Manual of Environmental Best Practices for Snow and Ice Control

Prepared as part of
"Development of a Snow and Ice Control Environmental Best Management Practices Manual"

CLEAR ROADS
research for winter highway maintenance

Western Transportation Institute

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for Snow and Ice Control

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Prepared for the

Minnesota Department of Transportation and the Clear Roads Program

by
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Developing a Snow and Ice Control Environmental Best Management Practices Manual

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A manual on environmental best management practices used for snow and ice control was developed using information gain from a literature review, survey, and follow-up interviews. The document presents information on commonly used snow and ice control products and their potential impacts, and pathways into the environment. Following this information is presented on many aspects of snow and ice control operations from material handling and storage, application techniques and equipment, advanced technology for decision making, environmental management tools, pre-storm to mid-storm practices, post storm clean-up, and training. The manual summarizes common areas for improvement in snow and ice control practices to realize material and cost saving, while reducing impacts to the environment.</td></tr>
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Table of Contents

List of Tables

List of Figures

Introduction

The objectives of this research project are to analyze and make comparisons of the impacts of abrasives, chlorides, acetates, formates, glycerols, glycols, and organic by-products; and to compile the current environmental best practices for using chlorides. To accomplish this, the Task 1 literature review sought information on the impacts of chemical deicers and abrasives and their associated impacts to air, surface and ground water, roadside soils, flora and fauna. The review also documented currently available knowledge of cost-effective equipment, practices and strategies that allow winter maintenance professionals to use the right amount of material in the right place at the right time, in an effort to achieve the "Triple Bottom Line" of sustainability (economy, social, and environmental). The Task 2 Survey and Interviews were used to capture information from winter maintenance practitioners on the current state-of-the-practice, best practices, and lesson learned. The interviews were developed into Case Studies. The Task 3 Analysis of previous tasks processed the information, gained from the literature review and survey, into easy to use at a glance tables used in the manual. Information gained from Tasks 1-3 has been used to create the Task 4 Snow and Ice Control Environmental Best Practices Manual.

There are many ways to describe environmental best practices, including sustainability, green, context sensitive, environmental stewardship, and triple bottom line, and many of these terms are used in this document. These are more than just buzz words; instead they describe ideas, practices and concepts that are important and relevant to snow and ice control operations that produce savings in materials and costs- and reduce environmental impacts.

Sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, sustainable snow and ice control practices overlap with those that minimize their environmental footprint. For example, material application methods such as anti-icing or pre-wetting solids allow for the minimum amount of product to be applied, in effect putting less product into the environment and therefore creating less of an environmental impact. Similarly, improved training, material storage and handling, and enhanced road weather information all contribute to environmental best management practices (BMPs) that minimize the potential risk associated with snow and ice control operations including reducing the need for later clean-up and mitigation, and reducing environmental reporting requirements, in some cases.

The initial movement toward sustainability for state and provincial departments of transportation (DOTs) was driven by compliance with regulating agencies (McVoy et al., 2012). Work by Joen and Amekudzi (2005) found that almost all DOTs include the concept of sustainability in their mission statements, capturing the attributes of system effectiveness and efficiency, and system impacts on the economy, environment, and social quality of life. McVoy et al. (2012) found that most snow and ice control practitioners believe that they have a good understanding of how their work impacts the environment and have resources available to them on this topic. If this is the case, then why is this project necessary?

At the 2013 Winter Maintenance Peer Exchange, participants were challenged to think of traditional winter maintenance "best practices" in a new light (Pape, 2013). Traditionally, these have been regarded as practices that save material, costs, and person-hours while providing increased efficiency through the use of improved equipment, technology, and management. Yet, implementation and acceptance of newer practices sometimes moves at a glacial pace because of lack of understanding, resistance to change, risk aversion, insufficient training, and inadequate resources. Much information is available as to the effectiveness of the newer technologies and techniques which should enhance their use and dissemination. This raises the question: how do snow and ice control practitioners move forward with adopting best practices? Relying upon the experience of peers has the most credibility. Ways to share and collect feedback on such experience include: communicating successes and failures, encouraging Project Champions, conducting cost-benefit studies, taking the risk of implementing unconventional practices, setting small attainable goals, and continually working on improvements before, during, and after implementation.

For the purpose of this document, best management practices (BMPs) will refer to those related to source control, i.e., any product, practice, or technology that can reduce potential adverse environmental impacts from snow and ice control operations. For example, in Canada improvements in salt storage and handling, training, and a reduction in road salt application rates can be attributed to changes in environmental policies and development of codes of practices, and how they were implemented by maintenance staff (Stone et al., 2010; Perera et al., 2010; TAC, 2013). Many of these BMPs are highlighted in this document. Note that BMPs typically refer to stormwater quality management tools like swales, ponds, and catchment basins that catch or slow the movement of water, allowing suspended solids to settle out and water to infiltrate the ground. These BMPs work well at slowing water movement, reducing erosion, and improving water quality but do not remove chlorides and thus can cause more harm than good. Once chloride-based products go into solution, removing the product or the associated anions (Cl^-) can be challenging, as chloride ions do not degrade in the environment. Instead, they accumulate and cannot be easily removed. For these reasons, the standard practice seems to be to dilute the solution, not remove it. Alternative methods include designing and managing ways to apply less material, such as anti-icing, performing regular calibration of application equipment, and continuous learning/feedback, or adding snow fences to the roadside.

This document presents information on snow and ice control environmental BMPs organized as follows:

- a Summary of Survey Results,
- Level of Service for Measuring and Quantifying LOS,
- Environmental Management Tool,
- Training,
- Monitoring and Keeping Records,
- Snow and Ice Control Materials,
- Facility Management,
- Material Storage,
- Loading and Handling,
- Operational Strategies(such as plowing),
- Material Selection,
- Material Application Equipment,
- Equipment Calibration,
- Vehicle Washing,
- Corrosion Prevention,

- Weather and Pavement Equipment and Technology,
- Sensors to Improve Snow and Ice Control Operations,
- Smart Snowplows,
- Mid-Storm Adjustments,
- Post-Storm Operation (such as sweeping)
- Summary of the identified winter maintenance environmental BMPs.
- Following the reference section in the appendices the survey questions and full results can be found, a list of interviewees, and case studies.

Summary of Survey Results

In a survey conducted for this research project, respondents in Maintenance at state DOTs, and local and provincial transportation agencies, were asked if their agencies have staff that is directly responsible for compliance with environmental regulations. Responding agencies indicated that many do have environmental staff (76%, n=23) available to maintenance operations. Of the responding agencies, a third (33%) indicated that a protected watershed basin or a managed storm water area such as a “low-salt” or “no-salt” zone was within their jurisdiction. A follow-up question asked how these areas were determined and monitored. Reponses indicated that agencies are:

- Measuring salt usage with scales and reporting on usage in storm reports.
- Using MS4 permits with the state environmental agency.
- Studying sites in partnership with the State DOTs (MnDOT, NYSDOT), State PCA or City/State Department of Environmental Protection or Conservation, and the local watershed district.
- Conducting regular sampling on TMDL-listed streams (Oregon and Washington State DOTs) or by the State DES (New Hampshire).

Respondents were asked if their agencies had experience with any commonly cited environmental issues associated with winter maintenance operations (Figure 1). Ranked highest, and of greatest concern, were corrosive effects of salt and other chlorides, followed by salt contamination of surface and groundwater, infiltration and sedimentation of sand and other abrasives, and lake, stream, groundwater, or well contamination. Comparatively, the effect of salt and other deicing chemicals on roadside soils, vegetation, and wildlife, and air contamination by crushed roadway abrasive particulates and salt, or post-storm dust abatement from use of abrasives/sand were rated as less of a concern.

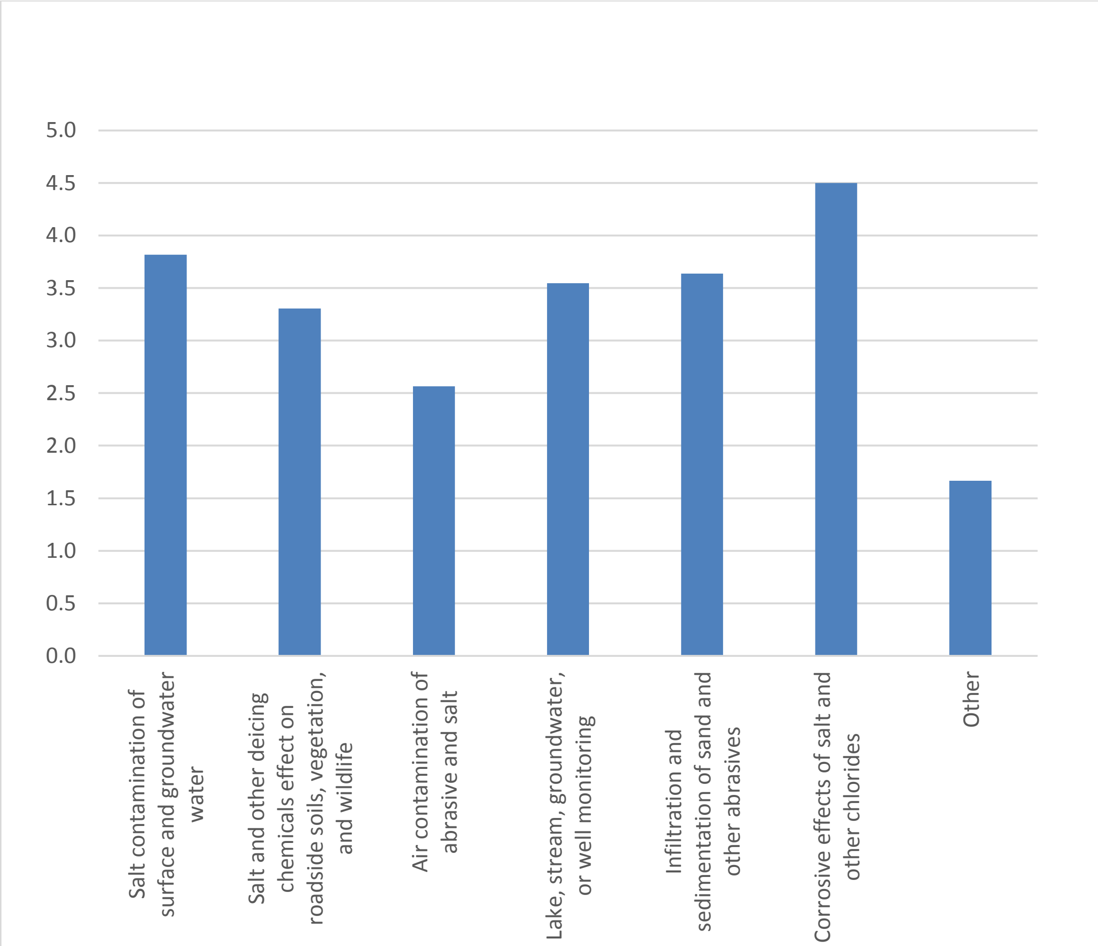

Figure 1. Average rating by responding agencies of their experience with environmental issues commonly associated with winter maintenance operations (ranked, 1- low concern, to 7-high concern).

A minority of respondents replied yes (26%, n=8) when asked if their agencies have salt mitigation programs to deal with contamination of public and private drinking water sources from road salt. The issue of well contamination is generally driven by factors such as improper storage of snow and ice control chemicals, unsuitable snow removal and piling locations and modes, and may be regionally sensitive. This may explain why only certain agencies report having mitigation programs in place. To build on this, respondents were asked if their agencies had experience working with compliance agencies or private groups to handle salt mitigation efforts. The majority (76%, n=22) did not have experience in this area, indicating that this is one area for improvement. Respondents were then asked if any measures had been implemented in the process of working with compliance agencies or private groups. Training staff and contractors on proper storage, handling and application of materials was most commonly reported, followed by including needed improvements to facilities, equipment and materials in operating, capital and capital improvement budgets and communicating to higher officials the need to ensure compliance (Figure 2). The following comment by one respondent is a good example of collaboration: “In one area NHDOT has a partnership with NHDES, USEPA and 4 towns in the region to adhere to findings from a recent TMDL study.”

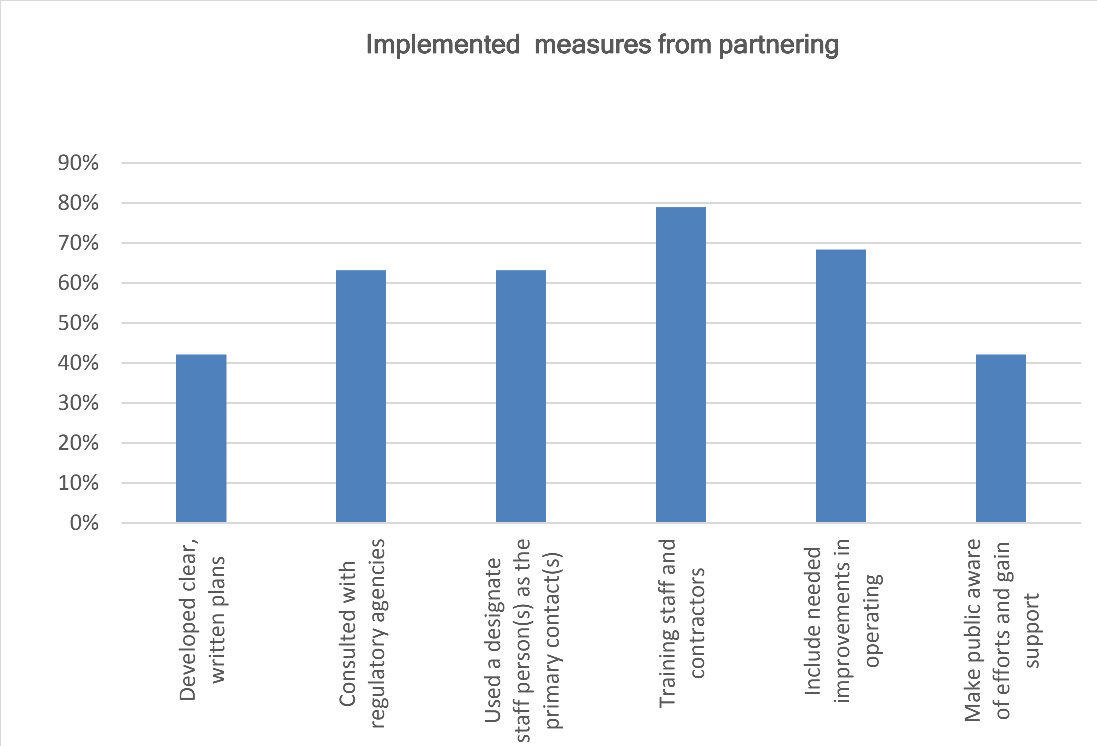

Figure 2. Measures that have been implemented by responding agencies in the process of working or partnering with compliance agencies or private groups.

Respondents were asked if their agencies provided outreach to the public to make them aware of proper salt, sand, and deicer chemical use on the various road types. Eleven respondents (36%) said yes, including comments such as the following, on communication efforts:

- Coordinating at the local level as questions arise, and proactively bringing the concept of liquid products to the public's attention.
- Developed a brochure and web site to address this.
- Works with local officials to improve outreach to specific locations.

Level of Service

Level of Service (LOS), in the context of winter road maintenance, explains the type of metric used to determine how a road is maintained using winter maintenance practices (Veneziano et al., 2014). LOS is used to indicate the degree of effort to achieve an acceptable level of road surface condition for winter travel, by products of which are safety and mobility. State DOTs are continually challenged to provide a high LOS on roadways and improve safety and mobility in a cost-effective manner, while at the same time minimizing adverse effects to the environment, vehicles, and transportation infrastructure. *It should be noted that there is no universally accepted, established or mandated standard or specification for winter maintenance LOS though there are suggested "guidelines.''*

DOTs have traditionally considered level of service related to roadway safety as more of a priority, compared to other less well-characterized or slower developing impacts, such as declining water quality (Fay et al., 2014). A survey of winter maintenance practitioners found that the majority of agencies use some form of established LOS, such as when snow and ice control measures begin, cycle-time to complete one pass on a route, a pavement condition to be achieved (i.e., "bare pavement curb-to-curb'' for arterials and highways, center-lane cleared only on residential streets and low-volume roads) within certain time parameters following a storm, observed travel speed or traffic volumes by route classification, or on measured friction values (Veneziano et al., 2014). In some cases, agencies have used different objectives or metrics, or a combination of objectives and metrics to define and determine if the LOS has been achieved.

In the survey conducted by Veneziano et al. (2014) over 90% of agencies (33 of 36) had an established LOS or other metric used to classify the extent to which roads are maintained during and after a winter storm. All of the identified LOS guidelines focused on providing the public with "reasonable and feasible" safety and mobility throughout a storm event. Thus, safety and mobility were the highest ranked winter maintenance goals by survey respondents (Veneziano et al., 2014). The survey also found that though most agencies have not evaluated the effectiveness of their winter maintenance LOS guidelines they had made revisions to them in recent years. Reasons why agencies had made changes to their winter maintenance goals and LOS guidelines include:

- New data such as weather severity indices or friction measurements were available and needed to be incorporated.
- New equipment and technology used for snow and ice control ,
- Changes in selected materials or application rates necessitated the change of goals or LOS guideline.
- A specific type of event, such as a catastrophic crash or a high-profile failure to maintain a major route to desired levels resulted in a review of strategies and tactics.
- An agency had scaled their operations back to avoid exceeding their current LOS goals.
- Changes in road classification, traffic levels or priority levels.
- Focused research on road user expectations led to revisions.
- Political pressures and influences.
- Decision to lower LOS for low volume roads.
- Population and employment growth or decline, resulted in the need for increased or decreased LOS.
- Staff consolidations and improved efficiency led to revisions (Veneziano et al., 2014).

As indicated, many of the reasons cited for LOS revisions reflect recent advances in winter maintenance practices and operations, while others are the result of socio-economic shifts. In a survey conducted for this project respondents were asked if their agencies' LOS guidelines had been revised to address the environmental impact of snow and ice control products; 34% responded yes, and 63% responded no. This implies that salt pollution-related concerns were not a driving factor in most LOS changes. DOTs tend to set goals related to salt management in yards (e.g., salt pile management, checklists, and environmental management systems) and application (e.g., equipment calibration and training, application feedback) separately from LOS, which most often applies to roadway conditions. A case study of Maine DOT's change in LOS is presented in Appendix D Case Studies.

Measuring and Quantifying LOS

In recent years, a variety of methods to describe and quantify LOS have been developed by different agencies. The most commonly used methods are (Blackburn et al., 2004):

1. Visual assessment of pavement conditions.
2. Visual determination of the time pavement area is snow/ice covered compared to the total storm time.
3. Customer satisfaction surveys.
4. Friction measurements and rating slipperiness.

Winter maintenance LOS is often characterized by the pavement condition (Ye et al., 2012). To assess the functionality of their LOS guidelines MnDOT sought input from the public on a Winter Severity Index, which the public could rate from 0 to 100. "Bare pavement regain time," the amount of time required to achieve bare lane driving conditions after a storm ends, was used as the visual determination. MnDOT found a high public satisfaction rating was achieved when 90% bare lane driving conditions were evident on the road (Keranen, 2002; Maze et al., 2007; Kipp et al., 2013). The following snow and ice conditions were determined to be acceptable by the population surveyed:

- 10 – 50 ft spots per mile
- 2 – 250 ft spots per mile
- 2– mile per 20 miles
- 2 – ½ mile per 10 miles
- 8 – ¼ mile spots per 20 miles (Keranen, 2002).

Figure 3 shows the derivation of bare pavement regain time which is used by MnDOT.

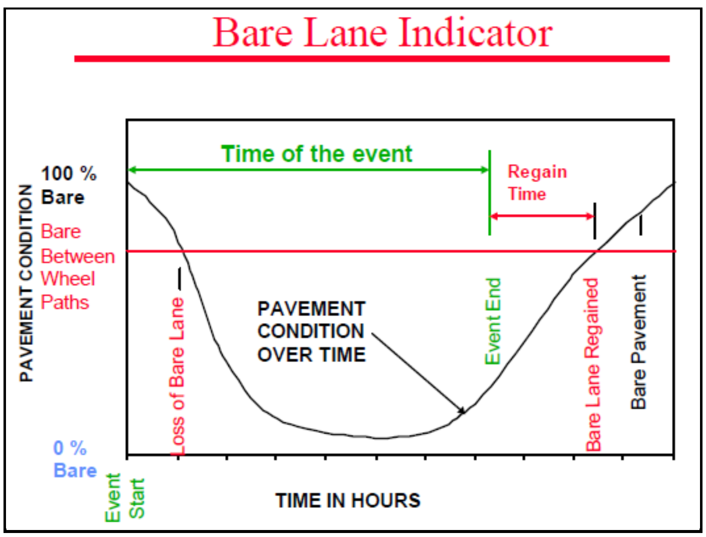

Figure 3 Derivation of bare pavement regain time (Keranen, 2002).

The Idaho Transportation Department (ITD) recently completed an assessment of their LOS guidelines by surveying the public and using focus groups (Veneziano et al., 2014). A visual assessment of LOS was used. The options included general categories in use by ITD (good, fair, poor, and black-ice road conditions), along with the practices and efforts that were required to achieve the level of LOS, and their respective costs (Veneziano et al., 2014).

Roads in “good” condition consist of bare pavement, either dry or wet, with clearly visible pavement markings. Tactics to achieve “good” conditions include anti-icing, deicing and plowing during and after the storm, and use of abrasives in spot locations (e.g., curves) (Veneziano et al., 2014). Maintenance is conducted throughout the storm and normal roadway conditions are restored as quickly as possible after snowfall ceases. Figure 4 shows examples of “good” road conditions as defined by survey and focus group participants (Veneziano et al., 2014).

Figure 4 Examples of “good” road conditions (Veneziano et al., 2014; photos courtesy of WTI and MDT).

Roadways in “fair” condition consist of intermittent bare pavement and markings, with wheel paths clear in at least one lane in each direction. Tactics to achieve “fair” conditions may include anti-icing, deicing and plowing during and after the storm, and abrasives may be applied in spot locations (Veneziano et al., 2014). Maintenance is conducted during the storm as resources permit, and efforts are made to restore these routes to normal conditions after snowfall ceases. Less funds are spent on labor, fuel, materials and equipment. However, in comparison to “good” condition, drivers may experience increased stress, safety concerns and decreased mobility. Figure 5 shows the images of a “fair” condition road as defined by survey and focus group participants (Veneziano et al., 2014).

Figure 5 Examples of “fair” road conditions (Veneziano et al., 2014; photos courtesy of WTI and MDT).

Roadways in “poor” condition consist of intermittent wheel paths in one lane in each direction. Fewer resources are expended, with most efforts focused on snow clearance and material treatment after the storm. Abrasives are commonly applied in spot locations where additional traction is needed. Routes of tertiary ranking are often low volume roads and streets. Maintenance is conducted on a limited basis during the storm as resources permit, and efforts are made to restore these routes to normal, conditions within a reasonable time period following a storm. Routes maintained in “Poor” condition do provide adequate mobility for prudent drivers with properly equipped vehicles, and cost significantly less to maintain. The traveling public will likely experience increased stress, safety problems and decreased mobility on these routes. More effort is required to restore the route to a normal condition following the storm; this effort is conducted during normal operating hours thus minimizing overtime costs (Veneziano et al., 2014). Figure 6 shows the images of a “Poor” road as defined by survey and focus group participants (Veneziano et al., 2014).

Figure 6 An Example of “poor” road conditions (Veneziano et al., 2014; photos courtesy of WTI and MDT).

Black ice is a condition where the road may appear to be in “Good” or “Fair” condition, but a very thin, mostly invisible layer of ice is present. This presents a significant hazard to drivers, particularly when it is encountered unexpectedly. Treatment of black ice can include the use of chemicals or abrasives for melting and to enhance traction (Veneziano et al., 2014). Figure 7 shows the images of a road with “Black Ice” that were presented to survey and focus group participants (Veneziano et al., 2014).

Figure 7 Examples of “black ice” road conditions (Veneziano et al., 2014; photos courtesy of WTI and MDT).

Pavement friction can be a reliable tool to assess LOS guidelines (Yamamoto et al. 2004). Yamamoto et al. (2004) showed that there is a proportional relationship between increasing the coefficient of friction with the use of deicing, anti-icing, and sanding the roadway. Friction measurements were analyzed to measure the efficiency of deicer, anti-icer, and sand performance. In Norway they use the friction coefficient threshold of 0.25 when spreading sand on snow packed roads (Al-Qadi et al. 2002). Colorado DOT (CDOT) is currently testing the use of non-contact friction measuring devices to assess winter maintenance product performance. Since these were installed on traffic poles, CDOT personnel have noticed an initial performance difference among winter maintenance products, as well as a difference in bare pavement regain time. Bare pavement regain time is the performance measure used by CDOT to assess product performance, which has been found to better assess longer-term product performance (Fay et al., 2013).

In a survey conducted for this project respondents were asked to provide information on the LOS for specific routes types. For major limited-access highway, freeway, and expressway, and primary surface arterials, bare pavement for all lanes (BPA) is the most common LOS (Figure 8). For secondary arterial and collector roads bare center of roadway only (BPC) is the most common LOS. Generally, for residential roads, alleys, park service roads, parking lots, sidewalks, and bike paths the LOS varied greatly and was dependent on the responding agency.

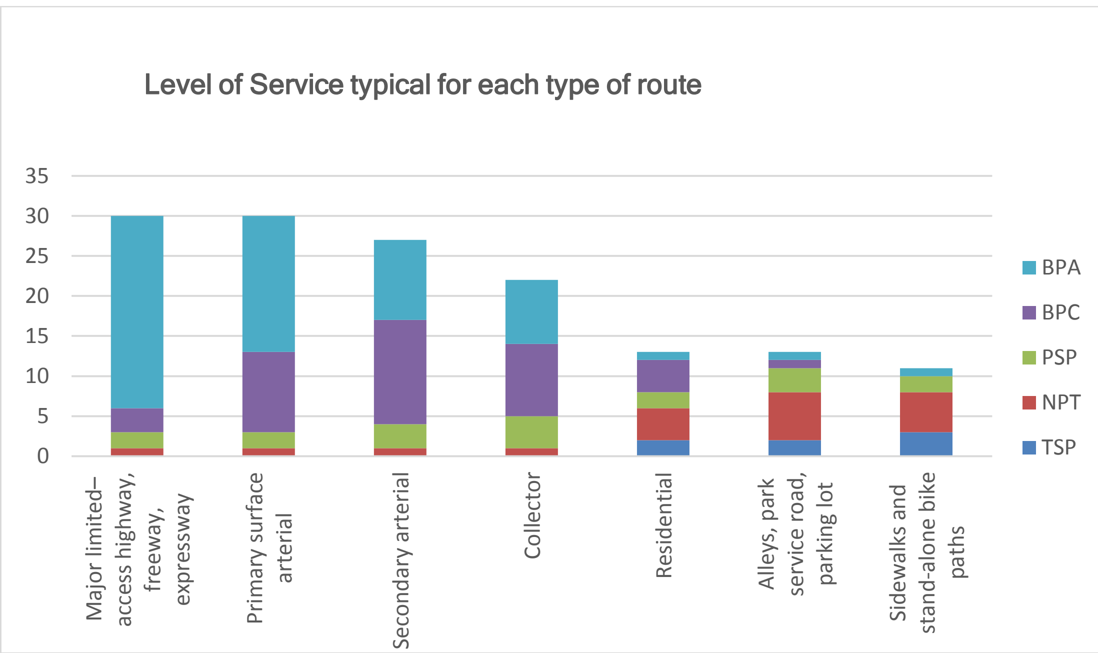

Figure 8 Level of service for route types based on survey responses. (BPA=bare pavement for all lanes, BPC=bare pavement center of roadway only, PSP=plowed, packed snow, NPT=no plowing or treatment, TSP=trouble spots only treated)

Environmental Management Tools

This section will provide information on environmental management tools that have been developed for transportation agencies including Environmental Management Systems and how these systems can be used to track Environmental Performance Measurement.

Environmental Management Systems

AASHTO's definition of an Environmental Management System (EMS) is the organizational structure and associated responsibilities and processes, procedures, and tools for integrating environmental considerations and objectives into the ongoing management decision-making processes and operations of an organization. In layman's terms, environmental management systems are a tool used to systematically assess which environmental aspects of an operation's work are most significant, how well controlled they are, and how any adverse environmental impacts should be handled (McVoy et al., 2012).

The AASHTO Center for Environmental Excellence published the *Practitioner's Handbook for Developing and Implementing an Environmental Management System in a State Department of Transportation*, which can be used as a "how to" guide for establishing an environmental management system (AASHTO, 2007).

The US Environmental Protection Agency (EPA) developed a Compliance Focused Environmental Management System (CFEMS), because they found many cases of non-compliance were due to inadequate EMSs (Sisk, 2005). The CFEMS aids organizations in developing EMSs that will improve compliance with applicable environmental requirements and improve performance through setting and achieving environmental objectives. (More information on this topic can be found at http://www2.epa.gov/enforcement/guidance-compliance-focused-environmental-management-system.)

Rodrigue et al. (2013) described an EMS as a set of procedures and techniques enabling an organization to reduce environmental impacts and increase its operating efficiency. The following EMS best practices and procedures were identified (Rodrigue et al., 2013):

- Match transportation facilities, operation, or projects with environmental components
- Link environmental components with regulatory requirements
- Assess risk, impacts, and responsibilities
- Identify environmental issues to be addressed
- Consider commercial strategies and operations of private and public sector organizations
- Introduce best practices
- Undertake continuous monitoring and auditing

Two common Environmental Management Systems are EMAS and ISO 14001 which are described below.

Eco-Management and Audit Scheme (EMAS)

EMAS was created in 1993 by the European Union with the goal of providing firms with a framework and operational tools to permit better protection of the environment (Rodrigue et al., 2013). First, environmental impacts and the various types of environments that are affected by operations and activities are identified. Environmental aspects of the EMAS that should be considered include:

- Resource utilization (e.g., use of raw materials, energy, etc.)
- Water management
- Air emissions
- Water pollution

- Noise and vibration nuisance
- Land contamination
- Indirect impacts caused by suppliers, contractors, or customers
- Others: Flora and Fauna, Visual impact; Community impact, Transportation impact, Nuisance, Site Security, etc.

Second, a step-by-step evaluation of each activity and the identified impacts is completed. Each impact is then assessed in relation to developed criteria by the organization (Rodrigue et al., 2013). These criteria must evaluate the potential damage to the environment, the fragility of the environment, the size and frequency of the activity, the importance of the activity for the organization, the employees and local community, and the legal obligations of environmental legislation.

ISO 14001

The International Standard Organization developed ISO 14001 (http://www.iso.org/iso/iso14000), a set of norms for industry to reference for environmental management systems and sustainability (Rodrigue et al., 2013). The following three categories were developed to measure environmental performance:

- IEC – indicators of environmental conditions
- IMP – indicators of management performance
- IOP – indicators of operational performance

These indicators generally identify the most significant environmental impacts associated with transportation operations, and are used to evaluate, review and increase the environmental performance of organizations. The indicators need to be constant, credible, and measurable information based on data that relates environmental performance to the organization’s environmental objectives, targets and policies.

Based on his review of Environmental Management Systems, Rodrigue et al. (2013) identified four tasks that are the administrative responsibility of the transportation industry:

- Identifying the impacts.
- Devising a calendar of operations – looking at short, medium, and long term objectives.
- Establishing benchmarking – identifying the minimum standard (or starting reference point), setting goals, and tracking progress. Establish standards based on science, engage the public and public administration, and integrate standard with practices.
- Implementing measures of control – environmental certification.

The organization identifies improvement opportunities and sets environmental goals and objectives, continuing to improve and diagnose performance and shortfalls in a systematic way.

Examples of State DOT Implemented EMSs

A review of State DOTs found that implementation of EMSs is increasing, and more organizations were considering or had plans to implement EMSs; however, there were some areas that still need clarification or improvement (Kissel, 2006) including:

- clearly refining and defining what an EMS is and is intended to do;
- providing a clear understanding of FHWA’s stance on using EMSs;

- having organizations develop EMSs around their current business practices;
- focusing on overall quality management and improvements;
- improving the timing of implementation; encouraging sharing between organizations and states;
- and having support from AASHTO.

Examples of lessons learned and case studies can be found in this document (http://environment.transportation.org/pdf/environ_mgmt_sys/EMSreport.pdf).

McVoy et al. (2012) highlighted the EMS used by Caltrans as a successful example of integrating environmental management into a DOT maintenance division (Figure 9).

Program	Purposes	Audit/Self-Evaluation	Reporting Results
California - Caltrans			
Caltrans' Integrated Maintenance Management System (IMMS) provides the principal accountability mechanism for the Division of Maintenance.	The Division of Maintenance has an audit of its activities conducted in the roadside environment and at yards and stations.	Environmental performance evaluations are conducted in accordance with The Maintenance Activities Compliance Review Plan at http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-05-999_99_2.pdf and the Maintenance Facilities Compliance Review Plan at http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-05-999_99_3.pdf Each document contains the evaluation criteria.	The Division of Maintenance tracks its environmental compliance activities and generates the following databases. They're summarized and reported annually to the State Water Resources Control Board and other regulatory agencies. • Erosion Inventory Database, • Storm Drain System Inventory Database, • Illegal Connection/Illicit Discharge Database, • Pesticide Use Database, • Maintenance Facility and Activity BMP Implementation Database, • Facilities Pollution Prevention Plans (FPPPs) Database, • Training Database, • Level of Service (LOS) -- a performance-based system designed to measure progress on departmental goals.

Figure 9 Example of an EMS system used by Caltrans measuring compliance, stewardship accomplishments, and metrics (McVoy et al., 2012).

The literature review identified the following benefits that can be gained from using Environmental Management Systems (AASHTO, 2007; McVoy et al., 2012):

- Reductions in the number, type, and severity of compliance incidents
- Pollution and waste reductions
- Recovered resources
- Streamlined permit and document review and approvals
- More effective management at all levels
- Increased environmental awareness
- Employee training
- Non-conformity/corrective action tool
- Cost savings

- Environmental compliance and continuous improvement – ability to apply process to every operation
- Recognition of the strength of employee involvement
- Facilitation of good housekeeping, well maintained, clean, and well organized facilities
- Simplified documentation
- Opportunities to integrate with other management systems
- Positive public relations

The following business performance improvements were also identified:

- Reduced regulatory oversight schedule and cost burdens.
- Faster project delivery and, in turn, labor savings through streamlined reviews and approvals.
- Improved relationships with external stakeholders.
- Increased workforce efficiency.
- Cost savings and cost avoidances resulting from the integration of environmental needs and opportunities into both long-range and day-to-day activities.

Research has shown that the benefits realized from using an EMS are similar, regardless of the type of EMS implemented (Rodrigue et al., 2013).

Environmental Performance Management

Environmental Performance Measurement (EPM), often referred to as "green asset management", is the comprehensive performance tracking for the complete range of maintenance activities in keeping with potential environmental impacts (McVoy et al., 2012). Cambridge Systematics (2008) developed *Guidelines for Environmental Performance Measurements* with examples of the use of environmentally focused performance measurements in transportation. They found that there are many readily available EPM initiatives that consider sustainability, environmental benefit agreements, green or environmentally sensitive design, construction, maintenance, operation, an increased number of BMPs, context sensitive solutions (CSS), and context sensitive design (CSD). They identified some hurdles that may impede progress, but found that many agencies are successfully using EPMSs.

Some EPMs provide a quantitative assessment of how maintenance programs can impact across the "Triple Bottom Line" (economic, social, and environmental) of sustainability. However, these EPMs are just beginning to emerge. Successful EPMs in this category include auditing, planning, and measurement of metrics (McVoy et al., 2012).

The following *guidelines for implementation* were recommended (Cambridge Systematics, 2008):

- *"Build upon existing and emerging practices. Start simple, and then gradually move towards more advanced approaches.*
- *Utilize an incremental or time-phase approach to implementation, but one that is guided by trends and longer-term goals.*
- *Recognize that 'one size does not fit all.'*
- *Work with partners and stakeholders in areas of environmental performance measurement. Work in an interdisciplinary group.*

- *Environmental performance measurements should be introduced throughout all phases of management practices and should include economic, the natural environment, communities, and the human and social environment.*
- *An environmental performance measurement program should be developed and implemented as part of a larger agency wide performance measurement program. Existing performance management programs can be expanded to include environmental considerations."*

Cambridge Systematics (2008) identified the following *key management attributes* for a successful environmental performance measurement program:

- Start with small, manageable actions and then build from their success.
- Have commitment and support from top-level leadership.
- Having project champions be career or senior level leaders.
- Create a culture of performance measurement with employee participation and buy-in.
- Be able to link performance measures to actions, and forward progress.
- Consistent reporting internally and externally.

Cambridge Systematics (2008) reported that agencies employing EMS regularly have identified three primary benefits: better assessment of current projects, improved communication within the agency, and linking with other agencies through common goals. Generally, agencies had a positive experience with using environmental performance measures. Positive experiences gained from using the environmental performances measures included "gaining support from upper management and the ability to align environmental objectives with other agencies' missions and fostering interagency cooperation." Identified challenges include data collection efforts, the quality of the data once collected, and inadequate resources.

Survey results show that environmental performance measurement is valuable when the results are quantifiable (Cambridge Systematics 2008). According to this survey, environmental performance measurement is applicable in a variety of processes that allow agencies to link the policies, goals and visions. This survey also shows that there is an increasing concern and awareness about the link between transportation and the environmental, and the use of environmental performance measures is likely to become more common.

A Guidebook for Sustainability Performance Measurement for Transportation Agencies (NCHRP 708) provides a "flexible framework" which DOTs can use to apply concepts of sustainability through performance measurement. This is a user's guide and has case study examples in each section that highlight how various states and agencies have been successful (Zietsman et al., 2011).

One of the most well-known DOT EMS examples applied to winter maintenance is PennDOT District 10's ISO 14001 EMS, which encompasses salt pile management and walkaround checklists, calibration, and training. A case study on this topic can be found in Appendix D Case Studies

Training

The importance of training cannot be overstated as the success of any best practice (management system, strategy, technology, or product) hinges on the appropriate implementation by knowledgeable personnel.

A survey conducted for this project asked winter maintenance professionals if they are trained on the proper use of snow and ice control materials, including application rates and methods. The majority of respondents (90%) responded yes, with over half stating that training was conducted at least annually. Survey responses indicated that contractors may not be trained as frequently. Respondents were asked if they were trained specifically on environmental issues related to snow and ice control practices, and 70% stated that they were. Responses varied from collaborative training within their agency and State Department of Environmental Conservation, to annual training touching on this subject. Survey respondents were then asked if they felt the environmental training they received was adequate. About 60% felt their environmental training programs were adequate, and 30% felt they were not adequate. Comments provided by survey respondents indicated that while they have training programs, there is always room for improvement. General environmental training conducted by state transportation agencies does not typically include winter operations; instead focusing on in-water or near-water work, stormwater BMPs, endangered species, etc.

McVoy et al. (2012) conducted a survey of DOT personnel regarding access to environmental BMP training. According to the findings, 89% of respondents said their agency provided environmental training specifically for maintenance and operations personnel, and that the maintenance and operations staff understood the potential environmental impacts and ecological value of their work activities. For most (90% of respondents), the environmental guidance material was readily available in the form of manuals or guidance documents.

State DOTs interviewed by McVoy et al. (2012) identified the following as the most effective characteristics of training programs:

- Have managers, knowledgeable staff, and/or staff respected for their expertise conduct the training sessions.
- Utilize hands-on field training activities as much as possible, particularly with installation and maintenance of stormwater, erosion, and sediment control measures.
- Provide guides, handbooks, and other materials that can be readily taken into the field.
- Encourage active participation in the training sessions, and encourage people with interdisciplinary responsibilities and expertise to participate, including staff from other program areas (design, construction, environmental), other regulatory and resource agencies, NGOs, and other stakeholders.
- Use teleconferences, webinars, online courses, CDs, and other methods to link staff in different geographical and organizational levels for interdisciplinary training, communication, and coordination. For example, one agency has monthly hour-long webinars available statewide, which are held weekly at the same time, day, and call-in number. The convenience of the regular schedule increased the dialogue among staff about current and common issues and practical strategies.

Fay et al. (2014) discussed training snow and ice control staff and personnel and its role in effective and efficient use of chloride roadway deicers. Comprehensive training programs were recommended that demonstrate the purpose and value of what is being taught, address staff concerns and potential resistance to change, and help ensure competency in tasks. Successful trainings should identify learning goals and have a logical progression (Eckman et al., 2011).

Northumberland (2011) developed a list of snow and ice control staff training recommendations and the frequency for which the training should be conducted (Figure 10).

Job Class	**Training**	**Frequency**
Operations Manager	RWIS - Weather Forecasting	Once
	Snow and Ice Colloquium	Annually
	Proper use of infra-red thermometers	Once
	Interpretation of weather and pavement conditions	Once
Roads Foreman	Salt Smart – T.A.C. Train-the-Trainer	Once
	RWIS - Weather Forecasting	Once
	Proper use of infra-red thermometers	Once
	Interpretation of weather and pavement conditions	Once
	Combination Plow Training	Once
Operator	Annual driver training updating	Annually
	Bi-annual staff meeting – pre and post-session	Bi-annually
	Annual updating of winter maintenance routes	Annually
	Winter road patrol sheets - Proper record keeping	Annually
	Proper use of infra-red thermometers	Once
	Combination Plow Training	Once

Figure 10. Recommended staff training topics and frequency for each (adapted from Northumberland, 2011; Fay et al., 2014)

Additional training topics requested by survey respondents included training in wetlands, water quality, waste management, local and endangered species, permits and permitting agencies, and cultural resources (McVoy et al., 2012). The US EPA recommended supervising maintenance engineers occasionally participate in in-service training courses covering groundwater hydrology; environmental aspects of planning, design, and construction; and procedures for complying with federal and state environmental law (US EPA, 1974).

Snow and Ice Control Training Programs

There are many available resources for snow and ice control environmental training and certification programs, as well as additional resources on similar topics which are summarized here.

Training and Certification Programs, and Resources

Many organizations have developed training programs including:

- American Association of State Highway and Transportation Officials (AASHTO),
- Snow and Ice Pooled Fund Cooperative Program (SICOP),
- Pacific Northwest Snowfighters Association (PNS),
- Clear Roads,
- Aurora,
- American Public Works Association (APWA),
- National Association of County Engineers (NACE),
- International Erosion Control Association (IECA),
- Transportation Research Board (TRB),
- Transportation Curriculum Coordination Council (TCCC),
- the Salt Institute (SI),
- Transportation Association of Canada (TAC),
- Local Technical Assistance Programs (LTAP),
- National Institute for Certification in Engineering Technologies (NICET),
- University Transportation Training Programs and
- individual State DOT Training Programs and Resources.

The current NCHRP Synthesis project “Training and Certification of Maintenance Workers” highlights the need for a collective understanding of the state-of-the-practice in maintenance training. (Results from this project should be available in early 2016.)

An example of state DOT training programs and resources highlighted by McVoy et al. (2012) is the annual Maintenance Academy held by CDOT. The program trains about 1500 employees each year on environmental ethics and hazmat. New hires participate in a two-week training program, and existing staff participate in a one-week program. Other examples include the Maintenance Academies, Snow Universities, annual snowfighter training in districts, and miscellaneous equipment and safety training.

Many state DOTs, like New York , Oregon and Washington , have developed documents to aid their staff in applying environmental best management practices. Many others have training methods and programs such as new hire training, Highway Maintenance Seminars, and tailgate meetings, which are discussed in more detail in McVoy et al. (2012).

List-Servs and Social Media Resources

The Snow and Ice List-Serv is a useful resource that connects practitioners, researchers, and vendors through open forum discussion. LinkedIn has many groups that are open and/or invitation only on a variety of snow and ice control related topics.

Simulator Training

Some states use high-fidelity simulators as training tools. MnDOT and Utah DOT (UDOT) train snowplow drivers using a simulator (CTC & Associates, 2008; Leaner and Greener, 2012). The simulator scenarios have been developed to address user needs in managing incidents and can be customized. Use of the simulator was found to decrease accident rates, costs, and fuel use (CTC & Associates, 2008).

Private Training Organizations

CTC & Associates (2009) provided information on commercially available training programs including Ice & Snow Technologies Inc. on snow and ice control practices, and can be focused on specific environmental issues or BMPs relevant to a location. Asset Insight Technologies (AIT) offers training on managing winter maintenance and scenario-based training which can be customized to the needs and issues present at each site, including winter maintenance environmental BMPs as they relate to each site's needs.

Training Modules under Development

Chloride Reduction Training is currently being developed for the Illinois DOT. The final product will be a one-day training on chloride reduction techniques and up to 12 web-based videos. This training module discusses chloride contamination; source locations for contamination; and demonstrated best practices for reducing chloride use on roadways, parking lots, and sidewalks. Clear Roads and MnDOT recently awarded funding for the development of training materials, including presentations, course guides, exams, and other support material. The project should be completed in 2015.

Cost-Benefit of Training

Successful winter maintenance training programs have been shown to reduce deicer use while maintaining the stated LOS, and improving winter maintenance operator practices (Eckman et al., 2011). Many survey respondents agreed that the training helped their agency to mitigate or reduce the impacts of chloride deicers. A summary of some of the responses are given below as an example (Fay et al., 2014):

- The amount of salt in traction material has been reduced, while training has increased to educate operators (Pennsylvania DOT).
- Continued operator training, equipment calibration, and improved delivery systems are focusing on placement and retention of product. The goal is to apply only the amount of product necessary to meet our needs (Montana DOT).
- Reduction of salt in our sand, increased operators training, and utilization of MDSS (Colorado DOT).
- Operators are all given training in Salt Smart principles (Manitoba Infrastructure & Transportation, Canada).
- Efforts made in the past 5 years include intensified Best Practices training for shop managers and front-line forces, post-storm reviews, updated SMP (salt management plan) and training sessions that reinforce benefits of salt management within the Snowfighters Training Program for operators (New Brunswick Department of Transportation, Canada).

- Training sessions were held and more will be held over the coming years so that users can use the devices to their full potential (Ministry of Transport of Quebec, Canada).

Monitoring and Keeping Records

Monitoring environmental parameters and practicing effective record management of snow and ice control products and related procedures can aid in materials savings, create a more effective working environment, increase efficiency, reduce person and equipment hours, and enable cost savings. Collected data help DOTs report on point source and non-point source runoff from roadways or stockpiles (Fay et al., 2013). Monitoring chloride concentrations on and along roadways and in adjacent water bodies can provide an indication of potential impacts to stream biota (Fay et al., 2014). Furthermore, information from monitoring chloride concentrations in salt-vulnerable areas can inform selection of appropriate winter maintenance and mitigation strategies (TAC, 2003). A municipality in Canada implemented a monitoring approach that included maintenance agencies working with their local conservation authority to add chloride sensors to their stream monitoring network (Fay et al., 2013).

Monitoring may include (TAC, 2013):

- Baseline condition or benchmarking of site conditions or the surrounding area.
- Tracking the amount of material bought, delivered, used; these amounts should be reconciled at the end of each year, at a minimum.
- Compliance with good housekeeping practices.
- Establishing permanent monitoring wells and implementing a regular groundwater monitoring program, to allow for early detection and improvements in storage and handling.

A quality assurance (QA) plan should be developed prior to sampling and analysis. The sampling design plan should discuss what types of samples are being collected, where they are being collected, the timing of sampling, and how the samples should be handled. The analysis protocol should discuss the test methods being used, the analysis methods for the data, and any relevant reporting parameters. The QA plans should be available, on site, reviewed prior to the initiation of sampling or analysis, and followed by trained staff (US EPA, 2002).

For toxicity testing, QA plans should be developed for laboratory toxicity testing and should consider sample replicates and controls, food sustainability, reference toxicants, and performance evaluations of samples (ELAP, 2008).

The following issues should be considered before initiating a water monitoring program (TAC, 2003):

- At what frequency and where will samples be collected?
- Will sampling be continuous (in-situ) or periodic (grab samples or grouped samples)?
- Will there be health and safety issues with data collected during/post storm events or will maintenance of sensors be needed during storm conditions?
- Will the data be communicated back to a central location automatically?
- Will sampling location need power and telephone capability for data communication (or could it use solar with cell phone and avoid issue)?

- Will there be any confounding data such as chlorides entering the environment from other sources (such as private use or private contractors, water softeners, landfills, or wastewaters)?

Consider maintaining the following records, at a minimum: winter severity ratings, total number of events requiring road salt application during the winter season, and materials usage. Table 1 shows a list of recommended records and reports.

Table 1. Example list of records and reports maintained during the winter season (Northumberland, 2011)

Title Description	Title Description
Salt/Sand/Grit Inventory	Inventory record of salt materials delivered to works yard including date, supplier, quantity, etc.
Road Patrol	Daily record of road conditions
GPS Vehicle Report	Report generated by GPS unit installed on maintenance vehicles detailing date, time, speed, trip length, etc.
Dickey-John Spreader Controls	Continuous reporting of application of materials on Roadways
Daily Activity Reports	Daily record of Operator's activities performed through the Shift

Transportation agencies should consider keeping detailed records of the following items and issues (TAC, 2003; Highway Deicing Task Force Report, 2007):

- Confirm that all snow and ice control materials are stored under cover
- Confirm that all storage sites include collection and treatment of wash water and drainage
- Inspection and repair records for application vehicles
- Purchase and stockpiling records for snow and ice control materials
- Brine production quality control (e.g., concentrations)
- Pavement temperature trends in daily logs, along with pavement conditions, weather conditions and winter treatment strategy
- Temperatures, snow depths and durations during snow/ice storms
- Traffic levels during snow/ice storms with
- Total length of road (lane miles) on which snow and ice control materials are applied
- Storm and overall winter severity ratings
- Total number of events requiring snow and ice control material application during the winter season

- Materials usage
- Description of snow and ice control materials used for winter road maintenance
- When each piece of equipment was calibrated, results of calibration testing, and who conducted the calibration.
- Average concentration and frequency of sampling at each sampling location, if available.

Storm severity is a combination of storm impacts and the relative difficulty of mitigating the impacts (Strong et al. 2005; Farr and Sturges 2012). A winter (or weather) severity index (WSI) turns weather impacts relative to storm severity into a numerical value. A WSI can be applied to each storm event, or for a whole year, or for a winter season. A WSI is an important parameter to consider when relating winter maintenance practices to impacts to the environment. For example, if chloride concentrations are being monitored during a winter season that is experiencing unusually cold weather with a lot of precipitation, and has required more or higher deicer applications, chloride values may be higher than in typical years. In this case applying a WSI to the calculation would normalize the data so that above-average snow, average, and below-average years can be compared.

The importance of monitoring and keeping records, including data collection and data analysis cannot be stressed enough. Many transportation agencies have realized significant cost and material savings and identified effective practices through monitoring and data collection. An example is the development of a model by the Iowa DOT that allocates salt to garages based on weather conditions and policy usage requirements (Fay et al., 2014). To establish the model, Iowa DOT needed to have historic weather data, information on salt use at the garage level, the number of lane-miles and prescribed LOS for each road type for each garage, environmental parameters measured by RWIS, and actual working hours. The collected data was used to create a salt budget for each garage, providing a program evaluation tool for Iowa DOT to manage their salt use.

Another example of using collected data to identify best practices is the use of Life-cycle assessment (LCA). An LCA is a framework for evaluating the environmental impacts of products or processes over the entire life cycle. In the context of winter road treatment, an LCA would enable the comparison of all steps in the delivery and use of a product, from mining raw materials, manufacturing or processing the chemical, storage and application, to the eventual fate in the environment. Much like full-cost accounting quantifies all of the infrastructure and environmental costs of chloride-based treatments and their alternatives; an LCA provides quantitative measurements of the environmental consequences of different decisions that would be useful for transportation agencies, chemical suppliers and environmental scientists seeking improvements in winter road treatment processes (White and Shapiro 1993; Fitch et al. 2013).

Snow and Ice Control Materials

In cold-climate regions such as the northern United States and Canada, winter maintenance is often the activity of highest priority for transportation agencies. Large amounts of solid and liquid chemicals (known as deicers) as well as abrasives are applied on roadways to keep them clear of ice and snow. Abrasives are not deicers but serve to provide a temporary friction layer on the pavement. The deicers used by transportation agencies are mainly chloride-based salts. Acetate-based deicers (potassium acetate, sodium acetate, and calcium magnesium acetate—

CMA) have also been used on some winter roadways. Airports use mainly acetates and glycols as deicers for their pavements and aircrafts, respectively. In addition, formates (sodium formate and potassium formate) and bio-based products have emerged as potential alternative deicers (Shi et al., 2009). Deicer laden runoff can become point source or non-point source pollution and can negatively impact soil, plants, animals, and waters. Figure 11 and Figure 12 outline the pathways of deicer movement in the environment (Cheng and Guthrie, 1998; Fischel, 2001; Levelton Consultants Limited, 2007).

Deicers are composed of a variety of active ingredients and additives, which allow for the development of unique blends to address a wide range of conditions; however, this can in turn lead to environmental problems associated with air, surface water, ground water, roadside soil, roadside vegetation, roadside fauna, and humans. Below is a summary of each of these impacts by product type.

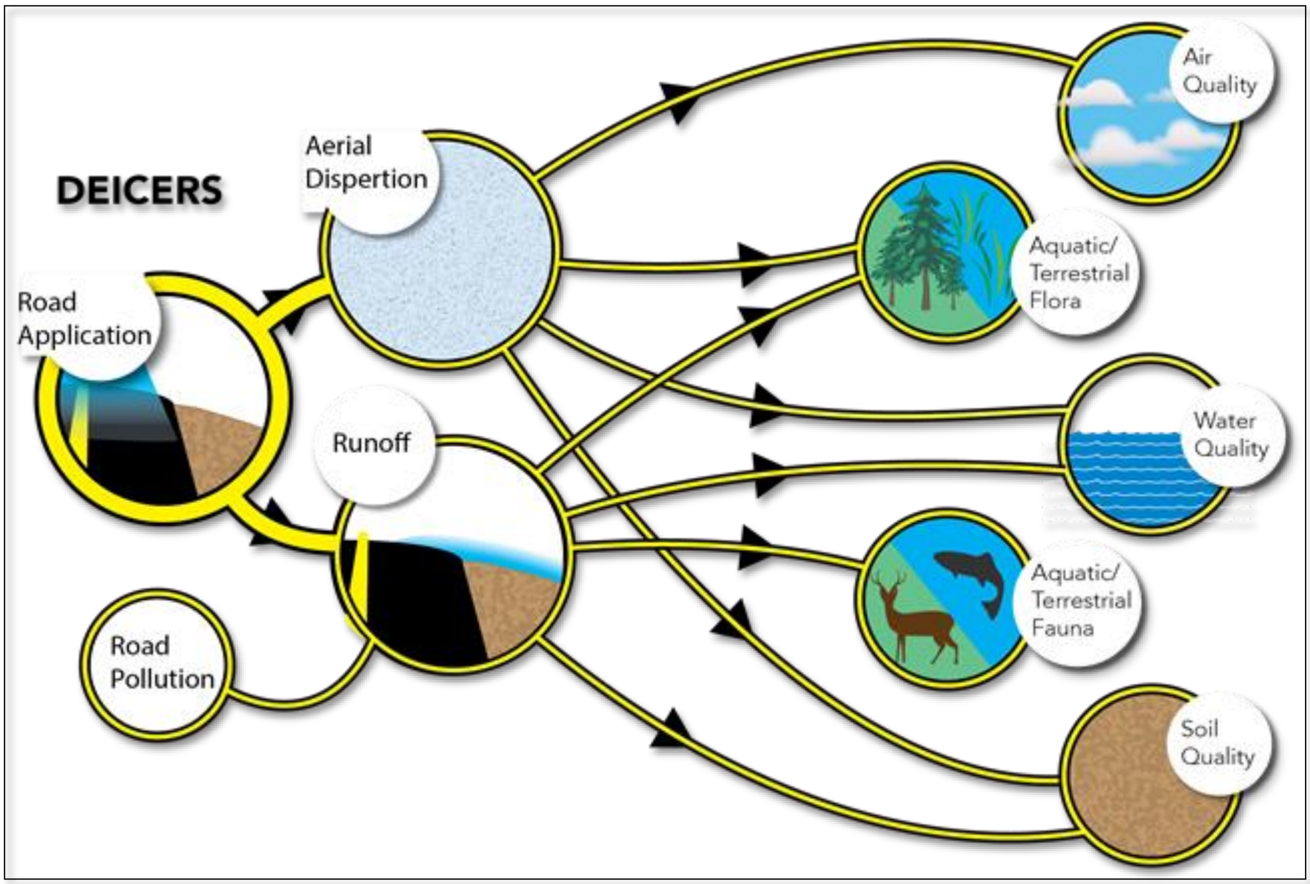

Figure 11. Pathway of deicer migration into and movement within the environment (adapted from Cheng and Guthrie, 1998).

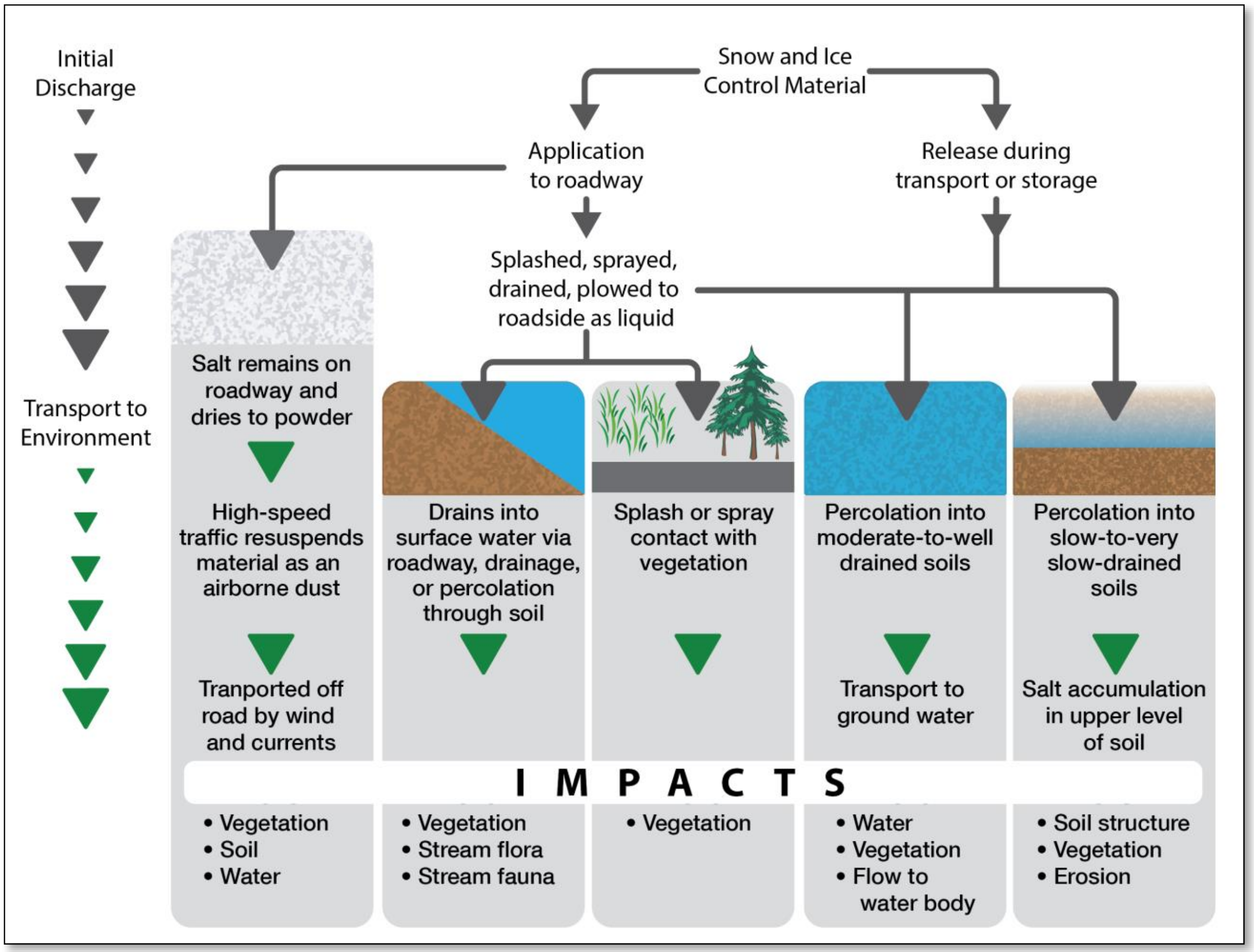

Figure 12. Environmental pathway model modified from Levelton Consultants Limited (2007), showing deicer footprint on the environment.

