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Review of Reduced Salt, Snow, and Ice Management Practices for Commercial Businesses

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Abstract

Chlorides (frequently sodium chloride) are used to improve safety and access to roads and other surfaces in winter. However, chlorides also pose risks to aquatic life and raises human health concerns as they move to surface waterbodies and infiltrate groundwater. In response, many government bodies have adopted winter maintenance best management practices (BMPs) that reduce the amount of chlorides used while providing service and safety. Commercial businesses maintaining parking lots, driveways, and other surfaces have been shown to contribute as much as 50% of the chloride loads to local waterbodies in some areas, but less is known about the potential benefits of private contractors to implement similar BMPs. In addition, many existing resources on the topic are designed for municipal audiences, creating a knowledge gap about the feasibility of private companies to adopt these practices. The authors identified 14 BMPs common to municipal plans with the potential to be adopted by private contractors through a literature review. These practices aim to increase the efficiency of salt applications, and/or decrease environmental impacts while delivering a similar level of service and cost over time. The authors considered potential barriers and benefits to private contractors adopting and using these BMPs. Benefits included reduced liability (e.g., risk of lawsuits), costs, environmental impacts, and improved service. Barriers included additional staff time and training, increased materials, equipment, and maintenance costs. Additional research is needed to ground-truth these predicted motivations and barriers; a greater understanding of private contractor behaviors can enhance educational efforts that promote reduced salt practices.

Keywords

infrastructure, infrastructure management and system preservation, maintenance management systems, maintenance level of service (LOS), human factors, human factors of infrastructure design and operations, general, planning and analysis, environmental analysis and ecology, planning/environmental linkages, sustainability and resilience, transportation and sustainability, resource conservation and recovery, transportation systems resilience, natural hazards and extreme weather events, extreme weather events, methods and practices, road salt, rock salt, sodium chloride, best management practices, runoff, surface water, environmental impacts, impervious surfaces, winter maintenance, urban development, low-salt practice, reduced-salt practice

Chloride-based products, including sodium, calcium, and magnesium chlorides, have been used to reduce ice formation on paved surfaces in the United States since the 1930s (Figure 1) (*1, 2*). Paved road surfaces in the United States increased by an estimated 37% between 1970 and 2003 (*3*), while estimated annual road salt use increased 43% between 1975 and 2003 (*4, 5*). Road salt application in the United States, including governmental and commercial sources, has exceeded 20 million metric tons in recent years (*4–6*).

As the 21st century progresses, combined impacts from climate change and urbanization are predicted to

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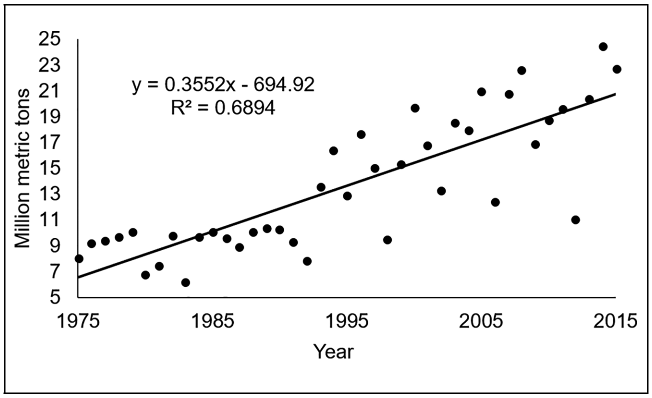

Figure 1. Road salt use in the United States between 1975 and 2015.
Source: United States Geologic Survey, 2005, 2017, 2018 (*4–6*).

result in decreased snow packs (*7*), increased amounts and variability of winter precipitation (*8*), and increased impervious surfaces (*9*). The use of deicing materials is expected to increase in the future as each winter storm typically requires multiple site visits for clearing and materials application (*10, 11*). Accordingly, chloride concentrations are predicted to continue to increase in waterbodies across the United States (*9, 12*).

Chlorides used in winter maintenance have multiple negative impacts and contribute to steady increases in chloride concentrations in lakes across the Midwest and Northeast United States (*9, 13, 14*). Small lakes, waterbodies near major roads and highways, and waterbodies in watersheds with a greater percentage of impervious surfaces can be most affected (*14*). Numerous studies demonstrate observed or potential impacts from increased chlorides used for winter maintenance to drinking water sources (*12, 13, 15, 16*), natural lake processes (*17*), aquatic communities (*9, 13, 16, 17*), and soil and vegetation (*18, 19*).

