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STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 2

WINTER MAINTENANCE PRACTICES

2.1 INTRODUCTION

Winter road, parking lot, and sidewalk maintenance is crucial for public safety and economic activity throughout the Southeastern Wisconsin Region (Region). Since the 1950s, this maintenance has relied heavily on the application of deicing agents, primarily chloride-based salts. The need for deicing was driven by the expansion of highway networks and the public expectations of “bare pavement” conditions. However, the widespread use of these materials has caused significant chloride pollution, threatening aquatic ecosystems, drinking water, soil health, vegetation, and infrastructure.[1]

Municipalities often lead in adopting advanced winter maintenance practices due to public accountability, environmental regulations, and resource availability, but significant opportunities exist to improve winter response performance among private contractors and homeowners. Maximizing the reduction of environmental and infrastructure damage requires a holistic strategy involving all parties. This strategy includes data-informed planning, appropriate material selection, precise application using calibrated equipment and trained operators, environmentally sound storage practices, and ongoing training. This Chapter details state-of-the-art technologies and best management practices (BMPs) used by public agencies, private contractors, and property owners to mitigate chloride pollution from winter maintenance activities.

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[1] *See SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024, and SEWRPC Technical Report No. 63,* Chloride Conditions and Trends in Southeastern Wisconsin, *in progress.*

2.2 PUBLIC WINTER MAINTENANCE PRACTICES – STATE, COUNTY, AND MUNICIPAL

Winter maintenance operations present a complex challenge for transportation and public works agencies; requiring them to manage safety, mobility, fiscal responsibility, and the environment. Historically, prioritizing transportation and traffic safety led to the extensive use of road salt, which is known for its effectiveness and relatively low initial cost. However, growing concern and awareness of the environmental harm caused by road salt has created a mandate to reduce its application. This section details state of the art technologies, policies, and best management practices designed to minimize the impact of public winter maintenance operations on both infrastructure and the environment.

Shifting Public Expectations for Winter Road Maintenance

One of the greatest challenges to reducing deicing chloride use is the long-standing public expectation of "bare pavement" and the demand to drive at normal speeds during or immediately after a major winter storm. This expectation was reinforced historically by state and local agency policies. For instance, the Wisconsin Department of Transportation (WisDOT) adopted a "bare pavement" policy for state highways in 1956, and similar standards were common nationwide. Although WisDOT later updated this policy to a "passable roadway" standard (first in the 1970s and again in 2002), the demand for pristine winter road conditions persists today. Even now, several jurisdictions in the Chloride Impact Study area still maintain some form of bare pavement policy.[2]

Achieving the traditional bare pavement standard requires continuous, high-volume application of chemical deicers, which has negative impacts on the environment, infrastructure, and economic budgets. Historically, the pursuit of this standard was guided by a subjective visual assessment from snowplow operators, who were instructed to achieve fully clear roadways. This subjective method was unreliable, as assessments were often influenced by poor visibility or liability concerns, which commonly led to an abundance of caution and the over-application of deicing salts.[3] This historical practice is a primary contributor to the rise in observed chloride levels in the streams, rivers, lakes, and groundwater across the Region, as detailed in SEWRPC Technical Report No. 63, *Chloride Conditions and Trends in Southeastern Wisconsin* (in development).

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[2] *SEWRPC, Winter Road Maintenance Survey for Southeastern Wisconsin Municipalities [Unpublished internal survey data], June 2024.*

[3] *National Cooperative Highway Research Program Transportation Research Board of the National Academies,* Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility, *November 2002.*

Transitioning to a Passable Roadway Standard

Redefining policy regarding the level of service for municipal winter maintenance is a critical step to achieving measurable chloride reduction while maintaining functional safety. Current municipal winter road maintenance operations are transitioning from the resource-intensive "bare pavement" model to a more sustainable "passable roadway" standard.[4] This standard prioritizes functionality and safety over appearance, ensuring that roads are accessible, and specifically recognizes that some snow and ice will likely remain on the pavement for certain amounts of time after a winter storm. The effectiveness of this policy shift hinges on effective public expectation management and successfully transferring some responsibility for safe driving back to the motorist.

To effectively implement the shift to passable roads, many agencies adopt a tiered service prioritization. For example, the City of Milwaukee designates streets as arterial (high volume, transit routes, emergency access) or residential. During a winter storm, crews focus on keeping arterial streets open and passable. Once those main streets are considered passable, the City shifts operations to residential streets, aiming for safe and passable travel at reasonable speeds, even if compacted snowpack remains. The City estimates it takes 18 to 24 hours after the snow stops to complete operations across its 7,000 lane miles.[5]

Part of implementing the shift to passable roads includes the need to adopt more measurable and objective metrics. This can be accomplished by using the "bare pavement" goal not as an immediate and continuous operational target, but as a defined time-bound metric to measure post-storm performance. The shift is from a subjective visual goal to an objective time goal. For instance, the Minnesota Department of Transportation (MnDOT) achieves this by measuring the "time to reach bare pavement" across its highway system and setting different performance goals based on traffic volume.[6] Heavily traveled routes maintain shorter time-to-clearance goals (e.g., 4 hours after a storm ends), while lower-volume roads are assigned

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[4] *WisDOT defines a "passable roadway" as a roadway surface that is free from drifts, snow ridges and as much ice and snowpack as is practical and can be traveled safely at reasonable speeds. Reasonable speed is considered a speed that a vehicle can travel without losing traction. During and immediately after a winter storm event, a reasonable speed will most likely be lower than the posted speed limit. Motorists can expect some inconvenience and will be expected to modify their driving practices to suit road conditions.*

[5] *City of Milwaukee Department of Public Works "Snow and Ice Control Operations" website: www.city.milwaukee.gov/dpw/operations/snowoperationstatus, accessed October 7, 2025.*

[6] *Iowa State University Center for Transportation Research and Education,* Performance Measures for Snow and Ice Control Operations, December 2007.

longer clearance targets (e.g., 12 hours after a storm ends). This measurable and performance-based approach enacts the concept of tiered service and replaces the unreliable and subjective visual assessments. Several local communities in the study area have indicated the use of similar measurable time-to-clearance metrics.[7]

The ability of agencies to achieve safe and passable conditions depends on multiple variables such as storm severity, roadway temperatures, and available resources. Tools like Road Weather Information Systems (RWIS) and Maintenance Decision Support Systems (MDSS) are critical for winter maintenance operations managers. These systems analyze current and forecasted conditions, helping agencies to define an achievable and safe level of service without resorting to excessive salt use.[8] These systems will be discussed in more detail later in this Chapter.

Public Education and Expectation Management

For the transition to a sustainable level of service to succeed, the public must be educated on proposed practice and strategy changes. They must also know their role in adjusting driving behavior to weather conditions. The most successful agencies supplement policy changes with proactive and clear public education campaigns. A successful example of a collaborative approach is the Wisconsin Salt Wise program, a partnership dedicated to reducing salt use by educating agency and commercial winter maintenance professionals, private property owners, and the traveling public. The central messages should educate the public about the true environmental and economic costs of bare pavement policies while emphasizing shared responsibility for winter travel safety. Three critical public messaging points include:

- The environmental cost of bare pavement policies: Outreach is necessary to clearly link the historical expectation of bare pavement to the unacceptable levels of chloride contamination in the surface water and groundwater of the Region. When citizens understand this connection, resistance to the new level of service standard decreases.

- Discourage non-essential travel: Agencies must strongly urge the public to limit travel during major winter storms. The modern flexibility of remote work allows many employees to work from home when necessary, which aligns public behavior with the reduced level of service during

[7] *SEWRPC, Winter Road Maintenance Survey for Southeastern Wisconsin Municipalities*, op. cit.

[8] *US Department of Transportation, Federal Highway Administration, "Weather-Responsive Management Strategies Fact Sheet," www.ops.fhwa.dot.gov/publications/fhwahop20015/fhwahop20015.pdf, accessed October 6, 2025.*

the maintenance response. This will also protect winter maintenance crews and minimizes agency liability.

- Matching driving speed to road conditions: Education should stress that a "passable" road is not a "normal" road. Motorists should be reminded to drive at significantly reduced speeds that are appropriate for conditions and to increase following distances to account for snow covered streets. By defining the achievable road conditions, agencies can transfer some of the responsibility for safe traveling back to the driver.

Planning and Decision Making

Effective planning and decision-making are the foundation for a modern winter maintenance program. While a "passable roadway" policy sets the goal, the planning phase determines the actual operational response by transforming weather forecasts, environmental data, and community and agency specifics into strategies that can be implemented in the field. The most successful modern winter maintenance operations implement strategic and data-driven approaches to balance considerations of public safety, budget constraints, and environmental impact.

Winter Maintenance Policies

For a public winter road maintenance program to be most effective, a formal winter road maintenance policy should be established. The written policy document provides agency maintenance crews with guidelines to meet specific objectives for snow removal, deicing, and anti-icing efforts. These documents also serve to inform the public of the procedures being followed so that they can have a better understanding of an agency's snow and ice removal operations. A well-defined policy is important for several reasons:

- Establishing Levels of Service (LOS): The policy clearly defines what acceptable road conditions look like during and after a storm. By defining specific LOS targets for different tiers of roads, agencies can justify the use of less salt where conditions allow it and manage public expectations.

- Liability: In the event of legal issues related to winter road conditions, a written policy can demonstrate that an agency followed a documented and reasonable plan. This is critical for showing due diligence, especially when implementing chloride reduction strategies.

- Operational Consistency: A written policy ensures that regardless of which supervisors or operators are on duty, the approach for operations remains consistent across the jurisdiction.

A written policy also provides maintenance managers with clear guidelines for when and how to respond to a storm event. Based on a survey of public winter maintenance managers in southeastern Wisconsin, less than half indicated that they have a formal snowfall accumulation threshold for when a maintenance policy or plan goes into effect. For those communities with a threshold in place, most indicated they begin snowplow operations after one to two inches of snow accumulates, while others use lower thresholds of 0.5 to 0.75 inches.[9]

While a winter maintenance policy establishes the broad goals and framework for an agency, it is common for state-of-the-art operations to supplement this with a specialized salt management plan (SMP). The SMP provides the technical roadmap for minimizing chloride use and impacts in a jurisdiction. The plan documents specific application rate charts based on specific conditions, schedules equipment for calibration, and provides strategies for protecting areas that are particularly sensitive to salt, such as wetlands or areas near municipal wells.[10]

Notably, modern planning has shifted from reactive plowing to proactive measures to weaken the bond of snow to the pavement when snowfall begins. Many jurisdictions in the Region reported that they determine the activation of anti-icing operations proactively based on the potential for snow and ice during the approach of a winter storm.[11] For this transition from a reactive approach to a proactive and predictive approach to be most successful, an advanced level of data integration is required. To manage this complexity in data and avoid information overload, modern agencies are increasingly turning to automated decision-support technologies. Automated decision support systems will be discussed in detail later in the Chapter.

Personnel and Training

Adopting a modern chloride management strategy may require updates to procedures, practices, and equipment. The most advanced technologies and strategies are only effective if the personnel executing

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[9] *SEWRPC, Winter Road Maintenance Survey for Southeastern Wisconsin Municipalities [Unpublished internal survey data], June 2024.*

[10] *Transportation Association of Canada, "Syntheses of Best Practices – Road Salt Management," April 2013.*

[11] *SEWRPC, Winter Road Maintenance Survey, June 2024,* op. cit.

them are properly trained. The success of these changes relies heavily on buy-in from administration, managers, and operators. To make this shift successful, a comprehensive training program that proves the effectiveness of new methods and technologies and ensures that winter maintenance personnel are skilled in implementing the new strategies is critical.

State of the art training and certification programs for winter maintenance emphasize the science of snow and ice management. Key training components include:

- How to monitor pavement temperatures and understand treatment options: Salt effectiveness drops significantly once pavement temperatures fall below 15°F. Understanding best materials and methods for specific pavement conditions ensures the most effective results and prevents the waste of salt.

- The relationship between chemical concentration and freezing points: This knowledge helps operators understand which materials are best to use for specific conditions.

- Equipment calibration is a cornerstone of any chloride reduction plan: Training ensures that every operator knows how to verify that the amount of salt being dispensed matches the setting on the spreader controller. This reduces over application caused by mechanical drift.

Many agencies in the Region participate in formal training and certification programs with great success. These programs provide assurance that an operator understands the science of snow and ice removal and has mastered the best management practices for chloride reduction. Some of the main training programs include:

- Wisconsin Salt Wise is a coalition of organizations from across Wisconsin working to reduce salt pollution in the lakes, streams, and groundwater of the State. Salt Wise is the leader in the State in public outreach as well as training for winter maintenance professionals (both public and private sectors), having trained more than 900 industry professionals in 2025 alone.[12] Their municipal winter maintenance workshops focus on best management practices to keep paved areas safe, guidance on determining the right amount of salt, benefits of liquids, and case studies from local maintenance managers. Wisconsin Salt Wise also offers equipment open houses, regular webinars that share the

[12] *Allison Madison,* Wisconsin Salt Wise 2025 Annual Report, *2026*.

newest strategies for chloride management, and a website that provides information on application guidelines, calibration, model policies, and links to other training resources.[13] Numerous municipalities in the Southeastern Wisconsin Region and around the State have credited trainings provided by Wisconsin Salt Wise for their successes in substantially reducing salt usage; saving tax payer dollars and reducing environmental impacts while maintaining safe roads.[14]

- Minnesota Pollution Control Agency "Smart Salting" program has established robust certification models that some Wisconsin agencies use as a benchmark.[15] These programs offer organizational and property management certifications for operators and supervisors/administrators to help improve effectiveness and chloride reduction while keeping roads and parking lots safe. The program reports that participating organizations were able to reduce their salt usage between 30 and 70 percent.

- The American Public Works Association (APWA) offers nationally recognized snow and ice control workshops offering certificates for public fleet management, winter maintenance operators, and winter maintenance supervisors.[16] APWA also hosts an annual North American Snow Conference that provides expert-led snow and ice education sessions and venders that exhibit the latest winter maintenance solutions in the industry.

Mechanical Snow and Ice Removal

The primary tool for any winter maintenance operation is the mechanical removal of snow and ice using snowplows with specialized cutting edges. This process is the most cost-effective and environmentally sustainable method for maintaining safe roadways. A study by the Western Transportation Institute and Clear Roads analyzed the costs and benefits of various winter maintenance strategies and found that plowing had a particularly high benefit-cost ratio of 5.3:1.[17]

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[13] *See www.wisaltwise.com.*

[14] *See www.wisaltwise.com/Take-Action/Winter-Maintenance-Professionals/Municipal-Champions* .

[15] *See Smart Salting training at www.pca.state.mn.us/business-with-us/smart-salting-training.*

[16] *See APWA Certificate Programs at www.apwa.org/education-careers/certificate-programs.*

[17] *Montana State University Western Transportation Institute,* Benefit-Cost of Various Winter Maintenance Strategies, *Clear Roads Report No. CR13-03, September 2015.*

The primary objective of plowing is to physically separate snow and ice from the pavement surface, a process sometimes referred to as "mechanical deicing." By prioritizing mechanical removal, agencies can significantly reduce the volume of chemicals required to treat the remaining snow accumulation. State-of-the-art operations emphasize removing as much snow as possible before applying deicing chemicals, preventing the materials from being diluted by heavy snowpack which leads to waste and unnecessary environmental impact.

The most effective strategy for managing chloride use is proactive anti-icing operations to reduce the ability of the snow to bond with the pavement (discussed in detail later in this Chapter) and to begin plowing early in a winter storm. While initiation of plowing operations varies depending on the municipality, specific storm conditions, and road priority, some agencies will begin partial plowing operations with as little as one or two inches of snow. Full plowing of local residential streets often has a higher trigger, typically 3 to 4 inches and is usually only initiated after the main routes are considered passable at reasonable speeds. High frequency passes can prevent snow from being compacted into hard pack by vehicle tires. Once snow is compacted and bonded to the pavement, the amount of deicer required to treat that snowpack increases greatly.

When chemical agents are necessary in coordination with mechanical removal, timing is critical to maximize the effectiveness of the deicer (strategies for deicing will be discussed in more detail later in this Chapter). Operators are generally instructed to allow some time for the chemical to penetrate and undercut the snowpack before making the next plow pass. Industry guidelines sometimes suggest waiting at least 30 minutes after application (or 90 minutes in temperatures below 15°F) before returning to plow.[18]

While specific policies vary by agency and road conditions (snow depth, drifting, ice), the winter maintenance industry generally recognizes suggested truck speed ranges that balance mechanical efficiency, operator and public safety, and snow displacement. In addition to safety concerns, driving too fast can damage the plow, the truck, and the road surface. If plowing is occurring in combination with deicing application, recommended speeds may differ. The following ranges are derived from common practices outlined by a combination of agencies and publications:

- High-Speed Highways or Interstates (25 to 35 mph): Necessary to generate the kinetic energy required to cast snow over guardrails and away from the shoulder.

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[18] *Washington State University,* Material Application Methodologies Guidebook, *Clear Roads Report CR15-01, April 2019.*

- Rural Two-Lane Roads (20 to 30 mph): Balances the need for casting the snow with the safety requirements of narrower lanes and oncoming traffic.

- Urban and Residential Streets (10 to 15 mph): Minimizes the risk of throwing snow onto sidewalks, parked cars, or driveways while reducing damage to infrastructure like curbs and manholes.

- Intersections and Turns (less than 10 mph): Maximizes maneuverability and prevents the plow from tripping or jumping during tight turns.

Tandem or gang plowing is a technique utilizing two or more plows driving in a staggered formation to clear multi-lane roadways in a single pass. Figure 2.1 shows the tandem plowing strategy being utilized by the City of Oak Creek Public Works Department to clear three lanes of Drexel Avenue. The lead truck moves snow from the innermost lane to the right, and the following truck(s) immediately move that same snow further toward the outer shoulder. This formation can help prevent the formation of long ridges of snow between lanes (sometimes referred to as windrows), which can cause motorists to lose control during lane changes. Furthermore, it provides a uniform surface for the efficient application of deicers.

Modern plow efficiency has been improved through specialized plow configurations like reversible plow, wing plows, underbody scrapers, and tow plows, along with advanced blade technologies such as live-edge and multi-layer blades. These tools conform better to uneven road surfaces and reduce vibration, further reducing the amount of chemical agent applied. These technologies are detailed in the "Winter Maintenance Equipment and Technology" section later in this Chapter.

Snow and Ice Control Materials

The selection of snow and ice control materials is a critical operational decision that needs to balance performance, safety, environmental and infrastructure preservation, and cost. While traditional operations relied mostly on mechanical removal, rock salt, and abrasives, modern maintenance standards require a diverse toolbox of chemical agents to maintain safe and passable roadways in varying weather conditions while preserving the environment and critical infrastructure.[19] This section details the physical properties and operational constraints of the primary deicers and anti-icers used by public agencies. These include chloride-based salts, acetates, formates, bio-based additives, urea, and propylene glycol. Understanding the

[19] *National Cooperative Highway Research Program,* Report 577: Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts, *2007*.

specific chemical capabilities of each material is critical for implementing the advanced deicing and anti-icing strategies discussed later in this Chapter.

Principles of Chemical Melting

Despite common beliefs, most deicing chemicals do not melt ice through heat generation. Instead, they function through a process known as freezing point depression. While aggressive chemicals like calcium chloride and magnesium chloride do release heat (exothermic) to jump-start the process, standard rock salt actually absorbs heat (endothermic) to work. Fundamentally, most chemicals used in winter maintenance function because when the solute dissolves in water, it interferes with the ability of the water molecules to bond into rigid ice crystals. This interference lowers the temperature where the water freezes, allowing it to remain in a liquid state (or brine) at temperatures well below the normal freezing point of water (32°F).[20]

The theoretical performance limits of any deicing or anti-icing chemical are shown in its phase diagram. A phase diagram is a graphical representation that maps the relationship between the concentration of a chemical solution (on the x-axis) and its freezing temperature (on the y-axis). As shown in Figure 2.2 these diagrams typically exhibit a characteristic "V-shape" or downward trajectory that reveals three critical operation factors of the chemical agent:[21]

- Freezing Point Curve (the downward slope): As more chemical is added to the water, the liquid freezing point drops. For example, a 10 percent salt solution freezes at a lower temperature than pure water (0 percent solution).

- The Eutectic Point (the bottom limit): Every chemical has a "thermodynamic floor" that is the absolute lowest temperature at which it can remain a liquid. This occurs at a precise "eutectic concentration." Below this temperature, the solution will freeze regardless of how much chemical is added.

- The Solubility Limit (the upward slope): Adding chemical beyond the eutectic concentration causes the crystallization temperature to rise. In this region of the phase diagram, the solution is saturated.

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[20] *Minnesota Pollution Control Agency,* Minnesota Stormwater Manual: Winter Parking Lot and Sidewalk Maintenance "Physics of Salt and Deicing," *August 2022.*

[21] *S.A. Ketcham, D. Minsk, R.R. Blackburn, and E.J. Fleege,* Manual of Practice for an Effective Anti-Icing Program, *U.S. Army Cold Regions Research and Engineering Laboratory, June 1996.*

As temperatures drop or concentration increases, the chemical precipitates out of the solution as solid crystals. In maintenance operations, this can lead to sludge buildup and clogged equipment.

The phase diagrams shown in Figure 2.2 compare thermodynamic properties of common municipal deicers and provide insight into their cold-weather performance hierarchy.

- Sodium Chloride (NaCl): Represented in Figure 2.2 by white circles, sodium chloride shows the shallowest curve. Its freezing point drops to a theoretical eutectic limit of approximately -6°F at a 23.3 percent concentration. However, as temperatures approach this limit, the melting capacity of the material diminishes significantly, making rock salt inefficient for melting ice at pavement temperatures below 15°F.

- Calcium Chloride ($CaCl_2$): Represented in Figure 2.2 by the black triangles, calcium chloride exhibits a significantly deeper performance curve. It reaches a theoretical eutectic point near -60°F at 32 percent concentration. This ability to remain liquid in extreme cold makes it a common tool for sub-zero emergency deicing.

- Magnesium Chloride ($MgCl_2$): Shown in Figure 2.2 with black circles, this agent performs better than sodium chloride but not as aggressively as calcium chloride, with a eutectic point near -28°F at a concentration of roughly 21.6 percent.

- Potassium Acetate (KAc): Represented in Figure 2.2 by the solid black squares, KAc shows an aggressive drop in freezing point, dropping to about -76°F at 50 percent concentration. Unlike the sharp "V" of the chlorides, its sustained liquid range explains its performance for critical infrastructure like airports, despite the high costs. [22]

It is important to distinguish between the eutectic limit (theoretical) of a material and its practical working temperature (performance in the field). Phase diagrams represent the ideal laboratory conditions where concentrations are perfectly maintained. In the field, two factors prevent achieving these theoretical limits. First, as ice melts on the road, it adds water to the solution, constantly diluting the chemical concentration and raising the freezing point. Maintaining the perfect eutectic ratio (e.g. 23.3 percent for rock salt) on an

[22] *L. Fay and M. Akin, Western Transportation Institute Montana State University,* Investigation of Alternative Deicers for Snow and Ice Control, *March 2018.*

active roadway is not possible. Second, while a chemical may theoretically work at its eutectic limit, the reaction often happens too slowly to be useful. For example, while sodium chloride can melt ice at -6°F, it would take hours to do so which would be too slow to improve road conditions for active traffic. Therefore, agencies use practical working temperatures to provide a necessary safety margin against refreezing and to ensure melting occurs within a reasonable timeframe.

Chloride-Based Materials

Chloride salts are the backbone of public winter maintenance programs because they are fairly abundant, reasonably priced, and have well established supply chains. While all chloride-based materials share a similar chemical mechanism of dissolving into a brine to lower the freezing point of water, their capabilities vary significantly based on their eutectic limits as described in the previous section. Descriptions of the chloride-based salts commonly used in winter maintenance operations are given below and a summary of attributes for each winter maintenance material is provided in Table 2.1.

Sodium Chloride

Sodium chloride (NaCl) is a granular product that has been the most common deicing agent used by public winter maintenance operations since the 1950s. This is due to its availability, lowest relative cost (see Table 2.2), and effectiveness for breaking the bond between snow or ice and road pavement. Sodium chloride is generally applied in two distinct forms:

Solid Rock Salt

Used for traditional deicing, rock salt requires adequate friction and heat produced from traffic to dissolve into a brine. Only when rock salt has dissolved into a brine can it begin to melt snow or ice. The theoretical performance of rock salt (see its phase diagram in Figure 2.2) indicates a eutectic limit of approximately -6°F, but practically in the field, the reaction is too slow at that low temperature to be operationally useful.

- Best Use: Rock salt is best utilized for traditional deicing on roadways with moderate to high traffic volumes where pavement temperatures are above 15°F. The heat and tire agitation from traffic are essential to crush the granules and generate the friction needed to create the melting brine. Rock salt is the standard material for treating roads after snow has already bonded to the pavement ("reactive" maintenance). To improve performance, rock salt is most effective when "pre-wet" with a liquid (such as salt brine or magnesium chloride) at the plow spinner during application, which jump-starts the melting process and helps the granules stick to the road.

- Limitations: The primary limitation of rock salt is its poor performance in cold temperatures, as its effectiveness plummets at pavement temperatures below 15°F and it effectively stops working at around 10°F. Additionally, dry rock salt is known to have significant bounce and scatter losses. One study showed that between 10 percent and 45 percent of dry salt applied to a roadway can bounce off the pavement into the ditch immediately upon application, depending on the speed of the salting truck.[23] Because solid rock salt relies on traffic to work well, it is often ineffective on low-volume rural roads. Environmentally, rock salt is highly corrosive to steel including on vehicles and bridges; degrades concrete through accelerated freeze-thaw cycles, and is harmful to soil health, vegetation, and aquatic life.

Salt Brine

The rate at which salt goes into solution can be accelerated in several ways. It can find moisture or liquid on the pavement surface to start the brine generation process, or a liquid can be added to the salt particles before they are placed on road surfaces.[24] Sodium chloride is increasingly used in winter maintenance in liquid brine form. Salt brine is simply a solution of rock salt dissolved in a specific ratio of 23.3 percent salt to 76.7 percent water. This specific concentration is critical because it matches the eutectic point of NaCl (see Figure 2.2), which yields the lowest possible freezing point of -6°F. If the concentration of NaCl is too low (diluted) or too high (supersaturated), the freezing point will rise rapidly, making the fluid less effective. While mined rock salt is often used to make brine, some agencies use "solar salt" for brine production. Solar salt is produced by evaporating seawater in open ponds and is typically more pure (99 percent NaCl) compared to mined salt. While solar salt is slightly more expensive than rock salt, the lack of impurities and insoluble material (dirt and grit) can significantly reduce sludge buildup in brine-making tanks and decreases equipment maintenance needs.

- Best Use: Salt brine is the primary tool for anti-icing applications and is typically applied approximately 24 hours before a storm. The brine prevents the snow-pavement bond from forming, making plowing significantly easier. It is also the standard agent for pre-wetting solid rock salt at the application spinner of a truck, which reduces bounce and scatter and jump starts the melting of ice. In some specific conditions, salt brine can be used for direct liquid application during a winter storm

[23] *Michigan Department of Transportation,* Salt Bounce and Scatter Study – Project Summary Report, *MDOT Operations Field Services Division, November 2012.*

[24] *U.S. Department of Transportation Federal Highway Administration,* Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel, *Publication No. FHWA-RD-95-202, June 1996.*

to melt falling snow instantly without the scatter of solid salt. Pre-wetting and direct liquid application will be discussed in further detail later in this Chapter.

- Limitations: Like rock salt, the practical operational use of salt brine is generally limited to pavement temperatures above 15°F. A critical risk of salt brine use is dilution. Because the brine is already 76.7 percent water, it can be quickly diluted by heavy snowfall or rain, losing its melting capability and potentially refreezing if the intensity of the snowfall overcomes the application rate. Furthermore, unlike calcium chloride, sodium chloride brine does not generate heat (it is endothermic) and can not easily punch through thick, compacted ice or hard snowpack. Salt brine therefore is best suited for prevention than for breaking up existing thick ice. Storage of salt brine can also be a challenge because the water can evaporate over time, altering its concentration and causing salt crystals to fall out of solution.

Magnesium Chloride

Magnesium chloride ($MgCl_2$) is commonly used to extend the operational range of winter maintenance chemicals into colder temperatures. This agent is exothermic (releases heat as it dissolves) and is hygroscopic, meaning it actively attracts and absorbs moisture from the air. Magnesium chloride is typically purchased and stored in liquid brine form (approximately 30 percent concentration) to avoid the hardening issues associated with its solid form. It is often used in a blend rather than a straight product.[25]

- Best Use: As shown in the comparative phase diagrams in Figure 2.2, magnesium chloride has a lower eutectic point than sodium chloride, remaining a liquid down to approximately -28°F, though the practical application is generally limited to pavement temperatures down to -10°F. Liquid magnesium chloride is an ideal pre-wetting agent as it has a slightly more oily consistency compared to the watery nature of salt brine which can help the coated salt granule adhere to the pavement, further reducing bounce and scatter losses. Additionally, because it is hygroscopic, once on the road, the magnesium chloride coating on pre-wetted rock salt can pull humidity from the air to keep the granule wet. Conversely, sodium chloride salt brine can dry out if the wind pics up or humidity drops, potentially causing the salt to return to a dry solid and blow away. Lastly, by coating rock salt in magnesium chloride (which has a lower practical working temperature), the salt crystal is enveloped

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[25] *Minnesota Pollution Control Agency, www.stormwater.pca.state.mn.us/how_salt_works_and_overview_of_deicing_chemicals, accessed December 2025.*

in a chemical that can allow it to burrow into the ice at temperatures where brine-wetted salt particles would freeze on the surface.

- Limitations: Magnesium chloride is more expensive than rock salt (see Table 2.2). While less corrosive to steel than rock salt, it can be more damaging to concrete. Because it is hygroscopic, magnesium chloride can also stay wet longer, potentially leading to slick conditions if not used correctly.

<u>Calcium Chloride</u>

Calcium chloride ($CaCl_2$) is the most aggressive low-temperature agent among the chloride-based winter maintenance chemicals. Unlike sodium chloride, which needs to absorb heat to dissolve, calcium chloride is exothermic, releasing heat when it contacts water. It is also hygroscopic, meaning it actively attracts and absorbs moisture from the air. Like magnesium chloride, calcium chloride is primarily purchased as a liquid for public winter maintenance operations (approximately 32 percent concentration).

- Best Use: Calcium chloride is often the preferred agent for emergency deicing in deep freeze conditions because its exothermic characteristics allow it to release significant heat when it touches water, allowing it to rapidly penetrate thick ice and hard-packed snow. Its phase diagram (see Figure 2.2) shows a very low eutectic limit, allowing it to remain in a liquid state down to approximately -60°F at 30 percent concentration. However, its lowest practical melting point is at pavement temperatures of -20°F.

- Limitations: Calcium chloride is the most expensive form of chloride salts and is therefore often used as a blend rather than a straight product (see Table 2.2). Calcium chloride is considered highly corrosive to steel and concrete, even more so than rock salt. Because it is hygroscopic, calcium chloride can also stay wet longer, potentially leading to slick conditions if not used correctly.

Non-Chloride Chemicals and Alternative Materials

Recent awareness and public concern about the negative impacts to infrastructure and the environment caused by using traditional road salts has led to the introduction of numerous alternatives and/or supplemental chemical substances/additives as additional tools for winter road maintenance. In scenarios where chloride-induced corrosion to infrastructure is unacceptable, or where natural areas are particularly sensitive, communities may choose to use alternatives to chloride products for winter deicing.

Acetates

Acetates are some of the most commonly used non-chloride deicing and anti-icing materials. Acetate-based agents are biodegradable and non-corrosive to structural steel, making them useful for bridge decks, airfield pavements, and environmentally sensitive areas. It should be noted however that some research has shown that acetates can exert some negative impacts to concrete and asphalt.[26] While chemically classified as organic compounds because of their carbon structure, acetates are synthesized industrial chemicals and are distinct from the "bio-based' agricultural additives discussed in the following section. Some states use acetates in designated no-salt zones. However, acetates are often considered cost-prohibitive for general municipal roadway maintenance as are usually used in specialized situations (see Table 2.2).

Potassium Acetate (KAc)

Typically applied as a liquid, potassium acetate offers excellent cold-weather performance, maintaining its liquid state at significantly lower temperatures than any chloride agent.

Its phase diagram (see Figure 2.2) shows a eutectic temperature of -76°F at high concentrations of approximately 50 percent, making it more reliable than rock salt or magnesium chloride in deep freeze conditions.

- Best Use: KAc is sometimes the choice for anti-icing critical bridges in low temperature situations because it is non-corrosive to structural steel (e.g., rebar), has a very low freezing point, and creates a reliable barrier without the risk of refreezing from concentration changes. Applications on bridge decks are sometimes deployed by Fixed Automated Spray Technology (FAST) systems that are remotely triggered by temperature sensors.

- Limitations: While KAc functions well in cold temperatures, it lacks the aggressive burn that calcium chloride provides in an emergency because it does not generate heat. It will melt ice with pavement temperatures as low as -15°F, but it is slower to act. While KAc is non-corrosive to structural steel, it can be aggressive toward galvanized steel components like guardrails and signposts, so managers should monitor these assets for accelerated corrosion when using this agent. KAc is often considered cost prohibitive for general municipal winter maintenance and is usually only reserved for targeted, high-value applications. Environmentally, acetates are safe for vegetation but can moderately increase biological oxygen demand (BOD) in nearby surface waters and cause temporary oxygen

[26] *Western Transportation Institute,* Field Usage of Alternative Deicers for Snow and Ice Control, *Transportation Research Synthesis Report 1706, September 2017.*

depletion in surface water during decomposition which can stress or suffocate aquatic life, although this is typically less than sugar-heavy agricultural by-products.

Calcium Magnesium Acetate (CMA)

CMA, which is often supplied in pellet form, functions differently than chlorides. Rather than creating a strong melting brine, CMA interferes with the physical structure of how the snow crystals interlock to prevent it from bonding to the pavement. This makes the snow easy to plow away, even though it has not technically melted the snow.

- Best Use: CMA is non-corrosive to structural steel and does not damage new concrete like rock salt can, so it is often specified for use on newly poured concrete (less than two years old). Some structural engineers mandate CMA for the top decks of parking ramps to protect steel rebar inside the concrete from corrosion caused by chloride products. Because CMA is biodegradable and generally safe for vegetation, it is a good option for roads passing through wetlands or near drinking water reservoirs where chloride contamination is a concern.