Abrasives

Impacts of Abrasives

Abrasives (e.g., sand or grit) have been used for many decades for winter operations to provide temporary traction on snowy or icy pavement. Abrasives are typically used on roads with low traffic and low level of service (LOS) (Blackburn et al., 2004). Abrasives, especially those not pre-wetted, had limited effectiveness on snowy or icy roads with higher vehicle speeds; as such, the use of abrasives will not necessarily improve mobility on many roads (CTC & Associates, 2008). Schlup and Ruess (2001) provided a balanced perspective on the use of abrasives and salt, based on their impact on safety, economy, and the environment. The detrimental environmental impacts of abrasives are generally greater than those of deicers (Staples et al., 2004). It would take a significantly higher amount of abrasives to maintain a reasonable LOS, relative to the amount of deicer that would be required.

Abrasives for snow and ice control are relatively inexpensive, but the damage caused by their repeated applications, along with substantial clean-up costs, can make them less cost-effective. The use of abrasives can negatively impact water quality and aquatic species, air quality, vegetation, and soil, and therefore incur hidden costs. Even after cleanup, 50% to 90% of the sand may remain somewhere in the environment (Parker, 1997). Depending on their particle size, abrasives may greatly contribute to air pollution, can potentially cause serious lung disease, and are listed as a carcinogen (Fischel, 2001; Nixon, 2001). Particles smaller than 10 microns (0.01 mm) in diameter, known as PM-10 regulated by the US EPA, may become suspended in the air causing eye and throat irritation, and contribute to respiratory problems. Communities with excessive PM-10 particles in the air may surpass limits imposed by the Clean Air Act and therefore be categorized as "non-attainment" areas (Williams, 2001). In such communities, the use of abrasives is only allowed on a limited basis (Chang et al., 2002).

Abrasives also pose significant risks for water quality and may threaten the survivability of aquatic species especially during spring runoff (Staples et al., 2004). The risks may include: increased water turbidity from suspended solids, clogging of streams and storm water drains, and reduced oxygenation within the stream and river beds. Particles less than 2 mm in size are especially problematic as they can block the movement of oxygen into streambed gravel. Increased quantities of particles less than 6 mm in size can smother macro-invertebrates and fish eggs, affecting both food chains and fish reproduction (Staples et al., 2004). Finally, abrasives used for snow and ice control can also exacerbate the environmental stress on roadside soil and vegetation.

A summary of information on abrasives and salt/sand are provided in Table 2,Table 3,Table 4, and Table 5.

Table 2. Summary of information on abrasives commonly used in snow and ice control operations.

	Product Type	Liquid/solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Abrasives	Sand	Solid	100-1000 lbs/l-m	Typically used on roads with low traffic and lower LOS, including areas near roads that have highly sensitive water resources or wildlife habitat. In addition, useful on low volume roads near hills, curves, and intersections and when pavement temperatures are lower than 10°F.	$6-16/ton*	Provides temporary traction. Easily lost from road surface. Pre-wetted abrasives stay on the road surface longer and show great performance.	Abrasive piles should be covered to avoid loss of material from erosion. *The additional clean up costs for abrasives should be considered in the purchase cost. Reported sweeping costs ranged from $62.95 per mile (annually), or $1.5 to $5.9 million total for annual sweeping costs.
	Cinder	Solid	100-500 lb/l-m		$20/ton*		
	Crushed rock/gravel	Solid	100-500 lb/l-m		$11-15/ton*		
	Pre-wet abrasives	Pre-wet solid	100-1000 lbs/l-m		$12-14/ton*		

Table 3. Summary of information on common issues, impacts, and benefits of abrasives used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Abrasives (sand, cinders, etc.)	Accumulate in stormwater inlets and pipes, need to sweep roads after snow/ice has melted, pitting of windshields and vehicle bodies from tire-projected particles, wearing or obstruction of mechanical parts on vehicles used for spreading.	Decrease air quality, by increasing PM10,can lead to air quality non-attainment issues.	Increase turbidity, decrease gravel and rock pore space leading to limited oxygen supply. Can alter stream and roadside habitat, and decrease aesthetics.	Will accumulate, and can serve as a reservoir for chlorides.	Can accumulate on foliage and in adjacent soils that contact the roots, potentially causing stress.	Particles less than 2mm in size can block the movement of oxygen into streambed gravel. Increased quantities of particles less than 6mm in size can smother macro-invertebrates and fish eggs.	Can potentially cause serious lung disease, and are listed as a carcinogen. Eye and throat irritant. Inhaled particulate matter may increase breathing difficulties.	Temporarily increase friction on the road surface. Abrasives are an inert material and have no de-icing capability unless a liquid or solid de-icing material is added.

Table 4. Summary of information on salt/sand commonly used in snow and ice control operations.

	Product Type	Liquid/solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Salt/Sand	salt/sand blends	solid/sand (Blended at 5-50% salt/sand)	400-1000 lbs/l-m	Typically used on roads with low traffic and lower LOS. In addition, useful on low volume roads near hills, curves, and intersections.	$18-24/ton (for 10% salt/sand)*	Provides temporary traction. The addition of chlorides improves workability, starts the melting process, and help keep abrasives on the road. Pre-wetted abrasives stay on the road surface longer and show great performance.	With the addition of any amount of chlorides to sand you must now apply all storage and handling practices that apply to chlorides (see below). *The additional clean up costs for abrasives should be considered in the purchase cost.

Table 5. Summary of information on common issues, impacts, and benefits of salt/sand used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Salt/sand blends	Accumulate in stormwater inlets and pipes, need to sweep roads after snow/ice has melted, pitting of windshields and vehicle bodies from tire-projected particles, wearing or obstruction of mechanical parts on vehicles used for spreading. The addition of chlorides increases corrosive potential, and increases impacts to soil, water, flora and fauna.	Decrease air quality, by increasing PM10,can lead to air quality non-attainment issues.	Increase turbidity, decrease gravel and rock pore space leading to limited oxygen supply. Can alter stream and roadside habitat, and decrease aesthetics. Cl, Na, Ca, and K ions easily go into solution, migrate, and can harden the water. Can cause density stratification in small receiving waters potentially causing anoxic conditions at depth. K and Ca can mobilize heavy metals.	Will accumulate, and can serve as a reservoir for chlorides. Cl, Ca, and K can mobilize heavy metals. Na can accumulate in soil and reduce soil permeability leading to increased soil density. Ca can increase soil permeability and aeration. Mg can increase soil stability and permeability. NaCl can reduce soil permeability and aeration and increasing overland flow, surface runoff, and erosion.	Can accumulate on foliage and in adjacent soils that contact the roots, potentially causing stress. Cl contact with foliage can cause leaf singe, browning, and senesce. Cl contact can lead to osmotic stress. MgCl2 and CaCl2 can cause damage to vegetation such as growth inhibition, scorched leaves, or even plant death. Salt tolerant species are recommended as roadside vegetation where Cl based deicers are used.	Abrasive particles less than 2mm in size can block the movement of oxygen into streambed gravel. Increased quantities of particles less than 6mm in size can smother macro-invertebrates and fish eggs. Cl have little to no impact when ingested unless at extremely elevated concentrations. Direct ingestion of salts by mammals and birds has caused behavior changes and toxicity. Concentrations of 250 mg/L have been shown to cause changes in aquatic community structures. Use of chlorides on roadways may lead to increased wildlife-vehicle collisions and reduced wildlife habitat by reducing plant cover or by causing shifts in plant communities.	Abrasives can potentially cause serious lung disease, and are listed as a carcinogen. Eye and throat irritant. Inhaled particulate matter may increase breathing difficulties. Chlorides are a skin and eye irritant. Can increase Cl, Ca, K, and Na concentrations. Consuming more than 1500 mg of Na per day can increase the risk of stroke, heart failure, kidney disease, osteoporosis, obesity, renal stones and stomach cancer. Drinking water with Na concentrations >20 mg/L can lead to hypertension. Anti-caking agents may contain cyanide, a known carcinogen.	Temporarily increase friction on the road surface. Abrasives with chloride added initiate de-icing, keep the material on road surface, and provide a higher LOS than abrasives alone.

Chlorides

Impacts of Chlorides

Field tests have shown that 20% to 63% of the sodium chloride (NaCl)-based deicers applied to highways in Sweden were carried through the air with 90% of them deposited within 65ft of the roadside (Blomqvist and Johansson, 1999). Chlorides are readily soluble in water and difficult to remove, thus concerns have been raised over their effects on water quality, aquatic organisms, and on human health (TRB, 1991; Environment Canada, 2010). The chloride salts applied on winter roads can migrate into nearby surface waters and impact them via various pathways. Generally, the highest salt concentrations in surface waters are associated with winter or spring thaw flushing events (Stevens, 2001; Ramakrishna and Viraraghavan, 2005).

In addition to direct influx of road runoff into surface waters, chloride salts applied on winter roads can also percolate through roadside soils and reach the water table, thus posing an environmental risk for groundwater (Defourny, 2000; Albright, 2005). Research has shown that 10% to 60% of the NaCl applied to roads enters shallow subsurface waters and accumulates until steady-state concentrations are attained (Environment Canada, 2010). Improper salt storage has caused problems with well water and reservoir concentrations. Wells most likely to be affected are generally within 100 feet down-gradient of the roadway in the direction of groundwater movement (TRB, 1991). Watson et al. (2002) reported that Cl concentrations exceeded the US EPA secondary maximum contaminant level of 250 mg/L for drinking water (US EPA, 2006) at seven wells down gradient from the highway during late winter, spring, and summer samplings. The chloride limit was exceeded only in water from wells with total depth less than about 10 ft below the land surface. Sodium concentrations in water periodically exceeded the US EPA drinking-water equivalency level of 20 mg/L in both the uppermost (deicer affected) and lower one-third of the aquifer.

Salt and other chloride-based deicers can pose an environmental risk for soils, as the salt concentrations in roadside soils have been found to positively correlate with the rate of salt application (Jones et al., 1992). Cunningham et al. (2008) found that in an urban environment, magnesium (from magnesium chloride ($MgCl_2$) deicer application), was most abundant in soils adjacent to roadways even though NaCl was the most frequently used deicer. The sodium was found to rapidly leach from the soil, decreasing toxicity to plants but increasing input to adjacent waterways. Green et al. (2008) found the use of chloride-based deicers affects ammonification, possibly by increasing soil pH and by nitrification in roadside soils. The elevated sodium concentration in soil tends to displace naturally occurring calcium and magnesium, and disperse the organic and inorganic particles in the soil pores, reducing soil permeability and aeration and increasing overland flow, surface runoff, and erosion (Public Sector Consultants, 1993; Defourny, 2000; Fischel, 2001; Ramakrishna and Viraraghavan, 2005; Nelson et al., 2009; Environment Canada, 2010).

Salt and other chloride-based deicers can have detrimental effects on plants, in particular, roadside vegetation (Nevada DOT, 1990; Bäckman and Folkeson, 1996; Fischel, 2001; Wegner and Yaggi, 2001; Environment Canada, 2004; Cekstere et al., 2008; Trahan and Peterson, 2008; Munck et al., 2010). Roth and Wall (1976) suggested that roadside vegetation is subject to environmental stress and the elevated salt concentrations “can only further impair natural balances and accentuate this stress.” Road salt exposure due to spray within 33 to 65 ft of the road was demonstrated to cause a greater severity of foliar (leaf) damage than uptake through the soil alone (Viskari and Karenlampi, 2000; Bryson and Barker, 2002). Many studies have indicated that needle necrosis, twig dieback, and bud kill are associated with areas of heavy road salt usage, with trees and foliage down wind and facing the roadside are more heavily affected than trees further away (Sucoff et al., 1976; Pederson et al., 2000). Shrubs and grasses in general can tolerate increased NaCl concentrations better than trees (Sucoff, 1975). A study performed in Massachusetts evaluated the impacts of NaCl on vegetation near roadways (Bryson and Barker, 2002). Of the species tested, pines and sumacs had the most widespread, severe damage while grasses, ferns, maples and oaks were tolerant of high salt concentrations. Sodium concentrations in damaged pine needles were about 75 times as high as those in healthy pine needles. The highest sodium concentrations associated with pine needles and maple leaves was 3356 mg/kg and 249 mg/kg, respectively at 10 ft from the road. Similar to NaCl, $MgCl_2$ and calcium chloride ($CaCl_2$) can cause damage to vegetation such as growth inhibition, scorched leaves, or even plant death (TRB, 1991; Public Sector Consultants, 1993; Trahan and Peterson, 2008). Field and greenhouse studies have found direct application of $MgCl_2$ to be more damaging to plant foliage than NaCl, causing decreased photosynthesis rates on exposed foliage adjacent to roadways (Trahan and Peterson, 2008). In wetlands with elevated deicer concentrations, a decrease in plant community richness, evenness, cover, and species abundances has been observed (Richburg et al., 2001). In wetlands specifically, reducing and/or halting deicer treatment can allow for native plant recovery after multiple water years, but this includes the re-introduction of non-native species as well (TRB, 1991; Moore et al., 1999).

Road salt may accumulate on the side of roadways following deicer applications and during spring as snow melts; in areas with few natural salt sources, this could attract deer and other wildlife to the road network (Bruinderink and Hazebroek, 1996). The presence of wildlife on roadways to glean deicing salts has led to increased incidents of wildlife-vehicle collisions (Forman et al., 2003). Chloride salts used for snow and ice control generally pose minor impacts on fauna, since it is rare for their concentrations in the environment to exceed the tolerance level of animals (TRB, 1991; Jones et al., 1992; Lewis, 1999; Silver et al., 2009). Nonetheless, ingestions of road salts have been associated with mammalian and avian behavioral and toxicological effects (Forman et al., 2003). Additionally, road salts may reduce wildlife habitat by reducing plant cover or by causing shifts in plant communities - in effect, decreasing food sources and/or shelter (Environment Canada, 2010). Field data and modeling of the effects of road salt on vernal-pool-breeding amphibian species found that embryonic and larval survival was reduced with increasing conductivity[1]. The negative effects varied as a function of the larval density and the distance from the road, with the greatest impacts occurring within 150 ft of the road (Karrker et al., 2008).

A summary of information on chlorides can be found in Table 6 and Table 7.

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[1] Conductivity increases with increasing ion concentrations. Chloride (Cl^-), from NaCl (salt), $MgCl_2$, or $CaCl_2$ snow and ice control products, is a common ion that can cause an increase in conductivity if present at high enough concentrations.

Table 6. Summary of information on chloride based products commonly used in snow and ice control operations.

<table>
<tr><th></th><th>Product Type</th><th>Liquid/solid</th><th>Application rate</th><th>Conditions and pavement temperature ranges</th><th>Cost</th><th>Performance</th><th>Storage and Handling Needs</th></tr>
<tr><td rowspan="4">Chlorides</td><td rowspan="2">NaCl</td><td>Solid</td><td>100-800 lb/l-m</td><td rowspan="2">32 to 15°F; Pretreatment or anti-icing is not recommended if blowing snow or rain are predicted or are occurring.</td><td>$30-100/ton</td><td rowspan="2">NaCl is commonly used for deicing (rock salt), anti-icing and pre-wetting (salt brine).</td><td rowspan="4">Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site.
Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.</td></tr>
<tr><td>Liquid</td><td>10-40 gal/l-m (anti-icing); 8-20 gal/l-m (pre-wetting)</td><td>$0.04-0.09/gal</td></tr>
<tr><td rowspan="2">$MgCl_2$ and $CaCl_2$</td><td>Solid</td><td>100-500 lbs/l-m</td><td rowspan="2">The effective temperature for $MgCl_2$ and $CaCl_2$ are 32 to -5°F and 32 to -15°F, respectively. Pretreatment or anti-icing is not recommended if blowing snow or rain are predicted or are occurring.</td><td rowspan="2">$MgCl_2$:$100/ton; $MgCl_2$: $0.50-0.90/gal; $CaCl_2$: $120-300/ton</td><td rowspan="2">$CaCl_2$ and $MgCl_2$ work at colder temperatures than NaCl. At low relative humidity, their residue on roads can attract moisture, which can result in slippery conditions under certain circumstances.</td></tr>
<tr><td>Liquid</td><td>10-40 gal/l-m (anti-icing); 8-20 gal/l-m (pre-wetting); DLA 50-70 gal/l-m</td></tr>
</table>

Table 7. Summary of information on common issues, impacts, and benefits of chloride based products used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Chlorides (NaCl, $MgCl_2$, $CaCl_2$)	Very corrosive to vehicles and roadway metal infrastructure (signal, sign and lighting poles, bidge super structure, guardrails, etc.), very caustic to skin and certain clothing (leather gloves, footwear), and know impacts to water, soil, and flora and fauna. Chlorides can cause physical deterioration to pavement materials via salt scaling, chemical reactions, and aggrevating aggregate-cement reactions ($MgCl_2$ dissolving limestone).	Can be converted to Cl radicals by UV and these free radicals may affect the ozone layer.	Cl, Na, Ca, and K ions easily go into solution, migrate, and can harden the water. Can cause density stratification in small receiving waters potentially causing anoxic conditions at depth. K and Ca can mobilize heavy metals.	Cl, Ca, and K can mobilize heavy metals. Na can accumulate in soil and reduce soil permeability leading to increased soil density. Ca can increase soil permeability and aeration. Mg can increase soil stability and permeability. NaCl can reduce soil permeability and aeration and increasing overland flow, surface runoff, and erosion.	Cl contact with foliage can cause leaf singe, browning, and senesce. Cl contact can lead to osmotic stress. $MgCl_2$ and $CaCl_2$ can cause damage to vegetation such as growth inhibition, scorched leaves, or even plant death. Salt tolerant species are recommended as roadside vegetation where Cl based deicers are used.	Cl have little to no impact when ingested unless at extremely elevated concentrations. Direct ingestion of salts by mammals and birds has caused behavior changes and toxicity. Concentrations of 250 mg/L have been shown to cause changes in aquatic community structures. Use of chlorides on roadways may lead to increased wildlife-vehicle collisions and reduced wildlife habitat by reducing plant cover or by causing shifts in plant communities.	Skin and eye irritant. Can increase Cl, Ca, K, and Na concentrations. Consuming more than 1500 mg of Na per day can increase the risk of stroke, heart failure, kidney disease, osteoporosis, obesity, renal stones and stomach cancer. Drinking water with Na concentrations >20 mg/L can lead to hypertension. Anti-caking agents may contain cyanide, a known carcinogen.	A 15% reduction in product usage was reported when brine was used to pre-wet salt. The use of liquid brine for deicing was reported to have produced approximately 50% materials savings as compared to the use of solid rock salt.

Acetates and Formates

Impacts of Acetates and Formates

The high cost of acetates (potassium acetate (KAc), calcium magnesium acetate (CMA), and sodium acetate (NaAc)) and formates (sodium formate (NaFm) and potassium formate (KFm)) have hindered their wider application by highway agencies (Vitaliano, 1992; Cheng and Guthrie, 1998; Fischel, 2001; Keating, 2001). Testing of soil, vegetation, and streams on the North Island of New Zealand where CMA was used for both anti-icing and deicing had shown no negative impacts (Burkett and Gurr, 2004). CMA generally works as a deicer similar to NaCl, yet it can require 50% more by weight than NaCl to achieve the same results (Wegner and Yaggi, 2001). Relative to NaCl, CMA is “slower acting and less effective in freezing rain, drier snowstorms, and light-traffic conditions” (Ramakrishna and Viraraghavan, 2005). Other disadvantages of CMA include the air quality impacts and poor performance in thick accumulations of snow and ice and in temperatures below 23°F. Field reports suggest that CMA requires about 30% more material and does not work well below 20°F (personal communication, P. Brown, March 2015).

The most pronounced environmental issue associated with acetate-based deicers is the biochemical oxygen demand (BOD) increase that reduces available oxygen for organisms in the soil and aquatic environments (LaPerriere and Rea, 1989; Fischel, 2001). The acetate ion happens to be the most abundant organic acid metabolite in nature, and its biodegradation could lead to anaerobic soil conditions or localized dissolved oxygen (DO) depletion in surface waters (TRB, 1991; D’Itri, 1992; Horner and Brenner, 1992; Defourny, 2000). Data pertaining to a NaAc/NaFm-based deicer suggests that during the spring thaw runoff, short periods of oxygen depletion in receiving waters may occur, with potential danger in warmer weather (Bang and Johnston, 1998). Multiple studies have found KFm to cause no undesirable changes in the groundwater chemistry, owing to biodegradation in topsoil (Hellsten et al., 2005a; 2005b). An aquifer scale study on the fate of KFm found KFm to be easily biodegraded at low temperatures (28 to 43 °F (-2 to 6 °C)) in soil microcosms, whereas chloride ions from deicing products used in previous winters had accumulated in the aquifer (Hellsten et al., 2005b).

The effect of acetate-based deicers on plants can vary depending on the type of plant and the concentration present. For Kentucky bluegrass, red fescue grass, barley, and cress, it was found that CMA was less toxic than both NaFm and NaCl, which were of equal toxicity (Robidoux and Delisle, 2001). CMA can enhance plant growth by improving soil permeability and providing needed calcium and magnesium as nutrients, which may be a valuable characteristic in areas where heavy salt use has resulted in soil compaction (Fritzsche, 1992). A NaAc/NaFm-based deicer has been demonstrated to have positive impacts on pine and sunflower growth, acting as a fertilizer at concentrations of ~0.5 g/kg (or 500 mg/kg = 500 ppm) of soil. At higher concentrations of 4 g/kg, detrimental effects have been observed including low germination rates, low biomass yield, lateral stem growth, suppressed apical meristem growth, browning of leaves/needles, and senescence (Bang and Johnston, 1998). KFm concentrations less than 4 kg/m^2 were found to have detrimental effects on vegetation (Hellsten et al., 2005a).

There are also mixed effects of acetate-based deicers on animals. In general, CMA has low aquatic toxicity while KAc and NaAc have greater aquatic toxicity (Fischel, 2001). A NaAc/NaFm-based deicer was reported to cause apparent fish disorientation, concave abdomen and spinal curvature, observed gill distention, and death (Bang and Johnston, 1998). Acetates and formates have been shown to promote bacteria and algae growth (LaPerriere and Rea, 1989; Bang and Johnston, 1998). For the invertebrate *Eisenia fetida*, CMA was found to be less toxic than NaFm or NaCl, which were of equal toxicity (Robidoux and Delisle, 2001).

A summary of information on acetates can be found in Table 8 and Table 9, and formates in Table 10 and Table 11.

Table 8. Summary of information on acetate based products commonly used in snow and ice control operations.

	Product Type	Liquid/solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Acetates	NaAc (Sodium acetate)	Solid/liquid	Near 32°F (thin ice) = 190-320 lbs/l-m; 10°F (1 inch ice) = 600-1500 lbs/l-m	Working temperature down to 0°F. Commonly used at airports and many parking garages.	$1000-1500/ton	Contains no chlorides. Excellent melting properties, works faster at and at lower temperatures than NaCl.	Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site. Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.
	CMA (Calcium magnesium acetate)	Solid/liquid	250-400 lbs/l-m; heavier initial application, lighter as the storm continues.	Working temperature down to 0°F. CMA does not work well below 20°F.	$600-2000/ton	CMA performs similar to NaCl, but requires 30 - 50% more by weight than NaCl to achieve the same results. Relative to NaCl, CMA is considered slower acting and less effective in freezing rain and light-traffic conditions. CMA can be used straightly or in combination with salt and sand.	
	KAc (Potassium acetate)	Solid/liquid	60-80 gal/l-m (de-icing); 25-60 gal/l-m (anti-icing)	32 to -26°F; performs quicker than CMA at lower temperatures. Commonly used at airports.	$600-1200/ton	KAc works in quickly, quicker than glycols and less slippery.	

Table 9. Summary of information on common issues, impacts, and benefits of acetate based products used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Acetates (NaAc, CMA, Kac)	Can cause elevated BOD in waters.	Overall low impact including deicer aerosols.	Can leach heavy metals. Can exert a high BOD, can cause oxygen depletion. Can increase turbidity and hardness of water. K can cause eutrophication of water.	Ca and Mg can mobilize heavy metals, increase soil stability, and permeability. CMA degradation may increase soil pH.	Few effects have been observed. At low concentrations acts as a fertilizer, at elevated concentrations detrimental effects have been observed including low germination rates, low biomass yield, lateral stem growth, suppressed apical meristem growth, browning of leaves/needles, and senescence.	Can exert a high BOD which may cause anoxic conditions in aquatic environments. KAc and NaAc appear to be more toxic than CMA. Can promote bacteria and algae growth.	Skin and eye irritant. Ca and Mg can increase water hardness.	CMA can enhance plant growth by improving soil permeability and acts as a source for needed calcium and magnesium as nutrients, which may be a valuable characteristic in areas where heavy salt use has resulted in soil compaction. A NaAc/NaFm-based deicer has been demonstrated to have positive impacts on pine and sunflower growth, acting as a fertilizer at concentrations of ~0.5 g/kg (or 500 mg/kg = 500 ppm) of soil.

Table 10. Summary of information on formate based products commonly used in snow and ice control operations.

	Product Type	Liquid/solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Formates	NaFm (Sodium formate)	Solid/Liquid	Near 32°F (thin ice) = 125-250 lbs/l-m; 10°F (1 inch ice) = 400-1000 lbs/l-m	Working temperature is effective down to 0˚F. Commonly used at airports.	\$200-350/ton	Fast-acting	Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site. Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.
	KFm (Potassium formate)	Solid/Liquid		Working temperature is below -58°F. Commonly used at airports.	\$1000-1600/ton	KFm is efficient at de-icing.	

Table 11. Summary of information on common issues, impacts, and benefits of formate based products used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Formates (NaFm, KFm)	Can cause elevated BOD in waters.	Overall low impact including deicer aerosols.	Can leach heavy metals. Can exert a high BOD, can cause oxygen depletion. Can increase turbidity and hardness of water. K can cause eutrophication of water.	Ca and Mg can mobilize heavy metals, increase soil stability, and permeability. CMA degradation may increase soil pH.	Few effects have been observed. At low concentrations acts as a fertilizer, at elevated concentrations detrimental effects have been observed including low germination rates, low biomass yield, lateral stem growth, suppressed apical meristem growth, browning of leaves/needles, and senescence.	Can exert a high BOD which may cause anoxic conditions in aquatic environments. KAc and NaAc appear to be more toxic than CMA. Can promote bacteria and algae growth.	Skin and eye irritant. Ca and Mg can increase water hardness.	A NaAc/NaFm-based deicer has been demonstrated to have positive impacts on pine and sunflower growth, acting as a fertilizer at concentrations of ~0.5 g/kg (or 500 mg/kg = 500 ppm) of soil.

Glycol and Glycerin

Impacts of glycols and glycerin

The environmental issues associated with glycol-based deicers are increased BOD and carcinogenic effects to stream fauna. Glycol-based anti-icing fluids used at airports are far more toxic to aquatic organisms than glycols used as roadway deicers (Kent et al., 1999), possibly due to the concentrations being used. Ethylene and propylene glycols increase the BOD of receiving waters, with propylene glycol exerting a higher BOD (U.S. Navy, 2010). Ethylene and propylene glycol deicers have endocrine disrupting properties, and this may be attributed to additives in the products (Corsi et al., 2006). Ethylene glycol is acutely toxic to mammals and occasionally has led to the death of animals following large consumption. When ingested, ethylene glycol depresses the central nervous system and can be fatal to humans even in small quantities, whereas propylene glycol is essentially non-toxic. Glycols have been shown to inhibit plant growth, but only slightly more than salt (Kawasaki et al., 1983). Hartwell et al. (1995) found ethylene glycol to feature high degradation rates by aerobic microorganisms with low bioaccumulation potential. They also found ethylene glycol to feature low adsorption potential by soil particles and thus high mobility in soil.

Similar to the glycolic type of polyhydric alcohols used as deicers, glycerin (also called glycerol or glycerine) is also an effective anti-freezing agent. Glycerin has a relatively low freezing point when mixed with water (Chauhan et al., 2012), and is often used as an anti-freeze or ice-inhibiting constituent (Kormann, 1937; Keenoy, 1941). Contrary to some glycols (e.g., propylene glycol) glycerin is less expensive and has the advantage of being an anti-caking agent and can enhance melting. It has been discovered that glycerin added in a small percentage as an exterior coating will decrease the caking of salt in both bulk storage and bag storage, and will increase the ice melting (Ossian, 2007; Ossian, 2012).

Generally glycerin deicers are less toxic than chloride deicers due to the inherent non-toxic property of glycerin. For instance, glycerin deicers have minimal adverse influence on receiving soil structure and permeability, and some components of glycerin (e.g. carbon (C) and nitrogen (N)) can be absorbed by vegetation (Wang et al., 2014). However, glycerin may be slightly harmful to some species of animal and plant under certain conditions. It was reported that glycerin has multiple effects on plant cell metabolism (Aubert et al., 1994) and could inhibit the activity of some enzymes at elevated concentrations, especially for organisms which are not salt tolerant (Heimer, 1973). If glycerin were ingested by an animal, potential impacts may include hemolysis, hemoglobinuria, renal failure, fatty liver, and convulsion (Tao et al., 1983). For fish glycerin is a contraceptive and has an adverse consequence on the fertility (Alvarenga et al, 2005). The cellular effects caused by glycerin include changes in cytoplasmic events due to increased viscosity by intracellular glycerol, altered polymerization of tubulin, alteration of microtubule association, effects on bioenergetic balances, and direct alteration of the plasma membrane and glycocalyx (Hammerstedt and Graham, 1992).

A summary of information on glycols can be found in Table 12 and Table 13, and for glycerin in Table 14 and Table 15.

Table 12. Summary of information on glycol based products commonly used in snow and ice control operations.

	Product Type	Liquid/ solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Glycols	Ethylene glycol	Liquid	50-2000 gal/l-m (at 55% or 45% glycol concentration)	Propylene glycols work down to -74°F. Commonly used to deice aircrafts. Depending on their intended application may contain thickeners and additives such as corrosion inhibitors and surfactants.	$14-40/gal	Very effective at deicing	Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site. Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. : Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.
	Propylene glycol	Liquid			$10-20/gal		

Table 13. Summary of information on common issues, impacts, and benefits of glycol based products used in snow and ice control operations.

	Impacts						Quantified benefits
	Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Glycols	Overall low impact including deicer aerosols.	Can increase BOD to a greater extent than any other deicer. Readily biodegrades. Degrades in water faster than additives. Additives can be toxic.	Readily biodegrades. Propylene glycol degradation may reduce hydraulic conductivity in anaerobic soils. Ethylene glycol features high degradation rates by aerobic microorganisms, low bioaccumulation potential, and low adsorption potential by soil particles and thus high mobility in soil.	Glycol can inhibit plant growth.	Ethylene glycol is acutely toxic to mammals and occasionally has led to the death of animals following large consumption.	When ingested, propylene glycol is essentially non-toxic. When ingested, ethylene glycol depresses the central nervous system and can be fatal to humans even in small quantities. A known endocrine disrupter.	Preliminary research has shown the addition of glycerol and glycerin to salt brine will enhance anti-icing performance at cold temperature to the level comparable to $MgCl_2$ or KAc at reasonable costs, while producing substantial savings through reduced application rates, reduced corrosion to metals, and reduced impact on concrete or asphalt materials. For example, the blend of 80% glycerol with 20% NaCl showed promise in laboratory performance with comparatively low negative impacts.

Table 14. Summary of information on glycerin based products commonly used in snow and ice control operations.

	Liquid/ solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Glycerin	Liquid	Application rates vary depending on blended ratio	Glycerin has a relatively low freezing point when mixed with water and is often used as an anti-freeze or ice-inhibiting constituent.	$10-30/gal	Glycerin has a low freezing point when mixed with water, is used as anti-freeze or ice-inhibiting additive. Glycerin is less expensive than glycols and is an anti-caking agent. Glycerin added in a small percentage as an exterior coating will decrease the caking of salt in both bulk storage or bag storage.	Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site. Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.

Table 15. Summary of information on common issues, impacts, and benefits of glycerin based products used in snow and ice control operations.

	Impacts						Quantified benefits
	Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Glycerin	Overall low impact including deicer aerosols.	Reduce BOD and COD.	Glycerin deicers have minimal adverse influence on soil structure and permeability.	Glycerin has multiple effects on plant cell metabolism and can inhibit the activity of some enzymes at elevated concentrations, especially for organisms which are not salt tolerant. Some components of glycerin (e.g. carbon (C) and nitrogen (N)) can be absorbed by vegetation.	For fish glycerin is a contraceptive and has an adverse consequence on the fertility. If glycerin were ingested by animal species, potential impacts may include hemolysis, hemoglobinuria, renal failure, fatty liver, convulsion, and even death. Ethylene and propylene glycol deicers have endocrine disrupting properties.	May cause tissue dehydration, and reduced cerebrospinal fluid pressure. A slight diuresis from a single dose of 1.5g/kg or less. Mild skin irritant. May cause stinging of the eyes. High dose consumption can lead to temporary neurological issues and seizures.	Preliminary research has shown the addition of glycerol and glycerin to salt brine will enhance anti-icing performance at cold temperature to the level comparable to $MgCl_2$ or KAc at reasonable costs, while producing substantial savings through reduced application rates, reduced corrosion to metals, and reduced impact on concrete or asphalt materials. For example, the blend of 80% glycerol with 20% NaCl showed promise in laboratory performance with comparatively low negative impacts.

Organically derived or Ag-based Products

Impacts of organically derived or ag-based product

The common agro-based products are proprietary and generally contain chloride salts and low molecular weight carbohydrates. There are user concerns over possible attraction to wildlife. The deployment of agro-based products has been hindered by concerns over their toxicity to the aquatic ecosystems adjacent to highways (because of localized DO depletion from high phosphate, nitrate, or total organic contents), high cost, and quality control issues. The breakdown of organic materials can also lead to temporary anaerobic soil conditions. Phosphorus from deicers is usually introduced into the environment in concentrations of 14 to 26 ppm, and it spurs the growth of algae, thus reducing DO for other aquatic biota (Fischel, 2001). Algae growth may be spurred by critical levels of dissolved phosphorus as low as 20 ppb (Staples et al., 2004). The CDOT has set standards for phosphorus in magnesium-chloride-based deicers at 25 mg/L or less. Water quality standards can be set at lower limits than this. Michigan, for instance, has set a phosphorus limit in water at 1 ppm from point discharges (Public Sector Consultants, 1993).

A summary of information on organically derived or ag-based products can be found in Table 16 and Table 17.

Table 16. Summary of information on organically derived and or ag-based products commonly used in snow and ice control operations.

	Product Type	Liquid/solid	Application rate	Conditions and pavement temperature ranges	Cost	Performance	Storage and Handling Needs
Organically derived/ag-based	Corn syrup, corn steeps, and other corn derivatives; Beet juice; lignin/lignosulfonate; molasses; brewers/distillers by-product	Solid/Liquid	Application rates vary depending on blended ratio	Used as additives; mixed with solids, liquids and abrasives to improve performance. There is evidence to suggest these products reduce the freezing point.	Corn syrup: $12-35/ton; corn steeps: $156-192/ton; Cane Molasses: $345/ton Distillers grain: $95-140/ton	Reduces deicer corrosiveness and enhances longevity of deicer treatments on the road when used as an additive.	Solid material - Should be stored inside on a non-permeable surface. Loading should occur inside the building or on a non-permeable pad. Any spilled material should be cleaned up as soon as is possible. The storage building and loading pad should drain to a water collection pond, or have secondary containment to prevent the loss of material off site. Liquids - Should be stored in tanks, ideally double walled, inside or outside on a non-permeable pad. Isolation values are recommended when multiple liquid tanks are plumbed together. Pads should drain to a water collection pond. All storage tanks should have secondary containment at least large enough to retain 110% volume of the largest tank. Spilled material should be cleaned as soon as is possible.

Table 17. Summary of information on common issues, impacts, and benefits of organically derived and or ag-based products used in snow and ice control operations.

	Common Issues	Impacts						Quantified benefits
		Air	Surface and Ground Water	Soil	Vegetation	Fauna	Human	
Organically derived/ag-based	Clogging of equipment has occurred if not filtered.	Overall low impact including deicer aerosols.	Can cause temporary oxygen depletion in surface waters. Can contaminate water by nitrates. Localized DO depletion could occur from high phosphate, nitrate, or total organic contents. Phosphorus from deicers is usually introduced into the environment in concentrations of 14 to 26ppm, and it spurs the growth of algae, thus reducing DO for other aquatic biota. Algae growth may be spurred by critical levels of dissolved phosphorus as low as 20ppb.	May acidify the soil or cause leaching of metals into surrounding waters. Can cause temporary anaerobic soil conditions. The breakdown of organic matter may lead to temporary anaerobic soil conditions.	N/A	N/A	N/A	Reduces corrosion rates for chloride based products.

Facility Management

The design and operation of maintenance facilities can have a direct influence on potential contamination issues and loss of materials. Maintenance facilities may be specific to winter maintenance operations or be a central location for various maintenance activities. This section will cover material storage, loading, and handling; securing stockpiles, and yard and drain cleaning.

Material Storage

Proper storage of snow and ice control materials is a key component of managing an efficient and environmentally sensitive winter maintenance program. Effective storage practices save material from being lost to erosion, keep the material workable, and prevent it from leaving the site as runoff and impacting the surrounding soil, plants, ground and surface water (Salt Institute, 2013; TAC, 2013). Wind can blow material off piles and off site, and rain can cause a loss of 0.25% of a salt pile per annual inch of precipitation (US EPA, 1974). At the same time, snow and ice control product storage facilities have the greatest potential to impact the environment, because they are a single source that can release high concentration runoff into the environment (OWRC, 2012). The potential environmental impacts of these products decrease as they are applied to roadways, because the material is widely distributed across the driving lanes and over many miles, and the runoff can be further diluted by snow and ice (OWRC, 2012).

Best practices for snow and ice control material storage have been discussed and documented since the mid1970s. As early as 1974, the US EPA's *Manual of Deicing Chemicals: Storage and Handling* included the following recommendations:

- Covered storage of salt and other deicing chemicals is strongly recommended using permanent structures.
- General precautions and good housekeeping practices should be used.
- Personnel who administer and supervise highway maintenance should be knowledgeable of their environmental responsibilities.

State DOTs have had access to material storage best practices for over 40 years. In a survey conducted for this project, 97% of respondents stated that they stored salt or salt/sand mix on paved surface inside a covered structure. Just over 15% of respondents also state that they stored salt or salt/sand mix on an impermeable paved surface and covered with a tarp, and one respondent stores material on a permeable unpaved surface and uncovered. While slightly better, this echoes the results of a recent survey results for an Ohio DOT research project on salt storage facilities which found that 3 to 75% (26% median value) of inventoried salt storage facilities used by state DOTs and counties are still uncovered, and may also be on unsealed pads, or have insufficient covering (Walsh et al., 2014). Clearly, there is still a need to present and disseminate best practices on material storage. If all snow and ice control materials were stored using known best practices, contamination of surface and ground water from storage sites could be significantly reduced if not eliminated. A case study on The Stockpile Academy developed by PennDOT , which has been sharing best practices on material storage and good housekeeping for over a decade, and a second case study presenting information on Kansas DOT material storage and good housekeeping practices can be found in Appendix D Case Studies.

Solids Storage

There are many options for material storage, which range in their ability to prevent material loss as well as in price. Options include bins, pads, traditional domes, rectangular sheds or barns, high arch structures, and silos, which may be constructed from wood, steel, aluminum, fiberglass, concrete, or fabric (TAC, 2013). The Salt Institute (2013) is a reference guide for information on pile size and storage capacity of buildings, loading and storage styles, and techniques. The Ohio Water Resources Council (2012) created a table of pros and cons of common salt storage facilities in Ohio (Table 18).

Table 18. Salt storage facilities Pros and Cons (the more + the better) (OWRC, 2012).

	Affordable	Accessible	Strong	Durable	**Effective in preventing runoff**
Any structure without an impervious base and/or sidewall. 	+++	++	+	+	++
Any roof type on 3-sided impervious concrete base. 	++	+++	++	++	+++
Any 4-sided or dome structure on an impervious concrete base. 	+	+	+++	++	++++

The Ohio Water Resources Council (2012) recommends storing salt in structures with an impervious wall at least three feet high, or one foot higher than the salt contact zone, because they provide the most environmental protection. The walls should be free of gaps or cracks and sealed. The Wisconsin DOT (2013) requires salt-sand mixtures (defined as 5% salt or less) to be covered only from April 1 – October 1. Wisconsin DOT does not have any construction specifications for salt storage buildings, as long as the building has an impermeable pad and water proof covering.

Some practical considerations include: noting the prevailing winter wind direction and positioning building and doors with regard to sheltering loading operations, minimizing snow drifting around doorways, and keeping precipitation out of the storage areas (TAC, 2003). The

Stockpile Academy used by PennDOT uses the 10 ft rule, stating all material should be stored in building and set back at a minimum of 10 ft from any entry and exit points. When not in use, the front end of the pile facing out should also be covered by tarp, held down by sand bags (personal communication D. Jordan, February 23, 2015).

Other best practices include promoting indoor operation of all snow and ice control material handing activities where possible (OWRC, 2012; TAC, 2013), and routine storage facility maintenance including checking for roof leaks, tears, or damage and repairing them in a timely manner (OWRC, 2012). Good housekeeping practices are extensively covered in the Stockpile Academy training course. In addition to above mentioned best practices, the Stockpile Academy utilizes a quarterly assessment of each site by the site manager, and an annual assessment by a third party. This ensures that issues are addressed in a timely manner (personal communication D. Jordan, February 23, 2015). Note that salt and salt-sand blends - even mixes with relatively low salt concentration (20/1 or 10/1), need to be kept under cover and on an impervious surface.

Liquid storage

Spillage of liquid snow and ice control products can occur during production, delivery, and transfer to the spreader (TAC, 2013), and in storage if hoses and fittings break. Designers should consult with local environmental regulatory authorities regarding siting and containment requirements for liquid storage facilities (TAC, 2013). Liquid storage tanks should be protected from vehicle impacts, UV exposure (if possible), and should be installed with secondary containment around the storage tanks and liquid transfer point (TAC, 2013). Secondary containment for liquid storage tanks may consist of double-walled tanks and/or containment dikes (Michigan DEQ, 2007; TAC, 2013); however, double-walled tanks will not protect against leaks from broken fittings or hoses. Recommended secondary containment capacities are in the range of 100 – 125% of the capacity of the largest tank, or 10% of total tank capacity (Michigan DEQ, 2007; TAC, 2013). All valves, hoses, and pumps should be located within the secondary containment. A summary of secondary containment options for liquid deicer storage tanks is provided in Table 19 (Purdue, 2009; Oregon DOT, 2012). Note that all relief valves in secondary containment structures need to be kept closed except when releasing or collecting rainwater.

Results from a survey conducted for this project found that most agencies store liquid products above ground in tanks that the majority (52%) have secondary containment for some tanks but not all, while only 22% had secondary containment for all.

Table 19. Secondary containment options for liquid storage tanks (modified from Oregon DOT, 2012).

<table>
<tr><th colspan="4">Secondary Containment type</th></tr>
<tr><th></th><th>Bunker</th><th>Berm</th><th>Building</th></tr>
<tr><td>Description</td><td>4-sided concrete box with impervious surface. May have a drain valve to release water or a manual pump. Sealant used at joints.</td><td>A barrier that stops or slows movement of deicers out of the a defined area. May have a drain to release water.</td><td>Covered structure that does not allow deicers to flow out. Floor drain flows to a dead end sump, closed valve, or sanitary sewer. Buildings that do not confine spilled product do not provide secondary containment.</td></tr>
<tr><td>Materials</td><td>Concrete with rebar, eco-blocks, etc.</td><td>Compacted soil, grindings, sealed concrete</td><td>Building materials</td></tr>
<tr><td>Size</td><td>Moderate
Increase capacity by adding height.
Example for two 10,500 gal tanks:
• 15 x 30 x 5 ft or
• 14 x 36 x 4 ft or
• 18 x 32 x 3.5 ft</td><td>Large
Berms may be 2-3 ft high, slope 1:2 to 1:3. Size depends on slope of containment area.
Increase capacity by making wider or longer. Example for two 10,500 gal tanks:
• 50 x 25 x 2.5 ft or
• 85 x 25 x 1.5 ft</td><td>Moderate
Sizing is similar to bunker.
A portion of an existing building can be used.</td></tr>
<tr><td>Relative Cost</td><td>High
Cost depends on size, site conditions and location, material costs, and work to be done.
May require pumps or values to remove ponded water.</td><td>Low
Berms can be made with materials on hand.
Pump of valve may be required to remove ponded water.
Will require some type of sealant to make water tight.</td><td>Low
Modified existing structure by creating curbs or using a sump.
Or
High
New construction of a storage building.</td></tr>
<tr><td>Operations Issues</td><td>Frequent release of ponded stormwater at some sites.
Drain valves must be kept closed.
May develop cracks.
Seams or joints may leak and require maintenance.
Ponded water reduces containment capacity.</td><td>May provide containment for other products.
Frequent release of ponded stormwater at some sites.
Wall may fail, erode or develop cracks.
Inadequate sealing may allow spills to occur.
Ponded water reduces containment capacity.</td><td>Limit traffic movement.
Shelters employees from weather.
May provide containment for other products.
Inadequate sealing may allow spills to occur.
Spills may be release when entering the building.</td></tr>
<tr><td>Benefits</td><td>Impact protection
If tie downs are used protects from wind and seismic issues.
Provides ground water and soil protection.</td><td>Vary based on design.</td><td>Reduce sun (UV damage).
Impact protection.
Limits vandalism.
Provides ground water and soil protection.</td></tr>
</table>

Liquid products should be stored in well-maintained and labeled storage tanks (OWRC, 2012). Scheduled maintenance should be performed for all tanks fittings, valves, and pumps, and any leaks should be addressed in a timely manner. Example forms created by Oregon DOT for liquid storage poly tank inventory and inspection can be found in Appendix E. Poly Tank Inventory and Inspection Forms (Oregon DOT, 2012), and full description of terminology can be found in Purdue (2009) and Oregon DOT (2012). A case study of successful brine storage by Virginia DOT is presented in Appendix D Case Studies.

Material Loading and Handling

The following recommendations on material loading and handling were developed by Venner (2004) and are very relevant today.

- Sand and both solid and liquid snow and ice control products should be handled in a manner to minimize any contamination of surface or ground water. Care should be taken to prevent runoff from tanks. Covered handling for dry products is preferred.
- Liquid and solid products and sanding materials should be free of contaminants known to cause water quality problems. Some of these include: arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, other heavy metals, hydrocarbons. The Pacific Northwest Snowfighters provide a Qualified Product List which requires additional testing and reporting by product vendors beyond what is required on MDSS forms. (http://pnsassociation.org/)
- Extensive environmental contamination has been identified in the area of salt storage yards. Much of this contamination results from poor salt handling practices.

<u>Material loading, storage, and mixing</u>

- Conveyors are available which are designed to allow salt trailers to dump directly into the conveyor for movement into the storage facility. Conveyers should be used to fill salt domes.
- Loaders used to fill spreader vehicles are often fitted with buckets that are too large for the spreader hopper bodies, resulting in spillage. Though they have a slower production rate, smaller buckets are available for most loaders. Side dumping bucket attachments can also be used to provide quick precise loading. In the survey conducted for this project the majority (87%) of survey respondents stated that their agency has a policy or practices of not over-loading salt on trucks.
- Whatever equipment is used for moving salt, it should provide a way of tracking the flow so the quantities can be reconciled. Pre-loaded drop-hopper loaders meter salt into spreader trucks. Overhead silos can be pre-filled with salt to similarly meter salt into spreader trucks.
- Ideally, blended winter sand stockpiles are put up in favorable, dry conditions. Relatively dry sand stored indoors should not require more than 1-2% salt by weight; more moisture in the sand may require more blended salt (up to 5%), but the purpose is to keep the sand free-flowing, not to support melt action.
- Traditionally, blending took place on the apron to the storage shed, with several buckets of sand spread level, followed by one bucket of salt trickled on the surface; the resulting blend was loaded in the dome, and the process was repeated. This method is highly

inefficient and inaccurate, and produced sporadic result on the pavement surface. Equipment to support high-production stacking and uniform, light blends now involves a form of dual-auger pugmill or a twin conveyor feed. In either case, two supply lines are metered to an accurate ratio and the final conveyor stacks the completed mixture.

Brine Production Equipment

- The concentration should be checked with a hygrometer to measure the specific gravity of the solution. The percent of saturation is determined by reference to specific gravity charts for the specific solution temperature.
- Water supply flow rates are a critical factor. Production sites may require cisterns to ensure adequate water supply where well production rates are poor.
- Manufactured salt brine can be pumped directly into tanks mounted on the spreaders or transferred to holding tanks at the maintenance yards.
- Stored brine will normally stay in solution as long as there is not evaporation or a drop in temperature below the eutectic point of the product.
- Corrosion or rust inhibitors, and organic or agriculturally derived products will likely require special handing or mixing, in which case agitation or recirculation could be considered.
- Sampling containers and a refractometer or hygrometer should be available for sampling and testing product concentration.

An effort should be made to only handle delivered material once; additional handling can cause particle breakdown, segregation of materials, or loss of product (TAC, 2013). Work by Walsh et al. (2014) found conveyers to be the most cost-effective and efficient method for loading material into buildings, when compared to loaders; however, the fact that loaders are multi-use equipment was not considered. In many cases, conveyers were shared within or among districts.

Avoid overloading spreader vehicles to prevent spillage (TAC, 2013). Good housekeeping during stockpiling, mixing, loading, and off-loading can greatly minimize loss of material (OWRC, 2012). Proper design of storage facilities will aid in proper material handling. An example of the facility built and designed for winter maintenance operations is discussed in the case study on the Stockpile Academy found in Appendix D Case Studies.

Material should be loaded inside storage structures if possible (TAC, 2013). If loading outside, it should be done over an impermeable surface. If spills occur, they should be cleaned up as soon as possible (OWRC, 2012; TAC, 2013). If loading outside on an impervious surface, Michigan DEQ (2007) recommends having a containment dike around the loading area, and/or the area should be graded to direct runoff to a collection area. In the survey conducted for this project, secondary containment was common for liquid products, but not for runoff from solid storage. One respondent stated that they do have secondary containment for runoff from solid storage piles because of NPDES permitting, while another stated that only at the newer facilities do they have this.

Securing Stockpiles

Soil and water contamination may occur around the salt sheds or sand piles if poor housekeeping practices are in place. Key provisions for securing stockpiles involve ensuring provisions for proper salt storage and good repair, including verifying that: (Wisconsin DOT, 2015)

- All solid material is stored on a concrete or asphalt impermeable pad(s).
- Sites are served by a detention or containment structure to capture spills or runoff.
- Necessary permits are in place.
- Each subsite is located 50 feet or greater from any surface water.
- Each subsite is protected individually, or all in combination, by a berm or retaining wall adequate to capture spills or runoff (e.g., secondary containment).
- Buildings, pavements, and coverings must be kept in good repair so as to prevent direct contact of the salt with precipitation or with run-off from rain or ice and snow melt. Buildings and coverings must also prevent salt particles from becoming airborne due to wind.

To secure stockpiles, PennDOT staff developed Quality Assurance Evaluations for Maintenance Stockpiles and a Foreman's 15-Minute Stockpile Walkarounds (Venner, 2004). Recommended environmental BMPs include the following practices compiled from Iowa DOT PennDOT (2001), NYSDOT (2001), Missouri DOT (personal communication, J. Carney, Sept. 1, 2004), the Transportation Association of Canada (TAC, 2003), and the Government of Alberta (2010):

- **All storage facilities should be inspected and repaired regularly for roof leaks, floor cracks and wall leaks**.
- **All stored material is under a roof, on an impervious pad, in areas properly sized for truck and loader operations, stocked below fill line.** Piles of salt are not left exposed to the elements.
  - **Salt and mixtures of salt and sand are kept on an impermeable surface** like asphalt or concrete and in salt storage buildings whenever possible.
  - Under some circumstances, temporary (typically, less than one season) **"surge" piles may be utilized if placed on an impermeable surface and covered with adequate tarping weighted with sandbags, and bermed to contain runoff.**
  - **Doors to the salt sheds and domes are kept closed unless salt is being delivered or removed.** Keeping the door closed ensures that the salt remains in the shed, away from snow and rain. Material must be tarped within ten feet of doorway. (Maintenance staff at Iowa DOT designed and installed an innovative but basic canvas salt shed door that lifts easily, allows for full access, and provides substantial cost savings.)
  - **Where fabric buildings can withstand winter snows, such structures have offered one of the most cost effective methods to keep salt under cover** and provide winter storage of the mixes and other de-icing materials. Missouri DOT has found such buildings to be durable, low cost, spacious and able to be installed on a permanent or temporary foundation. Such buildings have provided storage space for 2,000 to 3,000 tons, with room to work inside. Salt runoff has been eliminated at the storage sites.

  - **With bay storage bins and crib storage, the front is open and when full, the salt is partially exposed.** Therefore, the following environmental protection items must be followed to guard against leaching and runoff. These BMPs are also necessary for crib storage, to guard against leaching and runoff, as crib storage is not roofed:
    - **The bituminous pad on which the building is placed must extend for a distance of 20 feet past the front of the building**.
    - **The building is not to be overloaded so that salt spills out** past the front of the building.
    - When fully loaded, **the front of the salt pile is to be covered by tarpaulins.**
    - A **sedimentation basin must be constructed to collect runoff.**
    - **The immediate area around the building is to be kept clean of salt spillage** that will normally occur when loading the bins or trucks. This is especially important for the pad surface in front of the building.
- **The area must be properly signed.**
- **Liquid deicing chemical storage tanks are located on level surface, within secondary containment, and protected from traffic by barriers (i.e., bollards, guide-rail, etc.).** A basic rule of thumb to determine storage needs is 1.5 times total lane miles to treat x recommended gallons per lane mile = amount of storage (ex: 1.5 x 200 x 50 = 1,500). Iowa DOT normally purchases 2500 gallon storage tanks because their cost per gallon is considerably less than other storage tanks. Other size tanks are available for limited space needs.
- **Area drainage is such that any spills can be contained on site.**
- **Placards or stenciled lettering are used to identify liquid tank contents.**
- **A minimum of two assessments, or evaluations, of the solid and liquid storage (e.g., the Stockpile Quality Assurance Evaluations) should be completed per year**, one in summer and one in winter. Each item identified for corrective action should be fixed or put on maintenance schedule.
  - **For Example; a "Stockpile Snapshot" is a cursory stockpile review that can be completed by anyone. Any deficiency noted should be addressed within two weeks.** A Stockpile Checklist is completed four times per year and reviewed.
  - PennDOT awards Silver and Gold Awards to County Maintenance Organizations for Model Stockpiles meeting certain criteria. If all five are met, a Gold Award is given. If four are met a Silver Award is bestowed. An award for "Most improved" is given as well.
- **Spills are cleaned up immediately, using necessary equipment.**
- **The detention basin or containment structure capturing salt laden runoff should be designed based on local and historic precipitation and snow water equivalent. The volume of the detention basin or containment structure should be monitored**

throughout the winter season, and excess salt laden water should be disposed of in an approved manner.

- **Any contractor activities at government-owned facilities should be monitored to ensure that they are following the operating plan for that facility.**
- **Operating plans should be developed by maintenance staff and the contractor**, if appropriate, in conjunction with DOT environmental staff.

PennDOT Salt Stockpile Management, Stockpile Academy, and Quality Assurance Program

PennDOT has stockpile-specific Preparedness, Prevention & Contingency (PPC) plans (personal communication, M. Ryan and P. Tartline, July 13, 1999) in the staging building that are revised annually. PennDOT uses a 50 element QA review, each tied into a department policy or regulation or a PennDEQ regulation. PennDOT has also developed a Stockpile Academy Training Program, which maintenance staff are required to attend on a 4-year rotating basis. PennDOT requires ongoing evaluation stockpile housekeeping measures, including a list of quality assurance responsibilities. The procedure for this checklist includes: (Ryan and Tartline, 2001)

- Completing the checklist for each stockpile by November 30, January 31, March 31 and June 30 of each year.
- The completed checklists are forwarded to the responsible Assistant Maintenance Manager for their review and signature.
- The Assistant Maintenance Manager forwards the signed checklist to the County Maintenance Manager.
- Within ten days of the completed checklist date the County Maintenance Manager forwards all Stockpile Checklists for his/her county to the Assistant District Engineer/Administrator-Maintenance (ADEM/ADAM) and the District Facilities Administrator (FA).
- The FA will determine appropriate corrective action in cooperation with the ADE/A-M, the County Maintenance Manager, Equipment Manager and Assistant Maintenance Managers.

As a result of their system, PennDOT has been able to work with PennDEP to have one permit per district with an EMS in place, rather than one permit per stockpile. PennDOT is not required to sample because an EMS and BMPs are in place and salt is stored under cover. Finding covered loading was not considered necessary because loading areas are paved, curbed, and contained.

PennDOT developed the 15-minute Stockpile Walkaround to be performed by the Maintenance Foreman, along with a shorter Stockpile Snapshot. Maintenance stockpile activities have been noted in a Stockpile Activity Protocol Matrix.

Yard and Drainage Clean-up

Prompt spring clean-up of winter maintenance, snow and ice control, and anti-skid materials prevents clogging of drains and pollution of surface waters and habitats. PennDOT's procedures call for bins and storage buildings, collection basins to be cleaned and repaired in the spring. A survey conducted for this project found that responding agencies most commonly use retention or detention ponds and berms around the perimeter of storage areas to contain salt laden runoff. Less commonly used were channels or ditches around the perimeter of the facility or wetlands and marshes, while about 20% of respondents had no measures in place to prevent salt laden runoff from leaving the site.

Inspection of Detention Structures

Inspection of detention basin, containment basins, and inlets may consider: inlet pipe, outlet pipe, flow line, elevation, catch basin or grate inlet, grate ground elevation, and silt storage. The capacity of these facilities varies. North Carolina DOT and Washington State DOT evaluate the total number of catch basins and drain inlets per 0.10 mile section and the total number of catch basins and drain inlets that are deficient, counting as deficient any catch basin or drain inlet that has:

1. 50% or more of the inlet grate blocked with debris, or
2. The catch basin has sediment buildup that reaches or exceeds the flow line elevation of the outlet pipe.

Both catch basins and drain inlets should be rated for blockage of the inlet grate. Containment basins can be rated for sediment build-up, using a flashlight and/or probe to determine if the structure still has silt storage capacity and to what degree (WSOT, 2003). Necessary maintenance should be noted.

With regard to facility drainage that requires secondary containment, the agency should check/ensure that secondary containment will hold the contents of the largest tank plus sufficient freeboard for a 25-year event rainfall (10%), be sufficiently impervious to hold a spill until it can be detected and cleaned up, be free of vegetation that would compromise the containment or inhibit inspections. Agencies should empty secondary containment only when there is uncontaminated storm water and only after testing of water quality and when safe to discharge to a pre-approved treatment system. The agency should remove and properly dispose of all trash. The agency should record each discharge event with date, time, volume released (may need to estimate), and where discharged to (e.g., local water municipality).