Winter maintenance best management practices (BMPs) are used to save costs, reduce negative environmental and infrastructure impacts from deicers, and meet water quality regulations all while delivering efficient and consistent service that maintains safety and accessibility for end users (*2, 20, 21*). In the United States, the Clean Water Act requires states and recognized tribal governments to monitor waters as well as to identify and maintain quality standards (*22*). As such, municipalities (especially with populations of 10,000 or more) are incentivized to reduce road salt use, and manuals for BMP usage and adoption typically focus on municipal audiences. Municipal, state, and provincial governments began adopting BMPs largely in the 1990s (*2, 20, 21*). However, commercial businesses and private contractors that maintain many surfaces in the winter including parking lots, driveways, sidewalks, and roadways are generally not subject to these regulations and have fewer resources tailored to them. Recommendations for BMPs may differ between commercial businesses and municipalities given the differences between these groups of professionals. Differences may include the types and sizes of surfaces treated, equipment used, number of staff, required financial investment, incentives to use or reduce salt use, and liability risk (*11, 20, 23*). This has led to lower documentation of private contractors' current practices compared with their municipal counterparts, and knowledge gaps around the rate of BMP adoption for these entities as well as incentives or barriers for BMP adoption.

Nonetheless, salt runoff from surfaces that commercial winter maintenance businesses maintain can be substantial. Runoff from private parking lots and roads has been demonstrated to contribute 40% to 50% of the chloride load to the environment in some watersheds (*24–26*). With an estimated 110,000 commercial winter maintenance contractors employed in the United States (*27*), research is needed to identify BMPs that these private contractors can implement with the most environmental, economic, and social benefits. To address this, the goals of this study are to review established BMPs and analyze their potential relevance, accessibility, benefits, and barriers for private contractor implementation.

Methods

The authors carried out a literature review of both peer-reviewed and gray literature to identify winter maintenance BMPs typically designed to reduce municipal, provincial, or state government use of chlorides during winter maintenance (hereafter called "low-salt practices," "recommended practices," or "BMPs"). The University of Vermont's (UVM) online library database (http://library.uvm.edu/), Web of Science (http://webofknowledge.com), and Google Scholar (https://scholar.google.com/) were used to identify peer-reviewed literature. Google and UVM's online library databases were used to search for gray literature. The review identifies governmental studies, municipal management plans, trade organization reports, outreach initiatives, and educational materials on BMPs. References cited in identified literature were assessed to identify a broader suite of BMPs. The literature search was initially carried out between January and December 2017. The search was repeated in December 2019 and February 2021, and then reviewed in August 2021 to ensure that a comprehensive suite of best practices was revealed.

Terms used in online searches focused primarily on identifying those low-salt practices that reduced the impacts of winter maintenance practices on water resources (Table 1). Practices that had the potential to

Table 1. Search Terms Used in Varying Combinations for the Literature Review to Identify Low-Salt Best Management Practices (BMPs)

Peer-reviewed literature search terms		Gray literature search terms
Additives	Rock salt	Best management practice(s)
Aquatic	Runoff	BMPs
Best management practice(s)	Snow removal	Driveway
BMPs	Sodium chloride	Low-salt practice
Deicing	Surface water	Management plan
Impervious surfaces	Urban development	Municipal(ity)
Low salt	Urban runoff	Parking lot
Low-Salt	Urban winter impacts	Private contractor
Maintenance	Water quality	Private road(way)
Private contractors	Winter transportation	Reduced salt practice
Reduced salt use		Road salt
Road Impacts		Sidewalk
Road maintenance		Snow removal company
Road salt		Winter maintenance plan

minimize salt contamination of surface or groundwater but that would not reduce the amount of chlorides used by practitioners or would require construction costs to the site (e.g., installing rain gardens or regrading parking lots) were excluded from the compiled list.

Long-term winter maintenance professionals and educators in the Northeastern and upper Midwestern United States were contacted through e-mails and informal interviews to ground-truth practices and their potential to be used by private contractors in these areas. The practices that met the feasibility criteria were then assessed for potential impacts (both positive and negative) on private contractor businesses. Specifically, low-salt practices described in resulting documents were assessed based on available literature for their potential to decrease or increase overall and implementation costs, liability (e.g., risk of lawsuits), environmental impacts, and service of private contractors.

