NCHRP

SYNTHESIS 449

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Strategies to Mitigate the Impacts of Chloride Roadway Deicers on the Natural Environment

A Synthesis of Highway Practice

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 449

Strategies to Mitigate the Impacts of Chloride Roadway Deicers on the Natural Environment

A Synthesis of Highway Practice

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Cover figure: An NJDOT truck spreads anti-icing material on a New Jersey road (*Courtesy*: New Jersey Department of Transportation).

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jo Allen Gause
Senior Program Officer
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This synthesis documents the range of methods, tools, and techniques used by transportation agencies to minimize the environmental impact of chloride-based roadway deicers. The report presents information on preventative measures designed to reduce the amount of chloride deicers entering the natural environment adjacent to roads, as well as strategies for reducing the impacts once the deicers are in the environment.

Information used in this study was acquired through a review of the literature and a survey of state departments of transportation and Canadian provincial transportation agencies. Follow-up interviews with selected agencies provided additional information.

Laura Fay, Xianming Shi, and Jiang Huang, Western Transportation Institute, Montana State University, Bozeman, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable with the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

STRATEGIES TO MITIGATE THE IMPACTS OF CHLORIDE ROADWAY DEICERS ON THE NATURAL ENVIRONMENT

SUMMARY

The past few decades have seen steady increase in the use of chloride roadway deicers for winter maintenance operations, along with the awareness of associated environmental risks. The United States currently spends approximately $2.3 billion annually to keep highways free of snow and ice, and the associated corrosion and environmental impacts add at least $5 billion. The environmental impacts of chloride roadway deicers depend on a wide range of factors unique to each deicer formulation and the location of application.

Chloride-based deicers used in winter maintenance practices can impact the environment adjacent to the road. The objective of this synthesis is to document strategies used by transportation agencies to mitigate the impacts of chloride roadway deicers on the natural environment, including the surrounding soil and vegetation, ground and surface water, aquatic biota, and wildlife. The scope of this synthesis covers solid and liquid chloride-based roadway deicers—sodium chloride, magnesium chloride, and calcium chloride.

Information presented in this synthesis was obtained through a comprehensive literature review utilizing information published domestically and internationally, including government reports, technical documents or webpages, journal publications, and conference presentations and proceedings. Additional information was gathered through a survey that was sent to all state departments of transportation (DOTs) and to Canadian provincial transportation agencies. A total of 40 state DOTs responded with a response rate of 80%, and 12 Canadian provincial transportation agencies responded with a response rate of 100%. Follow-up interviews with six selected agencies were conducted. Information gained from the interviews was converted into four case examples.

The synthesis presents information on identified proactive strategies used to mitigate the impacts of chloride road deicers on the natural environment. Proactive strategies entail preventative measures designed to reduce the amount of chloride deicers entering the environment, which can reduce the need for or dependence on reactive strategies. The effective practices identified from the survey and literature review and presented in this synthesis include salt management plans; staff training; monitoring and record-keeping; anti-icing, deicing, and pre-wetting practices; weather forecasting and Road Weather Information Systems; snowplows; vehicle-mounted spreaders; roadway and pavement design; vegetation management; innovative snow fences; and design and operations of road maintenance yards. Most methods, techniques, and tools can be used alone, paired in a series, or integrated to form a proactive mitigation effort. Survey responses identified proactive mitigation strategies as the most common methods currently used to mitigate the impacts of chloride road deicer on the natural environment.

Reactive strategies used to mitigate the impacts of chloride road deicers on the natural environment were also identified. Reactive strategies aim to reduce the impacts of chloride deicers once they are in the environment. The following effective practices were identified from the literature review and confirmed by survey responses: infiltration trenches and

basins; detention, retention, and evaporation ponds; wetland and shallow marshes; vegetated swales; and filter strips. Many of the strategies presented in this synthesis were designed for and are frequently used in stormwater management and aid only in the retention or capture of chloride-laden water and do not actually treat or remove chloride from the water. All of the presented strategies contribute to the effective treatment of both the velocity and the quality of highway stormwater runoff. The majority of the reactive strategies identified were not originally installed for this purpose, and their cost-effectiveness for chloride deicer environmental management has yet to be examined and validated. For deicer environmental management, reactive strategies may vary, and need to be designed, sited, installed, and maintained properly. Reactive strategies may be used individually or synergistically and a combination of reactive strategies can help enhance overall performance, increase service life, and preserve downstream water bodies.

This synthesis also presented information on new and emerging technologies identified through the survey and literature review including: synchronizing vehicle location and other sensor technology, maintenance decision support systems (MDSS), fixed automated spray technology, and thermal deicing methods.

Many of the proactive and reactive measures and the emerging technologies discussed can be used as performance measures to monitor the effectiveness of chlorides (e.g., MDSS) and/or the environmental impacts (e.g., vegetation management), if appropriate data are collected, processed, and reported. This information can then be assimilated into usable result-based standards and incorporated into salt management plans and monitoring and training programs.

Effective methods, techniques, and tools have been developed and are constantly evolving to minimize the impacts of chloride roadway deicers on the environment. The synthesis concludes that a combination of both proactive and reactive strategies may lead to better mitigation of environmental impacts. Strategies may vary, depending on the specific climate, site, and traffic conditions. The key is to select an appropriate suite of tools, techniques, or methods that can function most effectively for the given set of conditions.

This synthesis work identified main gaps in the knowledge base where additional research is warranted. The recommended research includes addressing knowledge gaps in the following areas:

- *Fundamentals* (e.g., benefits and risks of using liquids for anti-icing and deicing, impacts and implications of removing impaired roadside vegetation, cost-effectiveness and environmental impacts of agro-based deicers, fate and transport of pollutants),
- *Monitoring* (e.g., mobile salinity sensor, salt-tolerant vegetation, correlating the chloride loading in adjacent soils with deicer usage, effectiveness of salt management plans),
- *Strategies* (e.g., appropriate application rates for anti-icing and deicing, effectiveness of incentive programs, effective use of hot water, innovative use of roadside vegetation, efficiency of reactive strategies in cold regions), and
- *Technology* (e.g., anti-icing pavement, better chemical products, improved thermal road mapping).