- Limitations: This agent has a practical working temperature of approximately 20°F, making it comparable to rock salt in temperature performance, but significantly slower acting, and requires more material by weight to achieve the same results. CMA is often considered cost prohibitive for general municipal winter maintenance and is usually only reserved for targeted, high-value applications. Environmentally, while CMA is safe for vegetation, it can moderately increase biological oxygen demand (BOD) in nearby surface waters and cause temporary oxygen depletion in surface water during decomposition which can stress or suffocate aquatic life, although this is typically less than sugar-heavy agricultural by-products. Therefore, while CMA is ideal for protecting wetland soil and plants, it should be used sparingly in areas where runoff drains directly into stagnant ponds or small streams.

Sodium Acetate (NaAc)

Sodium acetate is typically supplied as a solid pellet. Like other acetates, it is biodegradable and non-corrosive to structural steel and aluminum.

This agent has excellent melting properties that work at faster and at lower temperatures (effective for pavement temperatures down to 0°F) than sodium chloride.

- Best Use: It is primarily used in parking garages, airport pavements, and specialized bridge decks where a solid material is required to prevent liquid runoff issues, but chloride corrosion is unacceptable.

- Limitations: Sodium acetate is significantly more expensive than chloride salts but is usually slightly cheaper than CMA. Its effective temperature range is also more limited than potassium acetate. While it works on pavement temperatures down to 0°F, its performance has been found to slow considerably below 10°F. It can also leave a powdery residue on pavements after drying.

Formates

Formates are a class of non-chloride deicing and anti-icing materials that are chemically similar to acetates but are derived from formic acid rather than acetic acid. Formates show similar ice melting performance to acetates. Also like acetates, they are valued for being biodegradable and non-corrosive to structural steel and aluminum, making them appealing for use on airport runways and high-value bridge decks. It should be noted however that some research has shown that formates can exert some negative impacts on concrete, asphalt, and galvanized steel.[27] Formates are considered relatively new to the winter maintenance world compared to chloride salts and acetate-based deicers. Formates generally have a lower BOD profile compared to bio-based additives or acetates, making them attractive for use on pavements directly adjacent to sensitive waterways. Similar to acetates, formates can be cost prohibitive for large-scale public road maintenance operations (see Table 2.2).

Potassium Formate

Potassium formate (CHO_2K) is typically supplied as a liquid at approximately 50 percent concentration. It is considered an aggressive low-temperature deicer and has a similar phase diagram to potassium acetate, capable of remaining liquid below -60°F.

- Best Use: The practical working temperature is generally cited as -15°F to -20°F, making it a potentially viable non-corrosive alternative to calcium chloride for deep freeze conditions. Because formates generally have a lower BOD profile compared to bio-based additives or acetates, they can

[27] Ibid.

be particularly useful for airports or bridges directly adjacent to sensitive waterways. Formates do not accumulate in the water over a period of years and do not appear to be a groundwater threat.[28]

- Limitations: Usage in municipal winter maintenance is extremely low because it is currently cost prohibitive, running 15 to 20 times the cost of rock salt. This agent can be corrosive to galvanized steel and have damaging impacts to concrete and asphalt pavements.

Sodium Formate

Sodium formate (CHO_2Na) is chemically similar to potassium formate but is typically supplied as a solid granule or powder. Unlike sodium chloride, sodium formate is not corrosive to structural steel. However, this agent can be corrosive to galvanized steel, concrete, and asphalt.

- Best Uses: Sodium formate has a practical working temperature down to 0°F and is considered fast acting. Because formates generally have a lower BOD profile compared to bio-based additives or acetates, they can be attractive for airports or bridges adjacent to sensitive waterways. It is also used in complex operational areas such as parking garages where liquids are difficult to manage and chloride corrosion is particularly unacceptable.

- Limitations: Usage in municipal winter maintenance is low because it is currently cost prohibitive. This agent can be corrosive to galvanized steel and have damaging impacts to concrete and asphalt pavements, although impacts to pavement are less severe than sodium chloride.

Bio-Based Additives

Some winter maintenance agencies now use bio-based additives derived from agricultural or industrial processing by-products to bridge the gap between the low cost of sodium chloride salt and the high performance of engineered chemicals. While these products vary in form, they all function through the introduction of carbohydrates and sugars into the brine matrix. Bio-based products are rarely used as standalone deicers but are almost always blended with salt brine or other liquid chlorides (typically at brine/bio additive ratios of 80/20 or 90/10) to enhance the performance of the primary chemical. All bio-based products share two significant drawbacks. First, they can introduce an increased biological oxygen demand (BOD) in local waterways. When these organic materials runoff into surface waters, their

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[28] *Minnesota Department of Transportation,* Chloride Free Snow and Ice Control Material, *Transportation Research Synthesis Report 1411, October 2014.*

decomposition consumes dissolved oxygen, which can stress aquatic life if the runoff is concentrated enough. Second, because these are usually proprietary products, detailed data is often lacking for the manufacturing process or the specific chemical makeup of the ingredients.[29]

Beet Juice Blends

These products are derived from the desugaring process of sugar beets and are the most prevalent commercially available organic deicing additives. The sugars in the solution provide corrosion inhibition and viscosity (tackiness). When blended with chloride products, the organic molecules coat the chloride ions, significantly reducing the corrosive impact on winter maintenance fleet equipment and infrastructure by as much as 70 percent when compared to straight salt brine. Additionally, the dark color of the liquid can increase the "albedo effect," absorbing solar radiation to raise pavement temperatures faster than clear brines.[30]

- Best Use: Beet Juice blends are commonly used for anti-icing. The sticky nature of the juice prevents the brine from drying out and blowing away, allowing managers to apply liquid anti-ice blends days in advance of a winter storm with confidence that it will remain on the pavement. The addition of beet juice to a salt brine blend can also lower the practical working temperature of the brine to 0°F to 5°F.

- Limitations: The primary complaint regarding beet juice is staining. The dark, sticky liquid can leave a brown residue on roadways and track into public buildings or private garages, leading to public complaints. It can also have a strong, distinct odor that some residents find unpleasant. Environmentally, when this additive is washed off the roads and into local streams, its decomposition will consume dissolved oxygen and increase BOD which can stress or suffocate aquatic life.

Corn-Based Additives

These products are often sourced from the fermentation by-products of ethanol production (Condensed Distiller Solubles - CDS) or corn steepwater.

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[29] *National Cooperative Highway Research Program Transportation Research Board,* Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts, *2007.*

[30] *A. Muthumani, L. Fay, D. Bergner, X. Shi,* Understanding the Effectiveness of Non-Chloride Liquid Agricultural By-Products and Solid Complex Chloride/Mineral Products, *Montana State Western Transportation Institute, September 2015.*

Like beet juice, they are high in carbohydrates which interfere with ice crystal formation. They function similarly to beet juice but are often lighter in color.

- Best Use: They are valued for their ability to suppress the freezing point of salt brine and improve its adherence to the road surface. Because they are often lighter in color than beet juice, they are sometimes preferred in urban areas where the aesthetics of brown pavement staining are a concern.

- Limitations: Corn-based additives can suffer from settling issues in storage tanks if not regularly circulated which can lead to inconsistent mixtures. They can also have a distinct fermentation odor that can be noticeable to the public, similar to brewing or making bread. Environmentally, similar to other bio-based additives, these materials will consume dissolved oxygen when they are decomposed in local streams. This can increase BOD which can stress or suffocate aquatic life.

Cheese Brine

Cheese brine is a salty liquid waste product from mozzarella and provolone production that naturally contains sodium chloride, dairy solids, and whey proteins. When mixed with rock salt, the organic solids help the salt stick to the road, while the sodium chloride can add to the melting effect.

- Best Use: The primary value is cost savings. It is widely available in some parts of Wisconsin at little to no cost from local creameries wanting to dispose of the waste. This makes it an attractive option for budget-constrained municipalities.

- Limitations: Widespread use is limited by supply chain consistency. Unlike manufactured chemicals or blends, the salt content of cheese brine can vary batch to batch. Operationally, these cheese solids require significant filtration to prevent them from clogging spray nozzles on application equipment. Environmentally, cheese brine has an extremely high BOD profile due to the dairy proteins which can pose a higher risk to waterways than other additives if runoff is not carefully managed. Cheese brine also contains chloride, so its use does not eliminate chloride loading.

<u>Urea (Nitrogen-Based Additives)</u>

Urea, $CO(NH_2)_2$, is a synthesized organic compound that is almost exclusively applied as a solid granule that is similar to rock salt in appearance. Urea is most widely known for its use as a high-nitrogen agricultural fertilizer.

Unlike chloride-based deicers that often release heat or work quickly, urea functions through endothermic reaction (absorbing heat) and acts much slower than chloride agents.

- Best Use: Historically, urea has been the primary alternative used at airports and in specialized roadway applications where corrosion protection is the absolute priority. Because it is chemically non-corrosive to steel and aluminum, it was a popular choice for runways and parking structures before the introduction of acetates and formates.

- Limitations: Urea use in modern municipal operations has drastically declined or been eliminated due to a combination of poor performance and severe environmental risks. Performance wise, urea has a relatively high practical working temperature (generally limited to 20° to 25°F) and melts ice significantly slower than sodium chloride. Environmentally, the primary concern is nutrient loading. When runoff containing urea enters surface waters, it hydrolyzes into ammonia and nitrates. This acts as a fertilizer, leading to rapid eutrophication and algal blooms which then deplete dissolved oxygen in streams and lakes. Consequently, the USEPA and state agencies heavily discourage its use near waterways.

<u>Propylene Glycol</u>

Propylene glycol is a synthesized organic liquid that effectively lowers the freezing point of water and can melt ice on pavement temperatures down to -20°F.[31] It is most commonly associated with the aviation industry where it is the primary component of aircraft deicing fluids. It is non-corrosive to metal and concrete.

- Best Use: In municipal applications the use of propylene glycol is extremely rare and typically limited to Fixed Automated Spray Technology (FAST) systems to treat bridges that are susceptible to corrosion from chloride anti-icers (FAST systems will be discussed in more detail later in this Chapter). Some FAST systems utilize glycol because it does not corrode the automated nozzle mechanics, but many have switched to potassium acetate because it is cheaper, performs similarly or better, and has a lower BOD profile.

- Limitations: Glycols are generally not considered for spray applications on roadways because they can leave a slippery, oily residue on the pavement that reduces tire friction. Environmentally, they

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[31] *MnDOT Transportation Research Synthesis Report 1411, October 2014,* op. cit.

have an extremely high BOD profile, which can deplete oxygen in local waterways and harm aquatic life. Additionally, the cost of propylene glycol is prohibitively high for general road maintenance compared to chloride or acetate alternatives (see Table 2.2).

Abrasives

Unlike the chemical deicers discussed previously, abrasives do not melt snow or ice. Instead, they are strictly traction agents, increasing friction on snow- or ice-covered roadway surfaces to allow tires to better grip the ice layer. Sand is the most common abrasive used in public winter maintenance operations in the Region, although some agencies may use crushed aggregate or volcanic grit. To maximize grip, municipalities typically specify "sharp" or "angular" sand rather than smooth river sand. Because sand relies on friction rather than a chemical reaction, it is the only material discussed in this Chapter that remains effective when pavement temperatures drop below -20°F, when other chemical agents fail. While it works at any temperature, a small amount of salt is commonly blended into a sand pile to prevent the moist sand from freezing into solid chunks during storage.

Because sand is chemically inert, it does not cause corrosion to steel or concrete. However, the high-velocity impact of sand particles can physically chip paint and windshields on vehicles. At roughly $25 to $35 per ton, sand is the cheapest material by volume that has been discussed, but when factoring in the required spring cleanup (street sweeping, cleaning catch basins) and disposal fees, the total operational cost of sand can exceed that of rock salt. Sand does not dissolve, so in addition to collecting in storm sewers and ditches, when it runs off into waterways, it settles on the stream bottoms and can smother critical aquatic habitats and fish spawning grounds. Additionally, as traffic grinds the sand into fine dust, it can become airborne particulate matter and contribute to urban air pollution. Finally, while sand improves traction when it is applied on top of snowpack or ice, it can greatly decrease traction when resting directly on pavement.

In southeastern Wisconsin, the use of abrasives has declined significantly, particularly in urbanized areas due to the high cost of post-winter cleanup, MS4 storm water compliance requirements, and environmental impacts. However, it remains a critical tool of last resort for emergency traction during extreme cold (below -20°F) and for ice storms. It is also used for managing rural roadways where low traffic volumes prevent the friction and mixing necessary for rock salt to be effective.

Winter Maintenance Material Blends

Modern public winter maintenance operations often use blends of multiple materials to maximize performance while reducing costs, material waste, and environmental impact. Blends allow agencies to move beyond the limitations of single-material strategies, such as dry rock salt, by combining complementary properties of different agents. While specific blending ratios often vary by agency based on local experience and resources, most begin with a base material (either rock salt or salt brine) and incorporate performance enhancers tailored to specific conditions such as pavement and air temperature and temperature trends, specific precipitation types and moisture content, and traffic volume.[32] Many agencies will also supplement these strategies with proprietary products, using them either as standalone treatments or as ingredients to enhance the performance of standard blends.[33]

Liquid Brine Blending (Liquid Blends)

Liquid blends are widely used for anti-icing and deicing applications. They can be applied directly to pavement as a Direct Liquid Application (DLA) or used to pre-wet solid rock salt before spreading. The application methods of DLA and pre-wetting will both be described in detail later in this Chapter. Common categories of liquid brine blending include a "hot mix," organic-enhanced brine, and triple blends.

<u>The Hot Mix</u>

A hot mix combines standard sodium chloride brine (23.3 percent) with magnesium chloride ($MgCl_2$) or calcium chloride ($CaCl_2$) to extend performance in colder conditions. Magnesium and calcium chloride have lower eutectic points and release heat as they dissolve, improving melting speed when pavement temperatures fall below the effective range of plain salt brine. Typical ratios include 90/10 (brine to $MgCl_2$ or $CaCl_2$) for moderate cold and 80/20 for extreme cold.[34] Ratios above 20 percent $MgCl_2$ or $CaCl_2$ are rare due to cost and diminishing returns. However, as with most of the blends discussed in this section, these ratios may vary slightly depending on operator preferences and experience.

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[32] *For the most current and detailed information for specific blends, including appropriate blends and application rates for specific conditions, and impacts of each see: University of Wisconsin-Madison Traffic Operations and Safety Laboratory,* Expanding Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-Icing, *Clear Roads Report No. CR 19-01, December 2021.*

[33] *For information on proprietary products that are environmentally approved and meet minimum corrosion-reduction standards, see Pacific Northwest Snowfighters and Clear Roads "Qualified Product List', December 4, 2025 and Minnesota Department of Transportation Office of Maintenance "Winter Chemical Catalog," October 2015.*

[34] *University of Wisconsin-Madison Traffic Operations and Safety Laboratory Clear Roads Report No. CR 19-01, December 2021,* op. cit.

Organic Enhanced Brine (Adhesion and Corrosion Blend)

This blend adds bio-based additives, such as beet juice or corn-derived products, to standard brine. These additives increase viscosity, helping the liquid to adhere to pavement and resist wind or traffic displacement. They also provide corrosion protection by forming a barrier on metal surfaces, reducing damage that chloride can cause by up to 70 percent compared to straight rock salt.[35] In addition, while the bio-based additives do not significantly increase melting power, they can improve brine stability and interfere with the formation of ice crystals, preventing a hard bond between the ice and the pavement.[36]

The ratios for organic-enhanced brines vary depending on whether an agency is focused on adhesion, corrosion protection, or cost-efficiency. The most common ratio used primarily to improve the stickiness of the brine is 90/10 (brine to bio-based additive). When the focus is corrosion mitigation, an 80/20 blend may be used.

Triple Blends

Triple blends are sometimes referred to as "super mixes" and combine all three components: salt brine, a hot chloride ($MgCl_2$ or $CaCl_2$), and a bio-based additive. The magnesium or calcium chloride component lowers the freezing point and accelerates melting, while the organic additive improves adhesion and corrosion resistance.

Common ratios of the triple blend include 80/10/10 (salt brine/ $MgCl_2$ or $CaCl_2$/bio-based additive) for general use and 70/20/10 for extreme cold.[37] Notably, $MgCl_2$ and $CaCl_2$ both attract water, which can sometimes make the road greasy or wet in high humidity. The bio-based component of the super mix can help buffer this effect, creating a more stable product on the pavement.

Treated/Pre-Wetted Rock Salt

Modern public winter maintenance increasingly relies on a solid/liquid hybrid known as pre-wetted or treated rock salt. This blend is essentially a delivery system that combines the bulk melting of granular salt with the fast-working chemistry of liquid deicers. While standard salt brine is the most common pre-wetting

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[35] *Montana State University Western Transportation Institute,* Benefit-Cost of Various Winter Maintenance Strategies, *Clear Roads Report No. CR13-03, September 2015.*

[36] *Minnesota Department of Transportation*, *Transportation Research Synthesis Report 1411, October 2014,* op. cit.

[37] *B. Claros, M. Chitturi, A. Bill, W. Nixon, and D.A. Noyce, December 2021,* op. cit.

agent, agencies often utilize hot mixes or organic-enhanced brine to improve the temperature range and stability of the blend.[38]

While traditional industry practice has called for adding 8 to 14 gallons of liquid per ton of solid rock salt, recent guidance—including standards from Wisconsin Salt Wise—recommends rates of 15 or more gallons per ton to further reduce total chloride application.[39] Furthermore, a more aggressive form of pre-wetting, known as "Shake and Bake," increases the liquid ratio to 40 or more gallons per ton of rock salt. The Shake and Bake application method aims to apply a fast-acting oatmeal-like slurry mixture of rock salt and brine to the road surface. In both application methods, the higher liquid ratio transforms the dry salt into a heavier and tackier material. This physical change is critical for these application techniques, as it alters how the material behaves when it exits the spreader (application techniques will be described in more detail later in this Chapter).

Dry rock salt is inherently endothermic, meaning it must absorb heat and moisture from its surroundings to dissolve into a brine before melting can occur. On cold and dry pavements, this process can take significant time, causing delays in clearing times. By pre-wetting the rock salt, the liquid coating provides the necessary moisture immediately and the melting process begins instantly upon contact with the road surface.[40] When the liquid treating the rock salt is a "hot mix", the blend becomes exothermic, releasing a heat-boost that allows salt crystals to burn through thick ice or snowpack more efficiently than dry salt granules.

Treating rock salt with organic-enhanced brines can also provide advantages. The complex sugars in these agricultural by-products increase the viscosity and stickiness of the pre-wetted rock salt, ensuring the liquid stays bonded to the salt granule during transport and prevents it from being stripped off by wind as it is thrown from the spreader. The bio-based component also helps the resulting slurry mixture stay on the road surface longer and resists the wash off effect that can be caused by melting snow and passing traffic.

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[38] *X. Shi, D. Bergner, S. Du, D. Keep, and C. Reed,* Review and Summary of Pre-Wet Methods and Procedures, Clear Roads Report No. CR 18-04, *Washington State University and Minnesota Department of Transportation, June 2021.*

[39] *Wisconsin Salt Wise, Road Deicing Application Rate Chart, 2024.*

[40] *X. Shi, D. Bergner, S. Du, D. Keep, and C. Reed, June 2021,* op. cit.

Winter Maintenance Material Storage and Handling

Properly managing the storage and handling of winter maintenance materials is a critical component of controlling chloride pollution. In southeastern Wisconsin, municipal and county yards may sometimes be located in close proximity to local waterways, making facility design that is focused on total containment and the elimination of point-source runoff essential.

Solid Salt Storage

Modern solid material storage aims to maintain the chemical integrity of deicing products while eliminating losses caused by leaching, vehicle tracking, or wind drift.

Wisconsin Salt Storage Regulations

The storage of bulk rock salt in Wisconsin is strictly regulated by Chapter Trans 277 of the *Wisconsin Administrative Code,* titled "Highway Salt Storage Requirements". This regulation establishes the mandatory standards for the storage of salt and sand-salt mixtures to prevent the contamination of both surface water and groundwater. The code applies to any person or agency storing bulk quantities of 1,000 pounds or more of sodium chloride, calcium chloride, or sand-salt mixtures containing more than 5 percent salt.

- Structure, Cover, and Pad Requirements: Rock salt and other solid materials are required to be housed within fully enclosed buildings or protected in a fully covered pile. Storage buildings must have walls and a roof designed to prevent contact with precipitation and protect the stockpile from wind erosion. If stored outdoors, the salt pile must be protected by an impermeable cover with sealed seams that is securely weighted or tied down. Only the "working face" of the outdoor salt pile may be exposed during active removal. In either case, salt must be stored on a base of asphalt, concrete, or another impermeable material designed to prevent salt or brine from infiltrating into the soil or groundwater. This base must be regularly inspected and maintained to remain free of cracks.

- Drainage and Runoff Control: Storage sites may not be located within 50 feet of the ordinary high-water mark of any lake or stream. It is important to note that many southeastern Wisconsin communities enforce stricter shoreline zoning ordinances, often requiring a 75-foot setback. Facilities must be designed to divert clean water (rain, snowmelt, and terrain runoff) away from the material storage area. Any precipitation that contacts the material or the loading pad must be directed into a holding basin with sufficient capacity to contain the runoff for proper management.

- Spillage: Any spill outside the covered structure must be immediately recovered and returned to the storage structure.

- Record Keeping and Inspection: Agencies are legally responsible for the inspection and maintenance of their facilities. They are required to maintain written records for six years, including facility locations, monthly minimum and maximum quantities of salt stored, and inspection results. Any site abandonment or closure must be reported to WisDOT within 10 days.

Solid Salt Storage BMPs

Effective solid salt storage is a cornerstone of modern winter maintenance, balancing functionality of the operation with protection of the environment. By prioritizing sufficient capacity, robust containment, and strategic facility design, agencies can operate efficiently while significantly reducing the risk of chloride contamination in local waterways and groundwater. The following best management practices outline the industry standards for facility construction and operation.

- Capacity and Inventory Management:
  - Facilities should be sized to hold 110 percent to 150 percent of the agency's average annual salt usage to allow for early summer purchasing and to buffer against severe winters.
  - WisDOT specifically targets a county storage capacity of 125 percent of the average annual usage based on the past five winters.
- Structure Design and Orientation:
  - Vertical Storage: High-clearance structures, such as high-arc gambrel sheds, fabric hoop buildings, and reinforced concrete domes, maximize vertical volume while minimizing the facility's footprint (see Figure 2.3).
  - Enclosed Loading: Modern storage structures provide enough vertical clearance for loaders to operate entirely inside the building, which prevents the tracking of salt into the yard, a primary source of chloride runoff at storage facilities.[41]

[41] *Clear Roads Report No. CR13-03, September 2015,* op. cit.

- Access Dimensions: Door openings should be at least 20 feet wide to accommodate the safe and easy access of front-end loaders and dump trucks.[42]

- Weather Protection: Building openings should be faced away from prevailing winter winds. For southeastern Wisconsin this typically means avoiding north or west exposures. Structures can be further sealed using industrial curtain doors or storm vestibules.[43]

- Pavement Base and Containment:

  - Salt storage bases must be impermeable surfaces and engineered to withstand the corrosiveness of chlorides and heavy machinery loads.

  - High-density asphalt is preferred over standard concrete due to its better corrosion resistance and flexibility during freeze-thaw cycles.

  - A waterproof geomembrane liner installed beneath the asphalt pavement floor can serve as a final safeguard against brine infiltrating through microscopic cracks in the pavement.

- Drainage and Runoff Control:

  - Sewer Isolation: Floor drains in salt storage areas should never have a direct connection to the sanitary or storm sewer systems.

  - Diversion: Earthen berms or concrete curbing should be installed on the up-gradient side of the facility to redirect clean stormwater around the salt storage pad.

  - Leakage Collection: In highly sensitive areas, under-drain collection systems (also known as a leakage collection and detection systems) can be installed beneath the asphalt pad to intercept and remove any brine that leaches through the pavement.

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[42] *The Salt Institute,* Salt Storage Handbook: Practical Recommendations for Storing and Handling Deicing Salt, *2015.*

[43] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual, *2023.*

- Traffic and Tracking Control:
  - Sites should utilize one-way traffic patterns to restrict where salt is tracked by vehicles.
  - Heavy-duty rumble strips or shaker grates at loading facility exits help vibrate loose salt off truck undercarriages before vehicles enter the public roads.
- Conveyor Loading Systems: For tall structures, using belt conveyors to load the salt pile is safer and more efficient than driving loaders onto the salt, as it reduces material compaction.
- General Operational Housekeeping:[44]
  - High output lighting is necessary inside the storage facility to ensure operators can effectively identify and clean up spills.
  - Roofs must be inspected regularly, as leaks can dissolve salt and create brine runoff.
  - Spilled salt should be swept or shoveled back into the pile immediately.
  - The loading apron outside the shed must be swept regularly to ensure that tracked salt does not dissolve during precipitation events.
  - Snow plowed from the yard or loading area should be stored on impermeable pad so that any salt-contaminated meltwater is contained.
  - Agencies should follow a "first-in, first-out" inventory strategy to prevent salt from hardening into blocks over time.
  - At the end of the season, any remaining salt should be consolidated and covered with a heavy tarp (even if stored inside a shed) to protect it from the summer humidity.

[44] Ibid.

Liquid Storage and Handling Systems

As southeastern Wisconsin communities transition towards high-liquid winter maintenance strategies, the capacity and complexity of liquid storage have increased. In Wisconsin, liquid winter maintenance materials are generally regulated under Chapter Trans 277 of the *Wisconsin Administrative Code*. While the code only explicitly discusses liquid calcium chloride storage and does not provide prescriptive construction standards for other liquid storage (unlike the detailed requirements for solid salt sheds), it mandates that any substance regulated by the WDNR be stored in facilities that "prevent the entry of that substance into the waters of the State." Additionally, under Chapter NR 216 of the *Wisconsin Administrative Code,* municipal and industrial storage sites must prevent illicit discharges of brine or any other liquid winter maintenance materials to storm water systems.

While many local agencies still operate effectively with low-tech liquid brine production and storage, the state-of-the-art management has moved toward highly automated and integrated systems designed to maximize precision and environmental safety. Because no single solution fits every municipality, agencies often adopt modular configurations that can be scaled based on specific needs and available funding (see Figure 2.4). These advanced systems focus on maintaining product consistency while providing safeguards against accidental spillage.

Advanced Storage Tank Technology

The foundation of a modern liquid storage facility is the selection of tanks that provide long-term durability and prevent leaks. While traditional single-walled tanks are still commonly used, modern facilities are moving toward multi-layered containment systems that reduce the risk of catastrophic failure.

- Double-Walled Construction: The modern industry standard for environmentally sensitive areas are high-density cross-linked polyethylene (XLPE) double-walled tanks. XLPE tanks offer superior stress crack resistance, impact strength, and chemical compatibility (non-corrosive).[45] The double-walled units essentially have a "tank within a tank" design, which provides built-in secondary containment and eliminates the need for external concrete dikes.

- Space Optimization: Advanced liquid storage sites often use vertical tank arrangements to maximize total storage capacity while maintaining a small footprint.

[45] *Montana State Western Transportation Institute,* Best Management Practices for Liquid Chloride Storage and Pumping Systems, *Clear Roads Report No. CR 22-02, December 2024.*

- UV Stabilization and Monitoring: While indoor storage is ideal for extending the life of a tank, outdoor tanks should be placed in areas with minimal direct sunlight to reduce ultraviolet (UV) damage. Operators must regularly inspect tanks for "chalking" which is a physical symptom of UV degradation and an indicator that a tank may be reaching the end of its service life. The life expectancy of liquid storage tanks typically ranges from 15 to 25 years and regular storage tank replacement plans can help reduce the chance of catastrophic failure.[46] Some modern state-of-the-art tanks now include UV inhibitor additives that can potentially increase the lifespan of the tank.

Precision Liquid Material Pumping and Blending Systems

Modern liquid facilities are able to accurately move and mix chemicals rather than just store them. High-flow hardware and intelligent controls ensure that concentrations are optimized for pavement temperatures while also loading trucks quickly (see Figure 2.5).

A common feature of state-of-the-art pumping systems is variable flow capability, which utilizes variable frequency drives (VFD) to modulate pump motor speed. Unlike fixed-speed pumps, variable flow allows for:

- Custom Blending: The system can accurately dial in specific ratios when mixing different liquid materials (e.g., salt brine and calcium chloride) to create custom blend ratios.

- Mechanical Longevity: Modulating the flow reduces the mechanical stress on plumbing and can extend the life of seals and gaskets.

- Loading Flexibility: High-volume centrifugal pumps can be adjusted to load larger tankers at maximum speed while slowing down for smaller truck tanks to prevent splashing and overfilling.

- Stratification Prevention: The control system can run the pumps at lower, energy-efficient speeds during scheduled circulation cycles to prevent heavier chemical components from settling at the bottom of the tank.

Advanced pumping stations sometimes use automated controls, such as programmable logic controllers (PLC), to maintain product consistency. By moving the deicing materials at set intervals, the system helps prevent stratification. Additionally, in-line blending technology now allows operators to mix multiple

[46] Ibid.

products during the loading process itself, creating custom blends for specific storm or pavement conditions.

Remote Monitoring

The integration of specialized sensors and cloud-based software provides real-time oversight of material inventories and environmental compliance. Modern storage tank systems are equipped with electronic level sensors that can provide very accurate volume readings. These systems can be programmed with automated alarms that can send alerts to staff if a leak is detected in a tank wall or if inventory levels of a material fall below a critical point. Additionally, digital flow meters can provide accurate data on how many gallons are loaded into each individual truck, which can greatly improve accuracy for record keeping and justifying salt-reduction efforts.

Environmental Protection and Contaminant BMPs

State-of-the-art facilities are designed with the assumption that equipment will eventually fail, making secondary physical barriers to protect surface water and groundwater resources critical for protecting surface and groundwater.

For facilities using single-walled storage tanks, modern containment can involve a concrete basin that surrounds the tanks. This dike-like structure is typically designed to hold between 110 percent and 125 percent of the volume of the largest tank within this basin. Additionally, advanced pumping stations and outdoor tanks should be shielded by industrial-grade bollard poles to prevent them from being accidentally struck by vehicles. Finally, maintenance and seasonal shut-down protocols are critical, including the thorough flushing of all pumps and pipes with fresh water during the off-season to prevent corrosion or chemical crystallization.

Salt-Laden Water Reclamation and Reuse

As described previously, the most effective facility management strategies are to prevent stormwater from becoming salt-laden in the first place. By implementing the solid storage BMPs discussed in the "Solid Salt Storage" section that aim to "keep clean water clean," agencies can significantly reduce the volume of salty runoff that requires handling. However, for the salt-laden stormwater runoff at storage facilities that cannot be avoided and for truck wash water, moving toward a chloride recovery model is a strategy that some modern facilities are exploring and implementing.

This strategy transitions from viewing salt-contaminated water as a waste product to treating it as a resource. State-of-the-art facilities are being designed to capture and recycle both the wastewater generated during winter maintenance vehicle wash-downs and the salt-laden stormwater runoff from storage yards. Traditionally, these contaminated water sources presented significant disposal challenges. For example, the State of Virginia Department of Transportation (VDOT) historically captured approximately 30 to 60 million gallons of contaminated runoff annually from their salt storage facilities and the disposal costs were millions of dollars each year.[47] Rather than discharging this water into sanitary sewers or the environment (which would likely be considered an illicit discharge under *Wis. Admin. Code NR-216*), advanced facility design can use internal floor slopes and external collection ponds to funnel all salt-laden water into a centralized reclamation system. Research from MnDOT[48] and VDOT[49] has shown that captured salt-contaminated water can be an ideal "pre-charged" water source for making salt brine for winter road treatment. By reusing the existing chloride found in this runoff and wash water, agencies can reduce both the volume of freshwater required and the amount of new rock salt needed to produce a standard 23.3 percent brine solution.

For larger-scale recycling of stormwater runoff from salt storage facilities, the VDOT study suggests that minimal filtration was necessary. In the study, untreated water from containment ponds was filtered only with a coarse filter (mesh size 80) to remove large debris before being pumped into the brine maker. The study found that the raw stormwater introduced less total suspended solids (TSS) and turbidity into the brine making process than did the raw rock salt typically used to produce the brine. The study found that the optimum conditions for efficient brine generation using the captured runoff involved using high flow rates and maintaining higher water temperatures. While less efficient, even the colder water temperatures typical of winter storage ponds were still viable for brine production. The study also found that the high salt concentration in the produced brine acts as a natural flocculant, promoting the rapid settling of fine particles within the tank. By allowing the final brine product to settle for approximately four hours, the study found that turbidity reductions of greater than 95 percent could be achieved, resulting in a high-quality product that was safe for application equipment.

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[47] *G.M. Fitch, V.O. Craver, J.A. Smith,* Recycling of Salt-Contaminated Stormwater Runoff for Brine Production at Virginia Department of Transportation Road-Salt Storage Facilities, *Virginia Transportation Research Council Research Report VTRC 08-R17, May 2008.*

[48] *S. Heger, J. Doro, M.C. Rutter, D. Gustafson, and S. Larson,* Investigating Wastewater Reuse at MnDOT Truck Stations, *MnDOT office of Research and Innovation Report 2019-22, May 2019.*

[49] *Virginia Transportation Research Council Research Report VTRC 08-R17, May 2008,* op. cit.

Winter maintenance truck wash water typically contains a higher level of organics and TSS that must be filtered out to prevent damage to brine production equipment or the clogging of nozzles. The MnDOT study explored the feasibility of capturing and utilizing truck wash wastewater for brine production and evaluated technologies to remove organics and TSS from wash-water while allowing the beneficial chlorides to remain. The research showed that both recirculating sand filters (RSF) and membrane bioreactors (MBR) would be feasible technologies to use for this purpose. The study determined that the MBR method would be the most cost-effective long-term solution for high volumes of truck wash water, as they effectively remove organics and solids with lower installation and maintenance costs than a traditional RSF. Additionally, MBR units offer a smaller physical footprint, making it easier to integrate into existing facility designs.

The economic justification for recycling salty runoff was found to be significant. The VDOT study showed that for agencies that faced high disposal costs, recycling stormwater for brine production can pay off the initial equipment investment in two to four years. By combining advanced reclamation techniques with thorough source control BMPs, winter maintenance facilities can effectively eliminate illicit salty discharges into local waterways and groundwater, while saving on material costs.