Results and Discussion

Overview of Identified BMPs

The literature review identified 14 low-salt practices and BMPs suitable for use by private contractors during winter maintenance in North America (Table 2). All 14 practices are known or predicted to minimize negative impacts of chlorides on the environment by reducing the amount of salt used. Four of the 14 (pre-wetting salt, using brine, anti-icing, and using treated salt) are documented in a manner that allows more precise quantification of chloride reductions. Predicting environmental impacts was often not possible for other practices as multiple BMPs are often used concurrently, which is considered a best practice in itself (*28*). When calculated for individual BMPs, salt (primarily NaCl) reductions ranged from 6% to 45% (Table 2). There is evidence that companies globally are driven to adopt practices that minimize environmental impacts and address customer interests in businesses acting with social responsibility (*29*). Reducing the amount of deicing materials used is potentially a primary motivator for private contractors to adopt BMPs because of ongoing cost savings also.

Implementing the BMPs leads to cost savings through the reduced volume of deicers required for 13 of the 14 BMPs (93%) with a 10% to 20% decrease in recurring winter management expenses reported (*47*), and as much as a 137% return on investment reported (*42*). Limiting salt use by implementing BMPs resulted in almost a half million dollars in savings over two years to a college campus after staff were trained in use of low-salt BMPs (*51*).

Nonetheless, initial set-up costs or the staff training time required may be a deterrent to BMP implementation for private contractors, especially those with a limited customer base, fewer staff, or limited service areas. Nine of the 14 BMPs (64%) would result in increased initial costs to invest in equipment, training, software, or infrastructure (Table 2). Initial investment costs for new technologies have been demonstrated to be a barrier to implementation by other groups, such as farmers (*52*). As 80% of private winter maintenance contractors operate as sole proprietors (*27*), this may be a significant barrier to implementation. Balancing these challenges, however, it was suggested that having many BMPs with initial investment costs can result in decreased costs over time as less salt or other materials would be needed to provide similar levels of service.

However, three of 14 identified BMPs (21%) were expected to result in sustained increased costs associated with the additional staff time required to implement them (Table 2). Sustained costs over time would be a barrier to implementation of BMPs for private contractors. However, sustained increased costs may be covered

Table 2. Best Management Practice (BMP) Requirements and Anticipated Benefits and Impacts

BMP type	Best management practice	Anticipated benefits and impacts			
		Environmental	Financial	Liability	Service
Planning	Create a management plan and contract with customers; route planning for efficient service (*30*)	Possibly decreased negative impacts by defining expectations (*11, 20, 31*).	Sustained increased costs for added time to define plan with customers. Increased or decreased costs and/or time for service completion (*11, 20, 30, 31*) depending on snow removal tasks and planning completed.	Decreased if limited liability is specified.	Improved understanding of expectations by both parties leads to perception of improved service.
Physical actions	Remove snow before salt application and frequently during storms (*11*) and consider site conditions when positioning snow piles (*20, 32, 33*)	Decreased negative impacts to surface waters by limiting use of salt and/or surface runoff. Infiltration via green stormwater infrastructure may reduce salt loading to surface waters, but may increase groundwater loading (*33*).	Sustained increased costs to support additional staff time. Decreased costs of materials, as less salt required.	No impact if melt water does not enter service area.	Improved service with less effort.
	Physically remove snow efficiently with properly maintained equipment (*11*)	Decreased negative impacts by limiting use of salt.	Increased costs of initial investment. Possibly decreased costs by using less salt or staff time as a result of improved surface clearing.	Little or no change.	Improved ability to clear surfaces efficiently and quickly (*11*).
	Cover stored salt (*11, 20, 34, 35*)	Decreased negative impacts as salt runoff to the environment is minimized, and leftover salt in truck can be returned to storage rather than spread (*35*).	Increased costs for initial investment to cover stored salt. Decreased costs over time as less salt used (i.e., lost in runoff).	Little or no change.	Little or no change to end user.
Altered techniques	Use equipment with adjustable application rates (*20, 31, 36*)	Possibly decreased negative impacts with more efficient salt use.	Increased costs for initial investment. Decreased costs by reducing salt use over time.	Decreased liability through improved surface safety.	Similar or improved service with less effort.
	Use weather forecasting (*31, 37, 38*) and surface temperature measurements (*11, 20, 35*)	Decreased negative impacts by more effectively using salt, and thereby using less salt.	Increased costs for initial investment in high tech weather system or weather service (*31*). If handheld infrared thermometer used, may add time to site	Decreased liability as a result of more targeted service for conditions.	Improved service as a result of more effective and targeted service.