CHAPTER ONE

INTRODUCTION

This synthesis presents information on strategies used to mitigate the impacts of chloride roadway deicers on the natural environment. Many of the identified solutions also could apply to mitigating the impacts of abrasives and non-chloride-based roadway deicers. Specific items that will be discussed include strategies used to control the source of deicer contamination without jeopardizing the level of service (LOS) on winter roads [salt management plans; staff training; monitoring and keeping records; anti-icing, deicing, and pre-wetting practices; weather forecasting and Road Weather Information Systems (RWIS); snowplows; vehicle-mounted spreaders; roadway and pavement design; proactive vegetation management; innovative snow fences; and road maintenance yard design and operation], those used to reduce the impacts of chloride roadway deicers once they are in the environment (infiltration trenches and basins; detention, retention, and evaporation ponds; wetland and shallow marshes; and vegetated swales and filter strips), and new and emerging technologies [synchronizing vehicle location and other sensor technologies, maintenance decision support systems (MDSS), fixed automated spray technology (FAST), and thermal deicing methods]. These items have been identified through a comprehensive literature review and practitioner surveys, aimed to guide state departments of transportation (DOTs) and others in promoting sustainable winter service and environmental stewardship best practices. The information will also help agencies meet regulatory requirements within their cultural, political, fiscal, technological and other constraints. Environmental needs can vary by region (e.g., urban vs. rural, marshlands vs. mountains) and a "one-size-fits-all" approach is unlikely to work effectively.

The past few decades have seen steady increase in the use of chloride roadway deicers for winter maintenance operations, along with the awareness of associated environmental risks. In the United States and Canada, more than US$2.3 billion and US$1 billion is spent annually on winter highway maintenance, respectively (TAC 2002; FHWA 2005). Chloride salts, primarily sodium chloride (NaCl), magnesium chloride ($MgCl_2$), and calcium chloride ($CaCl_2$), are the main freezing point depressants in a wide variety of snow and ice control products, as they are relatively low cost, easy to use, and safe for the applicator and road user. According to Salt Institute statistics, the United States in 2007 sold approximately 20.2 million tons of NaCl for use in winter road maintenance. The environmental impacts of chloride salts have been a subject of research since their use for highway maintenance became widespread during the 1960s (Hawkins 1971; Roth and Wall 1976; Paschka et al. 1999; Ramakrishna and Viraraghavan 2005). In a recent review, Fay and Shi (2012) presented a comprehensive survey of current knowledge and examined the environmental impacts of materials used for snow and ice control (e.g., abrasives, chlorides, acetates/formates, glycols, agro-based deicers, urea).

Existing knowledge may be utilized to minimize the environmental impacts of chloride roadway deicers. For instance, deicers that contain significant amounts of calcium (Ca) and magnesium (Mg) should not be applied near soils significantly contaminated with metals or where any mobilized metals could easily be released to a sensitive receiving water body (Horner and Brenner 1992). To promote sound environmental stewardship, agencies may consider a holistic view of snow and ice control and consider accounting for the indirect costs of road salting, such as the costs to roadside vegetation (Trahan and Peterson 2008) and to motor vehicles and infrastructure (Shi 2005). Efforts will continue in the areas of managing the footprint of chloride roadway deicers and minimizing the associated risk and liability.

When promoting environmentally responsible winter road service, public perception is an important aspect to consider. The general public often recognizes the need for and benefits of such operations, yet is concerned about the environmental risks associated with the use of chloride roadway deicers, traction sand, and other materials for snow and ice control. In the United States, water quality, air quality, and wildlife issues are regulated with the guidance of the Clean Water Act, Clean Air Act, and Federal Endangered Species Act. These laws also detail the identification and management of environmentally sensitive areas, such as those on the list of impaired streams for water quality and the list of PM-10 nonattainment communities for air quality. Despite their potential damaging effects, snow and ice control chemicals can reduce the need to apply abrasives and pose less threat to the surrounding vegetation, water bodies, aquatic biota, air quality, and wildlife.

Performance measures are tools used to assess progress toward achieving a defined goal (FHWA 2012). Environmental performance measures for winter maintenance oper-

ations can focus on ecosystems, habitat and biodiversity, water quality, wetlands, and/or air quality [Environmental Plan 2008; Strategic Highway Research Project (SHRP) 2009]. Nonenvironmental performance measures for winter maintenance operations may focus on mobility, reliability, accessibility, safety, or vehicle speed (Qiu and Nixon 2009; SHRP 2009; Usman et al. 2010). Regardless of the performance measure being assessed, data need to be collected to allow for comparison of products, equipment, road surface condition, and the like, as well as for recommendations and planning. Many DOTs have implemented programs to assess environmental performance measures (CTC & Associates 2007), but limited information on each program has been published. Organizations such as FHWA and AASHTO, however, have developed web-based tools and resources such as the Center for Environmental Excellence (http://environment.transportation.org/), Eco-Logical (http://www.environment.fhwa.dot.gov/ecological/eco_index.asp), and INVEST (https://www.sustainablehighways.org/). Information gathered from the assessment of performance measures can then be used to establish result-based standards in the field of winter maintenance. *Results-Based Winter Maintenance Standards*, a multiyear project currently underway through Aurora, aims to develop quantitative methods to understand the relationships between key aspects of winter maintenance (e.g., maintenance operations, road surface conditions, highway safety, mobility).

The environmental cost associated with chloride roadway deicers is a factor to be balanced with the value they provide. This is evidenced in a growing number of new initiatives to manage and limit deicer usage, such as the Transportation Association of Canada's Road Salt Management Guide, the Minnesota Pollution Control Agency's Metro Area Chloride Project, and the New Hampshire Road Salt Reduction Initiative. The recent NCHRP report *Grand Challenges: A Research Plan for Winter Maintenance* identified "balancing social, environmental and economic factors" as one of the six critical issues in advancing winter highway maintenance (Wilfrid A. Nixon and Associates 2010). In light of the ever-increasing urbanization and customer demand for higher LOS, this issue is anticipated to be one of the greatest and most persistent challenges for the highway agencies in the coming years. In this context, there is a need to identify ways to maintain acceptable LOS while minimizing the environmental cost of winter road maintenance.

METHODOLOGY

A review of all available literature, surveys, and interviews were used to assemble the information presented in this synthesis. Details on each of these tasks are presented as follows.

An extensive literature review was conducted to gather information on proactive and reactive strategies used to mitigate the impacts of chloride roadway deicers on the natural environment. Technical documents, government reports, journal publications, and conference presentations and proceedings were used initially to identify pertinent information, and from local, state, federal, and international governments and organizations as well as organizations that work to promote winter maintenance effective practices, on webpages, manuals, field guides and reports, and published specifications. The literature review information was used to shape the outline of the report and to create the survey and interview questions.

Information presented in this synthesis was obtained through a comprehensive literature review utilizing information published domestically and internationally, including government reports, technical documents or webpages, journal publications, and conference presentations and proceedings. Additional information was gathered using a practitioner survey. The survey was sent to all state DOTs and to Canadian provincial transportation agencies. A total of 40 state DOTs responded with a response rate of 80%, and 12 Canadian provincial transportation agencies responded with a response rate of 100%. Information gained from the survey was used to provide resources and information utilized in the report. Appendix A presents the survey questions and responses.