Anti-Icing/Pretreatment

A significant advancement in winter road maintenance is the shift from reactive deicing to proactive anti-icing. Anti-icing involves applying a freezing point depressant (typically a liquid sodium chloride brine) to dry pavement before a forecasted snow or ice event. Unlike deicing, the primary goal of anti-icing is not to melt accumulated snow or ice, but to prevent a strong bond from forming between frozen precipitation and the road surface.[50] By establishing a chemical barrier on the pavement surface, this strategy jumpstarts the melting process as soon as snowfall begins. MnDOT estimates that removing ice or snowpack after it forms (deicing) requires approximately ten times more energy than preventing its initial formation through anti-icing.[51] Studies have also shown that this proactive approach makes mechanical removal more effective, reducing the total "time-to-bare-pavement" by an average of 12 percent, or approximately two to three hours per storm event.[52]

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[50] *Wisconsin Department of Transportation Bureau of Highway Maintenance,* Highway Maintenance Manual, *September 2025.*

[51] *Minnesota Department of Transportation,* MnDOT Anti-Icing Guide, *September 2010.*

[52] *B. Claros, M. Chitturi, A. Bill, and D. Noyce,* Evaluation of Winter Maintenance with Salt Brine Applications in Wisconsin, *University of Wisconsin Traffic Operations and Safety Laboratory, December 2021.*

Anti-icing can improve traffic safety while reducing financial and environmental costs. Liquid anti-icing agents are generally preferred because they adhere to the road surface more efficiently than dry rock salt. This strong adherence minimizes material loss from bouncing, wind blow-off, or traffic spray, ensuring the chemicals can function more effectively and efficiently.[53]

The shift to liquid brine based anti-icing programs can reduce total winter salt usage by 20 percent to 50 percent, providing cost savings for the agency while drastically reducing the volume of chloride entering the environment. When mixed into liquid form, $1,000 of road salt can safely treat 224 lane-miles compared to 86 miles in granular form.[54] Although outfitting a truck for liquid application requires an upfront investment of approximately $2,000 to $30,000,[55] many agencies achieve a full return on their investment within a single winter season solely through salt savings. In addition to material cost savings, modern anti-icing programs can also save agencies money on labor costs. Because it is a proactive strategy, anti-icing can usually be performed during regular shifts before a forecasted storm hits, reducing the need for emergency overtime during the initial hours of a weather event.

Anti-Icing Application Techniques

Successful anti-icing operations depend on detailed procedures to ensure that materials are applied under optimal environmental conditions. The following framework from WisDOT outlines important considerations for effective anti-icing operations.[56]

- Timing: Best time to apply is generally 12 to 18 hours prior to a predicted frost, ice, or snow event. This allows the brine to dry and properly adhere to the pavement before precipitation starts. Some agencies will apply anti-icing agents up to 24 to 48 hours in advance of the precipitation, particularly if it allows the work to be done during ideal traffic periods.[57] However, forecast models should be in relatively strong agreement that the precipitation will occur so chemical agents are not unnecessarily applied. Ideally, agencies aim to apply during non-overtime hours to minimize costs.

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[53] *Wisconsin Transportation Information Center LTAP, UW- Madison, Department of Engineering, "Wisconsin Transportation Bulletin No. 22: Pre-wetting and Anti-Icing – Techniques for Winter Road Maintenance, December 2005.*

[54] *Wisconsin Salt Wise, "Success Stories," www.wisaltwise.com/Success-Stories, accessed March 4, 2026.*

[55] *Costs represent 2024 dollars.*

[56] *WisDOT Bureau of Highway Maintenance, 2025,* op. cit.

[57] *Washington State University, Clear Roads Report CR15-01, April 2019,* op. cit.

- Temperature: For sodium chloride brine, optimal application occurs when pavement temperatures are at or above 20°F or are forecast to rise above this threshold. Most anti-icing materials rapidly lose effectiveness at pavement temperatures below 15 or 20°F. When temperatures fall below this threshold, other chemicals can be used alone or added to the sodium chloride brine to improve performance, as described previously in the "Winter Maintenance Material Blends" section.

- Traffic: Ideal application times are during periods of low traffic volume. High traffic volume can prematurely remove the anti-icing residue before the storm arrives, necessitating reapplication.

- Material Preference: While pre-wetted salt can technically be applied prior to a winter storm event (i.e. an anti-icing application), liquid agents are preferred due to greater effectiveness and less waste. Sodium chloride brine is the most common and economical anti-icing agent; however, weather factors such as temperature and wind can impact the selection of optimal anti-icing agents, as described previously in the "Snow and Ice Control Materials" section.

- Residual Effect: Dried liquid agents can remain on pavement for up to four days if not diluted. However, without reapplication re-freezing may occur if rain, snow, or moisture from the air dilutes the residual agent.

- Streamer nozzles (also known as "drip" or "pencil" nozzles) are preferred over fan-style nozzles because they produce larger droplets that resist wind drift. Brine is most commonly applied in a "wet/dry" striping pattern. This pattern places parallel lines of liquid along the driving lane, typically spaced 8 to 12 inches apart (see Figure 2.6). By leaving dry pavement between the liquid stripes, surface friction is maintained for vehicles while ensuring the brine has sufficient volume to creep laterally and break the ice bond once the storm begins.

- When applying anti-icing material after extended dry periods with no rain or snow events, application rates should be reduced, particularly during the late fall or early spring seasons when pavement temperatures are warmer. Application of a liquid on a pavement surface that contains buildup of oil-based and rubber residues can lead to a slick surface.

- Anti-Icing should **not** be conducted:
  - Prior to forecasted rain or freezing rain events, as the material can easily be washed away and become ineffective.
  - When winds are greater than 15 mph because wind can draw moisture to the roadway and lead to refreeze. This is particularly true when using magnesium or calcium chloride blends.
  - When there is high potential for blowing and drifting snow because liquid agents can cause snow to stick to the roadway.

WisDOT provides operations managers with an anti-icing decision flow chart (see Figure 2.7) to determine if conditions are suitable for application.

Fixed Automated Spray Technology (FAST) Systems

FAST systems consist of permanently installed spray nozzles and sensors that are typically deployed on bridges, which are often the first locations to become slick or icy. These systems utilize real-time atmospheric and pavement data to automatically apply liquid anti-icing chemicals (often potassium acetate) at the precise moment surface conditions threatened to reach the frost or freeze point. After spraying, the system continues to monitor pavement conditions and can reapply as needed. This material delivery system eliminates the lag time associated with dispatching maintenance crews.

FAST systems generally operate either fully automatic, semi-automatic, or manual mode. Fully automatic systems activate without human intervention based on pre-set sensor thresholds and are ideal for remote bridges that freeze rapidly. Semi-automatic systems alert a supervisor or dispatcher when conditions are met, and the operator must remotely authorize the spray command via computer or mobile interface. Finally, manual systems need operators to trigger the system based on weather forecasts, similar to how they would dispatch a truck for pre-storm anti-icing.[58]

[58] *Washington State University,* Synthesis of Material Application Methodologies for Winter Operations*, Clear Roads Project 15-01, April 2019.*

Advantages of FAST anti-icing systems include:

- Immediate response and activation can eliminate the travel time of a maintenance truck, preventing the snow or ice bond as soon as conditions become treacherous.

- Reduces the need for overtime and specialized "bridge crews" for truck anti-icing operations.

- Studies have shown a 50 percent to 66 percent reduction in friction-related accidents on bridges equipped with FAST systems.[59, 60]

Challenges of FAST systems include:

- Nozzles can become clogged with road debris or damaged by cars or snowplows. The system requires regular flushing and sensor calibration. While some flushing can occur remotely on some systems, other maintenance requires on-site crews.

- Systems are expensive.

- If sensors are not calibrated correctly, the system may over-spray, leading to unnecessary chemical runoff or creating a slick surface if the brine concentration is too high for the current temperature.

- These systems are not recommended to be used with wind speeds greater than 15 mph and may not be as effective in treating heavy snow.[61]

Deicing Operations

From the beginning of winter road maintenance operations, the primary mission has been to improve the friction between vehicle tires and the pavement. Historically, this was accomplished through snow plowing and application of abrasives such as sand. In the 1950s, winter maintenance operations shifted toward

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[59] *Western Transportation Institute,* Benefit-Cost Analysis of CDOT Fixed Automated Spray Technology (FAST) Systems, *October 2014.*

[60] *S. Birst and M. Smadi,* Evaluation of North Dakota's Fixed Automated Spray Technology Systems, *Advanced Traffic Analysis Center Upper Great Plaines Transportation Institute, October 2009.*

[61] Ibid.

chemical maintenance with sodium chloride rock salt to break the bond of accumulated and packed snow. State-of-the-art deicing operations rely on the strategic application of the right material, in the right place, at the right time to achieve the intended results. These precision deicing application strategies are based on significant amounts of scientific data and studies to provide effective results while minimizing material waste.

Deicing Application Techniques

While anti-icing applications are proactive and designed to prevent ice or snow from bonding to pavement, deicing is a reactive strategy that is used when snow or ice has already bonded to the roadway surface. Deicing techniques are focused on breaking the existing bond between the frozen material and the roadway surface. Modern winter maintenance operators understand that deicers are not intended to melt all the snow or ice on a roadway but are best used to penetrate through the snowpack and create a brine layer that lies below the accumulation so it can be efficiently removed by mechanical plowing. The selection of a specific technique and best application rate is determined by complex relationships between pavement temperatures, precipitation type and intensity, and level of service goals.

Straight Rock Salt Application

In winter maintenance, dry rock salt is the most used chemical agent. The primary goal of applying rock salt is to penetrate the snowpack or ice and reach the pavement surface. When it reaches the pavement surface, the salt begins to dissolve and a brine is formed that breaks the bond between the road and the frozen material. This method is very effective and economical for deicing operations when pavement temperatures are above 15°F to 18°F. As described in the "Snow and Ice Control Materials" section, dry rock salt requires existing moisture to activate into a brine.

When dry granular salt is applied to roadways at high speeds, a significant amount of material (approximately 30 percent or more) can be lost due to bounce and scatter off the roadway. Therefore, the first objective when applying granular salt is to prevent it from bouncing off the driving lanes. Application techniques that help to keep rock salt on the road include:[62]

- Applying salt at the crown of the roadway to allow for salt to dissolve and move slowly downwards from the crown towards the shoulder (see Figure 2.8).

[62] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual, *2023.*

- Using a narrow-spread pattern and reduce scatter by applying at slower speeds and at a low point of discharge

Pre-wetting

Pre-wetting is an important tool for winter maintenance managers. This strategy involves coating solid granular deicing materials with a liquid chemical solution (usually salt brine) before application on the roadway. This process creates a "slurry" consistency that improves the performance of the material and overall efficiency. The primary goals of pre-wetting are to keep the deicing material on the road and accelerate the melting process. Major benefits of pre-wetting include:

- Less Waste: Dry salt is bouncy and when it hits pavement at high speeds, a significant portion can scatter off the road and into roadside shoulders and ditches. This reduces effectiveness and contributes to soil and water pollution. Pre-wetted salt is heavier and sticker, allowing it to adhere to the pavement and better resist loss of material due to traffic activity. In one field test, 80 percent of pre-wetted salt stayed on the road even after significant traffic, compared to only 15 percent of dry salt remaining.[63] Similar to dry salt, applying pre-wetted salt to the crown of the road will allow the brine to move slowly downwards from the crown to the shoulder of the road, allowing activated material to coat all traffic lanes (see Figure 2.8)

- Faster Melting: Dry rock salt (sodium chloride) requires moisture to dissolve and form a brine before it can begin melting snow and ice. Pre-wetting jump starts this process by providing the necessary moisture immediately upon application.

- Material and Cost Savings: Because pre-wetted material works faster and stays on the road (resulting in less bounce and scatter), agencies can achieve the same deicing performance while using less material. Studies found that agencies can typically reduce salt usage by 25 to 30 percent without reducing road safety.[64, 65]

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[63] *X. Shi, D. Bergner, S. Du, D. Keep, and C. Reed,* Review and Summary of Pre-Wet Methods and Procedures, Clear Roads Report No. CR 18-04, *Washington State University and Minnesota Department of Transportation, June 2021.*

[64] *Maine Department of Transportation,* Comparison Tests of Liquid Calcium and Salt Brine: A Controlled Experimental Evaluation of Rock Salt Pre-Wetting Liquids, *2003*.

[65] *M. Radaelli and R. Dizaji,* Combined Analysis of Pre-Treated Salt Trials, *Ministry of Transportation Ontario, 2017.*

Various liquid materials are used for pre-wetting, with standard salt brine (23 percent concentration) being the most common. However, the effectiveness of pre-wetting depends on pavement temperatures. Plain salt brine loses effectiveness and can begin to freeze when pavement temperatures drop below 15°F. In these colder conditions, agencies often switch to magnesium chloride ($MgCl_2$) or calcium chloride ($CaCl_2$) brine blends. As noted in the "Snow and Ice Control Materials" section, these agents are exothermic (release heat as they dissolve), making them much more effective at breaking the bond between ice and pavement in extreme cold. Table 2.3 describes when agencies typically switch between different pre-wetting chemicals based on pavement temperature.

Because $MgCl_2$ and $CaCl_2$ are much more expensive than NaCl, maintenance teams often use a "hot mix" blend as previously described in the "Winter Maintenance Material Blends" section. This strategy lowers the working temperature of the liquid without relying exclusively on one expensive chemical.[66] Additionally, some agencies incorporate bio-based additives to increase the viscosity of the mixture, helping it adhere to the road better while also reducing corrosion on vehicles.

There are several methods to pre-wet the dry salt prior to application. These include:[67]

- On-Board Pre-Wetting: This is the standard and most effective method used by most agencies. This method involves carrying liquid tanks on the truck and applying the liquid to the solid material just before it is spread onto the roadway. This is considered the most effective method because the solid material is more uniformly coated with liquid. This application system is typically comprised of a liquid tank, a pump system, a spray bar, and a controller.

- Stockpile Pre-Wetting: This less common method involves applying liquid to the materials at the stockpile before the material is loaded into the truck. This method has significant downsides including potential leaching of brine and material loss. In addition, this method lacks the flexibility of on-board systems and operators cannot make volume adjustments as needed once the pile is treated and placed on the truck.

- Shower-Spray Loading: This method involves spraying the dry salt with liquid as it is being loaded into the truck, typically using an overhead spray bar.

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[66] *X. Shi, et. al, 2021,* op. cit.

[67] Ibid.

“Shake and Bake” Application

The deicing application method known as Shake and Bake (also known as high-volume pre-wetting or slurry technology) is technically a form of pre-wetting. However, it is usually considered a distinct strategy because of the substantial increase in liquid volume used compared to typical pre-wetting. While standard pre-wetting involves slightly dampening rock salt to help it stick to the road, Shake and Bake takes this concept further by using significantly more liquid (generally 70:30 solid-to-liquid ratio) to create a fast-acting oatmeal-like slurry mixture. Because the salt is already dissolving before it hits the ground, nearly 100 percent of the material is kept on the road surface. This slurry can work 30 to 45 minutes faster than dry salt. General suggested application rates for the Shake and Bake strategy are summarized later in the “Application Rates” section.

Agencies sometimes switch from a standard pre-wetting approach to the Shake and Bake method when they shift from maintaining a road to recovering a road. Managers may decide to use the Shake and Bake approach under the following conditions:

- Breaking Hardpack: When snow has already bonded to the pavement or traffic has compacted the snow into ice, standard pre-wetted salt often sits on top of the snowpack or ice and dissolves slowly. The high volume of liquid in the Shake and Bake slurry can punch through the ice layer and down to the pavement surface, breaking the bond to the pavement so snowplows can scrape it off the road on the next pass.

- Colder Temperatures: At temperatures of 0°F to 15°F, dry rock salt is ineffective because there is not enough ambient moisture to dissolve it into brine. Standard pre-wetting helps but is often not enough to sustain a reaction. By saturating the salt with 50+ gallons of liquid per ton (often adding calcium chloride or organic additive to the brine at lower temperatures), all the moisture needed for the reaction is provided from the application. This releases immediate heat from the chemical reaction and forces the salt to work in temperatures that standard dry rock salt or pre-wetted salt would fail.

- High Winds and High-Speed Traffic: On open highways or bridges that tend to have strong crosswinds, even a pre-wetted salt can blow off the road before it can be effective. The slurry mixture of a Shake and Bake application is much heavier and “splats” onto the road. It has no bounce and scatter, ensuring that 100 percent of the material stays in the wheel tracks where it was placed, even with large vehicles driving at a high rate of speed.

- Rush Hour Recovery: If a snow event intensifies right before the high traffic of rush hour, maintenance managers sometimes need to skip the 20 to 30 minutes lag time needed for rock salt to begin working. The slurry applied from the Shake and Bake strategy can work instantly. This is critical for clearing lanes quickly before the traffic can form hardpack and ice that is much more difficult to remove from the pavement.

While this strategy can be effective and necessary in certain situations, it is not a method that agencies use for every storm. Because this method uses liquid at a very high rate, trucks need to return to the public works yards much more frequently to refill their liquid tanks. This can reduce overall fleet efficiency.

To perform this strategy effectively, particularly for extremely heavy pre-wetted slurries, specialized equipment is typically necessary. This system requires components that standard trucks lack: high volume hydraulic pumps that can move 18 gallons per minute or more, a macerator (or slurry generator) that uses an auger to crush the rock salt and aggressively mix it with the liquid before it reaches a specialized spinner assembly, and high-capacity saddle tanks (typically with capacities of 400-800 gallons). [68]

Direct Liquid Application

Use of liquid brines in winter operations has been somewhat common in practice for years, but its use has primarily been limited to either anti-icing (pre-storm application) or used for pre-wetting. As described previously, it is common for significant quantities of rock salt to be lost due to bounce and scatter, vehicle movement, or plowing action. Using direct liquid application (DLA) as a deicing tool to manage active winter storms is an emerging practice. Instead of dropping rock salt and waiting for it to turn into a brine, DLA sprays liquid deicing agents directly onto existing accumulated snow, minimizing loss of applied materials and providing quicker melting action, allowing agencies to reach their specific level of service goals faster. This method is growing in popularity in Wisconsin because it works instantly. DLA is typically only effective in storms with rapid cycle times (plows returning every 60 to 90 minutes) or lighter snow.[69] DLA is not a good strategy for heavy snow as the liquid can be diluted too quickly and can cause refreeze.

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[68] *X. Shi, D. Bergner, S. Du, D. Keep, and C. Reed, June 2021,* op. cit.

[69] *Personal communication with a local winter maintenance manager in southeastern Wisconsin indicated that his agency uses direct liquid application in light accumulations of no more than ½ inch. Anything over that amount makes the route cycle times too great for the method to be effective and efficient. He noted that agencies that have enough liquid capacity on a truck and short route cycle times can use DLA for entire routes, using no rock salt. The keys to this are pavement temperatures and route times. Liquids alone "live fast, die young," with great initial performance but not the longevity of*

A study conducted by the Traffic Operations and Safety Lab at the University of Wisconsin-Madison analyzed the use of liquid brine as a primary tool for winter storm fighting.[70] The study found that routes treated with liquid reached "bare/wet" pavement conditions over two hours faster on average compared to control routes treated with granular rock salt (a 12 percent reduction in time). By skipping the solid to liquid phase change, the brine began working immediately, allowing plows to clear the road down to the pavement surface sooner. The study also found that the average reduction in total salt usage was 23 percent across the participating counties (including Washington County within the Southeastern Wisconsin Region). In addition, liquid-treated routes consistently showed higher friction ratings during and immediately after the storm compared to rock salt. Finally, the study compared the cost of equipment upgrades (tanks, sprayers, bulk storage) against the savings in material and found that the cost savings from purchasing 23 percent less salt annually over ten years outweighed the capital costs of retrofitting trucks and installing liquid storage infrastructure. This translated to an average benefit-cost ratio of 1.92 for interstate, state highways, and county highway routes.

Jefferson County, Wisconsin, is a national pioneer in "liquid-only" plow routes. They have found that during appropriate conditions (pavement temperatures above 15°F), the County could clear roads faster than trucks using rock salt, while also using 44 percent less salt than similar routes.[71] The County estimated that an overall reduction in salt use of 35 percent would result in 5,000 less tons that they would need to purchase, resulting in almost $400,000 savings for the County.[72] Jefferson County winter maintenance managers estimated that they could cut salt use by around 50 percent with the use of liquids and improved employee training.

Typically, operators utilize high-pressure stream nozzles and increased application rates to melt through the existing snow and ice. This pressure allows the liquid to quickly reach the pavement surface, where it can spread laterally to break the bond from the bottom up. While the standard pattern for DLA has been

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a solid material so re-application is necessary sooner. This manager has seen effective results by directly applying liquid with a "trickle" of salt (100-200 lbs/mile) to get the best of both worlds and add some cushion to the route cycle time.

[70] *B. Claros, M. Chitturi, A. Bill, and D. Noyce,* Evaluation of Winter Maintenance with Salt Brine Applications in Wisconsin, *University of Wisconsin Department of Civil and Environmental Engineering Traffic Operations and Safety Laboratory, December 2021.*

[71] *P. McDivitt, "Liquid Asset: County Reduces Road Salt, Saves Money with Brine," University of Minnesota Center for Transportation Studies Local Technical Assistance Program, June 2019.*

[72] *Reported in 2019 dollars.*

the same “wet/dry” striping used in pre-storm anti-icing methods, some agencies have been increasingly testing targeted patterns to reduce liquid volumes and improve efficiency. Common spread patterns used for the DLA strategy include (see Figure 2.9):[73]

- Wet/Dry Striping (Standard): The most common application method for DLA is the same pattern most commonly used for anti-icing brine application. This pattern uses stream nozzles to place parallel lines of liquid along the driving lane, typically spaced 8 to 12 inches apart. This pattern allows the liquid to creep laterally and break the ice bond.

- Crown-of-Road Application: This technique is used by Jefferson County, Wisconsin, and utilizes a compact spray bar (typically three feet long with five nozzles) to treat the center crown of the road. The goal is to allow the brine to migrate outward, treating the inner wheel paths of both lanes with a single pass.

- Wheel Path Targeting: This DLA application strategy has been utilized by the Iowa DOT. This method concentrates the full application rate into narrower patterns specifically in the wheel paths to accelerate the creation of bare-pavement tracks.

Deicing and Anti-Icing Material Application Rates

Determining the appropriate application rates for anti-icing and deicing materials can be a complex process that depends on factors such as material type, application method, pavement temperatures and trends, weather trends, snowfall intensity, and cycle times.[74] The primary goal of material application is to apply only the amount necessary to achieve the desired result: either preventing a bond between snow and pavement (anti-icing) or breaking an existing bond (deicing). Precision application minimizes chloride loading to the environment while maintaining safe and passable roadways.

While guidance in this section is based on extensive field data and experiences from multiple agencies, it should be treated as a starting point. Agencies are encouraged to consider their local experiences and specific community needs for deicing material application rates. Factors such as micro-climates, traffic volume, and available resources may require an operator to adjust rates above or below these standardized

[73] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual*, 2023.*

[74] *In public winter road maintenance, cycle time refers to the total amount of time it takes for a snowplow or material application vehicle to complete a designated route and return to the starting point to begin a subsequent pass.*

recommendations to achieve the necessary results. Furthermore, some agencies may use Maintenance Decision Support Systems (described in detail in the "Winter Maintenance Equipment and Technology" section later in this Chapter) to determine route-specific application rates.

General Material Guidance

Wisconsin Salt Wise has provided recommended baseline deicing application rates for dry and pre-wetted salt for municipal operations based on pavement temperatures (see Table 2.4). For pavement temperatures above 15°F dry rock salt is generally recommended to be applied at 150 to 350 lbs/lane-mile, and pre-wetting allows for lower dry salt application rates (100 to 300 lbs/lane-mile) because the added liquid helps the salt adhere to the road, reducing the bounce and scatter losses.[75] For standard pre-wetting, Wisconsin Salt Wise recommends using at least 15 gallons of brine per ton of rock salt. The Shake and Bake deicing method calls for a higher liquid-to-solid ratio, using 40 or more gallons of brine per ton of rock salt with a reduced rock salt application rate of 100 to 200 lbs/lane-mile.

Once pavement temperatures fall below 15°F, dry rock salt should not be used. Instead, pre-wetted salt can be applied (250-350 lbs/lane-mile), and the wetting agent should be switched from a straight sodium chloride brine to a blend containing calcium chloride or a proprietary enhancer. Similarly, the Shake and Bake method should transition to a brine blend at temperatures below 15°F (see Table 2.4).

General anti-icing application guidelines for straight sodium chloride salt brine range from 20 to 60 gal/lane-mile and should be applied proactively before the arrival of a winter storm. However, straight salt brine is typically not recommended when pavement temperatures are below 15°F and falling, as there is a risk of the solution freezing on the road surface before the precipitation begins. For magnesium chloride or calcium chloride, application rates generally range from 15 to 65 gal/lane-mile depending on pavement temperatures. Because these chemicals are hygroscopic and can attract ambient moisture to create slippery conditions on dry pavement, it is recommended to apply them as the storm hits rather than hours in advance.[76] Salt brine blends typically follow the same application rates as straight sodium chloride brine,

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[75] *Similarly, for highway maintenance, WisDOT provides recommended application rates for rock salt in its Highway Maintenance Manual. These application rates range from 100 lbs to 400 lbs/lane-mile for dry rock salt and from 100 lbs to 300 lbs/lane-mile for pre-wetted salt.*

[76] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual*, 2023.*

though for any proprietary products, operators should strictly follow the manufacturers' instructions to ensure both safety and performance.[77]

Beyond the initial application, operators should consider the residual longevity of the material. While anti-icing establishes a preventative barrier, its effectiveness is eventually degraded by heavy precipitation or by vehicle tires physically removing the material from the driving lanes. Using "stream" nozzles rather than a fine mist or fan pattern can help mitigate this loss because traffic naturally spreads the concentrated liquid lines into a thin, protective film across the pavement. Application nozzles will be discussed in more detail in the "Winter Maintenance Equipment and Technology" section later in this Chapter.

Weather and Road Surface Condition-Specific Guidelines

A more detailed framework for both anti-icing and deicing application rates can be found in the Washington State University and Clear Roads publication, *Material Application Methodologies Guidebook.*[78] This resource provides a series of tables that categorize application rates based on storm type, intensity, and pavement conditions. These tables include a "Dry" road surface condition, which provides the recommended rates for proactive anti-icing performed before or right as a storm begins. The remaining pavement conditions in each table (e.g., Icy Patches, Slush, Snow Cover) provide the reactive deicing rates for when precipitation is already present on the roadway. These tables include guidelines by snow type and amounts and are summarized below.

- Light Snow: Guidelines for snowfall of less than 1 inch per hour or less than 4 inches in a 24 hour period are provided in Table A.1 adapted from the *Material Application Methodologies Guidebook*.

- Moderate Snow: Guidelines for 1 to 2 inches per hour or about 4 to 8 inches in a 24 hour period are provided in Table A.2 adapted from the *Material Application Methodologies Guidebook*.

- Heavy Snow: Guidelines for intense events exceeding 2 inches per hour or more than 8 inches in a 24-hour period are provided in Table A.3 adapted from the *Material Application Methodologies Guidebook*.

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[77] Ibid.

[78] *Washington State University,* Material Application Methodologies Guidebook, *Clear Roads Report CR15-01, April 2019: www.mdl.mndot.gov/items/CR1501G.*

- Freezing Rain: Specific rates for icy conditions where dilution potential is at its highest are provided in Table A.4 adapted from the *Material Application Methodologies Guidebook*.

The *Material Application Methodologies Guidebook* emphasizes that the optimal rate is not a single number but a range that must be adjusted based on the intensity of the storm and the moisture content of the snow. These additional guidelines are provided in the Guidebook to help interpret the tables.

- Use the lower end of the range for lower service goals or shorter cycle times.

- Use the higher end of the range for higher service goals, long cycle times, or greater dilution potential.

- Plow to remove as much snow or ice as possible before deicing material application.

Advanced Guidance for Liquids and Low Temperatures

Building on the previously described guidebook, the University of Wisconsin-Madison Traffic Operations and Safety Laboratory and Clear Roads published updated guidance for agencies transitioning toward liquid-only strategies.[79] That report expands on previous research by providing specific application rates for proactive anti-icing on dry surfaces and direct liquid application (DLA) deicing on actively accumulating snow or ice. It is particularly useful for agencies operating at lower temperatures (below 15°F) where straight salt brine was previously not recommended.[80]

Winter Maintenance Equipment and Technology

Public winter maintenance has changed dramatically in recent decades, moving from a traditional reactive approach to a precise science, adding proactive measures to the operations. This progress is driven by breakthroughs in every part of the winter road maintenance industry. Modern equipment is smarter and more durable, featuring high-tech plow blades that clear more snow in fewer passes and precision application systems that apply exactly the right amount of deicing or anti-icing material. These mechanical advances work together with new sensors that act as the "eyes and ears" of the road, giving crews real-time

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[79] *University of Wisconsin – Madison Traffic Operations and Safety Laboratory,* Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-Icing, *Clear Roads Project 19-01.*

[80] *See Tables A.5 through Table A.10 adapted from Clear Roads Report 19-01 for detailed guidance on liquid application rates based on road surface conditions and pavement temperatures.*

weather updates. Modern calibration techniques ensure that every piece of machinery works correctly and prevents waste of material. Together these advances in technology allow municipalities and other public agencies to keep roads safer while also saving money and protecting the environment from excess salt.

Monitoring and Sensing

A major part of today's high-tech and proactive public winter maintenance programs is the ability to monitor current pavement conditions and predict future weather impacts. Monitoring and sensing technologies provide the real-time data needed to move away from one-size-fits-all salt applications. The following subsections summarize some of the state-of-the-art tools that allow public winter maintenance operators to coordinate their response with the precise timing and intensity of a storm event.

Maintenance Decision Support Systems (MDSS)

Managing winter maintenance operations can be complex and requires managers to consider public expectations, budget constraints, and a large influx of available real-time weather and road condition data. The Federal Highway Administration (FHWA) introduced the concept of a Maintenance Decision Support System (MDSS) in the late 1990s to tackle the growing complexities of winter maintenance operations and information overload faced by maintenance managers.[81] MDSS are sophisticated, computer-based tools designed to integrate complex data inputs into a usable form. These systems combine state-of-the-art atmospheric weather forecasting and pavement models with the strategies and operational rules of a specific agency. This allows the system to translate raw data into detailed, route-specific recommendations for road treatment, including optimal timing, appropriate material type, and suggested application rates.[82] The fundamental objectives of an MDSS are to:[83]

- Utilize, supplement, and combine various road and weather data into one integrated and easily understandable format.

[81] *. Pisano, A. Stern, and W. Mahoney, The Winter Maintenance Decision Support System (MDSS): Demonstration Results and Future Plans," Federal Highway Administration Road Weather Management Program, November 2003.*

[82] *P. Pisano and R. Alfelor,* The FHWA Maintenance Decision Support System (MDSS) Prototype*, Federal Highway Administration Road Weather Management, Publication No. FHWA-HOP-05-061.*

[83] *Maintenance Decision support System (MDSS) – Research Applications Laboratory, www.ral.ucar.edu/solutions/products/maintenance-decision-support-system-mdss, accessed October 31, 2025.*

- Generate diagnostic (current) and prognostic (predicted future) maps of road conditions.
- Provide clear decision support by generating specific recommendations for treatment types, timing, locations, and application rates.

Benefits of MDSS include:

- Improved Safety: Providing real-time, route-specific information helps keep roads safer for the public.
- Increased Efficiency: Helps crews deploy the right resources at the right time, improving operational efficiency.
- Cost Savings: By optimizing the use of materials, especially deicing salts, communities can significantly reduce costs.
- Reduced Environmental Impact: Using less deicing chemicals helps to lower the environmental impact of winter maintenance activities.
- Better Planning: Allows for better coordination and a more consistent approach to winter maintenance across different crews and areas.

MDSS operation relies on several essential inputs, including advanced weather forecasts, data from Road Weather Information Systems and mobile sensors, knowledge of the physical and chemical characteristics of various deicing chemicals, and specific agency operational rules (such as level of service goals). It is important to note that while MDSS help synthesize large amounts of data to assist winter maintenance managers with making decisions, the operator must combine this tool with their knowledge and experience to make appropriate real-time decisions.

The next sections provide a brief description of some of the critical information inputs for a MDSS.

Advanced Weather Forecasting Services

Advanced weather forecasting services use sophisticated models to provide short-term, high-resolution atmospheric predictions. These predictions include the location of a rain-snow boundary and predicted precipitation amounts. MDSS architecture typically use a "data fusion" approach, taking inputs from multiple forecast models to increase the robustness and reliability of the predictions.

Road Weather Information Systems (RWIS)

Road Weather Information Systems (RWIS) are integrated systems that collect, process, and distribute real-time weather and road condition data that is essential for feeding the MDSS. The core field equipment used to gather data for RWIS are known as the Environmental Sensor Station (ESS).[84] RWIS are typically owned by state departments of transportation. For instance, WisDOT currently owns approximately 70 RWIS systems set up around the State highway network and contracts with an RWIS consultant to manage its RWIS program.[85] WisDOT delegates operational responsibility for its most critical road networks to the 72 county highway departments, and information from the State's RWIS is disseminated to these agencies to give county managers the information they need to plan their response to winter storms.

The sensors of an ESS typically measure atmospheric data (air temperature, humidity, wind speed and direction, and precipitation) and pavement data. There are two categories of pavement sensors: active sensors and passive sensors. Active pavement sensors are typically embedded in roads and measure pavement conditions such as surface temperature, wetness (wet, dry, frozen), and the true pavement freeze point temperature. Active devices create heating and cooling cycles to accurately measure the precise freezing point even when deicing chemicals are present. Passive sensors are built with thermal properties similar to the surrounding road to give an accurate pavement surface temperature. Some passive sensors can also track changes in roadway surface conductivity, which provides an indication of the chemical concentration remaining on the roadway surface. Since chemical concentration directly impacts the actual freezing temperature of the surface, conductivity is a vital measurement for accurate modeling and treatment planning.[86]

Figure 2.10 shows a typical RWIS ESS station found in Wisconsin. Typically, the most prominent feature is a sturdy, vertical structure (usually a pole or a lattice tower) that is used to mount the atmospheric sensors at specific heights above the ground and often have closed-circuit television cameras. Near the base of the

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[84] *P. Pisano and R. Alfelor,* op. cit.

[85] *Personal communication with WisDOT, October 2025.*

[86] *J. Manfredi, T. Walters, G. Wilke, L. Osborne, R. Hart, T. Incrocci, and T. Schmitt,* Road Weather Information System Environmental Sensor Station Siting Guidelines*, Federal Highway Administration Road Weather Management, Publication No. FHWA-HOP-05-026, April 2005.*

tower is an enclosed cabinet or box that houses the remote processing unit or data logger that collects the data from all the sensors and sends the data back to the agency's server via radio or a cellular network. Some stations will also include solar panels to power the devices in remote locations.

The cost of implementing and operating an RWIS varies greatly based on the system's scale and ownership model. A full-scale RWIS ESS (including a camera and comprehensive sensor suite) typically costs approximately $92,000 for initial procurement and installation. Ongoing expenses include annual operating and maintenance costs of about $2,000 plus the expense of any necessary part replacements.[87] To manage costs and maximize coverage, some agencies, including WisDOT, utilize smaller mini-RWIS units, which are typically leased systems that cost approximately $3,000 per year. These leased systems are generally self-installed, and the annual cost covers all necessary replacement parts.