(continued)

Table 2. (continued)

BMP type	Best management practice	Anticipated benefits and impacts			
		Environmental	Financial	Liability	Service
			maintenance. Minimal costs to maintain (*31*). Decreased costs over time by improved planning and implementation of practices leading to reduced salt use. Can lead to reduced staff time required (*31*), and 10%–20% decrease in winter management expenses (*39*).		
	Treat surfaces before snow and ice accumulation (anti-icing)	Decreased negative impacts by using less salt and increased efficiency (up to 25% less salt) (*40*).	Increased costs for initial investment of equipment (*31, 41*). Decreased costs by reducing salt use over time and by reducing required snow/ice removal efforts by preventing bond between snow/ice and surface (*20*). As much as a 137% return on investment (*42*).	Decreased liability through improved surface safety.	Improved by ability to prevent snow and ice buildup (*35*).
Alternatives to dry NaCl	Use brine	Decreased negative impacts by using less salt (30%–45% reduction) (*43, 44*).	Increased costs for initial investment of equipment or ongoing costs to purchase pre-made brine. Decreased costs by using less salt over time as compared with dry application of salt to surfaces (*44*).	Decreased liability as a result of less snow and ice buildup on surfaces.	Improved ability to prevent snow and ice buildup.
	Pre-wet salt (as it exits the vehicle) (*20, 45*)	Decreased negative impacts by using 20% (*11*) to 30% (*20*) less salt. Scatters less than dry salt (*35, 43*). Infiltrates groundwater 5% less than dry salt (*35*).	Increased costs for initial investment to buy equipment to pre-wet salt (*45*). Potentially decreased costs as less salt required to provide same level of service (*45*).	Decreased liability as a result of less snow and ice buildup on surfaces as evidenced by decreased crash frequency (*46*).	Improved ability to prevent snow and ice buildup. Improved service as a result of minimized scatter of salt (*35, 43*).
	Use treated salt (*20, 40, 45, 47*)	Decreased negative impacts by using less salt (*40*), 25%–40% reduction (*45, 48*).	Increased costs for initial investment to buy equipment to treat salt, to cover treated salt (*45*), to	Decreased liability as a result of less snow and ice buildup on surfaces and decreased time to	Reduced snow and ice buildup by reducing scatter (*47*). Improved service by reducing time

(continued)

Table 2. (continued)

BMP type	Best management practice	Anticipated benefits and impacts			
		Environmental	Financial	Liability	Service
		Scatters less (*20, 47, 35*). Less corrosive than pure sodium chloride (*48*).	train staff in new methods, and/or to purchase more expensive pre-treated salt. 25% to 12 times more expensive than NaCl (*40*). Decreased costs overall as less salt required to provide same level of service (*45, 47, 48*).	clear pavement (*35*).	to bare pavement (*35*). Lower usable temperatures than NaCl (*48, 49*).
Alternatives to dry NaCl	Use alternative materials	May decrease negative impacts by using less material and/or be less toxic to plants or animals (*11, 31*). May cause impacts such as eutrophication, cyanobacteria blooms (*31, 43*), oxygen depletion in waterbodies (*41, 50*).	Up to 10 times more expensive than NaCl (*31*). Potential for decreased overall costs as less material is needed for similar results (*31*). Alternative materials may be less corrosive to infrastructure compared with NaCl (*11, 31, 41*).	Decreased liability through and improved surface safety.	Improved service by more effective bond prevention between surface and snow/ice or by improved snow/ice melting.
Maintenance and record-keeping	Calibrate and maintain equipment	Decreased negative impacts by using salt more effectively and therefore using less salt (*11*).	Increased costs for investment in calibration staff time and equipment (*20*). Potential decreased materials costs by ensuring more uniform applications (*20*).	Little or no change.	Similar or improved service with less effort.
	Track salt use and conditions by route, vehicle and driver (*20, 43*)	More consistent and predictable salt usage through tracking (*20*) may lead to decreased excess usage and may decrease environmental impacts.	Increased costs for initial investment to train staff or set up tracking systems (*20*). Possible decreased costs by reducing salt use over time.	Decreased liability by having record of treatment provided.	Improved ability to prevent snow and ice buildup.
Education and staff training	Provide training, resources, and education to staff on BMPs	Decreased negative impacts by increased/ improved BMP usage (*11, 20, 31*).	Possibly sustained increased costs as a result of training time (*20*). Possible decreased costs by reducing salt use over time.	Decreased through more effective service (*20*).	Improved by more efficient, consistent service (*20*).

by increases in customer rates to provide sustainable services, particularly if associated with a sustainable certification on the part of the contractor. In the field of tourism, there has been evidence of consumer perceptions being more positive when an operator has a sustainable certification (*53*), and support for modest increases in fees to support sustainable practices (*54*). Support may be influenced by socioeconomic status and regional economic conditions. More research is needed to assess winter maintenance sustainable certification programs, their costs, and consumer support for both.