Inspections should ensure that bulk storage containers are compatible with the material stored inside and have secondary containment as well as:

- Contain necessary pressure and temperature
- Keep any bypass valves sealed and closed (locked)
- Record inspection and tank testing
    - Visual inspection monthly of tank and secondary containment, looking for:
        - Corrosion and deterioration
        - Product discharges inside containment
        - Dents or holes
        - Scraped paint
        - Cracked valves or fittings

        - Any other visual damage that may jeopardize the integrity of the tank or containment
        - Cracks
        - Facility effluents
    - Testing by certified tester or equivalent
        - Performed according to manufactures standards and recommendations
        - Conducted at intervals recommended by industry or engineer (above ground tanks are usually tested every 10 to 15 years)
        - Must be done when changes are made that may affect the integrity of the tank or if it was damaged.
    - Records of inspections and testing should be kept onsite.
- Inspect water before discharge under responsible supervision
- Test each container for integrity on a regular schedule, and whenever you make material repairs, making sure to keep records. Methods include but are not limited to
    - Hydrostatic testing
    - Radiographic testing
    - Ultrasonic testing
    - Acoustic emissions testing
    - Other non-destructive shell testing

Spill Prevention Control and Countermeasures (SPCC) Plans

Spill Prevention Control and Countermeasures Plans are required for large volumes of materials that can reach waters of the U.S., which include lakes, rivers, streams, dry creek beds, ditches, wetlands, and tributaries to these.   Manmade structures such as dikes and equipment should still have a plan in place. Spill prediction is generally required to identify what would cause a spill and where would it flow and then list and describe containment, including: dikes or berms that are sufficiently impervious to contain spilled material until it is cleaned up; curbing, culverting, gutters or other drainage; weirs, booms or other barriers; and spill diversion or retention ponds. If a facility cannot physically put in containment, the agency must explain why, conduct integrity testing of tanks and leak testing of pipes and valves more often, develop a contingency response plan (40 CFR 109), and have a written commitment of manpower and equipment to stop a spill and clean it up. Records must be kept for three years with the plan and signed by supervisor, and include the following:

- Frequency of testing and inspection of tanks
- For tank, piping, valve inspection and testing
- Water drained from containment
- SPCC plan review every five (5) years

One person must be designated as responsible for SPCC requirements and conduct and document periodic briefing on recent problems and new spill prevention measures (frequency determined by need). Security may be required.

- Facility or area with tanks must be fenced unless occupied 24 hours a day to deter vandals, commensurate to location, and gated and locked when not occupied.
- Master flow and drain valves on tanks and containment must be secured in the closed position unless in use (locked).
- Pump starter controls must be locked and only accessible to authorized personnel.
- Loading and unloading connections must be capped when not in service and locked if they can result in a release.
- Adequate lighting to detect and cleanup spills at night and deter vandals.

Facility loading and unloading areas must have secondary containment for the largest tank plus 10 percent such as a quick drainage system, catch basin or treatment system, curbing or speed bump type berms, diversion to secondary containment, trenches, sumps, or USTs.

Drain Management

Many DOT facilities have floor drains in buildings and surface drains in the “yard” that discharge washwater and stormwater through underground pipes or open ditches, a ditch, or a right-of-way culvert, or off-site to a neighboring property and, potentially, to the waters of the state. Effluents can include waste water from washing salt trucks during the snow and ice season. Flows from maintenance yards may ultimately reach waters of the state, either indirectly or via direct discharge into a side ditch. Discharges from floor drains to surface and ground waters are generally regulated through the National Pollutant Discharge Elimination System (NPDES) and state administered NPDES programs, often called SPDES. NPDES/SPDES permits are issued and required for discharges to waters of the state. Some facilities have oil/water or oil and grit separators as interceptors; however, such separators are not effective in removing soluble contaminants such as salt from the discharge.

Caltrans, Maine DOT (2002), and NYSDOT (2001) utilize some of the following BMPs for drainage management.

- Consider whether a floor drain discharge is truly necessary. If not, plug the floor drains with a plumber’s plug or concrete. If the drain is permanently closed and no discharge can occur, a grit collector, oil/water separator, and NPDES/SPDES permit would not be required. A permit would be required for a grit collector and oil/water separator that discharge floor drain waters to surface water. Such permits may involve requirements to change vehicle parking patterns and perform vehicle maintenance only in areas away from the floor drains.
- Direct discharges from floor drains to groundwater through leach fields, septic systems, or dry wells should not be allowed.
- At facilities that do not discharge shop floor drain effluent to a Publicly Owned Treatment Works (POTW), oil/water separators should be used for wash-water. Oil/water separators are effective at removing non-soluble oil and other petroleum products, but do not remove substance in solution, such as antifreeze and chlorides from road salt. At some facilities, the oil/water separator is connected to a tank, catch basin or holding pond where the wash-bay effluent collects before being conveyed offsite. A hazardous waste or liquids recycling contractor pumps the contents of the separator or the holding tank, when needed. All floor drain effluent must be forced to pass through an

oil/water separator prior to being discharged from the system (i.e. before flowing to a tank, sewer district pipe, or infiltrated onto the surrounding grounds).

- Shop floor drains should be segregated from wash-bay drains and the flow should terminate at the oil/water separator or, beyond, at a holding tank. Shop floor drains are intended to capture any spills of automotive fluids occurring during vehicle maintenance. No other liquids, including wash-water, should be allowed to enter the drain.
- Centralize vehicle repair and maintenance when possible, to avoid contamination of facility storm-water discharge.
- Where possible install a grit collector and oil/water separator and connect to a municipal sewer system which eliminates the need for a NPDES/SPDES permit.
- Managers are responsible for knowing where floor drains discharge, and for compliance with agency policies. Managers should keep a current database of the method for managing wastewater from garage floors. This database should include, at a minimum, the presence and type of construction for floor drains and the method of managing effluent, as well as any changes to the construction or management of this effluent.
- Hazardous waste containers (e.g., oil and gas cans) should be provided with secondary containment where risk of damage is high (such as from vehicles) or where impacts from a spill would be severe (such as spills to floor drains that discharge to the ground). Secondary containment must be capable of holding 110% of the waste container volume.
- Weekly inspections of hazardous waste storage areas should be performed.
- An Emergency Action Plan should be developed in accordance with Bureau of Labor Standards/OSHA (29 CFR 1910.38) requirements for Hazardous Waste Operations and Emergency Response (29 CFR 1910.120(a)(i)(v)) state Emergency Response Planning Procedures for each facility storing hazardous waste.
- Good spill prevention practices should be used. These include, at a minimum:
    - Keeping waste containers closed when not in use;
    - Protecting containers from damage from vehicles or other equipment;
    - Use of containers that are in good condition (not severely dented or rusty);
    - Use of funnels when pouring liquids into waste containers; and
    - Conducting periodic inspections of waste storage areas.

Various states (e.g., Georgia, Wisconsin, California, Virginia) conducted studies designed to test the effectiveness of various structural BMPs and investigate the costs of design or purchase, as well as installation and maintenance. BMPs include: (Corson, 2003)

- **Reduce the sources of potential contamination throughout the state by centralizing truck washing at facilities already connected to POTWs (Publicly Owned Treatment Works) amenable to accepting brine discharge.** This may involve extra driving, and POTWs to which washing facilities are connected may have imposed limits on the volume of washwater or the levels of chloride and cyanide discharged from the facility. Washing facilities may be at such a distance from the others that moving trucks for washing is inconvenient or impractical, regardless of the cost; however, when usable facilities are accessibly located, this is a cost effective option.

- **Connect every truck washing facility to an amenable POTW.** Costs of extending the line can be shared with other dischargers in some cases, though some facilities are too remote to make this a practical option.
- **Contain wash water in holding tanks and haul to an amenable POTW.** INDOT found this is the most cost effective option for facilities that 1) cannot afford to connect to a POTW; 2) cannot discharge wash bay effluent to a POTW because of prohibitions; 3) will install brine making equipment and can use wash water in this process or 4) will continue to spread road salt for all or some snow/ice events. Vacuum trucks or bulk tank trucks (with a pump), if available, can be used to reduce hauling costs. While some POTWs will not accept transported liquids, a pick-up service might be arranged where amenable POTWs can be located (Corson, 2003).
- **Line existing and newly constructed holding ponds with a clay layer or plastic impervious liner** and design the structure to hold the maximum volume of melt water, wash water and precipitation for the local evaporation rates. No overflow is allowed.
- **Install catch basins, settling tanks, and holding ponds to remove suspended particles.** Dissolved chlorides cannot be removed in this fashion. It may be difficult to remove sediment from holding a pond, especially those lined with plastic. Unless properly maintained, holding ponds can collect debris and serve as a harbor for algae blooms, wild fowl, and reptiles. The cost of constructing a holding pond as a BMP must be weighed against the costs of cleaning and maintenance and the potential for groundwater contamination via a perforated or breached liner. Evaporation cannot be relied on to reduce the total volume contained because it is periodically replenished by precipitation. Prohibiting any discharge from a pond will mean that the contents will need to be pumped and hauled to an amenable POTW as is necessary. POTWs may not accept the captured water is brine concentrations are too high. Alternatively, the unevaporated content can be pumped to tanks, if available, and used as brine makeup solution or hauled to another facility for this purpose (Corson, 2003).

New Hampshire Department of Environmental Services (2003), Oregon Department of Environmental Quality (2001), and others have identified BMPs for vehicle washing facilities. The following BMPs can be added to existing and or new agency facilities to minimize the potential for environmental contamination from polluted runoff:

- **Warning signs should be posted to not dump vehicle fluids, pesticides, solvents, fertilizers, organic chemicals, or toxic chemicals into catch basins.** Catch basins are chambers or sumps which collect runoff and channel it to the stormwater drain or to the sanitary sewer. Vehicle wash facilities should **stencil warnings on the pavement next to the grit trap or catch basin**. All signs should be **in a visible location and maintained for readability**.
- **Care should be taken to minimize wash water run-off from cleaning operations.**
    - Minimize water use to reduce potential for unpermitted non-stormwater discharges (e.g., provide a positive shutoff type of hose nozzle).
    - When possible, truck beds should be cleaned using a dry cleanup technique (sweep up or shovel out).

    - Use low pressure (brush and hose with nozzle only. no power booster or steam cleaning)
    - Exterior and frame wash only
- **No detergents should be used**, as they emulsify oil in the oil/water separator and make the separator ineffective and may violate a DOT's NPDES/SPDES permit by introducing new chemicals. Using alternative cleaning agents such as phosphate-free, biodegradable detergents for vehicle washing can also reduce the amount of contaminants entering storm drains. (This may counter the vehicle washing requirement to prevent corrosion, such as if a salt neutralizer is used. This wash water may need to be collected and handled separately.)
- **Where possible, indoor wash facilities with controlled floor drainage should be utilized.** Where wastewater is not to be disposed to a sanitary sewer, grassed swales (shallow, vegetated ditches) or constructed wetlands (retention ponds with emergent aquatic vegetation) can be used to hold wastewater and allow contaminant removal through infiltration and filtration. The above mentioned structural BMPs will not remove chlorides, and may lead to contamination of nearby surface water, and shallow groundwater or wells.
- **Washwater may otherwise be collected in a sump, grit trap, or containment structure to be pumped or siphoned to a vegetated area so that complete percolation into the ground occurs.** Washwater runoff can also be disposed of into an infiltration basin/trench. The use of a bioswale with an oil/water separator will virtually eliminate the total suspended solids, oil and grease, and heavy metals discharged provided both are properly sized (Oregon DEQ, 2001). The above mentioned structural BMPs will not remove chlorides, and may lead to contamination of nearby surface water, and shallow groundwater or wells.
    - **Disposal of washwater should occur on ground surfaces with vegetated cover, preferably grasses, a minimum of 250 feet in length before a surface water body.** A distance of 250 feet was based on a hydraulic conductivity of 0.2 gal/ft/day, volume per day of 150 gallons, and a swale with a width of 3 feet.
    - **Complete percolation in the swale should occur with no direct discharge** to the surface water. Discharge into a grassy swale for treatment should not occur within 24 hours after a rainfall event or if water remains ponded in the swale.
- **Wash areas should be located on well-constructed and maintained, impervious surfaces** (**i.e., concrete or plastic**) **with drains piped to the sanitary sewer or other disposal devices.** The wash area should extend for at least four feet on all sides of the vehicle to trap all overspray. Enclosing wash areas with walls and properly grading wash areas prevent dirty overspray from leaving the wash area, allowing the overspray to be collected from the impermeable surface.
- **The impervious surfaces should be marked to indicate the boundaries of the washing area and the area draining to the designated collection point.**
- **Washing areas should not be located near uncovered vehicle repair areas or chemical storage facilities**; chemicals could be transported in wash water runoff.
- **Regularly inspect and maintain the designated areas**, facility wash racks, designated cleaning areas, wash pads, clarifiers, oil-water separators, sumps and sediment traps.

Regularly clean wash areas, grit traps, or catch basins to minimize or prevent debris discharge, such as paint chips, dirt, cleaning agents, chemicals, and oil and grease into storm drains or injection wells.

- **A wash water treatment sequence may include such elements as a grit trap, an oil/water separator, a dosing tank with siphons or pumps, and a multi-media filter bed with underdrains.**
  - Discharge from underdrains must meet effluent limitations.
  - Maintenance of a multi-media filter should consist of cleaning, removing the top inch of sand once every six months; when the total depth of filter sand fall below 18-inches, the sand should be replaced. If clogging and/or short circuiting occurs as observed by uneven infiltration in the filter or formation of surface cracks, the sand should be replaced.
  - A Spill Prevention, Control and Countermeasure (SPCC) Plan, in accordance with 40 CFR 112, should be prepared and implemented to prevent the entry of pollutant loads beyond the capabilities of the treatment system.
- **Contractual provisions should require contractors to use cleaning practices consistent with DOT requirements**.

Recycling systems reduce or eliminate contaminated discharges to stormwater drains and injection wells by reusing the wash water until the water reaches a certain contaminant level. The wastewater is then discharged to a collection sump or to a treatment facility. Collection sumps are deep pits or reservoirs that hold liquid waste. Vehicle wash water accumulates in the collection sumps, and is pumped or siphoned to a vegetated area (such as a grassed swale or constructed wetland). Sediment traps can also be used to strain and collect the vehicle wash water, prior to pumping or siphoning the wash water to a vegetated area. The use of a recycling system can reduce or eliminate the contaminant discharge to stormwater or sanitary sewer while greatly reducing the amount of water used in the process. Some DOTs are installing brine making at truck washing facilities so wash water can be used. This solution can also be used to "spray the load" of salt/sand mix and/or to fill saddle tanks for spraying the mix as it passes through the salt spreader.

Recycled wash water has been successfully used by one of the largest bus transport companies operating in Borsod County, Hungary. In 1985, they installed a new, water-saving wastewater treatment facility for wastewaters resulting from washing at the central service plant. The commercial transportation system uses detergent-free, high pressure, hot water to remove dirt and grime from the car bodies and engines of the buses. The resulting wastewater is mechanically treated with filters consisting of sand and activated carbon. After this pretreatment, about 15 to 20% of the wastewater is discharged into a conventional sewerage system. This discharge prevents the accumulation of TDS and organic substances in the remaining water which is recycled for use in the carwash. This discharged water meets the water quality requirements for all categories. The remaining water that is to be recycled is subjected to ozonation to prevent anaerobic digestion of organic materials which produces foul odors, and then filtration. Once filtered, the water is resupplied to the carwash. For the commercial vehicle washing recycling facility, the initial investment costs were about $80,000, with a further investment of $1,600 for reconstruction after about 10 years of operation. Maintenance costs were about $4,000/year. The estimated period for recovery of this investment was about 1.3

years based upon typical usage within the region. The technology achieved 80% recycling of water (United Nationals Environmental Program).

In addition to the recycling of wash water, BMPs associated with recycling wash water include: (Oregon DEQ, 2001)

- Recycling treatment equipment should be properly operated and maintained to achieve compliance with all conditions of the permit.
- Backwash water or concentrate water should be properly discharged to sanitary sewer.
- Liquid concentrate discharged to the sanitary sewer should meet all pretreatment standards and other requirements of the local Sewer Authority.

Solids, grit, or sludge should be disposed in a manner that complies with State administrative rules.

Operational Strategies

Snow Removal

One of the most important methods for winter road maintenance involves the mechanical removal of snow and ice from roadways using snow plows. Most winter maintenance operations use similar equipment for plowing, typically single axle and tandem axle dump trucks with plows, rotary plows, and loaders (Conger, 2005; Williams and Linebarger, 2000). Depending on local policies, snow plowing is initiated after a specific amount of snow has fallen and is covering the roadways. Snow plows are used to scrape the snow and ice from the roadway to ensure safe driving conditions. A series of snow plows may be used to cover a larger road surface, which is known as tandem plowing, or a single snow plow may be responsible for removing snow and ice on a particular road section. The ultimate goal of winter maintenance operations is to create safe driving conditions through the removal of snow and ice from roadways. Through the use of efficient snow removal, transportation agencies can achieve cost saving, a reduction in the use of deicing materials, and improved pavement conditions.

For many years, the standard design for snow plows consisted of a single rigid steel or carbide cutting edge. The Transportation Association of Canada (2003) made the following recommendations on blade types:

- Rubber and polymer/plastic blades have been tried to minimize damage to catch basins, bridge expansion joints, centerline pavement markings and raised reflective markers, etc. These blades can be used to effectively "squeegee" the surface to remove slush in areas where the ambient temperatures usually rise above the freezing point during daylight hours after a storm. In areas with colder temperatures the use of theses blades has not been as successful (TAC, 2003).
- Special plow blades with sliding segments that move up and down vertically facilitate the thorough clearing of rough or distorted pavement, reducing the amount of snow and ice chemicals required. The manufacturers also claim that these blades minimize damage to the plow and truck from hitting obstructions, such as catch basin covers, as less force is required to retract one segment clear of the obstruction. These blades are well suited for high speed and rural plowing (TAC, 2003).

New research and development has focused on innovations for snow plow blades (CTC and Associates, LLC, 2010). A new blade design was developed to allow more versatility, and to increase performance, service life, and maintainability. The new design consists of a two blade system in which a sacrificial blade, made of a flexible cutting edge, is used to cut through snow and ice, and an independently operated blade, which is used to remove excess liquid or slush. A prototype design for the multiple blade system is shown in Figure 13.

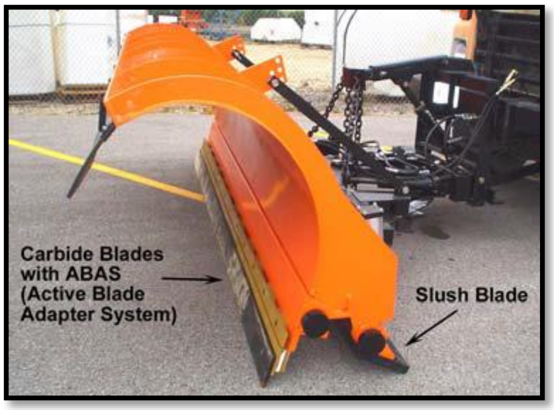

Figure 13 Prototype snow plow blade design (CTC & Associates LLC, 2010).

Snow plows and other winter maintenance equipment have been continually evolving with the advancement of technology. Various configurations of snow plows have been developed in order to accommodate specific conditions. In addition, the type of plow used on a particular truck may be related to the mounting properties of the truck. For example, heavier trucks with high horsepower ratings are needed for tow plows and front end plows, due to the weight they are towing. Wide front end snow plows can only be used on trucks with a gross vehicle weight rating of 26,000 lbs or more (FHWA, 2012). Common plow types and configurations are described in the following subsections. An overview and pictures of the different types of snow plows are also presented in Table 20.

Table 20 Various plow configurations.

Plow Type and Description	Photo	Reference
The front end plow is the most common type of plow, which offers good performance and versatility. The front end plow is mounted on the front of a vehicle and some have the option of changing the angle from side to side.		Robert Dunning Valdez District Superintendent robert.dunning@alaska.gov
The wing plow is often integrated with the front end plow to clear a wider road surface and transport snow further away from the roadway, which helps prevent snow from blowing and drifting on the road surface.		http://www.publiquip.com/zarc/International-S2600-Snow-Truck--1964616575.htm
A second configuration of the wing plow consists of the wing plow mounted further back from the front end plow.		IDOT Snow Plow by Illinois Department of Transportation
The tow plow is a large plow towed behind a vehicle. It is often used to span a wide road surface to minimize the number of passes and plow trucks needed to plow the width of the road. The use of tow plows significantly reduces the costs associated with labor and fuel.		http://www.iowadot.gov/maintenance/TowPlowPhotos.html
Underbody plows are typically installed on deicer spreader equipment to prevent reduced visibility of the road surface compared to front end plows. This gives the operator a better visual inspection of the roadway surface, which allows operators to remove any loose snow and ice immediately prior to deicer application.		Phil Larochelle Équipement Inc.

Front End Plows

The front end snow plow is a common type of snow plow used for winter maintenance operations. The front end snow plow is mounted onto the front of a truck and is controlled by hydraulics. The operator is able to adjust the position and angle of a front end snow plow to accommodate various operating conditions (Ketcham et al., 1996). Wider front end snow plows are becoming more popular, because a 14-ft wide front end plow can provide advantages such as the ability to completely clear a 12-foot lane in one pass, thus reducing the need for a second pass and the exposure between traffic and snow plow trucks (FHWA, 2012). Furthermore, the wider plow can clear the center line markings and push snow further away from the roadway (FHWA, 2012).

Side-Wing or Wing Plows

The front end plow effectively removes snow and ice from roadways; it can be integrated with a wing plow to cover more area and transport snow further away from the side of the roadway. A side-wing plow typically requires a truck with a higher horsepower rating of 325 to 400, due to the increase in snow load being moved (Conger, 2005). When space is limited, a wing plow may not be suitable (Conger, 2005). In recent years, an increase in the use of side-wing plows has been reported, and more recently the innovation of dual wing plows is becoming popular (Conger, 2005). Dual wing plows consist of a 12-ft wing on both sides of a maintenance truck as well as the front plow. The three blades are controlled by the operator, with various combinations available for changing conditions. Dual wing plows are much more versatile and can clear two full highway lanes or up to 24ft of roadway in one pass, which is equivalent to the work done by three standard snow plows (Dorsey, 2013). A picture of a dual wing plow is shown in Figure 14.

Figure 14 Photo of a dual wingplow (Rizzo and Moran, 2013).

Underbody Plows

An underbody plow gives the operator an advantage in terms of visibility of the road surface, because it is not directly in front of the operator’s field of view. Therefore, underbody plows are typically installed on equipment designed to apply deicers to allow the operator a better visual of the road surface and to remove any loose snow and ice immediately prior to deicer application. In addition, underbody plows are considered to be the most effective because of the downward forces on the plow blade, which eases snow removal (Nixon and Potter, 1997). Important for the environment, the use of underbody plows on deicer application equipment can significantly reduce the amount of deicers applied to roadways by removing excess snow and ice preceding deicer application. Figure 15 is an image of an underbody plow.

Figure 15 Underbody plow in service (www.meiren.ee).

Tow Plow

Tow plows are used in conjunction with a front end plow. A truck with a front end plow pulls the tow plow behind and controls its position. The tow plow offers versatility for winter maintenance operations when clearing snow and ice from a large highway segment, a multi-lane roadway, or a wide roadway. Tow plows enable one operator to clear widths of up to 25ft with a range of 11 to 25-ft at high speeds (FHWA, 2012). A tow plow can be used to reduce the number of passes needed to remove snow and ice from a roadway or reduce the number of plows needed on a road segment, which leads to lower costs associated with fuel savings, and reduced operator and vehicle hours. Figure 16 is a view of a tow plow from the rear.

Figure 16 Picture of a tow plow from the back (Anderle, 2013).

Tow plows can attach to a snow plow truck equipped with air brakes and hydraulic controls, which can be used to control the tow plow. Alternatively, two hydraulic valves can be added to replicate the control stick of the front plow, such that one stick controls the tow plow (FHWA, 2012). However, additional hydraulic circuits are needed for tow plows equipped with spreaders (FHWA, 2012).

Tandem or Close Echelon Plowing

Another plowing option includes tandem plowing and close echelon plowing techniques, which use multiple plow trucks staggered across a highway segment. This is effective at removing snow for multi-lane highways. Multiple lanes are cleared of snow with one pass as shown in Figure 17 (Rizzo and Moran, 2013).

Figure 17 Tandem plowing technique (Rizzo and Moran, 2013).

V-plow

Front mounted V-plows (Figure 18) can effectively handle deeper accumulations of snow. These plows have been designed to lift snow over adjacent windrows and to balance side loading by pushing snow to both sides. Use may be limited to areas with high snowfall rates and as back-up units to open roads closed during severe storms (TAC, 2003).

Figure 18. New York City Department of Sanitation V-plow.

Icebreaker

The Alaska DOT has recently been exploring new developments in snow removal maintenance equipment. The Alaska DOT has implemented a new device known as an icebreaker, shown in Figure 19. The icebreaker, which can be raised and lowered, is a steel drum with spikes that attaches to the front of a maintenance truck. The icebreaker is approximately nine feet wide and weighs about 3,800 lbs, with an initial cost of $45,000 (Friedman, 2013). The spikes break up the ice to allow a snow plow to remove excess snow and ice from the pavement, and the device also provides a rough surface for better traction. The icebreaker is an alternative method for other techniques of breaking up and removing ice from roadways, such as scraping the ice with serrated grader blades and underbelly plows (Friedman, 2013).

Figure 19 Icebreaker used by Alaska DOT (Friedman, 2013).

Snowplowing Best Practices

Plowing snow and ice from roadways is an effective best practice, which can reduce or eliminate the need for deicers. For example, if snow and ice are removed by effective plowing practices before they bond to the pavement, the need for deicers significantly decreases. When air and pavement temperatures are below 10°F, sodium chloride based deicers are much less effective at melting snow and ice and may cause snow to stick to the pavement under certain conditions. In this instance plowing is a more suitable road treatment option (Akin et. al., 2013). In addition, the implementation of plowing best practices can maximize snow removal from roadways and reduce costs such as operator and vehicle hours, fuel usage, and amount of product used (Environment Canada, 2000). A case study in Otterburn Park, Quebec reported a significant salt reduction of 73% through the implementation of effective plowing practices and improved training (Environment Canada, 2000). Most agencies establish plow routes based on factors such as traffic volume, emergency services, and local characteristics to improve snow removal efficiency (Conger, 2005).

The timing of snow plowing operations is also critical to the overall effectiveness of snow removal. Depending on local policy, snow plowing operations are usually most successful when initiated after one to two inches of snow have fallen on the roadways. After the storm event has concluded, a final clean-up plowing procedure is usually recommended with light salt application if necessary (NH DOT, 2014). However, this greatly depends on local conditions. The highest level of service can be achieved if snow plowing operations begins before the snow is able to bond to the road surface, which is usually before heavy traffic occurs. If deicing chemicals are applied, sufficient time is needed for the melting action to occur before a snow plow can remove the compacted snow and ice. In addition, the more time a deicer remains on the roadway, the more traffic can assist in breaking the bond between the snow and the pavement (Wisconsin Transportation, 2005). Effective plowing operations result in various benefits as shown in Table 21 and a cost comparison is provided in Table 22.

Table 21 Costs and benefits of various plowing techniques.

Technique	Costs	Benefits	Reference
Using wider front plows and tow plows	Conversion to 14-ft plow: $400/foot Tow plows reduce equipment investment by 20% to 30%	Reduced number of passes required Fuel savings Reduced labor required Increased snow removal efficiency	Lannert, 2008
High speed snow plow	Potential roadside damage	Reduced chemical usage Improved level of service due to flexible cutting edge	Gruhs, 2008
Use of underbody plows and improved overall plowing practices	Total costs including pre-wetting equipment: $53,700	Total savings from salt reduction $151,200	Environment Canada, 2000
Tow Plow	$93,000	20-30 % savings Plow 50% more miles 6-7 year return on investment Increased service life of 20-30 years compared to typical 12-15 years Operates at 40% of the cost of standard plow	Behnan, 2014 Michigan DOT

Table 22 Cost comparison of Tow Plow vs. standard plow truck (Akin et. al, 2013).

Parameter Comparison				
Equipment	*Fuel Efficiency (mpg)*	*Labor Cost ($/hr)*	*Operational Speed (mph)*	*Fuel Cost ($/gal)*
TowPlow	3	40	25	3.8
Regular (front) Plow Truck	5	40	30	3.8

Operational Comparison (per hour)			
Equipment	*Labor ($/hr)*	*Fuel ($/hr)*	*Total ($/hr)*
TowPlow	$ 40.00	$ 31.67	$ 71.67
Regular (front) Plow Truck	$ 80.00	$ 45.60	$ 125.60
Operational Comparison (per mile)			
Equipment	*Labor ($/mi)*	*Fuel ($/mi)*	*Total ($/mi)*
TowPlow	$ 1.60	$ 1.27	$ 2.87
Regular (front) Plow Truck	$ 2.67	$ 1.52	$ 4.19

Considerations for plowing

The type of plow and cutting edge must be selected and mounted properly on the vehicle, to operate in the required area, and achieve the desired performance. The selection of the appropriate type of plow, and proper adjustment of the plow will reduce costs and lessen the need to use salt to clear the roadway (TAC, 2003). Plows should be operated with sufficient weight on the blade to effectively cut through packed snow and ice, resulting in a near-bare surface, in order to minimize the amount of salt required to reach bare pavement (or the prescribed LOS). Plows for high speed operations should be fitted with shoes to prevent the plow from dropping into holes or catching on obstructions. Plows should be adjusted to minimize the amount of weight carried on the shoes, but the shoes should be close enough to the pavement to absorb the weight of the plow if the plow strikes an obstruction. Castors are sometimes substituted for shoes to minimize wear. Plows should be fitted with a tripping mechanism that will reduce damage to the plow if it impacts catch basin or manhole covers, curbing or other obstructions. The trip mechanism will also prevent the truck from being violently deflected from its traffic lane (TAC, 2003). Plows with an angle of about 55° between the blade and the road are the most efficient at moving large quantities of snow and cause the least amount of snow to be blown up at the front of the vehicle. Tests also show that an angle of about 75° between the plow blade and the road provides the most effective cutting of heavily packed snow and ice. One jurisdiction has used a 40° angle to improve snow pickup. A rubber extension flap fitted to the top of the moldboard of a front mounted plow, which extends well past the cutting edge, has been shown to effectively improve the operators' visibility by trapping some of the snow cloud kicked up by the cutting edge (TAC, 2003).

Over the course of a winter and multiple plowing operations snow will build up along roadways. Areas with limited space for plowed-snow storage may develop visual obstructions for drivers, act as a snow fence causing snow drifts to form on roads, and prevent future plowing operations from being productive once the snow capacity of the area is exceeded (TAC, 2003). In addition, accumulations next to guardrail, barrier walls, and bridge approaches can freeze solid and create an unsafe ramping condition. The piled snow, containing salt and other road contaminants, may need to be removed and disposed of or stored in an appropriate manner (TAC, 2003).

Loading, Hauling, and Dumping

The most cost effective and easily mobilized snow removal operation for isolated locations is using a loader to fill a conventional dump truck(s) with snow, which can then be hauled to appropriate snow storage or melting site (TAC, 2003). The capacity of the loader and the truck body will determine the production rate and how cost effective the operation may be. Auxiliary equipment may be required to increase the efficiency of the operation. For instance, a grader may "peel" a snow bank into a suitable windrow in order to accommodate the loader and truck. Traffic control is often required, and consideration should be given to doing this work at night (TAC, 2003).

Mobile Conveyors

Mobile conveyors are used to load snow from the shoulders or a windrow directly into trucks for removal. They can operate entirely on the shoulder, in line on the shoulder, so as to not disrupt traffic. They are useful in areas with high traffic volumes or limited access (TAC, 2003).

Snow Melting

The most efficient way to dispose of snow is to let it melt where it accumulates, but where space is limited, snow can be transported to a designated disposal site where it can melt on its own or be melted with a snow melter (TAC, 2003). When choosing a location to operate a snow disposal site some things to consider include:

- Minimizing the impacts on the natural environment and control nuisance effects, including noise, dust, litter and visual intrusion on adjacent landowners.
- Manage the discharge of meltwater to comply with local water quality regulations and protect surface and groundwater resources.

- Collect and dispose of onsite litter, debris and sediment from the meltwater in accordance with local waste management legislation.
- Snow handling, storage and disposal design should be practical (TAC, 2003).

Routine monitoring of the site including meltwater capacity, collection, and retention and discharge systems may be considered, including periodic collection of water and soil samples. This can be done using onsite monitoring equipment or samples which can be sent to an accredited laboratory. If retention ponds are being used to hold meltwater, consider annual cleaning of the ponds to maintain capacity to handle the worst case year snow load (TAC, 2003).

Three factors have been identified as related to how pollutants are released during snow melting, (1) the initial source of hauled snow, (2) the melt processes of stored snowfall, and (3) the shape of the snow storage areas and the snowfills (Wheaton and Rice, 2003). This study concluded that:

- Chlorides can be controlled passively through detention and dilution.
- Mobilization of metals and polynuclear aromatic hydrocarbons relates to chloride concentration, but a large fraction can be controlled with particulate capture.
- Particulate loading in melt water relates to the shape of the snow fill and the pad on which it is situated and can be controlled by manipulation of these elements.

The City of Toronto uses stationary and mobile snow melters (Figure 20) when they run out of the capacity to store the snow until it melts on its own (not necessarily every year) (Fay et al., 2013). They have dealt with several important issues:

- Treating all snow melt as stormwater runoff and handling it appropriately.
- Consider site grading for appropriate drainage.
- In the snow melt filtering processes, removing all grit and oils, and picking up all the debris.
- The snow melters are burning hydrocarbons and so there are associated emission and noise issues that need to be dealt with (e.g., location should be considered).

Figure 20 a) A snow melter in use by the city of Toronto staff during the winter of 2007/2008 and b) another snow melter in use by the city of Toronto staff during the winter of 2010/2011 (Courtesy of City of Toronto, Canada).

Geothermal energy has been used to melt ice and snow on roads, sidewalks, bridges, and other paved surfaces for years in locations around the world. Either heat pipe technologies or direct geothermal hot water can be used to heat the pavement. Because of the limited number of geographical locations with geothermal fluids above 100°F, the heat pipe technology is used more commonly in the United States. The costs of different geothermal heating technologies are in ascending order as follows: geothermal snow melting without heat pump (around $20/ft^2), ground source heat pumps ($35/ft^2 for typical highway bridge deck systems), and “hydronic” geothermal heating system. Total costs for the deck and heating system generally range from $100 to $150/ft^2. This high cost has limited its usage to only critical areas such as bridge decks and airports (Lund, 2000).

A system that combines the geothermal energy and summertime solar energy, known as the Gaia Snow-melting System, was introduced and evaluated in Japan for melting snow (Morita and Tago, 2000). The system utilizes the geothermal energy from shallow ground sources and auxiliary solar energy in the summer. The initial installation was found to be effective at melting snow and ice, and to be environmentally benign even under low temperatures for the month of January [averaging −8.3°C (17°F)]. The advantages of geothermal heat pump application of the Gaia System include reduced consumption of fossil fuels (and thus less CO_2 emission), reduced consumption of electricity with higher performance, and reduced urban heat island effect with heat exhaust going underground (Institute for Geo-Resources and Environment, 2007; Yasukawa, 2007).

Snow Blowers

Snow blowers can be used during storm conditions but work at slower rates than plows, and are normally used for post-storm snow removal. Blowers are also used to load trucks for snow removal in urban areas along roads with limited snow storage space. Snow blowers are more commonly used in areas with very high snowfall rates (TAC, 2003). Blowers are typically mounted on dedicated trucks, tractors, or are attached to large front-end loaders. They are available with hydraulic powered vanes to control the direction of the blower. They may also have hydraulic controls on the chutes to accurately direct the snow (TAC, 2003). Blowers can be used simply to widen the snow bank area and relocate the snow by blowing it beyond the bank toward the ditch line (where additional storage capacity may be available). All blower operators must be aware of wind direction and the visibility concerns for traffic. Blowers may leave some snow on the road surface that can then be plowed or treated to maintain safe driving conditions (TAC, 2003).

Material Selection

Implementation of material application best management practices by winter maintenance agencies can aid in reducing some of the impacts of winter highway maintenance on the environment. Appropriate snow and ice control chemicals should be selected based on local conditions and many other factors such as performance, cost, and impacts to the environment and infrastructure. Material application best practices consist of selecting the most effective snow and ice control material for a given road weather scenario combined with the most efficient application method to minimize loss of material, costs, application rates, and frequency of applications. The use of best practices will reduce the environmental impacts of winter maintenance while ensuring a high level of service is achieved. For example, five times more energy is needed to remove snow and ice from a roadway surface once the bond between snow and ice and the pavement has formed (Boselly, 2001).

Solids and Pre-wetting Solids

Chloride salts, also known as road salts including sodium chloride (NaCl), magnesium chloride, ($MgCl_2$), and calcium chloride ($CaCl_2$), are the most widely used snow and ice control chemicals (Fay et al., 2008). These chemicals can be used in solid form for deicing purposes, which is the reactive application of chemicals to roadways to break the bond between the ice and pavement. The use of solid chemicals for deicing improves road conditions, allows for higher traffic speeds, and reduces fuel consumption compared to only plowing. Furthermore, the use of solid snow and ice chemicals reduces the need for abrasives, which improves air quality (Cuelho et al., 2010). The effectiveness of deicing greatly depends on the chemicals and the equipment used by the winter maintenance agency (Chappelow et al., 1992). Solid chemicals are the most effective option on thicker snow accumulations. Recommended application rates for solid chloride based products range from 100 – 800 lbs/l-m depending on local road and weather conditions (Table 6). Local conditions to consider include weather, pavement temperature, and type of material being used.

Pre-wetting is the method of adding liquid chemicals to solid salts or abrasives prior to application on roadways, which has been shown to improve distribution on roadways, increase performance and minimize bounce and scatter, thus reducing the amount of materials required (Hossain et al., 1997; Michigan DOT, 2012). Dry salt and abrasives on roadways can be lost to the effects of wind, traffic, and bounce prior to actively melting snow and ice. By contrast, pre-wet solids adhere to the road surface, increasing longevity on the road and reducing the number of applications needed. A case study in Michigan observed that 96% of the pre-wetted materials were retained on the road surface, whereas only 70% of the dry material was retained on the road surface (Michigan DOT, 2012). A 15% reduction in product usage was reported when using brine to pre-wet salt, because the pre-wet salt showed high ice melting performance and better adherence to the roadway (Fay et al., 2014). Pre-wetting application at lower speeds will provide a tighter distribution pattern and loss of material will significantly decrease (Greenfield, 2013). Recommend application rates for liquid products added to solid material range from 8 – 20 gal/l-m (Table 6). Additional application rate guidelines are provided by The Salt Institute (2013) in *The Snowfighters Handbook: A Practical Guide for Snow and Ice Control.* Michigan DOT has also reduced the speed of application vehicles to reduce bounce.

A case study on how the use of pre-wetting has been used to modify winter maintenance practices and produced time, cost, and material savings is presented in Appendix D Case Studies.

Liquid Chemicals

Liquid snow and ice control chemicals include chloride based brine solutions, of which sodium chloride (NaCl), magnesium chloride, ($MgCl_2$), and calcium chloride ($CaCl_2$) are most commonly used, or agriculturally derived products, which are typically blended with chloride based products. Liquid chemicals are typically used for anti-icing, which is the proactive application of chemicals to a roadway surface prior to a snow event to prevent the formation of bonded snow and ice to a roadway aiding in snow removal. Additionally, liquid chemicals can be applied during storms for direct liquid application (DLA), which has been reported to have numerous benefits such as reduced application rates, faster post storm clean up, and reduced loss of materials. The use of liquid brine was reported to have produced approximately 50% materials savings as compared to the use of solid rock salt (Fay et al., 2013). Savings from decreased material usage, labor costs, environmental impacts, and increased levels of service result in overall savings of 10 to 20%, and a 50% reduction in the cost per lane mile (Nixon, 2002). The Colorado DOT reported a reduction of 55% in sand use and a decrease in the cost of winter operations from $5,200 per lane mile to $2,500 per lane mile when anti-icing techniques were used (Cuelho et al., 2010). Therefore, effective anti-icing strategies can reduce the environmental impacts of snow and ice control chemicals by reducing application rates, materials usage, and costs while maintaining a high level of service.

Anti-icing application rates range from 10 - 40 gal/l-m (Table 6). Magnesium chloride brines feature higher performance at lower temperatures than sodium chloride, and research has shown that $CaCl_2$ is more effective than NaCl due to its ability to attract moisture and stay on roadways (Ketcham et al., 1996; Shi et al., 2009; Warrington, 1998). Therefore, depending on the road and weather conditions, material selection is critical to determine the best performer to minimize material usage and the potential environmental impacts. Pretreatment or anti-icing is not recommended if blowing snow or rain will occur. Liquid chemicals on the road surface will cause blowing snow to adhere to the roadway surface and rain will dilute or wash away the liquid chemicals (Nixon, 2002). Additional guidance on anti-icing application rates and procedures is provided by FHWA in the Manual of Practice for an Effective Anti-icing Program (Ketchum et al, 1996).

Abrasives

Sand and abrasives provide limited benefits for winter highway maintenance by temporarily providing traction. Performance greatly decreases when vehicle speeds are greater than 30 mph, and there are additional costs related to clean-up (Levelton Consultants Limited, 2007). The use of dry sand and abrasives is generally not recommended because it has been shown that 50 to 90% of the sand remains in the environment after clean-up (FHWA, 1996). However, abrasives provide immediate traction and their use is appropriate under certain circumstances. This may include areas near roads that have highly sensitive water resources or wildlife habitat, where the sand can be captured and cleaned up post storm. In addition, abrasives can be useful on low volume roads near hills, curves, and intersections and when pavement temperatures are lower than 10°F (Levelton Consultants Limited, 2007). The recommended use of abrasives is summarized in Table 23 and application rates are summarized in Table 2.

Table 23 Recommended use of abrasives (Levelton Consultants Limited, 2007).

Type of Road	Use of Dry Abrasives
Freeways	Unsuitable
Rural roads, paved	Unsuitable
Rural roads, gravel	Only on low speed sections such as hills and curves
Rural intersections	Only on low speed approach length of gravel roads
High speed urban roads	Unsuitable
Low speed urban roads	Only in certain locations and when snowpack will persist
Urban intersections	Only when snowpack will persist

Despite the abundant amount of research supporting the use of chlorides and other products over the use of abrasives, sand may still be a preferred choice for some agencies. Locations where dry sand and other abrasives are appropriate include low speed roads (less than about 30 to 45 mph), hills, curves, and intersections. Dry sand applied on high-speed roads is short-lasting and ultimately not cost-effective (CTC & Associates, 2008). Sand usage can be reduced by limiting the frequency of re-application; by reducing bounce and scatter and taking steps to ensure the sand stays on the ice/snow-covered road longer. Several techniques that have been tried and used successfully to reduce sand usage include (Vaa 2004; Staples et al., 2004; Lysbakken and Stotterud, 2006; MTO, 2008; CTC & Associates, 2008):

- Pre-wetting sand with liquid deicers, such as salt brine.
- Pre-wetting sand with hot water (about 194°F or 90°C) at 30% by weight mix.

- Heating sand to about 356°F or 180°C (this is hotter than typical hot mix asphalt mixing temperatures).
- Switching to salt or other products.

Maintenance personnel should consistently monitor sand application rates to prevent over application and to minimize potential environmental impacts. Weather conditions will greatly affect application rates and application frequency for abrasives. The driver is frequently given an application range or application rate options for treatment. **To improve performance and adherence to the road, pre-wetting abrasives is recommended**.

Material Application Equipment

Departments of Transportation are now seeking sustainable practices through the use of newer technology to realize cost savings while maintaining the same or better LOS. Winter maintenance practitioners were surveyed and over 50% stated that technology, tools and methods implemented in the last 10 years were for cost saving purposes and has had the side benefit of reducing the amount of winter maintenance products used and reducing environmental impacts (Fay et al., 2013). From this survey anti-icing, pre-wetting and deicing were recommended application strategies by respondents to achieve higher LOS. A survey conducted for this project found that 90% of respondents had improved existing vehicles and equipment by adding or upgrading plows and spreader mechanisms. To further validate this trend, 90% of respondents stated that newly purchased vehicles had enhanced capabilities to improve treatment efficiency and or reduce material usage.

Material distribution systems are the front line in the application of anti-icers and deicers to the roadway. It is of great interest to agencies to apply the right amount of materials in the right location at the right time, and advanced material placement systems can assist in meeting these goals (Veneziano et al., 2010). Ideal systems lead to uniform distribution of applied materials on the pavement and minimal material loss due to bounce and scatter; as such, they allow for the use of reasonably lower application rates without reducing the level of service. This has the potential to translate to significant cost savings and environmental benefits (Fay et al., 2013).

Material application systems have been studied to various degrees. Recent work by Thompson (2014) summarizes solid material and pre-wet material spreaders; comparing overall performance, cost, bounce and scatter, and if they link with GPS data. In a nationwide survey, CTC & Associates (2010) collected information from snowy states to learn more about the best field practices pertaining to use of and adapting material spreaders and related equipment. Results have shown that more than half of the responding agencies use more than one type of material spreader, while two-thirds of the responding agencies use more than one type of delivery mechanism to get material from the spreader to the pavement. The listed delivery mechanisms include: zero velocity spreaders, dual spinners, spinners, modified spinners, homemade chutes and other types of mechanism. Common challenges identified in working with material spreaders include bearing failure and hydraulic motor and gearbox failure; clogging, clumping or refreezing of material in the chute; corrosion; difficulty making the transition from spinner to chute in installations lacking a remote-controlled gate; frozen spinners and augers; repeated adjustments or breakage of conveyor chains; and snow accumulating on the back of the truck, plugging the opening to the delivery system.

Solid Material Spreaders

Tailgate Spreaders and Reverse Dumping of Dual Dump Spreaders

The primary limitation of tailgate spreaders (Figure 21) is the inconvenience of raising the dump box and the possibility that the box will not be raised high enough to ensure that sufficient material is dumped in the hopper to provide consistent delivery. The rear discharge restricts the operator view of the operation and ability to ensure that the material is being discharged at the right location. The vertical clearance and the upward and rearward shift of the center of gravity when the box is raised can cause instability and is a safety concern in some areas (TAC, 2003).

Dual dump spreaders (Figure 22) were developed to overcome problems identified for tailgate spreaders while still providing a multi-purpose spreader that could be used year round. They function as regular rear dumping bodies when not being used to apply winter maintenance materials (TAC, 2003). Disadvantages of this spreader are the high weight compared to a regular dump truck, and the need to raise the body while driving to move the material to the front of the truck. This reduces the truck’s stability and care is required by the operator to ensure that sufficient material covers the cross conveyor at the front to maintain a precise application rate. The pivots have been a source of failure and replacement is expensive (TAC, 2003).

Figure 21 A conventional tailgate spreader (Nixon, 2009).

Figure 22 Iowa DOT tailgate dual augers equipped with a modem pre-wetting system (Burkheimer, 2008).

Multipurpose Spreaders

Multipurpose spreaders incorporate benefits from the other types of spreaders. For example, the design of the U-shaped box ensures that material does not get hung up in the box and that all material can be easily removed from the box at the end of the shift. Material is either discharged in a windrow using a chute for concentrated action, or spun across the lane using spinners (TAC, 2003). The spreader provides precise application rates and all the advantages of distribution in front of the rear wheels. Cross conveyors are easily removable during the summer so that there is no tare weight penalty. The units are lightweight and provide year round use, and the body can be easily switched to carrying construction materials (simply by installing a pan or tray across the floor conveyor). As these units can carry substantial loads, care must be exercised to ensure that adequate truck components, axles, springs, and wheels are specified to carry the load. This is particularly important on combination units that are also equipped with snow plows (TAC, 2003).

Rear-Discharge Spreaders

Based on the premise that no salt particle should be placed dry onto the road surface, and that fine salt is the gradation of choice for prompt dissolving and melting, certain spreader design characteristics cater better to liquid and fine salt use in pre-wetted applications. The salt must be of a fine gradation in order for it to retain the brine moisture content and fine salt does not travel as easily on certain chain-type conveyor systems (TAC, 2003). For instance, Figure 23 shows the Ohio DOT trucks equipped with onboard wetting systems to apply brine or other liquids to dry rock salt as it leaves the vehicle (Ohio DOT, 2011).

Hoppers can be configured to allow the snowplow to carry and spread both liquid and granular materials in different amounts, and are becoming popular in areas sensitive to certain chemicals and materials (Akin et al., 2013). As shown in Figure 24, a more advanced version of such systems has been patented, which claims to enable "coordinated application of a plurality of materials to a surface simultaneously and in desired proportions and/or widths automatically and/or selectively" (Doherty and Kalbfleisch, 2005).

Figure 23 Pre-wetting equipment used by the Ohio DOT (Ohio DOT, 2011).

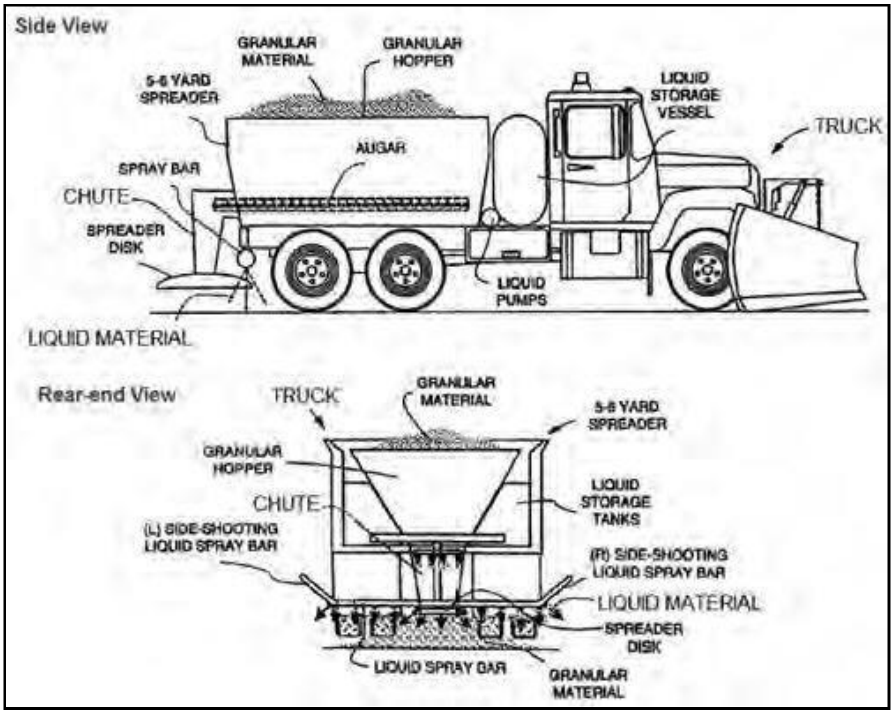

Figure 24 A system for synchronized application of a plurality of materials (solid or liquid) (Doherty and Kalbfleisch, 2005).

Liquid Application

Anti-icing

Anti-icing is defined as "the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a chemical freezing-point depressant" (Ketcham, 1996). Anti-icing is generally used ahead of a storm, or is applied to mitigate frost or black-ice either before or after the pavement is impacted. In general, liquid products are not considered practical for burning through thick snow and ice (Blackburn et al., 2004). Direct liquid applications can be applied over multiple lanes by trucks traveling at higher speeds (than conventional salt spreading) while maintaining operator and vehicle traffic safety.

The use of anti-icing has been increasing over the last decade (O'Keefe and Shi, 2005; Fay et al., 2014). According to a survey conducted by Fay et al. (2014), the majority of survey respondents (78%) indicated they have implemented anti-icing as a tool for reducing product application while maintaining or improving LOS. Anti-icing was also identified by the respondents as one of the ten most common practices that have been implemented or modified by their agencies.

Trucks used for straight liquid applications can range in size, to accommodate frame-mounted or slide-in tanks (TAC, 2003). Truck configurations may include:

- Small trucks with tanks ranging from those used as patrol vehicles (pickups to two-tons) to vehicles used for vegetation spraying or bridge washing in the off-season;
- Larger trucks used for water applications or calcium dust suppression applications in the offseason;

- Full-size, larger capacity tractor trailer tanker units used for long distance hauling in the off season (TAC, 2003).

Trailer-mounted tanks may also suit the liquid application requirement. Custom built units may be required for specialized high-speed, multi-lane, long-range applications. Mid-sized trucks used for direct liquid applications can also be outfitted with a plow and wing harness for subsequent use later in the storm. Tank, pump, and nozzle configurations, as well as the controller, will determine the preferred application practice and route range. Gravity-fed applications are also possible (TAC, 2003). The preferred applications make use of "pencil-sized" streams at 8 to 12 inches (200 mm to 300 mm) spacing. Use of stream applicators prevents misting or atomizing of the liquid that can then blow away before reaching the road surface. An alternative to pencil-nozzles is the use of tube trailers that run from each nozzle to the road surface and directly apply the liquid without the stream passing through the air. Considerations include, the tubes need to be adequately clamped, and the tubes will wear from contact with the pavement surface. Advantages include, the tubes provide better placement of liquid onto the road (TAC, 2003). The Alaska DOT produced a video titled *Anti-icing 101* that is a great source of information that defines anti-icing and presents information on how it is best used, as well as the economic, safety, mobility, and environmental benefits of using anti-icing (https://www.youtube.com/watch?v=TL9dvD1hyEQ). Figure 25 shows examples of anti-icing equipment.

Figure 25 Examples of anti-icing equipment used by Iowa DOT (Cornwell, 2010).

There is a risk of a decrease or loss of friction by up to 15%, caused by the mixture of warm winter temperatures (45° - 50°F), over application of products, precipitation on the road surface, and dirt and oil. However, these conditions most likely will only be present for a short time. In very rare cases, loss of friction or increased slipperiness has been reported from the use of salt brine, but that is more commonly associated with magnesium and calcium chloride brines (Wisconsin Transportation Bulletin, 2005).

Pre-wetting

Pre-wetting can be accomplished with equipment and spray tanks already in use on plow trucks. Pre-wetting can use as little as 8 to 20 gallons of brine per ton of salt (Table 6). Pre-wetting liquid can be applied directly on the spinner, or in the hopper using an auger, or both (TAC, 2003). In a recent case study, the use of brine to pre-wet salt resulted in a 15% reduction in product usage, as the pre-wet salt exhibited equivalent ice melting performance, better adherence to the road surface, and less loss to bounce and scatter (Fay et al., 2014). To further reinforce this, a Michigan DOT study reported material loss of up to 30% when dry salt is applied on dry pavement (Michigan DOT, 2012).

Slurry or High-Ratio Pre-wetting

Heavier applications of liquid chemical with rock salt, or mixed with abrasives can result in a “slurry” application that will burn through ice-pack and still provide some traction before actual break-up occurs (Akin et al., 2013). Recently developed spreaders allow for “high-ratio” or “slurry” salt application where rates of up to 70 gal (255 liters) of liquid is added per ton of salt, or a ratio of 30:70 liquid-to-solid by weight (Fay et al., 2013). This requires a large capacity of liquid onboard and adequate pumping capability that may not be possible or practical on a conventional retro-fitted unit. Areas that only have access to finer salt may find that the liquid component must be reduced since saturation can be achieved with less liquid. To solve this problem installing a crusher on the hopper to reduce the particle size may help (Fay et al., 2013). Figure 26 shows an example of some of the “slurry” units on the market today.

Figure 26 “Slurry” salt spreader units currently available (Cornwell, 2010).

Preliminary use and testing of the Stratos spreader allowed Maine DOT to reduce application rates by 25% due to the method used to calculate the solid salt to brine mixing ratio (Maine DOT, 2005). In addition to this improved melting and road conditions were noted by operators where the slurry material has been applied compared to lanes treated with conventional spreaders. While the purchase cost for Stratos spreaders may be higher than conventional spreaders, the materials saving realized from the slurry application method allow for the additional cost to be accounted for in 2 to 3 years of operation.

Electronic Spreader Controls

Currently, the vast majority of road agencies use spreader systems that are adjustable as to amount of material applied per lane mile. Spread rates can be manually reset by in-cab controls. The Minnesota DOT developed a spreader control that used on-vehicle friction sensors and vehicle location to automatically adjust a zero-velocity spreader (Erdogan et al., 2010). The controller that was developed was found to adequately apply granular materials up to speeds of 25 mph. A spreader controller “receives data from sensors, records this information in non-volatile memory, and transmits these data when the vehicle is in range of the base station” (Gattuso et al., 2005).

Modern spreaders use electronic groundspeed spreader controls to provide consistent, accurate application rates. The truck speed is monitored from the trucks speedometer drive, and the spreader output is adjusted to maintain a steady output at the set rate per mile (or kilometer) (TAC, 2003). Both open loop and closed loop systems are available to monitor material flow and provide increased accuracy of the spread rate (closed loop systems provide confirmation of the actual application rate). Electronic controllers automatically increase the output rate if a second spinner is actuated (if so equipped) to treat truck climbing and turning lanes. With some electronic units, calibration settings can be applied electronically using infrared controls (TAC, 2003).

Manufacturers can now provide units that record information about the amount of salt used, the time it was used, and the associated application rate, for analysis and control by the transportation agencies. Information that is captured can include: amount and type of material applied, gate position, run time, blast information, average speed, spread width/symmetry, etc. (TAC, 2003). Units are also available that incorporate global positioning systems (GPS) for automated vehicle location (AVL) and to identify where the material was discharged (either generating a passive history or a live transmission). There is currently no industry standard format in place for this information reporting; it is difficult to compare and combine the information from the units supplied by the various manufacturers (TAC, 2003).

A case study of Rhode Island DOT successful use of the closed loop spreaders is presented in Appendix D Case Studies.

Rearward Casting Spreaders (including Ground-Speed and Zero-Velocity Spreaders)

Casting material rearward has shown potential for salt use reduction by increasing the percentage of applied salt that is retained on the road and in the desired location on the road. Rearward casting is the rearward discharged of material at exactly the same speed as the spreading vehicle is traveling forward. The two velocity components cancel each other causing the material to drop on the road as if the spreading vehicle was standing still (TAC, 2003).

Zero Velocity Spreaders, a type of rearward casting spreader, can optimize the use of deicing material through the controlled distribution of the material (Figure 27). The material is dispensed at the same velocity of the forward motion of the equipment, which helps reduce bounce and scatter allowing more of the material to remain on the pavement and reduces salt runoff to the surrounding environment. Material savings of up to 40% have been reported (Nantung, 2001).

The zero-velocity spreader applies material in such a way that the material lands at a velocity that is zero relative to the road surface. The spreaders, which mix and spread liquid and solid deicers, use technology that enables plow trucks to apply products at speeds as fast as 45 mph, which increases efficiency and safety in terms of the speed differential between plows and traffic (Nantung, 2001). Research by Michigan DOT (2012) found that at speeds of 25, 35, and 45 mph material placement accuracy decreased with increased speed.

Figure 27 An example of zero-velocity spreader used by Pennsylvania DOT (Smith, 2014).

In 1994 and 1995, Iowa was the FHWA test site for the zero velocity spreader. At the time this was a new concept in roadway chemical spreaders. Minnesota DOT tested eight zero-velocity spreaders that same season and discovered savings of 30% or more. Zero-velocity spreaders allowed roads to be treated at speeds of 40 to 50 miles per hour while keeping up to 90% of the granular material on the road surface in the wheel tracks where it is most effective (Sharrock, 2002). Cost savings over two years were over $70,000 (1998 dollars). Nantung (2001) evaluated the use of zero-velocity spreaders to determine their effectiveness for the Indiana DOT. The primary benefit of the system was viewed to be the more accurate placement of material, producing significant potential for cost savings (Nantung, 2001). Maintenance downtime was identified as a potential cost of zero-velocity systems, as the hydraulic nature of the system could increase maintenance time compared to traditional spreader systems. Work conducted by Nixon (2009) found that three tested zero-velocity systems provided superior performance in terms of material retention on the road than the tailgate spreader or a chute system.