Follow-up interviews with six selected agencies were conducted. Information from the interviews was used to provide resources and information utilized in the report, and was converted into four case examples: closed loop controllers, vegetation management, snow disposal and melting, and making salt brine from recycled vehicle wash bay water. Appendix B presents the case examples.

REPORT STRUCTURE

Information in this synthesis is presented as follows. Chapter one introduces the reader to the topic of the synthesis, defines its scope and objectives, and describes the methodology section and the report structure. Chapter two provides a review of background information to provide context for the topic, including environmental issues associated with the use of chloride roadway deicers and overview of mitigation techniques. Chapter three discusses preventative measures designed to reduce the amount of chloride roadway deicers entering the environment, which can reduce the need for or dependence on reactive strategies. Chapter four discusses mitigation measures that reduce the impacts of chloride road deicers once they have reached the environment adjacent to the road. Chapter five presents information on recent advances identified by the survey respondents or identified in the literature review. Chapter six provides a summary of the key findings from each chapter and a discussion of knowledge gaps and areas for future research. The synthe-

sis is followed by Appendix A—Survey and Responses, and Appendix B—Case Examples, which highlight effective practices on the following topics: closed loop controllers, vegetation management, snow disposal and melting, and making salt brine from recycled wash bay water.

The report is designed to be used as an information guide and a reference document. Each topic has an additional resources section that provides further references.

CHAPTER TWO

BACKGROUND

This synthesis provides information on proactive and reactive strategies that can be used to mitigate the impacts of chloride-based roadway deicers on the natural environment. To provide context for the information presented in this synthesis, this chapter briefly reviews the potential environmental impacts of chloride roadway deicers on the environment and the mitigation strategies that have been implemented to reduce these impacts.

ENVIRONMENTS AT RISK

There are growing concerns over the impact of deicers on the transportation infrastructure, motor vehicles, and the environment (D'Itri 1992; Menzies 1992; Buckler and Granato 1999; Levelton Consultants Ltd. 2007; Shi et al. 2009a, b, c). Chloride ions (Cl^-) are conservative, which means once dissolved they do not degrade in the environment and remain in solution (Ministry of Environment 2011). The environmental impacts of chloride roadway deicers depend on factors unique to each formulation and the location of application. According to Ramakrishna and Viraraghavan (2005, p. 60), the degree and distribution of the impacts in the highway environment are defined by spatial and temporal factors, such as draining characteristics of road and adjacent soil, amount and timing of materials applied, "topography, discharge of the receiving stream, degree of urbanization of the watershed, temperature, precipitation, dilution," and adsorption onto and biodegradation in soil. A recent survey of winter maintenance practitioners found water quality to be of the greatest concern, with air quality, vegetation, endangered species, and subsurface well contamination also mentioned as highly relevant (Levelton Consultants Ltd. 2007). As early as 1971, a study by the U.S. Environmental Protection Agency (EPA) found highway chloride deicing salts able to "cause injury and damage across a wide environmental spectrum" and uncovered salt storage sites to be "a serious source of ground and surface water contamination" (Field and O'Shea 1992). More recent research confirm that repeated applications of chloride deicers and abrasives or "seepage from mismanaged salt storage facilities and snow disposal sites" may adversely affect the surrounding soil and vegetation, water bodies, aquatic biota, and wildlife (Buckler and Granato 1999; Venner Consulting and Parsons Brinckerhoff 2004; Levelton Consultants Ltd. 2007).

There is a need to better understand and assess the environmental impacts of chloride deicers, in an effort to conduct sustainable winter operations in an environmentally and fiscally responsible manner. Figure 1 is an environmental pathway model that illustrates how deicers can move in the environment and where the impacts can occur (Levelton Consultants 2007). Environments that can be impacted by deicers include soil, ground and surface water, and vegetation; the figure presents the chloride deicer impacts to each of these environments. Roadway winter operations are only one source from which chlorides can enter the environment, as other industries (e.g., water softeners) and private-sector (e.g., malls and parking lots) winter operations also introduce significant amount of chlorides.

Soil

Deicer migration into soils adjacent to roadways can cause the swelling and compaction of soil, change its electrical conductivity, and lead to loss of soil stability by means of dry-wet cycling, osmotic stress, and mobilization of nutrients (Environment Canada 2010). Factors that affect the concentrations of deicer in the soil are the type and texture of soil, as well as its water concentration, cation exchange capacity, permeability, and infiltration capacity (D'Itri 1992). Lundmark and Jansson (2008) used the dynamic modeling approach to successfully represent "the spread of deicing salt from road to surroundings, deposition in the roadside environment and the subsequent infiltration into roadside soil" (p. 215). With increasing distance from the road, the field observations confirmed a general decrease in the chloride content of soil, with supporting evidence in soil physical properties, vegetation properties, and snow characteristics. Amrhein et al. (1992) studied the effect of deicers on the mobilization of metallic and organic matters in roadside soils and found the heavy metal concentrations to generally increase with increasing salt concentration. Buzio et al. (1977) studied the distribution of salt near a deicing salt stockpile and its effects on soil, by sampling the soil from 17 sites on an adjacent slope, and found extensive lateral movement of chloride with subsequent leaching to a depth greater than 76 cm.

Ground and Surface Waters

The potential impact of chloride deicers on the groundwater is of great concern, especially in the long run, as it may