Costs are also linked with the liability coverage private contractors are required to pay. Of the BMPs identified in Table 2, 71% (ten of 14) are expected to result in decreased liability to the private contractors (e.g., by providing more consistent service, identifying customer expectations/level of service, etc.). Decreased liability is likely to lower insurance rates (*55*) when paired with a limited liability certification program, such as was developed in New Hampshire (*56*). BMPs that decrease liability increase the ability of the private contractors to implement the practices at a lower cost and may offset increased startup costs. All but one (93%) of the identified BMPs are expected to result in an improved level of service to customers (Table 2), with covering stored salt being unrelated to improved service.

A complementary benefit of implementing these practices is that reduced use of salt may also help minimize corrosion to infrastructure, including equipment used by contractors during winter maintenance and in some cases municipal infrastructure such as bridges (*48, 57–59*). In addition, reducing the amount of chlorides used may decrease equipment and corrosion-related maintenance costs for private contractors, automobile owners, and communities. In the United States, more than $8 billion in direct costs to highway bridges resulting from corrosion are estimated annually, and upwards of $23 billion in direct costs are estimated annually to automobiles resulting from corrosion (*60*).

The 14 identified best practices can be divided into six groups: planning, physical actions, altered techniques, alternatives to dry NaCl, maintenance and record-keeping, and education and staff training. Each of these groups is described in detail below.

Planning

Creating management plans and contracts are two ways private contractors can communicate the types of service they provide. Clear plans and contracts can set service expectations and greatly reduce environmental impacts as well as economic costs to both private contractors and their customers (e.g., agreed areas and frequency of service, acceptable level of service such as dry or wet surfaces) (*11, 20, 31*). Developing a formal management plan before maintenance begins allows for the incorporation of a fixed price for service. This incentivizes the reduced use of materials while meeting client expectations (*11*). Under a management plan, contractors can typically define the treatments that are needed, the usability expectations, and the serviceable area (*11*). In contrast, a contract without these details may result in unnecessary use of materials or time spent by private contractors (*11*), increasing the potential to use more salt than is necessary to maintain safe conditions. In addition, planning routes efficiently may decrease the time needed to complete service routes for single vehicles (*30*).

Liability and safety are concerns for both municipal and private organizations that provide snow removal services. Within management plans and contracts, avoiding "hold harmless clauses" that cause the contractor to be liable for risks outside the company's control is recommended (*11*). Limiting the liability of contractors can also involve setting the level of service expectations in a management plan. Agreeing on a level of service can help limit environmental impacts and costs by preventing the over-use of materials beyond the intention of both parties. For example, in New Hampshire (U.S.) training is available to private contractors to implement cost-effective and lower-impact practices (*56*). Such training is directly tied to a limited liability law that protects contractors, property owners, and property lessees from liability if best practices are followed and certain records are kept (*61, 62*).

Physical Actions

Low-impact physical BMPs that relate to the storage of deicing materials and the physical removal of ice and snow can be an effective way to minimize the salt needed and the environmental impacts of winter maintenance (*11*). These practices can reduce service times and costs to contractors, benefiting businesses (*11, 20*). They include:

- removing snow before salt applications and frequently during storms (*11*);
- considering site conditions, including road and parking lot grading, when positioning snow piles such as placing snow downhill of maintained surfaces to prevent snowmelt from passing over and freezing on those surfaces (*20, 32, 63*);
- physically removing snow efficiently with properly maintained equipment (*11*);
- covering stored salt (*11, 20, 34, 35*).

In addition, plowing and/or storing plowed snow piles away from waterbodies and storm drains can help minimize salt runoff to local waterways, though this does not reduce the use of salt. Snow removal operators and their clients should consider how runoff into green stormwater infrastructure may reduce chloride loading to surface waters and/or increase infiltration, but may increase chloride loading to groundwater (*33*). Storing plowed snow downhill of maintained surfaces may be challenging for private contractors to implement based on the sites that are maintained, which may have a limited selection of areas in which to store snow piles. Nonetheless, having this concept in mind when planning and implementing site winter maintenance is likely to reduce the quantity of piles placed in locations that may require additional salt to be used during pile melting.

Covering salt to be used during winter maintenance may require an initial investment for some private contractors, and may therefore be a barrier to use, if quantities used are sufficient enough to purchase bulk salt that requires storage outside of available structures. Other contractors may make salt purchases in bags and, as such, would not be subject to initial set-up costs.