Fully Automated Spreading System

Recently completed research by Thompson Engineering Company (2014) identified the following options for levels of automation of spreading systems:

- Sensor-driven automation - a system that adjusts application rates based on truck travel speed or pavement temperature (likely using a closed-loop ground speed controller).
- Position-driven automation – a system where application rates are preprogrammed based on roadway characteristics (e.g., bridges, hills, intersections, etc.), utilizing GPS.
- Remote control automation – a system where a supervisor at a central location can remotely adjust application rates on a single truck or the entire fleet based on current or forecasted weather conditions, traffic, etc.

The identified options for fully automated spreading systems provide guidance for equipment manufacturers for future technology development. The researchers found some winter maintenance personnel to be skeptical of this technology and recommendation training and education if this technology is going to be implemented. Fully automated spreading systems have the potential to significantly reduce application rates by applying material at predetermined application rates, using sensor technology, meteorological conditions, and weather forecasts to adjust application rates; thereby putting less product into the environment.

Equipment Calibration

Figure 28 Spreader calibration (Kimley-Horn, 2010).

Calibration ensures equipment is operating optimally, so the right amount of material can be applied and accurately accounted for by storm and season (Figure 28). Proper and frequent equipment calibration is a best management practice in itself, and can lead to cost and material savings, as well as reduced product in the environment. The TAC (2013) recommends calibrating (new) equipment:

- at the time it has been acquired or installed,
- prior to the start of the winter season and points throughout the season,
- or when material calculations show a discrepancy (Fay et al., 2013).

Calibration should be completed for each application method for each product type - liquid, solid, and pre-wet products, etc. The equipment that controls the spread pattern should also be calibrated to match the recommended application rates and ensure proper placement. Application equipment should also be set up so that material is only applied in the travel lane, avoiding scatter or bounce that can lead to material leaving the roadway and impacting the roadside environment (Fay et al., 2013). In conjunction with calibration, spreader and sprayer equipment should be set up so that they are mechanically restricted from applying more than a maximum amount of material approved for a given set of routes (Fay et al., 2013). This will further ensure that excessive amounts of material are not used during anti-icing and deicing operations. Critical system components include the automatic ground speed controller, the flight chain or belt, the gate opening, the chute, the liquid nozzles (if applicable), the spinner and the deflectors (NYSDOT, 2011).

Spreader calibration is a straightforward process that can be completed with a minimum of tools and equipment. It consists of calculating the pounds or gallons per mile of material that should be discharged at different controller settings and vehicle speeds (Salt Institute, 2007). Spreaders must be calibrated individually, as the same models used on two different vehicles can have varying application rates. Different calibrations must also be made for different types of materials for different spreader units. The goal of spreader calibration is to ensure that materials are being discharged at appropriate rates, minimizing wasted materials and reducing environmental impacts, as well as providing cost savings. The equipment used for calibration can be quite basic and includes a scale for weighing, a canvas or bucket/collection device, chalk, crayon or other markers, and a watch with second hand (Salt Institute, 2007).

The Salt Institute's "Snowfighters Handbook" presents an overview of the steps and calculations employed in granular spreader calibration. The steps in the process include:

1. Warm truck's hydraulic oil to normal operating temperature with spreader system running.
2. Put partial load of salt on truck.
3. Mark shaft end of auger or conveyor.
4. Dump salt on auger or conveyor.
5. Rev the truck engine to operating RPM (at least 2000 RPM).
6. Count number of shaft revolutions per minute at each spreader control setting, and record.
7. Collect salt for one revolution and weigh, deducting weight of container.

For greater accuracy, collect salt for several revolutions and divide by this number of turns to get the weight for one revolution (Salt Institute, 2007).

Similar procedures should also be used when calibrating equipment that applies liquid materials.

The Clear Roads pooled fund developed a calibration guide as part of a larger effort examining ground speed controller units (Blackburn, et al., 2009). This spreader calibration guide was developed for both ground speed controlled and manually controlled spreaders used to apply granular and liquid materials. The guidelines discuss various aspects of calibration and outline different procedures to use in performing such activities. Guidance is also provided regarding when calibration/recalibration should be performed, including:

- When the spreader/controller unit is first put into service.
- Annually, before snow and ice control operations begin.
- After major maintenance of the spreader truck is performed and after truck hydraulic fluid and filters are replaced.
- After the controller unit is repaired or when the speed (truck or belt/auger) sensors are replaced.

- After new snow and ice control material is delivered to the maintenance garage location (Blackburn et al., 2009).

In general, the spreader calibration process can take between 10 minutes and 1 hour, depending on the number of staff involved, the type of controller (open or closed loop), the number of materials calibration is being done for, and even the age of the vehicle (new equipment requires added time to calibrate from scratch). Past experience from agencies has indicated that 1 to 3 staff is used to complete calibrations, with 2 staff members generally being most widely used (Fay et al., 2013).

Habermann (2012) identified the following benefits from conducting annual salt spreader calibration including:

- The financial benefit of reduced salt usage, and increased accuracy in budgeting and ordering.
- Identification of units with high salt usage that require either repair or replacement.
- The calibration information can be used as a performance measure for truck hydraulic systems and electronic controls.
- Accurate information on the amount of chlorides applied within an area or even on a specific snow route.
- The calibrated equipment ensures a quality baseline for determining cost of service and level of service.

A survey conducted by Kimley-Horn (2010) revealed that agencies that calibrated their spreaders realized an 8 - 14% reduction in salt and grit use. This survey emphasized that several crews reported fewer runs to get the same results, due to calibration efficiencies. A survey conducted for this project found that 90% of responding agencies calibrate the solid spreader mechanism each season, while 76% calibrate the liquid application equipment each season. Follow-up comments suggested that while agencies are working toward the goal of more frequent calibration, follow-up from supervisors and top-down encouragement, policies, or directives of calibration may be needed to ensure it is prioritized and actually gets done. Mixed results were reported on whether contractors calibrate their equipment each season. When agencies were asked if they had made any efforts to improve calibration of solid or liquid application equipment, 58% responded yes, but 39% said no. For this reason **we recommend increased or improved equipment calibration as an area for transportation agencies and their contractors to reduce the impacts of snow and ice control operations on the environment.**

Vehicle Washing

Figure 29 A tandem axel salt truck being washed off following a salt spreading operation.[2] (Photo courtesy of the City of Toronto).

The Transportation Association of Canada identified vehicle washing operation and maintenance practices to reduce loss of material and reduce impacts to equipment (TAC, 2013). A survey conducted for this project found that 93% of responding agencies wash snow and ice control vehicles and equipment soon after each event. For some vehicle washing was done at a designed washed facility, while for other the equipment was hosed off. TAC (2013) make the following recommendation for vehicle washing:

- Vehicle washing can remove residual solids to minimize salt concentration in wash water.
- Wash vehicles indoors or where water can be contained.
- Properly dispose of wash water or reuse for brine production.

When maintenance equipment is washed, the wash water may contain dirt, salt, oil, and or grease. Therefore, the wash water needs to be captured and directed into a storage tank. If local regulations allow the use of this water in the production of salt brine, the wash water then needs to go through a properly designed oil and grit chamber. Otherwise, the wash water needs to be directed to the sewer system or an effective storm water management pond where particles are allowed to settle and the salt concentration can be reduced by dilution from other receiving surface water (TAC, 2013). In a survey conducted for this project, respondents were asked if wash water was captured before entering the sewer system or open ground, and 51% responded no, while 38% responded yes, and 6.5% responded yes and that it was then used for brine making or pre-wetting.

Many state DOTs have implemented systems by which the water used to wash their vehicles is recycled and then used to make salt brine onsite instead of using freshwater. Reusing the salt laden truck wash water will allow for material cost saving in making the brine solution and conserve water use (Alleman et al., 2004). Additionally, the amount of salt released as runoff into the local sewer system or the environment is likely decreased.

[2] Washwater is collected through the grates in the floor and stored in underground tanks in the washbay. From that point the recycled wash water can be pumped through the brine machine and stored as salt brine or be blended with an another product.

In 2009, maintenance section staff at Colorado DOT, Region 5 Section 3 developed their own brine-making production process that allowed them to produce 24,000 gallons in 4 hours (CDOT, 2012). This process has evolved to use recycled waste water from the maintenance patrol barn floors drains and wash bay. The recycled water is filtered for heavy metals and other pollutants, and then mixed to make the brine. For this innovative work, CDOT awarded Section 3 the 2012 Environmental Award.

Of particular interest to this project and other DOTs, Virginia DOT conducted a research project to look into the option of using recycled runoff for its onsite brine makers, including a cost-benefit analysis comparing only the costs of using recycled runoff with the option of hauling away the runoff (Craver et al., 2008). Recycling wash water was determined to be feasible, with recovery of all capital costs within two to four years depending on the severity of winters and the average amount of salt used. Based on these findings VDOT has moved towards a goal of recycling its entire collected runoff, an estimated 60 million gallons (Salt Institute, 2010). In average years, the recycled water will provide all of the water needed for brine making, an added environmental and cost-savings bonus.

Indiana DOT (IDOT) conducted a field investigation for a proof-of-concept brine production system using recycled truck wash water at the Monticello Sub-District Unit (Alleman et al., 2004). It was determined that the experimental brine making system would go in one of the vehicle wash bays because of existing interior drainage and plumbing. An agreement was reached with the local municipalities if a spill occurred. The total cost of materials for a “do-it-yourself” system was $3,055 (2000 US dollars). They had a 750 gallon brine manufacturing tank, a 2,200 gallon brine storage tank, and the capability to make 1000 gallons of brine per hour. In 2000 to 2001 approximately 3,600 gallons of salt brine were produced for pre-wetting. Starting in 2003 the brine from truck wash water also started being used for anti-icing. By 2004, six of the 33 brine making facilities established by INDOT were set up to use truck wash water to make brine, both an economical and environmentally productive transition.

Corrosion Prevention Measures

Figure 30 A maintenance vehicle showing extensive corrosion (Mills, 2011).

Corrosion is described as the deterioration of materials due to the chemical reaction with the environment (Shreir et al., 1994). Corrosion is a natural process caused by the materials tendency to return to a more natural, stable condition. For example, in humid air, iron will rust and return to its original form, iron oxide. The process of corrosion is rapidly increased by the exposure of unprotected metals and alloys to a variety of chemical compounds. Modern equipment are composed of a wide array of metals such as: carbon steel, cast iron, aluminum alloys, magnesium alloys, zinc alloys, and copper and copper alloys. All of these metallic components are subject to damage due to corrosive media (Shi et al., 2013). For instance, steel can be corroded by deicers (Shi et al., 2013), zinc by dilute sulfuric acid, and magnesium by alcohols (NASA-KSC, 1994). Corrosion occurs in different forms such as rusting; pitting; galvanic reaction; calcium or other mineral buildup; degradation due to ultraviolet light exposure; mold, mildew, or other organic decay and etc. (US GAO, 2013).

Research has shown an enormous financial loss is imposed annually to the world economy due to the damage caused by corrosion of metals and alloys. In United States this amounts to more than $220 million per year (Revie, 2011). More than 15% of the costs associated with corrosion are preventable by using simple corrosion preventative strategies (Revie, 2011). A study for Oregon DOT found that as a result of metallic corrosion (including corrosion caused by chloride deicers), $37,000,000 worth of equipment assets saw a 20% reduction in service life (from 15 years to 12.5 years) and $2,000,000 worth of equipment assets saw a 50% reduction in service life (from 20 years to 10 years). In 2011, the deicer-corrosion related repairs of all WSDOT equipment was estimated at $246,118 (Shi et al., 2013). The corrosion-related repair costs and preventative maintenance (PM) costs averaged 4.3% and 12.9% of all repair costs (excluding PM costs), respectively. For the WSDOT (with an equipment assets worth $168,558,632), Shi assumed that it is possible to reduce the total cost of corrosion related to deicer exposure by 20%, if WSDOT can increase its investment in equipment corrosion management by 75% and focus more on proactive maintenance (vs. reactive maintenance). As such, the benefit/cost ratio of further improving corrosion management of DOT equipment can be estimated to be: (20% × approximately $30 million) / (75% × approximately $1 million) = 8. This ratio is conservative because it does not take into account the indirect costs of equipment corrosion (estimated at 20% of the direct costs) (Shi et al., 2013).

There are many technologies available to prevent or mitigate the corrosion of metals; after-assembly coatings, salt removers (also known as salt neutralizers), spray-on corrosion inhibitors, frequent washing, etc. (Shi et al., 2013). For example, washing is a very effective way to reduce corrosion of vehicles especially in the northern part of the country, where a lot of deicers are applied to winter roadways (Nixon and Xiong, 2009). Washing with water alone or soap and water together is insufficient for removal of residual salt, and the use of salt neutralizers is strongly recommended to prevent crevice corrosion (Monty et al., 2014). The effectiveness of salt neutralizers is alloy specific; therefore using the wrong salt neutralizer can even accelerate corrosion (Monty et al., 2014). For more information on corrosion please visit the ClearRoads website (for the project titled *Best Practices for the Prevention of Corrosion of Department of Transportation Equipment: A User's Manual*).

Weather and Pavement Equipment and Technology

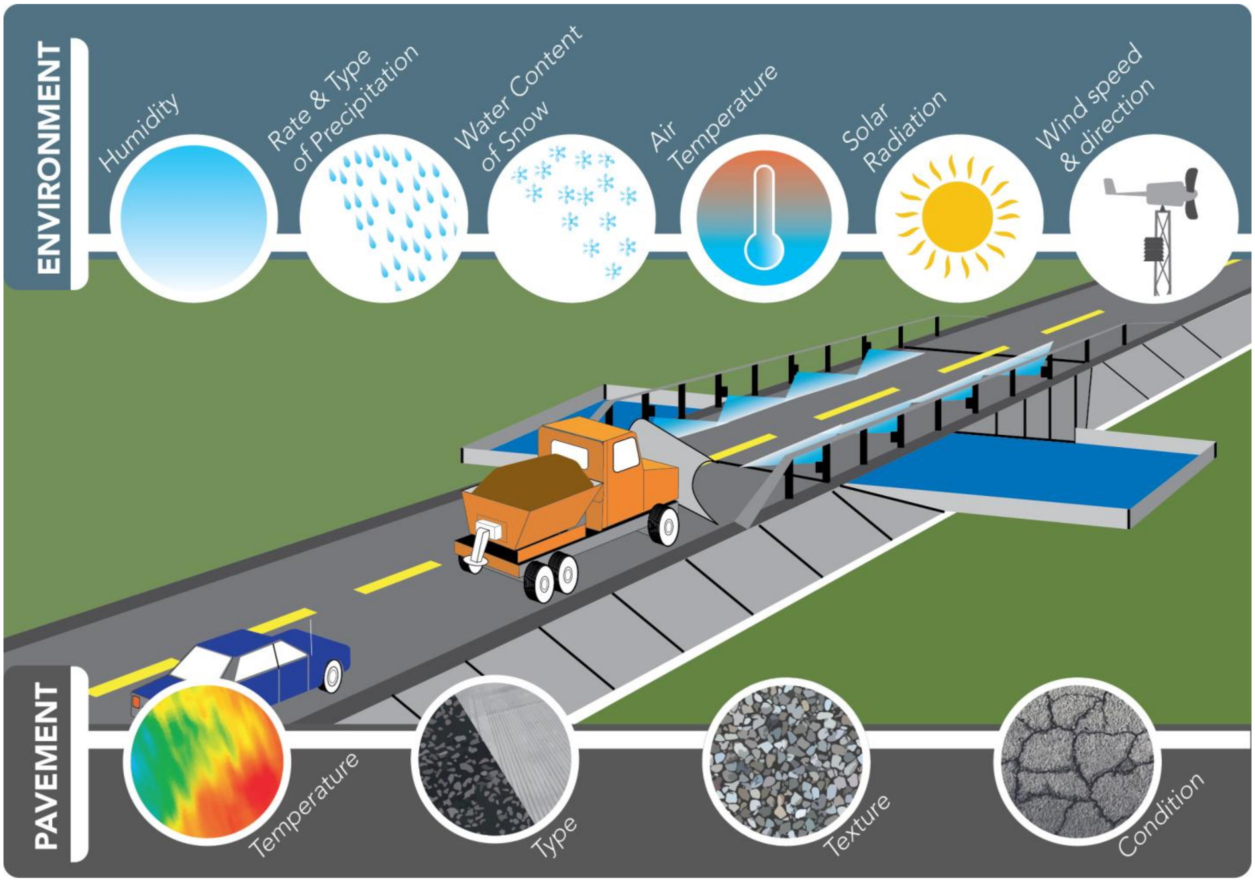

Figure 31 Environmental conditions and factors that influence pavement conditions and snow and ice control treatments (WTI).

Road Weather Information Systems (RWIS)

RWIS has been well documented through studies such as NCHRP Synthesis 344: Winter Highway Operations and the FHWA Test and Evaluation Project 28: Anti-icing Technology, Field Evaluation Report. The Strategic Highway Research Program (SHRP)-sponsored research in the early 1990s examined the potential benefits of improved weather information (Boselly et al., 1993; Boselly and Ernst, 1993) (Figure 32). The study analyzed the potential cost-effectiveness of adopting improved weather information (including RWIS and tailored forecasting services), which used a simulation model based on data from three U.S. cities. It indicated that the use of RWIS technologies can improve the efficiency and effectiveness as well as reduce the costs of highway winter maintenance practices. Ballard et al. (2002) identified a number of benefits available from RWIS in California, including the increased ability to obtain meteorologically accurate data and the potential for data dissemination and exchange with other agencies. Strong and Fay (2007) and Ye et al. (2009) found that Alaska's benefits from RWIS usage include fewer wasted materials and equipment along with other benefits such as reduced staff overtime, less misdirected staff time, and improved roadway LOS.

Figure 32 RWIS (photo courtesy of Kansas DOT).

A study is currently underway in Italy to examine the environmental benefits of implementing advanced RWIS. The research aims to quantify the impact of deicers on aquatic systems and air quality, and empirically evaluate the environmental gain due to the advanced RWIS. The CLEAN-ROADS project (http://clean-roads.eu/home) will test a state-of-the-art RWIS fully integrated with MDSS along with an environmental monitoring system (Pretto et al., 2014). In addition, a new cost-benefit tool has been developed by Vaisala, Inc. to provide an estimate of cost-benefits due to RWIS and MDSS.

Numerous studies have reached the consensus that the appropriate implementation of RWIS is cost-beneficial. McKeever et al. (1998) developed a life cycle cost-benefit model for RWIS using a site in Abilene, Texas. Direct savings (benefits) included reduced winter maintenance costs (patrol, labor, equipment, and materials), while indirect savings included reduced liability risk, accidents, pollution, and travel costs. It was found through the model that a savings of approximately $923,000 could be accrued over a 50 year period. Alberta Infrastructure and Transportation (2006) studied the costs and benefits of deploying RWIS in Alberta (2005-2006) and anticipated that RWIS would deliver $5.38 in benefits for every dollar spent. The estimated cost savings are derived from the efficient usage of winter maintenance equipment and de-icing chemicals, reduced rate of vehicle collisions, and efficient use of departmental staff. A study conducted in Idaho found a 40% reduction in material savings due to the introduction of RWIS (ITD, 2009). Based on these findings, Veneziano et al. (2014) assumed a conservative 15% in material savings and examined the costs and benefits of deploying a new RWIS for the state of Iowa. The results estimated a benefit-cost ratio of 3.8 for the agency alone (Iowa DOT) and a total benefit-cost ratio of 45.4 (Veneziano et al., 2014). Yet another recent study by the Michigan DOT (2010) found that RWIS helps in significantly reducing motorist travel time, by reducing traffic volumes. Other benefits of RWIS include reductions in traffic crashes and operating costs.

A survey conducted for this project found that 90% of respondent's transportation agencies have improved or expanded upon weather forecast and current condition monitoring sources. About 77% of respondents indicated that their agencies had expanded the RWIS or weather station networks. Based these findings the use of weather and pavement information and forecasts appears to be increasing to support winter maintenance operations.

Maintenance Decision Support System (MDSS)

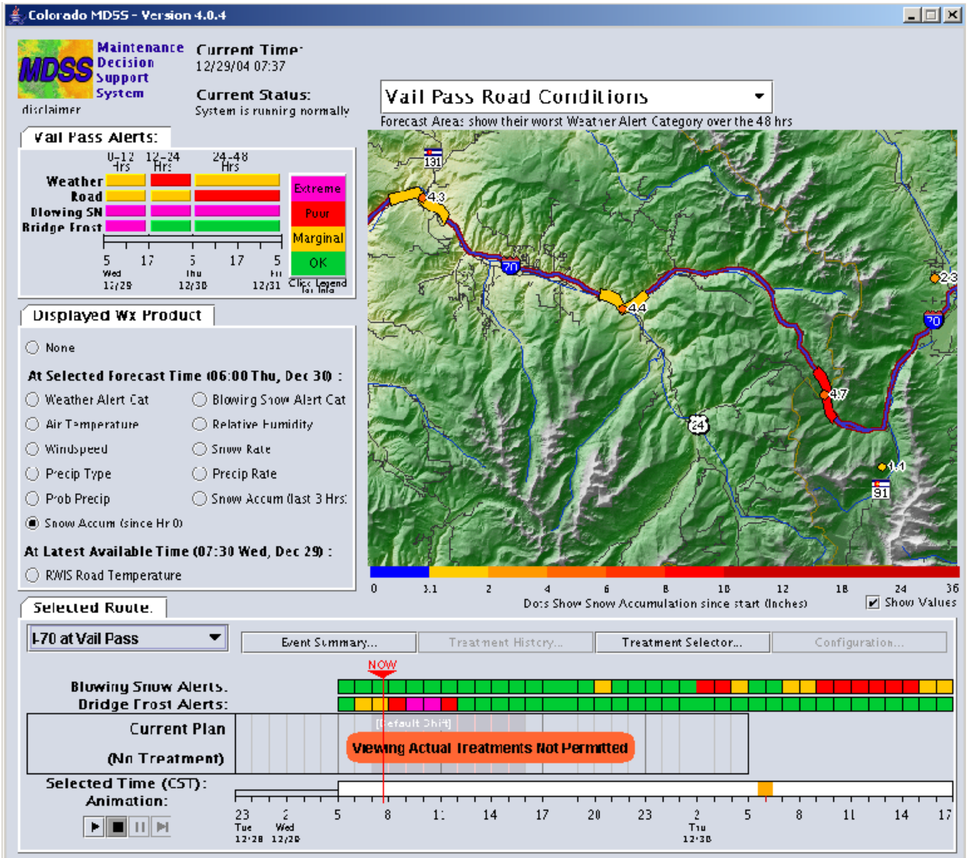

Figure 33 Maintenance Decision Support System (MDSS) (Paniati, 2007).

In addition to RWIS, the Maintenance Decision Support System (MDSS) has become increasingly more popular as a tool to provide accurate and reliable weather information to transportation agencies (Venner, 2003) (Figure 33). A RWIS integrated with MDSS assists maintenance personnel in the decision making processes of determining roadway maintenance activities. MDSS systems provide real-time and post-storm analysis to evaluate materials used, rate of application, and timing of application. The utilization of RWIS and MDSS can provide valuable information and be used to assist transportation agencies in determining the most effective strategies with reduced impacts and increased level of service (Mass DOT, 2012). MDSS software uses collected weather, pavement, traffic, and environmental data to develop road weather forecasts and make suggestions on products, applications rates and frequency of repeat applications or snow removal based on defined rules of practices. After each treatment occurs, and the information is input into the system, updated treatment options are provided.

A survey conducted for this research effort asked if responding agencies use MDSS. About half or 55% responded that they do use MDSS, and comments included that MDSS is being piloted in some states but is not used statewide. For those agencies that responded that they do use MDSS, the majority of users use the forecast (over 90%), suggested product and application rates (over 80%), as a management tool (75%), and to a lesser extent to review storms (over 55%), and as training tool (30%). This suggests that many of the agencies using MDSS are aware of its many uses and features. The remaining 45% responded that they are not using MDSS, and did not provide any follow up comments.

In general, MDSS is considered beneficial for the environment, safety, and cost reduction. Numerous studies have revealed that MDSS aids winter maintenance personnel in the decision making process and produces a significant benefit. A study conducted in Indiana found that by using MDSS, the salt savings in one winter (2008-2009) was about 228,470 tons ($12,108,910) and when normalized for winter conditions based on storm severity, total salt savings were 188,274 tons ($9,978,536) based on salt prices of $53/ton (McClellan et al., 2009). The observed decrease in salt use, or salt savings, reduces impacts on the environment. A case study conducted in Maine tracked 12 winter storm events and looked at the use of the MDSS as a maintenance tool, versus not using a MDSS (Cluett and Jenq, 2007). The results of the case study for the MDSS system were positive and strongly support future implementation of MDSS for winter maintenance operations. However, the study also cautioned that receiving too many alerts may be distracting at times and can be misleading during important warnings. A cost-benefit analysis of MDSS implemented in New Hampshire, Minnesota, and Colorado identified benefits as reduced material use, improved safety and mobility, and significant cost savings (Ye et al. 2009). The benefits were found to outweigh the costs associated with the technology in all three states, with benefit-cost ratios ranging from 1.33 to 8.67 due to varying conditions and uses of resources. Identified benefits also included reduced use of maintenance vehicles, and savings in material usage and fuel. A cost-benefit analysis of MDSS use over two winter seasons (2007 – 2009) in the City and County of Denver, Colorado found that MDSS is more effective in crew deployment compared to treatment mode (Cluett and Gopalakrishna, 2009). A recent case study developed a new benefit-cost analysis tool to determine the effectiveness of RWIS and MDSS. The case study examined the potential use of MDSS in one sub-district in Indiana found an agency benefit-cost ratio of 1.6 and the estimated total benefit-cost ratio of 3.1. In order to develop the tool, the study used a 15% reduction for both material savings and reduced crashes (Veneziano, 2014).

The Road DSS calculator (RDC) enables the user to enter the infrastructure and cost values, and the embedded algorithms in the RDC will provide a breakdown of direct and indirect cost savings for both the road authority and local community. Interestingly, RDS also estimates the environmental benefits such as the salt reduction, greenhouse gas creation reduction, and polluting emissions reduction due to the RWIS and MDSS (Bridge, 2014).

Fixed Automated Spray Technology (FAST)

Figure 34 A FAST system in action (Muthumani et al., 2014).

FAST technologies remotely sense the potential of frost or ice formation on pavement in light of atmospheric and pavement data from RWIS or an Environmental Sensor System (ESS), and apply anti-icers in a timely manner (Figure 34). There are sensitive structures and critical segments of the roadway network that need to be free of snow and ice in a timely manner, before the winter maintenance vehicles can travel to the site and treat them. During the winter season, accidents often occur on bridge decks or shaded areas where the surface temperature tends to be lower than the adjacent areas, potentially creating hazardous driving conditions such as frequent frost and black ice (Friar and Decker 1999, Barrett and Pigman 2001). With conventional mobile operations, it is difficult and costly to maintain prescribed levels of service and maintain traffic safety for locations far from maintenance garages (Christillin, et al. 1998), or in areas that experience high traffic volumes. In contrast, FAST is a technological solution designed to provide quick, effective delivery to high-risk locations prone to icy conditions and/or with high traffic volumes, while reducing the amount of labor and materials needed through timely prevention of ice formation/bonding or snow packing (Muthumani et al., 2014).

A complete FAST system includes a spray subsystem that delivers the anti-icing chemical onto the road surface and a control subsystem that triggers the spraying action. It is noted that there are two distinct hydraulic system design philosophies of FAST systems. The first (referred to as Type I), more common in North America, utilizes a pump located in a pump house to deliver the fluid to the nozzles some distance away. The delivery pressure needs to be rather high to overcome the hydraulic head loss in the delivery lines. In these systems the flow is metered by the size of the nozzle orifice. The reliability of these systems becomes more problematic as the nozzles get farther away from the pump. The second design philosophy (referred to as Type II), common in European systems, the pump at the pump house is used to fill a small pressurized vessel (tank) located in close proximity to each individual nozzle. When the signal to activate is given, a valve on the small pressure vessel is opened and the liquid is discharged through the spray head. This reduces the effect of the head loss, delivering a fixed amount for each activation (Ye et al., 2013).

A survey conducted for this project asked respondents if they use automated sprayers or FAST systems on bridge decks to prevent frost and ice. A limited number of agencies responded that they do use these systems (32%). Follow up comments suggested that some agencies tested these systems but no longer used them or do so in a very limited capacity.

A conceptual study for the MnDOT indicated that eliminating even one accident per year would provide a benefit-cost ratio greater than 1 for two automated systems installed at bridge locations (Keranen 1998). Another study indicated a benefit/cost ratio of 2.36 for a proposed FAST installation on a section of I-90 in Washington State, assuming a 60% reduction in snow and ice-related accidents (Stowe 2001). A couple of studies have documented positive results of FAST deployments in Europe. The largest FAST system in Europe was developed on an 8.15 km (5 mile) stretch of the A9 Lausanne bypass in Switzerland. A detailed economic analysis of the FAST system indicated a benefit cost ratio of 1.45. Similar results were found in Germany, where a FAST system that was installed in 1983 revealed a benefit-cost ratio of 1.9 (Bell et al., 2006). A FAST system (with a Type I hydraulic system design) was installed in 1984 along a 3.7 mile (6 km) long, topographically and climatically challenging road section between Hagen and Lüdenscheid in Germany. The benefits regarding road safety were assessed by considering the annual number of accidents due to winter conditions (e.g. snow and icy patches) in two seven-year periods before and after the system installation. The number of accidents was reduced by 58% and traffic congestion was also reduced, leading to an estimated benefit-cost ratio of 1.9 (Gladbach 1993). An analysis by the German Federal Highway Research Institute indicated a similar benefit-cost ratio for the various FAST systems deployed on the German Federal road system (Moritz 1998).

Another FAST system (with a Type II hydraulic system design) was installed along a 5 mile (8-km) long road segment of a six-lane highway in Switzerland that had an average daily traffic (ADT) volume of 70,000 vehicles per day (vpd). The salt brine, used in the FAST system, was stored in four main (3,170 gal (12,000 L)) and eight intermediate (528 gal (2,000 L)) tanks. The system could be either manually triggered, or automatically activated when the ice detection system of twelve active sensors detected ice or gave advanced warning of ice formation. A pre-installation analysis indicated a benefit-cost ratio of 1.45, considering capital, interest and depreciation costs, material costs, and savings due to accident reduction, and avoided mobile maintenance operations (Zambelli 1998).

The first FAST system in Canada (with a Type I hydraulic system design) was installed along a 550 ft (168 m) interchange ramp with an ADT of 3,000 vpd in Ontario. The sensors in place detected the roadway and atmospheric conditions and either sounded an alarm so that the maintenance personnel manually triggered the sprayers, or the spray operations were activated automatically. No winter weather-related accidents had occurred since the FAST installation (Pinet, et al. 2001). It also resulted in benefits to the environment by the elimination of chloride road salt use. Chemical costs for the potassium acetate used in the FAST, however, were approximately twice as much as anticipated ($12,000 (actual) vs. $5,000-7,000 (anticipated) per year), partly due to unnecessary spraying of the FAST. The estimated benefit-cost ratio was 1.13 and the investment was recovered in the first year of operation.

The installation, operations and safety benefits of a FAST system (with a Type I hydraulic system design) deployed on a 2,000 ft (609 m) long, six-lane wide Interstate 35W bridge over the Mississippi River in Minnesota was analyzed by MnDOT in 1999 (Johnson 2001). The system included eight parapet-mounted nozzles and 68 flush-mounted disc spray nozzles, as well as 38 valve units each controlling the chemical flow of two nozzles. Potassium acetate was the anti-icing chemical stored in a 3,100 gal (11,734 L) tank. Comparing the 2000-2001 winter season data with the climatologically similar 1996-1997 winter season, a 68% reduction in winter-related accidents was reported, at least part of which was attributable to the FAST system. The other benefits include reduced traffic congestion associated with winter crashes, improved productivity by lowering material costs and enhancing winter maintenance operations. For the $538,300 FAST installation, a benefit-cost ratio of 3.4 was estimated based on the cost savings assigned to reduced crashes and delays.

The North Dakota DOT (NDDOT) has installed two FAST systems (with Type I hydraulic system design) since 2002 at I-29 Buxton Bridge (near Buxton, ND) and I-94 Red River Bridge between Fargo and Moorhead, ND (Birst and Smadi 2009). The ND DOT district staff considered the two FAST systems to be very effective in treating the bridge structures, especially for frost conditions. Both systems were found to operate as expected in terms of spraying at the appropriate time, applying the proper amount of chemical agent and achieving the proper system pressure. The reliability of the systems was estimated to be 95% (communication problems did occur). Moreover, significant crash reductions were observed at both locations after the FAST systems were installed, with a 66% reduction at the Buxton Bridge location and a 50% reduction at the Red River Bridge location. Correspondingly, the benefit-cost ratios at these two locations were 4.3 (with 20 year period, net benefits of $1,257,869) and 1.3 (with 20 year period, net benefits of $675,184), respectively.

Sensors to Improve Snow and Ice Control Operations

Pavement sensors monitor surface conditions and can provide data for warning systems (e.g., ice warning). They can provide information for use in producing forecasts of pavement conditions based on temperature measurements. Pavement sensors can also measure chemical concentrations, providing information that can help determine when additional treatments should be made (Fay et al., 2013). Many available sensors also can measure the freezing point of the solution present on the roadway, providing insight into when diluted products may be likely to refreeze. Collectively, the information generated by pavement sensors can be used to monitor conditions, for planning, and carrying out treatment strategies (Fay et al., 2013).

There are two general types of sensors used to measure roadway weather conditions, invasive and noninvasive sensors. The invasive sensors, more commonly known as in-pavement sensors, are installed in the pavement, level with the road surface, and can use many different sensing technologies for determining roadway conditions. Noninvasive sensors are typically installed on the roadside or somewhere over the road surface and use non-contact means of monitoring weather surface conditions, this category includes mobile or vehicle mounted sensors (Fay et al., 2013).

In-pavement sensors use the dielectric characteristics of the condition present on the surface of the sensors to determine if the road is dry, damp, wet, or icy and to detect the presence of deicers (Schedler, 2009). The conductivity of the liquid present on a sensor can be used to determine the freezing point temperature of that liquid; this type of sensor is known as a passive sensor. An active sensor is one that actively heats or cools itself to directly measure the freezing point of a liquid present on the sensor (Jonsson, 2010). Some in-pavement sensors also utilize microwave radar to measure the depth of water present on the sensor (Schedler, 2009).

Non-invasive sensors can be mounted apart from the road surface, either above the roadway or at the roadside, handheld, or mounted on vehicles, and use spectroscopic methods, thermal radiation, or infrared radar methods to determine surface weather conditions from a distance. Infrared radiation and thermal radiation are measured to determine the temperature of the road surface. Spectroscopic measurements are used to determine the roadway surface condition (dry, damp, wet, ice, etc.) remotely.

A survey conducted for this project found that of while many of the responding transportation agencies use RWIS (over 80%) for real-time pavement condition observations, 90% used truck-mounted pavement temperature sensors, over 60% used in-ground pavement temperature sensors, and about 60% used CCTV or traffic cams. Other comments provided by respondents included the use of live patrols, MDSS, and observations from State Police and DOT personnel to provide real-time pavement condition information.

Friction sensors

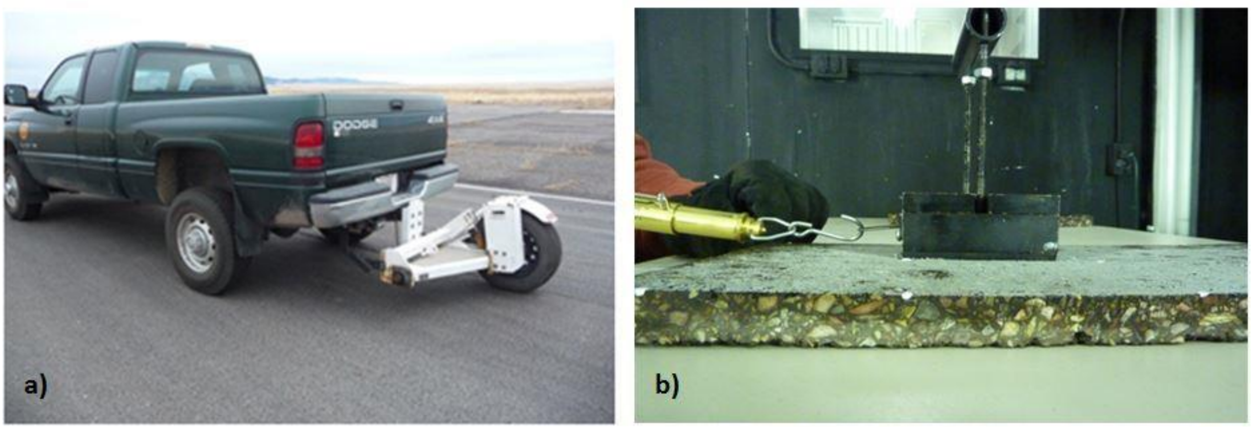

Figure 35 a) Halliday RT3 Grip Meter, and b) static friction tester.

Application of deicers is a key tool to improve the friction on roads affected by snow and ice. Deicers melt snow and ice and prevent, weaken or break the bonds between snow/ice and the pavement, facilitating removal by plows. The main function of deicers is to increase the friction coefficient between vehicle tires and the road surface. Friction is responsible for keeping vehicles on the road, especially when accelerating, braking, or turning. The presence of snow and ice can reduce friction to such levels that “almost any braking or sudden change of direction results in locked-wheel sliding and loss of vehicle directional stability” (Hall et al., 2009). Friction coefficient has been proven to be a useful tool in evaluating the performance of deicers. There are several options available to measure friction on roads. Most devices utilize an extra wheel that is either installed on a vehicle or towed behind a vehicle. Slip speed is a critical factor in friction measurements because the friction changes as the slip speed changes. Angled measuring wheels have also been used to quantify friction based on side force components. The Halliday RT3 Grip meter (Figure 35a) is one relatively common device used to measure sideway force friction coefficient. A study conducted for the Aurora program found the RT3 Grip meter to be a reliable tool for distinguishing changes in road grip with good fidelity and repeatability. The study also suggests combining GPS-Video positioning system and/or AVL technologies with the RT3 device to measure grip/friction as a deicer performance measure (Tilley et al., 2012). Static friction testers are more simplistic tools for measuring friction that can be used in the laboratory or field. This device uses the force required to initiate movement to calculate friction, and as shown in Figure 35b has a neoprene rubber pad to simulate friction between a tire and pavement.

Recent advances in intelligent transportation systems (ITS) and road weather information systems (RWIS) have made non-invasive road weather sensors viable options to estimate friction coefficient. Non-invasive sensors use infrared spectroscopy principles to measure road surface conditions from above the roadway and estimate friction using algorithms based on the presence of snow, ice or water. Work by Jonsson (2010) found that friction metrics can be calculated from the temperature and surface conditions. A recent study to test the reliability of the non-invasive friction sensors (Vaisala DSC-111) found that grip levels were found to be highly correlated with the coefficient of static friction (Ewan et al., 2013) (Figure 36a,b).

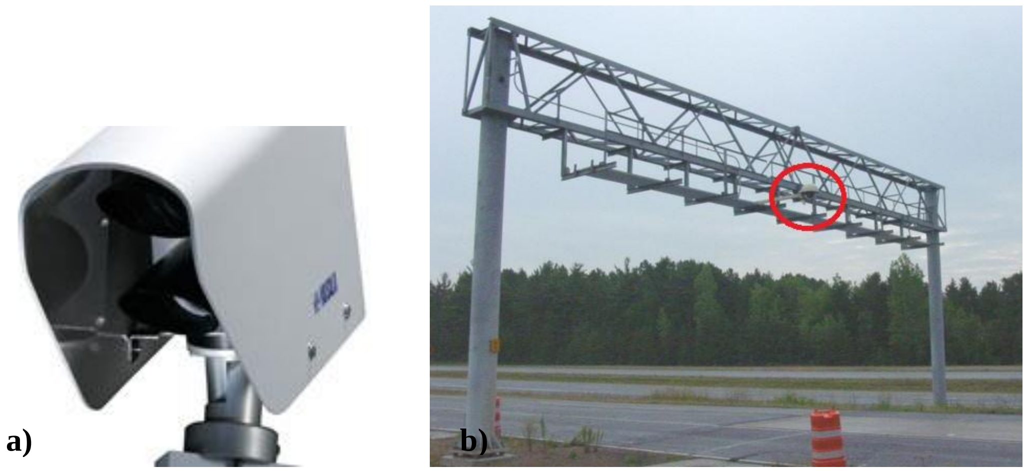

Figure 36 a) Vaisala DSC-111 sensor (www.viasala.com), b) infrared road ice detection (IRID) sensor (Rios-Gutierres and Hasan, 2003).

Three different styles of use can be considered for friction sensors (Nixon, 1998):

- as a direct and immediate measure of road surface quality,
- as a source of road user information and/or warnings,
- as a means of controlling chemical application.

In a survey conducted by Nixon (1998) on the relationship of friction to crash rates, traffic volume and speed, a cost-benefit ratio of 3.38 was found for using the friction sensors in winter maintenance operations. This means every dollar spent on friction sensors would save more than three dollars in expenses. In addition, a reduction of annual salt usage of 25% was estimated.

A survey conducted for this project found that 30% of responding transportation agencies use friction as a tool to monitor pavement condition. Some respondents indicated that friction is only measured at RWIS stations, and others indicated they are looking into using this technology.

Colorado DOT is currently testing the use of non-contact friction measuring devices to assess winter maintenance product performance. Since installation on traffic poles, CDOT personnel have noticed an initial performance difference between winter maintenance products, as well as a difference in bare pavement regain time. Bare pavement regain time is the performance measure used by CDOT to assess product performance and is an assessment of longer-term product performance. This suggests that the non-contact friction measurements provide a good estimate of both short and long-term product performance. Based on these results, CDOT has been able to reduce winter maintenance product application rates for one of the products and still satisfy the bare pavement regain time performance measure that is targeted for CDOT's current funding level. Similar research is being conducted at four other sites in the US and Canada (Fay et al., 2013). An ongoing research project by CDOT called *Highway Deicing Products and Applications Best Practices* is measuring pavement friction and trying to correlate this data with deicer type and application rate. The results of this research should be available in early 2017.

Chloride, Residual salt, and Salinity sensors

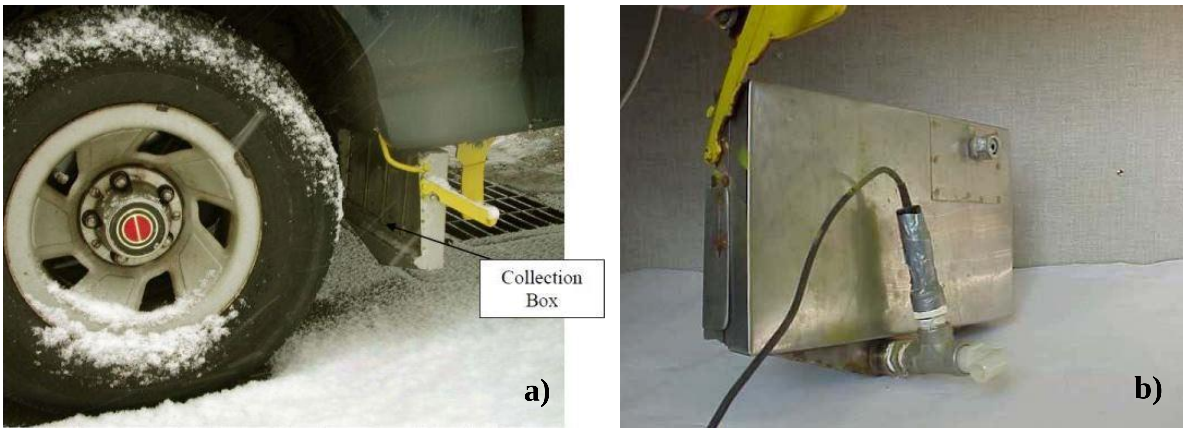

Figure 37 a) photograph of collection box and b) rear-view collection box with conductivity probe (Garrick et al., 2002a).

Salinity sensors can be used to monitor the residual salt concentrations on the road surface, helping maintenance managers make educated decisions related to chemical application and reapplication (Ye et al., 2012). Salinity sensors have been traditionally employed in road weather information systems (RWIS), which focus on the pavement conditions and meteorological conditions of a small sample area (typically less than 0.1 sq. ft.) (Fleege et al., 2006; Strong and Fay, 2007). The working mechanism of such in-pavement salinity sensors generally entails the measurement of brine conductance, a passive approach, or freezing-point depression, an active approach (Turune, 1997). There are also portable instruments, such as the SOBO-20 (portable but not vehicle mounted), that sprays a water and acetone mixture onto the enclosed pavement surface area and subsequently calculates the salt quantity based on the electrical conductivity of the fluid (Lysbakken and Lalague, 2013). More recently, non-invasive sensors that rely on algorithms to estimate the salt concentrations on pavement have been used (Bridge, 2008).

Potential advantages of using on-vehicle salinity sensors include monitoring the concentration of the solution on a road surface along entire stretches of roadways, which allows for more accurate application rates, and integrating measurements from salinity sensors with automatic spreader controls to apply the right amount of product in the right place. There are two general methods for on-vehicle salinity sensors, measuring the conductivity of collected tire splash (Garrick et al., 2002a, 2002b) (Figure 37a,b) and the refractive index of an aqueous solution atop of the road surface (Iwata et al., 2004; Mexico Company, 2010). Inexpensive handheld salinity measuring devices are also available, but may pose safety issues. An on-going research project with the Aurora consortium is investigating options for mobile salinity sensors and field testing. This work should be completed in early 2017. Preliminary findings suggest that mobile salinity sensors available in Japan, Europe, and prototypes in the US may be viable options for integration into winter maintenance operations.

Mitchell et al. (2004) investigated the decay of residual deicer on several pavement types in Ohio and then used the field and laboratory data to predict the amount of residual chemical on three types of pavement as a function of time and traffic. These values were then used to predict the ideal application rate for given precipitation conditions. Lysbakken and Norem (2011) and Blomqvist et al. (2011) developed models to account for processes and factors that define the change of salt quantity on road surfaces after salt application.

In addition, Atkins (2007) identified two non-contact methods of measuring salinity on pavement: laser-induced fluorescence (LIF) (Hammond et al., 2007) and laser-induced breakdown spectroscopy (LIBS) (Nail and Kumar, 2004). Both LIF and LIBS have been successfully used in architectural, defense and medical applications. These technologies have the potential for development into viable traffic-speed residual salt measurement techniques. However, some important issues need to be addressed before these techniques are used in monitoring residual salt concentrations on pavement. These include operator and road user safety related to exposure of the laser discharge (in particular with LIBS), and the need for the device to measure salinity on both wet and dry surfaces.

Pavement Temperature and Thermal Mapping Sensors

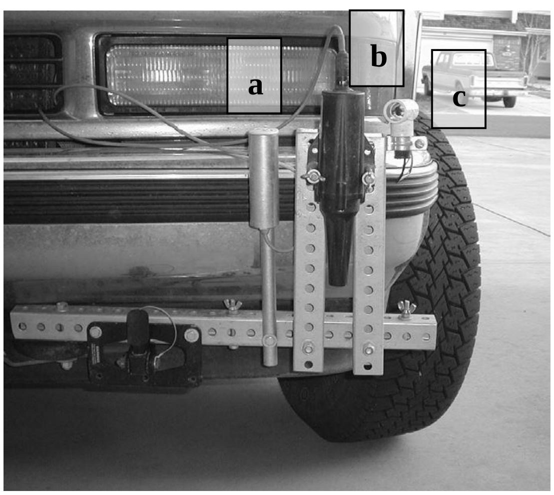

Figure 38 A surface temperature measurement devices a) Roadwatch™ IR sensors (Ye et al., 2012) b) control products IR sensor, and c) air temperature sensors.

Surface temperature measurement devices generally use vehicle-based, non-contact infrared (IR) sensors to absorb infrared emissions from the road surface, the quantification of which provides an indirect measure of pavement surface temperature. Such devices typically consist of an IR sensor, a processor, and a display unit. The entire sensor assembly can be mounted on the maintenance vehicle to allow continuous and rapid monitoring of pavement temperature (Figure 38) (Tabler, 2004). Advantages of using such devices include the ability to measure the exact surface temperature along an entire roadway network and having real-time road surface temperature data to support decisions regarding chemical applications. This leads to optimizing the use of chemicals and improving the level-of-service experienced by roadway users. Surface Patrol™ manufactured by Control Products, Inc. (Vancouver, WA) and RoadWatch™ manufactured by Sprague Devices (Michigan, IN) are the two most commonly used IR pavement temperature sensing products (Scott et al., 2005).

A study sponsored by the Aurora Consortium evaluated various models of in-pavement temperature sensors in varying environmental conditions, as well as two vehicle-mounted temperature sensors the Control Products 999J and Sprague RoadWatchTM. One group of tests analyzed the acclimation time of a mobile sensor as it is moved from a warmer environment to four colder environments. The goal was to simulate conditions in which maintenance vehicles transition from a heated garage into a colder environment. The test results indicated that on average the Control Products sensors took 20 minutes to acclimate within 1.8°F (1°C) of the actual temperature of the road surface, whereas the Sprague sensor took approximately 39 minutes to achieve the same accuracy. As expected, the greater the initial temperature difference between the pavement and the sensor, the longer the acclimation time for the sensors (Scott et al., 2005).

Aurora also conducted tests to determine the effect the varying ambient temperatures have on the mobile sensors. Initially, the two mobile sensors were configured to measure the temperature of an ice/water bath at room temperature (65°F or 18°C) and their measurements were allowed to stabilize. Measurements were also taken when the two sensors and the ice/water bath were moved to a chamber at a temperature of 32°F (0°C). When moved into the colder chamber the Sprague RoadWatch™ sensor initially overcompensated for the change in environment and underestimated the surface temperature, and then corrected itself but overestimated the surface temperature, before reporting the actual room temperature. The Control Products sensor had a shorter adjustment period before it was accurately reporting the temperature (Scott et al., 2005). Similarly, another study pointed out that the Control Products sensor has an external air temperature sensor whereas the Sprague sensors housing has a built-in air temperature sensor, sheltering it from the ambient conditions. Air temperature is a key input for the algorithm to calculate the pavement temperature, the error in air temperature measurement could lead to an error in pavement temperature measurement. For this reason, the Sprague sensor may not provide as accurate a measurement of air temperature as the Control Products sensor, or may take longer to acclimate and to report the actual temperature (Tabler, 2003).

A field trial evaluation was also conducted with the mobile sensors mounted on the front bumper of a test vehicle. From both laboratory and field tests, it was determined that the pavement type has a noticeable effect on the measurement accuracy of the mobile sensors. On average, mobile sensors were 0.9°F (0.5°C) more accurate on concrete pavement than on asphalt. The study also concluded that the overall performance and accuracy of vehicle-mounted sensors was similar to in-pavement sensors (Scott et al., 2005).

In 1999, the Missouri DOT conducted a research project to evaluate the benefits of the Sprague RoadWatch™. The project included a laboratory test as well as a field evaluation of 50 mirror-mounted pavement temperature sensors distributed throughout the state. The laboratory test showed good sensor accuracy. Materials savings of $185,119 during the winter of 1998–99 was estimated, not including the savings from personnel and equipment. Conservatively assuming one year as the life of the sensors, the project team calculated the benefit–cost ratio to be 9.49.

Thermal mapping, or thermography, can also be used to determine thermal profiles of road surfaces. This approach can be used to infer pavement temperatures between sensor locations, as well as for forecasting temperatures at given points. Thermal mapping can be accomplished by using inexpensive hand-held radiometers or vehicle-mounted sensors specifically designed to measure pavement temperature. Thermal measurements are typically made in the early morning to ensure that there is minimal change of temperature during the measurement process. Data from thermal mapping has been used to forecast pavement temperatures in locations without RWIS stations, to site RPU stations, and to aid in the development of treatment strategies (Fay et al., 2013).

On-Board Freezing Point and Ice-Presence Sensors

Figure 39 Frensor device mounted on the highway maintenance concept vehicle (Andrle et al., 2002).

On-board freezing point and ice presence detection systems are not as well established as some of the other technologies reviewed and have not been widely deployed for field use. There are many potential advantages of using such systems, including the ability to map the road surface conditions along an entire roadway network and detect localized ice patches as well as obtaining greater knowledge of the effects of deicing and anti-icing chemicals on the road surface (Ye et al., 2012). One promising and relatively well-developed vehicle-mounted sensor technology used to measure freezing point and ice presence is the Frensor, developed by Aerotech Telub (Ostersund, Sweden) along with the Swedish National Road Administration. Frensor was successfully installed and tested on the highway maintenance concept vehicle (Figure 39) (Andrle, 2002).

The sensors are mounted behind the vehicle's wheels where the tire spray is collected and then isolated by closing the system using a pneumatic bladder. Similar to the in-pavement active sensors, the measurement is determined through a series of cyclic warming and cooling cycles of the sample. The time it takes to complete a measurement cycle varies with respect to the pavement condition (i.e. dry, wet or snow/ice covered). The measurement results are reported as follows (Ye et al., 2012):

- Freezing point temperature – if the amount of liquid is sufficient to allow determination of freezing point temperature.
- Moist – if a freezing point is detected and the amount of liquid is insufficient to allow the determination of freezing point temperature.
- Dry – no freezing point is detected.

After determining the freezing point of the sample, the test sample is removed using pressurized air, and a new sample is collected. A computer program is used to log the data, present the data to the operator, and transmit the data (Ye et al., 2012).

The greatest concern with the Frensor unit was the need to manually clean the sensor heads during field use. Based on this, it was determined that an automatic cleaning device, which can also alert the operator of a dirty sensor, was needed. The whole system was not tested for repeated accuracy, but based on the test results the team concluded that the system is generally reliable (Missouri DOT, 1999).

Other conceptual designs for measuring freezing point and ice detection have been proposed, but are still under development. Tran (2004) patented a device for mobile road condition detection, which uses a digital camera, temperature sensor, and an ultrasonic sensor. The sensors provide image data, air and road temperature, and roughness data. The data obtained are filtered for easier processing and then compared with the reference data to generate a road condition report. The comparison between the filtered data and the reference data yields the road condition classification such as dry, or the presence of snow, ice or water, as well as the road surface material such as concrete, asphalt, sand or gravel. Another patented technology is a surface condition sensing and treatment system, which includes an Electromagnetic Radiation (EMR) transmitter used to determine one or more characteristics of a road surface such as friction, the presence of ice or snow, and freezing point temperature as well as depth, density and composition of the road surface material. The system includes a graphical information system (GIS) based material spreader control system and a temperature sensor. The system features manual or automatic material spreader control by using the information obtained from the sensing devices and weather forecasts. The system can be controlled both remotely and locally, and the data may be transmitted from the vehicle for processing. The researcher indicated that the entire system may also have a vehicle-mounted application (Doherty et al., 2005).

Vehicle-mounted freezing point and ice-presence detection sensors may offer a cost-effective solution for agencies to overcome the practical infeasibility of having a dense network of in-pavement sensors. However, information regarding available technologies related to vehicle-mounted freezing point and ice-presence detection sensors is very limited since most of the technologies are currently under development (Shi et al., 2006). No information on cost versus benefits of these technologies was found. USDOT is currently investing in prototype development.

Millimeter Wave Radar Sensors (MWRS)

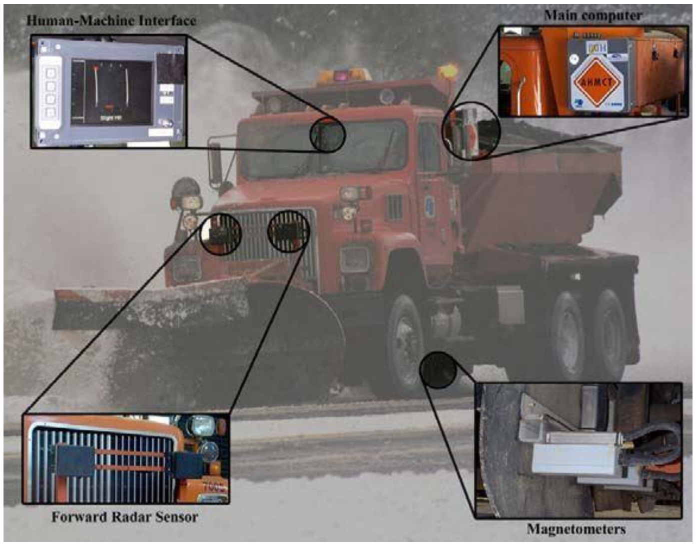

Figure 40 RoadView Technology (Shi et al., 2006).

Millimeter Wave Radar Sensors (MWRS) are a primary technology used to assist snowplow operators, and operators of other winter maintenance vehicles in their ability to detect objects, whether located in front, to the side, or behind the vehicle (Shi et al., 2006). MWRS is the most promising Collision Warning System (CWS) in use. Millimeter wave radar sensors have also been used in trials on transit buses, garbage trucks, overland trucks, automobiles, and at railroad crossings, with rear object detection MWRS technology being the most frequent application (Shi et al., 2006).

The millimeter wave radar system is a type of general radar system. RADAR, which stands for Radio Detection and Ranging, works by sending out signals that reflect off objects in their path, and the radar system detects the echoes of signals that return (Ye et al., 2012). Millimeter wave radar specifically employs electromagnetic waves with wavelengths from 1 to 10 millimeters. MWRS is considered a short-range radar; but relative to other CWS technologies MWRS has a longer range of object detection of up to 300 ft. Radar can determine a number of properties of a distant object, such as its distance, speed, direction of motion, and shape. Radar can detect objects out of the range of sight and works in all weather conditions, making it a vital and versatile tool for many industries (Ye et al., 2012).

Advantages of using MWRS systems included detecting obstacles in front of, behind and to the side of vehicles. Another advantage is that this can be done over long ranges and also in extreme conditions such as heavy rain and snowstorms (Ye et al., 2012). MWRS has had two notable field tests in the United States; RoadView™ (Figure 40) was tested in California and Guidestar™ was tested in Minnesota.

RoadView™

Roadview, the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) has conducted several studies on Advance Snow Plow (ASP) systems, and created its own trademarked system known as RoadView™. Roadview™ (Figure 40) includes a collision avoidance feature that utilizes millimeter wave radar that allows for operations during fog, rain, and falling snow (Shi et al., 2006).

Guidestar^{TM}

Guidestar was tested by the MnDOT Intelligent Transportation Systems (ITS) program, which also includes Intelligent Vehicle Initiatives (IVI). One project within Guidestar^{TM} is the use of MnDOT's Advanced Snow Plow collision avoidance system developed by Altra Technologies, Inc. (ATI). ATI's CWS consisted of four major components:

- A forward collision warning system.
- A secondary forward collision warning system mode focused on mail boxes, guard rails, signs, and stalled vehicles that may be off to the side of the road but are likely to be in the path of a deployed wing plow.
- A rear collision warning system to alert drivers of vehicles approaching the rear of the snowplow. The rear object detection system does not warn the snowplow driver; it simply flashes an external strobe light when it detects a car approaching too quickly and too closely from behind.
- A side object detection system that consists of two radar sensors on each side of the plow, one on each side of the front fender and one in each rear corner. The side CWS provides an audible warning to the driver only when the directional signal is turned on and if an obstacle is within ten feet of the side of the truck (Booz-Allen and Hamilton, 2000). (There is an audible tone and visual display for the side object detection system and both primary and secondary modes of the forward collision warning system (Booz-Allen and Hamilton, 2000)).

A study in 2002 evaluated the RoadView^{TM} system design to determine the challenges faced by the snowplow operators while using the technology, focusing on use in low-visibility conditions (Cuelho and Kack, 2002). The study assessment included a cost/benefit analysis of the system and identified needs and variables associated with the technology with respect to safety, mobility and operation; utilizing a survey of operators. The study focused on areas in Idaho, Montana, North Dakota and Wyoming and found that "operators have a high perceived usefulness of the technology that it would assist in detecting obstacles and provide lane position information." The cost-benefit analysis results indicated Roadview^{TM} to be most cost-effective in areas with high traffic and inclement weather conditions. The study was unable to calculate a cost-benefit ratio due to limited data. Very limited cost versus benefits data is available on this technology.