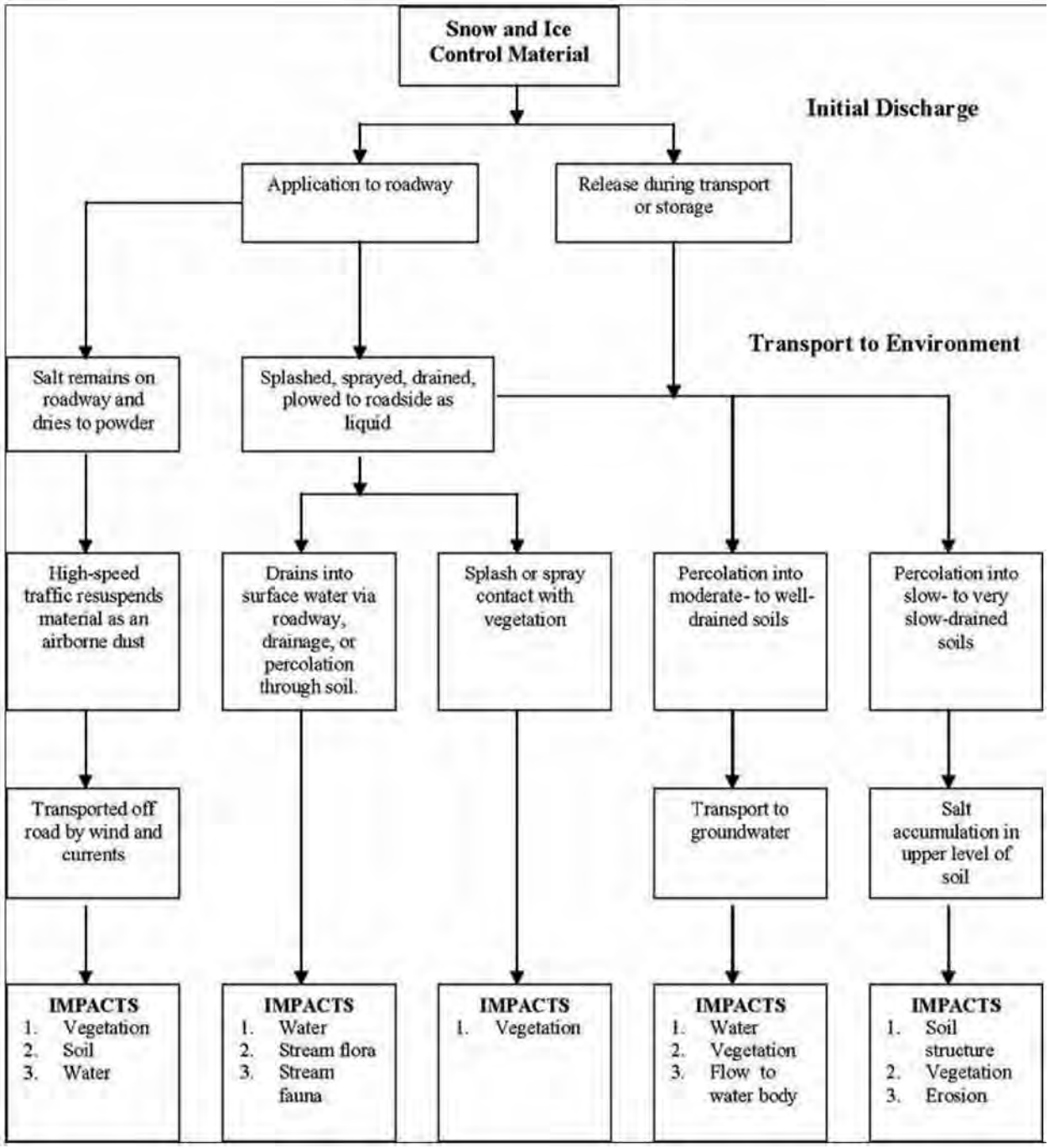

FIGURE 1 Environmental pathway model modified by Levelton Consultants (2007), showing the deicer footprint on the environment.

undermine the quality of drinking water and increase the health and corrosion risks. One identified health risk related to deicers in the public water supplies is toxemia associated with pregnancy (Sorensen et al. 1996). However, most water supplies do not test high enough on a regular basis to warrant concern. Health risks associated with water quality were also addressed in the Road Salt and Winter Maintenance for British Columbia Municipalities report; however, it was stated that "water would become unpalatable to most people before these conditions would arise" (Warrington 1998, sect. 2.2). For humans, long-term exposure to sodium may lead to hypertension (EPA 2003). Groundwater contamination from deicers depends on the frequency of the precipitation, the texture and drainage characteristics of the roadside soil, the distance between the groundwater and the surface and the roadway, the permeability of the aquifer material, the direction and rate of groundwater flow, and the deicer application rate (D'Itri 1992). For example, shallow and localized aquifers are at greater risk of contamination than deep and regional water sources.

According to Eldridge et al. (2010), chloride criteria recommended by the EPA for fish species for chronic conditions should not exceed a 4-day average of 230 mg/l and for acute conditions not to exceed a 1-hour average of 860 mg/l. Both chronic and acute criteria should not be exceeded more than once every 3 years on average. State limits on chlorides could be even more stringent. Anthropogenic sources of sodium that can significantly contribute to surface water include road salt, water treatment chemicals, domestic water softeners, and sewage effluent (EPA 2003). Pollutants, originating from salting, sanding, and other maintenance activities, pose threats to water resources (Hanes et al. 1970; Sorensen et al. 1996; Missoula City–County Health Department 1997; Rosenberry et al. 1999; Turner–Fairbank Highway Research Center 1999; TAC 2003d; Corsi et al. 2010) and potentially impair the water quality or alter the aquatic habitat. However, the damaging impacts depend on site-specific conditions and concentrations of pollutants in the receiving environments. A case study found that about 55% of road salts are transported in surface runoff with the rest infiltrating through soils and into groundwater aquifers (Church and Friesz 1993). Work by Corsi et al. (2010) found road salt to cause detrimental impacts to surface water on local, regional, and national scales, with short- and long-term impacts to streamwater quality and aquatic life. The degree to which the surface water is contaminated from deicers is a function of the amount of time the deicer takes to reach the water body, the dilution factor, the residence time of the water body, and the frequency and rate of deicer application (D'Itri 1992). The impact of deicers on receiving waters may be negligible in many cases, depending on the type and designated use of the receiving water, and on the drainage system used to discharge the runoff (Turner–Fairbank Highway Research Center 1999). In addition, groundwater and vulnerable aquifers can be affected by any material applied or spilled on the land, including deicers and abrasives.

Vegetation

Common deicer exposure mechanisms to plants include increased concentrations in the soil and water that can result in uptake by plant roots, or accumulation on foliage and branches owing to splash and spray (*TRB Special Report 235* 1991). Runoff from salt stockpiles was found to significantly damage nearby trees and to reduce the number of plant species available in soils. Salt concentrations higher than 15,000 ppm were found leaching from salt stockpiles (Buzio et al. 1977). (Appendix B provides details on the topic of needle browning.) Hanes et al. (1970) described the three major effects of salt on plant growth. First, salt can increase soil salinity and alter the osmotic pressure gradient, inhibiting the uptake of water by plant roots. Second, salt accumulations can occur in plant tissues. Third, salt can induce ionic imbalances, causing plant injury symptoms such as desiccation and leaf burn. Deicing salt exposure resulting from spray within 33 to 65 ft (10 to 20 m) of the road was demonstrated to cause a greater severity of foliar damage than uptake through the soil alone (Hofstra and Hall 1971; Viskari and Karenlampi 2000; Bryson and Barker 2002). On primary highways within 100 ft (30 m) of the road, highway agencies estimate that 5% to 10% of the plants in high-use sections are affected by deicers, and report that shrubs and grasses can tolerate increased concentrations better than trees. Plants with broader leaves are generally affected more than plants with narrow leaves (*TRB Special Report 235* 1991). Many studies have indicated that needle necrosis (death), twig dieback, and bud kill are associated with areas of heavy deicing salt usage, with trees and foliage down wind and facing the roadside more heavily affected than trees further away (Hofstra and Hall 1971; Lumis et al. 1973; Sucoff et al. 1976; Pedersen et al. 2000). Studies have shown that the slope of the roadside adjacent to the treated roadway is an important variable in defining the extent of plant injury from deicer treatment, with vegetation showing effects up to 20 ft (6 m) away on flat surfaces, 40 to 55 ft (12 to 17 m) away for steep down slopes, and only 10 ft (3 m) up slope (*TRB Special Report 235* 1991).