Altered Techniques

There are a variety of BMPs that relate to altering salt application techniques, all of which include upfront costs because of the equipment or training required. Contractors may integrate some or all of these practices depending on the resources that are available to them.Some of these are summarized below.

Using equipment that allows adjustable salt application rates. Some equipment allows for the operator to adjust the rate of materials application, with variations in the range of settings. The ideal application rate of materials may be informed by the speed of the vehicle, storm and weather information, surface temperature, and the mixture of materials being used, including the application materials described below (*11, 20, 31, 36*). Determining the most effective application rate may require additional staff time and training. However, adjusting the application rate as appropriate to the surface and weather conditions can be very effective at reducing material costs and environmental impacts while maintaining a similar level of service (*11, 20*).

Using weather tracking and surface temperature measurements to inform salt application. Information such as anticipated snowfall, road temperature, and storm tracking can be all be used to better target surface treatment (*11, 20, 31, 35*). Weather information can be obtained from public governmental sources or from private companies that have established a Road Weather Information System that provides detailed weather information that private contractors can use (*31*). Contractors can also pay a fee to obtain weather details specific to their service area (*20*), though this may be cost prohibitive to small businesses. Implementing weather information services into winter maintenance may also require additional contractor training or time but can be beneficial to reduce materials use and labor during storms. Tracking surface temperatures can be done inexpensively with a handheld infrared thermometer. However, stepping out of the vehicle to use the thermometer will reduce the speed of site maintenance, which may be a barrier to implementation. Also, pavement temperatures may vary within a location (e.g., based on shade), which may, in turn, result in too little or too much salt being spread to achieve the desired surface conditions, or in decreased confidence in the technology, leading to limited use of it.

Treating surfaces before storm events when possible, known as anti-icing. Anti-icing, as opposed to deicing a surface after snowfall, can increase the efficacy of materials by preventing initial buildup, or in the case of larger snowfalls, can aid in melting buildup from underneath while the surface is plowed, or a second application of materials is used. Additional time or planning may be required to treat areas before a storm, but the integration of weather and surface temperature information into anti-icing practices can make this process much more efficient (*2, 11, 20, 31*).

Alternatives to Dry NaCl

Using pre-wetted salt, treated salt, liquid brine, or alternative deicing agents (commonly referred to as chemical additives) can be an effective way to increase the usability of surfaces while decreasing environmental impacts caused by salt (*2, 11, 20, 36, 48*). Each of these alternatives to dry salt results in environmental and service benefits, leading to predicted decreased liability, and sometimes decreased overall costs.

By dissolving salt in water and applying the mixture to surfaces (brine), the amount of salt required can be significantly reduced (*2, 11, 20*). Brine adheres better to paved surfaces, reducing the displacement from traffic, wind, and bouncing off the surface while being applied, while increasing melting speeds (*20*). When applied before a storm (i.e., anti-icing), it can effectively prevent formation of a bond between ice or snow and the pavement (*45*). However, additional upfront time, cost, and equipment are likely required for contractors to use a brine. Other challenges of using brine include needing the salt-water mixture to be at or very close to 23.3% solution (*45*). Purchased brine may not arrive at this concentration or may be subject to evaporation during storage. If brine is at a slightly higher or slightly lower concentration, the result could be a freeze up of surfaces rather than the prevention ice formation (*45*). Further, in some locations, brine has earned a negative reputation as being exceptionally corrosive to vehicles (e.g., Pollhamus [*64*]) It can also freeze within the machinery being used to spread the brine (*65*). These reasons are all barriers to use of brine for private contractors. However, a motivation for using brine is that salt use can be decreased by up to 45%, and service can be improved by preventing the bond between the surface and the ice or snow as in anti-icing (*44*).

Pre-wetting salt is defined as wetting the salt with a liquid as it leaves the vehicle, typically water, water collected from washing trucks, or brine (*20*). By combining dry salt with a brine (which may be made with NaCl or another material, such as CaCl or $MgCl_2$), similar though fewer (*45*) benefits to using a liquid brine are seen (e.g., increased melting speed, better adherence to road surfaces) (*20*). The additional weight of pre-wetted salt versus dry salt may hinder private contractors from using it if they operate with only pickup trucks in their fleet, which may not be able to handle added weight (*45*).

So-called treated salt is deicing material (typically NaCl or a salt/sand mixture) that is treated with an alternative deicing agent before being stored (*20*). Treatment materials vary, with some proprietary materials used (*40*). Motivations for private contractors to use treated salt include: it requires less material to achieve a similar level of service as dry salt (*40*); it scatters less (*47*); it can have reduced corrosivity (*48*); and it can result in bare pavement comparatively more quickly (*40*). In addition, it can be applied without any specialized equipment other than what is used to spread traditional salt (*45*). A barrier to the use of treated salt by private contractors is the higher cost compared with untreated salt (Table 2). However, for some treated salts, higher costs were negated by savings in the amount of material needed, resulting in overall costs savings to use treated salt (*47*).

