**Units**	**Sample Concentration**					**Hypothetical Runoff Concentration***					**Receiving Water Guidelines**
		NaCl Brine	Snow Melt	Diluted Snow Melt	Fusion 2350	Caliber M1000	NaCl Brine	Snow Melt	Diluted Snow Melt	Fusion 2350	Caliber M1000	
Chloride	mg/L	145500	950	72800	74000	153600	285.9	1.9	143.0	145.4	301.8	120
Sodium	mg/L	78000	67200	75000	57200	1352	153.2	132.0	147.3	112.4	2.7	--
Magnesium	mg/L	35.4	2	22.6	53.6	64200	0.07	0.00	0.04	0.11	126.1	--
Copper	ug/L	0.02	0.02	0.02	2.08	0.02	0.00	0.00	0.00	0.00	0.00	5
Iron	ug/L	1.48	38.4	12.16	14.08	1.04	0.00	0.08	0.02	0.03	0.00	300
Lead	ug/L	0.1	0.1	0.1	0.1	0.1	0.00	0.00	0.00	0.00	0.00	5
Chromium	ug/L	0.04	0.48	0.16	0.04	0.04	0.00	0.00	0.00	0.00	0.00	--
Zinc	ug/L	0.04	4	1.24	1.6	0.04	0.00	0.01	0.00	0.00	0.00	20
Total Organic Carbon	mg/L	18	158000	44800	47600	16920	0.04	310.4	88.0	93.5	33.2	--
Potasium	mg/L	215	4740	1510	8190	821	0.42	9.3	3.0	16.1	1.6	--
Total Nitrogen	mg/L	11.56	748	196.4	3400	19.32	0.02	1.47	0.39	6.68	0.04	--
Nitrate+Nitrate-N	mg/L	3.27	741	251.7	134.7	1.86	0.01	1.46	0.49	0.26	0.00	2.9
Phosphate	mg/L	0.075	52.4	16	1.98	0.292	0.00	0.10	0.03	0.00	0.00	--
Total Phosphorus	mg/L	2.22	112.2	34.2	54	0.231	0.00	0.22	0.07	0.11	0.00	0.03

* Runoff concentration is calculated based on an application rate of 3 L/1000 square feet, assuming dilution from 5 cm of snowmelt over the area of application. Five centimeters of snow was converted to water at a ratio of 10:1, resulting in a liquid equivalent of 5 mm.