Aerial drift of deicers resulting from vehicular splash, plowing, and wind has also been observed to impact vegetation adjacent to roadways. Nicholson and Branson (1990) showed that deicer particulates deposited on the road could be removed and re-suspended by vehicular traffic. Wet conditions, increased vehicle speed, wind currents, and updrafts generated by vehicular traffic can cause redistribution of deicers off the roadway into the adjacent environment (Kelsey and Hootman 1992). Generally traveling from 6 to 130 ft (2 to 40 m), deicing particles have been observed up to 330 ft (100 m) from the roadway (Lumis et al. 1973; Blomqvist and Johansson 1999; Trahan and Peterson 2007). Kelsey and Hootman (1992) observed sodium deposition within 400 ft (122 m) of a toll way and sodium-related plant damage within 1,240 ft (378 m) of the toll way. Field tests have shown that 20% to 63% of the NaCl-based deicers applied to highways in Sweden were carried through the air, with 90% of them deposited within 65 ft (20 m) of the roadside (Blomqvist and Johansson 1999).

Native plant succession or loss of native plant species as a result of deicer use has been observed in soils and in low flush-rate surface waters adjacent to roadways, as well as in wetland-type environments that receive water flow from treated roadways. 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 reintroduction of non-native species as well (*TRB Special Report 235* 1991; Moore et al. 1999). A study of a bog contaminated with salt from a leaching deicer pile showed a decline in native plant species and introduction of non-native plant

species (Wilcox 1986). Within 4 years of the contamination event, native plants were returning to the bog.

Other Environmental Risks

A study from the Michigan DOT suggested that endangered and threatened species and the habitat on which they depend for survival could be adversely affected by the use of certain deicers (Public Sector Consultants 1993). In extremely sensitive environments, small applications of deicers may be detrimental to the ecosystem. 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). Deicers are generally at most low to mild skin and eye irritants to humans as can be referenced in their Materials Safety Data Sheet. Issues arise when there is direct ingestion of product, generally in the case of wildlife.

MITIGATION TECHNIQUES

This section presents a brief summary of practices used to mitigate the impacts of chloride roadway deicers on the natural environment, with a focus on those identified from the survey of winter maintenance practitioners (see Figure 2).

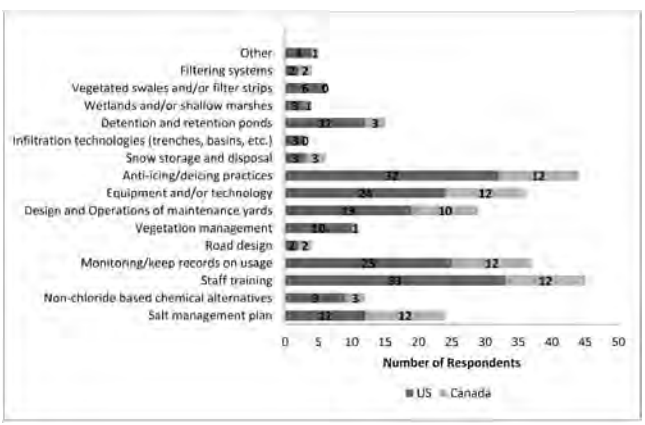

FIGURE 2 Methods, techniques, or tools identified by survey respondents as being used to reduce chloride roadway deicer usage or the impacts of chlorides on the natural environment.

Mitigation is the process of taking steps to avoid or minimize negative environmental impacts. A wide variety of mitigation techniques and approaches used to reduce deicer environmental impacts have been explored. Strategies can be implemented in technology, management, or both. The practices can be divided into two groups, the first of which focuses on the preventative and proactive approach to reduce amount of salts used, lost, or wasted, and the second of which focuses on the reactive approach to capture or retain salts once applied so as to reduce their impacts on the adjacent environment. Figure 2 shows that the most frequently used proactive and reactive mitigation strategies used by DOT practitioners and Canadian provincial government practitioners include anti-icing and deicing practices, staff training, equipment and/or technology, monitoring and keeping usage records, maintenance yard design and operation, salt management plans, detention or retention ponds, and vegetation management.

The proactive practices aim to "utilize the minimum amount of material necessary to achieve the desired outcome (or LOS)" and to keep the chlorides on the road, following the 4-R's (right material, right amount, right place, and right time) principle (TAC 2003i). Ninety-one percent of survey respondents stated that their agency had made efforts in the past 5 years to reduce the amount of chloride deicers applied during winter maintenance operations (n = 35 in United States, n = 12 in Canada). Survey respondents were asked if any official or unofficial policy changes have been made to encourage the use of less chloride deicing material. In general, the responses from Canada were in the affirmative, whereas the responses from the United States were in the negative and any changes that were encouraged were unofficial.

Little information is available from the winter maintenance community on reactive strategies, such as removing the chlorides from the environment adjacent to the road following winter maintenance activities. This is likely because chloride ions will not break down over time and they cannot be easily treated or removed from the environment. The vast majority of the reactive strategies identified were not originally installed for this purpose. Survey respondents were asked if they had observed chloride deicer mitigation in the adjacent roadside environment from implementation of strategies for other purposes, and many respondents indicated that they had observed mitigation of chloride roadway deicers in the environment adjacent to the road following implementation of strategies for other purposes [63% (United States n = 21, Canada n = 9) responded yes and 38% (United States n = 15, Canada n = 3) responded no]. Eighty percent of the survey respondents that indicated they had observed this stated that the original reason for implementation of the strategy was for *cost-savings* purposes as a result of budgetary constraints, which had the side benefit of reducing impacts of chlorides on the environment by reducing the overall amount of chlorides put in the environment. Other strategies that survey respondents had implemented for other purposes and observed the side benefit of chloride roadway deicer mitigation in the roadside environment include the following:

- Stormwater treatment techniques,
- Implementation of new technology [automatic vehicle location (AVL), AVL/Global Positioning System (GPS), RWIS, MDSS, pavement temperature sensors, and localized forecasting],

- Management strategies [monitoring salt use, operator training (e.g., proper application rates), good housekeeping, and streamlining operations], and
- Pre-wetting.