A variety of so-called alternative deicing materials and agents can be used to provide effective service, especially at extreme temperatures (below −10°C) when sodium chloride becomes ineffective at preventing buildup (*2*). However, these materials may be cost prohibitive or limited in availability (*20, 31*), which may make them more difficult for contractors to acquire. Alternative application materials may be more attractive to property managers or other stakeholders by comparison with private contractors as a result of their potentially lower impact on property including bridges and other metal infrastructure (*2, 36, 41, 57*). However, certain alternative deicing agents can present different environmental challenges compared with chlorides. For instance, those with acetate or high sugar content have been demonstrated to decrease dissolved oxygen levels and increase biochemical oxygen demand in waterways (*1*), which may result in negative outcomes for aquatic life. Possible new impacts (depending on materials used) should be considered against possible reduced impacts (from less or different materials used) as well as the specific use case (temperature, infrastructure, cost, etc.) when considering alternative deicing materials.

Maintenance and Record-Keeping

By maintaining and calibrating equipment as needed, as well as selecting equipment that is appropriate for surface and weather conditions, removal methods can be more effective while reducing the amount of melting agent required (*11*). This includes routinely checking and calibrating equipment according to the manufacturers' instructions such as: calibrating spreaders so that deicing materials are applied at an expected rate, checking that blades and plows are not worn, and ensuring proper installation of on-board pre-wetting equipment plumbing to prevent leaking or dumping liquid application materials (*11*). In addition, equipment choice can vary based on the conditions. For example, a contractor may need to select an appropriate plow for a given surface, or use drop spreaders on sidewalks or other small areas versus broadcast spreaders on large parking lots (*11*). Continued maintenance and calibration of equipment is necessary to ensure application rates match expectations and do not result in excessive or inadequate application of materials (*11, 20*). Maintenance and calibration can take additional time, potentially acting as a barrier to adoption by private contractors. However, savings in reduced usage of materials or staff time during applications (e.g., by having a well-maintained plow edge to maximize snow and ice removal) (*11*) may offset added staffing costs.

Education and Staff Training

Training on environmental impacts and BMPs is recommended for contractors to facilitate reduced use of salt and thus to reduce environmental impacts (*11, 20, 31*). Having trained staff who understand how to implement recommended best practices and the reasoning behind each practice also increases overall safety and the level of service provided (*11, 20, 31*). Training opportunities and educational resources are available to both municipal staff and private contractors (Table 3). However additional research on how winter maintenance contractors decide what practices to implement could inform and improve outreach campaigns and training that promotes lower-impact practices for this group (*66, 67*).

Resources designed for online self-guided learning vary, from fact sheets comparing the utility of different techniques and their environmental impacts, to comprehensive reviews of BMPs (*11, 20, 68, 74*). Online training videos are also available, and often review BMPs,

Table 3. Examples of Resources and Training Available to Private Contractors

Group	Resources and training initiatives	Target audience
Clear Roads Institute	National Winter Safety Campaign (*68*)—public relations toolkit for municipalities to promote behavior changes; educational materials for road users; publications detailing BMPs	Municipal staff
Minnesota Pollution Control Agency	Smart Salting Certification Training (*69*)—Certifications for municipal staff and private contractors through in-person trainings. Level 1 is based on the Minnesota Snow and Ice Control Field Handbook for Snowplow Operators (*70*) or the Winter Parking Lot and Sidewalk Maintenance Manual (*45*). Level 2 focuses on leadership education and BMP usage through the Smart Salting Assessment Tool (*71*).	Municipal staff and private contractors
New Hampshire Department of Environmental Services	Green SnowPro Training (*62*)—fee-based in-person training for individuals to become a certified Commercial Salt Applicator. Certified "Applicator" benefits include state promotion, liability protections for companies, their clients, and associated properties. Educational materials for also available online.	Private contractors
Snow & Ice Management Association (SIMA)	Certified Snow Professional (72)—certification acquired through proof of employment as a snow professional, or through 15 education hours of SIMA-approved trainings. "Advanced Snow Management University"—fee-based online 30-day training and certification. "SIMA Training Center"—fee-based on-demand training courses and webinars on a variety of topics.	Private contractors
Transportation Association of Canada	Synthesis of Best Practices (*11, 73*)—purpose-built publications and analysis on BMPs, including for highways, private roads, snow and salt storage, and more.	Municipal staff

Note: BMP = best management practice.

equipment, or general business practices (*68, 75*). While self-directed learning is important, the use of many of these materials may be limited to those contractors who are personally motivated to learn best practices. The Snow & Ice Management Association (SIMA) offers a variety of training opportunities associated with certifications, which may serve as an additional motivator for participation (*75*).