Light detection and ranging (LIDAR) sensors

Figure 41 An example of a) a mobile LIDAR system, and b) an image of a road surface obtained using the LIDAR technique (Yen et al., 2011).

Visible image sensors rely on hue, saturation, and brightness to detect the roadway surface condition by comparing the images to clear road condition. Light detection and ranging (LIDAR) sensors consist of a laser transmitter/receiver unit that produces a laser pulse (Figure 41). The emitted laser pulse propagates until it meets an obstacle, in this case, the roadway surface, which scatters light in all directions. The receiver stage senses a return pulse and detects any changes in intensity, wavelength and phase (Ye et al., 2012). The round-trip travel time of light, the intensity change, the wavelength change and any phase change provide information to determine properties of the reflecting surface. Radiometer sensors operate similarly to LIDAR sensors, except that instead of measuring the wave period or intensity, the energy is measured. LIDAR sensors are more accurate because the reflected light properties can be retrieved, whereas radiometer sensors collect data containing information about both emitted and reflected signals (Ye et al., 2012).

LIDAR are commercially available in production vehicles as adaptive cruise control (ACC) components. The ACC technology overlaps with collision warning technologies to a large extent, as it uses light amplification by stimulated emission of radiation (LASERs) or RADAR to monitor and maintain vehicle speed as well as the distance to the other vehicles. LIDAR and RADAR both use active sensor technology; that is, the sensors used in these collision warning systems broadcast or emit a signal, then detect and interpret any returned signals to indicate the presence of and distance to an object. LIDAR may be continuous-wave or pulsed, focused or collimated, with many other possible variations in configuration (Shi et al., 2006).

The WSDOT conducted a survey for the cost-benefit analysis of mobile LIDAR based on a 15,000-mile estimate. The cost-benefit analyses consisted of seven mobile LIDAR deployment options. It was presumed that the data collection could only be done for half of the year. Moreover, for making the calculations simpler, a uniform labor rate of $50 per hour was estimated for all personnel needed for data collection and processing. The results showed a savings of $6.2 million in six years (Yen et al., 2011). In another survey conducted by the State of Minnesota, a benefit to cost ratio of 3.5 was calculated based on a detailed digital elevation model and floodplain maps, and quotes, using LIDAR (Hallum and Parent, 2009).

Currently the use of LIDAR is limited to "good weather", clean pavement, and temperatures above 32°F (0°C). At this point in time, additional work is needed for LIDAR to be an effective tool for winter maintenance operations.

Laser-Wavelength Road Condition Sensors (LRSS)

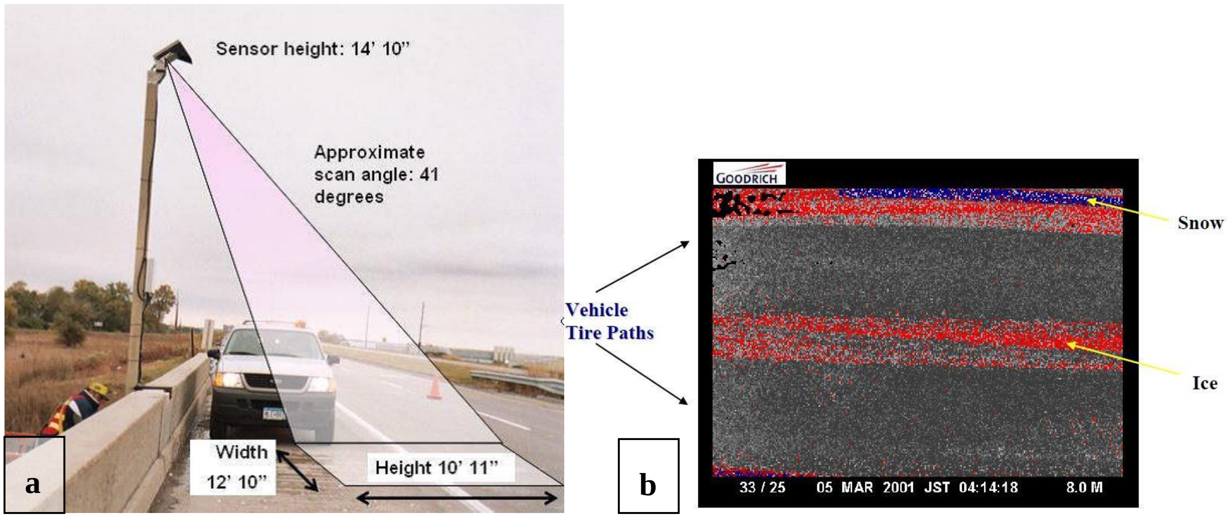

Figure 42 a) Viewing area and camera position for an LRSS system, and b) a typical picture of a road surface taken by the LRSS (Greenfield, 2008).

LRSS, developed by Scanmatic, is a laser-based measuring device. Operational tests of the Scanmatic LRSS system were conducted with the device mounted at the roadside. The system includes a sensor that detects road surface conditions using an eye-safe laser that illuminates a large area of the road surface (20 × 30 degrees) with ranges of up to 75.5 ft (23 m) (Figure 42). The advantages of this set-up are that it is not invasive, as there is no need to embed it into the road surface, and its maintenance costs are low (Paulsen and Schmokel, 2004). The images in the LRSS outputs are 200 × 300 pixels, which offer 60,000 detection points that are each analyzed and classified in distinct colors as dry, snowy, icy, or wet areas. In addition to the display function, the LRSS can calculate the percentage of coverage of water, snow, or ice and generate alarms based on a defined threshold percentage. A typical unit is light (20lbs, or 9 kg), relatively small in size (9 x 15 x 13 inches (23 × 38 × 33 cm)), and operates on voltages that are available through average batteries available in trucks (10–14 V). The primary use of the LRSS has been on roadsides, but a slightly modified unit that is stabilized on a truck and installed and located properly could potentially be used to make this sensor vehicle-based (Shi et al., 2006), this would require field trials to ensure feasibility.

According to Greenfield (2008), "the cost of the LRSS was also found to be prohibitive for deployment by the Iowa DOT, limiting any installation to the most vital or troublesome roadway segments. The camera was purchased for a price of $25,500. This price is many times the cost of an individual Iowa RWIS pavement sensor. Widespread deployment may become more appealing in the event that the unit price declines or if future versions of the LRSS offer additional capabilities beneficial to the Iowa DOT."

Smart Snowplows

In the last decade or so, various advanced vehicle-based sensor technologies including automatic vehicle location (AVL), mobile RWIS technologies, visual and multispectral sensors, and millimeter wavelength radar sensors, have been developed to support winter maintenance operations. Among them, Shi and et al. (2007) found AVL systems and road surface temperature sensors to be the only ones that had matured enough to become fully operational; the remaining technologies were still in the development and testing phases. A survey conducted for this project found 70% of responding transportation agencies use technology like GPS and AVL to more accurately track, monitor, and record material application and plowing. This shows the technology has been integrated into winter maintenance operations, but follow up comments indicated that for many transportation agencies it is only used on a limited number of trucks, the organization has been slow to pick up the technology, or that issues have occurred that prevent the technology from functioning.

AVL is a technology that integrates vehicle location information with other information from the vehicle to provide temporally and spatially referenced information on a maintenance vehicle's activities (Allen, 2006). In addition to vehicle location information, AVL provides real-time information such as application material and application rate (Vonderohe, 2004), which can assist in storm response and guide storm event planning by providing previous storm event histories (Ye et al., 2012). The enhanced vehicle tracking and dispatching capabilities through AVL have been proven to reduce response time; improve resource management, coordination, and information-sharing; reduce staff fatigue during peak operations; improve the efficiency of overall winter maintenance operations; and reduce chemical consumption while achieving comparable or higher LOS (Meyer and Ahmed, 2003; Anthony, 2004; Ye et al., 2012).

A research project currently underway by the National Center for Atmospheric Research (NCAR) is focused on providing weather information for every major roadway in the United States and pushing connected vehicle and Vehicle Data Translator (VDT) output to several DOTs and non-DOTs. The research is concentrating on providing segment by segment road weather information, which will further help winter maintenance agencies to efficiently react to winter road conditions (Chapman, 2014). In his work, Perrier et al. (2007) emphasizes the importance of merging road weather information systems, weather forecasting services, winter road maintenance equipment, geographic information systems, global positioning systems, communication systems, computer systems, and optimization techniques to better address winter road maintenance (such as MDSS).

Many states are testing or using Global Positioning Systems/Automatic Vehicle Location (GPS/AVL) equipment on vehicles performing winter maintenance. In addition to tracking vehicle location, data can be pulled from sensors to help with asset management, route optimization, more efficient dispatching, optimized chemical application, material usage reporting, material staging, and other applications (Hille and Starr, 2008; Allen, 2006; Henry and Wendtland, 2007). A preliminary review of literature indicated the effectiveness of GPS/AVL was generally found to be favorable. It appears that as the technology has matured, its benefits and effectiveness have become increasingly better understood and accepted. A comprehensive survey in 2011 by Virginia DOT with responses from 33 states indicated GPS/AVL technologies are widely implemented, and there are many hardware and software applications available. The survey also identified several issues (cellular dead spots, software malfunctions and compatibility issues, hardware problems) and solutions (choosing certain systems/versions and not others, implementing more differential GPS, querying raw truck data for analysis, etc.) (Venner, 2011). Clear Roads and MnDOT recently released a request for proposal titled *Synthesis on GPS/AVL Equipment Used for Winter Maintenance* which should be completed in early 2016. The release of this synthesis topic shows that there is a pressing need for more information on this topic.

A wide range of issues with hardware, installation, and software indicates the need for a clearinghouse in which previously-reported problems and any documented solutions for brand-specific equipment is assembled. Such a clearinghouse would provide DOTs the information needed for upgrades and new purchases. GPS/AVL was mentioned on AASHTO's Snow and Ice List-Serve several times over the last seven years, including queries regarding brands, feedback, best practices, and links to surveys. Because many cities (e.g., Ann Arbor, MI; Hudson, OH; and many others) and DOTs have GPS/AVL-specific information about pros, cons, problems and solutions available, the information just needs to be compiled. Information sources include past surveys (e.g., 2007 UCLA Business graduate students, 2009 Western Transportation Institute, 2011 Virginia DOT, 2012; Venner, 2004), past SNOW-ICE List posts, research reports that include case studies, and snow and ice control manuals and handbooks.

Now is a time of quick progress for smart snowplow with the use of wireless technology. Companies like Lufft and the developed MARWIS system mobility collect pavement data, and integrate it with weather and road weather condition information, and provide the information real time to the vehicle driver. The information can be stored and reviewed. Ultimately the goal is to link the information with an MDSS style platform to provide a weather forecast, and product and product application rate recommendations to further support winter maintenance operations.

Mid-Storm Adjustments

As conditions can rapidly and unexpectedly change as a storm progresses, operations managers and supervisors must respond quickly and accordingly. Flexibility and adaptability are critical for keeping roadways safely passable and with the efficient and effective use of materials with the least detriment to the environment. For example, spreading deicer material during an intense snowfall then re-plowing the roadway soon afterwards is a waste of material and time. Sufficient time must be allowed for the materials to melt snow/ice. Re-applying material before earlier applications have fully activated is an obsolete practice that has been supplanted by much research and practical experience. However, the public as well as the agency staff and elected officials need to better understand the chemical processes of de-icers; specifically, that more is not necessarily better. Many factors, principal among them current air and pavement temperatures, pavement moisture, traffic activity, application rate, and type of material, determine how fast melting takes.

In addition to those factors, managers need to assess rate (intensity) and type of snow-fall (dry vs. wet), projected duration and final accumulated snow-fall total, forecasted temperature direction (increase or decrease) and wind speeds, traffic volume until the end of the storm, micro-climate problems caused by topography and the availability of trucks and operators. As an example, a late winter-early spring snow starts early on a work-day morning; the storm is expected to be 2-4", lasting until about noon. Temperatures at the onset of the storm are in the low-30s °F and are forecasted to rise during the day to above freezing. Light winds and sunshine in the afternoon; overnight temperatures are predicted to not drop below 32°F. Likely most if not all the snow would naturally melt off the roadways by nightfall. A sound decision, then, would be to plow arterial and collector streets and spread little if any material at the beginning. Should temperatures not rise as expected or be forecasted to drop below freezing overnight than a light application of materials may be warranted, particularly if there is a chance of black ice.

In another scenario, dry, blowing snow begins in late afternoon in January as a cold front pushes through; pavement and air temperatures will be well below freezing and plummet overnight. Spreading dry salt will not be that effective as the pavement has little moisture and the snow likely has low water content. Plus, salt alone is not effective below 15-20 °F. In this case, applying a liquid anti-icer with a lower working temperature range would be a good option.

Managers and supervisors need to use reports from operators in the field, citizens, public safety (police and fire) units, and information from RWIS and CCTV, if available, to evaluate progress and overall conditions. But they must also avoid reacting too quickly until determining if just a few isolated problems or a general condition is evolving. Depending upon the duration of a storm, managers may also need to adjust material application rates if potential shortages are likely.

Post-Storm Operations

Ideally, once the snow has stopped then winter maintenance operations would conclude shortly thereafter. That is possible with light snow and temperatures remaining around the freezing point, or higher. Often, though, work continues long after the last snowflake hits the ground. Much depends upon an agency's stated Level of Service (LOS); to determine what the roadways should look like after all is done. LOS may vary depending upon the priority classification of the road; high-speed, multi-lane highways and surface arterials typically have bare pavement, curb-to-curb (or edge-to-edge) as the LOS and lesser roads and streets may have only bare pavement in the wheel track or none at all.

Total accumulation is an important factor as to when operations cease. As so dramatically illustrated by the record-setting Boston winter of 2015, removal operations continue without interruption for days in order to clear even a single track on most side streets and to keep major streets open. In addition, temperatures were well below freezing and even 0°F, rendering salt ineffective. Boston resorted to hauling snow and dumping it in the Bay, regardless of potential contaminants. Snow-melters were also used, which were discharged into the sewer systems. Of course, this was an extreme situation but it underscores the fact that major plow-and-spread operations can continue for some time after snowfall ends.

As with mid-storm adjustments, managers must assess all pertinent information and decide on how to proceed post-storm. Will temperatures rise or plummet? What is the probability of continued drifting across roadways caused by sustained high winds? When is the next storm expected? How to deal with chronic problem spots such as ice build-up caused by groundwater seepage at a location?

Many agencies, particularly those that usually have milder winters, will likely have time between storms, and after sufficient melt off, to sweep the roadways of accumulated sand and other traction material. As addressed in more detail in the next section of this document, sweeping reduces the proliferation of airborne nuisance particulates and sedimentation in drainage systems.

Likewise, clean-up of equipment and maintenance yards is an important activity at this time. More details on that and handling unused materials are found in other sections of this document.

Lastly, excessive snow accumulations coupled with severe cold in recent winters in many areas of the U.S. has caused significant flooding as melting occurred. Aside from damages to infrastructure and private property, flooding may also carry de-icer material and abrasives into areas that would normally not be affected by such contaminants. Though quite diluted, their potential harmful effects on the environment need to be considered.

Pavement Sweeping after Melt-off

Street sweeping can significantly reduce the amount of sand or abrasives released into the surrounding environment due to melt-off events. Street sweeping is recommended in the early spring after melt-off but before any substantial rainfall events occur (Staples et al., 2004). Street sweeping equipment includes air sweepers equipped with vacuum systems, which efficiently remove fine particulates (Staples et al., 2004). It has been reported that the cost of combined broom and vacuum sweepers can be approximately two times higher than a traditional sweeper alone. However, the operational costs and service life are comparable (Staples et al., 2004). Figure 43 and Figure 44 show pictures of a street sweeper equipped with a vacuum system and a mechanical broom street sweeper, respectively. MDT uses broadcast sweeping with grasshopper brooms which are cheaper and faster than pick-up brooms, but does use pick-up brooms on median rail, bridges and for curb and gutter cleaning (personal communication J.Juelfs, March 2015).

Figure 43 Picture of a street sweeper with vacuum system (www.cityofhaydenid.us).

Figure 44 Picture of mechanical broom street sweeper (www.sweepers.com).

Material captured in street sweeping may contain pollutants such as petroleum hydrocarbons and metals, it is recommended to perform tests on the recovered material to determine if hazards are present. A pre-approved site (such as a landfill) should be used to dispose of spent abrasives (NYSDOT, 2011), or they can be land-applied, bio-treated, or thermo-treated depending on the contents. However, the reuse or recycling of street sweepings is recommended if local regulations permit. Options include reuse as snow and ice control materials or as construction aggregates (Staples et al., 2004). Results of a study conducted by the Montana Department of Transportation (MDT) indicated that the most cost-effective option for collected traction sand is the reuse of the collected material as abrasives for winter maintenance because low chemical and metals concentrations were found in the recovered sand (Mokwa and Foster, 2013). Additional practices to recycle recovered sand include mixing it with gravel or other aggregates to produce materials that can be used in plant mix surfacing, cement treated base, and shoulder gravel or top surfacing. The reuse or recycling of recovered abrasives can reduce costs by reducing the amount of abrasives purchased by winter maintenance agencies and eliminating landfill disposal costs (Mokwa and Foster, 2013).

Table 24 Risk, compliance issues, and management examples for highway generated water (modified from the Oregon DOT, 2001).

Waste	Toxicity/Risk	Compliance issues	Management Examples
Vactor[3] Waste -Catchment Cleanout -Sediment Ponds -Bridge Culverts	**High** (in urban areas). Typically the most contaminated road waste. Hydrocarbons and metals are common. Historical pollutants can be present. **Low to high** depending on factors such as ADT, land-use, maintenance schedules, etc. **Low** (if content of silt or fine soils is low).	Vactor waste must be separated into liquids and solids prior to disposal. Each waste must be disposed of separately. Many waste disposal rules apply. ODOT Environmental and DEQ can offer guidance. Even free of toxins, litter, and trash, vactor waste requires proper placing and erosion control.	• Develop alternative disposal options such as bioremediation or composting. • Pursue alternative decanting techniques (retrofit sewerage manholes for liquid field disposal, treat vactor slurries with flocculent, etc.). • Partner with other agencies and share waste disposal facilities. • Construct ODOT decant facilities that separate vactor waste into liquids and solids. Landfill solids and dispose liquids to sewer.
Sweepings Winter Sand	**Low to High** Litter and sharps will be obvious. Hydrocarbons and metals are a concern. Urban sweepings usually test high in toxin levels. **Low** (with quick pick up). Less time on roadway reduces litter and toxins.	Similar to vactor solids in risk and environmental concerns. Testing may be needed to determine toxin levels. Litter and trash must be disposed of at permitted waste facilities.	• Test, characterize, and sort for reuse. • Develop re-use options: compost, shoulder repair, fill, concrete, etc. (remove trash by screening). • Develop and permit disposal sites (partnering). • Thermal treatment (incinerator). • Landfill.
Ditching Spoils	**Low to Medium** Generally risk is low but urban ditchings have tested positive for toxins (hydrocarbons, metals, historical pollutants, chemical dumping, etc).	Storage sites must be suitable (protect wetlands and streams). Clean soil is a pollutant if it is not contained (erosion control).	• Use as fill material in appropriate locations. • Partner in give-away programs if material is suitable (agriculture, construction, etc.). • Develop and permit disposal sites.

The cost of sweeping post-storm and with melt-off cleaning operations are frequently not included or considered in the purchase cost of abrasive materials. Annual sweeps costs reported by various state DOTs are provided below:

- In FY14 MDT spent $1,685,811 to sweep 26,782 miles for and average cost per mile of $62.95 (personal communication J.Juelfs, March 2015).
- RIDOT owns 18 brooms, with a replacement value of $165,000 each. The broom last about 8 years, with an hourly rate of $72. Operations and Maintenance costs for a sweeper are $30 per curb mile. Assume 750 sweeping hours per year per broom (25

[3] Vactor waste is waste associated with stormwater runoff from roads.

weeks x 30 hours per week), the estimated annual street sweeping cost for RIDOT is $5,946,750 (personal communication, J.Baker, march 2015).

- Annual clean-up costs associated with the use of abrasives in Maine is estimated be about $1.5 million. Maine has realized cost savings of about $90,000 annually, through reduced use of abrasives. These values were estimated based on historical data of material use and reduced windshield claims (personal communication, B. Burne, March 2015).

It should be noted that whether or not abrasives are used, roads will still need to be swept at least once annually. It can be assumed that the pace of sweeping operations would increase with less sediment to pick-up. Overall, production time should improve with lower sand use and drainage systems will not fill up as quickly.

Summary of Winter Maintenance Environmental BMPs

A number of studies have established the impacts of winter maintenance materials on the roadside environment, particularly to soils, plant life and aquatics (Mills and Barker, 2002; Hagle, 2002; Akbar, et al., 2006). While proper material storage, maintenance of equipment, appropriate application rates, and preventative procedures and specialized equipment have made great strides in reducing or eliminating the environmental impacts of winter maintenance materials, it is impossible at the present time to completely prevent all roadside contamination. The occurrence of contamination has led in recent decades to greater public concerns and complaints stemming from winter maintenance practices that transportation agencies must consider and address. Different approaches have been developed and used by agencies to address such concerns and complaints. Some of these approaches are proactive and seek to address or minimize issues before they arise, providing agencies with a means to address public concerns by showing what is already being done. In other cases, a reactive approach is employed to address public complaints that arise from potential contamination.

The Environmental Protection Agency has laid out practices to prevent pollution to waterways from the operation and maintenance of highways (US EPA, 1993). These practices included several specific to winter maintenance operations.

- Cover salt storage piles and deicing materials to reduce surface water contamination and locate such piles outside of the 100 year floodplain.
- Regulate the application of deicers to prevent over application.
- Use specialized equipment (e.g., zero velocity spreaders, pre-wetting) to apply granular materials so that they remain on the roadway.
- Use alternative materials such as sand and salt substitutes in sensitive ecosystems.
- Avoid dumping snow into surface waters (US EPA, 1993).

The Maryland Department of the Environment has also laid out best management practices for winter maintenance, including:

- Avoid the use of salt and deicers when more than 3 inches of snow have accumulated.
- Use treatment materials at an appropriate temperature for the specific product.
- Use salt and deicers only when a storm is imminent, and sweep and remove materials from the roadway if a storm does not occur.

- Apply materials only when and where necessary.
- Calibrate equipment and train operators in proper application procedures.
- Mix sand with granular materials for added traction and to reduce chemical use.
- Consider alternative materials that require lower application quantities.
- Store materials in a dry, covered area on an impervious surface (Maryland Department of the Environment, undated).

The prior discussions have detailed proactive approaches to prevent and reduce environmental contamination. However, when such contamination does occur and the public contacts an agency regarding it, steps should be taken to alleviate and address concerns and complaints. The New York State DOT, in addressing public complaints stemming from site contamination from maintenance yards, recommended the following steps be taken:

- Locate the contaminated site on a map and observe what highways or maintenance facilities are located nearby to determine potential sources of contamination.
- Interview staff if a maintenance facility is located near the affected site to determine if materials were left uncovered and, if so, to recommend actions to address the issue.
- Review historical data (photos, maps, and water quality data) to determine if past maintenance facilities may have contributed to the contamination.
- Inspect the site and neighboring areas to determine whether other sources (e.g., septic systems) have contributed to the contamination and to observe whether any significant amounts of winter maintenance products are visibly present (Venner Consulting, 2004).

The Transportation Association of Canada recently identified common winter maintenance operations that may lead to loss of materials, and identified mitigation strategies for these (Table 25), as well as proactive maintenance operations that can be used to reduce the loss of material (Table 26).

Table 25 Cause of material loss and mitigation strategy (TAC, 2013).

Loss of Materials	Effective Guiding Principles
Spillage of salt during handling procedures	Promote indoor operations. Collect and dispose of onsite contaminants.
Salt dissolved from uncovered stockpiles	Place stockpile inside storage facilities. Control site drainage.
Spillage of liquid chemicals during production or handling	Use low permeable surfaces to reduce infiltration and control runoff.
Vehicle Washing	Collect and reuse or properly manage site drainage to comply with local water quality regulations.
Salt dust from exposed salt piles	Properly cover stockpiles and control emissions.

Table 26 Effective operations and maintenance used to reduce the loss of snow and ice control materials (TAC, 2013).

Practice	Effective Operations and Maintenance
Salt Handling	• Load spreaders inside • Minimize spills and sweep pads immediately after a spill • Avoid overloading spreaders • Calibrate spreaders • Return excess salt and sand to storage facility after a storm
Vehicle Washing	• Remove residual solids to minimize salt concentration in wash water • Wash vehicles indoors or where water can be contained • Properly dispose of wash water or reuse for brine production
Sand and Salt Mixing	• Mix inside or on low permeable pad • Mix during good weather to prevent loss due to precipitation or wind • Store mixture into storage facility.
Salt Brine Production and Storage	• Proper design of water supply • If regulations allow, use wash water or stormwater for brine production • Provide secondary containment near storage tanks • Inspect tanks, pumps and pipes to ensure no leaks

These approaches provide both proactive and reactive measures that can be used to address public concerns and complaints regarding contamination. While it may be impossible to eliminate all contamination associated with winter maintenance practices, particularly from the use of deicers, it is possible to significantly prevent such issues from having an impact outside of the right of way, and when issues do arise to address them in a timely and effective manner.

Conclusions and Recommendations

Agencies responsible for snow and ice control on public highways, roads and streets have a clear mandate to keep the surface transportation system functionally safe and mobile. Plowing alone cannot meet that charge; de-icing materials and abrasives for enhanced traction are needed as well and usually in large quantities. Rock salt has been the most commonly used de-icer and that will continue for the foreseeable future. However, growing concerns about the potential adverse effects of salt, calcium chloride and other chemicals on the natural and built environment - soil, vegetation, wildlife, surface and ground water, air, pavement, metal infrastructure components, and vehicles must be addressed. This topic has been extensively researched and will continue to be in the future. Studies substantiate that deicing materials can and do cause problems. Some effects are readily evident such as roadside vegetation "burned' by chlorides and rusting and corrosion of metal bridge components and sign, signal and light poles next to the roadways. Determining the negative impacts on wildlife, water and air requires more empirical measurement, particularly as to the long-term residual effects. Corroborating those findings with actual usage of specific de-icers and abrasives may be problematic in "real-world" situations and subject to challenge and dispute by the industry. Nonetheless, there is sufficient body of knowledge based on research and practical experience to unequivocally state that such materials must be better selected and used not only for environmental reasons but for economy, efficiency and effectiveness. The old days and old ways of literally dumping salt on a road through an open tailgate are over.

Winter roadway maintenance operations is viewed through an entirely different paradigm now; managers must meet the higher expectations of the public as there are more vehicles and more miles traveled per motorist than before as our nation continues to be increasingly dependent on the automobile. Concurrently, managers must contend with constrained funding, both in operational and capital budgets; unit costs for materials, fuel, personnel and equipment maintenance increase annually but funding often does not keep the same pace. Additionally, they must comply with more environmental and workplace regulations and mandates. Considering all of the above, managers must find improved ways to provide snow and ice control.

The following recommendations for consideration and future research were developed based on identified research gaps and needs from the literature, survey and follow-up interivews.

- Levels of Service and related policies: providing reasonable and feasible snow and ice control based upon defined priorities and classifications, and road user expectations.
- General strategies and tactics: route optimization; weather forecasting; activation; anti-icing (pre-treatment of roads); timing of treatment;
- Materials (selection): determining what is best for specific conditions; affordability and availability; adverse properties;
- Application rates: minimal but most effective;
- Equipment: plows and spreaders; calibration; techniques; clean-up after a storm;
- Personnel (including contractors): training ,quality control;
- Facilities: proper storage, handling and containment;
- External mitigation methods: street sweeping, detention basins, roadway design

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Appendix A Survey Questionnaire

Appendix B Survey Results

Survey Summary

The survey was distributed through the online survey tool Survey Monkey to learn about the snow and ice control environmental best management practices used by winter maintenance agencies. The survey was distributed in September 2014 and was open for responses for two weeks. The purpose of this survey was to gather information from winter maintenance professionals at state, provincial and local transportation agencies on their experience, challenges and lessons learned with encountered environmental concerns raised in winter snow and ice control practices. The survey consisted of 56 questions. Detailed information about response rates and individual answers to each question are provided below.

Q1: Please provide your name, phone number, email address, and agency name.

A total of 39 responses from 24 States within the U.S. were received from California (n=1), Colorado (n=1), Delaware (n=1), Illinois (n=1), Iowa (n=2), Kansas (n=1), Massachusetts (n=1), Maine (n=1), Missouri (n=1), Minnesota (n=1), Nebraska (n=1), New Hampshire (n=1), New York (n=1), North Dakota (n=2), Ohio (n=1), Oregon (n=1), Pennsylvania (n=1), Rhode island (n=1), Virginia (n=1), Vermont (n=1), Washington (n=2), West Virginia (n=1), Wisconsin (n=8), and Wyoming (n=1) (Figure 89).

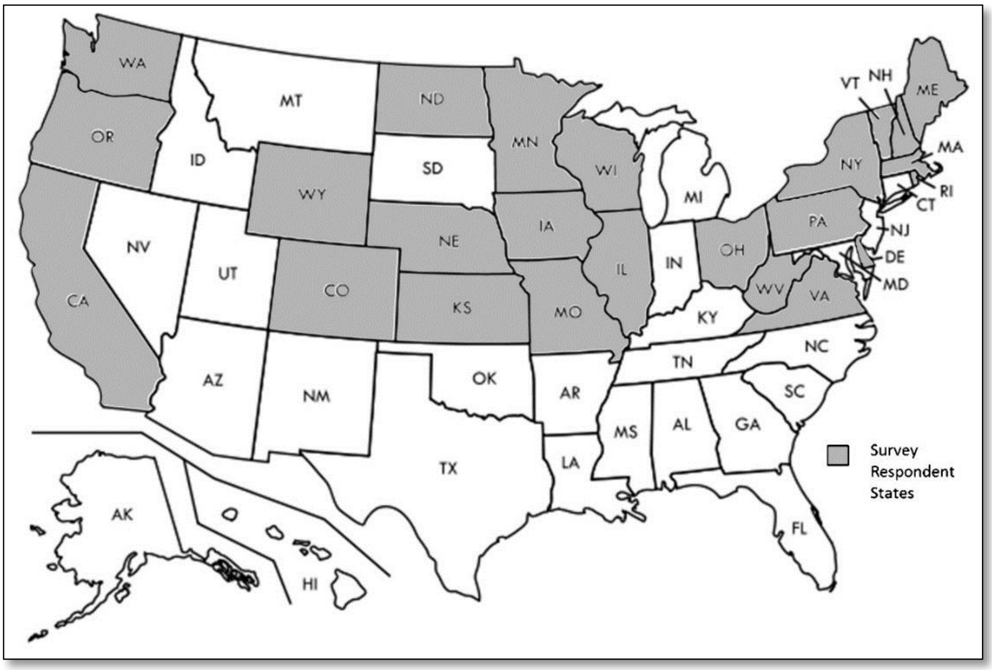

Figure 45. States that responded to the survey.

Q2. Please indicate the agency type that you belong to.

There were 35 responses to this question, with 4 respondents skipping this question. Survey respondents were mainly from “State or Province” (60.0%), “County or local road district” (20.0%), and “Municipal (village, town, township, and city)” (14.3%) winter maintenance agencies. There were also a few other representatives from “Federal lands” (2.9%) and “Transportation/tollway/bridge/tunnel or transit authority” (2.9%). Specific response count and response percent for each agency type are presented in Table 27.

Table 27. Number of responses for each agency type.

Agency Type	Response Percent	Response Count
Municipal (village, town, township, city)	14.3%	5
County or local road district	20.0%	7
Transportation/ tollway/bridge/ tunnel or transit authority	2.9%	1
State or province	60.0%	21
Tribal or territorial	0.0%	0
Federal lands (NPS, BLM, DOD)	2.9%	1
Others	0.0%	0
	answered question	**35**
	Skipped question	**4**

Q3. Please provide your agency jurisdiction.

There were 32 responses collected for this question, of which 19 respondents answered all three questions about the area (sq. miles or sq. km), lane-miles or lane-km, and population of the agency jurisdiction, and 13 respondents provided partial information. Detailed responses are shown in Table 28.

Table 28. Responses on the agency jurisdiction.

Agency	Agency Jurisdiction		
	Area (Sq. mile or sq. km)	**Lane-miles or lane-km**	**Population**
Green Lake County Highway Department, WI		300 lane-miles	
Taylor County Highway Department, WI		800	19000
Juneau County Highway Department, WI		242	
Green County Highway Department, WI	576	400	20000
Shawano County Highway Department, WI		515 lane-miles	41600
Colorado DOT	104094 sq. miles	23000+ lane-miles	5268367
Illinois DOT	57914	44808 lane-miles	12882135
Waukesha County Highway Department, WI	576	2000	350000
Vermont Agency of Transportation		14,158 total miles of roadway	
Rhode island DOT	1212	3300	1050000
West Virginia Division of Highways	24000	75,000	1800000
Minnesota DOT		30,597 lane-miles	
Wyoming DOT	120000 sq. miles	34,000 lane-miles	600000
City of Grandview, MO	15	255	25300
city of Cedar Rapids, IA	72	1600	126000
Delaware DOT	2500 sq. miles	7,000 miles	900000
Washington State DOT		+/- 20,000	

Agency	Agency Jurisdiction		
	Area (Sq. mile or sq. km)	**Lane-miles or lane-km**	**Population**
City of Tracy, CA	27 sq. miles	2,800	84000
Massachusetts DOT		17,000 lane-miles	6692824
Kansas DOT	800,000 sq. miles	25,300 lane-miles	2.9 million
Washington State DOT	20000		7000000
New York State DOT		36000	
Virginia DOT	40, 767 sq. miles	+125,000 lane-miles	8001024
Oregon DOT		9500	
Nebraska Department of Roads		23000	
Maine DOT	35,385 sq. miles	8300	1.329 million
North Dakota DOT	70,704 sq. miles	17,049 lane miles	672591
North Dakota DOT		17,036	700000
Iowa DOT	56,272 sq. miles	24,615 lane miles	3,090,416 (2013)
Ohio DOT	40,861 sq. miles	43,000 lane miles	11570808
New Hampshire DOT	9,304 sq. miles	9,200 lane miles	1323489
Pennsylvania DOT	NA	92,000	NA

Q4. Please provide the Level of Service typical for each type of route using the codes below, where BPA=bare pavement for all lanes; BPC=bare pavement center of roadway only; PPS=plowed, packed snow on surface; NPT=no plowing or treatment; TSP= trouble spots only treated (intersections, hills, curves) and plowed.

A total of 34 respondents answered this question, with 2 of them only providing answers but not showing the agency name. According to the collected data, for the “major limited-access highway, freeway, and expressway”, the level of service reported as used by respondents was bare pavement for all lanes (BPA) 80% of the time, followed by bare pavement center of roadway only (BPC) 10% of the time (Figure 90). For the “primary surface arterial”, “secondary arterial”, and “collector”, the top two levels of service used by responding agencies were bare pavement for all lanes (BPA) and bare pavement center of roadway only (BPC). But compared to “major limited-access highway, freeway, and expressway”, the proportions of BPA for these three types of routes dropped to 56.7%, 37%, and 36.4%, respectively; while BPC was shown to be used more commonly 33.3%, 48.1%, and 40.9% respectively. Probably because most respondents were from State and County highway departments (80%), the responses to the first four types of routes (“major limited-access highway, freeway, and expressway”, “primary surface arterial”, “secondary arterial”, and “collector”) were occupied 70.3% of total response count (n=155). In addition, there was a sharp contrast between the first four and the other three types of routes: “residential”, “alleys, park service road, parking lot”, and “sidewalks, and stand-alone bike paths”, since no plowing or treatment (NPT) showed the highest share for all the three types, only followed by a smaller proportion of plowed, packed snow on surface (PSP) and trouble spots only treated (TSP). For example, BPC (30.8%) and NPT (30.8%) were reported as two kinds of frequent treatment for the residential route, and PPS (15.4%) and TSP (15.4%) were then most commonly level of service treatment. No plowing or treatment (NPT) was the most commonly used level of service treatment for both “alleys, park service road, parking lot” (46.2%) and “sidewalks and stand-alone bike paths” (45.5%), followed by PSP (23.1%) for “alleys, park service road, parking lot” and TSP (27.3%) for “sidewalks and stand-alone bike paths”. These results make sense considering the responding population and the routes they are responsible for. Additional comments provided by respondents are shown in Table 29.

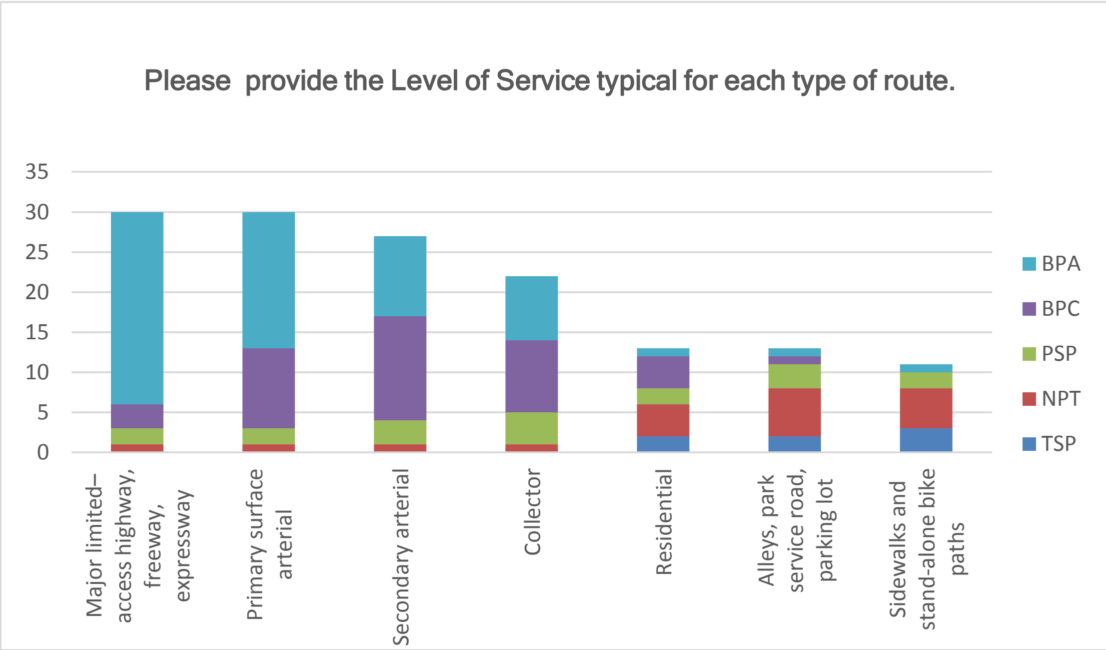

Figure 46. Treatment conditions of listed types of routes and the number of responses that fall into each category.

Table 29. Additional comments on the level of service for each type of routes

Agency	Comments
Colorado DOT	CDOT is only responsible for State, US, and Interstate routes. We have 24 hour coverage on facilities over 1,000 AADT, and 14 hour coverage (0500 - 1900) on routes with AADT <1,000.
Waukesha County Highway Department, WI	We do not plow residential, alleys or sidewalks.
Vermont Agency of Transportation	Not responsible for anything other than State Highways. Vermont Agency of Transportation operates under a Corridor Priority System as noted in our Snow and Ice Control Plan. Action and treatment varies based on type of roadway and trips. See http://vtransoperations.vermont.gov/sites/aot_operations/files/documents/AOT-OPS_SnowAndIceControlPlan.pdf for our winter roadway plan and http://vtransoperations.vermont.gov/winter_maintenance_plan for our map.
West Virginia Division of Highways	DOH services in system roads only.
Wyoming DOT	WYDOT LOS is based on time plow is in service
Maine DOT	Time to bare pavement varies with corridor priority. Parking lots eventually bare up. Sidewalks and bike paths are locally maintained.
North Dakota DOT	NDDOT only maintains state system highways.
New Hampshire DOT	These are levels after the storm, not during. NHDOT does not winter maintain residential, alley's or sidewalks.

Q5. Has your agency revised the Levels of Service (LOS) guidelines to address the environmental footprint of snow and ice control products? If yes, please explain in the additional comments box.

Eleven of the 34 responses to this question were “YES”, 22 answered “No” and 1 showed “N/A” (Figure 47). This highlights a research need and area for DOT to focus efforts. (The necessity of conducting such revision should be highlighted) Additional comments provided by respondents are shown in Table 30.

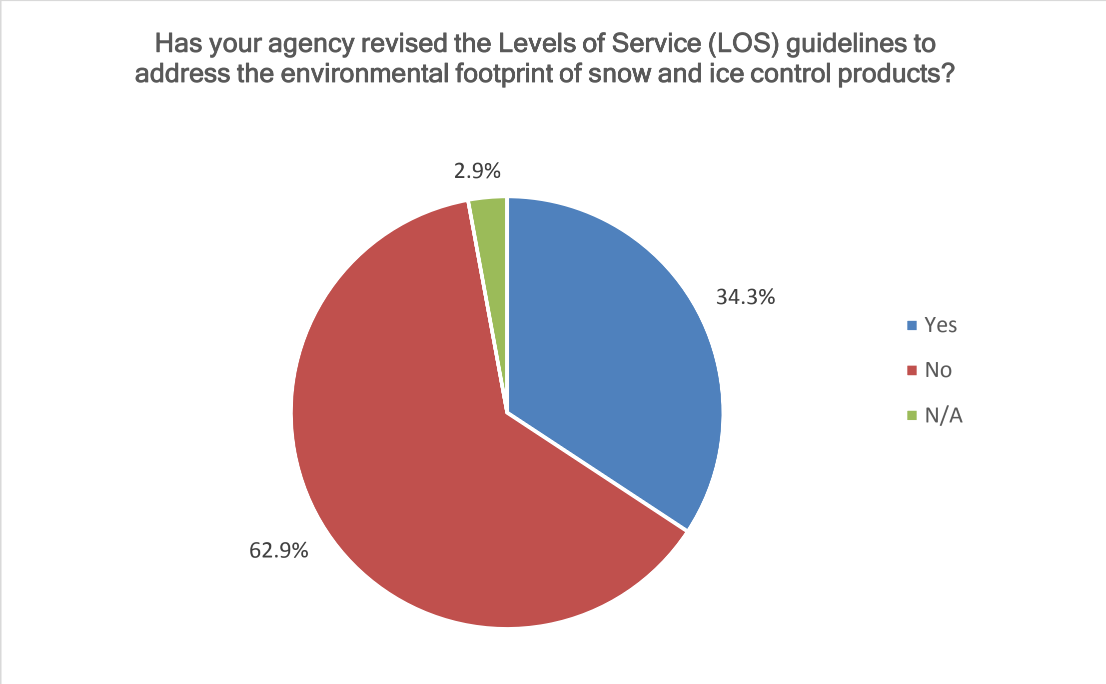

Figure 47. Survey answers about revising the LOS guidelines to address the environmental concern of snow and ice control products.

Table 30. Additional comments on the reason of revising the LOS guidelines.

Agency	Comments
Illinois DOT	We no longer require clear pavement on low ADT routes.
Door County Highway Department, WI	Salt brine usage lowered return trips.
Vermont Agency of Transportation	See comments above under #4 and review our Snow and Ice Control Plan at this site http://vtransoperations.vermont.gov/winter_maintenance_plan.
City of Grandview, MO	We have lowered LOS and use a mix of chemicals based on weather conditions and time/day.
Washington State DOT	Sensible salting. The right amount at the right time in the right place.
Maine DOT	We established a set of priority corridors with defined average cycle lengths, time to bare pavement and average salt usage.
Iowa DOT	LOS guidelines currently under review.
New Hampshire DOT	Few areas have gone to a low or no salt LOS. Low volume roads only and after concurrence with local officials and public hearings.

Q6 Does your agency have a Winter Weather Operations Plan (WWOP) or a Snow Plan for Snow and Ice Control?

33 responses were obtained for this question with 2 of them not showing the agency name; most (28) were “Yes”, but 5 answered “No” (Figure 48). Additional comments were all from respondents who marked with “YES” and are shown in Table 31.

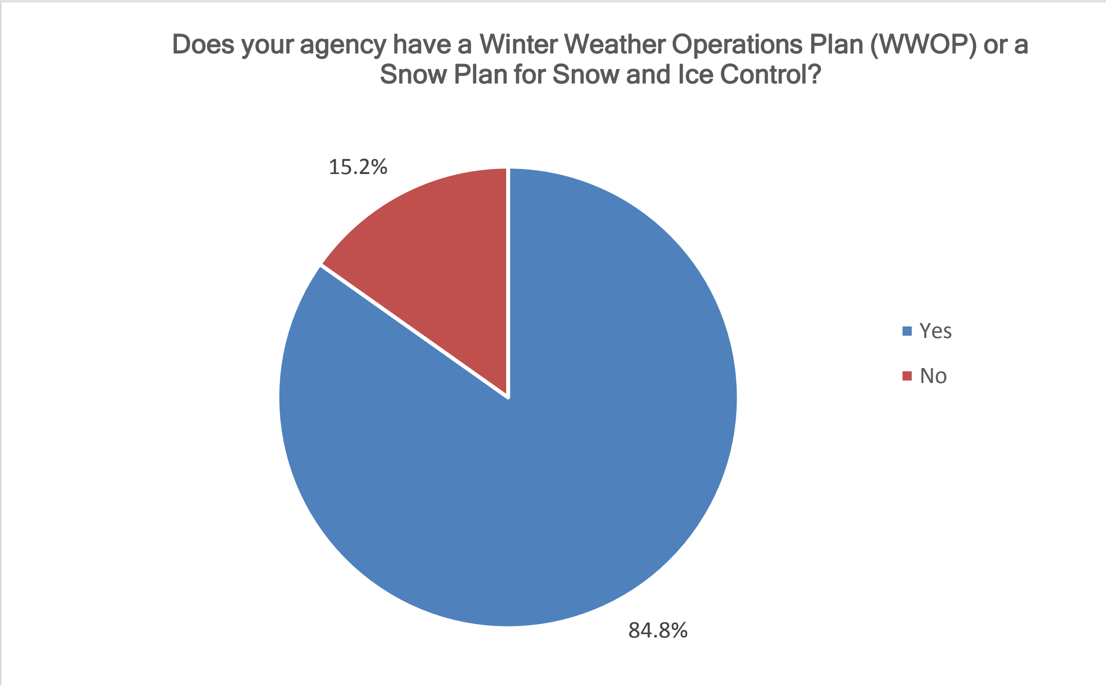

Figure 48. Survey answers to about having a WWOP or a Snow Plan for snow and ice control.

Table 31. Additional comments on the reason of making snow and ice control plans.

Agency	Comments
Vermont Agency of Transportation	http://vtransoperations.vermont.gov/winter_maintenance_plan.
West Virginia Division of Highways	Route maps and guidelines.
Oregon DOT	Each of 14 maintenance districts develop and implement a winter Ops plan.
Maine DOT	It's included with our Level of Service Policy.
New Hampshire DOT	I am assuming this refers to a "policy".

Q7. Does your agency's WWOP include a Salt Management policy or plan to reduce or limit usage of salt and other materials and their impact on the environment?

A total of 33 respondents provided answers to this question with 2 of them not showing the agency name; over half (n=19) answered "Yes", 5 answered "No", 8 answered "somewhat", and 1 answered "N/A" (Figure 49), which implied basically reducing or limiting the usage of salt and other snow and ice control materials had raised the focus of most agencies over their environmental issues. Additional comments from respondents are provided in Table 32.

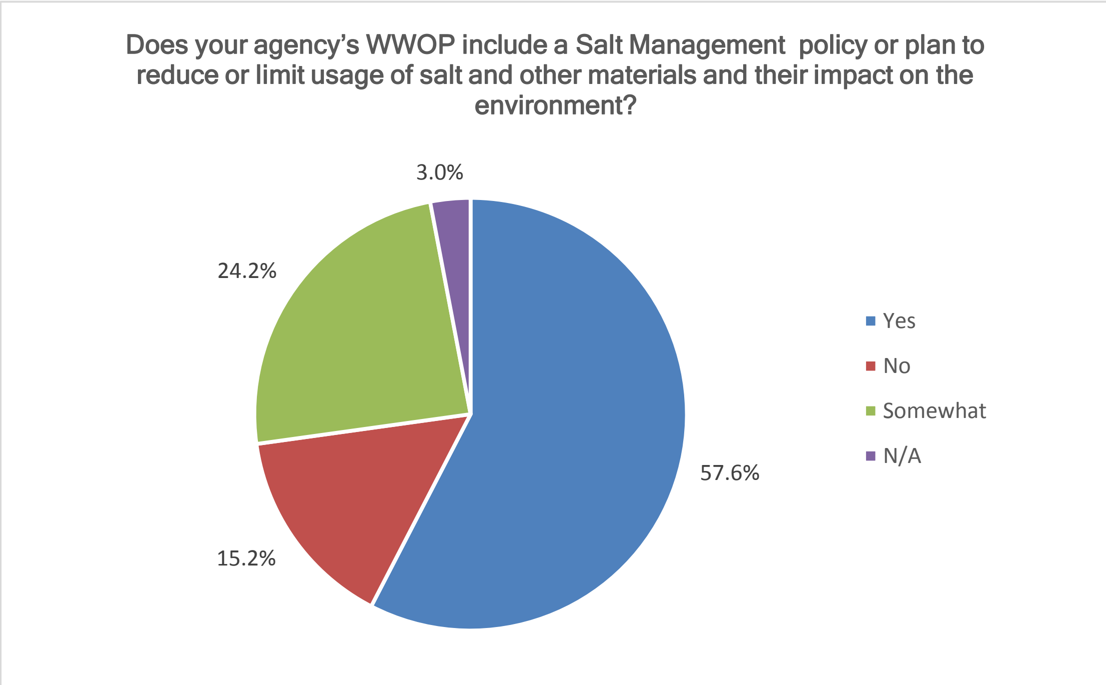

Figure 49. Survey answers about including a salt management policy or plan.

Table 32. Additional comments on the reason of including a salt management policy or plans.

Agency	Response	Comments
Vermont Agency of Transportation	Yes	We utilize an MDSS to help us decide on treatments.
Oregon DOT	Yes	ODOT uses salt in two pilot locations. We have a policy that outlines best management practices to minimize potential adverse effects on the environment.
Maine DOT	Somewhat	There are elements in our snow and ice policy, but not a self-standing salt management policy.
North Dakota DOT	Yes	Using MDSS to only put what is needed on the road.
New Hampshire DOT	Somewhat	Salt Management Plan has been drafted but not approved.

Q8. What factors determine the type of material used and application rate for each event (check all that apply).

Over 80% agencies provided responses for this question (n=33) with 2 of them not showing the agency name. In this question, each agency could list all factors determining the type of snow and ice products and application rates for each event, and according to the data collected, 18 agencies did so. Among the listed options, the top three factors were reported to be “Type of initial precipitation (drizzle, rain, freezing rain, light snow, heavy snow, etc.)” (93.9%), “Pavement temperature” (90.9%), and “Pavement condition at onset (clear, dry, wet, snow or ice covered, etc.)”(90.9%), followed by four secondary factors: “Expected intensity (rate of snowfall or icing)” (87.9%), “Expected temperature change (fall or rise)” (87.9%), “Expected duration (time)” (84.8%), “Time of onset (day, night, work-day, weekend)” (81.8%) (Figure 50). “Wind speed” had the lowest response percent (63.6%), showing that all these factors were playing important roles in the determination of material type and application rate. Additional comments are provided in Table 33.

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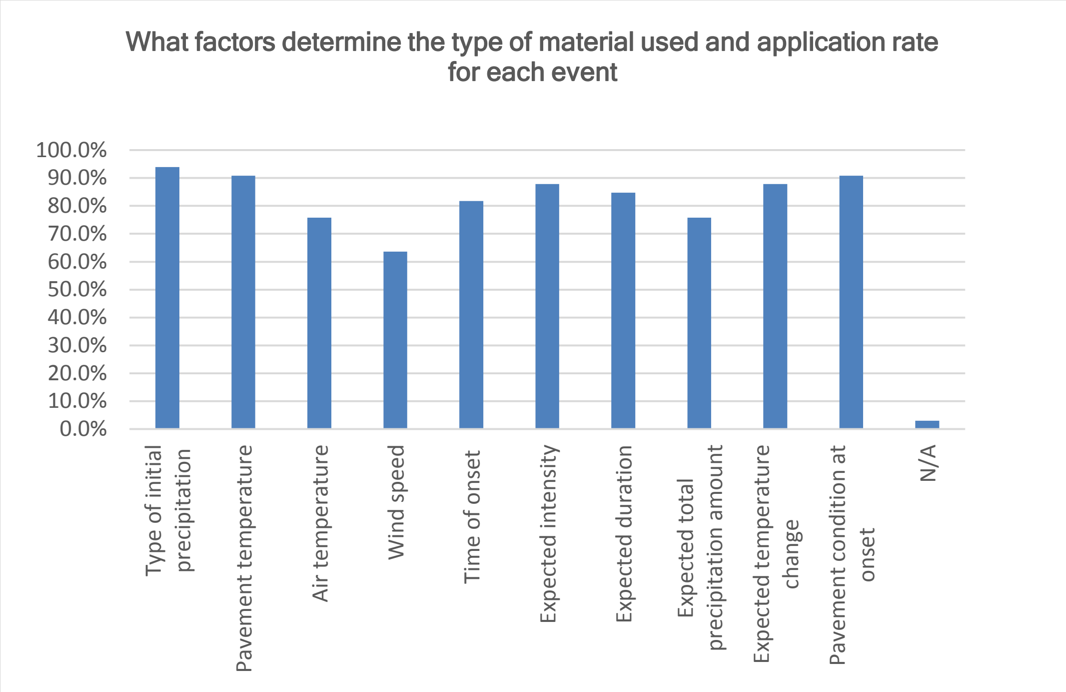

Figure 50. Survey result showing the response percent of important factors in the selection of snow and ice control materials.

Table 33. Additional comments on the factors determining maintenance material and application rate.

Agency	Comments
Colorado DOT	We are converting operations to Brine and are seeing reduction in salt usage.
Vermont Agency of Transportation	Refer to http://vtransoperations.vermont.gov/winter_maintenance_plan
West Virginia Division of Highways	Informal, there is no written protocol.
North Dakota DOT	Using MDSS.

Q9. Are agency staff trained on the proper use of materials including application rates and methods? If yes, please explain how frequently in the comment box (e.g. once when hired, annually, as products change, etc.).

There were 33 responses to this question with 2 of them not showing agency name; 31 answered "YES", only 1 answered "NO", and 1 answered "N/A" (Figure 51). Of the 31 agencies with positive answers, 2 provided supplementary remarks about

“Contractors trained - yes”, 2 gave “Contractors trained - no”, and 23 showed additional comments about the training frequency in Table 34.

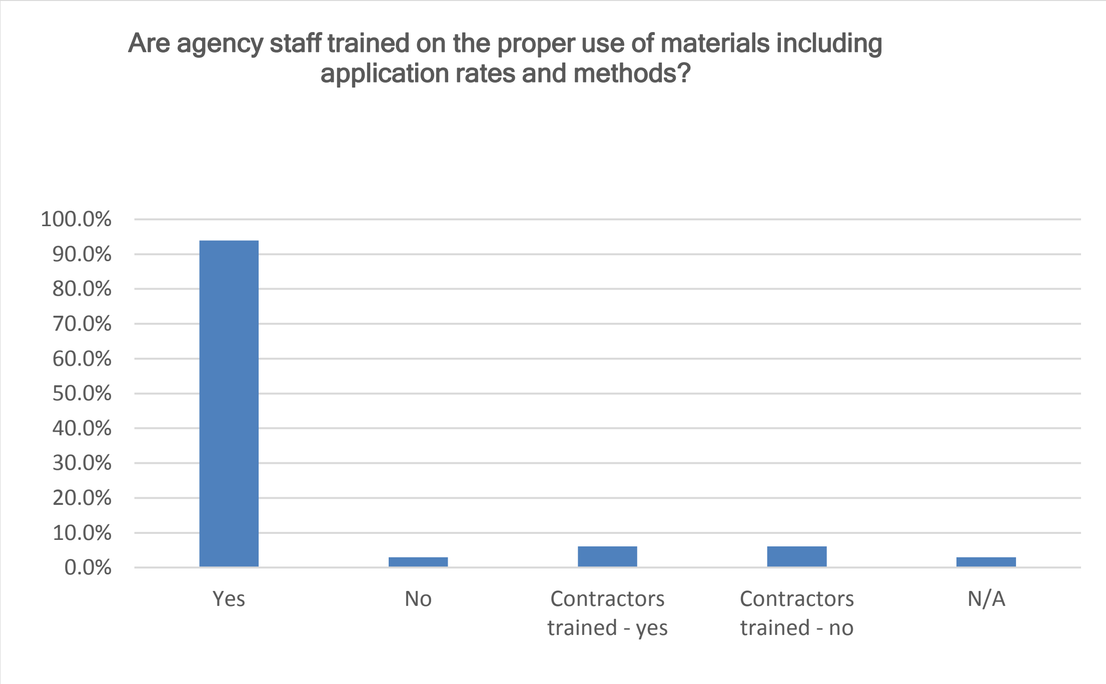

Figure 51. Survey results about the training conditions of agency staff.

Table 34. Additional comments on the explanations of training frequency.

Agency	Comments
Green Lake County Highway Department, WI	Annually.
Colorado DOT	New hires receive 40 hours of training. Veterans 8 hours annually.
Door County Highway Department, WI	Annual company refresher.
Waukesha County Highway Department, WI	Annually and as products change.
Vermont Agency of Transportation	New employees and annual refresher.
Minnesota DOT	When hired, annual fall 'Get Ready for Winter" meetings, Snow Plow Operator Training.
Wyoming DOT	During local foremen training for their sections.

Agency	Comments
City of Grandview, MO	Annually.
Washington State DOT	Yearly.
Massachusetts DOT	All staff must do annually training.
	Annually or as needed.
Kansas DOT	Each fall before winter - doing more now than ever.
Washington State DOT	Annually.
New York State DOT	Annually.
Virginia DOT	Trained annually prior to winter.
Oregon DOT	Initially and training is made available annually. Training is modified to reflect current technology, practice, and products.
Nebraska Department of Roads	Annually or with a product change. Each district may define proper use of material differently.
Maine DOT	Initially within one year of hire, then on-the-job training.
North Dakota DOT	At least yearly.
North Dakota DOT	More than once when hired. Reinforced sporadically.
Iowa DOT	Annually at a minimum.
Ohio DOT	Once a year or more.
New Hampshire DOT	State employees' mandatory every three years and before new employees plow. Contractors are voluntary but the Department pays them for their attendance. Probably over half of the contractors attend NHDOT training.

Q10. Does your agency provide training on environmental issues associated with winter maintenance practices?

There were 33 responses to this question with 2 of them not showing agency name. Almost 70% agencies (n=23) provided training on environmental issues associated with winter maintenance practices, 9 responded “NO”, and 1 answered “N/A” (Figure 52). Additional comments from respondents are provided in Table 35.