Because they were not designed specifically for mitigating the impacts on chloride roadway deicers, the cost-effectiveness of these strategies for deicer environmental management has not yet been examined and validated.

When survey respondents were asked if their state or agency has made any effort to mitigate or reduce the impacts of chloride deicers (either through reduced chloride deicer use or by reducing the impacts of chlorides to the natural environment), 88% responded yes (n = 35 United States). Defined application guidelines or performance specifications were also available on the following practices:

- Use of chlorides for winter maintenance practices—95% (U.S. responses only) said yes,
- Tools or methods to determine the effectiveness of chlorides used in winter maintenance practices—48% (U.S. responses only) said yes, and
- Tools or methods to quantify the environmental impacts of chlorides used in winter maintenance practices—only 28% (U.S. responses only) said yes.

In other words, although state DOTs are making an effort to mitigate or reduce the impacts of chloride deicers, the amount of information available to aid in this process is still limited. This confirms the need for this synthesis work and more in-depth research to address relevant knowledge gaps.

Additional Resources for Chapter Two

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CHAPTER THREE

PROACTIVE MITIGATION STRATEGIES

This chapter presents information on strategies used to control the source of chloride deicer contamination without jeopardizing the LOS on winter roads. These are preventative measures designed to reduce the amount of chloride deicers entering the environment, which can reduce the need for or dependence on reactive strategies discussed in chapter four.

Proactive strategies used to mitigate the impacts of chloride road deicers on the natural environment identified from the practitioner surveys and literature review and presented here include salt management plans; staff training; monitoring and keeping records; anti-icing, deicing, and pre-wetting practices; weather forecasting and RWIS; equipment technologies; vehicle-mounted spreaders; roadway design; vegetation management; innovative snow fences; and road maintenance yard design and operation. This synthesis does not discuss other proactive strategies that could reduce chloride deicer usage, such as the use of non-chloride roadway deicers and the incorporation of environmental staff in maintenance practices (Staples et al. 2004). Most methods, techniques, and tools presented in this chapter can be used alone, paired in a series, or integrated to form a proactive mitigation effort.

Research in progress on this topic includes the updating of "Chapter 8, Winter Operations and Salt, Sand and Chemical Management" of NCHRP Report 25-25(04) *Environmental Stewardship Practices, Procedures and Policies for Highway Construction and Maintenance* (2004); and the TAC Salt Management Guide. The Clear Roads Pooled Fund (www.ClearRoads.org) has recently sponsored research to establish effective deicing and anti-icing application rates (i.e., updating FHWA anti-icing guidelines), to understand the chemical and mechanical performance of road salts on specialized pavement types, and to improve snowplow design and the like.

SALT MANAGEMENT PLANS

Salt management plans (SMPs) provide the maintenance agency with a strategic tool through which its commitment to effective salt management practices can be fulfilled while maintaining its obligation to providing safe, efficient, and cost-effective road management. SMPs apply to all winter maintenance staff and personnel (including hired contractors), and protect the people and the environment (TAC 2003a). An SMP is generally agency-based and aims to follow these principles concurrently: safety, environmental protection, continual improvement, fiscal responsibility, efficient transportation systems, accountability, measurable progress, communication, and a knowledgeable and skilled workforce (TAC 2003a). Key components of an SMP may include the following:

- A statement of policy and objectives
- Situational analysis—on-road use, salt-vulnerable areas, sand and salt storage sites, snow disposal sites, training, etc.
- Documentation
- Proposed approaches
- Training and management review (TAC 2003a).

The TAC recommends applying general and broad guidelines developed at the federal level to the development of local guidelines, considering the amount of salts used; roadway systems; funding constraints; local weather conditions; and variability in conditions across a country, state, province, county, or municipality (TAC 2003a). A successful SMP may feature the following:

- It is based on policy with guiding principles from a high-level organization.
- It is activity based, with each activity assessed at the outset against clearly established standards or objectives showing minimized environmental impacts.
- Deficiencies in current operations are identified and corrective actions are established and implemented.
- Required actions are documented in policies and procedures and communicated throughout the organization.
- Activities are recorded, monitored, audited, and reported periodically to assess the progress and identify areas for further improvement.
- Gaps between actions and desired outcomes are identified and corrective actions are developed and implemented, with necessary modifications made to policies and procedures and appropriate training.
- The review cycle continues on an ongoing basis (TAC 2003a).

The city of Windsor, Ontario, specified responsibilities of each personnel in an SMP as follows:

- *Executive Director, Operations*—Has corporate responsibility for the SMP.

- *Maintenance Manager*—Ensures that the SMP is developed, maintained, and implemented consistently across the organization. Oversees the maintenance and upgrading of the winter maintenance facilities in compliance with the SMP.
- *Fleet Manager*—Purchases, maintains, and calibrates the winter maintenance fleet in compliance with the SMP.
- *Coordinator/Supervisor/Foreman*—Ensures that winter maintenance activities are carried out in compliance with the SMP.
- *Winter Maintenance Personnel*—Carries out winter maintenance duties in accordance with the policies and procedures set out in the SMP as directed by their manager.
- *Technical Support Manager*—Assists in the development of methods to compile performance measures in compliance with the SMP (City of Windsor 2005).

An SMP set out by Renfrew County in Canada consisting of the following eight stages (Pinet 2006):

1. Salt management plan
2. Training
3. Winter roads condition model
4. Route optimization
5. RWIS
6. Pre-wetting
7. Updated salt management plan
8. Revised operational plan.

In addition to implementing SMP on existing roads, negative impacts of chloride roadway deicers need to be considered during the new road design and construction stages. For a Highway 175 extension in Quebec, Canada, the developmental plan considered existing maintenance operations and developmental means and established objectives to reduce the impacts of road salts during design and construction (Tremblay and Guay 2006).

With the basic SMP guidelines, agencies can further improve the SMP to accommodate their budget plans and climatic and road conditions. One such improvement by the city of Toronto, Canada, entails innovative salt management practices, such as implementing electronic salt dispensers to control the salt flow, mixing sand into the salt when conditions permit, and pre-wetting the road salt (Welsh 2005). The Road Salt Working Group in Canada and another working group with Environment Canada released a best practices manual in 2004 that provides guidance for municipalities to develop their own SMPs. The TAC is currently updating the salt management guide from an amalgamation of earlier guides and the 2010–2011 best practices sheets (Peter Noehammer, personal communication–Case Study Interview, Toronto, Mar. 28, 2012).