In-person training opportunities are also available, some of which culminate in certifications for contractors seeking to implement these practices (*62, 75*). The Green SnowPro training offered through the New Hampshire Department of Environmental Services (*62*) is a unique example that allows individuals to become certified Commercial Salt Applicators. This requires a $100 fee that covers an individual's attendance at a full-day workshop on using environmental BMPs and cost-reduction strategies. In addition, certified Commercial Salt Applicators are required to pass an exam and log records of deicing materials usage, dates of applications, and weather conditions (*62*). As an incentive, certified contractors hold certain liability protections and benefit from publicity through the New Hampshire Department of Environmental Services. Liability protections extend to the certified contractors, their clients, and the property owners on sites maintained by certified contractors, protecting against slip and fall liability claims when BMPs are followed (*61, 62*).

Review Limitations

Limitations of this study include some assumptions of possible motivations that private contractors may have as well as barriers to adopting BMPs. While some barriers and motivations are commonly cited in the literature (e.g., economic incentives and liability risks), others (e.g., environmental impacts and customer expectations) are described less completely in relation to winter maintenance private contractors. In addition, as BMPs are typically designed for a municipal audience, BMP adoption by private contractors could present unique challenges, benefits, or outcomes. More in-depth research on private companies providing winter maintenance services is needed to verify these barriers, motivations, and the current adoption rates of established BMPs. A final limitation is that BMPs are highly case dependent and it is difficult to know the exact chloride reduction that can be expected in a given situation. While the environmental impacts of chlorides are well documented, it is difficult to assess the environmental benefit of a particular BMP without extensive knowledge of the specific case. Contractors, property owners, or others would likely need to track chloride usage over time before and after implementing BMP(s) to assess exact chloride reductions and possible environmental changes.

Conclusion

Removing snow and ice from roads and other impervious surfaces through the winter is vital for safety and accessibility in cold-weather regions throughout North America. Despite the rising costs of materials, the amount of application materials used has risen steadily over time, leading to increasing environmental impacts and human health concerns. In particular, chloride concentrations in surface waters have increased. BMPs are designed to reduce environmental impacts from winter maintenance activities by reducing the amount of deicing material used (typically NaCl) while improving snow and ice management service through increased efficiencies. Municipalities are motivated to implement BMPs via environmental regulations to identify and maintain quality standards. However, private contractors may also be substantial contributors to increasing chloride concentrations but are not subject to these regulations.

This review identified 14 BMPs that, while typically designed for a municipal audience, are likely applicable to private contractors. About a third of the identified BMPs (36%, five of 14) require little to no increased cost or changes in equipment while providing consistent service and the potential for reducing road salt usage. Most of the BMPs (79%, 11 of 14) are expected to either to reduce or not change sustained costs once implemented. In addition, most of the BMPs (71%, ten of 14) are expected to result in decreased liability to the private contractors. Many of the identified BMPs therefore may be beneficial to private contractors, especially as BMPs are recommended to be selected based on current practices, customer needs, service areas, capacity and so forth, to be most effective. Further research into the characteristics of private winter maintenance companies is needed to better understand the sizes and types of areas they service and current BMP adoption rates.

Research is also needed to explore how motivations and barriers identified through this study play a role in contractors' decision-making processes. Possible barriers identified in this study include perceived or actual startup costs for equipment or staff training to implement BMPs, ongoing costs, undefined customer expectations, and liability concerns from using less deicing material. Potential motivations for private companies to adopt BMPs include greater efficiency of applications and cost savings, improving service consistency, decreasing liability concerns, and reducing environmental impacts. This review suggests that a study of the characteristics and motivations of private contractors could inform future training, outreach, and resources for this group that are economically, socially, and environmentally beneficial.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Holden Sparacino, Kristine F. Stepenuck; data collection: Holden Sparacino, Kristine F. Stepenuck; analysis and interpretation of results: Holden Sparacino, Kristine F. Stepenuck; draft manuscript preparation: Holden Sparacino, Kristine F. Stepenuck, Rachelle K. Gould, Stephanie E. Hurley. All authors reviewed the results and approved the final version of the manuscript.

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