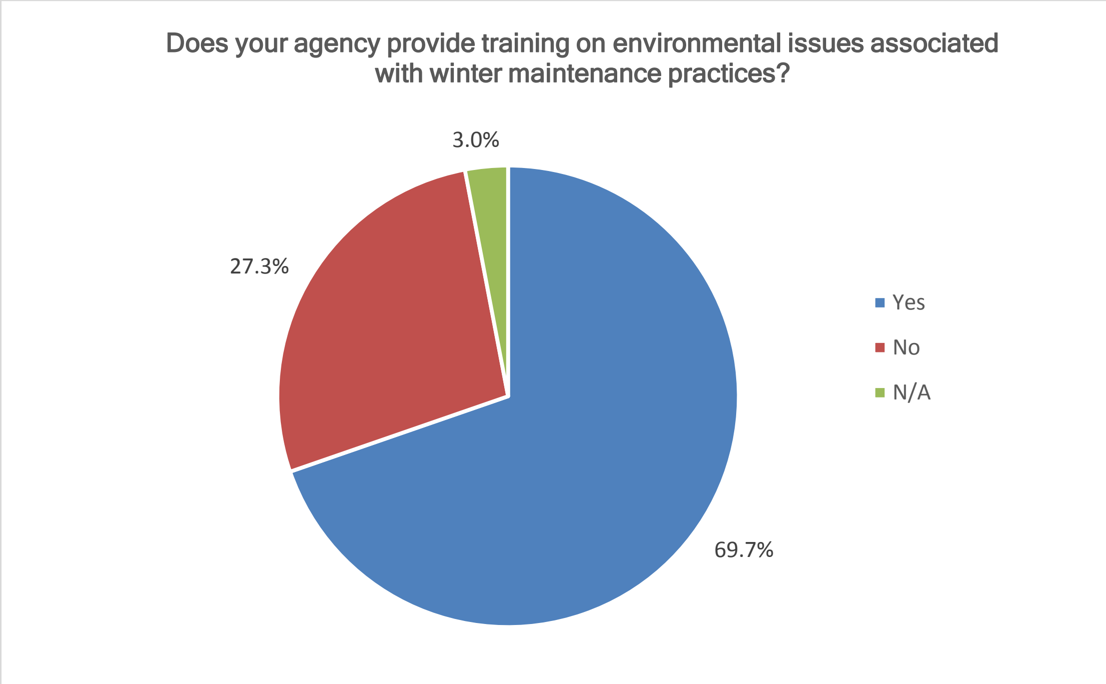

Figure 52. Survey results about agencies' training on environmental issues.

Table 35. Additional comments on agency's training on environmental issues in winter maintenance practice.

Agency	Comments
Door County Highway Department, WI	Annual company refresher.
Vermont Agency of Transportation	We are doing this in collaboration with the State Department of Environmental Conservation and extending this training to Municipalities.
Kansas DOT	Proper storage of salt.
Virginia DOT	Most areas touch on the subject.
Maine DOT	Our snow college training (the one that occurs within one year of hire) includes an environmental impacts module.

Q11. Do you feel the agency's staff is adequately informed on environmental issues associated with winter maintenance practices?

33 responses were collected for this question with 2 of them not showing agency name. 21 agencies answered "YES", 10 answered "NO", and 2 answered "N/A" (Figure 53). Additional comments are provided in Table 36.

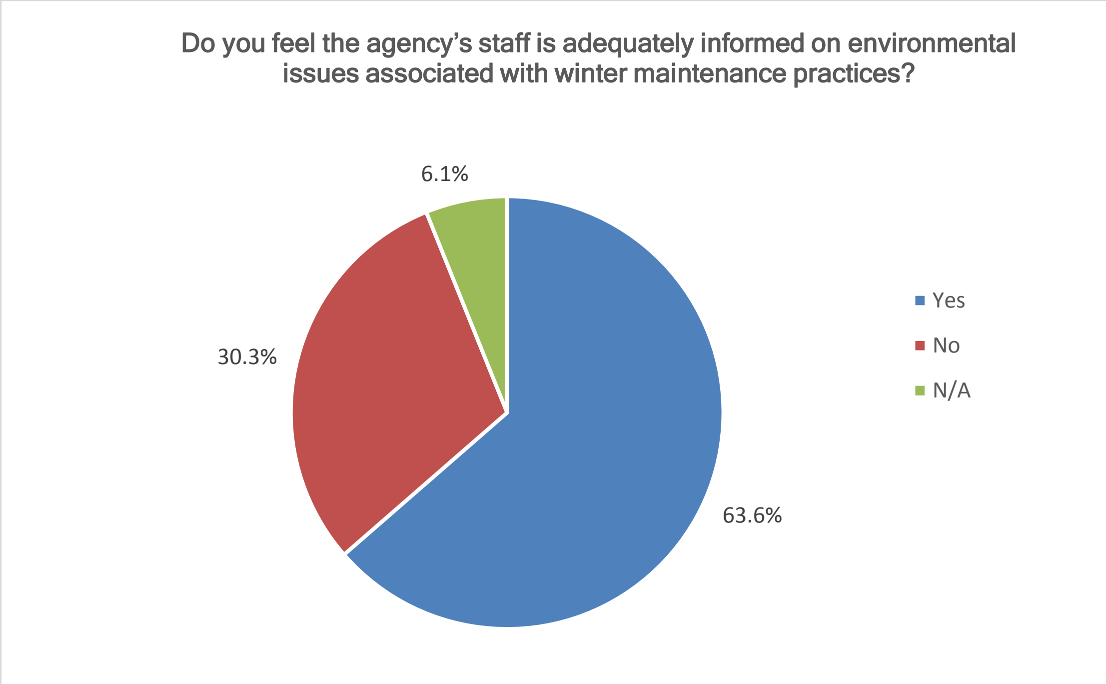

Figure 53. Survey results showing if staff is adequately informed on environmental issues associated with winter maintenance practices.

Table 36. Agency's Additional comments on informing staff the environmental issues.

Agency	Comments
Vermont Agency of Transportation	Ongoing training is necessary can do more and are building a Winter Maintenance Academy.
Rhode island DOT	Good always be improved.

Q12. To better understand material usage the agency uses the following measures.

34 responses were collected for this question; 3 of them didn't show agency names and 3 of them answered N/A. Of the four listed options, "Keeps detailed records of the type and amount of product used" was reported to be the most frequent method for better understanding of material usage (85.3%), followed by "Tracks material use per route or per event" (76.5%) and "Analyzes data collected to determine if adjustments need to be made" (70.6%); "Electronic scales to measure and record the amount of material used" only occupied 32.4% of 34 responses (Figure 54). Additional comments on the "other" category are provided in Table 37.

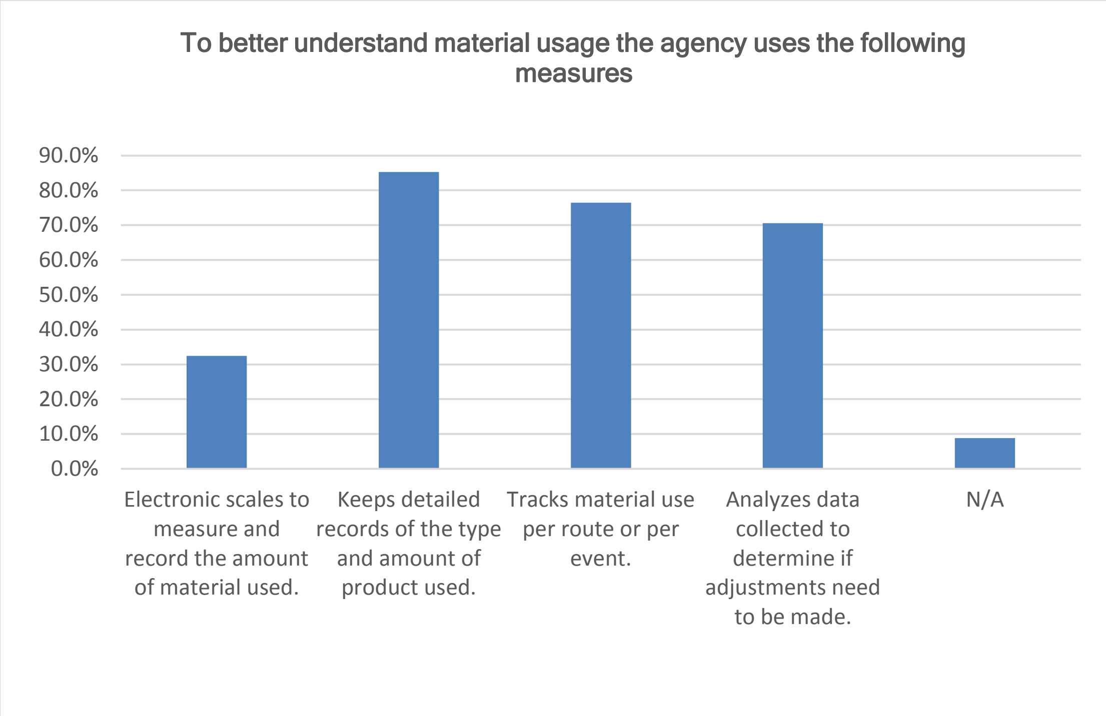

Figure 54. Percentage of responses to the listed measures for better understanding of material usage.

Table 37. Agency's Additional comments on measures for better understanding of material usage.

Agency	Comments
West Virginia Division of Highways	Record keeping and analysis are inconsistent.
Wyoming DOT	Adding precise units to track material output more accurately.
Virginia DOT	Some districts do more analyzing than others.
Nebraska Department of Roads	Amount of salt used per shift by each truck is usually tracked although not required.
Maine DOT	We have a research project that involves the use of onboard truck scales.
North Dakota DOT	We have a good maintenance management system that associates material usage to routes and specific storms.
Iowa DOT	We have the ability to track per event but only do so on occasion.

Agency	Comments
Ohio DOT	We have all of our snowplow trucks outfitted with Spreader Controls and GPS/AVL systems.

Q13. Has your agency made any effort to reduce or eliminate the general use of abrasives; or limited the use only where traction is needed at trouble spots?

A total of 30 agencies responded this question with 2 of them not showing agency name. 90% confirmed their efforts in reducing or limiting the general use of abrasives, and only 10% answered “NO” (Figure 55), which reflected a good trend of controlling the use of abrasives in the winter maintenance practices. Four supplemental comments were provided and are shown in Table 38.

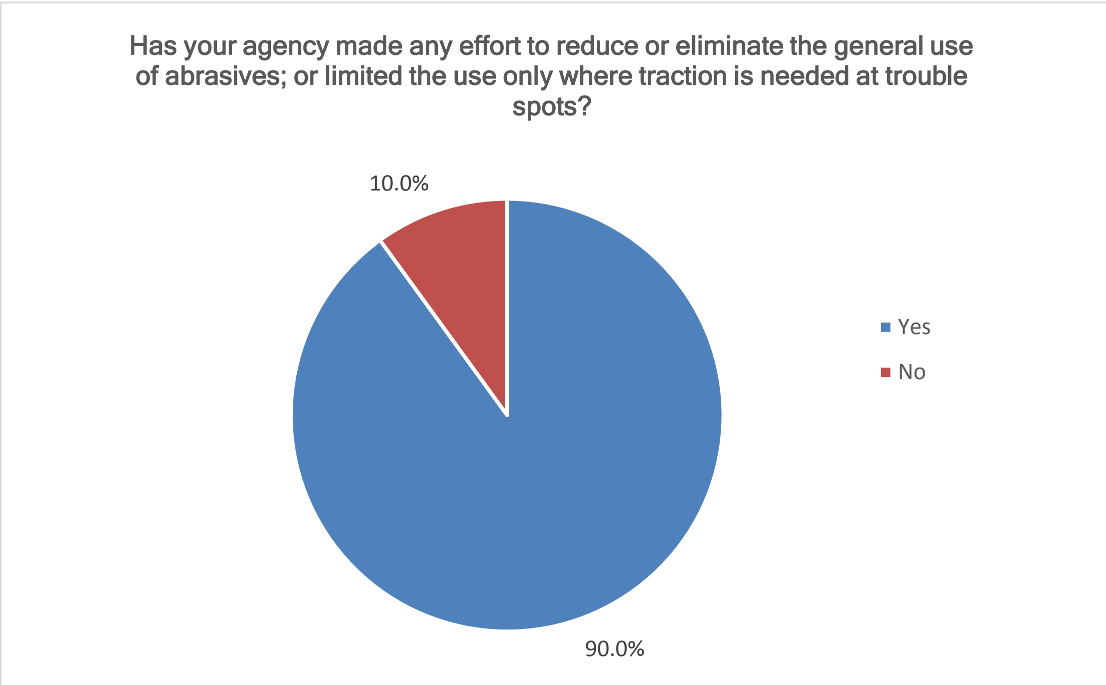

Figure 55. Percentage of responses to the question about agencies’ effort on abrasive usage.

Table 38. Agency's Additional comments on abrasive usage.

Agency	Comments
Vermont Agency of Transportation	Used on trouble spots only.
Kansas DOT	Trying to go to a more straight salt program and use the abrasives in colder weather and low volume roads.
Maine DOT	We have reduced from over a half million cubic yards of abrasives per year, to about 15 to 20 thousand.
North Dakota DOT	Slowly making progress.

Q14. Does your agency sweep streets or roads after each event to remove salt residue and abrasives?

Of the total 30 responses to this question, only 4 agencies answered "YES", 80% agencies (n=24) gave "NO", 1 answered "YES but not sure about the frequency", and 1 answered "N/A" (Figure 56), revealing post-event street sweeping/cleaning is a potential area for improvement, and the lack of sweeping may be an environmental concern. Additional comments are listed in Table 39.

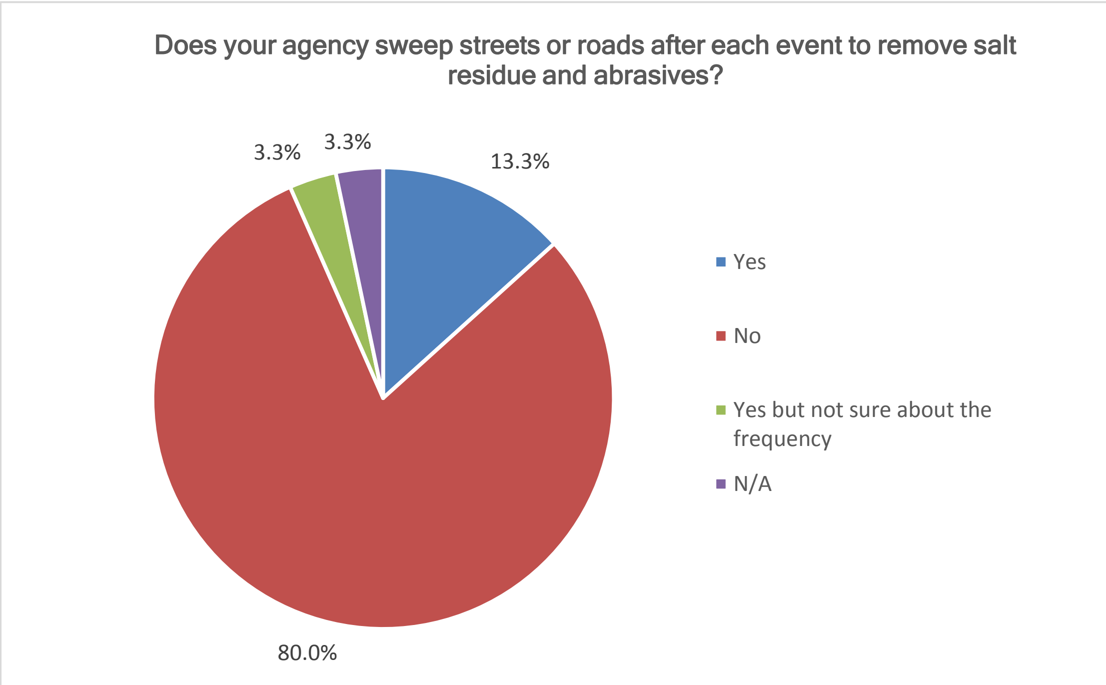

Figure 56. Percentage of responses to the question about post-event sweeping.

Table 39. Agency's Additional comments on salt residue and abrasive sweeping.

Agency	Comments
Colorado DOT	Within 72 hours.
Minnesota DOT	Sweeping will occur in the Spring.
City of Grandview, MO	Sweep at end of season.
North Dakota DOT	Only in environmentally sensitive areas.
Oregon DOT	Not after each event- depends on location. ODOT sweeps to remove sanding material as we don't use solid salt deicers.
Maine DOT	We sweep where needed and use vacuum trucks to clean out catch basins.
Ohio DOT	We sweep in the spring.
New Hampshire DOT	Except at end of season, not after each storm.

Q15. Are there other management practices implemented by your agency to reduce the environmental footprint of snow and ice control? If yes, please explain.

There were 27 responses to this question; of which almost half checked "YES" (n=12), half checked "NO" (n=14), and 1 answered "N/A" (Figure 57). Detailed supplemental instructions indicating the reasons for their answers were received in Table 40.

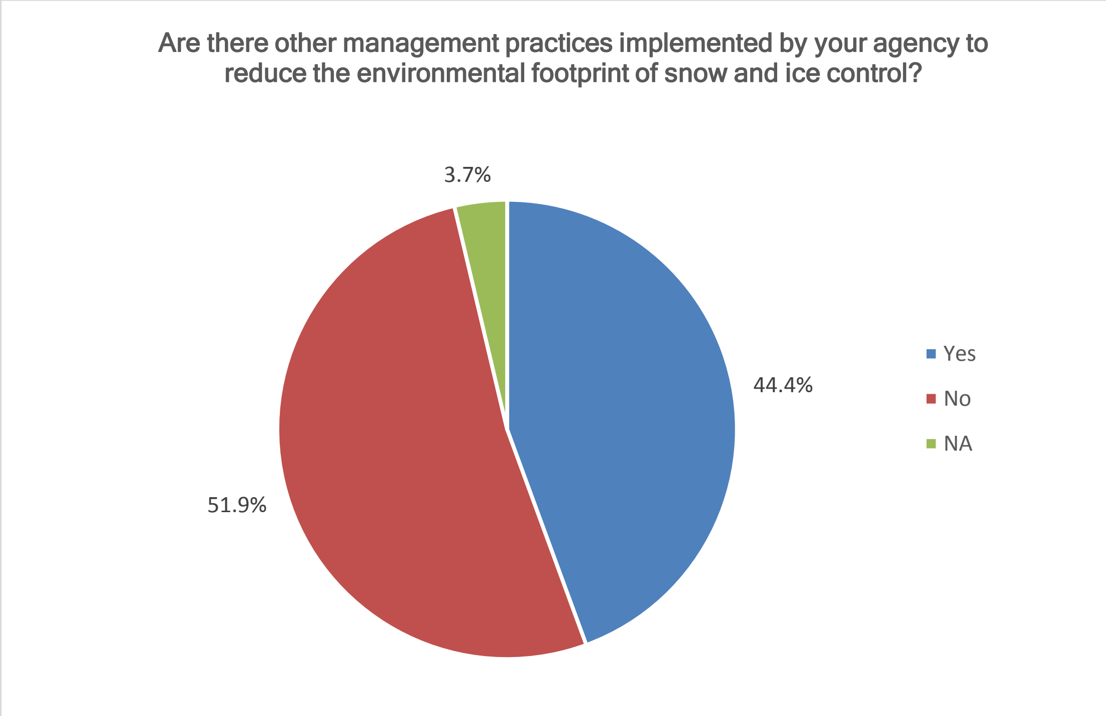

Figure 57. Percentage of responses to the question about implementing other management practices.

Table 40. Additional comments to the management practices implemented by agencies.

Agency	Comments
Colorado DOT	Secondary containment of liquids at all yards. All "salt" piles are in sheds.
Minnesota DOT	Working to integrate MDSS/AVL technologies in all trucks, conduct salt spinner calibration classes to interested agencies.
City of Grandview, MO	Take a measured approach that includes holding off on first salt application. Also take advantage of the residual effects of various deicing chemicals.
City of Cedar Rapids, IA	Brine use, bought our own machine.
Washington State DOT	Advanced application techniques including use of slurry, inclusion of organic inhibitors, and just in time applications.
Kansas DOT	All storage is inside buildings, under cover.
Washington State DOT	Roadside Soil and water sampling/testing.

New York State DOT	Salt storage under cover; reduced application rates; strong management of material application; various chemicals used.
Virginia DOT	All winter anti-icing or de-icing materials are kept under cover or in double walled or SPCC compliant tanks.
Ohio DOT	We cover all of our salt storage facilities and place the material on solid surfaces. Our new facilities are designed to contain storm water runoff and reduce the amount of turbidity in the waterway.
Maine DOT	We have modified spreaders to use more liquids and have been working with newer plows and blades to better remove snow and ice.
Iowa DOT	Increasing the use of brine as a pre-treatment. Limit the use of sand-salt mixtures.
Pennsylvania DOT	Utilize new spreader technology, also have stockpile QAs and BMPs for our stockpiles, pre-wet salt.

Q16. For each product used please provide a typical application rate (per lane mile or kilometer) of these materials for primary highways and surface arterials?

There were 29 responses for this question. The response percent for each listed material was reported as: sand (79.3%), cinders (51.7%), crushed rock/gravel (41.4%), treated salt (75.9%), and untreated salt (75.9%) (Figure 58). Responses indicate that sand, treated salt and untreated salt were the most commonly used materials, although there was significant use of other materials. There were also 6 responses reporting “Other materials” (including Ice Slicer (n=1), Calcium chloride (n=1), Liquid Magnesium chloride (n=1), and Salt Brine (n=3)) and 8 responses marking “Mixed materials” (including Salt/Sand (n=5), Salt/Abrasive (n=1), Sand/Ice Slicer (n=1), Salt/Stone (n=2), Salt/ Cinders (n=1), and Salt/ Ice B' Gone (n=1)). Detailed application rate for these materials are shown in Table 41.

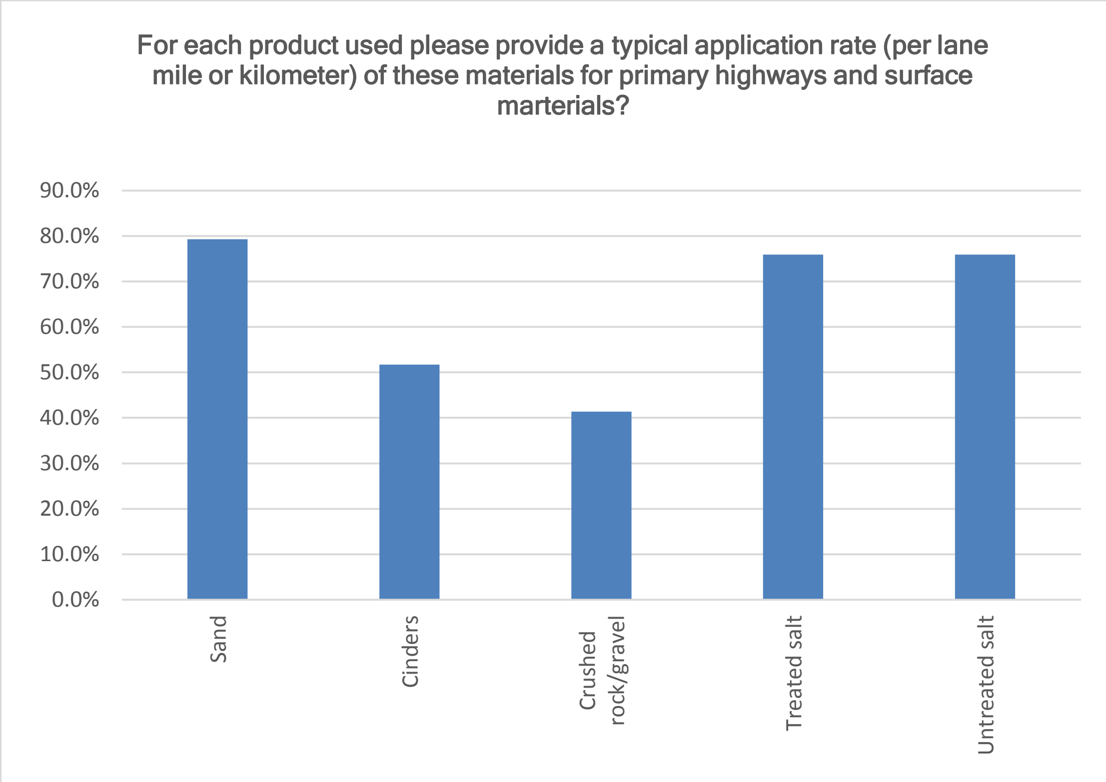

Figure 58. Survey result showing the response percent of listed highway and surface materials.

Table 41. Survey results showing application rate of materials for primary highways and surface arterials.

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
Green Lake County Highway Department, WI	Lane mile				250	300		
					100-400			
Green County Highway Department, WI	Lane mile			500	300			As needed
Shawano County Highway Department, WI	Lane mile	600			200			
Colorado DOT	Lane mile	100-500 lbs	N/A	N/A	100-500 lbs		Ice Slicer 100-300 lbs	
Marathon County Highway Department, WI	Lane mile	500	N/A	500	350	400		

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
Door County Highway Department, WI	Lane mile	N/A	N/A	N/A	N/A	200-300		Salt/Sand 10% - Hills curves when warranted for traction
Waukesha County Highway Department, WI	Lane mile	0	0	0	0-600	0	0	0
Vermont Agency of Transportation	Varies							
West Virginia Division of Highways	Lane mile	300-450	300-450			250-500		Salt/abrasives1:2, 2:1, 3:1 Ratios
Minnesota DOT	Lane mile (Rates adjusted based on conditions & falling or rising temperatures)				80-320 lbs/two-lane mile treated w/salt brine, 70-600 lbs/two-lane	100-400 lbs/two-lane mile		

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
					mile treated w/other blends			
Wyoming DOT	Lane mile	600-800 lbs						200-400 lbs/lm Sand and Ice Slicer mix (50-50)
City of Grandview, MO	Lane mile	300	0	0	250	300	0	300 - Sand/Salt = 3/1
City of Cedar Rapids, IA		50/50 mix when used				250 lb/mile per application	Calcium Chloride when under 15 degrees F	50/50 mix when used
Delaware DOT	Lane mile	500			400	400		
Washington State DOT	Lane mile	400 - 800 lbs	N/A	N/A	100 to 400 lbs	N/A	N/A	Sand/salt - varies
		1000 lbs/l-m or less	1000 lbs/l-m or less		200 lbs/l-m	200 lbs/l-m	brine 50 gal/l-m	

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
Kansas DOT	Lane mile				Pre-treated brine 200 - 400		Salt Brine 50 -60 gal	50:50 salt and sand 200-400
Washington State DOT	Lane mile	200 lbs	200 lbs	200 lbs	150 lbs	150 lbs		200 lbs Sand Salt Blend
New York State DOT	Lane mile	400-900			180	200		300-400
Virginia DOT	Ponds per lane mile	N/A	N/A	N/A	150-400	200-600		Salt/Stone 200-400
Oregon DOT	Lane mile	Roughly one yard per lane mile	Roughly one yard per lane mile		250-400 lbs	250-400 lbs	Liquid mag chloride: 30-45 gal	
Nebraska Department of Roads					200	300		500 (salt/gravel)

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
Maine DOT	Lane mile	800 lbs (when used)				250-300 lbs		Pre-wetting: Ice B' Gone (30%) Salt Brine (70%)
North Dakota DOT	Pounds per lane mile	300			300	300		20/80, 50/50 salt sand mix
Iowa DOT	Lane mile	Situation dependent - Will use a 50-50 mix of sand/salt	Do not use	Do not use		100-300 lbs/l-m		
Ohio DOT	Lane mile	None	None	None	250 lbs/l-m	None	Salt Brine for direct application 30 to 40 gallon/l-m	50/50 mix with salt at about 300 lbs/l-m
New Hampshire DOT	Lane mile	As needed				250 lbs		

Agency	Please indicate per lane mile or kilometer here:	Sand	Cinders	Crushed rock/gravel	Treated salt	Untreated salt	Other (specify product)	Mix (specify)
Pennsylvania DOT	Pounds per lane mile	Do not use	150	Do not use	100-250	Do not use		50/50 salt / cinders 100-250

Q17. What inorganic liquid materials are routinely used by your agency? (For all that apply provide application rates)

28 responses were collected for this question. Of the four listed inorganic liquid materials, sodium chloride (salt brine) was marked as the most commonly used material by agencies (85.7%); calcium chloride and magnesium chloride were also used frequently, 50.0% and 57.1% respectively; but no agencies reported using potassium chloride (n=7) (Figure 59). 8 agencies reported using the following blended materials:

- Magnesium chloride and beet juice,
- 10% beet, 15% magnesium and 75% brine at 8 gal/ton at salter,
- 70/30 Geomelt (beet juice) in brine,
- Beet Juice/Calcium Chloride (liquid) 50-60 gal/mile,
- Salt brine and calcium chloride 50-70,
- Ice Be Gone/Salt brine (IBG/SB) blend (30/70); 10 to 20 gal/ton,
- Salt brine and calcium chloride mix 90/10, and
- 80/20 brine/$MgCl_2$, same application rates as brine.

Detailed application rate of each agency for listed inorganic liquid materials, blended materials and other materials are presented in Table 42.

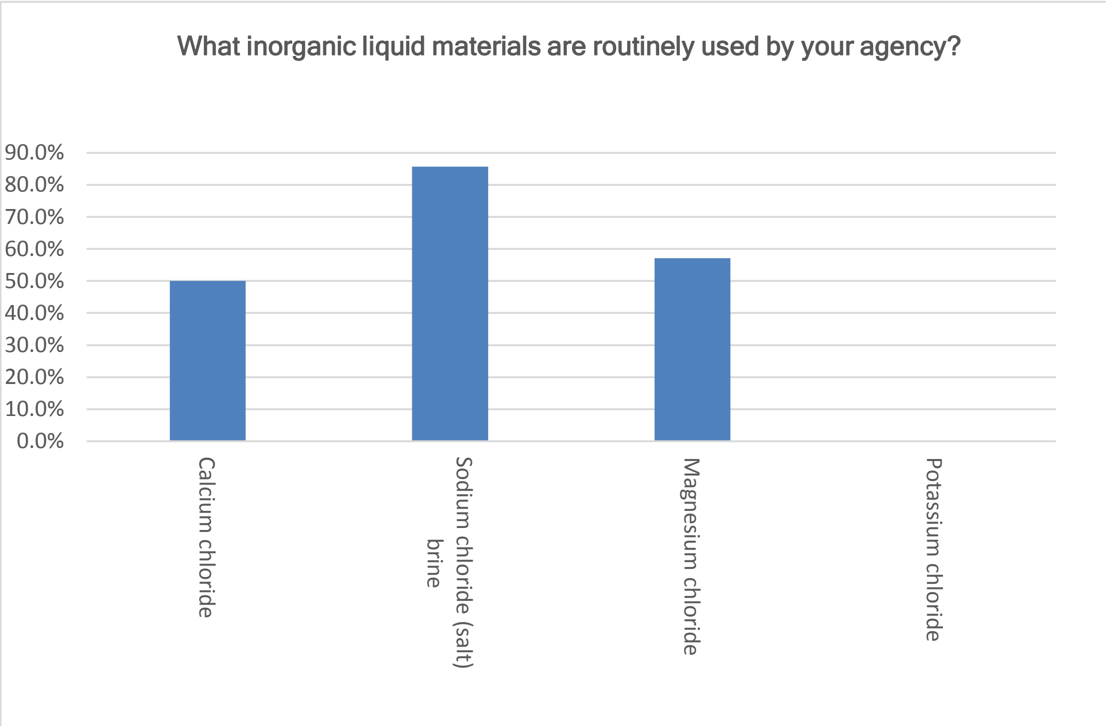

Figure 59. Survey result showing the response percent of listed inorganic liquid materials.

Table 42. Survey results showing application rate of inorganic liquid materials.

Agency	Calcium chloride	Sodium chloride (salt) brine	Magnesium chloride	Potassium chloride	Blend (specify)	Other (specify)
Green Lake County Highway Department, WI	Varies	Varies			Magnesium chloride and beet juice	
		7 gallons				
Green County Highway Department, WI		8 gal/ton				
Shawano County Highway Department, WI		Gravity Feed				
Colorado DOT	N/A	20 - 100 gallons	20 - 100 gallons	N/A	N/A	Cold temp mag 15 - 100 gallons
Marathon County Highway Department, WI		8 gal/ton of salt pre wet at salter			10 beet,15 mag and 75 brine 8 gal/ton at salter	
Door County Highway Department, WI		10 gal/mile				

Agency	Calcium chloride	Sodium chloride (salt) brine	Magnesium chloride	Potassium chloride	Blend (specify)	Other (specify)
Waukesha County Highway Department, WI	8-20 gal/ton of salt	8-20 gal/ton of salt	0	0	0	
Vermont Agency of Transportation	Varies					
West Virginia Division of Highways	Varies	80 gal/l-m				
Minnesota DOT		20-50 gal/l-m	15-25 gal/l-m			
Wyoming DOT		6-10 gal/ton of sand			70-30 Geomelt (beet juice) in brine	
City of Grandview, MO	150 pounds per 12 tons of salt	0	30-50 gal/l-m (liquid)	0	Beet Juice/Calcium Chloride (liquid) 50-60 gal/l-m	30-50 gal/l-m (Beet Juice)
City of Cedar Rapids, IA	3% ratio if under 15 degrees					
Delaware DOT		50 gal/l-m				

Agency	Calcium chloride	Sodium chloride (salt) brine	Magnesium chloride	Potassium chloride	Blend (specify)	Other (specify)
Washington State DOT	10 - 40 gal/l-m	15 - 50 gal/l-m	10 - 40 gal/l-m	N/A	N/A	N/A
		Brine 50 gal/l-m	Freeze guard 25 gal/l-m anti-icing only			
Kansas DOT		50-60 gallons per lane mile	Pre-treated salt			
Washington State DOT	20 gallons	30-40 gallons	20 gallons			
New York State DOT	8 gal/ton	40 gallons	8 gal/ton			
Virginia DOT	10-20 gal/ ton of salt	50-100 gal/l-m	20-60 gal/l-m	N/A	Salt brine and calcium chloride 50-70	
Oregon DOT			30-50 gallons			
Nebraska Department of Roads		60-80	40-60			

Agency	Calcium chloride	Sodium chloride (salt) brine	Magnesium chloride	Potassiu m chloride	Blend (specify)	Other (specify)
Maine DOT		50 gal/l-m (anti-icing/DLA) 60 gal/ton on some spreaders	Ice B' Gone (mag blended with molasses) 10 gal/ton		IBG/SB Blend (30/70); 10-20 gal/ton	
Iowa DOT	Situation dependent	10-30 gal/l-m	Do Not use	Do not use		
Ohio DOT	1 gal/ton for pre-wetting	Salt Brine for direct application 30 to 40 gal/l-m	None	None	Salt brine and calcium chloride mix 90/10	Aqua Salina +
New Hampshire DOT	8 gal/ton for pre-wet	50 gal/lm for pretreat, 8 gal/ton for pre-wet	8 gal/ton for pre-wetting		80/20 brine/$MgCl_2$, same application rates as brine	
Pennsylvania DOT						We do not routinely use any inorganic liquid materials

Q18. What organic liquid materials are routinely used by your agency? (For all that apply provide application rates)

There were only 10 agencies that responded to this question. For the population that responded to this survey, on one third use organic liquid materials in their winter maintenance practices. A summary of responses is shown in Table 43.

Table 43. Survey results showing application rate of organic liquid materials.

Agency	Calcium magnesium acetate (CMA)	Potassium acetate	Potassium formate	Urea	Agricultural by-products (beets, corn, molasses)	Other (specify)
Green Lake County Highway Department, WI					Beet juice	
Waukesha County Highway Department, WI	0	0	0	0	8-20 gal/ton	
Vermont Agency of Transportation	Varies	Varies	Varies	Varies	Varies	Varies - see http://vtransoperations.vermont.gov/sites/aot_operations/files/documents/AOT-OPS_SnowAndIceControlPlan.pdf
Wyoming DOT						Beet juice
City of Grandview, MO					30-50 gal per e-mile	
Washington State DOT	N/A	10-25 gal/l-m, one location only	N/A	N/A	Only as additives to chloride products, 5-20%	N/A
Washington State DOT		20 gallons				

Maine DOT					Ice B' Gone blend as described above	
North Dakota DOT		On a some bridge decks and in two FAST			Beet product	
Ohio DOT	None	None	None	None	Beet Heat Sever and Concentrate 7 gal/ton	

Q19. Does your agency pre-wet (adding liquids at the time of application) dry materials?

Of the 30 responses to this question, 27 marked "YES", 2 showed "NO", and 1 had "N/A" (Figure 60). Based on the population of respondents to this survey, pre-wetting is commonly used practiced in winter maintenance operations. Additional comments provided by respondents are reported in Table 44.

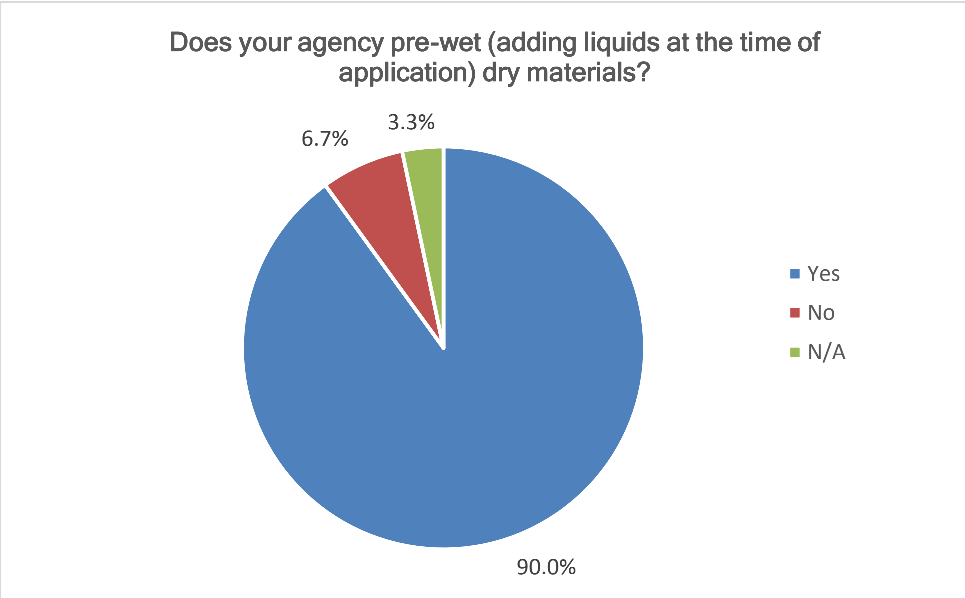

Figure 60. Percentage of responses to the question about pre-wetting dry materials.

Table 44. Agency's Additional comments on dry material pre-wetting.

Agency	Comments
West Virginia Division of Highways	At some locations.
	Limited applications, but we are adding more capability to fillet.
Oregon DOT	It is a recommended best management practice, but not always used.
Maine DOT	All trucks have on-board pre-wetting systems.

Q20. Does your agency pre-treat (adding liquids to salt prior to or at the time of stockpiling) dry materials?

30 responses were collected for this question; 11 agencies would pre-treat dry materials prior to or at the time of stockpiling, 18 agencies would not, and 1 agency marked "N/A" (Figure 61). Three supplementary comments are reported in Table 45.

Based on survey responses regarding use of pre-wetting or pretreating, pre-wetting is used by more agencies than pretreating. Based on the provided follow-up comments, pretreatment appears to be used by agencies that do not have onboard pre-wetting equipment.

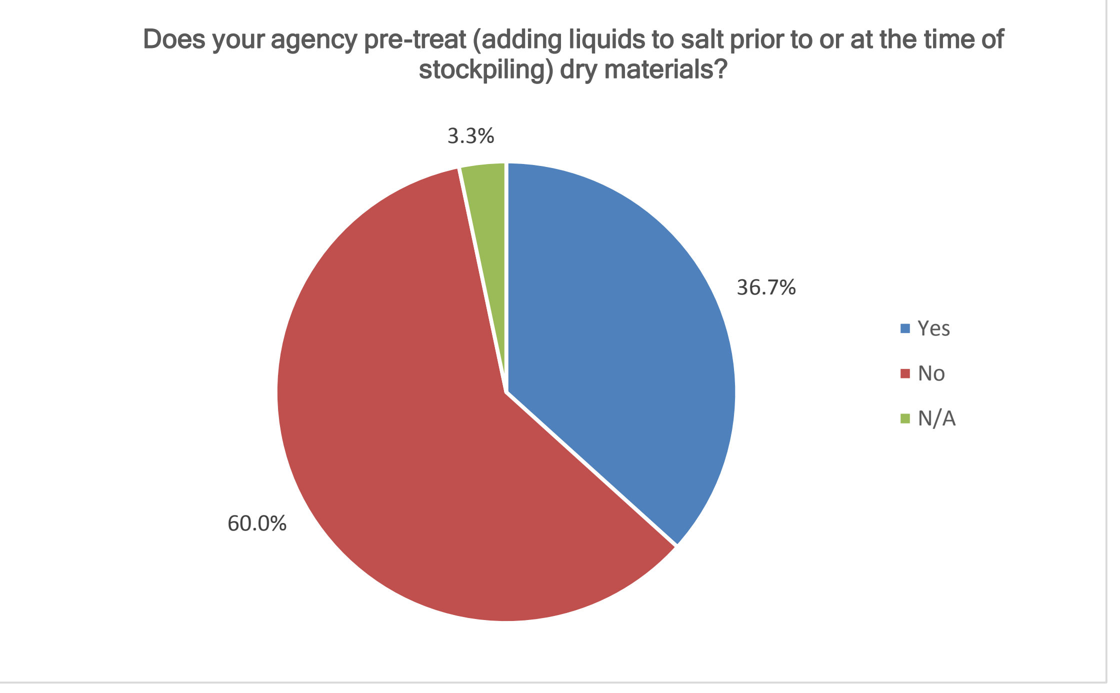

Figure 61. Percentage of responses to the question about pre-treating dry materials.

Table 45. Agency's Additional comments on dry material pre-treating.

Agency	Comments
Marathon County Highway Department, WI	A little pile.
Washington State DOT	Minimally, where trucks aren't equipped. Most are.
Maine DOT	Occasionally, but not a widespread strategy due to the on-board systems.

Q21. What factors did your agency consider in selecting what materials to use?

A total of 30 agencies answered this question, of which each agency could check all the factors, not limited to one. The top two factors considered when selecting materials by responding agencies were "Availability" (90%) and "Cost per unit" (83.3%), followed by five secondary factors: "Existing vehicles and equipment for application" (76.7%), "Existing storage facilities" (70%), "Better anti-ice/de-ice effect at lower temperatures than traditional materials" (66.7%), "Proven/accepted performance" (63.3%), and "Effect on environment" (60%) (Figure 62). As a whole, product performance and agency's existing product and application equipment were shown to play an important role when selecting snow and ice control materials, while comparatively, external factors had less influences in this process, such as “Cost of retrofitting existing or purchasing new vehicles or equipment to handle new and different materials” (n=11), “Relied on what other agencies were using” (n=6), “Compliance with regulations, laws” (n=6), “Mandate or direction from higher officials” (n=4), and “Vendor offered a good deal” (n=1). Two additional comments were provided and are shown in Table 46.

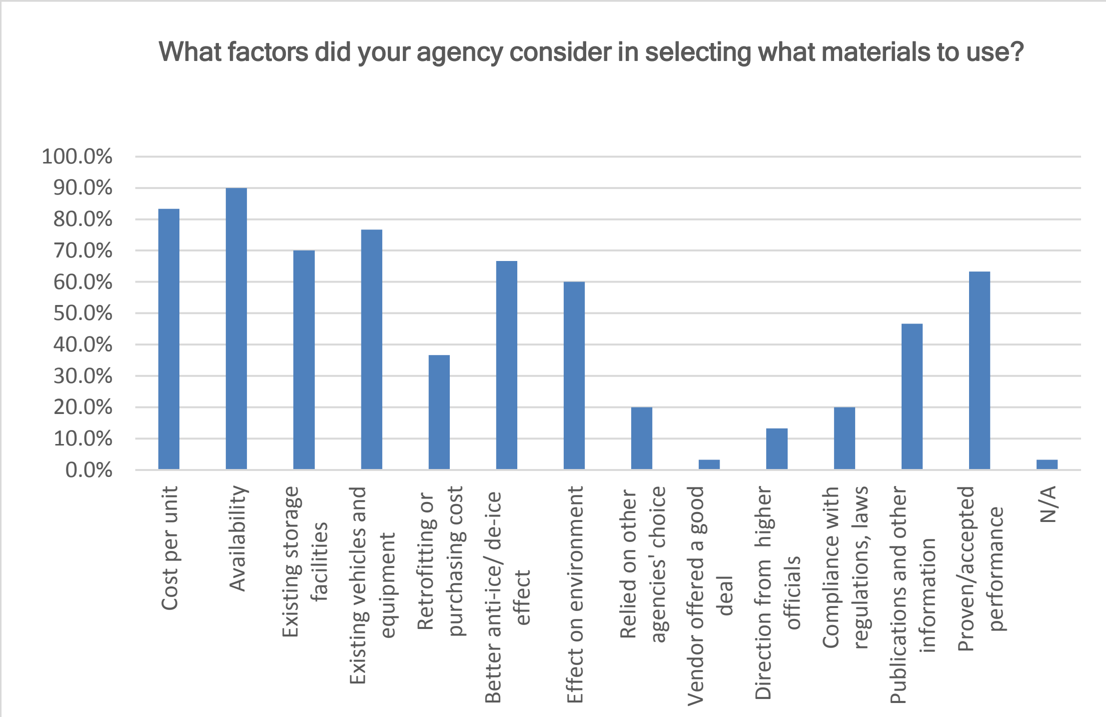

Figure 62. Percentage of responses to the factors that agencies considered when selecting materials.

Table 46. Agency’s Additional comments on factors considered in material selection.

Agency	Comments
Oregon DOT	Corrosively.
Maine DOT	We chose Ice B' Gone partially for it being listed by the EPA as designed for the Environment" and its lower chloride level.

Q22. How does your agency store salt or salt/sand mix?

There were 31 responses for this question with 3 of them not showing agency names. Of the seven salt storage options listed, the responses were pretty concentrated (Figure 63): 30 agencies chose to store salt or salt/sand mix “on paved surface inside covered structure” (96.8%), with 5 agencies storing materials “on impermeable paved surface and covered with tarp”, 2 agencies storing materials “at another agency, cooperative, or vendor site”, and 1 agency storing salt or salt/sand mix “on a permeable unpaved surfaced and covered with a tarp". According to survey result, no agency stored salt or salt/sand mix "on impermeable unpaved surface and covered with tarp", "on a permeable unpaved surface and uncovered", or "underground". Additional comments are shown in Table 47.

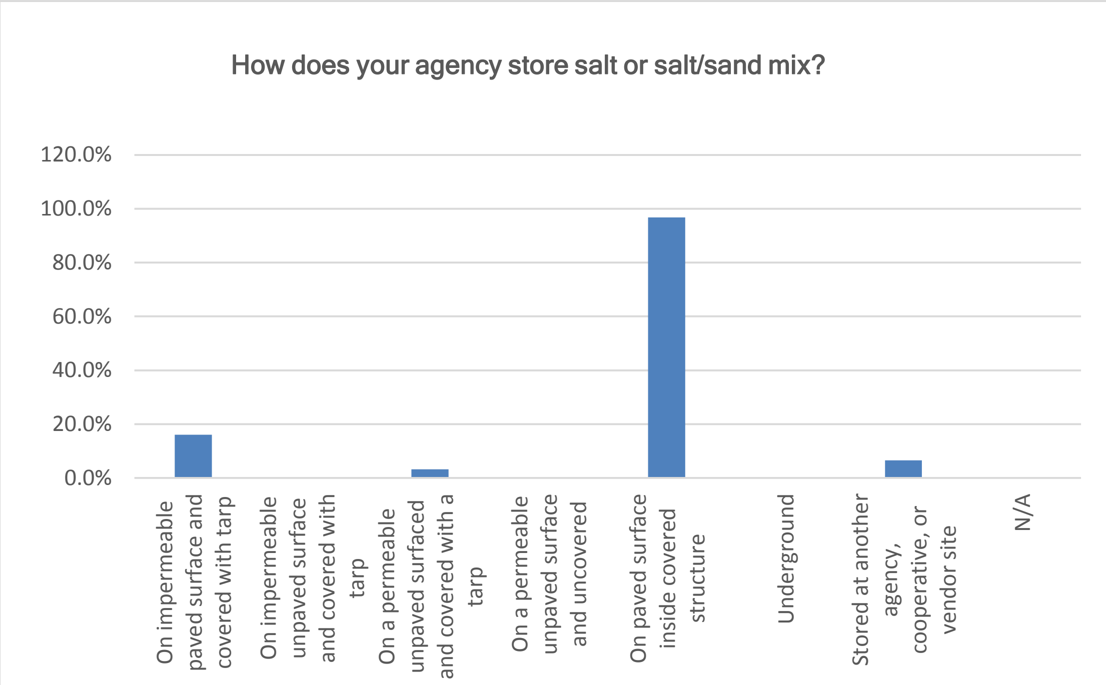

Figure 63. Percentage of responses to the factors that agencies considered when selecting materials.

Table 47. Agency's Additional comments on factors considered in material selection.

Agency	Comments
Oregon DOT	Two storage locations in Oregon are on paved and sealed surface with concrete-walled structure with a tarpaulin cover large enough to load, unload, and store all materials inside and under cover.
Maine DOT	We have some remaining outdoor salted sand piles that we cover with a "hot sand" or spray material to minimize infiltration. We are working to put all piles in buildings.

Q23. Are liquids products stored in tanks?

31 responses were collected for this question. Similar to Q22, the responses for this question were also very concentrated. Of the listed 4 locations for liquid storage tanks, 100% of agencies store the liquid products in tanks "above ground" (n=31), only 12.9% of agencies use "portable (trailer-mounted)" tanks (n=4) and 3.2% use tanks "underground" (n=1) (Figure 64). Oregon DOT provided an additional comment on this question: "We have maybe two portable (trailer mounted) tanks statewide, and most are stationary poly tanks."

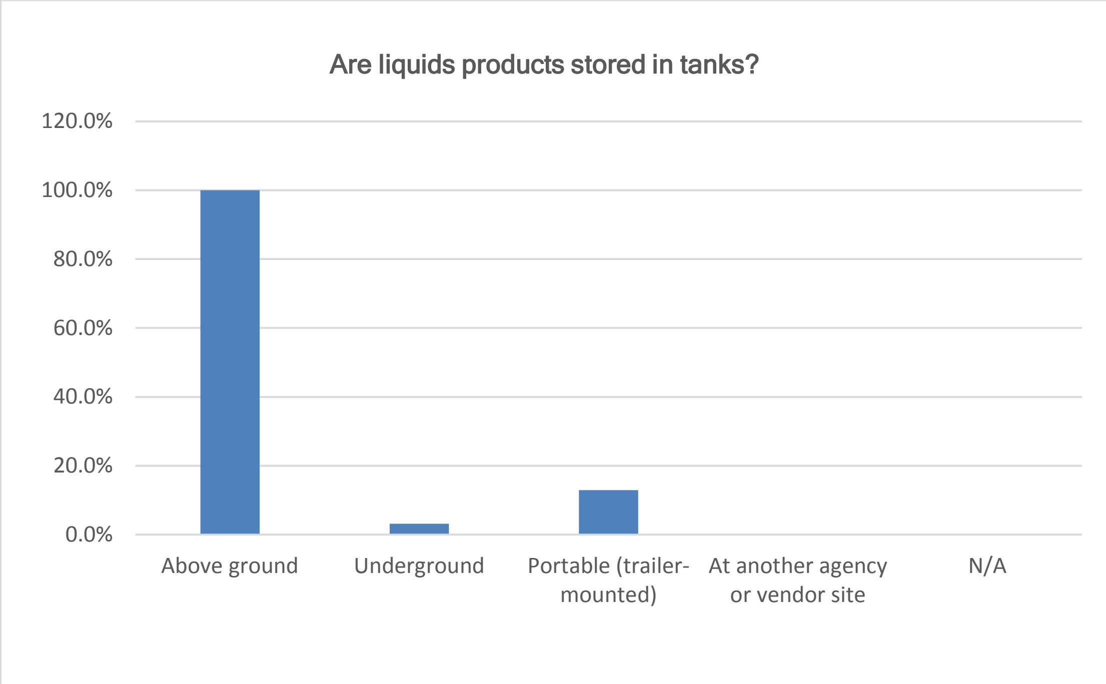

Figure 64. Percentage of responses to the storage method of liquid products.

Q24. Do you have secondary containment for all piles and liquid storage containers?

There were 31 responses for this question; 8 answered “YES”, 7 answered “NO”, and 16 answered “Some but not all” (Figure 65). Generally speaking, 77.4% of agencies had secondary containment for all piles and liquid storage containers. Additional comments provided by respondents are shown in Table 48. Based on these results, secondary containment seems to be recognized as important for liquid products, but less understood for solid piles. This is an area we should explain/explore in this document.

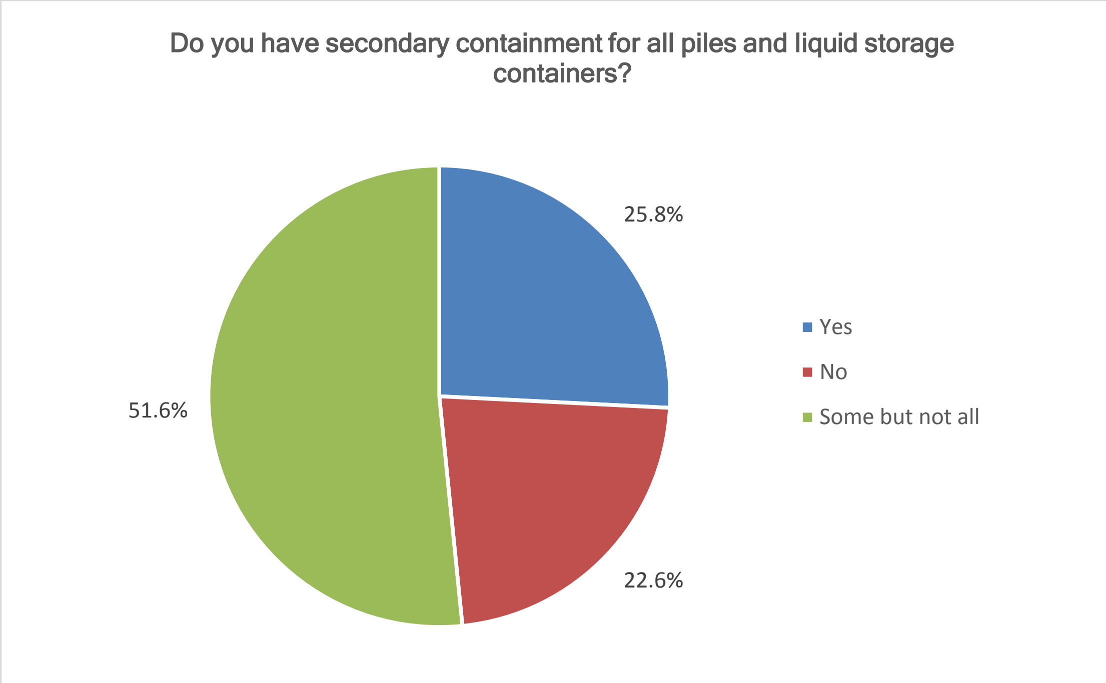

Figure 65. Percentage of responses to the question about secondary containment.

Table 48. Agency's Additional comments on secondary containment.

Agency	Comments
West Virginia Division of Highways	Yes for tanks, no for salt piles.
Washington State DOT	All NPDES areas and many others.
Oregon DOT	Not sure what 'secondary containment' would look like for solid product....concrete walls of both salt structures are sealed, paved sealed surface, and the structures are three-sided with a door on one side. Secondary containment for liquid storage is determined based on risk factors.
Iowa DOT	Our new facilities are designed to contain runoff in case of a spill.
Ohio DOT	Liquid-Yes; Salt-No.

Q25. Does the agency have a practice/ policy prohibiting over-loading salt on trucks to prevent spillage?

Of the 31 responses for this question, 87% marked "YES", and only 13% answered "NO" (Figure 66). Additional comments are shown in Table 49.

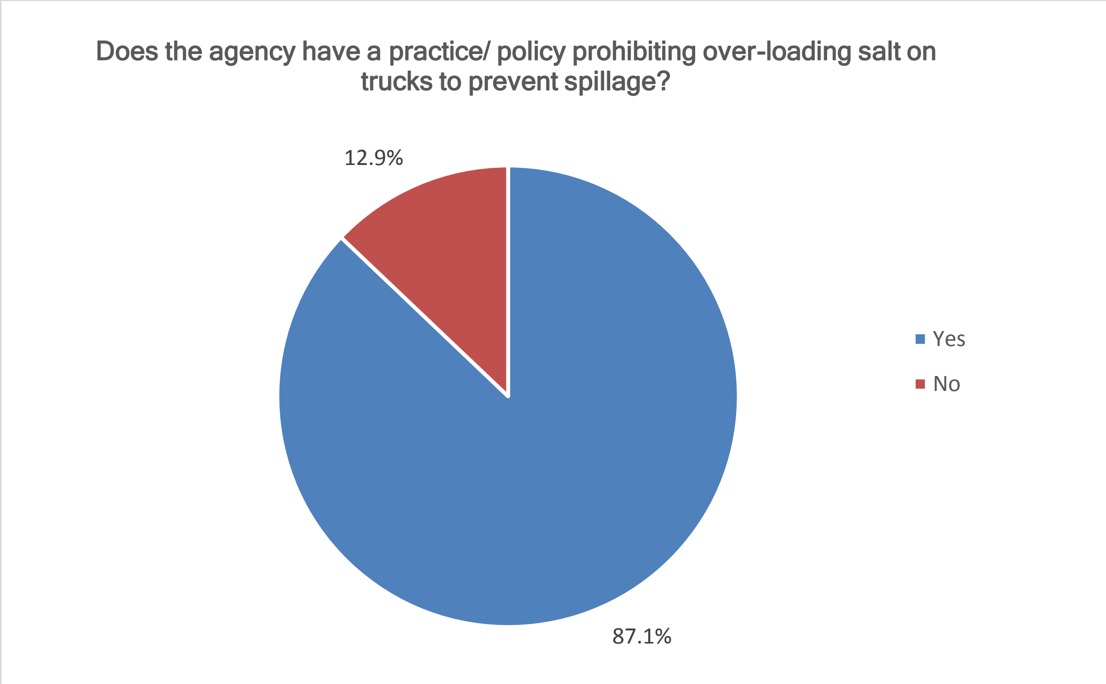

Figure 66. Percentage of responses to the question about over-loading policy.

Table 49. Agency's Additional comments on the establishment of practice/policy to prohibit over-loading salt on trucks.

Agency	Comments
	Practice yes; policy no.
Maine DOT	That is not specified in our policy. Seems pretty obvious, but perhaps it should be added.

Q26. Does your agency wash snow and ice vehicles and equipment soon after each event when possible?

29 agencies of the total 31 responses provided "YES", and the other 2 answered "NO" to this question (Figure 67). Six additional comments are shown in Table 50.

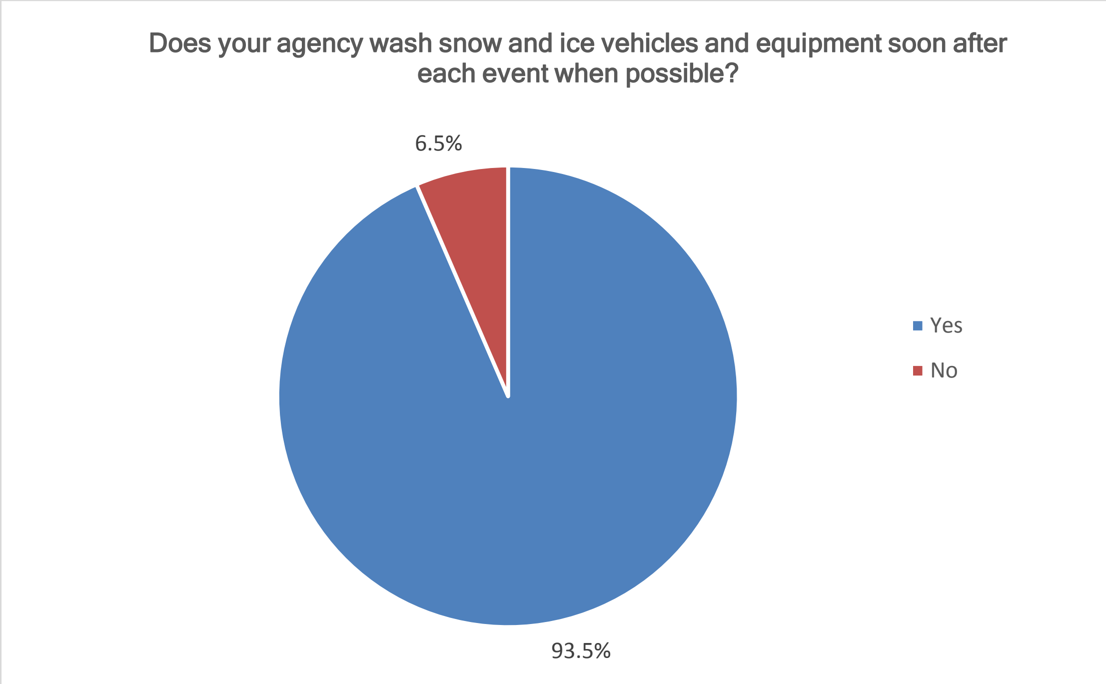

Figure 67. Percentage of responses to the question about if agency washes snow and ice vehicle and equipment after each event.