In this synthesis work, the survey respondents were asked (1) if their state or agency has made any effort to mitigate the impacts of chloride deicers, either through reducing chloride deicer usage or by reducing the impacts of chlorides to the natural environment; and (2) if their state or agency has implemented any tools, techniques, practices, or strategies to reduce the impacts of chloride deicers. The following are the responses pertinent to SMPs:

- Developed an SMP based on the Environment Canada Code of Practice (city of Toronto, Ontario, and Manitoba Infrastructure & Transportation, Canada).
- Produced a statewide SMP that dictates the documentation of salt usage data by (maintenance) shop, snow route, and truck in an effort to identify both champions and excessive salt users; intensified best practices training for shop managers and front-line forces; joined MDSS Pooled Fund Study; performed post-storm reviews; and increased anti-icing and pre-wetting (practices) (Maryland DOT).

Additional Resources for Salt Management Plans

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STAFF TRAINING

Winter maintenance staff and personnel training is of particular importance for the effective and efficient use of chloride

roadway deicers. The success of winter maintenance operations often hinges on changing the daily practices and perceptions about chloride deicer usage and updating the related value system and workplace culture. Such changes often require the personnel at different levels, including managers, supervisors, operators, and hired contractors, to learn new ideas, technology, and skills, and to accept and implement new approaches. Research has suggested that only 20% of the critical skills are obtained through training, whereas the remaining 80% is learned on the job (TAC 2003b).

A comprehensive training program is recommended to demonstrate the purpose and value of new procedures, address resistance to change, and ensure competency of personnel carrying out their duties. The training can also focus on using less deicer without compromising public safety or mobility. The TAC (2003b) training components include the following:

- A needs assessment of the staff.
- Considering who to train and how best to convey the information to an audience and maximize the learning (e.g., verbal/visual aids, group discussion, practical application).
- Designing the training program to identify the learning goals, components, and logical progression, and develop a lesson plan.
- Determining the training methods (e.g., in class, in field, post-storm debriefing).
- Potentially having a current staff member trained to train other staff, so as to add credibility and provide opportunity for follow-up questions and feedback.
- Evaluation of the training program (including training material implementation).
- Assessing how much transfer of training occurred and the need for refresher courses.

The first step of training is to identify the learning goals; for example, LOS guidelines, principles of ice formation, chemistry of road salts, and the environmental impacts of road salts. Annual training close to the onset of the snow and ice season is desirable in order to ensure current learning goals are taught, reinforced, and tested. The level of comprehension of the learning goals and compliance should be monitored throughout the snow and ice season. Refresher sessions are strongly recommended to reinforce the learning goals (TAC 2003b). The power of positive messaging has been proven effective in mitigating the adverse effects associated with adult training. For instance, using statistical data to provide regular feedback to operators, such as posting annual material or cost savings, can reinforce the importance of their efforts. Operators are encouraged to share information, experiment with new concepts, and challenge old ideas (TAC 2003b).

The important role of technology in staff training has been validated by agencies. One powerful training tool is computer-based training, developed under the leadership of AASHTO and for the winter maintenance staff in state and local governments. The course consists of several lessons of about 40 units, covering several winter roadway management topics (http://sicop.transportation.org/Documents/CBT_Flyer_v2b%5B1%5D.pdf). The computer-based training was updated with the latest research and operational techniques by 2010 and was converted to a web-based application in 2012 (Lee Smithson, personal communication, Sep. 14, 2012). Another advanced tool for training is the high-fidelity simulator, which has been utilized to enhance the performance of Utah DOT maintenance operators (snowplow drivers). In such a simulator, different scenarios have been developed to address the DOT user needs in managing incidents and to customize the training program. Overall, the simulator training was found to decrease the accidents ratio and reduce cost and fuel usage when the performance of simulator trainees was compared against that of a control group (CTC & Associates 2008).

In this synthesis work, the survey respondents identified annual operator training and "snow universities" as an important tool to reduce the impacts of chloride deicers on the natural environment. Many survey respondents agreed that the training helped their state or agency to mitigate or reduce the impacts of chloride deicers. Some of the responses are given below as an example:

- We have reduced the amount of salt in traction material and increased our training to educate the operators (Pennsylvania DOT).
- Through ongoing operator training, equipment calibration, and improved delivery systems focusing on placement and retention of product. Our 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 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).

Additional Resources for Staff Training

Smithson, L.D., "Achieving Technology Transfer with Interactive Computer-Based Training," presented at SIRWEC 2006 XIII International Road Weather Conference, In the *Proceedings SIRWEC 2006, Applied Research Lectures*, Turin, Italy, Mar. 25–27, 2006, pp. 164–169.

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Training*," TAC, Ottawa, ON, Canada, Sep. 2003b [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-2.pdf.

Transportation Association of Canada (TAC), TAC, Ottawa, ON, Canada [Online]. Available: http://www.tac-atc.ca/.

MONITORING AND RECORD KEEPING

To facilitate deicer environmental management, environmental parameters relevant to chloride deicers must be monitored, with good records kept on deicer applications. Such data will greatly assist the understanding of deicer migration from work sites (or roadways) to the surrounding fields and downstream. Good practices of equipment calibration, deicer monitoring, and record keeping will also aid in assessing the extent of deicer impacts and the effectiveness of mitigation measures. The maintenance agency may document the following data on a regular basis:

- Salt stored under cover
- Storage sites with collection and treatment of wash water and drainage
- Inspection and repair records
- Stockpiling records
- Brine production quality control (e.g., concentrations)
- Pavement temperature trends in daily logs, along with pavement conditions, weather conditions, and winter treatment strategy (TAC 2003d).

To enable benchmarking, the maintenance agency may also consider obtaining a baseline condition of the working sites and surrounding areas before the deicer application. This will provide a reference for future monitoring and comparisons. The amount of material used during the year should be monitored. Advanced sensing devices (e.g., weight-in-motion or scale sensors) for truckload tracking can be combined with the routine monitoring to provide more accurate information for operators and managers (TAC 2003g). The maintenance agency may report the following activities or conditions:

- Total length of road on which salt is applied
- Winter severity rating
- Total number of events requiring road salt application during the winter season
- Materials usage (e.g., total quantity of road salts used)
- Description of non-chloride materials used for winter road maintenance
- State of calibration equipment
- Average chloride concentration and frequency of sampling at each sampling location, if available (*Highway Deicing Task Force Report 2007*).

A major component of deicer monitoring is the monitoring of chloride levels in roadways and in water bodies. Although it is not practical for most road authorities to monitor the chloride level in all the stormwater runoff from roadways, salt-vulnerable areas at least should be monitored. A good example comes from a municipality in Canada that worked with a local conservation authority to add chloride sensors to the stream monitoring network. Water monitoring can be complicated and the following issues may be examined before initiating a monitoring program (TAC 2003d):

- At what frequency will samples be collected?
- Will sampling be continuous or periodical?
- Will the data be communicated back to a central location automatically?
- What power and telephone capabilities for data communication will be needed at the sampling location?
- Are any confounding data present, such as chlorides entering the environment from other sources (private use or private contractors, water softeners, landfills, etc.)?