Southeastern Wisconsin Multi-Community Winter Road Observation Network

Several communities across Milwaukee, Waukesha, and Ozaukee Counties are currently exploring a collaborative partnership initiated by Southeastern Wisconsin Watersheds Trust (SweetWater) to establish a multi-community winter road observation network. This proposed initiative, tentatively planned for the fall of 2026, aims to install approximately 29 new in-road pavement sensors to supplement the 16 sensors already operating in several communities in Milwaukee County. By participating in this multiple community approach, the partners intend to bundle their purchase to secure a significant cost discount from the vendor while gaining access to a shared data portal. Another benefit of increasing the number of pavement sensors across these communities is the resulting improvement in forecasting strength, as the models become more accurate when there are a greater number of localized observations.

The planned network would utilize Vaisala GroundCast sensors, which are designed to provide high-precision pavement data without the need for an external power source or extensive infrastructure. These wireless units measure pavement temperatures at the road surface as well as at depths of 6 cm and 30 cm below the road surface. They also monitor the amount of residual deicing or anti-icing material remaining on the pavement. By integrating these observations with Vaisala weather modeling, the system provides location-specific forecasts that help maintenance operators make proactive, data-driven decisions. Optimizing the timing and application rates of deicing and anti-icing materials improves roadway safety while simultaneously saving taxpayer money and reducing chloride pollution.

[87] *Personal communication with WisDOT, October 2025.*

Mobile Sensors

To address the spatial limitations of fixed RWIS sites, winter maintenance vehicles are sometimes equipped with mobile sensors that serve as rolling data collection points. These systems provide real-time road and weather data, offering communities that do not have access to RWIS a way to collect similar data. Mobile sensor data relies on an Automated Vehicle Location (AVL) system to aggregate sensor readings and transmit them back to a central server. Common types of mobile sensors include:

- Infrared Pavement Temperature Sensors: These non-contact devices provide real-time road surface temperature readings, which are crucial for the MDSS to verify and adjust its predictive models for the specific route the truck is traveling (see Figure 2.11). These sensors are relatively economical compared to other mobile sensors, ranging from roughly $400 to $2,000.[88,]

- Friction Measuring Devices: These can provide a quantitative friction value that serve as a direct measure of road slipperiness and the resulting traction available to vehicles. Although a significant investment at around $25,000 per vehicle, this information is highly valuable for real-time condition reports.[89]

- Chemical Usage Sensors: Often integrated with spreader controllers, these devices can provide essential information regarding the amount and rate of deicing or anti-icing chemicals being distributed. This data is important for materials accounting, environmental compliance and reporting, and for the MDSS to estimate the residual chemical concentration on the road surface. The cost for control units associated with this measurement can vary from $200 to $8,000, depending on whether they include basic flow measurement or advanced Ground Speed Control (GSC) functionality.[90,91]

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[88] *Purdue University and Indiana Department of Transportation Aurora Project,* Mobile Weather and Road Condition Reporting Project Final Report, *May 2009. Costs are reported in 2009 dollars.*

[89] *Cost is represented in 2009 dollars.*

[90] *S. Andrle, R. McComber, C. Lee, C. Klipfel, 2002*, op. cit.

[91] *Cost reported in 2002 dollars.*

- Chemical Concentration Sensors: These measure the actual chemical concentration on the road surface or in the truck tank. These highly specialized mobile freeze-point detection devices can cost $10,500 or more per vehicle.[92,93]

Artificial Intelligence and Machine Learning (Smart MDSS)

The integration of Artificial Intelligence (AI) and Machine Learning (ML) is an evolving component of modern MDSS design. AI and ML algorithms can process the massive and diverse datasets of RWIS, mobile sensors, weather models, and historical records to identify patterns that may not always be obvious and continuously improve winter maintenance performance. Key applications of AI and ML within an MDSS include:[94, 95]

- Refined Predictive Modeling: ML models can learn from past storm events and compare predicted conditions against actual outcomes to continuously calibrate pavement freeze and thaw cycles. This could greatly improve forecasts.

- Optimize Resource Allocation: AI can analyze traffic patterns, incident locations, and real-time road conditions to recommend the most efficient deployment of specific maintenance vehicles and personnel. This can help ensure the level of service goals for an agency are met at the least possible cost.

- Chemical Application Rate Optimization: Machine learning models use real-time friction and chemical concentration data to precisely calculate the minimum effective application rates of materials, which can lead to large cost savings and reduced environmental impacts.

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[92] *S. Andrle, R. McComber, C. Lee, C. Klipfel,* Highway Maintenance Concept Vehicle – Final Report: Phase Four*, Center for Transportation Research and Education, Iowa State University, June 2002.*

[93] *Cost reported in 2002 dollars.*

[94] *M. Kessler,* Implementation of Artificial Intelligence to Improve Winter Maintenance, *Federal Highway Administration, Publication No. FHWA-HRT21-090, December 2021.*

[95] *A. Golalipour and Z. Liu,* Harnessing the Power of Artificial Intelligence (AI) to Improve Winter Maintenance Practices, *Federal Highway Administration, Publication No. FHWA-HRT-25-045, January 2025.*

Mechanical Removal Equipment

State of the art fleets use advanced plow configurations and blade technologies to maximize pavement traction. By maximizing mechanical removal, agencies can significantly reduce the amount of chemicals needed to clear any remaining snow and ice.

Plow Configurations

State and municipal winter maintenance agencies utilize a variety of plow configurations based on specific needs as well as characteristics of the road systems. Central to these configurations is the moldboard, which is the curved structural body of the plow that is designed to lift, roll, and throw snow away from the travel lane. The specific shape, location, and material composition of the moldboard are critical factors that determine the ability of a plow truck to clear snow at various speeds. The following descriptions provide an overview of these tools and high-level cost estimates. Precise pricing is difficult to nail down due to a high variety of blade materials, size, and hydraulic capabilities. Therefore, the cost ranges provided represent general points of reference rather than exact quotes. These estimates are derived from WisDOT and MnDOT procurement records and cost-benefit studies from Clear Roads and the Western Transportation Institute.[96,97] Estimated cost ranges reflect data collected between 2013 and 2024.[98]

- Front-Mounted Plows: These are the most common plow configurations for winter maintenance and are categorized into two primary types; one-way plows and reversible plows (see Figure 2.12).
    - One-way plows have a fixed angle and a tapered, funnel-like shape designed to throw snow to the right (only discharging snow to one side). This configuration is usually used for high-speed highway clearing because the design allows the plow to throw snow far off the shoulder. Estimated cost range per plow: $8,000 to $15,000.[99]

[96] *Montana State University Western Transportation Institute,* Benefit-Cost of Various Winter Maintenance Strategies, *Clear Roads Report No. CR13-03, September 2015.*

[97] *Montana State University Western Transportation Institute,* Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment, and Operations Phase 2, *August 2013.*

[98] *Costs have not been adjusted for inflation.*

[99] *Costs generally include the plow, blade, and plow-side lift frame. Costs do not include the truck-side hitch or the hydraulic integration (hoses, valves, and cab controls) which are typically part of the initial build-out of the truck.*

  - Reversible plows are a curved, rectangular shape and can be hydraulically angled straight, left, or right based on the configuration of the road. While slightly less efficient for high-speed plowing when compared to one-way configurations, their versatility makes them the standard for most municipal operations where the throw direction of snow must change frequently to avoid blocking driveways or intersections. Modern versions allow operators to adjust the pitch of the blade to either scrape hard-packed snow or "float" over gravel surfaces. Estimated cost range per plow: $10,000 to $18,000.[100]

- Wing Plows: These 6-to-8-foot plows are mounted on one or both sides of the front end of a truck, allowing for clearing adjacent lanes and/or shoulders in a single pass (see Figure 2.13). Most modern wing systems are hydraulic systems that give the operator control to expand or contract the wing as needed.[101] These are typically mounted in addition to a front-mounted plow. By extending the plow path, wing plows allow a single truck to clear adjacent lanes or shoulders. This allows agencies to clear more lane-miles with fewer total trucks. Estimated cost range per plow: $12,000 to $22,000.[102]

- Underbody Scrapers: These plows are mounted to the truck chassis between the front and rear axles, allowing the operator to apply significant downward pressure to break up compacted snow and ice from a roadway (see Figure 2.14). Underbody scrapers are sometimes referred to as "mechanical deicing" because they can significantly reduce the amount of chemicals needed to reach bare pavement in hardpack ice situations. These can operate as a standalone configuration or in combination with front-mounted plows and wing plows. The blades are typically made of heat-treated carbon steel for durability. Massive hydraulic cylinders are typically required on these setups to maintain 200 PSI or more of downward pressure. Estimated cost range per scraper: $14,000 to $24,000.

- Tow Plows: These are steerable trailer-mounted plows (typically 26 feet wide) that are pulled behind a traditional plow truck. When deployed, the trailer swings out to the side of the rear of the truck,

[100] *The higher end of this range includes "live-edge" sectional blades and heavy-duty hydraulic cylinders required for high-speed reversing of the plow angle.*

[101] *D. Bennett and Dr. T.A. Lasky,* Optimizing Tow Plow and Wing Plow Deployment, *Clear Roads Project 1034818/CR19-03, December 2021.*

[102] *This price range generally includes the wing moldboard (structural body) and the wing posts (the mounting hardware). It does not usually include the heavy-duty "wing-ready" reinforcement of the truck frame.*

allowing an operator to clear two or three full lanes in one pass (see Figure 2.15). Tow plow trailers are often equipped with integrated solid or liquid deicing application systems. These are typically only used on large flat interstate corridors or multi-lane highways and their performance diminishes on steep grades due to the additional weight and traction requirements.[103] Estimated cost range per plow: $70,000 to $200,000.[104]

Advanced Blade Technology

Snowplow blades, or cutting edges, are bolted to the snowplow moldboard and are the component of the plowing system that makes contact with the road surface. The field of winter maintenance has seen rapid advancement in plow blade technology. While high performance blades typically require a higher initial investment, they offer better clearing performance, typically last longer, and provide significant vibration reduction.[105] Minimizing vibration is important because it protects road infrastructure and utilities, extends the life of the vehicle and equipment, and reduces physical strain for plow operators. When all factors are considered, upgrading to advanced cutting edges often offers a high return on investment by extending the life of the equipment and reducing the amount of chemical deicers needed.[106]

Advanced snowplow blade technology includes the following innovations:

- Multi-Layered Blades: Instead of a solid piece of steel, these blades are constructed with a combination of materials. A common configuration uses a hardened tungsten-carbide insert sandwiched between protective layers of steel plates or encased in high-density plastic or rubber. This layered design can provide substantial noise reduction, extend the life of a blade, and dampen the vibrations that can damage equipment. Many modern cutting edges combine multi-layered durability with live edge blade articulation.

- Sectional/Segmented Blades: Unlike traditional cutting edges that consist of a single continuous 10- or 12-foot piece of steel, sectional blades come in multiple smaller segments, typically 12, 18, or 24 inches in length (see Figure 2.16). These blades offer flexibility and simplified maintenance. For

[103] Ibid.

[104] *The higher end of this range reflects the inclusion of steerable trailer axels and integrated material application systems.*

[105] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual*, 2023.*

[106] Ibid.

example, if an operator hits a manhole cover and damages a portion of the blade, they only need to replace damaged segment rather than the entire 12-foot blade.

- Live Edge Blades: A specialized type of sectional blade, live edge systems feature segments mounted on an independent suspension. This allows 12-to-24-inch segments to individually move vertically to articulate with the unevenness of roads (see Figure 2.17). By conforming to the crown of the road or depressions, these blades provide a "squeegee" effect that removes significantly more snow and ice in a single pass than a rigid one-piece blade. An Ohio Department of Transportation study found that flexible blades that incorporated tungsten carbide inserts encased in rubber reduced impacts with the roadway and produced longer wear life, as well as reduced noise and vibration resulting in less operator and equipment fatigue, and reduced maintenance and labor needs. Notably, flexible blades tested by Ohio DOT lasted 4 to 5 times longer than traditional blades and there was an 85 percent decrease in labor hours required to maintain or replace the blades.[107]

- Multi-Blade Systems: These configurations use separate blades on a single plow frame, each optimized for a specific function. A typical setup might include a primary cutting edge for heavy snow removal followed by secondary blades designed to clear slush or scarify hard-packed snow and ice (see Figure 2.18). These systems can clear variable road conditions with a single pass, with research showing they can remove up to 25 percent more material than traditional single-blade setups.[108]

Material Application Equipment

Modern and efficient winter maintenance operations rely on the precision and reliability of material spreaders to meet public safety and environmental stewardship goals. High-performance spreading equipment ensures that deicing and anti-icing agents are applied at exact and consistent rates, reducing waste and minimizing the loading of chlorides into local waterways. Investing in durable, well-calibrated machinery is a major step for agencies to optimize their salt usage, lower operational costs, and maintain high levels of service for their communities.

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[107] *Montana State University Western Transportation Institute*, *August 2013,* op. cit.

[108] *CTC & Associates, LLC,* Multiple-Blade Snowplow Project Final Report, *Clear Roads Report, December 2010.*

The following performance characteristics of material application equipment are critical for efficient and sustainable winter maintenance operations:[109]

- Controls must deliver precise application rates that remain consistent regardless of material volume and material variations or weather conditions.

- Suppliers must provide test results proving the equipment achieves specified application delivery under all operational conditions.

- Application equipment must be simple to load and intuitive to operate to ensure consistent performance across all staff shifts.

- Equipment should be designed to withstand extreme cold, high moisture levels, and constant exposure to corrosive materials.

- All electrical wiring, lighting controls, and hydraulic components must be housed in vapor-proof, sealed systems to prevent premature failure.

- Spreaders should be fitted with screens to block frozen clumps or debris that could jam the conveyor or chain mechanisms.

- Cab shields should be installed to ensure all salt enters the box during loading and to prevent material from spilling onto the truck chassis or the ground.

- The geometry of the container/bin holding the material must allow for the easy and total removal of all residual salt or other material.

- Adaptable designs or removable hoppers that allow trucks to be repurposed for other municipal operations during the non-winter months is typically preferable.

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[109] *Transportation Association of Canada,* Synthesis of Best Practices Road Salt Management: 9.0 Winter Maintenance Equipment and Technologies*, 2013.*

- Lifespans of equipment can be increased by using low-alloy steel coated with chlorinated rubber or epoxy-based primers. Fiberglass bodies are lighter and allow for increased cargo possibilities but are more expensive than steel.

Dry Granular Spreaders

Dry granular spreaders are foundational pieces of equipment for public deicing operations. These systems are designed to hold winter maintenance materials (typically bulk rock salt) and deliver them to the pavement. While reliable, the efficiency of these systems is highly dependent on the mechanical interface between the delivery method (how the salt leaves the truck) and the distribution mechanism (how the salt is broadcast across the lane). Selecting the appropriate spreader requires matching the equipment's specific design characteristics to the requirements of the application. The following are common spreader configurations and spinner assemblies used in public winter road maintenance operations.

- Hopper (V-Box) Spreaders: Hoppers (or V-Box spreaders) are standard spreaders for high-volume road or highway maintenance due to their high capacity (up to 15+ cubic yards) and centered weight distribution. These are large, self-contained "V" shaped bins that are typically inserted into a dump truck body after the tailgate is removed; however, a hopper can also be set on a flatbed or hook-lift truck (see Figure 2.19).[110] Hoppers typically have a steel body (but also come in polyethylene bodies), and use a longitudinal conveyor chain, belt, or auger and a power drive to move salt to the rear for application. Conveyor chains and belts can be more accurately calibrated than augers. The material application rate can be controlled by adjusting the discharge conveyor and the gate opening on the body. Modern hopper designs including rear discharge, slide-in units with a longitudinal agitator bar and belt conveyor are gaining popularity for pre-wetted applications.[111] Estimated costs for hopper spreaders range from roughly $4,000 to $23,000 depending on capacity, material, and drive type (electric or hydraulic).[112]

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[110] *Washington State University,* Material Application Methodologies Guidebook, *Clear Roads Report CR15-01, April 2019.*

[111] *Transportation Association of Canada,* Synthesis of Best Practices Road Salt Management: 9.0 Winter Maintenance Equipment and Technologies*, 2013.*

[112] *Costs represent 2025 dollars and are based on a combination of sources including SaltDogg Inc, Northern Tool Inc, O'R?eilly Equipment Dealer Listings, and State of Michigan Procurement Contract #200000000034.*

- Tailgate Spreaders (Under-Tailgate): Tailgate spreaders are dependable, cost-effective units mounted to the rear of a dump box or smaller trucks with hydraulic connections for the spinner (see Figure 2.20). Material is typically fed into the spreader chute by gravity, requiring the operator to raise the dump box to feed the hopper. This raising of the dump box can occasionally shift the vehicle's center of gravity and create stability concerns. Once material is fed into the spreader, rear conveyors or augers feet the material to spinners or chutes. Tailgate spreaders are typically less expensive than hopper spreaders, with estimated costs ranging from roughly $1,000 to $6,000 depending on whether the unit is a small hitch-mount unit for a pickup or a heavy-duty hydraulic under tailgate unit.[113]

- Dual-Dump Spreaders: These are not just truck attachments, but specialized multi-purpose truck bodies designed to function as both a standard dump truck and a high efficiency spreader (see Figure 2.21). These function as standard rear-dumping bodies when they are not being used for applying winter maintenance materials but can be reconfigured to tip forward, moving material onto a conveyor to a front-mounted distribution point that discharges material to the left side of the truck body. This placement of the discharge ahead of rear wheels allows for better operator monitoring, improved traction, and the vehicle maintains a more stable center of gravity. While dual-dump spreaders offer multi-season utility, they are heavier than standard dump trucks. Costs for an 11-foot to 14-foot combination sloped-side dump and spreader body range from approximately $31,500 to $38,000.[114]

Spinner Assemblies

While the spreader meters the volume of salt, the spinner (the rotating disk at the discharge chute) is responsible for the spread pattern and width. The technical performance of a spreader is often limited by the placement accuracy of its spinner. Generally, the spinner should be no higher than 12 to 18 inches from the pavement surface to minimize bounce and scatter losses.[115] Common spinner assemblies include:

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[113] *Costs represent 2025 dollars and are based on a combination of sources including SnowEx Equipment Guide, TruckOrTrack Municipal Sales Guide, and State of Michigan Procurement Contract #200000000034.*

[114] *State of Michigan Procurement Contract #200000000034. Costs represent 2025 dollars.*

[115] *Washington State University,* Material Application Methodologies Guidebook, *Clear Roads Report CR15-01, April 2019.*

- Standard Centrifugal Spinners: These are the most common type of spinner in municipal fleets and consist of a flat disk with fixed vertical vanes (see Figure 2.22). As material drops onto the spinning disk, centrifugal force flings material outward. These spinners are highly prone to bounce and scatter loss, with up to 40 percent of material loss occurring at speeds exceeding 25 mph. To reduce this material loss, standard spinners are sometimes outfitted with rubberized "skirts" (see Figure 2.22). These skirts are intended to force the material to hit the road at a more vertical angle and ensure the salt remains in the travel lane. Costs range from approximately $200 for a simple replacement spinner disc to $1,500 or more for a complete hydraulic motor and chute assembly.[116]

- Directional and Asymmetrical Spinners: These advanced units allow the operator to shift the spread pattern (left, center, or right) from the cab using a touchscreen and without moving the truck (see Figure 2.23). By adjusting a shroud or spinner shield or changing the drop point of the salt onto the disk, the operator can precisely target the crown of the road or avoid spraying parked cars and oncoming traffic. Costs for these spinners can range from $1,500 to $3,500 depending on the complexity of the internal baffles and dedicated directional motors.[117]

- Zero Velocity Spreaders: These systems perform with a high level of granular application precision by discharging salt at a speed and direction equal and opposite to a truck's forward velocity (see Figure 2.24). By canceling out the momentum of the truck, the salt can drop vertically onto the road with near-zero horizontal movement. This allows for effective road treatment at higher speeds (35 mph or more) while ensuring a high percentage of material is applied to and stays in the targeted lane.[118] Some studies found that these systems can lead to salt reductions of up to 70 percent and faster bare pavement results.[119] The performance of zero velocity spreaders is often enhanced when used with pre-wetted salt. Zero velocity spreaders are rarely sold as standalone units without the

[116] *Northern Tool Parts Catalog, Paris Supply Inc, and State of Michigan Procurement Contract #200000000034.*

[117] Ibid.

[118] *Venner Consulting and P. Brinckerhoff,* Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance, 2004.

[119] *G.F. Mitchell, W. Richardson, and A. Russ,* Evaluation of ODOT Roadway/Weather Sensor Systems for Snow & Ice Removal Operations/RWIS Part IV: Optimization of Pretreatment or Anti-Icing Protocol, *Ohio DOT Technical Report FHWA/OH-2006/24, 2006.*

supporting controller and sensor logic. For units that include a specialized head, integration sensors, and required controllers the costs can range from roughly $10,000 to $25,000.[120]

- Dual Spinner Systems: These systems are most commonly used on wide-body spreaders or airport equipment and utilize two independent disks that rotate in opposite directions (see Figure 2.25). These are best used for wide roads where 30 to 40 feet swaths of pavement must be treated in a single pass.

<u>Pre-Wetted Granular Application Systems</u>

While dry granular spreaders are the traditional baseline for winter maintenance, their efficiency is limited by material loss due to bounce and scatter and the slow activation time of dry salt. Pre-wetted granular spreaders address the limitations by integrating liquid storage and delivery systems into the dry equipment platforms described in the "Dry Granular Spreaders" section. By adding a liquid chemical (typically sodium chloride brine or brine blend, calcium chloride, or magnesium chloride) to the dry salt at the point of discharge, the material becomes heavier and stickier, allowing it to stick to the pavement and begin the melting process immediately.

Pre-wetting systems can come in many different styles and levels of sophistication (see Figure 2.26). These systems typically function as an add-on or integrated enhancement to the hopper and tailgate spreader systems previously discussed in the "Dry Granular Spreaders" section. Liquid can be added to the granular salt at the spinner, auger, or conveyer, all of which have shown to be effective.[121,122] The transition from dry to pre-wetted application requires three specific hardware categories to manage the liquid-to-solid ratio.

- On-Board Liquid Storage Saddle Tanks: Typically, high-density polyethylene tanks are mounted to the truck either externally or internally or mounted to the tailgate to carry the liquid brine needed for pre-wetting. To maintain vehicle stability and comply with gross vehicle weight rating, these tanks are sometimes baffled to prevent "sloshing" of the liquid while the truck is in motion. Capacity of pre-wetting saddle tanks are usually smaller than those of direct liquid application systems and typically range from 200 to 1,750 gallons of combined volume. Larger tanks allow for more efficient treatment and less trips back to the yard to refill.

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[120] *Clear Roads Cost-Benefit Analysis Toolkit, Clear Roads Project 11-01, June 2010.*

[121] *Some operators have experienced less freeze up if liquid is mixed in a portion of the auger closer to the discharge point.*

[122] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual*, 2023.*

- Liquid Delivery Pumps and Flow Meters: To ensure consistent application rates (typically ranging from 8 to 15 or more gallons per ton of rock salt), pre-wetting systems use electric or hydraulic pumps. Modern systems utilize closed-loop flow meters that communicate with a central controller (detailed later in the "Electronic Spreader Controls" section) to adjust liquid volume based on the ground speed of the truck and the auger speed that is feeding the dry salt.

- Injection Point (Chute vs. Spinner): The point where the liquid and granular materials meet is critical. In standard setups, a spray bar is commonly located in the discharge chute, coating the salt as it falls. Some systems incorporate more than one nozzle at the spinner to help with increased liquid application rates.[123] Advanced systems may use internal auger injection, where the liquid brine is sprayed onto the salt while it is still inside the conveyor. This ensures full wetting of every granule before it reaches the spinner.

Basic pre-wetting kits cost roughly $2,500 to $5,500 depending on size of tanks and pumps.[124] Some advanced pre-wetting systems incorporate on-board manifolds that allow the operator to switch between different liquids from the cab when pavement temperatures are fluctuating, which can add several thousand dollars to the cost of the system. For example, an operator may choose to pre-wet with standard salt brine when temperatures are above 15°F but switch to calcium chloride during the route if pavement temperatures drop below effective salt brine temperatures.

Slurry Generators

Unlike standard pre-wetting which only slightly dampens the salt with liquid, the more aggressive Shake and Bake method aims to apply an oatmeal-like slurry mixture (see the "'Shake and Bake' Application" section earlier in this Chapter for more details). Slurry generator systems use a high-speed mixing chamber or a "crusher" to grind a portion of the salt and mix it with a high volume of brine (typically 50 or more gallons per ton of salt). Crushing the salt granules allow it to dissolve into the slurry quickly. An example of a truck equipped with a slurry generator system is shown in Figure 2.27.

Slurry makers require high volume hydraulic pumps with significantly higher flow rates than required by standard pre-wetting systems. Because the slurry material is heavy and viscous, slurry application systems

[123] *Minnesota Pollution Control Agency,* Smart Salting for Roads Manual*, 2023.*

[124] *State of Michigan Procurement Contract #200000000034. Costs represent 2025 dollars.*

often use a specialized chute designed to prevent clogging with the thick slurry. Costs for slurry generators range from $8,500 up to $20,000 or more.[125]

Liquid Application Systems

Liquid application systems, or brining systems, can span a broad spectrum of sophistication, ranging from home-made assemblies to highly engineered and integrated tanker systems. The capital investment for liquid brine application equipment varies significantly based on the level of precision, capacity, and automation required.

At the entry level, many municipal operations begin with basic setups consisting of a simple plastic tank, a gas-powered centrifugal pump, and a PVC spray bar mounted to a standard truck bed. For example, the City of Lake Geneva built a simple brine application system with a 250-gallon plastic tank that is used to treat their bike trail system (see Figure 2.28). These home-built systems can often be assembled with spare equipment laying around the public works yard. If all the components need to be purchased, costs to build these rigs can range from $1,500 to $5,000.[126]

A common middle ground for liquid application systems are professional skid-mounted units that are commonly used for municipal anti-icing operations. These systems typically feature 500 to 1,000-gallon high-density polyethylene tanks and are designed to slide into the bed of a standard municipal dump truck. They often include hydraulic-driven pumps and professional spray manifolds, providing a balance of high capacity and vehicle versatility (see Figure 2.29). This configuration allows municipalities to use existing medium-duty trucks for liquid applications during pre-storm windows without the investment required for a dedicated, single purpose tanker. Cost for a common municipal brine application system can range from $10,000 to $25,000 or more.[127]

High-capacity systems that use modern industrial-grade tankers are becoming more common for long-route county, state, or interstate highway anti-icing applications (see Figure 2.30). These high-capacity tankers can carry 1,500 to 5,000 gallons of liquid material and often are equipped with extendable or folding spray bars that allow one vehicle to treat multiple lanes or wide highway shoulders in a single pass. These sophisticated units utilize electromagnetic flow meters and GPS-integrated telematics to ensure that

[125] Ibid.

[126] *Costs represent 2024 dollars and are sourced from personal correspondence with municipal public works managers.*

[127] Ibid.

application rates are precisely metered relative to vehicle speed and pavement temperatures. High-capacity tanker systems require large up-front capital investments but commonly exhibit strong cost-to-benefit ratios. Costs for these systems can vary widely depending on size and technology, ranging from $35,000 to $150,000 or more.[128]

Fixed Automated Spray Technology (FAST) Systems

Fixed Automated Spray Technology (FAST) systems, as described previously, are typically installed on high-risk infrastructure such as bridges. These systems consist of four primary components.

- Road Weather Information System (RWIS): These are the "eyes" of the system. They include atmospheric and pavement sensors.

- Control Unit: This is the brain of the system that processes sensor data and can be programmed with specific logic. For example, it can be programmed to activate the pump and spray system "if pavement temperature is below 35°F and falling, and surface moisture is detected."

- Pump and Storage Station: A localized tank and a pump system often housed in a climate-controlled cabinet near the site.

- Distribution Network: This is a series of pipes leading to spray nozzles. These nozzles are either disk-style (recessed into the pavement) or parapet-mounted (fixed to the side of bridge rails) (see Figure 2.31).

FAST systems are high-capital investments typically reserved for high-risk locations. Because these systems are custom engineered for specific sites. Initial installation costs can range roughly from $200,000 to over $1,500,000 or more depending on the length of the area to be treated, sensor integration, and complexity of the piping.[129, 130]

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[128] Ibid.

[129] *This range represents estimated costs for multiple FAST systems in 2005-2014 dollars.*

[130] *Western Transportation Institute, October 2014,* op. cit.

Electronic Spreader Controls

Moving from manual to precision material application for winter road maintenance is driven by the Electronic Spreader Controller. This in-cab interface acts as the central processing unit that synchronizes a maintenance truck's hydraulic system with real-time data to ensure accurate material delivery (see Figure 2.32). Modern controllers have replaced simple hydraulic dials with sophisticated software capable of managing granular, pre-wet, and liquid applications.

One of the primary functions of a modern controller is groundspeed orientation. Modern control systems monitor the speedometer or GPS system of the truck to automatically adjust the material output from the spreader. If a truck stops at a traffic light, the groundspeed control system immediately stops material application. Then, as the truck accelerates, the system increases the discharge volume to maintain a consistent application rate. These systems are available in "open loop" or "closed loop" configurations, with closed-loop systems providing the highest level of accuracy by using sensors to confirm the actual volume of material discharged.

Advanced controllers offer specialized features that go beyond basic speed adjustments. For example, modern controllers can automatically increase output when a second spinner is activated for climbing hills or turning lanes. Another common feature is a "blast" mode that allows operators to briefly trigger a higher output of salt for known trouble spots such as bridge decks, hills, or intersections, with the system then automatically returning to the set rate once the trigger is released. Additionally, advanced controllers often support simplified maintenance through infrared-applied calibration settings, and settings can be transferred to other trucks to ensure consistency across an agency fleet. For data-driven management, some units can monitor and log operational data such as material type, application rates, gate positions, and blast information. When electronic controls are integrated with GPS and Automatic Vehicle Location (AVL), these controllers generate precise records of where and when material was discharged. This capability allows for detailed post-storm analysis, fiscal accountability, and a record of service for potential liability defense.

The cost for electronic spreader controls can vary significantly based on specific configurations, hydraulic integration, and whether the system is or configured to an agency's specific needs. Generally, unit costs range from roughly $3,500 to $6,500.[131]

[131] *These costs represent 2025 dollars and are based on conversations with local agency managers.*

Dynamic Spreading Systems

Dynamic Spreading Systems represent the current state-of-the-art for smart salting strategies for material application systems. Unlike standard systems where the operator selects a fixed application rate (e.g. 150 lbs/lane-mile), a dynamic spreading system uses real-time environmental data to automatically adjust the salt or brine output as the truck moves. The goal is to provide the exact amount of chemical needed to achieve the targeted friction levels, thereby reducing both costs and chloride loading.[132] These systems are often linked to Maintenance Decision Support Systems that allow the truck to not only react to the road beneath it but also receive recommended rates from a cloud-based weather model.

These systems rely on a feedback loop between the truck's electronic controller and external sensors. Typically, an infrared sensor is mounted on the truck's side mirror (see Figure 2.11), to continuously scan the road surface for pavement temperature, snow or ice thickness, and friction levels. The brain of the spreader compares this real-time data to a pre-set level of service goal and adjusts the material output to meet those goals. For instance, if the sensor detects a cold bridge deck, the controller can automatically increase the deicer application rate. When the truck moves back onto a warmer, sunlit road, the system instantly throttles the salt back to the minimal effective dose. Some studies report that well-maintained and calibrated dynamic spreader systems have been shown to reduce unnecessary road salt application by over 40 percent.[133]

The general costs for Dynamic Spreading Systems range from roughly $7,000 to $15,000 or more per vehicle.[134] This includes the necessary sensors, advanced software integration, and any necessary subscription costs.

Rear-Mounted Camera Systems

To supplement the data provided by the controller, many agencies now utilize high-definition rear-mounted camera systems (see Figure 2.33). These systems are positioned to provide a direct view of the spinner assembly and discharge chute which are typically blind spots for the operator of most styles of material spreaders. Cameras allow the operator to detect "bridging" in the hopper (lack of delivered product) or

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[132] *J. Pokkinen, "Revolutionizing Winter Road Maintenance with Dynamic Spreading and Mobile Detector MD30," Vaisala Blog, Published August 22, 2024, www.vaisala.com/en/blog/2024-08/dynamic-spreading-and-mobile-detector-md30* .

[133] *D. Kelting and C. Laxon,* Review of Effects and Costs of Road De-icing with Recommendations for Winter Road Management in Adirondack Park, *Adirondack Watershed Institute Report # AWI12010-01, February 2010.*

[134] *These costs represents 2025 dollars.*

mechanical failures such as a jammed auger or broken chain, preventing a route from being untreated without the operator's knowledge.[135] Operators can also visually confirm the effectiveness of directional spinners and shrouds, ensuring that salt is reaching the crown of the road and not being wasted in the shoulder or oncoming traffic. State-of-the-art systems utilize infrared night vision for low-visibility conditions and self-cleaning lenses, using air or water blasts to clear the salt brine and road grime that accumulates on the camera.

Costs for rear-mounted camera systems can vary greatly depending on whether it is a standalone monitor or a smart system integrated into the existing spreader control screen. Most systems at the very least incorporate rugged cameras that feature infrared night vision and self-cleaning lens washing kits. Generally, systems can range from $800 to $2,500 per vehicle, but costs can rise substantially depending on features.[136]

Brine Production Systems

Modern winter road maintenance relies on the precision of brine making equipment to achieve the specific salt-to-water ratio to maximize effectiveness while minimizing chloride loading to the environment. Investing in on-site brine production improves municipal efficiency, protects water quality, and reduces costs. In-house production eliminates the need to travel to other communities to refill truck brining tanks. For instance, prior to launching their own on-site brine production, City of Wauwatosa winter maintenance staff reported that using external facilities for refilling routinely required 40 to 60 minutes per trip.[137] Economically, producing brine on-site drops costs to approximately $0.13 to $0.20 per gallon, compared to $0.40 to $0.60 per gallon charged by vendors or neighboring communities.[138]

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[135] "Bridging" occurs when granular material (rock salt) fuses together to form an arch over the discharge outlet or the conveyor system. Even though the hopper appears to be full, a hallow cavity forms underneath the "bridge" of salt. Because the material is no longer falling onto the auger or conveyor, the spreader continues to run, but no salt is actually being applied to the road.

[136] These costs represent 2025 dollars.

[137] Cargill Case History, "Wauwatosa, Wisconsin Finds Brine Maker that's Sized and Priced Just Right," Cargill Deicing Technology, February 2015.