Table 50. Agency's Additional comments on washing of snow and ice vehicle and equipment.

Agency	Comments
Rhode island DOT	We try to hose them off, but we do not have access to a truck wash.
West Virginia Division of Highways	Immediately after each snowfall.
City of Grandview, MO	When weather allows.
Washington State DOT	That is the policy. Not always followed unfortunately.
Oregon DOT	Not sure how often this happens. It is recommended after each event.
Ohio DOT	We try to wash vehicle as soon as practical after a storm.

Q27. Does your agency capture wash water before entering sewer system or open ground?

There were 31 responses for this question; 12 answered "YES", 2 answered "Yes, and it is recycled for brine making, pre-wetting, etc.", over 50% of responses answered

"NO", and 1 answered "N/A" (Figure 68). Additional comments are shown in Table 51. Based on these responses, this is a potential area for improvement.

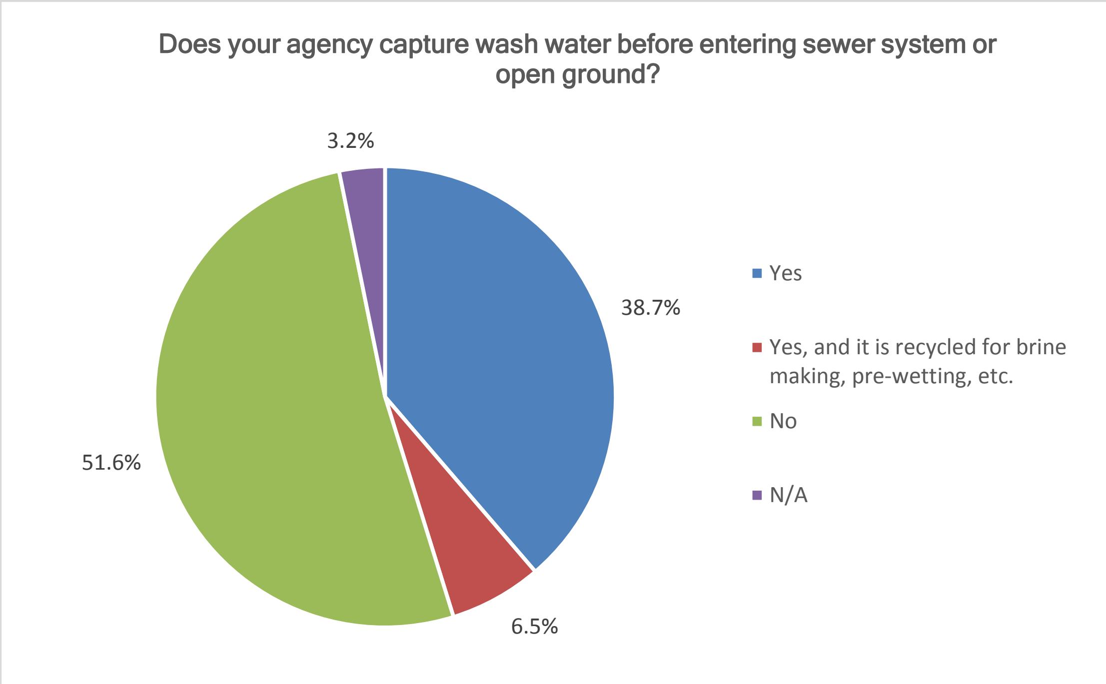

Figure 68. Percentage of responses to the question about if agency captures wash water before entering sewer system or open ground.

Table 51. Agency's Additional comments on capturing wash water before entering sewer system or open ground.

Agency	Responses	Comments
Vermont Agency of Transportation	No	We are working towards recycling for brine, pre-wetting, etc.
City of Grandview, MO	Yes	Water goes to sanitary system.
Oregon DOT	No	We have two wash facilities for solid salt- one is connected to sanitary the other captures wash water above ground in lined pool where material is allowed to evaporate and solids are hauled to the municipal dump. We have statewide guidance for washing to address regulatory concerns. We hook up to sanitary whenever feasible.
Maine DOT	Yes	In some cases, the sewage treatment facilities accept the salty water.
Ohio DOT	Yes	We capture our wash water. Some places are making brine, in other areas it is sent to a sanitary sewage treatment facility.
New Hampshire DOT	No	Registered wash areas with NHDES with approved work instructions.

Q28. Does your agency have structures or devices used to control/contain salt-runoff at maintenance facilities? (Check all that apply)

There were 29 responses for this question. Agencies could check all the listed answer options, not limited to one. Based on the survey results, over half of the responding agencies used "Berm around perimeter of storage area" (55.2%) and "Retention/detention pond" (65.5%) to control/contain salt-runoff at maintenance facilities (Figure 69). A small portion of the agencies use "Channel/ ditch around perimeter" (31%) and "Wetlands/marshes" (6.9%). 20.7% of agencies had no structures or devices used to control/contain salt-runoff. Additional comments are provided in Table 52. While the population the responded to this question shows the use of structures and devices to control and contain salt-laden runoff, this is potential area for improvement as well.

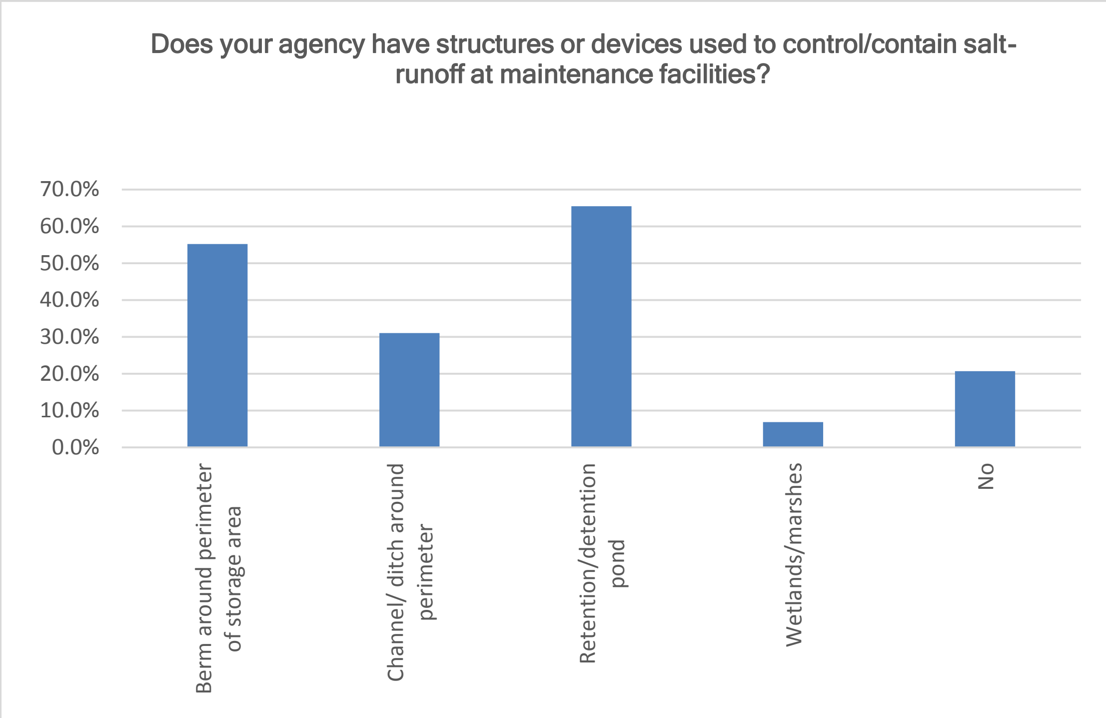

Figure 69. Percentage of responses to the salt-runoff control structures or devices.

Table 52. Agency's Additional comments on structures or devices used to control/contain salt-runoff at maintenance facilities.

Agency	Comments
Green Lake County Highway Department, WI	Berm along one side of facility.
Oregon DOT	Two solid salt storage sheds are graded toward the center of the storage facility. Any solid salt that is tracked is swept up and put back on the pile under cover.
Ohio DOT	Our newer facilities have retention/detention ponds and ditches that collect storm water.

Q29. Does your agency incorporate roadway design features into new construction or major reconstruction that help minimize use of salt and other chemicals?

Of the 31 responses for this question, about 32.3% of agencies incorporated roadway design features into new construction or major reconstruction, while over half of the responding agencies had no such incorporation, and 4 marked "N/A" (Figure 70). Additional comments are reported in Table 53. There is a lot of potential for improvement by agencies in incorporating roadway design features into new construction and reconstruction. This can be approached using environmental management systems and other planning tools.

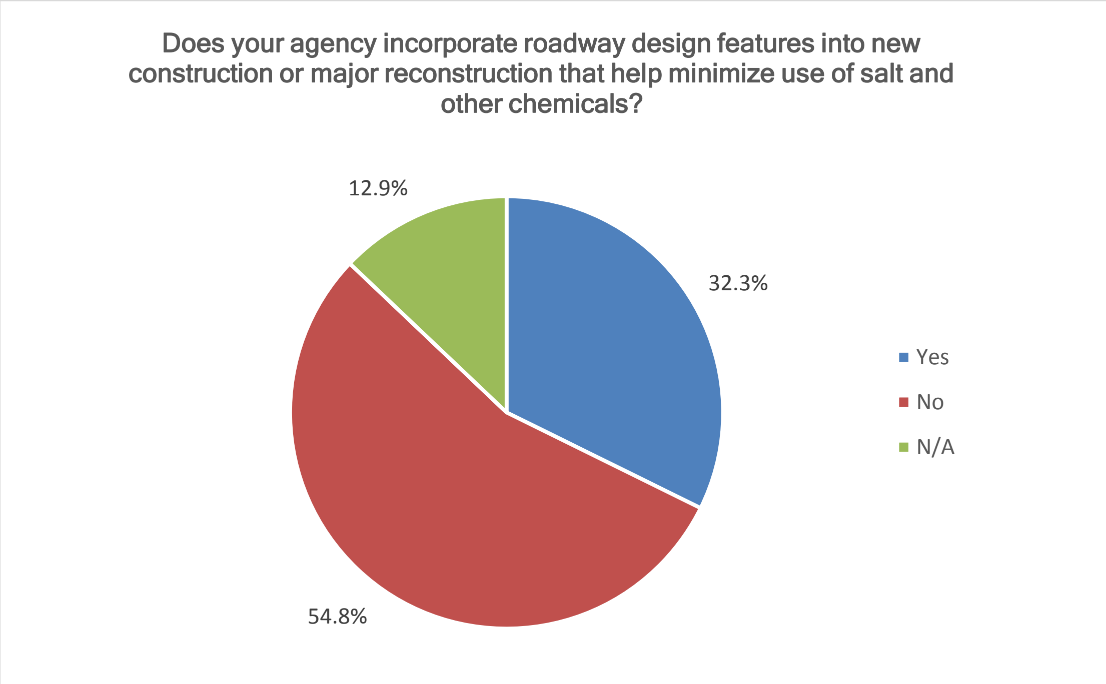

Figure 70. Percentage of responses about incorporation of roadway design features.

Table 53. Agency's Additional comments on incorporation of roadway design features.

Agency	Comments
Vermont Agency of Transportation	Not sure what these features might be?
Washington State DOT	Not to my knowledge.
Oregon DOT	Not that I'm aware of.
Nebraska Department of Roads	High friction surfacing for bridge decks.
Maine DOT	We are internally draining islands more often to eliminate refreeze.

Q30. Has your agency constructed roadside features such as detention ponds, marshes, or wetlands that help divert meltwater with chemicals from directly entering streams, lakes, and other bodies of water?

For the roadside feature construction, a total of 30 agencies answered this question; 17 marked "YES", 10 gave "NO", and 3 answered "N/A" (Figure 71). Additional comments are provided in Table 54. This is a potential area for improvement.

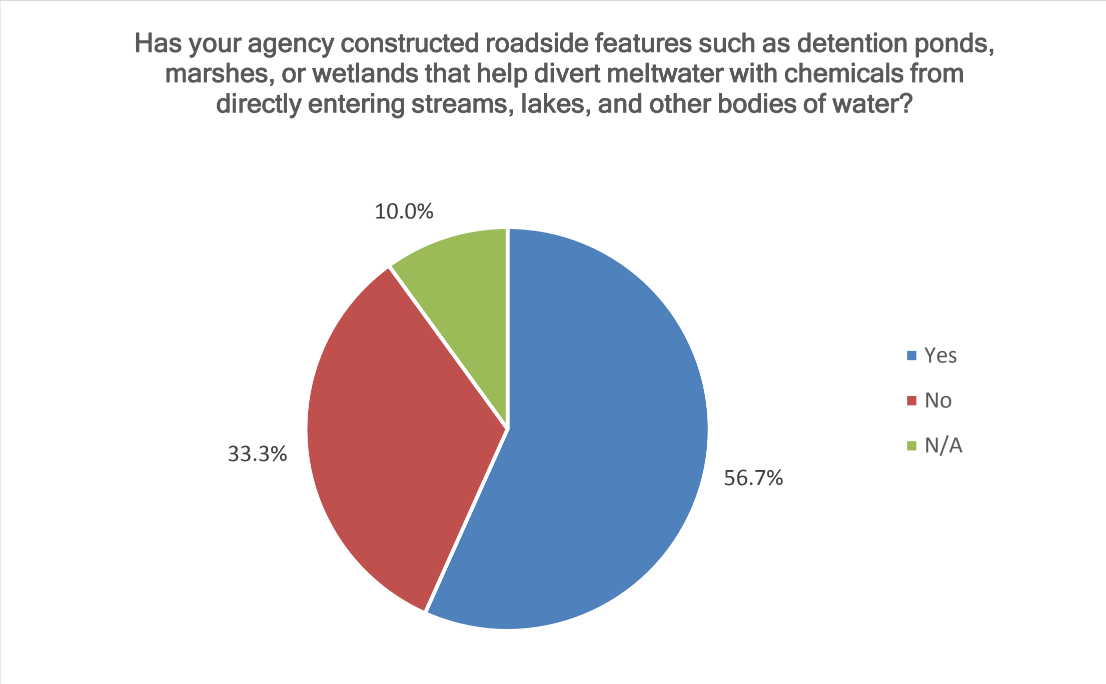

Figure 71. Percentage of responses to the question about if agency has constructed roadside features.

Table 54. Agency's Additional comments on construction of roadside features.

Agency	Comments
Vermont Agency of Transportation	Do have SWTPs not targeted at capturing winter deicing materials but it does help divert.
Washington State DOT	In every project.
Oregon DOT	ODOT has installed water quality facilities as part of construction projects.
Iowa DOT	Unsure.
Ohio DOT	At our garage facilities and some of our rest areas. The detention ponds are for all types of pollutants.

Q31. Does your agency plant salt-tolerant vegetation in the right-of-way?

There were 30 responses offered for the question of planting salt-tolerant vegetation; only 11 agencies had "YES", and 19 answered "NO" (Figure 72). Three supplementary comments are provided in Table 55. This is a potential area for improvement. We should considering following up and finding out why so little salt tolerant vegetation is used.

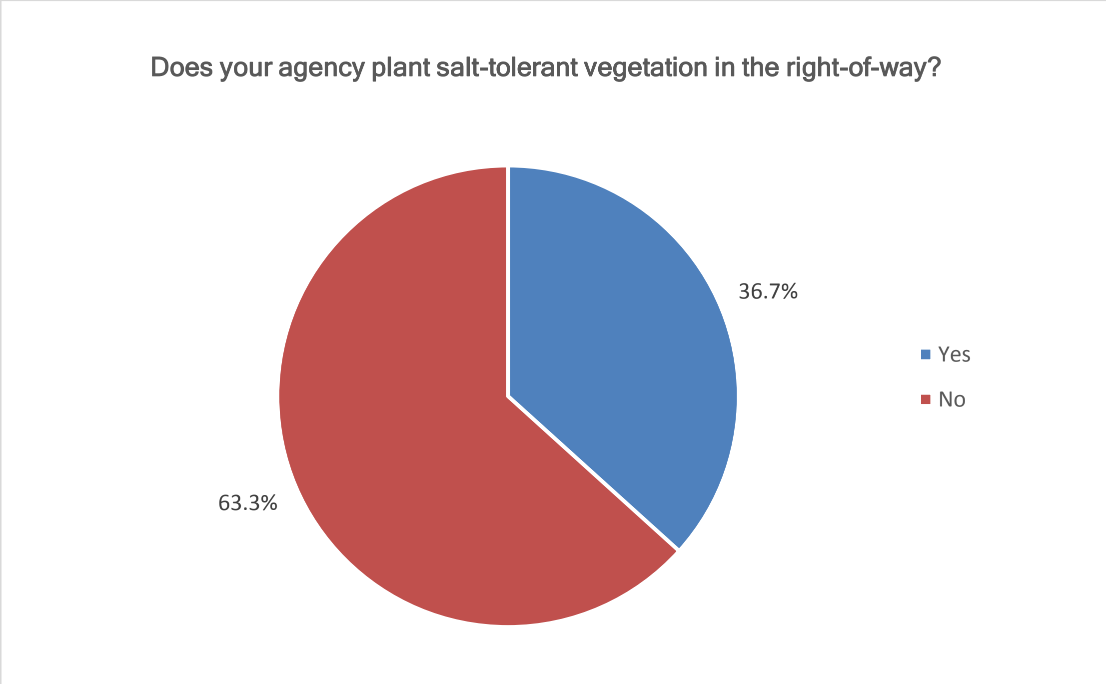

Figure 72. Percentage of responses to the question about planting salt-tolerant vegetation in the right-of-way.

Table 55. Agency's Additional comments on planting salt-tolerant vegetation in the right-of-way.

Agency	Comments
Washington State DOT	But being considered in some areas.
Nebraska Department of Roads	All plantings on the shoulders are salt tolerant mixes.
Iowa DOT	Unsure.

Q32. Does your agency use permanent or temporary snow fencing?

For the question about using permanent or temporary snow fencing, 31 responses were collected, of which 14 answered "YES", 12 answered "Yes, this includes using living vegetation snow fences", and 5 answered "NO" (Figure 73). Overall, about 84% of responding agencies use snow fencing or living snow fencing. Virginia DOT had an additional comment like "Much reduced from years past".

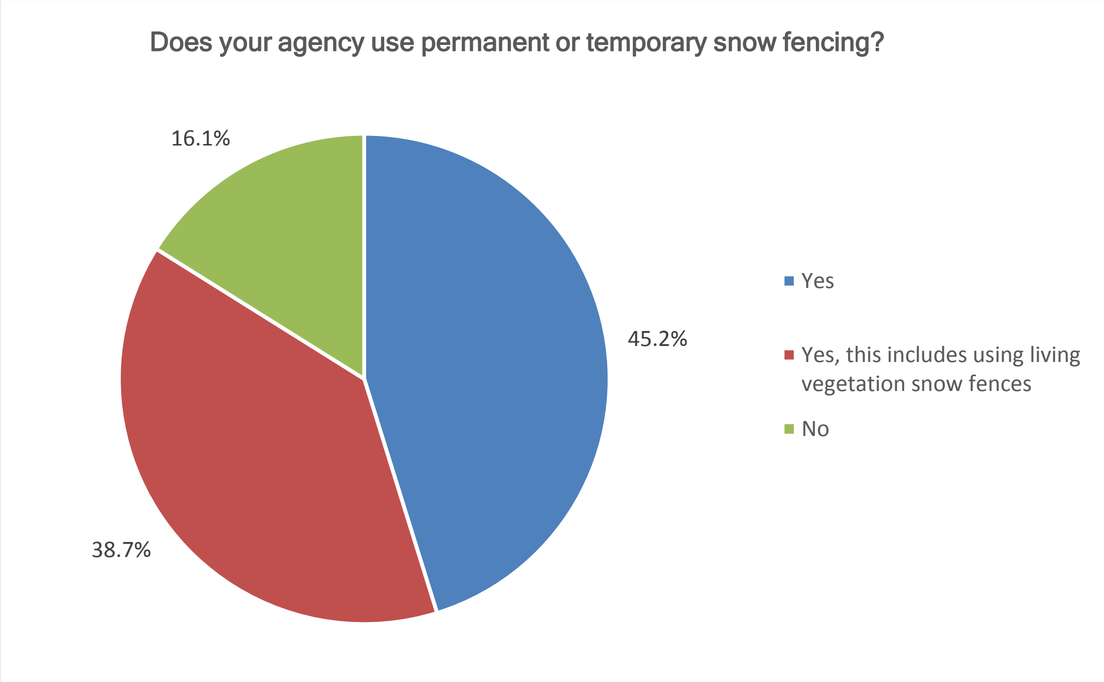

Figure 73. Percentage of responses to the question about using permanent or temporary snow fencing.

Q33. Does your agency use the following snow and ice control strategies?

31 responses were collected for this question. According to the survey result, of the listed snow and ice control strategies, 90.3% of responses were reported to use "Anti-icing liquids alone in advance of storm onset", followed by 87.1% of "Pre-wetting at the spreader to reduce bounce and scatter". Less than half of agencies chose to use "Direct liquid application (DLA)" (45.2%) and "Pre-treatment of stockpile or buying pre-treated salt" (41.9%), only 25.8% would like to use "Slurry or 70:30 (solid : liquid) pre-wetting" and no response was obtained for the use of "Thermal deicing" (Figure 74).

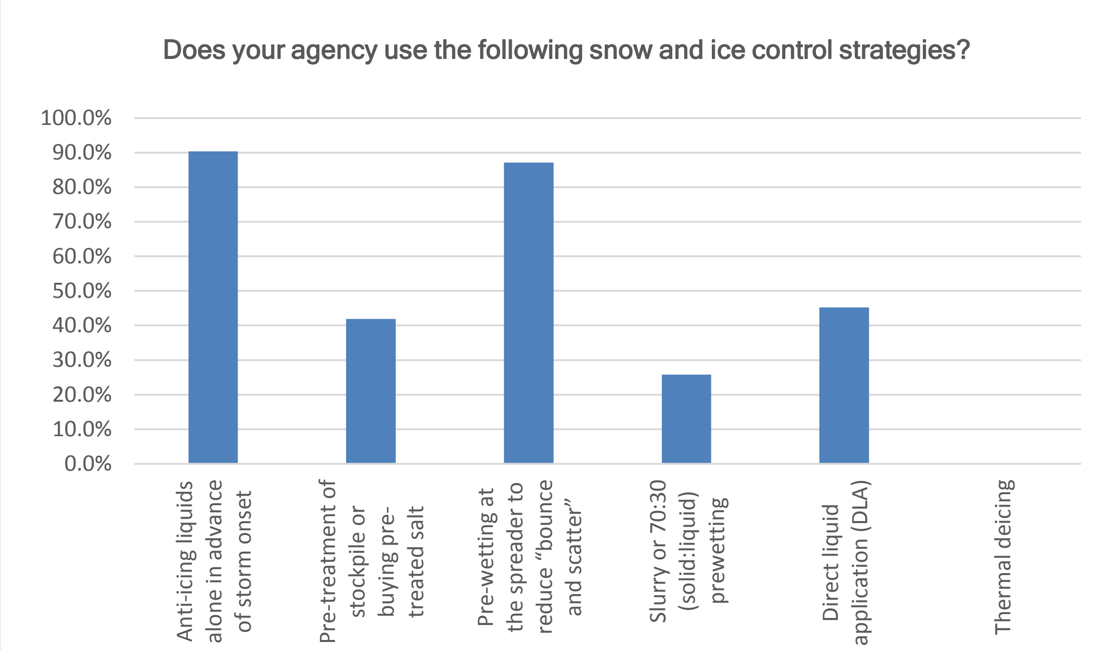

Figure 74. Percentage of responses about using permanent or temporary snow fencing.

Q34. Does your agency use automated sprayers, or the FAST (Fixed Anti-icing Spray Technology) system, on bridge decks to prevent frost and ice?

There were 31 responses for this question; 10 agencies confirmed their usage of automated sprayers or the FAST system with "YES", but about two thirds of agencies (67.7%) did not have experience using this technology (Figure 75). Additional comments are provided in Table 56.

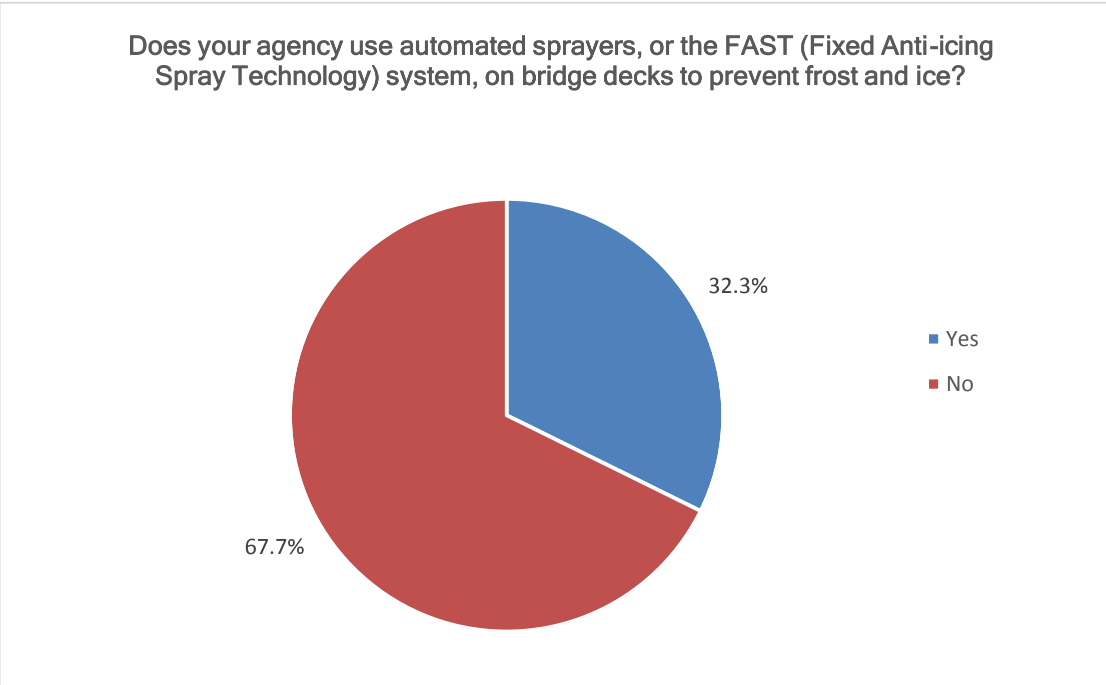

Figure 75. Percentage of responses to the question about using automated sprayers or the FAST system.

Table 56. Agency's Additional comments on using automated sprayers or the FAST system.

Agency	Comments
	We have tried several all have been de-commissioned.
New York State DOT	Very limited use.
Virginia DOT	Have utilized FAST systems but no longer use them.
North Dakota DOT	Two structures.

Q35. Has your agency improved/ expanded weather forecast and current condition monitoring information sources?

90% of total 30 responses for this question answered "YES" and 3 agencies answered "NO" (Figure 76). Oregon DOT stated that "ODOT uses NOAA for forecast and has expanded use of RWIS".

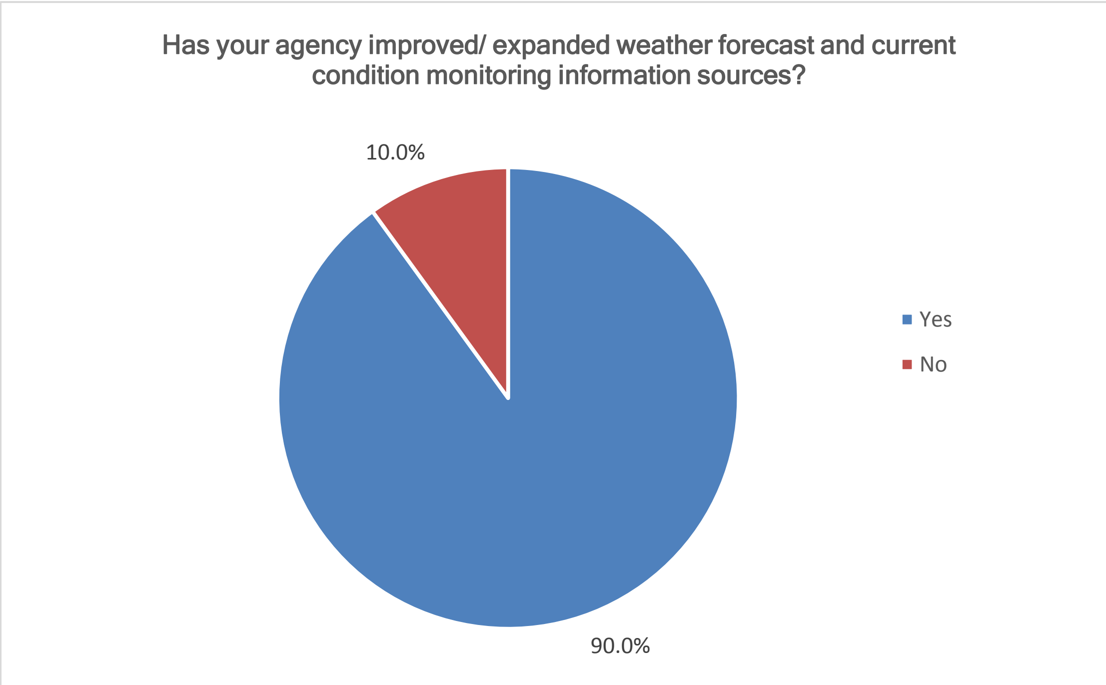

Figure 76. Percentage of responses to the question about improving/ expanding weather forecast and current condition monitoring information sources.

Q36. Has your agency expanded the RWIS or weather station network?

Similar to Q35, a large proportion of agencies (77.4%) among the total of 31 responses for this question answered “YES”, and only 7 answered “NO” (Figure 77). Additional comments are provided in Table 57.

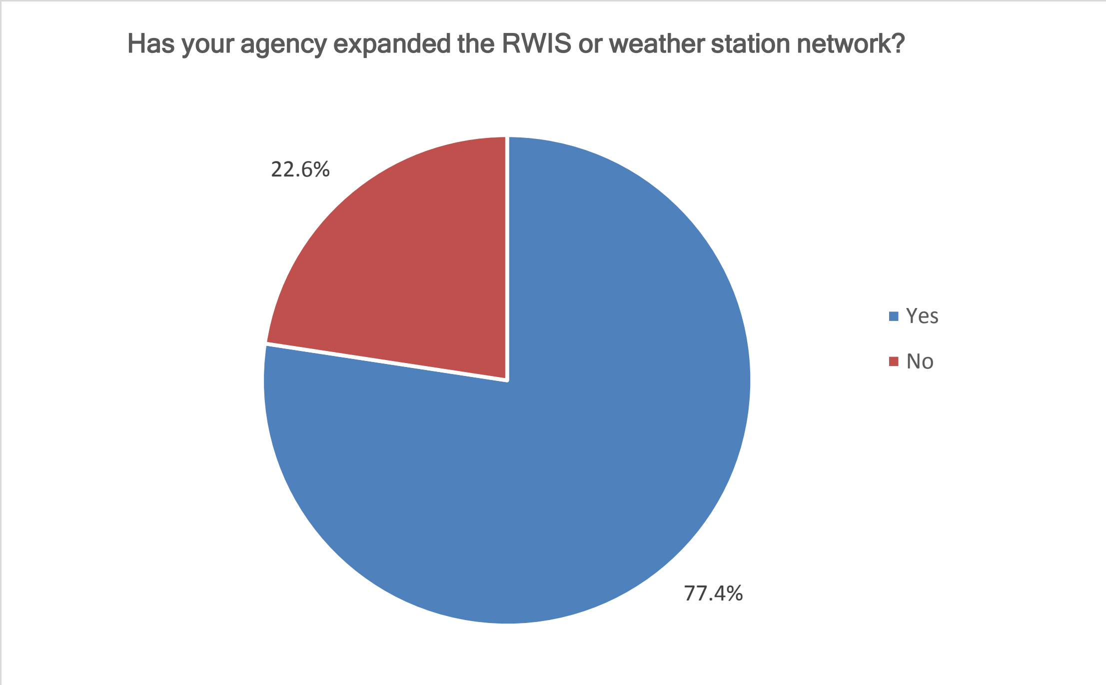

Figure 77. Percentage of responses to the question about expanding the RWIS or weather station network.

Table 57. Agency’s Additional comments on expanding the RWIS or weather station network.

Agency	Comments
Maine DOT	Not lately. They have proven expensive and difficult to keep running reliably.
Pennsylvania DOT	It’s currently under bid.

Q37. Does your agency use MDSS (Maintenance Decision Support System)?

Of the 31 responses for this question, 17 answered “YES”, and 14 answered “NO” (Figure 78). Additional comments are provided in Table 58.

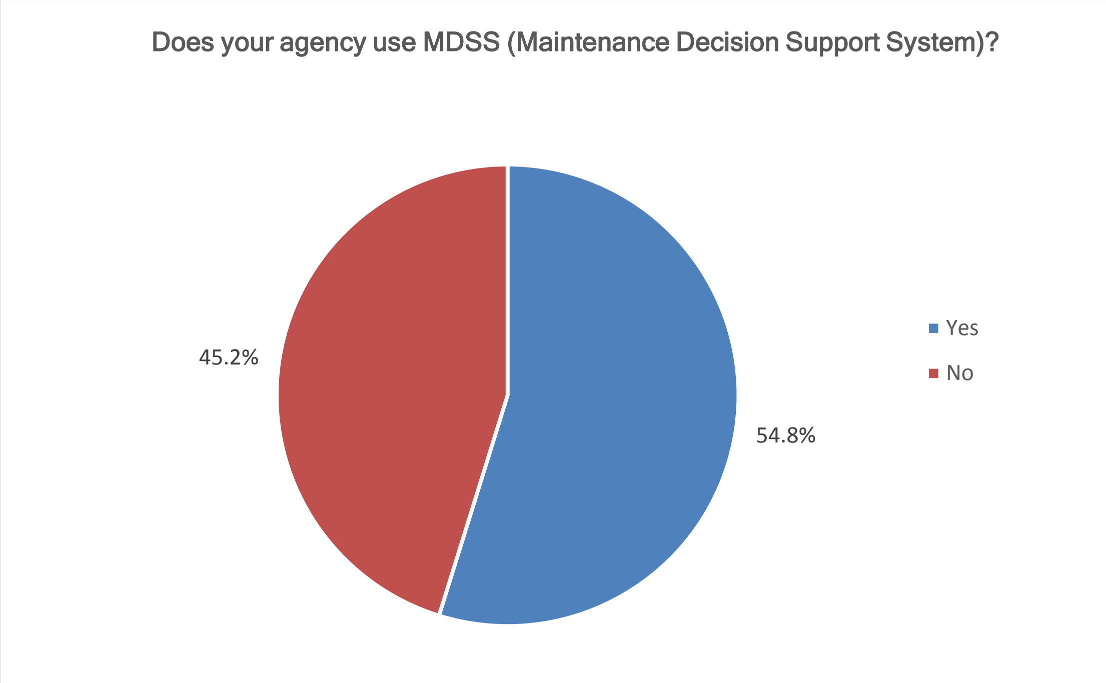

Figure 78. Percentage of responses to the question about using MDSS.

Table 58. Agency's Additional comments on using MDSS.

Agency	Comments
New York State DOT	Only in limited areas as a test pilot. Not statewide.
Pennsylvania DOT	We piloted it.

Q38. If yes, please check all of the features of MDSS your agency uses.

Based on the 17 "Yes" responses in Q37, a follow-up question about how MDSS is used was asked. The responses are presented in Figure 79. Among the options, over three quarters of agencies used the following features of MDSS: "Forecasts" (94.1%), "Suggested product and application rates/treatment" (82.4%), and "Management tool" (76.5%). Over half used the feature of "Reviewing storms" (58.8%), and only 5 responses were collected for using MDSS as a "Training tool" (29.4%). Therefore, generally MDSS was used more as an assistant tool in winter maintenance practice than a management or for training purpose.

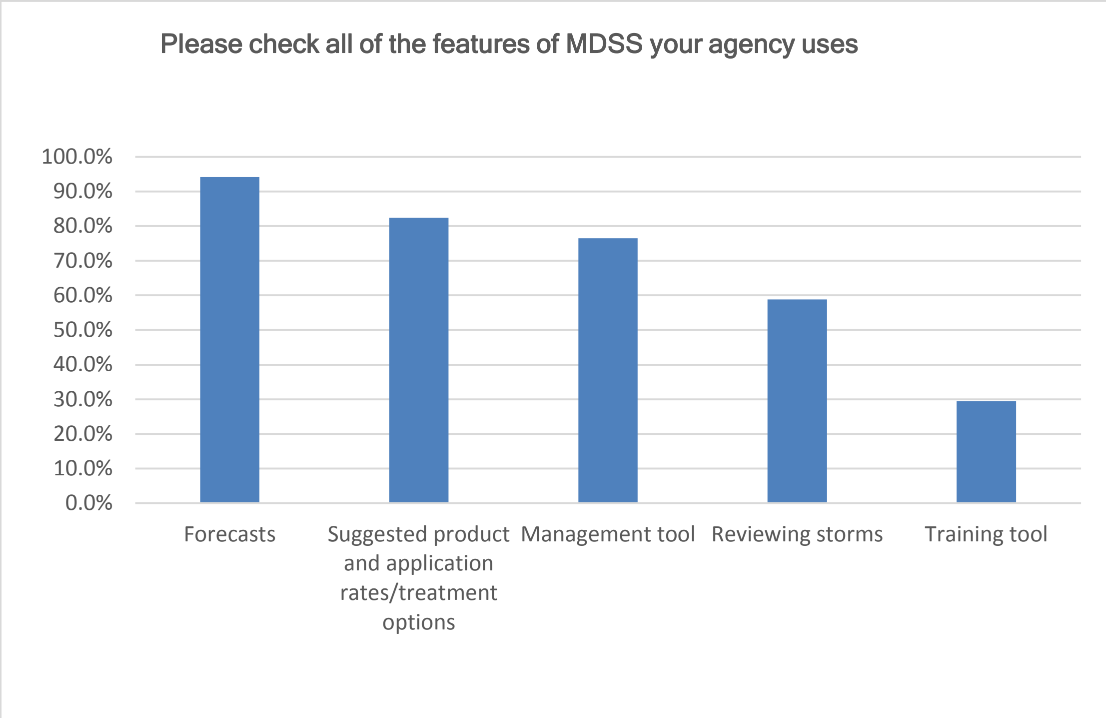

Figure 79. Percentage of responses to the features of MDSS.

Q39. Does your agency utilize technology such as GPS/AVL to more accurately track, monitor, and record material application and plowing?

There were 30 responses obtained for this question; 21 answered "YES", and 9 answered "NO" (Figure 80), showing a reliance of most agencies on the advanced technologies in winter maintenance practice. Additional comments are provided in Table 59.

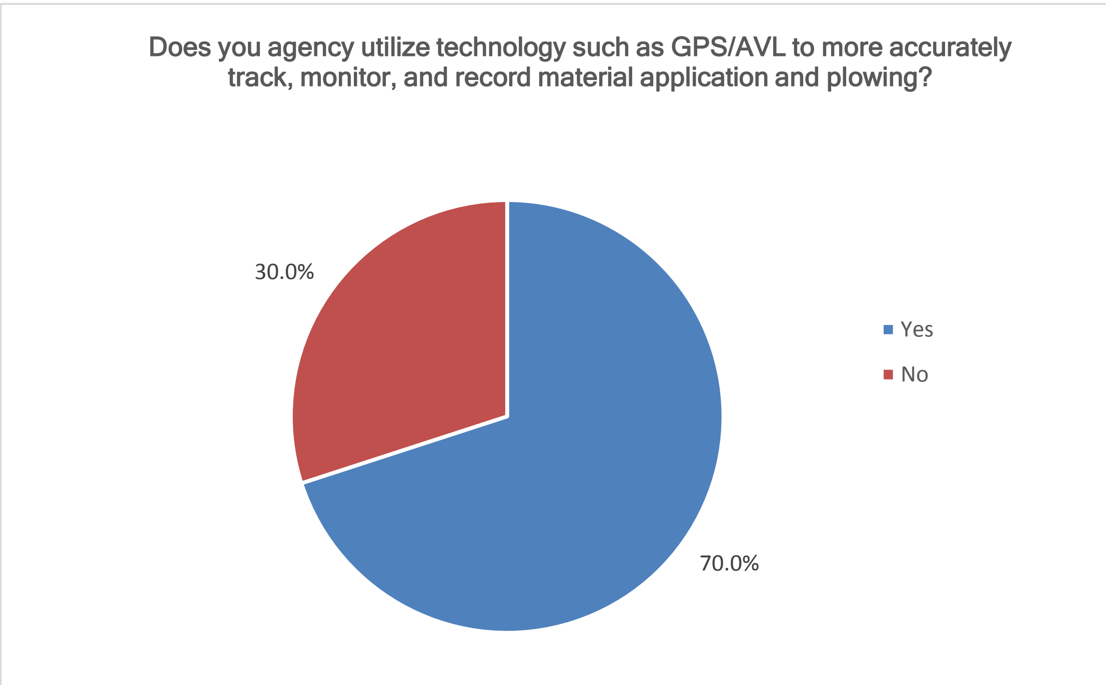

Figure 80. Percentage of responses to the question about utilizing technology such as GPS/AVL.

Table 59. Agency's Additional comments on using GPS/AVL technology.

Agency	Comments
Green Lake County Highway Department, WI	GPS/AVL is installed but does not work.
New York State DOT	Limited number of trucks.
Nebraska Department of Roads	Limited use.
Oregon DOT	We are evaluating use of technology as a pilot project.
Ohio DOT	We currently have a pilot program.
Maine DOT	About a quarter of our fleet uses Cirrus Drive-by (Wi-Fi) Downloading. We are working toward 100%.
New Hampshire DOT	Getting there slowly.

Q40. Has your agency improved existing vehicles and equipment by adding/ upgrading plows and spreader mechanisms?

For the question about improving existing vehicles and equipment, there were 31 responses for this question; 28 marked "YES", and 3 marked "NO" (Figure 81). Based on the response to this question, it appears the responding agencies have funding for equipment upgrades. Oregon DOT provided an additional comment: "Not sure what this means. Plow bits are replaced when needed; new plows are ordered when needed; design is considered when ordering new. We have been outfitting sanders with pre-wet systems to reduce bounce and scatter of cinder/sanding material".

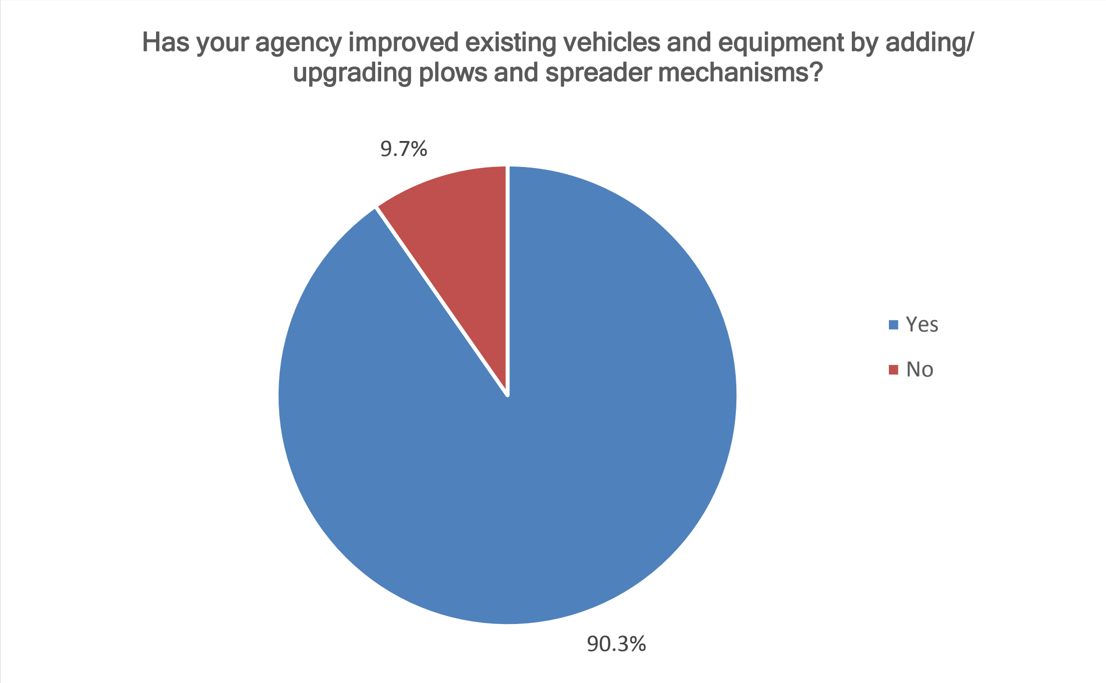

Figure 81. Percentage of responses to the question about improving existing vehicles and equipment.

Q41. Has your agency acquired new vehicles with enhanced capabilities to improve treatment efficiency and/or reduce material usage?

The same total response (n=31) and proportion distribution (90.3% answered “YES”, and 9.7% answered “NO”) were received with Q40 (Figure 82). Maine DOT had an additional comment stating “We are using underbody blades more often and installing upgraded spreader controls”.

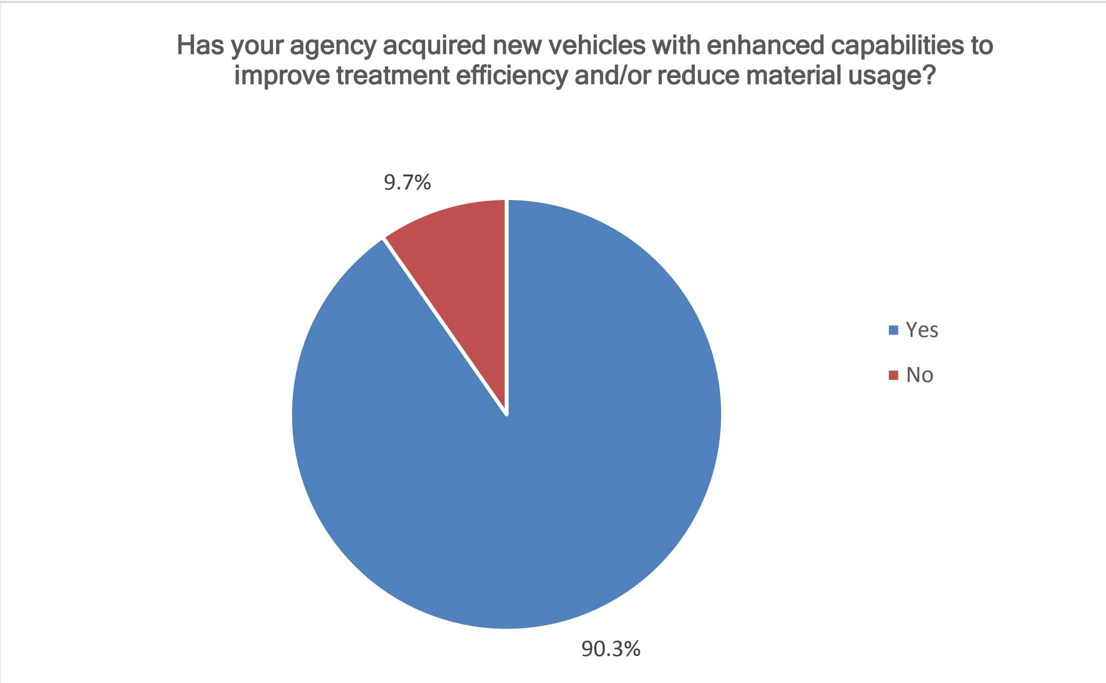

Figure 82. Percentage of responses to the question about new vehicle acquisition.

Q42. Are spreader mechanisms on agency trucks calibrated each season?

30 responses were collected for this question. Based on the survey result, 90% of agencies calibrated their spreader mechanisms on agency truck each season, but 10% of them didn't. 3 responses were reported to choose "Contractors calibrate - yes", 1 response chose the option "Contractors calibrate - no", and no agency selected the option of "No spreader mechanism; use "raised bed/open tailgate" methods" (Figure 83). There were two additional comments from Wyoming DOT and Kansas DOT (Table 60). Even though the survey results indicate 90% of agencies are calibrating spreader mechanisms, we recommend this as a potential area for improvement because frankly 100% of agencies should be calibration at least once a season. There may also be a disconnection between folks saying they are calibrating and it actually getting done, as well as how the equipment is being calibrated.

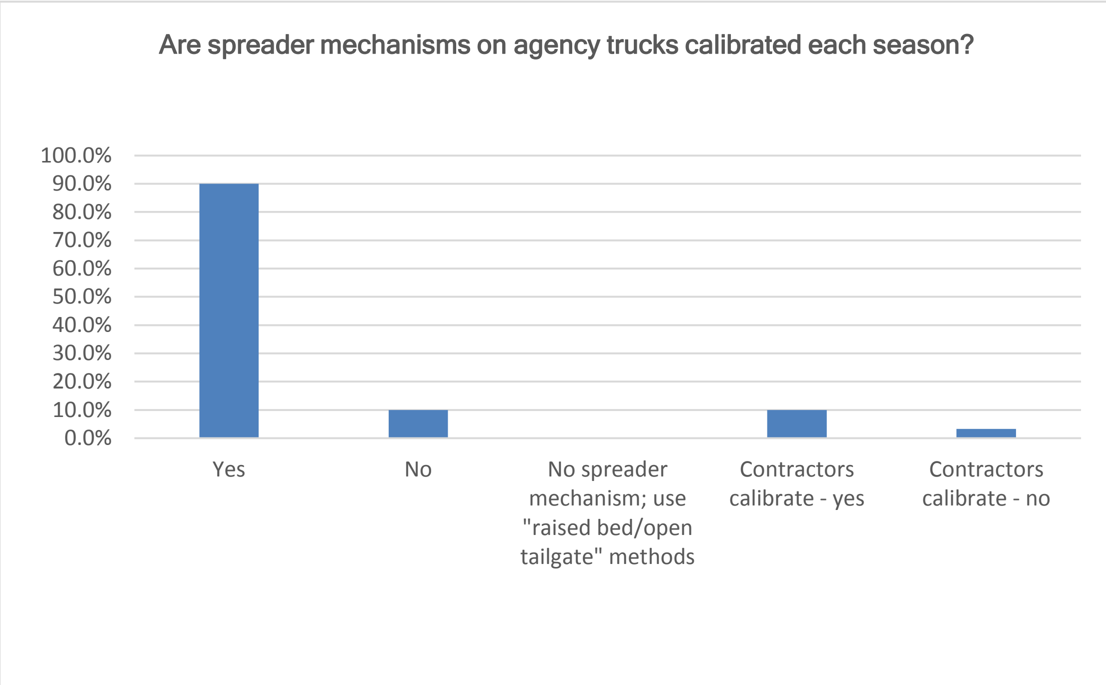

Figure 83. Percentage of responses to the question about spreader mechanism calibration.

Table 60. Agency's Additional comments on spreader mechanism calibration.

Agency	Comments
Wyoming DOT	They say it is done, not sure of accuracy.
Kansas DOT	In the process of implementing this practice.

Q43. Do the spreader mechanisms use ground-speed controllers?

There were 31 responses for this question; 28 answered “YES”, 3 answered “Not all trucks have”, and no agency answered “NO” (Figure 84). Only one additional comment was provided by New Hampshire DOT stating “NHDOT-YES, Contractor-limited”.

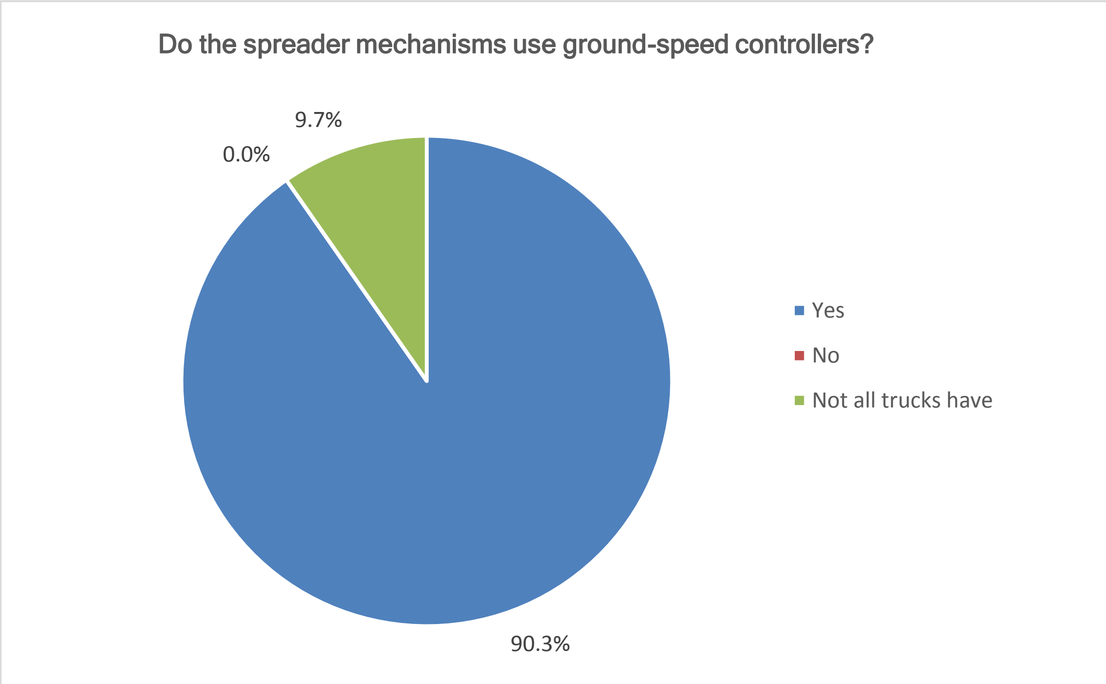

Figure 84. Percentage of responses to the question about using ground-speed controller in the spreader mechanisms.

Q44. Are liquid applicator spray bars on agency trucks calibrated/ adjusted each season?

30 responses were collected for this question. Based on the survey result, 76.7% of agencies calibrated/adjusted their liquid applicator spray bars on agency trucks each season, 23.3% of did not. In addition, 1 respondent reported “Contractors calibrate - yes”, and 1 respondent chose the option “Contractors calibrate - no” (Figure 85). There were two comments from Wyoming DOT and New Hampshire DOT which are presented in Table 61. Again, the overwhelming majority of respondents are calibrating, but there is still room for improvement.

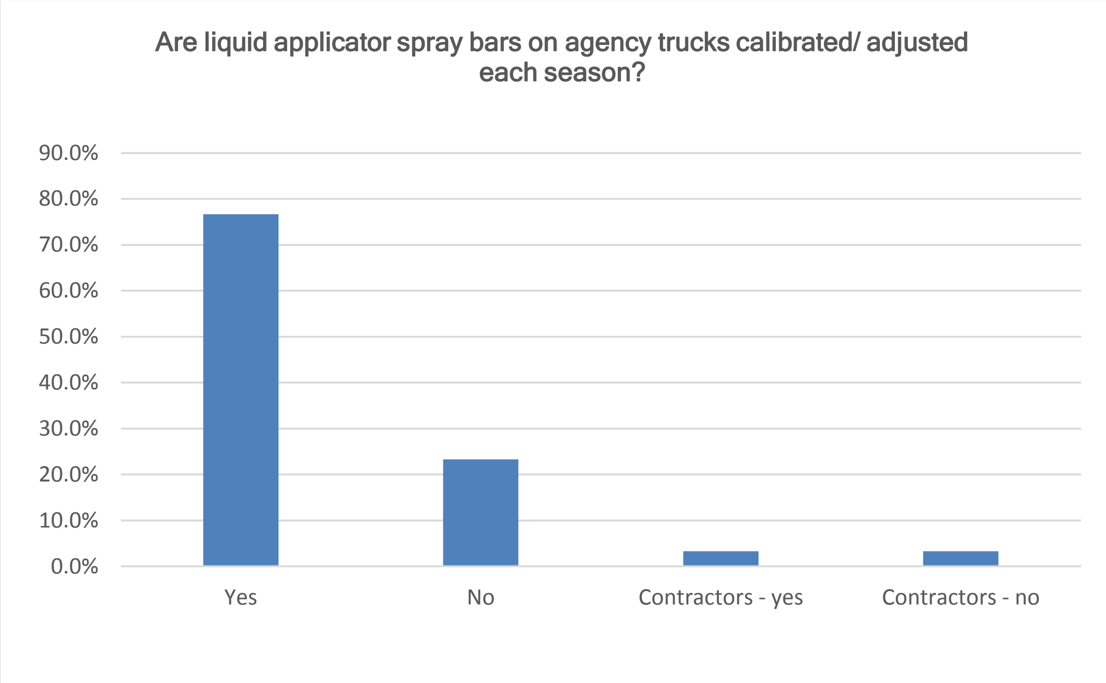

Figure 85. Percentage of responses to the question about calibration of liquid applicator spray bars.

Table 61. Agency's Additional comments on calibration of liquid applicator spray bars.

Agency	Comments
Wyoming DOT	Same as #42.
New Hampshire DOT	Only NHDOT has liquid capabilities.

Q45. Has your agency made any efforts to improve calibration of liquid and solid material application equipment? If yes, please explain in the additional comments box.

For this question, a total of 31 responses obtained. In addition to 18 "YES", 12 "NO", and 1 "N/A" (Figure 86), a collection of additional comments are reported in Table 62. This information is encouraging. Responding agencies appear to be improving calibration efforts.

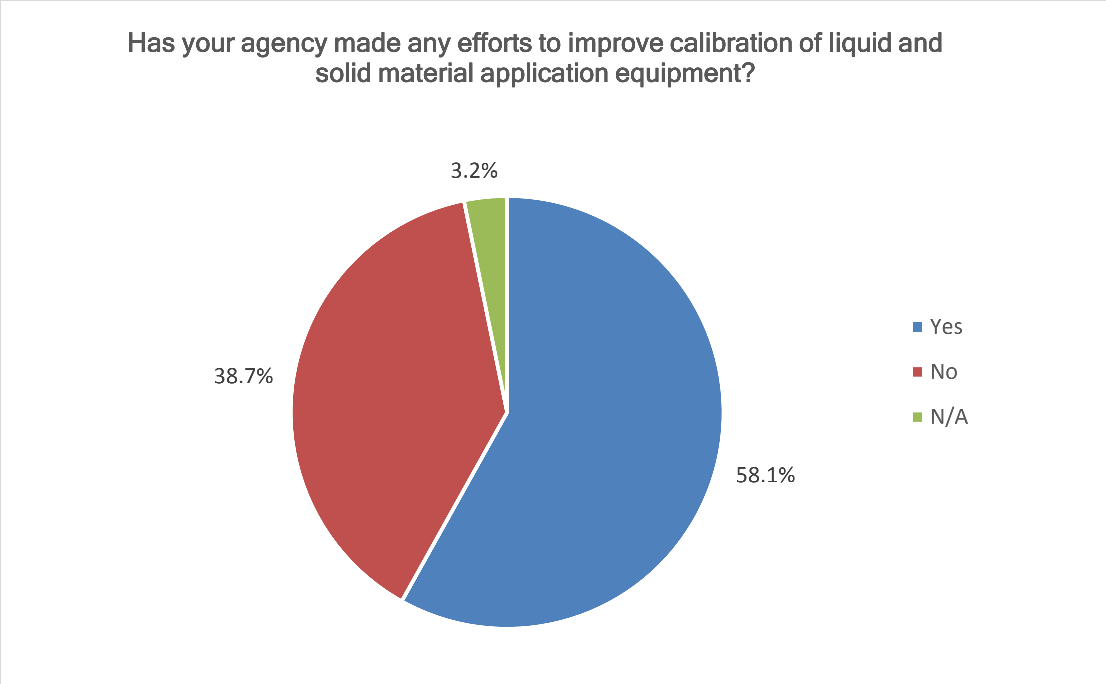

Figure 86. Percentage of responses to the question about utilizing technology such as GPS/AVL.