[138] M.J. Crow, S.E. Lucas, F. Phillis, and W.H. Schneider, "Determining the True Cost of Making Brine and Comparing Liquid Deicers," Presented at Transportation Research Board 98th Annual Meeting, 2019 and University of Wisconsin-Madison Traffic Operations and Safety Laboratory Clear Roads Report No. CR 19-01, December 2021, op. cit.

Similar to liquid brine application systems, brine making equipment can range widely in sophistication from manual-batch home-built units (see Figure 2.34) to fully automated systems (see Figure 2.35). Major components of common brine production systems include:

- The Production Unit:
  - Hopper: Typically made of stainless steel to resist the highly corrosive agents. Municipal-grade hoppers typically hold 5-8 cubic yards of rock salt.
  - Mixing Tank: This is the core of the system where water is introduced to rock salt. Modern tanks are designed to ensure the water achieves a full 23.3 percent saturation before being discharged. Modern mixing tanks use "down-flow" design, where water is sprayed over the salt bed and pulled through by gravity. This ensures consistent saturation and higher production speeds compared to simpler "up-flow" designs, which can sometimes have channeling of the water through the salt leading to inconsistent salinity levels.
  - Filtration Systems: Most municipal grade brine-making systems (such as the system shown in Figure 2.35) feature filtration systems that are critical for preventing sludge buildup and clogs in the nozzles of application sprayers and elsewhere in the storage and application process. Filtration systems often use multiple varying-sized screens to filter out everything from large solids, sand and debris, and other fine particles that are commonly found in bulk rock salt.
- Control Systems and Automation:
  - Manual systems (such as the system shown in Figure 2.34) require operators to manually add rock salt and water and check salinity with a handheld hydrometer to ensure the ideal salt brine concentration is achieved.
  - Automated systems use a programable logic controller (PLC) and sensors to monitor the density of the liquid brine in real-time. These systems automatically shut off water once the ideal salt brine concentration of 23.3 percent is reached.

- Pumping and Transfer Systems:
  - Submersible or External Pumps: High-flow pumps are required to transfer finished brine to storage tanks (see "Liquid Storage and Handling Systems" earlier in this Chapter) or directly into truck tanks.
  - Blending Manifolds: If the operator is adding brine enhancers such as calcium chloride or beet juice, specialized pipe systems, or manifolds, will inject the additives at exact ratios during the truck tank filling process.

Costs for brine production systems can vary significantly based on production capacity, the level of automation, and whether the system is home-built or professionally manufactured. Small municipalities often launch on-site brine making programs using custom, home-built units costing approximately $1,000 to $8,000. For example, a small community in southeastern Wisconsin built a brine production system for under $1,000 that produces 1,000 gallons per batch in roughly 8 hours. While these manual batch systems have lower production rates, they remain highly cost-effective for smaller service areas. In contrast, larger communities requiring high-volume output often need to invest in professional systems with costs ranging from $10,000 to $250,000.[139,140] These automated units feature integrated PLC controls, salinity sensors, and data logging, with production rates between 3,000 to 7,500 gallons per hour.

Bulk rock salt often contains impurities like sand and other fine particulates that can settle in storage tanks and clog brine application nozzles. While modern brine makers include internal filters, they can plug with sediment and require maintenance. Switching to solar salt (produced by evaporating seawater) can virtually eliminate these issues. With a typical purity of 99 percent NaCl, solar salt does not contain the insoluble materials found in mined salt, significantly reducing sludge buildup and equipment wear and tear. Additionally, the high purity allows solar salt to dissolve faster, potentially increasing brine production by 30 percent per hour.[141] For some municipalities, the higher cost of solar salt is offset by increased production efficiency, fewer clogs, and higher-quality brine.

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[139] *Cost represents in 2015 dollars.*

[140] *University of Wisconsin-Madison Traffic Operations and Safety Laboratory Clear Roads Report No. CR 19-01, December 2021,* op. cit.

[141] *University of Minnesota Local Technical Assistance Program Center for Transportation Studies,* Brine Production Improvements Project Factsheet, *July 2024*.

Equipment Calibration

Calibration is the most critical process for ensuring that application rates are accurate and that materials are not wasted. Without rigorous equipment calibration, it is common to see application errors of 20 percent to 50 percent, leading to significant unnecessary chloride loading to the environment. In fact, the City of Cudahy found that properly calibrating their equipment resulted in a 46.5 percent reduction in salt use and cost savings of roughly $60,000 annually.[142] Simply stated, a calibration procedure measures the amount of material discharged at various settings in relation to a truck's speed. This process ensures that the actual amount of material applied to the pavement matches the "set point" on the controller. Uncalibrated equipment often results in over-application, which is not only economically wasteful but also damages infrastructure and harms the environment. Equipment calibration should be performed separately for different materials such as straight rock salt, blends, pre-wetting applications, or liquid applications (see Figure 2.36 for an example of calibration of a pre-wetting salt spreader).

Prior to any calibrations, the truck should be run long enough for the hydraulic fluid to be warmed to normal operational temperatures and held constant because viscosity changes can affect motor performance. The truck engine should be held at a spreading RPM level, typically between 1,500 to 2,000 RPM to simulate actual field conditions.

Granular Application Calibration

Calibration processes can be categorized into three distinct technology levels based on how the application system monitors ground speed and material discharge. The manufacturer's specific calibration instructions should be followed for each piece of equipment.[143]

- Manually Controlled Systems: For spreaders without ground-speed oriented controllers, calibration involves calculating the pounds per mile discharged at various settings and truck speeds. Following procedures published by the Salt Institute, operators count the number of auger or conveyor shaft revolutions per minute at each control setting. Then, the operator collects the amount of material discharged in a single revolution and weighs the material to establish a constant weight-per-revolution metric. A calibration chart using this collected information is created and typically

[142] Wisconsin Salt Wise "Municipal Champions": www.wisaltwise.com/Take-Action/Winter-Maintenance-Professionals/Municipal-Champions (date accessed: January 15, 2026).

[143] *Blackburn and Associates,* Calibration Guide for Ground-Speed-Controlled Material Spreaders, *Clear Roads Project Number 05-02, February 2009.*

displayed in the truck cab, which the operator uses to manually adjust settings relative to their travel speed.

- Open-Loop Ground Speed Control: These systems monitor truck speed and adjust control valves to predetermined settings, but they lack a second sensor to confirm actual material flow. Calibration of these systems establishes a discharge constant within the controller based on a "catch" test while simulating ground speed. It is an "open" system because any changes in hydraulic variables (such as fluid temperature or mechanical wear) will result in application errors that the system cannot automatically detect or correct.

- Closed-Loop Ground Speed Control: These systems represent the industry standard for precision and use a second sensor to monitor both truck speed and auger or conveyor speed simultaneously. The controller constantly adjusts the hydraulic valve until the correct ratio between material discharge and ground speed is attained. Properly calibrated closed-loop systems should produce average discharge amounts within plus or minus 4 percent of the theoretical target.

- Calibrating these closed-loop units typically involves a software-driven calibration mode where the controller spins the auger for a set number of pulses or a set amount of time while counting pulses. The operator then weighs the discharged material and enters the value so the controller can automatically calculate a precise discharge constant. Because these systems have feedback sensors, it will then automatically adjust the hydraulic flow during a storm to maintain this exact pulse count relative to ground speed.

The following are commonly recommended frequencies and standards for spreader calibration:[144]

- Calibrate when a spreader or controller unit is first put into service.

- Calibrate each spreader before every winter maintenance season begins.

- Spot check equipment during the season to make sure that units are properly functioning and within calibration specifications.

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[144] *Washington State University,* Material Application Methodologies Guidebook, *Clear Roads Report CR15-01, April 2019.*

- Recalibrate after any repairs, when stockpiles are replenished (solid material gradation may vary throughout the season), or when material calculations show a discrepancy.

- Calibrate equipment separately for each material type (salt, sand, salt brine).

Liquid Spreader Calibration

Liquid spreaders used for anti-icing or direct liquid applications are calibrated to achieve a target number of gallons per lane-mile. Calibration must be performed with the spray nozzles in the discharge lines to account for the specific back-pressure conditions present during field operations. It should also be verified that liquid is uniformly released from all spray nozzles across the spray bar. Operators use adaptor hoses to capture the entire liquid volume released from the nozzles into a 5-gallon bucket. The captured liquid is then measured using graduated containers to determine the precise volume discharged over a timed interval or simulated distance.

Modern controllers provide distinct calibration modes for liquid systems depending on whether they are open or closed-loop. Closed-loop controllers use flow meters to monitor the amount of liquid being applied and adjust the pump speed to maintain the target gallons per minute or gallons per ton ratio. Open-loop controllers use a variable speed pump control to increase or decrease flow based on predetermined settings, but they lack the ground speed orientation required for precision chloride management. State-of-the-art controllers display and log the total gallons of liquid pumped, providing a comprehensive "as-applied" dataset for environmental reporting.

Liquid anti-icing application equipment should be calibrated at the beginning of every winter season. Application equipment should be recalibrated if it has been transferred to a different truck, modified, or repaired. Equipment should be monitored during use and recalibrated when performance appears to be questionable.[145]

Pre-Wetting System Calibration

Pre-wetting systems add liquid chemicals to dry solid material, typically at the spinner or in the chute. Both the dry solid material spreader and the liquid material applicator must be calibrated in a two-part process that ensures the precise delivery of both components at varying truck speeds. To ensure accurate pump

[145] *Wisconsin Department of Transportation Bureau of Highway Maintenance,* Highway Maintenance Manual, *September 2025.*

performance and account for specific material viscosity, the tanks of the truck should be at least half full of the actual liquid chemical rather than water during the test. First, the solid applicator (conveyor or auger) is calibrated by weighing the discharge of salt over a set interval to determine the exact pounds delivered per revolution. Second, the liquid applicator is calibrated by measuring the volume of brine or chemical pumped into a graduated container during the same period to establish the gallons per ton ratio. By inputting these independent mechanical values into the electronic control unit of the spreader, the system can automatically synchronize the two outputs, maintaining a consistent pre-set mixture regardless vehicle speed. Finallly, verification testing is preformed to ensure the system is operating with acceptable tolerances. This involves catching and weighing a solid discharge from a simulated distance and measuring small liquid volumes (approximately 0.5 to 0.75 gallons) to confirm the actual delivery matches the controller's calculated output.

Frequently Overlooked Equipment Calibrations

While material spreaders are typically the primary focus of calibrations, several other components of winter maintenance equipment play a critical role in material application and operational efficiency. Ignoring the calibration of these systems and equipment can lead to inaccurate data, which can undermine salt reduction goals.

- Road Temperature Sensors: One of the most overlooked calibration opportunities involves the in-road sensors and mobile infrared road temperature sensors. As described throughout this Chapter, pavement temperature is the most significant variable in determining the appropriate anti-icing and deicing application rates and an uncalibrated sensor can lead to both over- and under-salting.[146] These sensors can lose accuracy due to road film buildup or mechanical vibration. Calibration typically involves side-by-side verification using a handheld infrared thermometer. For the mobile pavement sensors, operators should verify that the truck's sensor matches the handheld unit across a range of surfaces, such as asphalt and concrete. Some sensor manufacturers also have units that the sensors are inserted into to check accuracy and to make adjustments as needed.

- Spinner Speed Control: The rotational speed of a spinner is vital for managing spread width. Some spinners allow users to calibrate this speed so that the spinner does not throw material too far onto the roadside or fail to cover the intended lane width.[147]

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[146] *B. Pickworth,* Granular & Liquid Deicer Calibration, *Wisconsin Salt Wise Wednesday Webinar Series, March 1, 2023*, www.youtube.com/watch?v=8ARAtIGw8Qs.

[147] *Blackburn and Associates, February 2009,* op. cit.

- Spreader Gate Opening Sensors: While operators often manually measure the gate height, some advanced units employ electronic gate sensors. If these are not calibrated correctly, the controller may think the gate is set to 2 inches when it is actually at 3 inches, leading to a large error in material application.[148]

- Pre-Wetting Flow Meters: While pump calibration is standard, calibration of the actual flow meter that records the gallons used is often ignored. If the flow meter has scaling or is clogged, the "as-applied" reports will be inaccurate.

- Vehicle Speed Sensors: Ground speed oriented controllers are only as accurate as the speed signal they receive. Agencies should verify that the truck's speedometer agrees with the controller readout. Discrepancies here will cause an error in material application across all speeds.[149]

- Plow Controls and Joysticks: Calibration for snowplows and the joysticks that control them is helpful for equipment longevity, operator precision, and to reduce potential operator fatigue. Modern truck cabs use sophisticated joystick controllers to manage the lift, angle, and wing functions of the plow. Over time, the center position of a joystick can drift, leading to unintended plow movement or sticking. Calibration ensures the electronic signal sent from the cab matches the intended hydraulic response. Adjustments can be made to the speed of the movement of plow components and the feel of how "touchy" the joystick reacts.[150] Furthermore, some state-of-the-art systems allow for "float" calibration, which ensures the plow maintains optimal pressure on the road surface.

Other Best Management Practices

In addition to the strategies and technologies discussed previously, there are several best management practices and programs that seek to manage chloride loading from winter maintenance activities. These BMPs are described in the following sub-sections.

Snow Storage Areas

Winter road maintenance sometimes requires relocating snow from impervious surfaces to designated storage areas. However, because this snow can accumulate high concentrations of road salt and other

[148] *Blackburn and Associates, February 2009,* op. cit.

[149] Ibid.

[150] *B. Pickworth, March 1, 2023*, op. cit.

deicing chemicals, these storage areas can become concentrated sources of chloride and other pollutants. Because chloride moves with water when it is dissolved, the meltwater from these snow storage areas can easily infiltrate nearby surface waters, wetlands, and shallow groundwater aquifers. While there are no specific regulations issued by WDNR related to snow storage, municipalities are legally bound by several layers of regulation to ensure these sites do not contaminate waters of the State, including MS4 permit requirements (NR 216), surface water standards (NR 102), groundwater standards (NR 140), and wetland standards (NR 103).

To protect local ecosystems and drinking water, disposal of snow should be on land where contaminants and debris can be gradually released, contained, or collected rather than dumping it on land that drains directly to surface waters, groundwaters, or storm drains. The following best management practices should be implemented for selection, operation, and maintenance of snow storage areas.[151, 152]

- Do not locate storage in floodplains, groundwater recharge areas, or wellhead protection areas. Avoid geologically sensitive areas including karst and shallow fractured bedrock (within 50 feet of the surface).

- Maintain significant distances from private and public drinking water wells, lakes, streams, and wetlands. Snow should never be dumped directly into any waterbody.

- Avoid placing snow piles over or immediately adjacent to storm sewer inlets, which provide a fast and direct conduit for chloride to reach local waterways.

- Where it is feasible, store snow on impervious and curbed surfaces with no storm sewer inlets. This allows for potential containment and controlled diversion of meltwater.

- Avoid locating storage areas directly up-grade of parking lots, sidewalks, and roadways. Meltwater that runs onto maintained pavement and refreezes may result in the need for double salting.

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[151] *WDNR, "Where To Go With The Snow, Snow Treatment and Disposal Guidelines for Municipalities," WDNR Publication PUBL-WR-154-06REV.*

[152] *Minnesota Pollution Control Agency, "Guidance and Recommendations for Storing Transported Snow and for On-Site Snow Storage,"www.stormwater.pca.state.mn.us/guidance_and_recommendations_for_storing_transported_snow_and_for_onsite_snow_storage, accessed March 6, 2026.*

- In high-risk areas, design storage sites so that meltwater is directed to a collection system. This water can potentially be routed to a sanitary sewer (with treatment plant approval),[153] lined evaporation pond, or even reused for brine making (see discussion of similar practices in the "Solid Salt Storage BMPs" and "Salt-Laden Water Reclamation and Reuse" sections)

- Ensure that the site is sloped so that meltwater flows away from sensitive habitats that are particularly vulnerable to chloride toxicity.

Roadside Vegetation Management to Leverage Solar Radiation

A recent Clear Roads study sought to quantify how roadside vegetation impacts winter road conditions and provide guidance on leveraging sunlight to melt snow and ice more efficiently.[154] A controlled field study found that shaded pavements were significantly colder than pavements that are exposed to direct sun, sometimes by up to 20°F, leading to snow and ice persisting an average of 5.2 hours longer. The study also revealed that pavements exposed to direct sunlight not only returned to bare pavement conditions faster, but in certain conditions provided potential salt use savings greater than 50 lbs/lane-mile. The most problematic roadside vegetation was located on the south side of east-west roadways, where it blocks the southern sky.

The study resulted in two primary deliverables to help agencies implement best management practices for roadside vegetation:

- Vegetation Management Guide for Winter Roads:[155] This manual provides strategies for identifying shade-prone segments and prioritizing vegetation removal or pruning. Various methods are

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[153] *Chlorides are not removed by conventional treatments at wastewater treatment plants, however the goal here would be to reduce the initial extreme spike in chloride concentrations in nearby sensitive waterways that commonly occurs upon "first flush" of concentrated chloride-laden meltwater. These extreme spikes in chloride concentration can be lethal to aquatic biota whereas chloride-laden meltwater that goes to a large WWTP would be diluted by millions of gallons of household wastewater prior to being discharged into a larger body of water where the impact could be much lower. This method would not be a good option for WWTPs that are approaching chloride limits of their discharge permits.*

[154] *D. Klimbal, C. Dindorf, A. Erickson, and W. Herb,* Using Vegetation Management Practices Near Roads to Leverage the Benefits of Solar Radiation, *Clear Roads Report CR 20-04, January 2026.*

[155] *D. Klimbal and C. Dindorf,* Vegetation Management Guide for Winter Roads, *Bolton & Menk, Inc, and MnDOT, January 2026.*

discussed including clearcutting, selective removal, and thinning to balance solar benefits with environmental and community concerns. Recommendations include:

  - Focus vegetation removal on the right shoulders of eastbound traffic (or anywhere blocking the southern sky). These areas most frequently cause problematic shading in the United States.

  - Prioritize management of evergreen forests because dense evergreen canopies can block over 50 percent of sunlight, whereas deciduous or mixed canopies allow for 10 percent to 20 percent greater sunlight penetration.

  - Use automated vehicle location (AVL) records to identify road segments that consistently require more salt for frequent spot treatments. These segments often indicate shade-prone areas.

  - Selective removal should be used rather than total clearcutting. Mature stands should be thinned to a target of 30 to 50 trees per hectare.

  - Use "thinning" (removing an entire branch back to its point of origin) rather than a "heading back" (cutting a branch back to an intermediate point rather than a point of origin) pruning approach to promote light penetration and airflow while maintaining tree health and natural aesthetic.

  - Time pruning during late fall or early spring when vegetation is dormant to minimize disease risk. Mid-to-late summer pruning can be helpful to specifically slow the growth of vigorous or shade-heavy species.

- Shadowcasting Model Workbook:[156] This is a Microsoft Excel-based tool that uses site-specific inputs such as geolocation, road orientation, and canopy height to calculate potential shading effects and energy loss. The tool allows managers to compare existing conditions with proposed management scenarios.

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[156] The Shadowcast Model was developed by Bolton & Menk, Inc. and is available for download here: www.clearroads.org/project/23-04/ .

Salt Take-Back Programs

Salt take-back programs and municipal salt recycling drop-offs are emerging as a strategy for protecting local waterways and groundwater from chloride pollution. Rather than allowing excess or unused deicing salt to wash into storm drains or end up in landfills where it can leach into groundwater, these programs provide a centralized location for residents and contractors to dispose of extra or swept-up material. In some municipalities, dedicated collection bins allow for the return of dry, unused rock salt at no cost. These marked bins provide a sustainable alternative to the common practice of over applying excess salt onto pavement at the end of a winter season. Municipalities will integrate the collected salt back into their own winter maintenance operations, typically by using it when producing salt brine.

Similarly, through their "Sweep the Salt" campaign, the Wisconsin Salt Wise partnership encourages residents, business owners, and contractors to sweep up leftover salt from dry sidewalks, driveways, or parking lots for reuse during future storms, saving money on future salt purchases. By treating salt as a reusable asset rather than waste, these programs help reduce excess chloride pollution in local watersheds while also adding salt reserves for the next season.

Potential Future Advancements

While the chloride reduction strategies and technologies discussed previously in this Chapter are already being implemented to some extent by public winter maintenance agencies with measurable success, the following sections focus on the potential next generation of winter maintenance tools and strategies. These emerging advancements, many of which are currently in the development or pilot phases, offer a glimpse into a future where municipalities might further reduce their chloride loading through innovative structural design and material science rather than chemical treatments.

Permeable Pavements

Permeable pavements such as porous asphalt, pervious concrete, and interlocking pavers, use interconnected voids to drain water into a sub-surface gravel layer allowing stormwater to percolate through the soils and into shallow aquifers. While primarily used for stormwater management, these systems also show promise for reducing chloride pollution. Because water drains through the surface of the pavement, rather than pooling, ice formation can be significantly minimized.

Research from the University of New Hampshire indicates that porous asphalt can maintain safety with up to 77 percent less deicing salt than traditional surface, sometimes requiring no deicer at all due to superior traction.[157] However, some local communities in the Region report using traditional salt rates on permeable installations. If salt application is not reduced, these systems may inadvertently provide a direct conduit for chloride to contaminate shallow groundwater. Additionally, some communities have experienced extensive damage resulting from plowing of these surfaces. Further research and practitioner education on care and maintenance of these installations are essential to ensure these pavements achieve their full intended environmental benefits.

To maintain the benefits described, specific material usage constraints and critical maintenance are necessary. First, sand or other abrasives should never be used on permeable pavement for traction as the fine particles quickly clog the surface voids and reduce the ability to infiltrate water. Second, periodic maintenance, such as vacuum sweeping, is typically required to clear out accumulated sediment and debris from the voids. While these maintenance needs are not specific to chlorides, they are linked to salt usage. If maintenance is not kept up and infiltration capacity is compromised, water will begin to pool and freeze on the surface, creating a scenario where the surface behaves more like traditional pavement, necessitating salt application and negating any potential environmental advantages.

Heated Pavements

While heated pavement is more common on private driveways, sidewalks, and small parking lots, this practice can also be an option for some public roadways as an alternative to chemical deicing. While uncommon in the United States, countries such as Iceland, Japan, and some Scandinavian countries have constructed heated roadway systems.[158] A common design for heated roads is to install piping under the pavement to circulate heated water. The water can be heated using geothermal energy, electricity from other renewable sources, or electricity from burning fossil fuels. Another technology used for heating roadways is electric heating mats under the pavement surface, particularly in critical areas such as bridges, intersections, and highway exits. While these systems can be expensive to install and operate, they are highly effective at maintaining clear roads during winter weather events. The operation costs could be reduced if the heating is powered by a renewable resource. These heating systems can lead to a reduction in accidents and road closures, which improve safety and reliability of roadways during the winter months. Additionally, cost savings can be realized through reduced plowing and salting, which can also lead to a reduction in chloride loading to the environment.

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[157] *R.M. Rosen, T.P. Ballestero, K.M. Houle, D. Heath, and J.J. Houle, "Assessment of Winter Maintenance of Porous Asphalt and its Function for Chloride Source Control,"* Journal of Transportation Engineering*, 140(2), 2013.*

[158] *British Broadcast Corporation, "How Different Nations Deal with Winter Weather," accessed on November 25, 2025.*

Electrically Conductive Concrete

While traditional heated pavements typically rely on external heat sources being piped into the pavement, electrically conductive concrete (ECON) transforms the concrete itself into the heating element by incorporating materials like carbon fibers or steel shavings to standard concrete mixes. When a low-voltage current is applied to the concrete slab via metal electrodes installed at the edges, the concrete acts as a resistor, generating heat uniformly throughout the material, melting snow on contact. Because the conductive fibers are distributed evenly throughout the concrete mix, the pavement can reach a target temperature faster and with less energy than traditional heated pavements. Furthermore, there are no fragile pipes or wires that are prone to breaking which reduces potential maintenance issues, and it is significantly more durable under the weight of heavy trucks when compared to traditional heated pavements.

The Roca Spur Bridge in Nebraska is the first application of conductive concrete for structural bridge decking. Completed in 2002, this 150-foot bridge deck utilized a mixture of steel shavings and carbon particles in 52 concrete slabs to maintain an ice-free surface.[159] This installation has been melting snow at a rate of approximately one inch per hour, effectively replacing the need for chemical deicers.

More recent pilot programs, such as those at the Des Moines International Airport (2016) and the Iowa DOT headquarters (2018) have focused on integrating smart automation into the technology. These studies have utilized carbon fiber-reinforced mixes and programmable logic controllers (PLCs) that trigger heating elements based on real-time moisture and temperature sensors.[160] These projects demonstrated that ECON can be managed via remote applications and is energy efficient, costing approximately $0.19 per square meter to clear a typical moderate snowfall.[161]

While the initial capital investment is higher than traditional concrete, the long-term benefits in labor savings, infrastructure durability, and environmental protection offer a potential cost-effective option for future municipal transportation projects.

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[159] *C.Y. Tuan, "Roca Spur Bridge: The Implementation of an Innovative Deicing Technology,"* Journal of Cold Regions Engineering, *Volume 22(1), March 2008.*

[160] *Iowa State University Institute for Transportation,* Self-Heating Electrically Conductive Concrete Demonstration Project, *Final Report, October 2021.*

[161] Ibid.

Phase Change Materials

Phase change materials (PCM) are increasingly being studied for having dual solutions for urban infrastructure, potentially offering significant benefits for both summer climate mitigation and winter safety. PCM-modified pavement contains pockets of phase change materials that act as a thermal sponge, soaking up pavement heat while in liquid state during the summer peaks and squeezing warmth back out by freezing when winter temperatures drop. Researchers have found that PCM modified asphalt mixes can have summer surface temperatures between 3.2°F and 18.5°F lower than standard asphalt. By preventing pavements from reaching extreme high temperatures, this technology can help combat the urban heat island effect and reduce structural damage to the pavement which occurs when asphalt softens under pressure.[162]

Conversely, in winter conditions, the thermodynamic process reverses. As ambient temperatures drop, the PCM materials solidify and release stored thermal energy back into the pavement. PCM-modified sections of pavement could reduce the total annual time spent below the freezing point (32°F) by up to 29 percent.[163] A separate study found that this latent heat release in colder air temperatures can increase pavement temperatures by approximately 3.6°F compared to conventional asphalt mixtures.[164] The study also found that this thermal release can delay the onset of freezing by 1 hour and 10 minutes, a critical window that helps prevent the formation of frost and black ice. This delay also can allow road surface temperatures to remain above the freezing point during the initial hours of a storm. By maintaining a slightly warmer surface, PCMs can prevent the initial bond between ice and pavement, which could eliminate the need for heavy pre-treatment when forecasted temperatures are right.

While still considered emerging technology, exploration of the use of PCMs in road infrastructure has begun to transition from laboratory simulations to field trials and specialized deployments, particularly on bridges and airfields.

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[162] *M.A. Montoya, D. Betancourt-Jimenez, M. Notani, R. Rahbar-Rastegar, J.P. Youngblood, C.J. Martinez, and J.E. Haddock,* Environmentally Tuning Asphalt Pavements Using Phase Change Materials, *Indiana DOT and Purdue University Joint Transportation Research Program, February 2022.*

[163] Ibid.

[164] *T.M. Phan, D.W. Park, and H.S. Kim, "Utilization of micro encapsulated phase change material in asphalt concrete for improving low-temperature properties and delaying black ice,"* Journal of Construction and Building Materials, *Volume 330, May 2022.*

Solar Roadways and Walkways

Solar roads and walkways, or photovoltaic pavements, integrate solar panels directly into the transit surface to generate electricity from sunlight. These modular panels are topped with high-strength, textured glass designed to maintain vehicle or pedestrian traction while allowing sunlight to reach the underlying solar cells. While the primary goal is typically to provide power to streetlights and electric vehicle stations, or contribute to the electrical grid, some designs incorporate internal heating elements. By using the solar energy generated to melt snow and ice on contact, these pavements could theoretically eliminate the need for traditional plowing and chemical deicers.

The most prominent municipal demonstration of this technology in the United States was installed in 2016 at Jeff Jones Town Square in Standpoint, Idaho. This pilot project led by Solar Roadways, Inc. consisted of modular structural panels embedded in a pedestrian plaza. While the project successfully demonstrated that integrated heating elements could keep surfaces clear of snow and ice during harsh winters, it also highlighted significant hurdles, including panel durability, moisture sealing, and the high cost of specialized glass. Despite these challenges, the installation provided critical data on how this innovative pavement can perform in public settings. Currently, this technology remains in the pilot phase due to high costs and concerns regarding its durability under heavy vehicle traffic.

Local Success Stories

Across the Southeastern Wisconsin Region, municipal winter maintenance has undergone a dramatic transformation, moving away from a traditional heavy salting approach to a sophisticated, data-driven science. In recent years, local communities, counties, and the State have made monumental strides in balancing public safety with environmental stewardship, adopting modern technologies and innovative strategies that were once considered out of reach for local budgets.

By integrating precision application methods, advanced equipment calibration, and proactive liquid treatments, many agencies are significantly reducing the chloride load entering the environment. This advancement represents more than just a change in equipment but is also a cultural shift within public works departments that is driven by a commitment to fiscal responsibility and the long-term protection of the Region’s freshwater resources. The following success stories are just a few examples of how communities are setting a new standard for sustainable winter road maintenance across the Region.

Walworth County

Almost all Walworth County Highway Department employees that are responsible for snow and ice control operations have been certified in the Wisconsin Salt Wise program, with several Facilities and Parks Department staff also trained. All 36 trucks that apply deicing or anti-icing material are calibrated annually, and significant improvements have been made over the last six years in establishing lower salt-use thresholds. With a significant shift from a rock salt-centric strategy to a brine-centric strategy which was implemented during the winter of 2019-2020 through the current winter season 2025-2026, the County has reduced their overall salt use by more than 50 percent while improving crash rate statistics over the same period.

The County's long-term goal has been to reduce the preventable winter accident rate and rank among the best counties in the State on a "per-100 million vehicle miles traveled" (VMT) basis, as recorded in WisDOT's annual Winter Maintenance Report. In the winter of 2020-2021, the Statewide average was 21 winter crashes per-100 million VMT, while Walworth County had 16 winter crashes per-100 million VMT, ranking fifth out of seven counties in the Southeastern Region. By the winter of 2024-2025, the County was tied for first in the Southeastern Region for winter safety statistics, with 11 winter crashes per-100 million VMT, well below the Statewide average (18 crashes) and the Southeast Region average (15 crashes). The County attributed this reduction in winter crashes to the flexible use of salt brine to treat highways before, during, and after winter storms.

During the winter of 2018-2019, Walworth County was the sixth highest County for rock salt usage, at 21.9 tons of salt per lane-mile. During that season, the County only used 44,000 gallons of brine for pre-wetting applications. By the winter of 2024-2025, Walworth County reduced their rock salt usage on roads to 6.7 tons/lane-mile, among the lower quartile in the State.[165]

While Walworth County has made significant improvements to its winter maintenance programs and strategies, they still feel there is room for more. The County continues to train staff annually, experiment with salt brine and calibration strategies, and analyze their performance on an individual storm basis to adjust their operations for optimal public safety while protecting the environment and County resources. Meanwhile, each year the County has witnessed increasing participation and partnerships with almost all municipalities within the County, which also continue to adopt new winter maintenance strategies.

[165] *See WisDOT Bureau of Highway Maintenance,* Annual Winter Maintenance Data 2024/2025, *November 2025*.

City of Oak Creek

Since 2019, the City of Oak Creek Public Works Department has been steadily advancing the way they maintain safer roadways throughout the winter season. What began with pre-season spreader calibrations, controller upgrades, and the addition of a 1,000-gallon anti-icing unit and brine-making system, has evolved into a comprehensive modernization of the City's snow and ice control operations.

In 2022, new leadership brought renewed focus and a strong commitment to operational efficiency. The winter maintenance fleet was enhanced with segmented plow blades, and the remaining controller upgrades were completed – significantly improving performance and reliability.

The final major enhancement arrived in 2023 with the installation of pavement sensors that deliver real-time and forecasted pavement surface data. This technology has transformed the department's response capabilities, enabling crews to make faster, data-driven decisions and ensuring safer travel conditions for all who live, work, and commute in Oak Creek.

Prior to these major improvements to their fleet and overall snow and ice fighting strategy, the City was using approximately 4,000 or more tons of salt per year. They have cut that in half, now averaging approximately 2,000 tons of salt used in an average season. While the City has invested almost $380,000 on new winter maintenance equipment, the annual savings on salt are estimated to be $120,000 per year.

Oak Creek Public Works remains proud to provide innovative, dependable, and cost-effective winter maintenance services that keep their community moving regardless of what winter brings.

City of Cudahy

Nearly a decade ago, the Cudahy Department of Public Works began a journey toward salt reduction from their winter road operations. By mastering the science of calibration, the City was able to cut its salt use by 46.5 percent. This step alone saved the City $60,000 annually which was reinvested into anti-icing equipment, V-Box hoppers, and electronic ground-speed controls. This modernization of their winter maintenance fleet netted an additional 20 percent reduction in salt usage. In recent years, Cudahy manages its 149 lane-miles using only 660 tons of salt in a severe winter, a massive drop from the previous average of approximately 2,000 tons a year. This success relies on the dedication and buy-in of the entire team, from plow operators to management.

City of Lake Geneva

Over the last decade, the City of Lake Geneva has modernized its winter maintenance operations, resulting in a 60 percent reduction in total material use. Key improvements include equipping all heavy plows with computer-aided spreaders and expanding the brine program; three trucks currently utilize brine tanks, with two more soon to be outfitted. The City has also transitioned from applying a sand-salt mix during winter storm events to applying 100 percent salt, improving efficiency and road safety while also saving many hours of staff time for street sweeping and cleaning catch basin. The City also purchased a calibration scale, which is shared with neighboring communities, to ensure equipment accuracy. In 2023, and again in 2025, the City purchased 6,000-gallon bulk storage tanks for brine. This allows the City to bypass trips to the Walworth County facilities to reload, saving time and resources on travel. Additionally, all operators are now Wisconsin Salt Wise certified, and a custom-built brine applicator has eliminated bulk salt use on the City's bike trails.

Village of Bayside

The Village of Bayside faces unique winter challenges, including lake-effect snow and narrow, low-traffic roads that limit granular salt activation. Moving away from an outdated policy of heavy, uncalibrated salt application, the Village now uses a data-driven approach. By utilizing two trucks equipped with pre-wetting systems and a cost-effective, homemade brine making machine, Bayside now adjusts application rates based on pavement temperatures and has reduced salt use by 33 percent. Additionally, programs like their Salt Take-Back initiative engage residents in the salt reduction mission.