Table 62. Agency's Additional comments on using GPS/AVL technology.

Agency	Comments
	Pre-season calibration is done in most areas.
Rhode island DOT	All contractors are required to calibrate prior to registering with the Department, we have offered some training as well.
Minnesota DOT	A calibration training class is offered to operators.
Washington State DOT	We have calibration boxes and PPT and video training.
	More frequent calibration.
Kansas DOT	Working on this process now.
Oregon DOT	We are working on a calibration campaign of sorts, but it hasn't been developed yet, just an idea.
Ohio DOT	Part of our GPS/AVL research program is reviewing our calibration methods and evaluating the amount of material coming out of our vehicles.
Maine DOT	The upgraded spreader controls have significantly simplified the calibration procedures.

Agency	Comments
Iowa DOT	Comparing the information from the cirrus controllers to actual material weights.
New Hampshire DOT	Prior to several years ago calibrations were only perform on new trucks or if work was done to a trucks hydraulic system. Now done at least yearly regardless.

Q46. What does your agency use for real-time pavement condition observations?

31 responses were collected for this question with 2 of them showing “None”. Based on the survey result, all the listed four options were frequently used by agencies’ for real-time pavement condition observation. The top priority was reported to be “Truck-mounted pavement temperature sensors” (90.3%), followed by “RWIS” (83.9%). Over half of agencies preferred to use “In-ground pavement sensors” (64.5%) and “CCTV such as traffic cams” (61.3%) (Figure 87). There were 4 additional comments which are shown in

Table 63.

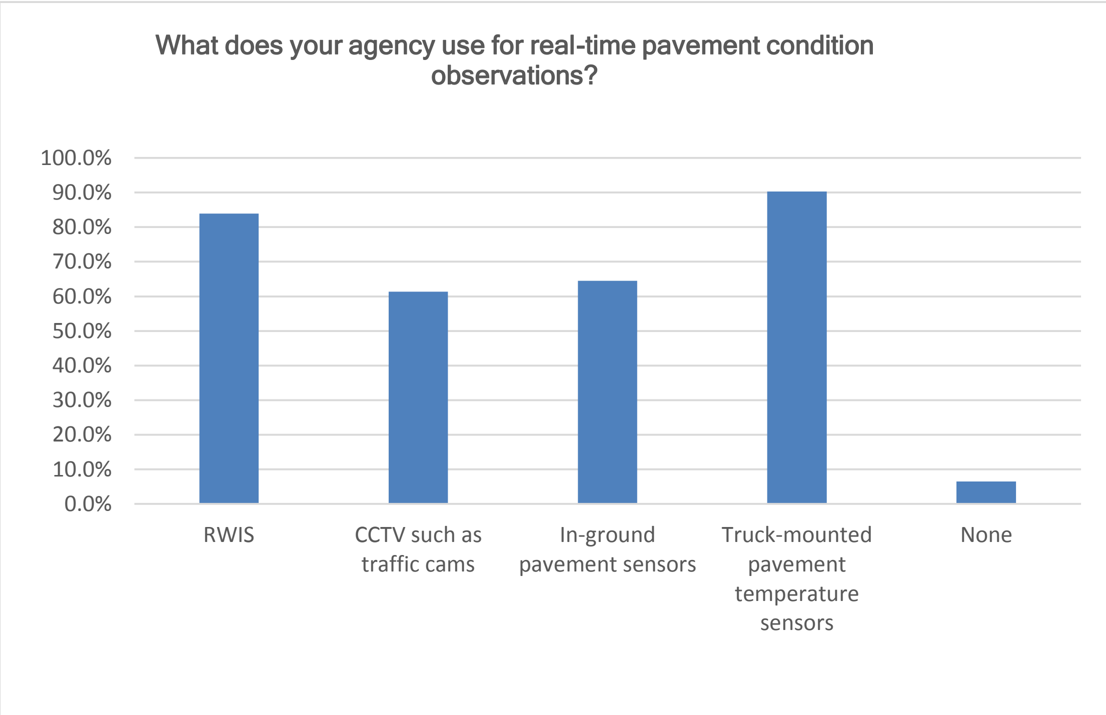

Figure 87. Percentage of responses to the measures used for real-time pavement condition observations.

Table 63. Agency's Additional comments on measures used for real-time pavement condition observations.

Agency	Comments
Rhode island DOT	Observations from State Police and RIDOT personnel.
Wyoming DOT	Live patrols.
North Dakota DOT	MDSS.
Maine DOT	RWIS and in-ground sensors are limited. Cameras are only on the interstate.

Q47. Does your agency use friction as tool to monitor pavement condition?

Of the 30 responses for this question, 9 agencies mentioned "YES" regarding using friction as tool to monitor pavement condition, 20 agencies marked "NO", and 1 answered "N/A" (Figure 88). Additional comments are reported in

Table 64.

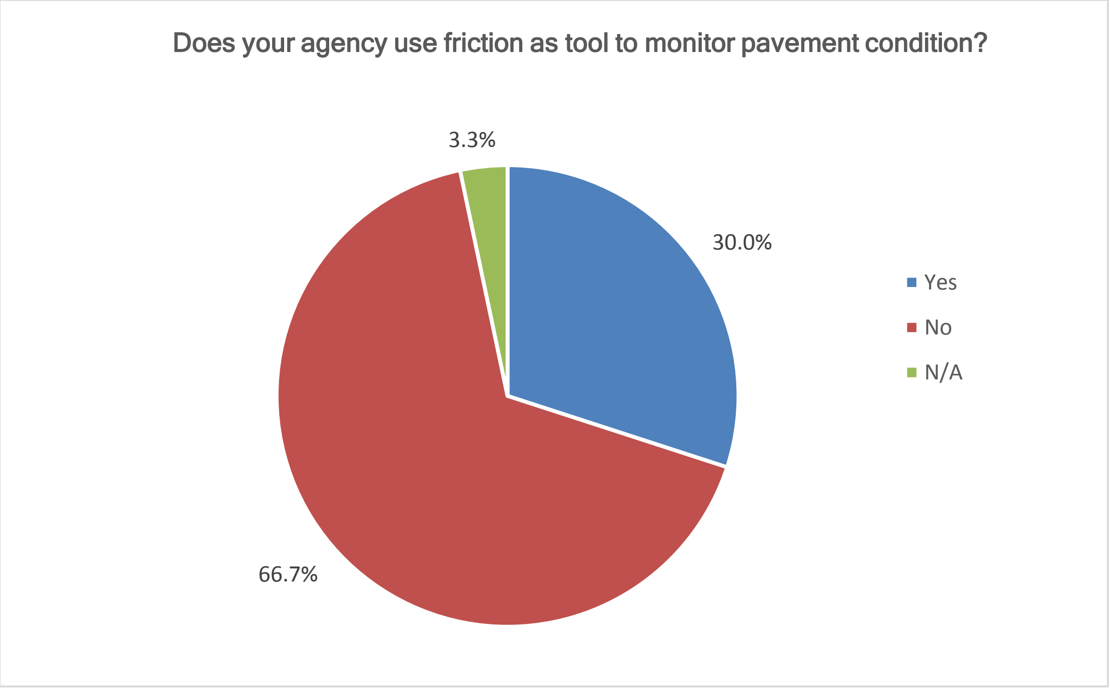

Figure 88. Percentage of responses to the question about using friction to monitor pavement condition.

Table 64. Agency's Additional comments on using friction as tool to monitor pavement condition.

Agency	Comments
Iowa DOT	We are looking into this.
New Hampshire DOT	Only at the RWIS stations, and only some of those stations.

Q48. Does your agency have environmental staff (staff who are involved with compliance agencies and/or the public with environmental regulations)?

Of the 30 responses for this question, 23 provided "YES", 6 answered "NO", and 1 answered "N/A" (Figure 89). The majority of positive responses to this question reveals that environmental issues have raised a concern to responding agencies.

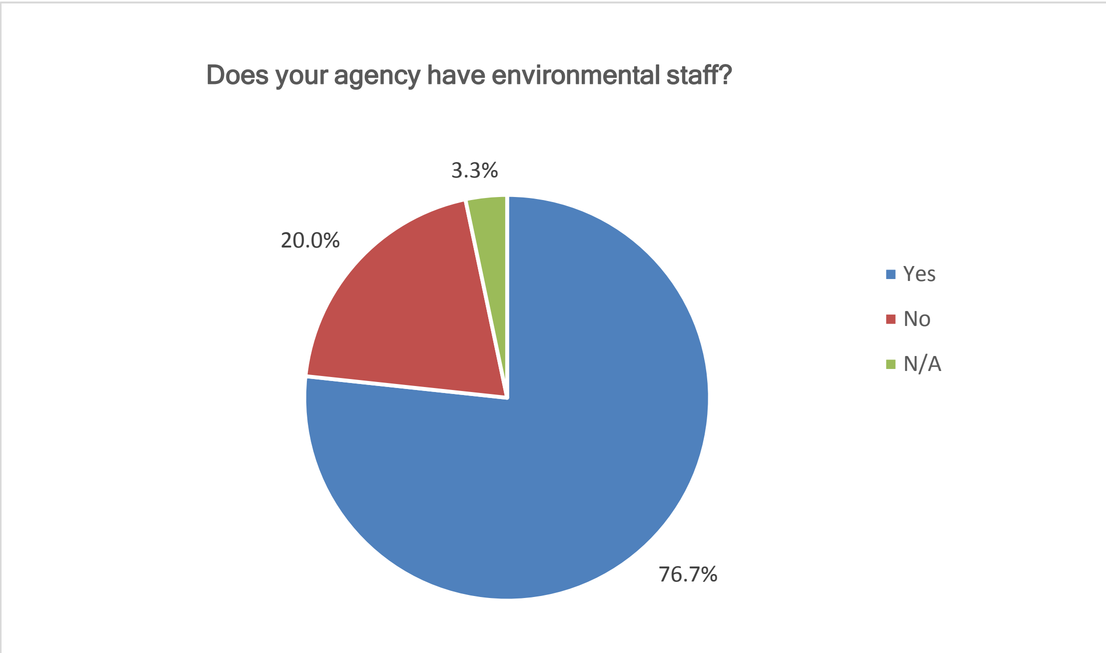

Figure 89. Percentage of responses to the question about if agency has environmental staff.

Q49. Is the agency's jurisdiction in part or all of a designated protected watershed basin or other managed storm-water area such as "low-salt" or "no-salt" roadways?

Of the 30 responses for this question, only one third agencies had their jurisdiction in part or all of a designated protected area, 19 agencies didn't have such situation, and 1 answered "N/A" (Figure 90). Additional comments are provided in Table 65.

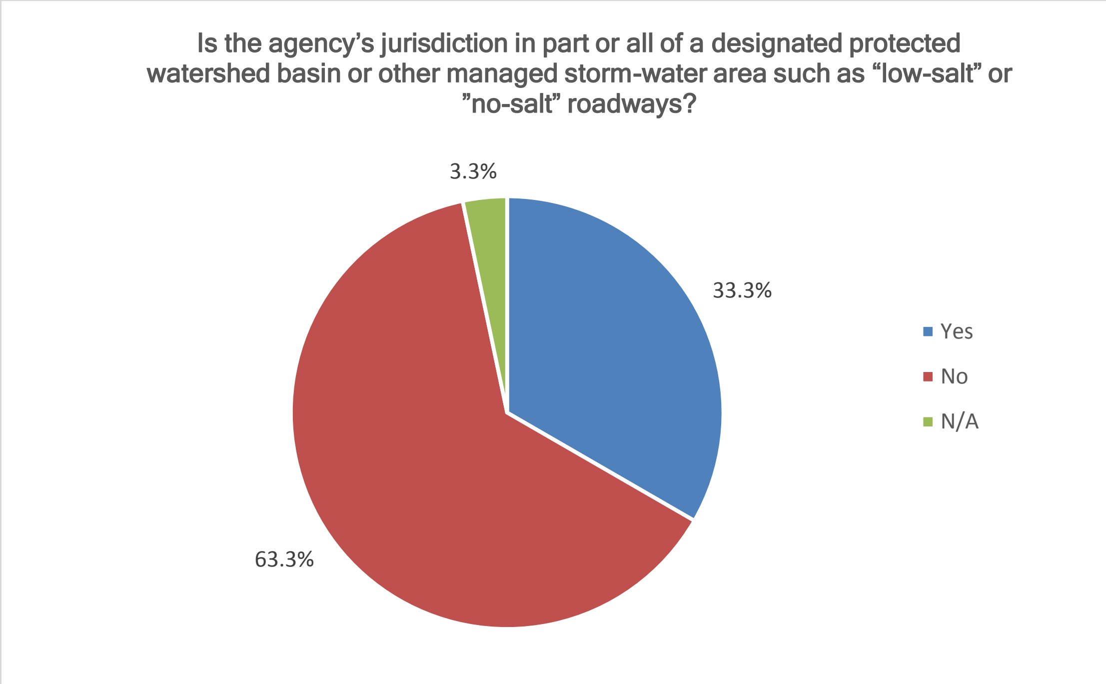

Figure 90. Percentage of responses to the question about protected watershed basin in jurisdiction.

Table 65. Agency's Additional comments on protected watershed basin in jurisdiction.

Agency	Comments
Wyoming DOT	Not sure.
Washington State DOT	None yet.
New York State DOT	In part.
Oregon DOT	ODOT is a designated management agency (DMA) for many streams with TMDLs.
Maine DOT	The corridor priorities dictate the level of service.

Q50. If yes, how are they determined and monitored?

Based on the 10 "YES" in Q49, 9 of them answered this follow-up question. Detailed information about the determining and monitoring methods are reported in

Table 66.

Table 66. Survey responses showing the determining and monitoring methods for the protected watershed basin in jurisdiction.

Agency	Comments
Colorado DOT	A few areas throughout the state are like this.
Marathon County Highway Department, WI	Storm Reports, salt usage by scales.
Rhode island DOT	Through our MS4 permit with state environmental agency
Minnesota DOT	One area has been identified and being studied jointly by the state DOT, state PCA and local watershed district.
Washington State DOT	Regular sampling.
New York State DOT	Established by NYC Department of Environmental Protection and NYS Department of Environmental Conservation.
Oregon DOT	TMDL streams are determined by the Oregon Department of Environmental Quality. ODOT monitors highway storm water runoff in an effort to characterize highway runoff.
New Hampshire DOT	State DES continually monitoring.
Pennsylvania DOT	This is a detailed question monitored by compliance with our MS4 permit.

Q51. Has your agency had experience in the following environmental issues? (Check all that apply and rate from highest to lowest concern, 1- low to 7-high)

There were 24 agencies responses to this question. The response rate for each listed environmental issue was all over 90% ($n \geq 22$), showing they are considered very important by responding agencies. Detailed responses and ratings are shown in Table 67 and the average ratings for listed environmental issues are presented in Figure 91. According to the survey results, “Corrosive effects of salt and other chlorides” was reported to have the highest average rating of 4.5. “Salt contamination of surface water, groundwater water”, “Infiltration and sedimentation of sand and other abrasives into storm water drainage systems”, and “Lake, stream, groundwater, and or well monitoring” were all shown to have an average rating of over 3.5, which implies that corrosion and water contamination were the major concerns raised by the responding agencies. Comparatively, “Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife” and “Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand" were rated lower.

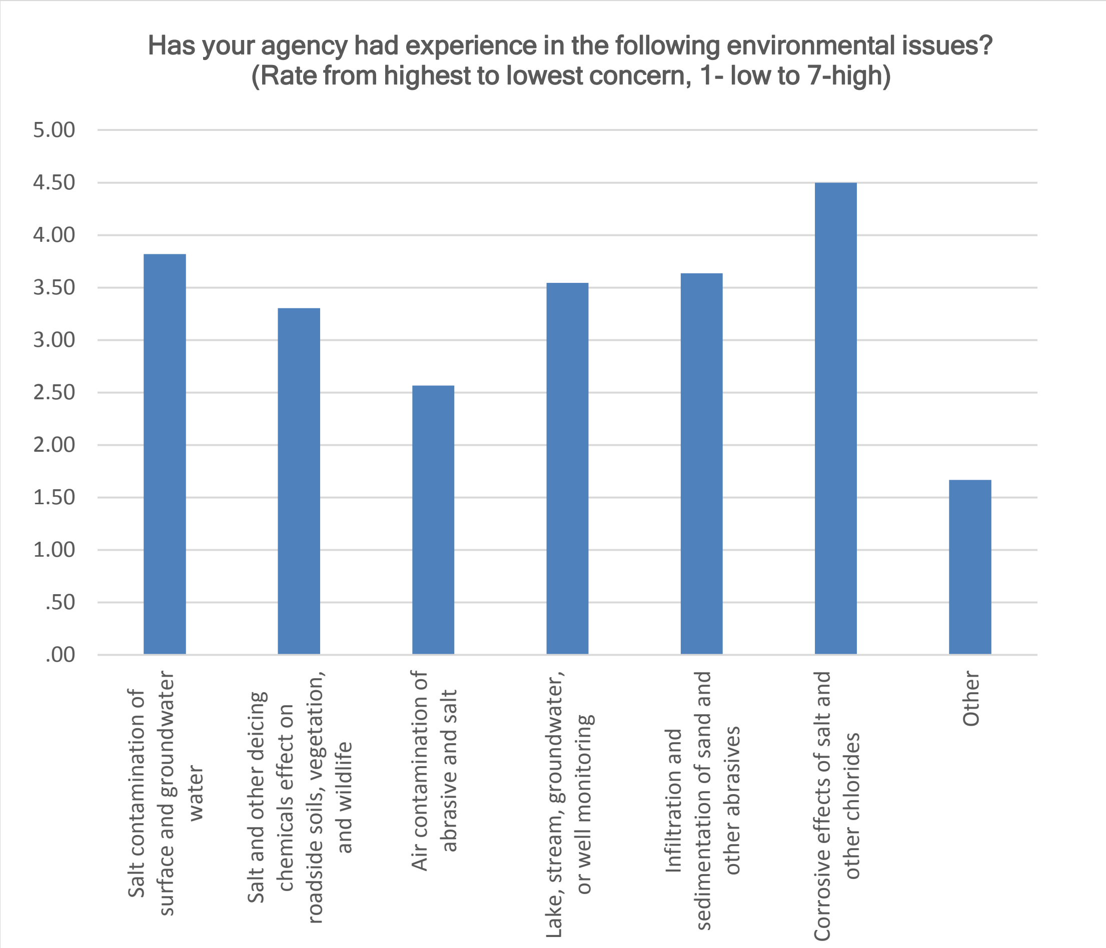

Figure 91. Average ratings of agencies to the listed environmental issues.

Table 67. Agency's rating on the listed environmental issues.

Agency	Salt contamination of surface water, groundwater water	Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife	Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand	Lake, stream, groundwater, and or well monitoring	Infiltration and sedimentation of sand and other abrasives into storm water drainage systems	Corrosive effects of salt and other chlorides	Othe r
Green Lake County Highway Department, WI	1	4	1	1	1	6	
Green County Highway Department, WI	2	3	1	2	1	1	
Colorado DOT	3	6	7		5	4	
Marathon County Highway Department, WI	3	2	0	3	4	5	

Agency	Salt contamination of surface water, groundwater water	Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife	Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand	Lake, stream, groundwater, and or well monitoring	Infiltration and sedimentation of sand and other abrasives into storm water drainage systems	Corrosive effects of salt and other chlorides	Othe r
Door County Highway Department, WI		1		2			
Waukesha County Highway Department, WI	7	3	1	6	5	4	2
Vermont Agency of Transportati on	5	4	1	2	6	5	
Rhode island DOT	7	3	2	4	5	6	1
West Virginia	1	1	1	1	1	3	

Agency	Salt contamination of surface water, groundwater water	Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife	Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand	Lake, stream, groundwater, and or well monitoring	Infiltration and sedimentation of sand and other abrasives into storm water drainage systems	Corrosive effects of salt and other chlorides	Other
Division of Highways							
Minnesota DOT	6	6	4	6	3	5	
Wyoming DOT	6	2	1	6	4	6	
City of Grandview, MO	1	1	1	3	5	2	
City of Cedar Rapids, IA	1	1	1	1	1	1	
Washington State DOT	1	5	3	3	4	6	
	4	5	7	4	5	7	

Agency	Salt contamination of surface water, groundwater water	Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife	Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand	Lake, stream, groundwater, and or well monitoring	Infiltration and sedimentation of sand and other abrasives into storm water drainage systems	Corrosive effects of salt and other chlorides	Other
Kansas DOT	7	3	2	6	5	4	
Washington State DOT	2	2	5	5	5	7	
New York State DOT	7	4	5	7	5	5	
Virginia DOT	5	5	1	3	1	5	
Oregon DOT			7				
Nebraska Department of Roads	1	5	1	1	3	2	
Maine DOT	7	3	4	7	5	6	2

Agency	Salt contamination of surface water, groundwater water	Salt and other deicing chemicals effect on roadside soils, vegetation, and wildlife	Air contamination of crushed roadway abrasive particulates and salt, or post storm dust abatement from use of abrasives/sand	Lake, stream, groundwater, and or well monitoring	Infiltration and sedimentation of sand and other abrasives into storm water drainage systems	Corrosive effects of salt and other chlorides	Other
North Dakota DOT	1	2	1	2	2	4	
Ohio DOT	6	5	2	3	4	5	

Q52. Does your agency have a salt mitigation program that deals with water contamination from road salt either in a public or private drinking water source?

Even though the water contamination from road salt has been widely recognized, only 8 of the total 30 agencies responded "YES" to having a salt mitigation program, and most agencies (n=22) had no such program (Figure 92). The issue of well contamination is generally driven by factors such as improper storage of snow and ice control chemicals, unsuitable snow removal and piling locations and modes, and may be regionally sensitive. This may explain why only certain agencies report having a mitigation program in place. Additional comments are reported in

Table 68.

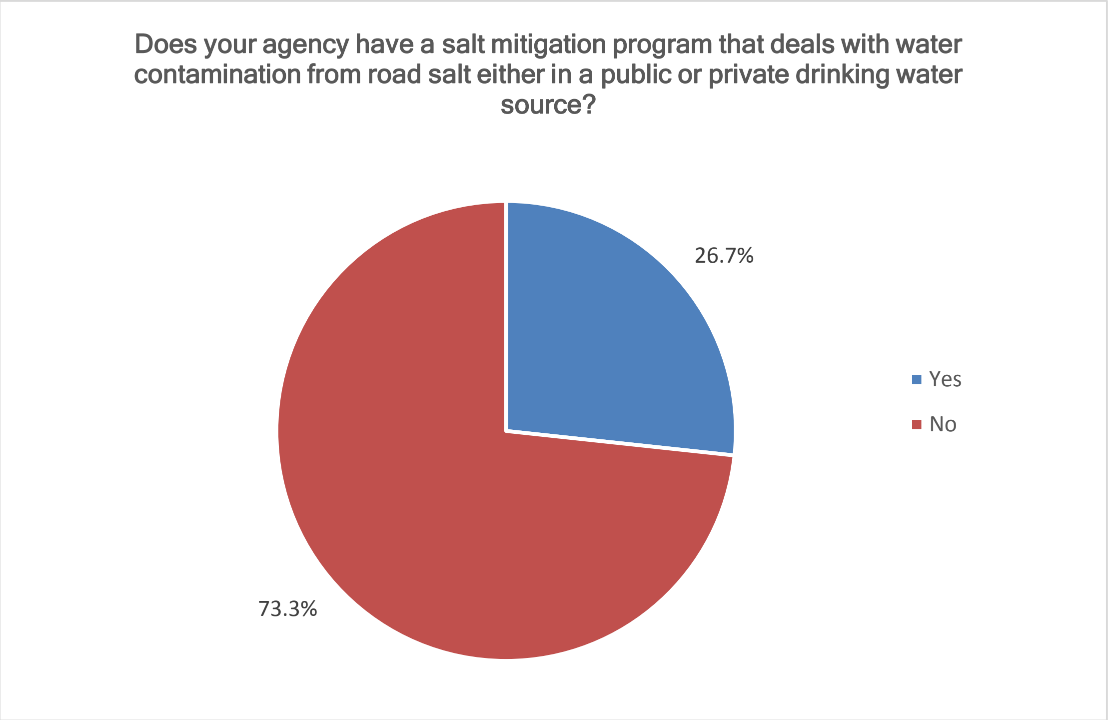

Figure 92. Percentage of responses to the question about having a salt mitigation program.

Table 68. Agency's Additional comments on salt mitigation program.

Agency	Comments
Kansas DOT	On a case by case basis.
Maine DOT	If we are notified of, or identify a well with contamination, we investigate the potential sources. If it appears to be caused by our actions, we will replace the well.
New Hampshire DOT	One person section that receives complaints and investigates. If well shows 12 months of chloride level greater than 250ppm then parcel receives either new well or damage award, assuming certain criteria is also met.
Pennsylvania DOT	Place signage at drinking water supplies.

Q53. Does your agency have experience working or partnering with compliance agencies or private groups?

There were 29 responses for this question; 22 had no experience working or partnering with compliance agencies or private groups, while 8 did have experience, and 2 answered "N/A" (Figure 93). Additional comments are provided in Table 69. This is a potential area for improvement.

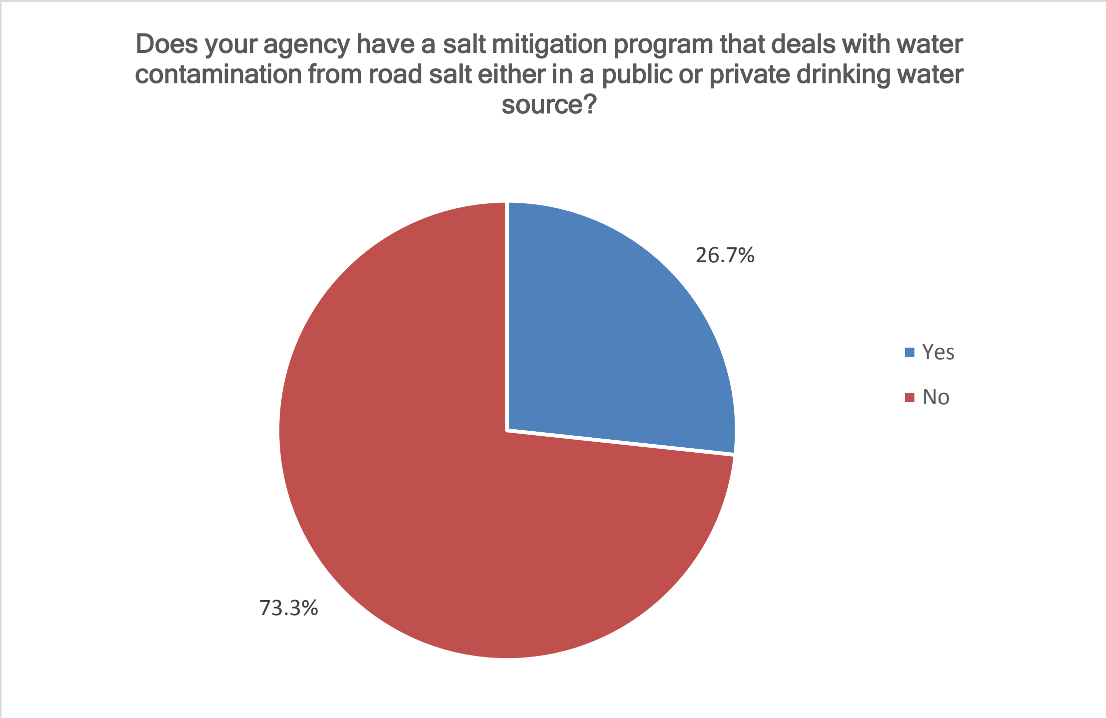

Figure 93. Percentage of responses to the question about working cooperation.

Table 69. Agency's Additional comments on working cooperation.

Agency	Comments
West Virginia Division of Highways	In some areas, but not in winter operations.
Maine DOT	We are currently working on a similar BMP effort in Maine.
Iowa DOT	Unsure.

Q54. If yes, are you aware if your agency implemented any of the following in the process? (Check all that apply)

Based on the responses of Q53, there were 19 agencies answered this follow-up question. Among the listed measures, "Training staff and contractors on proper storage, handling and application of materials" was reported to have the highest response rate (78.9%), followed by "Include needed improvements to facilities, equipment and materials in operating, capital and capital improvement budgets; communicate to higher officials need for such to ensure compliance" with a response percent of 68.4%. "Developed clear, written plans" and "Make public aware of efforts and gain support" both had the same but lowest response percent (42.1%) (Figure 94). One additional comment was provided by New Hampshire DOT: "In one area NHDOT has a partnership with NHDES, USEPA and 4 towns in the region to adhere to findings from a recent TMDL study."

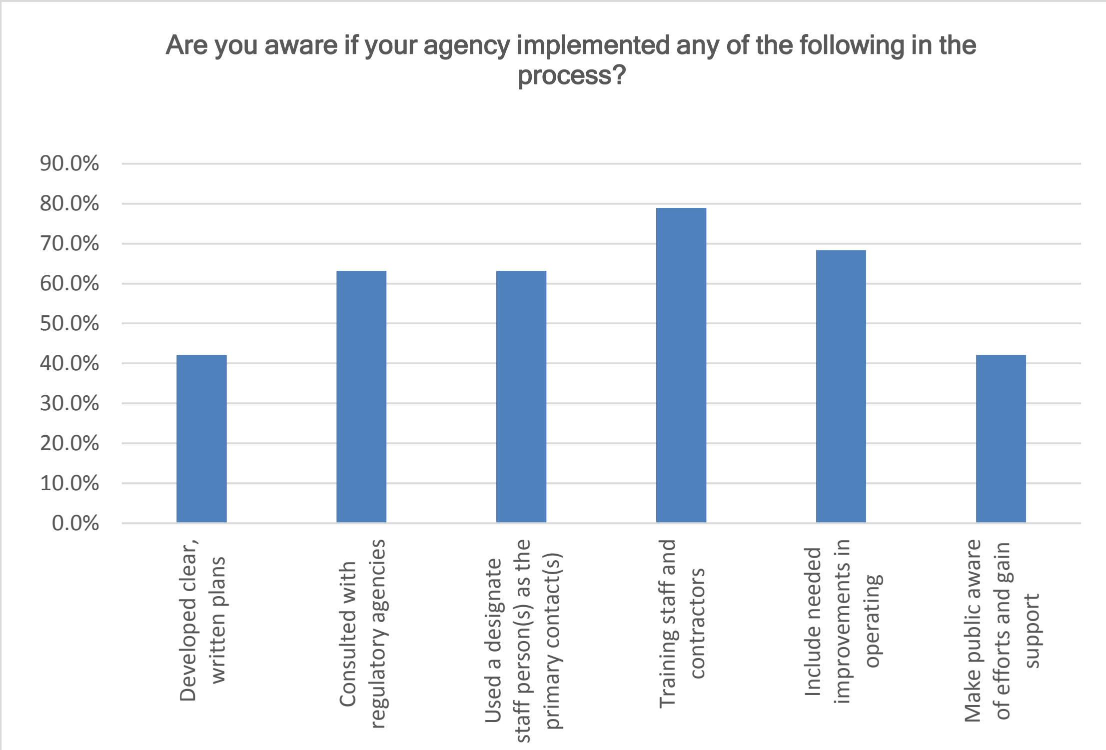

Figure 94. Percentage of responses to the listed measures implemented in the process of working or partnering with compliance agencies or private groups.

Q55. Does your agency provide outreach to the public to make them aware of proper salt, sand, and deicer chemical use on residential, commercial, and institutional properties?

A total of 30 responses were obtained for this question; 11 answered “YES”, 17 answered “NO”, and 2 answered “N/A” (Figure 95). Additional comments were reported in

Table 70. This is a potential area for improvement.

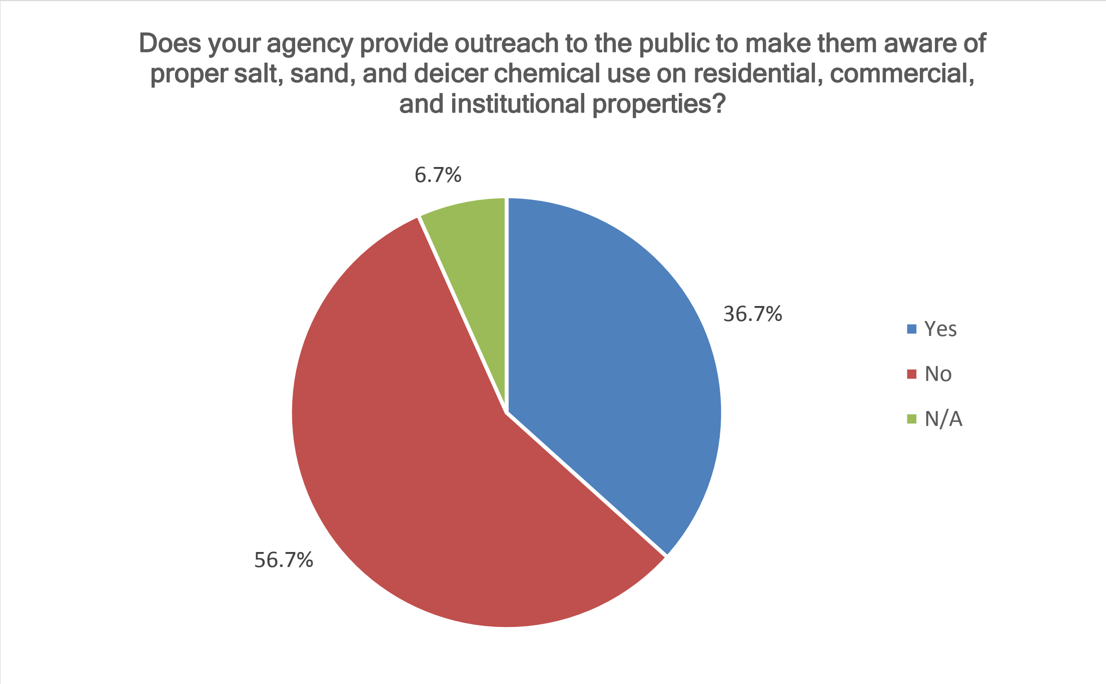

Figure 95. Percentage of responses to the question about working cooperation.

Table 70. Agency's Additional comments on working cooperation.

Agency	Comments
Vermont Agency of Transportation	Municipal only.
Oregon DOT	To some degree. ODOT coordinates at the local level as questions arise and proactively many years ago prior to embarking on the use of liquid deicer products (before which time we only used abrasives).
Maine DOT	We have a brochure and a web site. We also worked with the University of Maine to look at overall salt usage in Maine.
New Hampshire DOT	Often through the local officials that have better outreach in specific targeted locations.

Q56. Part of this project is to report success stories and lessons learned on the topic of environmental best practices in snow and ice control. If you have an example of either or both on this topic that you are willing to share please provide a short description here

There were only 8 agencies responded to this question, of which 7 agencies provided their success stories, 5 agencies showed the lessons learned, and 1 agency gave an additional comment. Details are presented in Table 71.

Table 71. Agency's responses on their success stories and lessons learned on the topic of environmental best practices in snow and ice control.

Agency	Success Stories	Lessons Learned	Additional Comments
Rhode island DOT	Implementation of closed loop spreaders resulted in significant reduction in environmental footprint and major financial savings/avoided cost.		
Minnesota DOT	Established an all liquid application on a specific route adjacent to water in which a significant drop chloride levels in the lakes.	Operator training is essential and appropriate usage depends on many factors specific to the location and conditions.	
City of Grandview, MO	Adjusting time of attack on a storm.	We can successfully delay an attack through creating a safety problem.	Many agencies that pre-wet do not take advantage of the pre-wetting by delaying their attack. By delaying attack, you lose the advantage of building a good slush layer that hold chemicals of the surface.
Washington State DOT		I think our experience with roadside chloride sampling applies as both a success story and lessons learned. Laura has info on that.	

Agency	Success Stories	Lessons Learned	Additional Comments
Kansas DOT	Invest in storage facilities so all materials are protected.		
Virginia DOT	Brine storage.	Retention Pond cleaning.	
Maine DOT	Prioritizing our roads and establishing level-of-service standards has probably been the biggest single improvement we have made that had statewide impact since our switch from using abrasives in a deicing/reactionary approach.		
New Hampshire DOT	I-93 corridor from Salem to Manchester- Documented, and accepted by NHDES and USEPA, 20% reduction in salt usage after BMP's were instituted, without reduction in LOS.	Need a good way to correlate salt usage to the variation of each winter to demonstrate any reduction. Also need good past data to stablish a base line for the predicted usage so actual can be compared.	

Appendix C Case Study Interviewees

Allen Williams, Virginia DOT

Brian Burne, Maine DOT

Clay Adams, Kansas DOT

Denis Randolph, City of Grandview, Missouri

Joseph Baker, Rhode Island DOT

Appendix D Case Studies

Establishing LOS Standards and Prioritizing Routes

In 2004 the Maine DOT (MDOT) started the process of reviewing its Maintenance and Operations practices. As a result in 2005 the level of service guidelines and maintenance management were redefined based on changes in practices; a shift from sanding to anti-icing. The LOS system used evolved from a tool used by only the Maintenance and Operations Department to full implementation across all MDOT programs including paving and capital projects. The redefined LOS priorities have been linked with plow route lengths, cycle times, and average salt usage and serve to develop asset-based budgets for their regions. A multi-state Maintenance Management System (MMS that was developed jointly with New Hampshire and Vermont allows for tracking of vehicle hours used, person hours, materials ordered and used, and various stockpile management activities. This data helps MDOT manage supplies, accomplishments and track efficiency throughout the season, as well as reconcile quantities purchased versus quantities used at the end of the season.

By 2014 and many iterations to systems, MDOT has realized cost savings and improved environmental stewardship as presented below.

- MDOT was able to retire 53 plow trucks based on route reprioritization and reclassification based on the shift to anti-icing, and the trucks being able to take on longer routes. This represents an annual vehicle operating cost savings of approximately $25,000 per truck or $1.3 million for all trucks retired annually. This is also a $10 million savings in replacement costs for these vehicles.
- MDOT was able to reduce sand and salt/sand storage needs by shifting to more anti-icing. Much of the material was stored in outside piles. By reducing the sand and salt/sand use this allowed for smaller, more affordable storage structure to be built. The original 3000 to 5000 yd^3 buildings cost $500,000 to $600,000, but the smaller structures that store 500 to 700 yd^3 cost $150,000 to $200,000. Providing a significant cost savings. By storing all of the material inside less material has been lost to the environment; there has been a decrease in leaching and contamination of wells, and a decrease in well contamination claims and replacement costs.
- Cost savings that have been observed but not yet quantified by MDOT include reduced sweeping time, reduced sand/salt production time, reduced catch basin cleaning, reduced build-up of sand in culverts and ditches, a reduction in windshield claims to zero. As a result, MDOT has picked up roughly 7 extra weeks for summer work that was otherwise dedicated to these activities.

Additional information on the LOS system used by MDOT can be found on the following webpages:

- http://www.maine.gov/mdot/winterdriving/pp.htm, http://www.maine.gov/mdot/about/assets/glossary/index.shtml#1

MDOT also offers a MapView of the state roads by priority level and provides traveler information to the public such as seasonal road closures and openings which can be found here:

- http://www.maine.gov/mdot/mapviewer/.

Adjusting the Time of Attack using Pre-Wetting

Mr. Randolph, from the City of Grandview, Missouri, has found that by holding back and not applying material, such as rock salt, at the beginning saves material normally lost due to bounce and scatter, and to the adjacent environment. This was an issue early in his career because salt from winter maintenance operations was getting into the tributaries leading to the Great Lakes in Michigan. Mr. Randolph found that if he applied material too soon, especially in cold conditions (10 °F) with winds, that road surfaces would glaze up with "black-ice" conditions, creating a more hazardous driving condition. Instead he would initially plow to remove any accumulated snow, allowing no more than about 2 inches of accumulation, then apply material allowing traffic to create a slush. They would then plow the slush off when it reached the 4 to 6-inch depth. By creating a slush, Mr. Randolph has increased the service life of blades by 300%, (due to reduced blading) replacing them every third years instead of every year, and reduced impacts associated with the plow vehicles by reducing plowing forces. Because of his delay in applying material, Mr. Randolph was also able to reduce material usage. Mr. Randolph noted that until the slush is cleared it can cause traffic to slow, but has never had any stoppage of traffic, and the reduced speeds tend to force drivers to drive at speeds more appropriate for weather conditions in general.

Mr. Randolph has also noticed residual material on the road prevents the ice/snow-pavement bond from occurring. This helps in the strategy of holding back at the beginning of a storm, since there is less concern about trying to remove packed ice later.

Mr. Randolph has been using pre-wetting since 1993. He uses many chemicals to treat the roads, and mixes them to match the temperature and conditions. Products he is currently using include beet juice, calcium chloride liquid and flakes, calcium chloride mixed with beet juice, sand with calcium chloride and beet juice added (applied at about 100 lbs/l-m). He has found that calcium chloride works well below 15 °F. He will be adding agriculturally derived corn product to his product list this year.

- Salt application rate – 300 lbs/l-m
- Pre-wetting application rate - 14 gal/l-m

Using these products he has observed little to no impacts to infrastructure and the adjacent environment.

To time his delayed attack, Mr. Randolph has used private forecast service but over the years has shifted to using the National Weather Service hourly forecasts. He has found that he typically can delay an attack by up to 2 hours. On the first pass he recommends using underbelly blades on plow trucks to blow snow off the roads and then to plow snow up to 6 or 8 inches in depth, then moving on to a series of front-end mounted plows. Mr. Randolph trained his staff to use plow blades as they were needed; starting with underbelly blades, then moving up to front end blades, all the way to V-plows depending on the amount of snow that needed to be moved. The crew changes out the blades themselves as needed during storm events. This has greatly helped reduced wear to blades.

An interesting side note to this is that upper management was not always supportive of his methods. He was asked why he was creating a slush and why the trucks were not out on the road salting early in storms. Ultimately he found that by showing them the quality of driving surface he was producing, the on target material usage, and good safety record they acquiesced.

Another interesting point to make is that Mr. Randolph's staff were all trained from the beginning by him so there were no buy-in issues or preconceived ideas to the varying techniques he was using. Mr. Randolph was able to train a maintenance staff to be very weather aware, material aware and to have very strong plowing skills. All of this took time and effort to achieve, but has led to time, material and equipment savings.

Based on observed staff fatigue and his ability to delay the attack time on storms, Mr. Randolph was able to reduce shifts from 20 hours to 12 hours. This not only made employees happy and reduced fatigue but he was also able realize cost savings from overtime hours.

Material Storage and Good Housekeeping

Over the last 25 years the Kansas DOT (KDOT) has expanded the number of storage facilities so that all of its salt and salt/sand mixtures can be kept in covered buildings on an impervious surface (Figure 96).   KDOT now has covered storage for about 200,000 tons of anti-icing material, about 25% more than its highest annual usage.

Figure 96 Typical storage buildings used by the Kansas DOT; (left) 1960-70's wood frame, (middle) dome with barn doors, (right) newer construction of a wash bay facility. Photos courtesy of Kansas DOT.

Having covered storage is only part of the solution. The KDOT storage facilities are not large enough to allow the delivery trucks inside, so all dumping takes place as close to the building as possible on an impermeable surface, and plow trucks are also loaded outside. If the surface of yard is not cleaned up after each delivery, and after each storm, you may end up with runoff that can impact adjacent land and, in some cases, shallow wells. KDOT is currently addressing a claim that runoff from one of our storages locations contaminated some water wells. This will involve the excavation of several thousand cubic yards of soil and replacing it with soil hauled in from another location. This experience has led to an increased awareness of the importance of housekeeping at KDOT maintenance facilities. Kansas DOT crews make an effort to clean loading areas after each delivery by scraping and brooming the pavement. At some locations a catchment basin has been constructed at the low point of the yard to capture salt laden runoff and allow the water to evaporate. The importance of housekeeping is covered in the KDOT Maintenance Manual and will be further emphasized in a snowfighting manual that is currently under development.

Kansas DOT used to wash its dump trucks and other equipment in the maintenance yards, but runoff became an issue as well as State regulations that prohibited the practice. For this reason, fully enclosed heated wash bays were built at all sub-area locations where access to a local sanitary sewer system was available (Figure 96).

Brine Storage

In Virginia, brine is stored in double walled tanks, which is all they order now, or they are stored in a containment pit. The containment pits are designed to have a holding capacity of the largest tank. Liquid storage tanks used by the VDOT range in size from 1000 to 5000 gallon capacity. Most tanks are also stored on pads, so that if a spill occurs the liquid will drain to a designed collection pond. (When asked if VDOT has had any issues with tanks or tanks fitting breaking, Mr. Williams stated that they did have some issues in the past but all of these tanks were removed from service and sold and that these were isolated incidences.) Virginia DOT stores salt brine, and liquid $CaCl_2$ and $MgCl_2$. The amount of each product stored at each facility varies, for example in Northern Virginia they use predominately $MgCl_2$ because of the number of bridges. Mr. Williams noted they have observed some corrosion from the use of these products, specifically on aluminum components. Virginia DOT is still looking into the cost-effectiveness of using corrosion inhibitors and ag-based additives to reduce the corrosion rate of chlorides. In the past Virginia DOT has observed reduced corrosion to maintenance vehicles from the use of corrosion inhibitors.

Closed Loop Spreaders

About six years ago the Rhode Island DOT (RIDOT) had first generation closed loop spreaders on about 30% of their winter maintenance fleet. The system had a manual upload/download system. RIDOT has since upgraded and retro-fitted all possible trucks with better technology available today on closed loop spreads, now using wireless uploading/downloading capabilities to the cloud. A total of 81 trucks have been upgraded, with AVL/GPS tied to about 61 truck spreaders.

Rhode Island DOT has been able to compare the estimated calibration rates versus the actual application rates. Overall RIDOT found they were applying 400 lbs/l-m on average using trucks without the closed loop spreader technology. They now average application rates of 250 lbs/l-m for trucks with the older generation and newer generation closed loop spreader technology. Because Rhode Island has been able to see significant material and cost savings, closed loop spreader technology has been highlighted as a performance measure best practice in the state. Rhode Island DOT is currently working with the Department of Justice and the U.S. EPA, using the example of the success of the closed loop spreader as a non-structural BMP for winter maintenance operations.

The importance of accurate application rates and the need for change was highlighted by a number of well contamination cases. Rhode Island DOT has observed a significant decrease in well contamination cases since implementation of closed loop spreader technology.

Rhode Island DOT is now working to get all contractors and vendors to use closed loop spreaders. To encourage the investment in equipment, RIDOT is offering a 20% bonus rate on with closed loop spreaders, but there have been no takers yet. Rhode Island DOT does not require this technology yet for contractors and vendors but may in the future.

The overall takeaway from RIDOT’s experience with closed loop spreaders is that putting less product out there equals material savings and reduced impacts to the environment. Over the years with implementation of practices like more focused training, calibration of spreaders, and now closed loop spreaders; RIDOT has seen step wise decreases in salt application rates with each while maintaining or improving LOS. This stresses the importance of investing in new technology to increase efficiency and improve upon existing training practices. Some lessons learned from RIDOT include;

- Staff need to see the progress and improvement over time to really buy-in to changes in practices,
- Once staff buy-in, this can be the best support for further implementation of a practice,
- And reinforcing to staff the fact that the technology is not being used to watch over them, but to improve the program as a whole.

Retention Pond Use and Maintenance

In the Salem, Virginia area alone, 31 facilities[4] have some type of chemical runoff protection. This may include all or some of the following: a collection pond, and oil and or grit separator. The collection ponds used by VDOT were built in the late 1980s to early 1990s. The collection ponds were part of an environmental plan developed by VDOT because a few pieces of property were contaminated and had to be purchased from the landowners. At many facilities they have older storage buildings that are not big enough to allow for loading and unloading of material inside. Instead all sites have loading pads that drain to the storage ponds. If the pads have been cleaned off and are not being used for loading deicing chemicals, a diversion valve is switched so that runoff flows to a separate stormwater treatment pond. The salt runoff ponds were designed to function as evaporation ponds, but they found that too much runoff water was being added to ponds for the evaporation rates that were present. To handle this Virginia DOT was having to pump water from the ponds frequently and dispose of it properly. By using the diversion value, the collection ponds only receive salt laden runoff allowing them to function as designed.

The collection ponds are lined with black liners that have lasted much longer than anticipated (15-20 years), and are only now being replaced. To maintain the ponds, they are cleaned out every couple of years. First the liquid is pumped out, and if no oil sheen is present, the water may be used as a dust suppressant on unpaved roads. Then the silt and trash that has accumulated at the bottom of the ponds is cleaned out and disposed of in the landfill. Before Virginia DOT used oil and grit separators, water quality monitoring was conducted frequently. Now that oil and grit separators are used water quality monitoring is conducted as needed, for example if sheen is seen on the collection pond.

A lesson learned by Virginia DOT, it that the ponds should be cleaned out regularly and frequently to avoid excess built up of silt and trash that can reduce the storage capacity and functionality of the ponds. Best practices identified by the Virginia DOT are the use of the diversion values to appropriately divert stormwater runoff to a separate treatment pond; and the use of oil and grit separators to prevent oil from reaching the collection ponds and reduce the amount of grit and silt reaching the ponds. As a general practice, when Virginia DOT is upgrading a storage facility – storage ponds, oil and grit separators, and diversion values are included in all plans.

[4] Statewide there are around 200 maintenance facilities with about 90% of these facilities having some kind of runoff containment. The remaining 10% goes to a municipal water treatment facility.

Stockpile Academy

The Pennsylvania Department of Transportation (PennDOT) developed a Stockpile Academy training session based on a need identified by the DOT for better housekeeping practices to improve salt management, reduce impacts to the environment, safety, and longevity of equipment and structures. Since 1993, the PennDOT Facility Management Advisory Committee (FMAC) has been responsible for the Stockpile Academy training as well as the development and updating of PUB 284 that created one policy manual, in one reference work, all of the information necessary to acquire, develop, maintain or divest PennDOT facilities. FMAC has historically been comprised of representatives from the PennDOT Bureau of Office Services (BOS), Bureau of Maintenance and Operations (BOMO), the PennDOT Engineering and Maintenance Districts, as well as other resources that are consulted as needed.

In 2010, the Pennsylvania Turnpike Commission (PTC) began using the Stockpile Academy training, and in 2012 the PTC began attending all PennDOT FMAC meetings and joint quality assurance inspections were conducted at both PTC and PennDOT Facilities throughout the Commonwealth of Pennsylvania. The goal was to identify best management practices throughout both agencies under a collaborative initiative called Mapping the Future.

The goal of the Stockpile Academy is to provide proactive approaches and tools for staff, so that reactive measures are not needed. The objectives of the Stockpile Academy are:

- To enhance knowledge and understanding of the proper management and maintenance of facilities.
- To train staff in best management practices for stockpiles.
- Review the Stockpile Environmental Quality Assurance process.
- And to receive information on areas of improvement, and areas that can continue to improve.

To accomplish these goals, the Stockpile Academy uses real world (usually within agency) issues that have been identified as problematic, and provides solutions. The PTC training material covers information on Energy Policy, Important Codes, Assessments, Safety, Salt Storage and Handling, Liquid Products, Vehicle Wash Facilities, Combined Facility Response Plan (CFRP), and more. What is unique to this training tool at the PTC is the use of an internal and external assessment tool. The internal assessment is conducted quarterly by a site manager, and the external assessment is conducted annually by a third party. These assessments are used to identifying best practices, and highlight areas for improvement. In some cases the assessments have been used as a part of the performance evaluation for managing staff.

A few examples of best practices in the Stockpile Academy highlighted here are the good housekeeping practices and the 10ft rule.

Good housekeeping practices include maintaining a neat and orderly facility. Not only does this reflect well with the public, but it allows for easier identification of spills and leaks, proper storage of safety equipment (first aid, fire extinguishers, etc.), but also overall improves safety and efficiency at the site. An example highlighted in the training program is the timely recycling of old tires. Used tires are often stored on-site until sufficient quantity is present to justifying the cost of disposal (Figure 97). Used tires collect water that can serve as mosquito breeding grounds which is not encouraged. In the PTC quarterly site assessment the used tire stockpile are assessed, and disposal is requested as necessary. This has increased used tire removal and reduced onsite trash.


Figure 97. The photo on the left if an example of tire storage prior to the use of the assessment tool in the Stockpile Academy. The photo on the right shows the newly constructed storage facility designed specifically for winter maintenance operations. Photos courtesy of the PTC.

The 10ft rule is used for salt and "hot mix" (50:50 salt: crushed rock) stored in structures. The rule states that materials should be clear of the door by 10ft to eliminate loss of material (Figure 98). In the off-season when the material is not being used, the front side of the material pile facing the door should also be covered with a tarp and held down with sand bags (not tires). The 10ft rule has reduced product lost from storage structures and reduced the presence of salt staining outside of the structures. To achieve the 10ft rule, buildings need to be properly designed. The PTC is now building larger salt storage facility, up to 10,000 ton capacity and smaller that are designed and engineered to best serve winter maintenance operations including sufficient space inside for dumping loads, load trucks, multiple product piles, that have paved and impermeable surfaces inside, eliminated perch point for birds, and are made of corrosion resistance materials (epoxy coated rebar, sealed concrete, and glue-laminated posts) to name a just a few changes. The cost of the new building can be easily justified by the 40 to 50 year design life, reduced impacts to infrastructure and the environment, and improve efficiency of salt management.

Since its creation at PennDOT, the PTC has evolved the training program improvements in stockpile management and general facility management have been observed as:

- Improved stockpile assessment scores.
- Reduced number of emergency response issues at facilities.
- Improved site organization and cleanliness.
- More accurate and timely reporting of issues or items that require repair or replacement.
- Staff knowing what to look for and who to report issues to.

The PTC acknowledges that the success of the Stockpile Academy training program lies in its continual evolution based on the changing needs of staff, getting the training to the regional managers, foreman, and assistant foreman to increase exposure to the information and acceptance, and having buy-in from senior leadership.

Figure 98 The 10ft rule. This photo shows how material is kept 10ft back from the door of the storage structure. Photo courtesy of PTC.

The following two checklists are the 15 minute stockpile walk around checklist and the stockpile checklist used by PennDOT.

PennDOT 15-Minute Stockpile Walk around Checklist

1. Are all salt & mixed materials stored under a permanently roofed building?
2. Is the salt loaded properly (at the front & sides of the storage structures)?
3. Have all visible signs of salt trailing away from the storage area been cleaned up?
4. Is water directed away from the entrances of the salt storage buildings?
5. Are all stored materials grouped together in separate areas with proper signs posted?
6. Are all drums & containers properly labeled & stored?
7. Are all compressed gas cylinders stored properly?
8. Do above ground storage tanks have proper containment?
9. Are confiscated or abandoned vehicles stored properly on the site (on paved pad)?
10. Is the equipment wash facility operating properly?
11. Are oil/water separators properly maintained?
12. Is there a stormwater management system in place & is it functioning properly?
13. Is the PPC Plan on site & updated within the past year?
14. Is the landscaping neatly maintained?
15. Are all required signs properly posted?
16. Have all necessary permits been updated & displayed?

17. Are all gates, locks & fences in place & in good repair?
18. Are all shingles in place on roofed structures?
19. Are all buildings & structures completely intact & damage free?
20. Are all of the buildings completely free of pigeons & other animals?
21. Do all buildings have proper identification signs & presentable paint jobs?
22. Are gutters & downspouts clear, free flowing, damage free & direct water away from buildings?
23. Have all fire extinguishers been identified by signs, inspected, and charged?
24. Is the safety station properly equipped?
25. Are the exhaust systems operating properly?
26. Are the proper clean sanitary facilities provided?
27. Is the site clear of trash & litter?
28. Are all of the lighting systems working properly?
29. Are all of the lightning rods & electrical systems damage free & working properly?
30. Are the truck heater outlets installed properly & operating with cords used or stored properly?
31. Has the emergency generator been tested in the last seven days?

PennDOT Stockpile Snapshot

1. All salt and salt premix materials stored inside a roofed structure?
2. Is the area around the entrance and inside the salt building water free?
3. Are there visible signs of salt trailing away from the salt building?
4. Are all buildings and structures completely intact and damage-free?
5. Are shingles missing from the roof of the salt building?
6. Are gutters and downspouts functioning properly and damage free?
7. Is there proper secondary containment of above ground storage tanks?
8. Do all buildings have proper ID signs and presentable paint jobs?
9. Is premix covered or under roof?
10. Is the site clean and litter free?
11. Are all gates, locks and fences completely intact? If no one is present are they locked?
12. Are all materials and entrance properly signed?
13. Is the landscaping properly maintained?

Appendix E. Poly Tank Inventory and Inspection Forms

Stationary Poly Tank Inspection Form

DATE	LOCATION OF TANK		ASSET NUMBER

OKAY	NEEDS ATTN.	WORK COMPLETE	SEE COMMENTS	ITEM	SEVERITY: OKAY	MINOR	MODERATE	SIGNIFICANT	SEE COMMENTS	ITEM
				EQUIPMENT REVIEW						**TANK REVIEW**
				Are pipes cracked or broken?						Is the tank damaged (e.g. dented, discolored, or flaking)?
				Is there damage to pipes from vibration, expansion, settlement, or impact?						Is there bending or swelling of the tank wall that is different from normal expansion?
				Are there leaks or drips (unusual moisture) along the pipe runs?						Does the tank wall feel spongy?
				Is the tank lid broken or missing?						Are cracks visible without using a detailed inspection test (listed below)?
				Are fittings or flanges pulling away from the tank?						**DETAILED INSPECTION of POLY TANK**
				Are the tanks, pipes, and fittings adequately supported and secured?						*Complete one or both tests if any response other than "okay" is checked on a tank review question*
				Are valves or gaskets misaligned, loose, brittle, or deteriorated?						**BLACK MARKER TEST – for a specific area** Are stress cracks visible in the tested area?
				Are pumps and other equipment adequate for the workload?						**LIGHT TEST – for the whole tank** Are stress cracks visible?
				Are plumbing fittings or hoses loose, broken, or worn?						*Complete test if stress cracks are observed. Recheck for stress cracks after baseball bat test.*
				Do pumps or other equipment need servicing or replacement?						**BAT TEST – for affected areas** Did the impact affect the tank?

COMMENTS:

INSPECTION FREQUENCY IS BASED ON THE SEVERITY OF VISIBLE DETERIORATION OKAY = ANNUAL; MINOR OR MODERATE = 6 MONTHS; SIGNIFICANT = OUT OF SERVICE	NEXT INSPECTION DUE BY:
INSPECTED BY:	REVIEWED BY:
	CREW SUPERVISOR:

Poly Tank Inventory Sheet

District: ______________________________ **Section** ____

Tank	Product	Capacity	Date Installed	Purchase or Manufacture Date	Specific Gravity	Location	Tank Identification	
							Equipment Number	Asset Number
1								
2								
3								
4								
5								
6								
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18								
19								
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research for winter highway maintenance

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