Village of Mount Pleasant

Approximately five years ago, the Mount Pleasant Department of Public Works (DPW) began using salt brine to pre-treat roads prior to winter storms in hopes of improving snow removal operations and reducing overall salt usage. The Village plans to add another brine truck to their fleet in 2026. Mount Pleasant DPW added their first pre-wetting system in 2025 to further reduce salt usage, with three more systems to be added in 2026. Approximately 75 percent of employees with snow removal duties are certified through Wisconsin Salt Wise training. All winter maintenance trucks equipped for salting operations are calibrated prior to each winter season. In the last five years, the Village estimates they have reduced overall salt usage by 25 percent to 30 percent and expects that reduction percentage to increase significantly in 2026 with their continued fleet and operational improvements.

Village of Paddock Lake

Between 2010 and 2020, the Village of Paddock Lake reduced its total salt use by 63 percent through improved staff training and a multi-faceted operational shift. Instead of the traditional broad spreading of granular salt, which has high "bounce-and-scatter" loss, staff now utilize windrow placement (placing salt along the crown of the road), allowing the brine to naturally migrate to the edges. The Village also utilizes "passive solar" strategies, drastically cutting salt on the 36 percent of Village roads with southern sun exposure. When temperatures drop, they use "bird's eye" gravel (a heavier aggregate than sand) to provide traction, which has the added benefit of limited loss to local waterways.

To validate these efforts, staff conduct monthly groundwater and sanitary sewer monitoring, which has confirmed a direct correlation between reduced road salt use and lower chloride levels. This success is a direct result of the Public Works staff's commitment to the chloride reduction plan.

Village of Slinger

Since 2021, the Village of Slinger has transitioned from visual assessments of how much salt application was needed to data-driven precision applications and a robust anti-icing strategy. As part of the strategy, the Village also installed a truck wash reclamation system that captures salty wash water and recycles it back into their brine maker. These improvements have slashed salt consumption by 200 to 300 tons per winter. Beyond the environmental benefits, the program is also budget friendly with the $37,500 in equipment upgrades leading to $18,000 to $27,000 in annual material cost savings.

Village of Summit

Since 2019, the Village of Summit Public Works Department has been systematically modernizing its snow and ice control operations. This evolution is driven by a mission of maintaining road safety while protecting the Village's lakes, rivers, and streams from chemical runoff. By transitioning away from older, manual methods, the department is moving toward a "smart salting" approach that prioritizes environmental stewardship alongside safety and operational efficiency.

The shift has been significant, moving from applications of sand-heavy blends that left excess residue to a precision-based salt and brine system. The Village has replaced outdated "on/off" spreaders with advanced control systems and pre-wetting equipment that allows staff to dial in application rates as low as 100 lbs/lane-mile. Significant investments, such as a 5,150-gallon brine storage tank and the purchase of a dedicated anti-icing unit in early 2026, allow staff to pre-treat roads and ensure salt adheres to the pavement rather than bouncing into ditches.

Looking toward the future, the Village is also refining its service standards to further reduce its footprint. While the level of service goal for main thoroughfares will continue to be bare pavement, low-volume residential streets will see more targeted chemical use reserved for high-risk areas like hills, curves, and intersections. Staff have received training in smart salting strategies through the Wisconsin Salt Wise program and the American Public Works Association. In addition, staff have partnered with Waukesha County and Force America to learn how to properly calibrate equipment prior to each winter season to ensure accurate application rates of materials. These combined equipment and strategy updates are projected to reduce total salt use by 20 percent or more during an average winter season.

Village of Walworth

Following a 2024 Wisconsin Salt Wise workshop, the Village of Walworth Public Works staff engineered a custom brine system using repurposed materials and shop parts. By building a brine maker from 55-gallon drums and constructing an application unit from a surplus 450-gallon pickup truck tank and a stop-sign post, the Village slashed salt usage from 10 tons to just one ton per winter storm – a 90 percent reduction. This $1,200 "do-it-yourself" investment saves up to $1,500 per storm event in materials and overtime, meaning the equipment paid for itself during its first use.

Town of Linn

In 2019, the Town of Linn began a complete rehabilitation of their snow and ice control program. A completely new policy was put in place that emphasizes increased frequency of mechanical snow removal and the utilization of industry BMPs. Additionally, a plan was created to update all snow and ice control trucks. Town practices such as using sand, not calibrating equipment, and not utilizing liquids in any way were progressively eliminated. Over the course of five years, the Town installed computer-controlled material dispensing systems, pavement and atmospheric sensing equipment, onboard liquid application systems, and plows with advanced cutting-edge systems for each front-line plow truck. Additionally, the Town employs two liquid spray units that are utilized for anti-icing applications prior to some snow events. During certain minor snow events, the Town uses the liquid spray units for direct liquid application (DLA) rather than salting. When the Town is able to use DLA rather than granular salt for deicing it saves approximately $2.25 per applied mile. All employees attend Wisconsin Salt Wise training and Superintendent Wittum assists the Salt Wise program coordinator with trainings.

Because of the financial investments and policy upgrades, the Town of Linn saves $20,000 or more annually on material purchases. These program improvements have equated to a reduction in salt use of approximately 35 percent. In the beginning of the program transition, the Town set a goal of 300 lbs/lane-miles for salt applications which the Town has exceeded, currently applying 268.5 lbs/lane-mile.

2.3 PRIVATE WINTER MAINTENANCE PRACTICES – PROPERTY OWNERS AND CONTRACTORS

While a lot of attention is paid to winter roadway salting on public roads and highways, chloride loading contributions from private practices is not inconsequential. Private roads and parking lots are typically serviced by winter maintenance practitioners that are contracted to remove snow and ice and provide safe ground conditions. Residential driveways, walkways, and adjacent public sidewalks are often maintained by individual homeowners or contracted winter maintenance service providers. As with public winter maintenance practices, the focus for private practices is to reduce or eliminate chloride sources to the environment through education, policies, equipment calibration, appropriate application rate, alternative deicers, smarter site layouts, and other methods.

Private Roads and Parking Lots

Salting of private roads and parking lots may contribute significantly to total chloride pollution.[166,167] Winter maintenance strategies can vary considerably between these two types of pavement. While roadways generally only have automobile traffic, parking lots experience both vehicle and foot traffic. Salt application on private roadways is typically delivered at a higher truck speed and directed at more narrow corridors as compared to parking lots, often resulting in a larger amount of salt bouncing off the roadway before serving its intended function. In contrast, dispersed salt in a parking lot often bounces to another part of the pavement rather than off the lot. Also, the higher speed and concentrated traffic on roadways can help to reduce snow and ice buildup in driving lanes, potentially reducing the amount of deicing products necessary. Parking lots, on the other hand, accommodate both vehicles and pedestrians and often receive low-speed salt application, which tends to keep the product on the intended areas of the pavement. Furthermore, in parking lots it is more practical to sweep up and remove excess salt remaining on the pavement after a storm event, often allowing for re-use of the deicing product.

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[166] *N. Perera, B. Gharabaghi, P. Noehammer, and B. Kilgour, "Road Salt Application in Highland Creek Watershed, Toronto, Ontario – Chloride Mass Balance", Water Quality Research Journal of Canada, 45: 451-461, April 2010.*

[167] *SEWRPC Technical Report No. 65,* Chloride Sources and Data for Chloride Loading and Mass Balance Analysis*,* 2025.

Pavement Clearance Expectations

Certain paved surfaces typically have a higher level of winter maintenance activities during a winter storm event. For private roads and parking lots, those serving large commercial properties are most likely to require bare pavement at all times. On the other hand, private roads serving residential properties may require a lower amount of winter maintenance.[168] Parking lots and adjacent walkways, entryway areas, and handicap parking stalls may receive a higher level of winter maintenance than other areas due to the high foot traffic and increased sensitivity for those locations. Determining an appropriate level of deicing combines the tradeoffs between the benefits and costs, where adequately safe conditions are to be achieved in an acceptable timeframe at a reasonable cost of materials, labor, and environmental and infrastructure impacts.

Users often have the expectation that paved surfaces should be cleared to bare pavement immediately after a winter storm event. This expectation of a higher winter maintenance level can be particularly prevalent for parking lots.[169] The expectation of quickly regaining bare pavement can result in overapplication of deicing salts to attempt to melt more snow in a shorter period of time. However, studies have shown that excess salt application does not yield higher melting rates beyond a certain point, and surplus salt on pavement can reduce traction and create less safe conditions. While applicators strive for optimal snow removal, users can also adjust their expectations on the degree to which the snow is removed and in what timeframe. They can adjust their driving behavior to account for the presence of snow and ice, such as staying home, or if they must go out then driving slower, using caution while turning, and braking early and gently when coming to a stop. Additionally, people can wear footwear that provides adequate traction while walking on snowy pavement. Similarly, they can walk cautiously to reduce the risk of slipping.

Altering expectations regarding the winter maintenance level may come not only from the users but also from property owners and managers. A property owner can request the applicator use anti-icing materials prior to a winter storm event to reduce the bonding of snow and ice to the pavement surface, making it easier and quicker to remove via plowing or shoveling during or after the event. Anti-icing and mechanical snow removal is a more effective and less salt intensive snow removal method than applying excess salt on top of a snowpack. Additionally, a larger time window could be granted to the applicator for which all the

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[168] L. Fu, R. Omer, and Z. Liaqat, "A Survey of Current State of Practice for Winter Maintenance of Parking Lots and Sidewalks", 2013.

[169] G.E. Grenato, L.A. DeSimone, J.R. Barbaro, and L.C. Jeznach, "Methods for Evaluating Potential Sources of Chloride in Surface Waters and Groundwaters of the Conterminous United States", 2015.

snow and ice must be removed, such as allowing up to 48 or 72 hours to regain bare pavement rather than the typical target of 24 hours. Property owners can also request that the service provider apply salt at a specified lower rate, as discussed in further detail in the next section of this Chapter. A main challenge for property owners and applicators in reducing the winter maintenance level is their exposure to liability from a slip and fall injury. This fear of legal action often leads to over-application of salt with the intention of reducing this liability. This is discussed in more detail later in this Chapter.

Recommended Application Rates

Many factors need to be considered in order to determine a recommended application rate for deicing and anti-icing products on private roads and parking lots. These considerations include type and amount of precipitation, pavement materials, pavement temperature and temperature trend (increasing or decreasing), and deicing or anti-icing material to be used. As such, there is no one application rate that is suitable for all conditions and factors. However, Commission staff reviewed the literature to identify general recommended ranges for application rates, which are presented in Table 2.5. Based on the literature, the average recommended dry rock salt application rate per storm event was approximately 3.5 lbs/1,000 square feet (ft^2), the average recommended pre-wetted salt[170] application rate was 2.5 lbs/1,000 ft^2, and the average recommended liquid brine anti-icing application rate was approximately 0.7 gal/1,000 ft^2. These rates are significantly lower than current application rates used by contractors, which can range from 6 lbs/1,000 ft^2 to 14 lbs/1,000 ft^2 for dry rock salt, with anecdotal evidence of rates as high as 20 lbs/1,000 ft^2 being used.[171] This suggests that parking lots are frequently over-salted, and there is capacity to reduce salt usage.

An important aspect of applying deicing materials at a recommended rate is calibration of equipment to ensure the actual spreading rate equals the intended spreading rate. This may include implementing training programs to teach operators and shop managers the correct method to calibrate the equipment being used across the entire fleet. It is important to check the calibration multiple times throughout the season and adjust the equipment accordingly. Similarly, it is important for applicators to have the means to measure the amount of material applied. It is not uncommon that the equipment used by applicators lacks the functionality to measure the amount of salt that has been spread.[172] This can pose a challenge for successfully implementing a recommended application rate.

[170] *Prewetted rock salt refers to adding brine to a dry salt mixture to enhance melting capabilities.*

[171] *SEWRPC Technical Report No. 65.*

[172] *L. Fu, R. Omer, and Z. Liaqat, 2013,* op. cit.

As recommended rates for applying deicing and anti-icing materials are often lower than the actual application rate used by many practitioners in the field, spreading at the recommended rate can save money for the contractor and/or the property owner via less material used. Aligning the environmental benefit with an economic benefit can be an important tool to achieve the desired reduction.

Reduce Area of Salted Pavement

Reducing the amount of pavement area that receives snow and ice buildup can also reduce the amount of salt used. This can include designing smaller surface parking lots or constructing covered lots, such as parking garages or underground parking facilities. An option for designing smaller surface lots is to not size the lot for the highest volume day of the year, but rather size it nearer to the average daily use. The amount of extra space needed beyond the average daily use can vary depending on the type of building, where shopping centers may have larger fluctuations in parking lot traffic than an office building with a consistent number of employees. During peak volume days, such as holiday shopping for retail buildings, overflow parking could be provided via public parking nearby. Alternatively, when no overflow parking is available, expectations may need to be changed to accept that vacant parking spaces may not always be available.

An alternative to smaller surface parking lots is to provide covered parking, such as parking garages and underground parking, where the pavement is protected from snow and ice, alleviating the need for deicing salt application. In addition to reduced salt use, the need for plowing and other winter maintenance services may be reduced, which can provide a cost savings. These structures, however, are typically significantly more expensive to construct than surface parking lots.

Slip and Fall Liability

Fear of "slip-and-fall" liability is one of the most cited reasons for the overuse of winter deicers, especially on private property. Both winter maintenance contractors and property owners fear lawsuits in the event of an injury due to snow or ice. To prevent this, they often over-apply salt and other deicing materials, believing that more product is safer and will protect them from accusations of poor maintenance.[173]

A certification program that offers a liability waiver to trained contractors could partially alleviate this widespread issue. The "Green SnowPro" program in New Hampshire, administered by the New Hampshire Department of Environmental Services (NHDES) is a primary example. This program protects certified

[173] *K. Hossain and L. Fu, Optimal Snow and Ice Control of Parking Lots and Sidewalks, iTSS Lab Department of Civil and Environmental Engineering, University of Waterloo, January 2015.*

contractors and their clients from lawsuits, except in cases of gross negligence or reckless disregard of the hazard, as long as they follow the best management practices (BMPs) for winter maintenance on roads, parking lots, and sidewalks published by NHDES. This liability protection has become the cornerstone of the program and a significant incentive for contractors to get certified. With this waiver, certified contractors feel confident using less salt while still maintaining safe conditions.

To get certified, applicators must complete a training course that covers topics like equipment calibration, anti-icing, brine making, pre-wetting with brine, efficient application rates, and effective plowing techniques. Applicators also must then pass an exam covering these subjects. Those that receive a passing score on the exam are eligible to apply for the Voluntary Salt Applicator Certification and Liability Protection Program. For recertification the program requires an annual re-application, a refresher course every two years, and retaking the full course and exam every six years. Certified professionals must also track their salt use and provide a written record describing their winter road, parking lot, and property maintenance practices. The written record must include the type, rate, and quantity of deicing materials used and weather conditions for each event requiring deicing.[174] The tracking program is intended to hold applicators accountable and to document salt usage from year to year.

The "Green SnowPro" program provides multiple benefits beyond liability protection. Using less salt leads to cost savings on materials for contractors and gives them a marketing advantage, allowing them to promote their services as environmentally friendly. The liability waiver also extends to property owners, offering them peace of mind. Some insurance companies may even provide discounts to businesses that hire a certified winter maintenance contractor. Preliminary data from NHDES shows a downward trend in chloride levels in the waterways of New Hampshire and annual reports from certified contractors show salt applications decreased by 30 percent, indicating the program is a successful tool for chloride reduction.[175]

Despite its success, the New Hampshire program faces some challenges. Some contractors are not consistently providing detailed documentation of their deicer use as the program requires, making it difficult to fully quantify the reduction in salt application. The program's long-term financial viability is also

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[174] *N.H. Rev. Stat. Ann. § 508:22(II) (2017).*

[175] *SEWRPC Technical Report No. 67,* Legal and Policy Considerations for The Management of Chloride*, February 2024.*

uncertain under its current fee structure. Lastly, while the liability waiver has been successfully defended in court to date, its strength may be further tested by more complex legal challenges in the future.

In 2023, the Wisconsin state legislature introduced and passed a similar bill for slip and fall liability protection, titled Senate Bill 52. This bill would have required the Department of Agriculture, Trade, and Consumer Protection (DATCP) to create a voluntary registration program for commercial deicer applicators. The program would have provided training to applicators on established best management practices, created and maintained a list of registered commercial applicators who have completed the training and passed the examination, and provided protection to the applicator or property owner who hires a registered applicator against liability damages from slip and fall incidents related to snow and ice when a registered applicator used methods taught in the training program. However, Senate Bill 52 was vetoed by the governor and not passed into law based on the objection from the governor to creating such broad immunity from liability as well as the lack of funding framework to support DATCP in the mandated development and implementation of the program.

Private Driveways and Sidewalks

The chloride contribution to waterways from winter deicing on private driveways and sidewalks is often assumed to be insignificant and is commonly an overlooked source of chloride,[176] however these surfaces can be the most over-salted areas in winter maintenance and may contribute significantly to chloride loading to the environment.[177] Deicing activity on private driveways and sidewalks is primarily done by individual homeowners, which often leads to over application of salt. This may be in part because many homeowners are often not aware of recommended salt application rates, the environmental harm of chloride pollution, and best management practices for deicing and anti-icing. Additionally, many homeowners manually apply salt rather than use a rate-controlled spreader, which can lead to higher application rates. Homeowner education on proper snow removal and salting methods is key to reducing salt use on driveways and sidewalks. This can include learning recommended salt application rates, using alternate deicing methods and materials, applying anti-icing materials in a timely manner to make snow removal easier, and sweeping up excess salt after bare pavement is regained following a snow event.

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[176] *G.E. Grenato, L.A. DeSimone, J.R. Barbaro, and L.C. Jeznach, 2015, op. cit.*

[177] *Minnesota Pollution Control Agency, "Winter Parking Lot and Sidewalk Maintenance Manual, Third Revision", June 2015.*

Recommended Application Rates

As discussed previously, several factors determine the recommended deicing application rate for the specific weather and ground conditions. The type of deicing or anti-icing material, pavement temperature, temperature trend, and type and amount of precipitation all contribute to determining the optimal application rate. As a result, there is no single recommended salt and brine application rate for all conditions. However, Commission staff reviewed general recommended driveway and sidewalk salting and anti-icing rates available in the literature. These findings are summarized in Table 2.6.[178] The average recommended dry salt application rate was approximately 3.6 lbs/1,000 ft^2, the average recommended application rate for pre-wetted rock salt was approximately 3.3 lbs/1,000 ft^2, and the average recommended application rate for anti-icing brine was approximately 0.6 gal/1,000 ft^2.[179] A rate of 3.6 lbs/1,000 ft^2 of dry salt is approximately equivalent to spreading a 12-ounce coffee mug volume of salt over a 20-ft long driveway or ten standard sidewalk squares.[180]

Most deicing salt for driveways and sidewalks is applied by individual property owners, not contracted applicators. Homeowners often apply salt by hand or with a walk-behind spreader, which can lead to over application. To ensure the correct amount of salt is applied, it is important to review the desired coverage after application. Figure 2.37 depicts the salt distribution density of the recommended dry rock salt application rate previously discussed. For driveways and sidewalks that are maintained by a contracted service provider, the practitioner can calibrate their equipment to accurately apply the desired recommended rate. Currently the use of brine and prewetted salt is uncommon for driveways and sidewalks, but their use is anticipated to become more prevalent in the future as homeowners become more aware of recommended salting techniques and application rates.

Using recommended salt application rates offers several benefits for homeowners. Since these rates are often lower than what is typically applied, using less salt can lead to a cost savings for the homeowner. Additionally, applying less salt helps protect plants and other landscaping from salt runoff, prevents damage to concrete surfaces, and reduces the amount of cleanup needed after the storm event.

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[178] *To note, the values in this table for the references cited are the same as in Table 2.5. This is because these studies aggregated parking lot and sidewalk salting into one recommended application rate, which makes the rates applicable to both tables.*

[179] *Current salt application rates for driveways and sidewalks were not compiled in SEWRPC Technical Report No. 65. Therefore, no comparison can be made with recommended application rates for driveways and sidewalks in this Chapter,*

[180] *Wisconsin SaltWise, www.wisaltwise.com/take-action/smart-salting, accessed July 2025.*

Sidewalk Deicing Ordinance Case Study

Policy initiatives are an effective means of limiting the amount of winter deicing salt applied to public sidewalks. Communities can pass ordinances that specify a maximum allowable amount of deicing materials that may be used during a winter storm event. These policies may also define a maximum permitted response time for residents to apply salt to the portion of sidewalk for which they are responsible. Ordinances could also recommend shoveling or snow blowing first to reduce the amount of salt needed as well as mandate the cleanup of excess salt following a storm event. Such ordinances may include a fee structure or other forms of penalty for noncompliance to serve as an enforcement mechanism.

The City of Madison, WI, provides an example of a policy designed to reduce the use of salt on public sidewalks. In November 2022 the City amended its existing snow and ice removal ordinance to "[limit] the use of salt or other melting agents to that amount necessary to treat the ice so that it can be removed."[181] The amended ordinance also requires that snow and ice removal occur no later than noon of the day following a snow event and that "excess salt and chemical melting agents may not accumulate on the sidewalk and must be removed following ice or snow melt."[182] Under this policy observations of violations can be submitted to the City by residents, and the City conducts an inspection of the site to confirm a policy violation. This ordinance includes a monetary penalty of 20 to 50 dollars for a first offense and 30 to 100 dollars for subsequent violations.

Since implementation, City staff have seen some change in municipal sidewalk winter maintenance, a portion of which is believed to be due to the ordinance.[183] Staff believe that the ordinance has been effective because it creates an enforcement mechanism for the initiative to clean up excessive salt. Despite the moderate success of the ordinance, there have been several challenges that have reduced its effectiveness. Primarily, enforcement of the policy has been difficult. Because it can take days for an inspection to occur after a citizen complaint has been received, changing weather and salt displacement often make it difficult to determine whether a violation has occurred. A second challenge is the public perception of liability. Many property owners over-apply salt out of fear of slip and fall accidents. To counter this, public education is essential to clarify that the ordinance only limits salt use to that which is *necessary*. Informing property owners of appropriate salt application rates and adequate documentation processes may help property

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[181] *City of Madison, Wisconsin, Code of Ordinances, Chapter 10.28 – Snow and Ice to be Removed from Sidewalks, November 2022.*

[182] Ibid. *[in reference to Madison Chapter 10.28]*

[183] *Personal communication with City of Madison staff (Phil Gaebler), May 2025.*

owners feel protected from this liability. Public education can also help with changing the mindset of the public with regards to winter sidewalk conditions. Rather than expecting completely clear sidewalks, pedestrians can be encouraged to walk only when necessary and to wear appropriate footwear and clothing during snowy or icy conditions. If this mindset is widely adopted and pedestrians prepare for the conditions accordingly, less salt may be necessary on public sidewalks.

Alternatives to Chemical Deicing

The use of chemical deicing and anti-icing materials, particularly sodium chloride (as rock salt or brine), calcium chloride, potassium chloride, and other compounds, is a widespread practice in winter maintenance. However, alternative, non-chemical materials and methods can also be used to remove snow and ice and/or improve traction. These include timely mechanical removal of snow and ice, applying granular materials like sand and gravel for traction improvement, installing underground heating systems to prevent accumulation of snow and ice, and designing landscapes to maximize direct sun exposure on the pavement to facilitate melting. Use of these alternative deicing methods may help reduce the amount of chloride loading to the environment from winter maintenance activities.

Timely Mechanical Removal

Timely mechanical removal of snow and ice can be an effective method of reducing the use of salt. Shoveling, snow blowing, or plowing during a snowfall event and/or directly after it can make the pavement functional without the excess use of salt. As discussed earlier in this Chapter, the use of anti-icing materials prior to a snowfall event can improve the effectiveness of mechanical removal by reducing the binding of the snow and ice to the pavement.

Completing the mechanical removal in a timely manner is crucial to its effectiveness, as snow that has been compacted by vehicular or pedestrian traffic can be substantially more difficult to remove down to the pavement surface. Pavement areas that have been effectively cleared of snow and ice can regain bare pavement relatively quickly with direct sun or winter dry air exposure, oftentimes without the need for application of additional deicing materials.

Traction Enhancement

The use of abrasives in winter maintenance can help improve traction for motorists and pedestrians. Sand is the most common traction enhancer, although gravel, finely crushed stone, cinders, ore tailings, and slags can also be used.[184] Abrasives are applied on top of compacted snow or ice, not on bare pavement, to provide increased traction; sand or other abrasives applied onto bare pavement can decrease traction.[185] Sand is most commonly used on roadway areas that require additional traction, including curves, hills, railroad crossings, and intersections. Traction enhancing abrasives can also be helpful in pedestrian areas and parking lots until bare pavement is restored. Abrasives offer the advantage of performing well at all temperatures, including very cold temperatures when chemical deicing materials will not work. Sand is often the preferred winter maintenance material for gravel roads, as deicing chemicals can soften the road surface and cause plows to scrape away the gravel. Lastly, sand is typically best suited for areas of lighter traffic volume and lower speeds, which helps keep the sand from being swept off the pavement.

While sand and other abrasives deliver the benefit of improved traction, they do have certain drawbacks. Sand can reduce the effectiveness of permeable pavement and pavers by clogging the pores and gaps and reducing the ability of water to infiltrate as designed. Abrasives can be cleaned out of porous pavement, however this is expensive and best avoided. Additionally, sand that gets washed off the pavement will often end up in streams and other aquatic systems, harming habitat. In streams the sand will fill the voids of gravel and other substrate, increase turbidity, and lead to sedimentation.[186] Sand can also accumulate in stormwater infrastructure such as catch basins, sewers, and stormwater ponds, decreasing their functionality and capacity, and requiring costly maintenance to remove the accumulated sand. Repeated wheel traffic can breakdown abrasives into particulates that can cause air quality concerns and be harmful to human health, especially for individuals with respiratory conditions such as asthma.[187] Many of the disadvantages of abrasives can be reduced by sweeping up and collecting it once the snow and ice have melted. Sweeping is more practical for parking lots and walkways than for roadways.

Sand and salt mixes are another common option for winter maintenance, however the specific ratio of the mix is crucial for effectiveness.[188] Adding salt to sand can help prevent the sand from freezing and keep it spreadable, with an optimal ratio of approximately 50 to 100 pounds of salt per cubic yard of sand. However,

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[184] *D.E. Amsler, "Snow and Ice Control", August 2006.*

[185] *Minnesota Pollution Control Agency, "Smart Salting for Parking Lots & Sidewalks", August 2022.*

[186] *United States Environmental Protection Agency, "What You Should Know About Safe Winter Roads and the Environment", September 2005.*

[187] *University of Wisconsin-Madison, "Wisconsin Transportation Bulletin No. 6 – Using Salt and Sand for Winter Road Maintenance", August 2005.*

[188] *K. Hossain and L. Fu, January 2015,* op. cit.

larger proportions of salt can render the sand ineffective, as too much salt in the mix will melt the snow and ice, causing the sand to sink down in the slush and become ineffective.[189] An alternative to mixing salt into the sand is to prewet the sand with liquid brine or other deicing liquid, which helps keep the sand on the surface of the snow and ice.

Heated Pavement

Heated pavement to melt snow and ice can be an effective alternative to using chemical deicing materials for driveways and sidewalks. In such systems, heating elements are installed underneath the pavement to raise the surface temperature above freezing to melt snow and ice. The two main technologies used in heated pavement systems are hydronic and electric coil heating.[190] Hydronic heating systems contain piping under the pavement surface that circulate hot fluid (typically glycol-based), which transfers heat to the driveway surface, as shown in Figure 2.38. The fluid can be heated by boilers using natural gas or renewables such as geothermal or solar energy. [191, 192] Hydronic heating systems can be costly to install, however operating costs are generally low, particularly if the fluid is heated using a renewable energy source. Electric coil heating systems are comprised of electric heating cables underneath the pavement to heat the surface, as illustrated in Figure 2.39. Heating systems with electrical cables generally have lower installation costs, however they consume large amounts of energy, and thus have a higher operating cost.[193] The operating cost of electric coil heating systems can be substantially reduced if the electricity is generated by renewable energy such as solar panels.

Both hydronic heating and electric coil heating systems for driveways can be configured to either melt the entire driveway surface, a portion of the driveway, or only melt the tire lanes. Heating only the tire lanes may result in ice buildup on the non-heated portion of the driveway as the meltwater flows away from the

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[189] *University of Wisconsin-Madison, August 2005,* op. cit*.*

[190] *N. Kayaci and B.B. Kanbur, "Numerical and Economic Analysis of Hydronic-Heated and Anti-Icing Solutions on Underground Park Driveways", January 2023.*

[191] *A. Nahvi, V.D. Pyrialakou, P, Anand, S.M.S. Sadati, K. Gkritza, H. Ceylan, K. Cetin, S. Kim, K. Gopalakrishnan, and P.C. Taylor, "Integrated stochastic life cycle benefit cost analysis of hydronically-heated apron pavement system", Journal of Cleaner Production, 224: 994-1003, 2019.*

[192] *Y. Cui, F. Zhang, Y. Shao, S. Twaha, and H. Tong, "Techno-Economic Comprehensive Review of State-of-the-Art Geothermal and Solar Roadway Energy Systems", September 2022.*

[193] *H. Wang and Z. Chen, "Study of critical free-area ratio during the snow-melting process on pavement using low-temperature heating fluids," Energy Conservation and Management, 50: 157-165, 2009.*

heated areas and refreezes. This may cause safety and additional maintenance concerns if the homeowner needs to shovel the non-heated portions. If the homeowner opts to salt the non-heated areas of the pavement to prevent the runoff from freezing on the driveway, a portion of the expected chloride reduction from the heated pavement would be lost. However, the cost of heating only the tire lanes would be expected to be lower than that of a full-driveway heating system due to its smaller size.

When using heated pavement to melt snow and ice, it is important to design the driveway or sidewalk to drain the meltwater away from any location where ponded water will cause a safety hazard when it refreezes. Ideally the meltwater should discharge onto a lawn or other unpaved surface that does not have pedestrian traffic. As the meltwater should not contain any chloride, particularly on driveways that have the entire surface area heated, there should be no damage done to vegetation in the receiving area. Another consideration for heated pavements is when an issue emerges with the hydronic piping or electric coils, the pavement may need to be removed in order to fix the problem. This can substantially increase the cost of the repair.

Porous Pavement

Permeable pavement is typically used as a stormwater control mechanism that is intended to allow stormwater to quickly infiltrate below the pavement surface without pooling or freezing. As a result of this rapid surface drainage, permeable pavement has been expected to require less application of deicing materials. A properly installed and maintained porous pavement lot may require up to 77 percent less deicing material compared to traditional asphalt lots.[194] Porous pavement can also reduce the prevalence of black ice and other ice buildup during melting events, reducing the need for salting between snowfall occurrences.[195] Additionally, porous asphalt can provide better traction compared to traditional pavement, which can further reduce the need for salt.[196]

For permeable pavement to reduce winter salting needs, proper design and maintenance is critical. The pavement should be designed with adequate depth and size of base course to accommodate freezing while still allowing infiltration. Snow should be removed from the porous pavement surface by shoveling and

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194 *R.M. Roseen, T.P. Ballestero, K.M. Houle, D. Heath, and J.J. Houle, "Assessment of Winter Maintenance of Porous Asphalt and Its Function for Chloride Source Control,"* Journal of Transportation Engineering*, 140(2): 04013007-1-04013007-8, 2013*.

195 Ibid. *(in reference to R.M. Roseen… 2013)*

196 Ibid. *(in reference to R.M. Roseen… 2013)*

snow blowing. When plowing is needed, the plow height should be set to avoid scratching or otherwise damaging the pavement. Sand and other abrasives should not be used for traction, as they can clog the pores and inhibit infiltration. Periodic maintenance is needed throughout the year to remove any fine debris that has accumulated in the pore spaces.

A particularly attractive option for driveways made of porous asphalt or permeable pavers is heated pavement. As discussed previously in this Chapter, pavement can be heated by using hydronic fluid circulated through pipes or electric heating elements beneath the pavement surface. Using heat to prevent accumulation of snow and ice can eliminate any need for salt and sand, which can clog the porous surface and reduce its infiltration capacity. It is important that the heating elements be installed properly so as to not inhibit the movement of water into the gravel sublayer. Additionally, heating can make plowing unnecessary, which can protect the surface from potential plow damage that can be problematic for some porous and permeable installations.

However, within the Region, several communities have reported that permeable pavements installed in their jurisdictions required chloride-based deicing efforts similar to conventional pavements. Conversely, one community in the Region reported that permeable pavements limited ice formation on the pavement, reducing the need for salt use. Considering these differing experiences, further research is needed to determine the effectiveness of permeable pavements in reducing salt use and chloride transport to waterways in the Region.

Sun Exposure

Direct sun exposure on driveways and sidewalks can be effective at melting snow and ice, potentially reducing the need to apply deicing salts. Driveways and sidewalks that are oriented to have southern exposure will receive the most direct sunlight and experience the highest degree of snow and ice melt.[197] Pavement material can also impact the speed of melting, where darker colored asphalt absorbs more solar radiation than concrete, increasing the speed of melting up to 10 percent.[198] Another important consideration of utilizing sun exposure to melt snow and ice is to reduce the amount of shade that is cast onto the pavement. This can be achieved by minimizing the number of trees planted along the driveway or walkway, planting trees along the northern edge rather than the southern edge, and/or planting deciduous trees along driveways and sidewalks rather than evergreens, which allows more sun to pass through during

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[197] *This statement assumes the location is in the Northern Hemisphere.*

[198] *K. Hossain and L. Fu, January 2015, op. cit.*

winter and reach the pavement. Additionally, during the design phase a building can be oriented to have the main entry facing south, thus receiving more direct sunlight to melt snow and ice and potentially reduce the amount of salt needed for winter maintenance. Further considerations for site layouts that can reduce winter salt use are discussed in detail later in this Chapter in the "Low Salt Infrastructure Design" section.

2.4 LOW SALT INFRASTRUCTURE DESIGN

While much of the discussion on reducing chloride pollution from winter maintenance focuses on reducing salt application to existing infrastructure, site layout features can also be incorporated during the design phase to reduce the need for salt in the first place. The main goal of low salt infrastructure design is two-fold: to improve the speed and efficiency of bare pavement recovery through direct sun exposure and to avoid hazards by eliminating areas where meltwater and blowing snow accumulate on paved surfaces.[199] As an approach for reducing salt use and pollution, low salt infrastructure design is an emerging concept. Engineering firm Bolton & Menk are leaders in this topic, and the strategies presented throughout this Section are chiefly based on their work.

Design aspects to facilitate melting from direct sun can include landscaping, site layout, and other considerations, as illustrated in Figure 2.40. Examples of low-salt design strategies that use direct sun exposure to limit the need for winter maintenance include:

- Trees can be located along the northern edge of the pavement to not cast a shadow on the pavement, increasing direct sunlight and lengthening melting time periods.

- Deciduous trees can be selected rather than evergreens for planting along the southern edge of pavement, as deciduous trees allow a large portion of sunlight through during the winter months when there are no leaves on the trees.

- Benches, large signs, and other features can be located on the northern side of paved surfaces to not cast shadows on the pavement.

[199] *Bolton & Menk, "Low Salt Design Guide", December 2024.*

- Roadways can be designed to have unobstructed southern exposure. Roadways with walls along the southern edge of the corridor, particularly on freeways and on/off ramps, can have much longer melting times due to the pavement being in shadow.

- Building floorplans can be designed to locate the main entrances with a southern exposure, which will provide them with direct sunlight to melt snow and ice.

- Parking lots and walkways can be positioned on the property where they would receive the most direct sunlight. Parking lots and walkways positioned to the north of buildings may be shaded by the structure and experience longer snow and ice melting times.

In addition to maximizing direct sun exposure, another aspect of site design that can reduce salt usage is to consider the direction of the prevailing winter wind. Trees, shrubs, signs, fences, walls, benches, and other site features can act as an inadvertent snow fence, as depicted in Figure 2.41. When located on the windward, or upwind, side of a paved area, these features will slow down wind velocity, causing snow to drop out and accumulate on the pavement and require additional snow and ice removal. By placing these features on the leeward, or downwind, side of the pavement, snow carried by wind will drop out away from the pavement and not cause increased snow removal concerns. As wind direction is variable by nature, there is no single location for these site features that will alleviate all snow deposition issues. However, designing for the prevailing winter wind direction will minimize snow drifting on the pavement.

Managing drainage from meltwater across parking lots, sidewalks, and roadways is another important aspect of smart salt design. Snow and ice that melts from sun exposure and flows across the pavement towards either a stormwater inlet or lower ground can cause a safety concern when it refreezes, as shown in Figure 2.42. For parking lots, this can be alleviated during the design process by locating the designated snow pile areas at down-grade locations near stormwater inlets, curb cuts, or other runoff discharge points. Roadways and sidewalks can be designed to avoid having higher grades directly adjacent to the pavement, which causes meltwater to flow across the pavement. When higher grades adjacent to the pavement are unavoidable, swales could be included in the design between the higher ground and the roadway to intercept meltwater and divert it away from the roadway or sidewalk. Reducing meltwater runoff across pavement can decrease the amount of salt needed to treat those areas when the meltwater re-freezes.

While horizontal drainage is often the most recognized form of runoff, vertical drainage can also contribute to unsafe winter pavement conditions. Vertical drainage primarily comes from discharge from downspouts, often conveying meltwater from building roofs. Buildings can be designed to have the downspouts discharge into greenspace or stormwater management installation. Downspouts that discharge onto pavement can create hazardous conditions when the runoff freezes, necessitating the use of additional salt to maintain safe pavement conditions, as shown in Figure 2.43.

Lastly, parking lot layout can also play a role in reducing the amount of salt needed for winter maintenance. Configurations that contain larger open areas are more conducive to large snowplow operation. While parking lot islands can be aesthetically pleasing and can potentially offer stormwater benefits, lots with numerous irregularly shaped islands can be very difficult for plow operators to navigate. Similarly, parking lot layouts with many small, disconnected banks of parking stalls can be problematic for large plows. Lack of access for snowplows can result in less snow being physically removed and more salt being applied to treat the excess snow.

Implementation of these low salt infrastructure design concepts can help to reduce the amount of deicing materials applied. By allowing direct sunlight to reach paved surfaces, solar radiation can melt snow and ice rather than use of salt and other chloride-containing compounds. Intentionally preventing blowing snow and meltwater runoff from entering pavement areas can reduce the amount of salt used. These considerations are often overlooked in the design process, as site development is typically focused on stormwater management and not winter maintenance. However, by also considering winter maintenance during the design phase, the site can be safer during the winter while potentially reducing chloride pollution and winter maintenance costs.

2.5 CHAPTER SUMMARY

This section summarizes key state-of-the-art technologies and best management practices used by public agencies, private contractors, and property owners to mitigate chloride pollution from winter maintenance activities.

Public Winter Maintenance Practices

Policy and Operations

- Shift to "Passible Roadways" Standards: Agencies are transitioning from the resource-intensive "bare pavement" policy to a more sustainable "passable roadway" standard that prioritizes safety and functionality over solely appearance.

- Managing Public Expectations: Successful salt reduction hinges on educating the public to limit travel during winter storms, drive at reduced speeds if travel is absolutely necessary, and accept that some snow may remain on the pavement for a period of time.

- Tiered Service Prioritization: Municipalities often use a tiered approach, focusing initial snow clearing efforts on high-volume arterial and emergency routes before moving to residential streets.

- Data-Driven Planning: Tools like Road Weather Information Systems (RWIS) and Maintenance Decision Support Systems (MDSS) allow modern agencies to analyze real-time forecasts and pavement data to create an optimal plan to clear snow and ice from roads and avoid excessive salt applications.

- Formal Salt Management Plans: Modern operations supplement general policies with technical plans that utilize precise application rate charts and regular equipment calibration schedules.

- Critical Role of Personnel Training: Programs like Wisconsin Salt Wise teach the science of snow and ice management, including the relationship between pavement temperature and chemical effectiveness. Many municipal winter maintenance managers credit their dramatic reductions in salt usage to these trainings.

Treatment Options

- Priority of Mechanical Removal: Physical plowing remains the most cost-effective and sustainable method for managing winter roads. Removing as much snow and ice as possible reduces the volume of chemical deicers needed.

- Pavement Temperatures are Key: Pavement temperature is the single most significant factor in determining the effectiveness of chemical treatments and the appropriate application rates. Relying on real-time data on pavement conditions is essential to prevent material waste and environmental damage caused by over applying deicing chemicals in sub-optimal conditions.

- Temperature Limits of Deicing Agents: The "practical working temperature" of a deicing agent describes the temperature to which the chemical shows deicing effectiveness in the field. Practical working temperatures of the major winter maintenance chemical agents are:

- Sodium Chloride: 15°F
- Calcium Chloride: -20°F
- Magnesium Chloride: 10°F
- Potassium Acetate: -15°F
- Calcium Magnesium Acetate: 20°F
- Sodium Acetate: 0°F

- Non-Chloride Alternatives: Acetates and formates are sometimes used as deicers for critical infrastructure (such as bridge decks and at airports) because they are non-corrosive to structural steel. They are also biodegradable and considered more environmentally friendly than traditional chloride salts.

- Bio-Based Performance Enhancers: Products like beet juice or corn-based additives improve brine adhesion to the road and can reduce corrosion on equipment by up to 70 percent. However, when runoff containing these bio-based additives enter streams their decomposition consumes dissolved oxygen and increases biochemical oxygen demand (BOD) which can stress or suffocate aquatic life.

- Proactive Anti-Icing: Applying liquid brine to roads before a winter storm can effectively prevent the bond between snow and pavement from forming, making it much easier to physically remove snow by plowing, and can potentially reduce total salt usage by 20 percent to 50 percent.

- Pre-Wetted Rock Salt Application: Coating granular rock salt with a liquid brine at the application spreader reduces “bounce and scatter” and can typically reduce salt usage by 25 percent to 30 percent. Adding a liquid to the rock salt also speeds up the melting process because sodium chloride requires moisture to dissolve and form a brine before it can begin melting snow and ice.

- “Shake and Bake” Slurry Application: This high-volume pre-wetting technique creates a fast-acting oatmeal-like slurry that can work 30 to 45 minutes faster than dry salt. It is optimally used as a heavy-duty deicing tool when immediate, aggressive action is needed to break an existing bond – such as when traffic has compressed snow into a dense, icy hardpack on the pavement

- Direct Liquid Application: Using a liquid deicer during an active winter storm is an emerging practice that provides instant melting and can reduce total salt usage by up to 23 percent. In the right conditions, DLA can also achieve "bare/wet" pavement conditions 12 percent faster on average compared to routes treated with granular rock salt.

- Use of Abrasives: Use of abrasives has declined significantly, particularly in urbanized, areas due to the high cost of post-winter cleanup, MS4 storm water compliance requirements, and environmental impacts. However, it remains a critical tool of last resort for emergency traction during extreme cold (below -20°F) and for ice storms. It is also used for managing rural roadways where low traffic volumes prevent the friction and mixing necessary for rock salt to be effective.

- Precision in Application Rates: Determining the optimal application rate is a data-driven process focused on applying the absolute minimum amount of chemical required to achieve a specific safety goal, which prevents wasting money and unnecessary chloride pollution. Rather than using a "one-size-fits-all" approach, modern managers must dynamically adjust these rates based on a complex set of real-time variables (most critically pavement temperatures and trends), as well as storm intensity, moisture content of the snow, and the current condition of the road surface (e.g., frost, slush, or bonded ice). This Chapter points to multiple references for application rate guidelines, but agencies are also encouraged to consider their local experiences and specific community needs for deicing material application rates.

Best Management Practices

- Routine Equipment Calibration: This is the most critical process for salt reduction. Without routine calibration of all winter maintenance material application equipment, application errors of 20 percent to 50 percent can be common.

- Regulated Material Storage: Wisconsin law (Chapter Trans 277) strictly regulates bulk salt storage, requiring impermeable pads, fully enclosed structures, and runoff containment.

- Chloride Recovery and Reuse: State-of-the-art facilities capture salt-laden truck wash water and yard runoff to recycle it as "pre-charged" water for making new salt brine.

- Advanced Plow Technologies: The winter maintenance industry has seen a rapid advancement in plow blade technology including sectional blades, live-edge blades, and multi-blade systems. These advanced blade technologies typically require a higher initial investment but offer better clearing performance, typically last longer, and provide significant vibration reduction.

- Local Chloride Reduction Success Stories: Municipalities and counties across the Region have made monumental strides in balancing public safety with environmental stewardship, adopting modern technologies and innovative strategies. Agencies have integrated precision application methods, advanced equipment calibration, and proactive liquid treatments that are significantly reducing the chloride load entering the environment while saving their residents money. These advancements also include a cultural shift within public works departments that is driven by a commitment to fiscal responsibility and the protection of freshwater resources and infrastructure.

Private Winter Maintenance Practices

- Recommended application rates for private parking lots, driveways, sidewalks, and roads are:
  - 3.5-3.6 lbs/1,000 ft^2 for dry rock salt
  - 2.5-3.3 lbs/1,000 ft^2 for pre-wetted salt
  - 0.6-0.7 gal/1,000 ft^2 for brine

- Slip and fall liability is a major factor that causes private contractors to over apply salt. A program that once completed could provide legal slip and fall liability protection and would encourage applicators to reduce the over application of salt.

- Sand and other traction enhancement materials should only be applied on top of compacted snow or ice. Sand placed on bare pavement can reduce traction.

- Alternatives to chemical deicing to reduce salt use include:
  - Timely mechanical removal of snow and ice.
  - Traction enhancement, such as sand, applied on top of compacted snow and ice.

- Heated pavement to inhibit snow and ice from building up on pavement.
- Porous pavement can allow runoff to infiltrate before freezing.

- Direct sun exposure can melt snow and ice and reduce the need for salt. Proper site layout can improve melting with direct sun exposure, reduce refreezing of meltwater, and minimize blowing snow accumulation on pavement.

- Certification programs modeled after New Hampshire's "Green SnowPro" provide a legal safety net by offering liability waivers to contractors who follow best management practices (BMPs), giving them the professional confidence to reduce salt usage significantly without the fear of litigation.

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STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 2

WINTER MAINTENANCE PRACTICES

TABLES

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Table 2.1
Attributes of Common Winter Maintenance Materials

Chemical	Lowest Practical Working Temperature	Corrosion Risk	Environmental Risks	Cost	Primary Best Use
Chloride Salts					
Rock Salt (NaCl) and Salt Brine (NaCl)	15°F	High	High: Chloride accumulation in surface and groundwater is toxic to aquatic life; degrades soil quality; toxic to roadside vegetation; potential to irritate pet paws.	Low	Most cost-effective deicing option for general roads, highways, parking lots.
Magnesium Chloride ($MgCl_2$)	-10°F	Moderate	High: Chloride accumulation in surface and groundwater is toxic to aquatic life; degrades soil quality; toxic to roadside vegetation; potential to irritate pet paws; can contribute to metal mobility.	Medium	Used in colder weather; Usually in liquid form for on-board pre-wetting (at the spinner); High speed direct liquid application deicing blends in cold conditions.
Calcium Chloride ($CaCl_2$)	-20°F	High	High: Chloride accumulation in surface and groundwater is toxic to aquatic life; degrades soil quality; toxic to roadside vegetation; potential to irritate pet paws.	High	Typically used in emergency response for deep freeze conditions; Critical intersections, hills, or curves requiring immediate traction.
Acetates					
Potassium Acetate (KAc)	-15°F	Very Low[a]	Moderate: Can lead to high Biological Oxygen Demand (BOD) in small stagnant waterbodies which may lead to temporary oxygen depletion during decomposition, which can stress or suffocate aquatic life, although this is typically less than sugar-heavy agricultural by-products; generally nontoxic.	Very High	Almost exclusively used in liquid form; Anti-icing for critical infrastructure because it is non-corrosive; Works in extremely low temperatures; Often applied by Fixed Automated Spray Technology (FAST) systems on bridge decks.
Calcium Magnesium Acetate (CMA)	20°F	Very Low[a]	Moderate: Can lead to high Biological Oxygen Demand (BOD) in small stagnant waterbodies which may lead to temporary oxygen depletion during decomposition, which can stress or suffocate aquatic life, although this is typically less than sugar-heavy agricultural by-products; generally nontoxic.	Very High	Corrosion-sensitive bridges/structures; Safer for new concrete (less than 2 years old); Zones near drinking water reservoirs or sensitive wetlands.
Sodium Acetate(NaAc)	0°F	Very Low[a]	Moderate: Can lead to high Biological Oxygen Demand (BOD) in small stagnant waterbodies which may lead to temporary oxygen depletion during decomposition, which can stress or suffocate aquatic life, although this is typically less than sugar-heavy agricultural by-products; generally nontoxic.	Very High	Fast acting; Sometimes used on high value infrastructure and parking garages.

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Table 2.1 (Continued)

Chemical	Lowest Practical Working Temperature	Corrosion Risk	Environmental Risks	Cost	Primary Best Use
Formates					
Potassium Formate (CHO_2K)	-20°F	Very Low[a]	Moderate/Low: Could raise BOD and cause temporary oxygen depletion in surface water during decomposition which can stress or suffocate aquatic life, although this is typically less than acetates and much less than sugar-heavy agricultural by-products; generally nontoxic.	Very High	Aggressive low-temperature deicer; Because they are biodegradable and less corrosive than chloride salts, they are appealing for use on airport runways and high-value bridge decks near sensitive waterways; Rarely used for municipal winter maintenance of streets or highways because of prohibitive cost.
Sodium Formate (CHO_2Na)	0° to 15°F	Very Low[a]	Moderate/Low: Could raise BOD and cause temporary oxygen depletion in surface water during decomposition which can stress or suffocate aquatic life, although this is typically less than acetates and much less than sugar-heavy agricultural by-products; generally nontoxic.	Very High	Low temperature deicer and considered fast acting. Because formates are biodegradable, have a lower BOD profile than bio-based additives or acetates, and are less corrosive than chloride salts, they are appealing for use on airport runways and high-value bridge decks near sensitive waterways; Rarely used for municipal winter maintenance of streets or highways because of prohibitive cost.
Bio-Based Additives					
Beet Juice	0°F to 5°F[b]	Inhibits Corrosion[c]	Moderate: Decomposition in waterways consumes dissolved oxygen and increases BOD which can stress or suffocate aquatic life; Products may contain phosphorus and nitrogen, leading to nutrient loading and potential algae blooms.	Medium	Typically blended with chloride products to significantly reduce corrosion on fleet equipment and infrastructure; Can lower practical working temperature of brine blend.
Corn-Based Additives	0°F to 5°F[b]	Inhibits Corrosion[c]	Moderate: Decomposition in waterways consumes dissolved oxygen and increases BOD which can stress or suffocate aquatic life; Products may contain phosphorus and nitrogen, leading to nutrient loading and potential algae blooms.	Medium	Typically blended with chloride products to significantly reduce corrosion on fleet equipment and infrastructure; Can lower practical working temperature of brine blend.
Cheese-Brine	-5°F [b]	Moderate[d]	Moderate: Decomposition in waterways consumes dissolved oxygen and increases BOD which can stress or suffocate aquatic life; Products may contain phosphorus and nitrogen, leading to nutrient loading and potential algae blooms; Product contains high chloride levels.	Very Low or Free	Typically blended with chloride products; Can lower practical working temperature of brine blend; Because the cheese brine contains sodium chloride, deicing cost savings may be realized if product is obtained for no cost.

Table continued on next page.

Table 2.1 (Continued)

Chemical	Lowest Practical Working Temperature	Corrosion Risk	Environmental Risks	Cost	Primary Best Use
			Nitrogen Products		
Urea $(CO(NH_2)_2$	20°F	Low/Moderate	High: Has the highest BOD profile of any material summarized here; Nutrient loading (ammonia and nitrate) of surface waters could lead to rapid algal blooms.	High	Historically used at airports and specialized roadway applications for its lower corrosive attributes, however use has declined dramatically due to environmental concerns.
			Glycol		
Propylene Glycol	-20°F	Very Low	High: Has a very high BOD profile which can stress or suffocate aquatic life; However it does not persist in waterways and is generally considered not to be directly toxic to vegetation and aquatic life.	Very High	Most commonly associated with aircraft deicing; Rarely used in road maintenance other than to pre-treat high-value bridges with Fixed Automated Spray Technology (FAST) systems.
			Abrasives		
Sand	Effective at any temperature	Non-Corrosive	Moderate/High: Sand will accumulate in storm drainage systems (ditches, sewers, manholes) and smother habitats in riverbeds that are critical to fish and invertebrates.	Very Low (purchase) High (cleanup)	Used strictly for traction; Effective at extremely low temperatures when deicing chemicals fail; Useful for hills, sharp curves, and intersections to prevent sliding; Used on low-volume roads or gravel roads where snowpack is commonly left on the road surface.

[a] *Acetates and formates are generally non-corrosive to structural steel (rebar and bridge beams). However, these agents are known to cause corrosion on galvanized steel (guardrails, light poles, etc.).*

[b] *Unlike engineered chemicals that have fixed chemical properties, bio-based additives are biological mixtures. Therefore, they do not have a single, fixed practical working temperature. Their performance depends entirely on the blend ratio that is mixed with the salt brine.*

[c] *While on their own, these bio-based additives inhibit corrosion, they are very seldomly used alone. Typically, these are mixed with salt brine, so the mixture should not be considered non-corrosive, but rather less corrosive.*

[d] *While cheese brine contains chlorides which can lead to corrosion, it also typically contains organic solids (whey/proteins) that can provide a mild corrosion inhibiting effect, making it slightly less corrosive than pure rock salt brine.*

Source: Clear Roads, Minnesota Pollution Control Agency, and SEWRPC

Table 2.2
Current Estimated Costs for Deicing Materials for Public Agencies: 2014-2024

Deicing Material	Primary Form	Estimated Municipal Cost	Cost Relative to Rock Salt or Salt Brine
Sodium Chloride Rock Salt	Solid	$60 - $95 per ton	1x (baseline)
Salt Brine	Liquid (23.3 percent)	$0.10 - $0.40 per gallon[a]	<1x (liquids baseline)
Magnesium Chloride	Liquid (30 percent)	$1.10 - $1.40 per gallon[b]	~3x Salt Brine
Calcium Chloride	Liquid (32 percent)	$1.40 - $1.90 per gallon[b]	~4x Salt Brine
Potassium Acetate	Liquid (50 percent)	$4.50 - $6.00 per gallon	~12x Salt Brine
Calcium Magnesium Acetate (CMA)	Solid	$1,000 - $2,500 per ton	~20x Rock Salt
Sodium Acetate	Solid	$1,000 - $1,900 per ton	~15x Rock Salt
Potassium Formate	Liquid (50 percent)	$5.50 – $9.50 per gallon	~15x Salt Brine
Sodium Formate	Solid	$1,200 - $1,600 per ton	~15x Rock Salt
Bio-Based Additives	Liquid (concentrate)	$1.40 - $2.50 per gallon[c]	~5x Salt Brine
Urea	Solid	$600 - $700 per ton	~7x Rock Salt
Propylene Glycol	Liquid (50 percent)	$6.00 - $10.00 per gallon	~20x Salt Brine

Note: These are rough estimates of product pricing based on estimated prices from multiple sources over an 11-year period (prices are not adjusted to a specific year). Prices fluctuate significantly based on region, proximity to salt mines/ports, freight costs, availability, and order volume (e.g., Statewide DOT contracts vs. single municipality bids). The estimates in this table represent typical bulk municipal bid prices for years between 2015 and 2024 winter seasons. Many of these products are not used alone but are commonly used as part of a blend.

[a] *Value represents production costs (salt+water+electricity) assuming the municipality makes the brine in-house, which is significantly cheaper than buying pre-mixed liquid chemicals.*

[b] *Magnesium Chloride and Calcium Chloride are rarely used as primary deicers due to the high cost per gallon. These are predominantly used for pre-wetting rock salt. Assuming the industry standard of 8 to 10 gallons of either agent per ton of rock salt, this adds roughly $10 to $20 per ton to the final treated salt cost. However, the goal of pre-wetting is to use significantly less rock salt.*

[c] *This price is for the raw concentrate (e.g., pure beet juice). These products are rarely used on their own and are commonly blended with brine (e.g., 80/20 or 90/10 brine to bio-based additive).*

Source: Fortin Consulting, Inc., Ninja De-Icer, WisDOT, State of Maine, Missouri DOT, Montana State University Western Transportation Institute, North Dakota DOT, and SEWRPC

Table 2.3
Typical Pre-Wetting Agents and Practical Working Temperatures

Chemical	Practical Working Temperature	Best Used When
Salt Brine (NaCl)	Above 15°F	Conditions are mild. Standard brine is the most cost-effective choice but freezes or becomes slushy below this range.
Magnesium Chloride ($MgCl_2$)	Down to -10°F	Temperatures drop below 15°F. It is often preferred over calcium chloride because it is less corrosive to metals.
Calcium Chloride ($CaCl_2$)	Down to -20°F	Temperatures are extremely cold. It is the most powerful common deicer for speed and low temperatures but is generally more expensive and corrosive than magnesium chloride.

Source: Clear Roads

Table 2.4
Recommended Road and Highway Deicing Application Rates Based on Road Temperature

Road Temperature	Pre-Wetting (lbs/lane mile)[a, b]	Dry Rock Salt (lbs/lane mile)	Shake and Bake Liquid Component (gal/lane mile)	Shake and Bake Granular Component (lbs/lane mile)
30°F+	100-150	150-200	40+	100
25-29°F	150-200	200-250	40+	150
20-24°F	200-250	250-300	40+	150
15-19°F	250-300	300-350	40+	200
Salt Brine Blend – 80/20 with Organic Agent[c] or 90/10 with Calcium Chloride		Not Recommended	Salt Brine Blend – 80/20 with Organic Agent[c] or 90/10 with Calcium Chloride	
5-14°F	250-350		50	200

Note: Operators should mechanically remove as much snow and ice as possible before applying deicing chemicals. It is important to note that the application rates provided in this table are a general guide that can often change as new technologies and methods emerge. In addition, recommended application rates are often adjusted based on specific detailed weather conditions. For more detailed recommended application rates, see the Clear Roads reports "Material Application Methodologies Guidebook" and "Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Ant-Icing."

[a] *The application weights shown here only represent the weight of the dry rock salt.*

[b] *Brine application for pre-wetting rock salt is recommended to be 15+ gallons per ton of dry rock salt.*

[c] *Examples of organic agents used for this 80/20 brine blend include commercial products Geomelt or BeetHeet. However, other organic agents may also be appropriate.*

Source: Wisconsin Salt Wise and SEWRPC

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Table 2.5
Recommended Deicing and Anti-Icing Application Rates for Private Parking Lots and Roads

Rate (lbs/1,000 ft^2)	Reference
	NaCl Rock Salt (Dry)
0.0-3.0	D. Sassan and S. Kahl, "*Salt Loading Due to Private Winter Maintenance Practices,*" June 2007.
0.8-3.0	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
1.4-9.9	D.E. Amsler, "*Are You Using the Right Amount of Ice Control Chemical?*"2004.
1.9-4.7	D. Noyce, A. Bill, M. Chitturi, B. Claros, and W. Nixon, "*Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-Icing,*" October 2021.
2.3-6.8	C. Fortin, "*Winter Maintenance Application Rates Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.
5.0	K. Hossain and L. Fu, "*Optimal Snow and Ice Control of Parking Lots and Sidewalks,*" January 2015.
	NaCl Rock Salt (Pre-Wetted)
0.8-2.5	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
1.2-3.9	D. Noyce, A. Bill, M. Chitturi, B. Claros, and W. Nixon, "*Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-Icing,*" October 2021.
1.6-4.8	C. Fortin, "*Winter Maintenance Application RaPtes Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.

Rate (gal/1,000 ft^2)	Reference
	Liquid (NaCl Brine)
0.3-0.6	C. Fortin, "*Winter Maintenance Application Rates Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.
0.3-0.8	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
0.3-1.3	D. Noyce, A. Bill, M. Chitturi, B. Claros, and W. Nixon, "*Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-Icing,*" October 2021.
0.6-1.5	D.E. Amsler, "*Are You Using the Right Amount of Ice Control Chemical?*" 2004.
0.8	K. Hossain and L. Fu, "*Optimal Snow and Ice Control of Parking Lots and Sidewalks,*" January 2015.

Source: SEWRPC

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Table 2.6
Recommended Deicing and Anti-Icing Application Rates for Private Driveways and Sidewalks

Rate (lbs/1,000 ft^2)	Reference
NaCl Rock Salt (Dry)	
0.8-3.0	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
2.3-6.8	C. Fortin, "*Winter Maintenance Application Rates Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.
5.0	K. Hossain and L. Fu, "*Optimal Snow and Ice Control of Parking Lots and Sidewalks,*" January 2015.
NaCl Rock Salt (Pre-Wetted)	
0.8-2.5	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
1.6-4.8	C. Fortin, "*Winter Maintenance Application Rates Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.

Rate (gal/1,000 ft^2)	Reference
Liquid (NaCl Brine)	
0.3-0.6	C. Fortin, "*Winter Maintenance Application Rates Guidance for Parking Lots, Sidewalks and Trails,*" September 2017.
0.3-0.8	Minnesota Pollution Control Agency, "*Smart Salting for Parking Lots & Sidewalks,*" August 2022.
0.8	K. Hossain and L. Fu, "*Optimal Snow and Ice Control of Parking Lots and Sidewalks,*" January 2015.

Source: SEWRPC

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Chapter 2

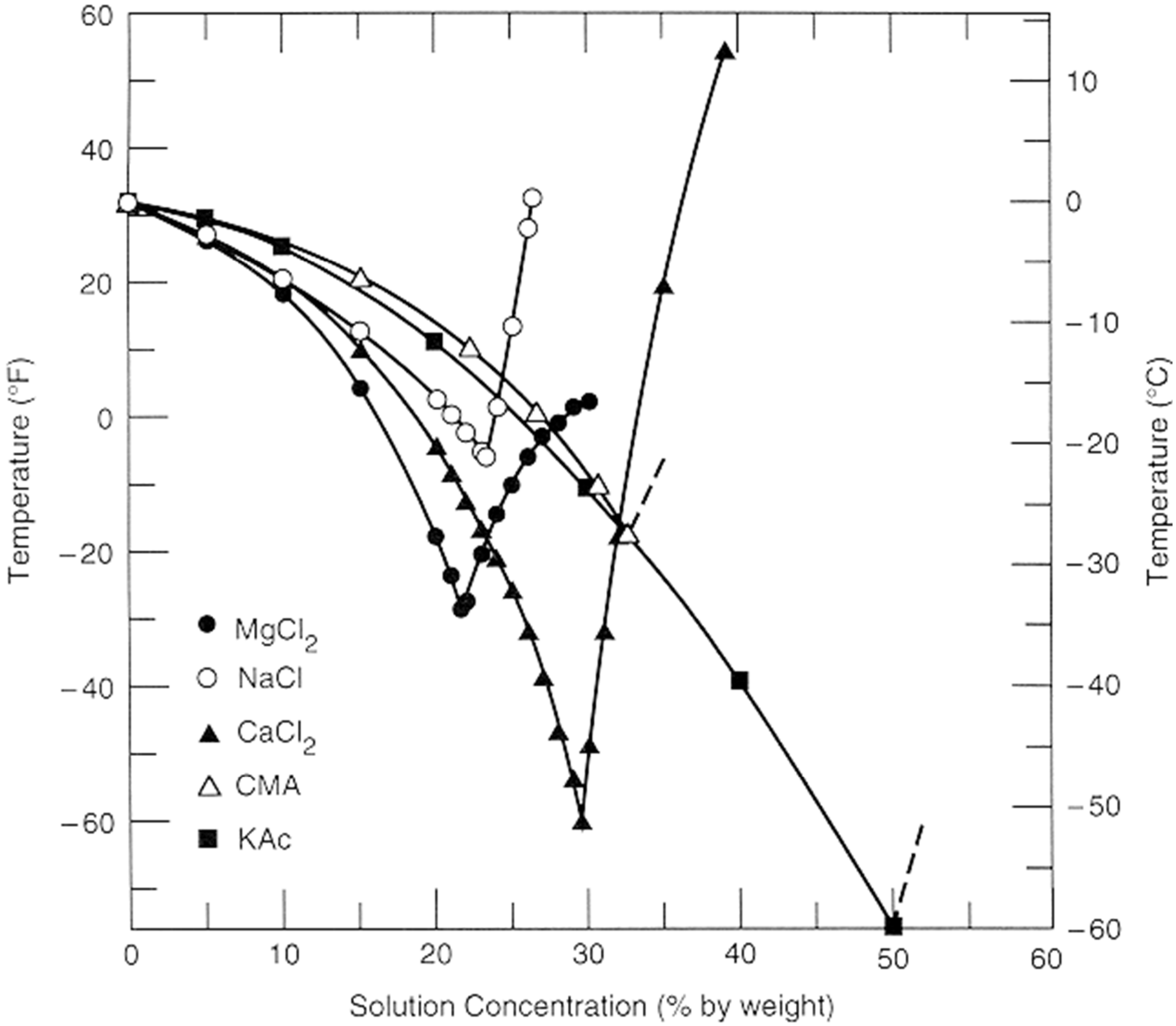
WINTER MAINTENANCE PRACTICES

FIGURES

Figure 2.1
Tandem Plowing in the City of Oak Creek, WI

Source: City of Oak Creek Public Works Department

Figure 2.2
Phase Diagrams for Chloride and Acetate Deicers



Source: Federal Highway Administration

Figure 2.3
Examples of Common Salt Storage Structures

Salt Shed (City of Oak Creek)

Hoop House

Salt Dome (Walworth County)

Source: City of Oak Creek Public Works Department, Walworth County Public Works Department, Wikipedia Commons, and SEWRPC

Figure 2.4
Examples of Liquid Storage Tanks in Southeastern Wisconsin

City of Lake Geneva

City of Oak Creek

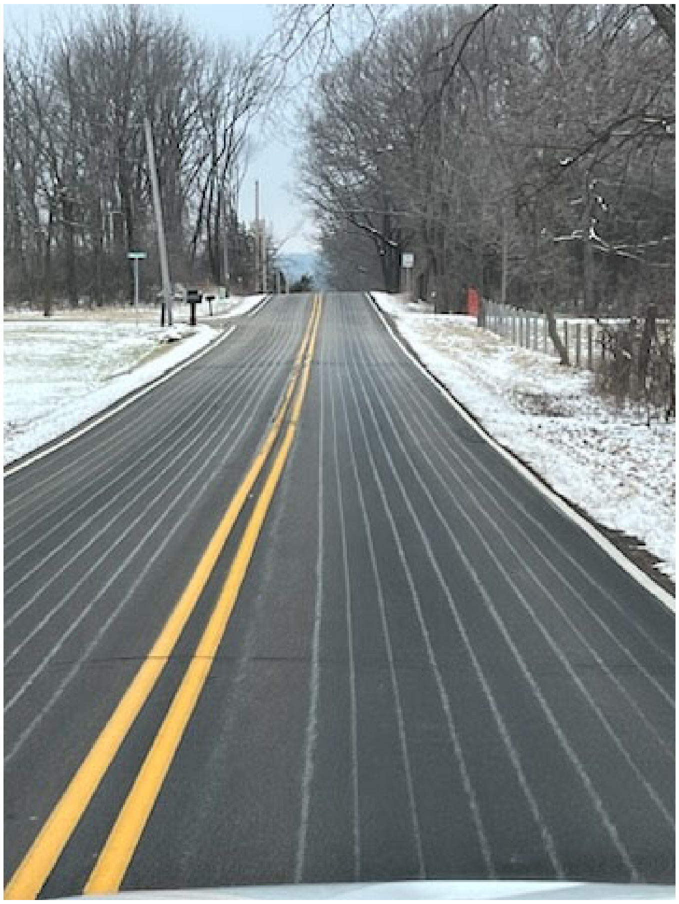
Town of Linn

Source: City of Lake Geneva Public Works Department, City of Oak Creek Public Works Department, Town of Linn Highway Department, and SEWRPC

Figure 2.5
Loading Truck Tanks with Liquid Brine Using High-Flow Pump and Intelligent Controls

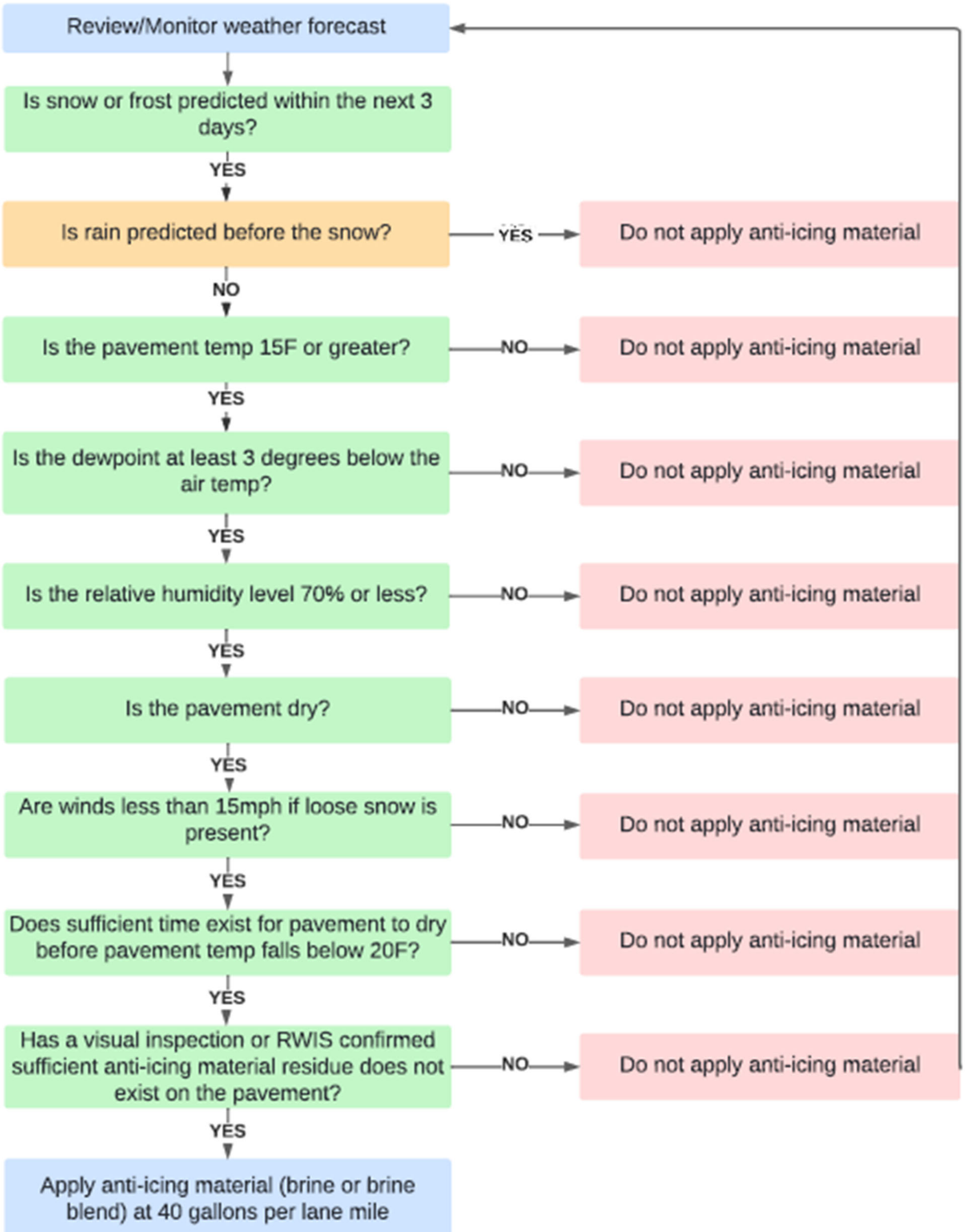
Source: SEWRPC

Figure 2.6
Anti-Icing Brine Applied in a Wet/Dry Striped Pattern



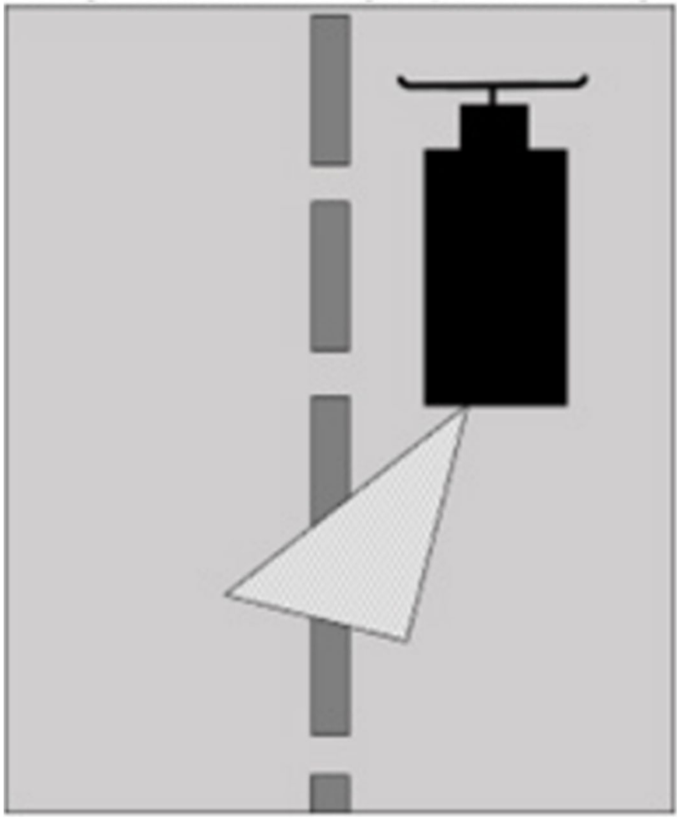
Source: Town of Linn Highway Department

Figure 2.7
Anti-Icing Application Decision Flow Chart



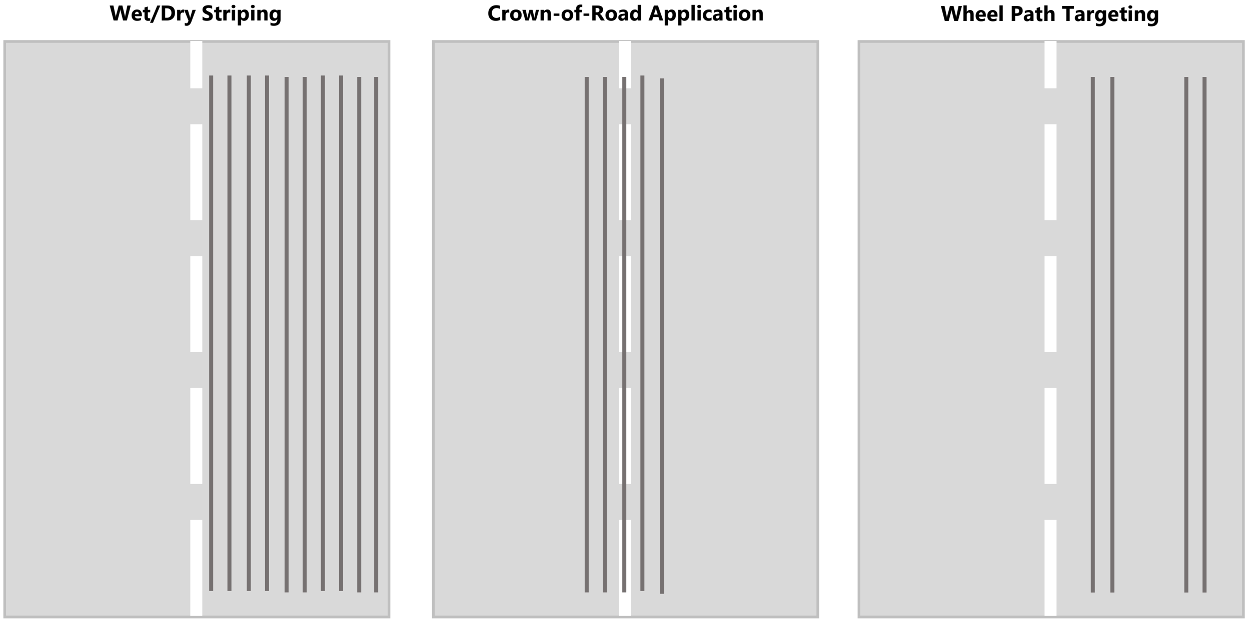
Source: Created by American Public Works Association and reproduced by Wisconsin Salt Wise

Figure 2.8
Dry or Pre-Wetted Salt Road Crown Spread Pattern



Source: Minnesota Pollution Control Agency and SEWRPC

Figure 2.9
Direct Liquid Application Spread Patterns for Public Roadways



Source: MnDOT and SEWRPC

Figure 2.10
Typical Road Weather Information System (RWIS) in Wisconsin

Source: Lead Creek Technologies and WisDOT

Figure 2.11
Truck-Mounted Mobile Infrared Pavement Temperature Sensor and In-Cab Display

Sensors are typically mounted on side mirror

In-cab display

Source: City of Oak Creek Public Works Department, Town of Linn Highway Department, and SEWRPC

Figure 2.12
Examples of Front-Mounted Plows

One-Way Plow

Reversible Plow

Source: Wikimedia Commons, Flickr User JMK40, and SEWRPC

Figure 2.13
Front-Mounted Reversible Plow
with Wing Plow Attachment

Source: City of Oak Creek Public Works Department

Figure 2.14
Example of an Underbody Scraper Snowplow

Source: Monroe Truck Equipment

Figure 2.15
Example a Tow Plow Attachment with Solid and Liquid Application System

Source: Colorado Department of Transportation and Flickr

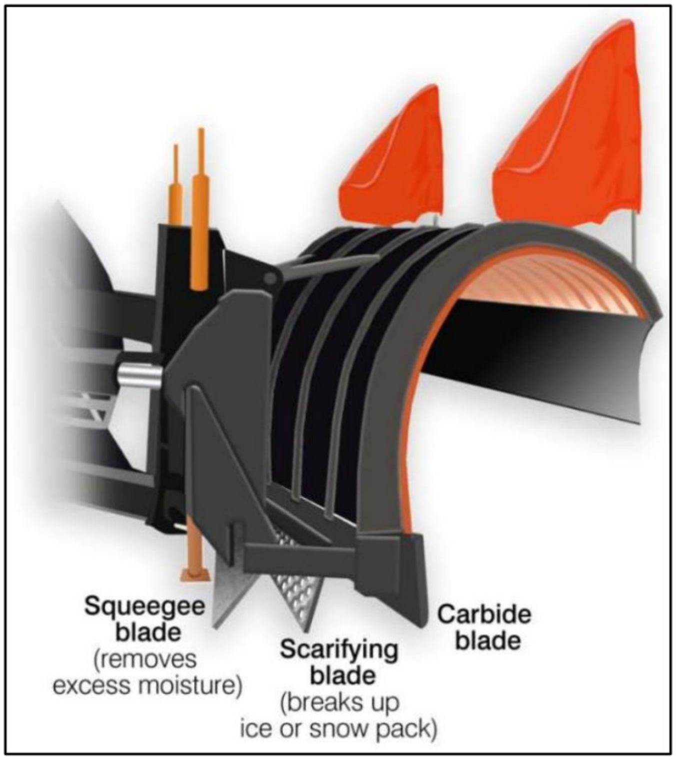
Figure 2.16
View of Sectional Blades on a Front-Mounted Plow

Source: Town of Linn Highway Department

Figure 2.17
Live Edge Blades on a Front-Mounted Plow

Source: Colvoy Equipment

Figure 2.18
Prototype Drawing of a Multi-Blade Configuration



Source: Iowa Department of Transportation and Clear Roads

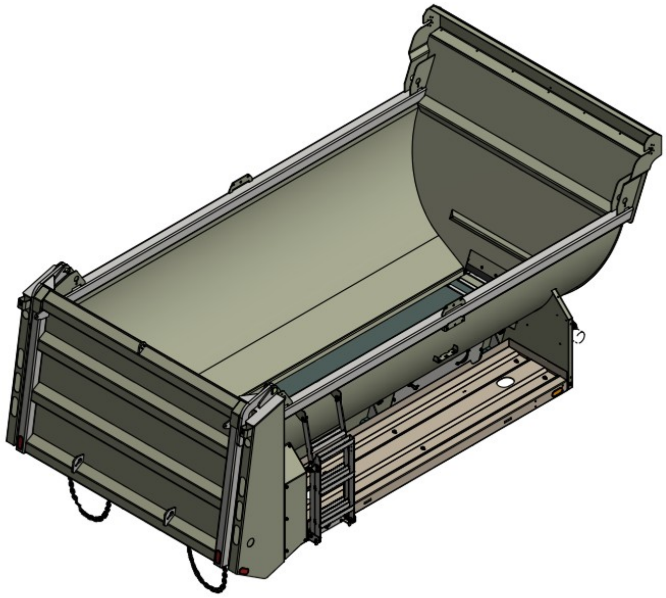
Figure 2.19
Examples of V-Box Hopper Spreaders

Source: Cliffside Body Corp and SEWRPC

Figure 2.20
Example a Tailgate Mounted Granular Salt Spreader

Source: City of Lake Geneva Department of Public Works

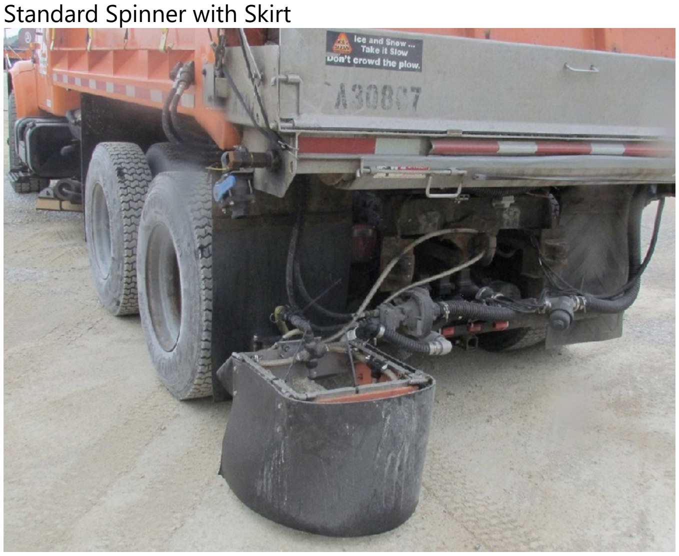
Figure 2.21
Dual Dump Truck Body Spreader System



Source: Viking-Cives Group

Figure 2.22
Standard Centrifugal Spinners on Tailgate Spreaders

Standard Spinner with Skirt

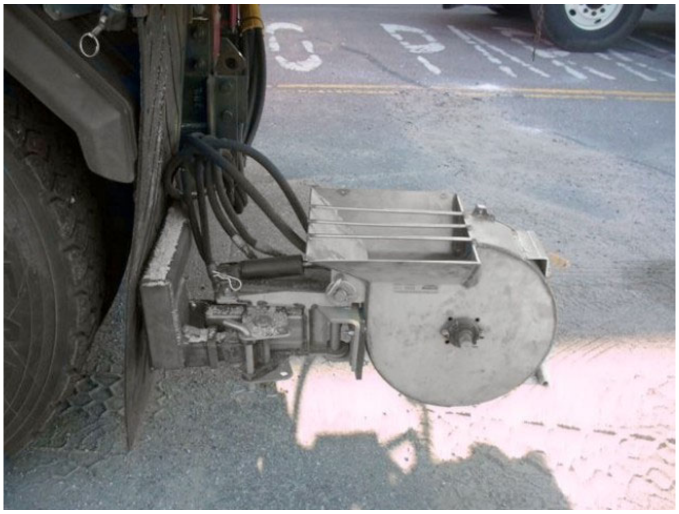


Source: Illinois DOT, Iowa DOT, and Clear Roads

Figure 2.23
Directional Spinner Mounted on V-Box Spreader

Source: Cliffside Body Corp

Figure 2.24
Example a Zero Velocity Granular Salt Spreader



Source: Henderson Products, Inc and Clear Roads

Figure 2.25
Dual Spinners Mounted on Tailgate Spreader

Source: Illinois DOT and Clear Roads

Figure 2.26
Examples of Pre-Wetted Salt Spreaders

Source: City of Lake Geneva Public Works Department, City of Oak Creek Public Works Department, and Cliffside Body Corp

Figure 2.27
Slurry Generator and Spreader System

Side View

Rear View

Source: Illinois DOT and Clear Roads

Figure 2.28
Home-Built Anti-Icing Brine System

Source: City of Lake Geneva Public Works Department

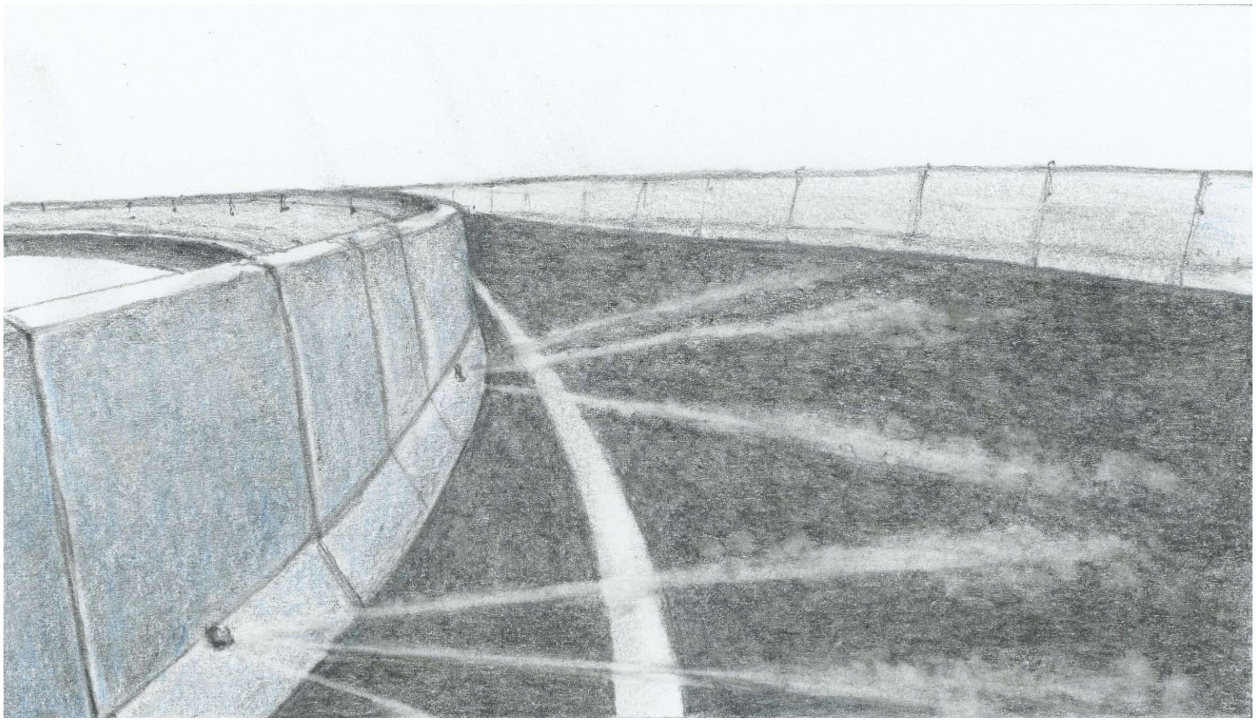
Figure 2.29
Municipal Anti-Icing Rigs

Source: City of Lake Geneva Public Works Department and City of Oak Creek Public Works Department

Figure 2.30
High-Capacity Anti-Icing Tankers

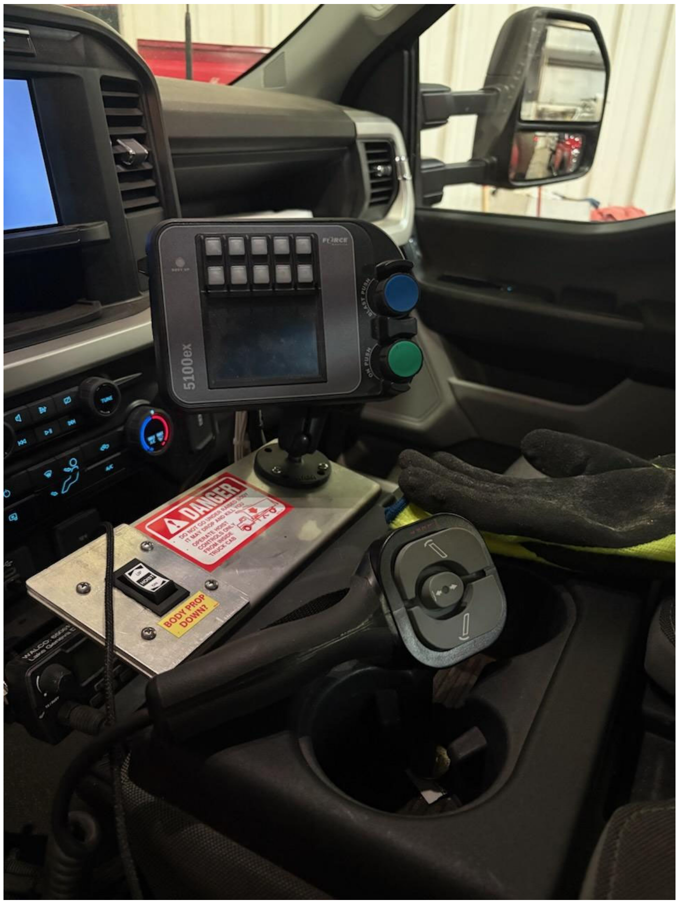
Source: SEWRPC

Figure 2.31
Fixed Automated Spray Technology (FAST) System for Brine Application



Source: SEWRPC

Figure 2.32
Example of an In-Cab Electronic Controller System



Source: City of Lake Geneva Public Works Department

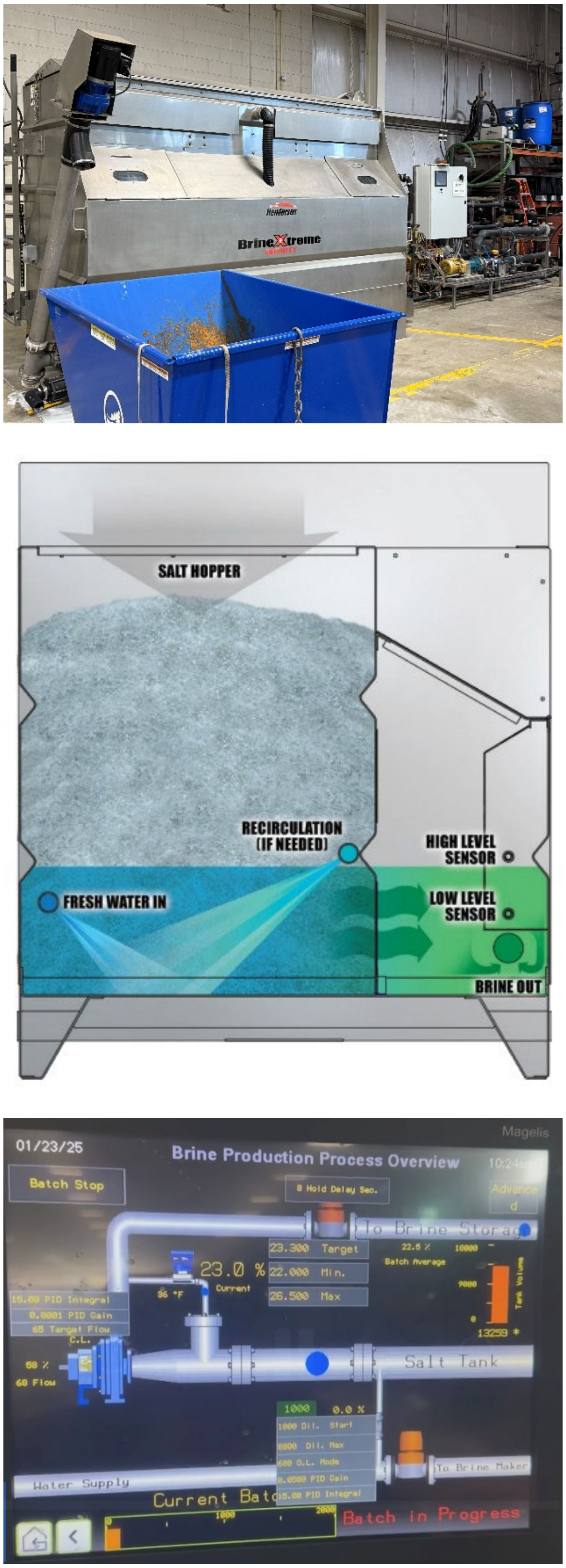
Figure 2.33
Example of an In-Cab Monitor for a Rear-Mounted Camera System

Source: City of Lake Geneva Public Works Department

Figure 2.34
Home Built Salt Brine Maker

Source: Town of Linn Highway Department

Figure 2.35
Modern Salt Brine Maker



Source: City of Oak Creek Public Works Department and Henderson Products, Inc

Figure 2.36
Calibration of a Pre-Wetting Salt Spreader on a One-Ton Truck in the City of Lake Geneva, WI

Source: City of Lake Geneva Public Works Department

Figure 2.37
Recommended Salt Application on Driveways and Sidewalks

Source: City of Madison, Wisconsin

Figure 2.38
Hydronic Heating System for Driveways

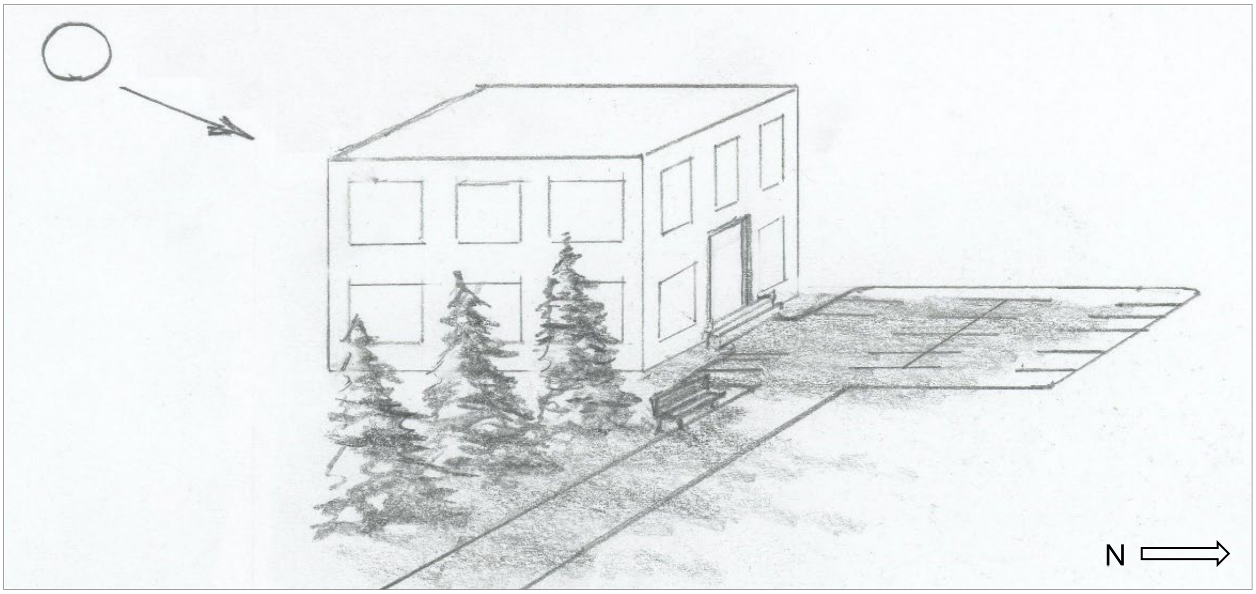
Source: flicker user Proheat Hydronic Heating

Figure 2.39
Electric Heating System for Driveways

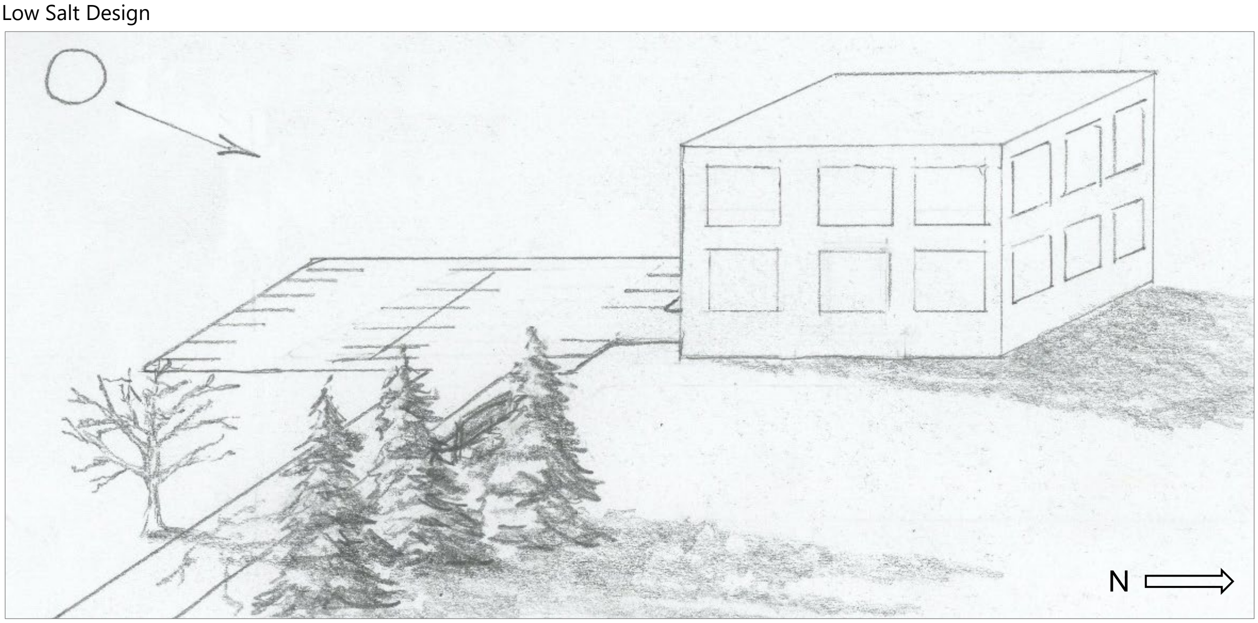
Source: Wikimedia user Bugsybanana

Figure 2.40
Site Layout to Maximize Melting from Sun Exposure

High Salt Design



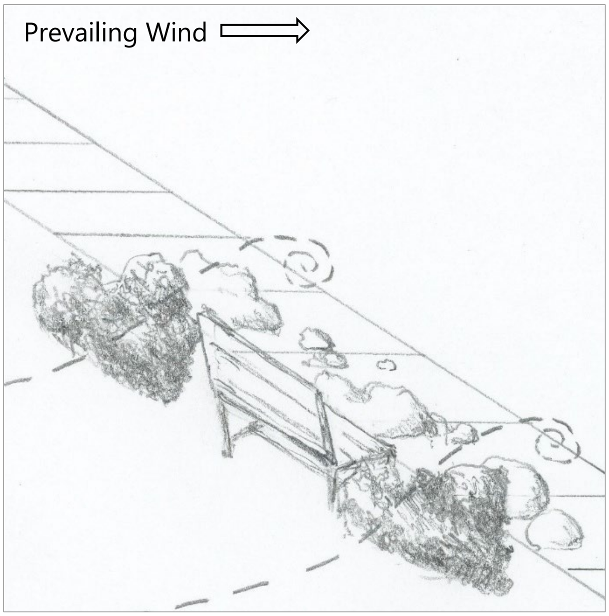
Low Salt Design



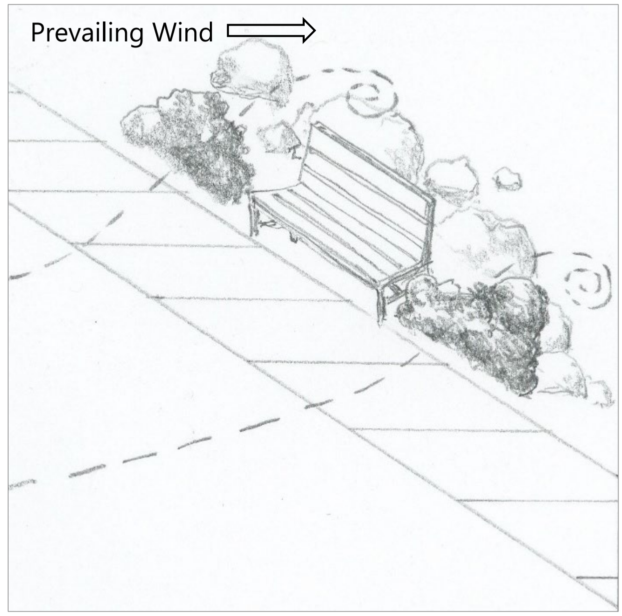
Source: SEWRPC

Figure 2.41
Snow Fence Effect from Landscaping

High Salt Design



Low Salt Design



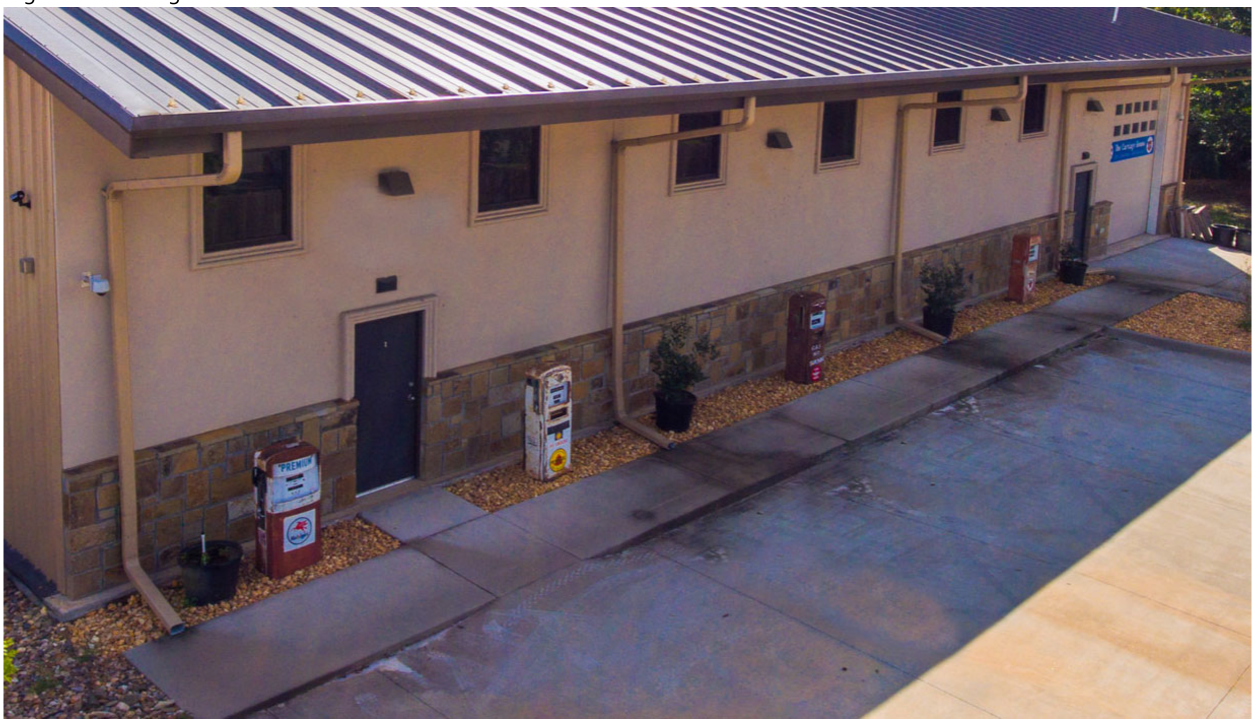
Source: SEWRPC

Figure 2.42
Drainage of Meltwater Across Parking Lot

Source: Wikimedia user Tony Webster

Figure 2.43
Drainage from Roofs

High salt use design



Source: Flicker user Steel Building Manufacturer

Low salt use design

Source: Flicker user ArmchairBuilder.com