Data obtained from the deicer monitoring and record keeping can be used to determine whether and how a particular measure (e.g., new winter maintenance technique) or event affects the natural environment (e.g., chloride levels in the aquatic environment). According to the TAC (2003g, p. 11), "specific staff should be tasked with monitoring what is brought onto each site, what is being discharged from the site, any onsite or downstream contamination and environmental impacts."

Many survey respondents recognized the importance of good practices in deicer monitoring and record keeping. Some of the responses are given below as an example:

- Monitor more than 100 sites statewide for chloride loading every spring and fall (Washington DOT).
- Have a couple of projects starting to track chlorides in the water and mitigation opportunities (Ministry of Transport of Ontario, Canada).
- Monitor wells at each maintenance facility and an Environmental Management Plan for chlorides (Alberta, Canada).
- In an effort to monitor salt usage rates, installed AVL equipment on a sample of 20 trucks (Kentucky DOT).
- Efforts made in the past 5 years include capturing salt usage data by shop, snow route, and truck in an effort to identify both champions and excessive salt users, auditing of salt usage (Maryland DOT).
- Maintenance management accounting system to monitor materials usage and application rates (New York DOT).
- Monitor our salt storage sites. Our goal is to reduce rain and surface water contact with salt storage piles (Ohio DOT).

Additional Resources for Monitoring and Record Keeping

Anderson, B., "Measuring Winter Maintenance—What's Behind the Numbers?" prepared for the 2004 Annual Conference of the Transportation Association of Canada, Quebec City, Quebec, 2004 [Online]. Available: http://transportationassociation.ca/english/resourcecentre/readingroom/conference/conf2004/docs/s17/anderson.pdf.

Environment Canada, *Code of Practice for the Environmental Management of Road Salts*, EPS 1/CC/5, Environment Canada, Gatineau, QC, Canada, Apr. 2004 [Online]. Available: http://www.ec.gc.ca/nopp/roadsalt/cop/pdf/1774_EngBook_00.pdf.

Perera, N., B. Gharabaghi, and P. Noehammer, "Stream Chloride Monitoring Program of City of Toronto: Implications of Road Salt Applications," *Water Quality Research Journal of Canada*, Vol. 44, No. 2, 2009, pp. 132–140.

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Drainage and Stormwater Management*, TAC, Ottawa, ON, Canada, Sep. 2003d [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-4.pdf.

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Pavement and Salt Management*, TAC, Ottawa, ON, Canada, Sep. 2003e [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-5.pdf.

ANTI-ICING, DEICING, AND PRE-WETTING PRACTICES

A successful highway winter maintenance program requires appropriate selection of chemicals for snow and ice control, the right equipment, well-trained staff, informed decisions, and proper execution of strategies and tactics (e.g., anti-icing, deicing, pre-wetting). Over the past two decades, maintenance agencies in North America have gradually moved from the use of abrasives to the use of more chemicals (Staples et al. 2004). The detrimental environmental impacts of abrasives generally outweigh those of chlorides, and the use of abrasives requires at least seven times more material than salt to achieve a comparable LOS (Nixon 2001). Abrasives, especially those not pre-wetted, have limited effectiveness on roads with higher vehicle speeds (CTC & Associates 2008). Rochelle (2010) evaluated various deicers in the laboratory and found that "the presence of chemical, regardless of chemical type, increased the friction of the pavement surface and reduced the shearing temperature as compared to non-chemically treated substrates for all pavement types, all application rates and all storm scenarios" (p. xiii). A combination of salting and snowplowing is considered the best practice for snow and ice control.

In more recent years, there has been a transition from mostly deicing to anti-icing wherever possible (O'Keefe and Shi 2005). As illustrated in Figure 3, anti-icing is the proactive application of chemicals (freezing-point depressants) to prevent the bonding of ice to the pavement (or prevent black ice formation), whereas deicing is the reactive application of chemicals to break the ice-pavement bond. Relative to deicing and sanding, anti-icing leads to improved LOS; reduced need for chemicals, abrasives, or plowing; and associated cost savings and safety and mobility benefits (Hossain et al. 1997; Kroeger and Sinhaa 2004; Conger 2005; O'Keefe and Shi 2005). Russ et al. (2007) developed a decision tree for liquid anti-icing for the Ohio DOT, which aimed to help maintenance supervisors consider a number of factors, including current road and weather conditions, the availability of maintenance personnel, and the best treatment strategy. Russ et al. (2007, p. 114) concluded that "if there is forecast winter weather likely to affect driving conditions… [and] there is no or very little salt residue on the road, pretreatment is recommended, except under the following conditions: (a) pretreatment would be rendered ineffective by weather conditions or (b) blowing snow may make pretreated roads dangerous."

FIGURE 3 Anti-icing (*top*) and deicing operations (*bottom*) (*Courtesy*: Wisconsin and Kansas DOTs, respectively).

Furthermore, a recent study (Peterson et al. 2010) sponsored by Clear Roads synthesized the current practices of during-storm direct liquid applications (DLA) and found DLA to be "a valuable asset for the winter maintenance toolbox." The identified benefits of DLA include reduced application rates, reduced loss of materials, faster post-storm cleanup, quick effect, further prevention of bonding, expanded toolbox, accurate low application rates, reduced corrosion effects, and leveraging proven benefits of liquids. In a case study, the shift from using rock salt to brine for deicing led to roughly 50% materials savings, as the standard application rate of rock salt and salt brine was 250 pounds and 50 gallons per lane mile, respectively, and 1 ton of rock salt makes about 1,000 gallons of brine (Dave Frame, CalTrans, personal communication, Apr. 5, 2012).

Depending on the road weather scenarios, resources available and local rules of practice, agencies use a combination of tools for winter road maintenance and engage in activities ranging from anti-icing, deicing (including direct liquid or slurry applications), and sanding (including pre-wetting), to mechanical removal (e.g., snowplowing) and snow fencing. When the pavement temperature drops below −12.2ºC (10ºF), salt is no longer cost-effective, and agencies thus utilize other chemicals either alone or as pre-wetting agent to enhance the performance of salt (Ohio DOT 2011) or apply abrasives to provide a traction layer on pavement. Pre-wetting is defined as the approach of adding liquid chemicals to abrasives or solid salts to make them easier to manage, distribute, and stay on roadways. Pre-wetting has been shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required (Hossain et al. 1997). Pre-wetting is preferable to the application of dry salt to roadways, which is susceptible to the effects of wind, traffic, and bounce before it can actively melt snow and ice. In a case study, the use of brine to pre-wet salt allowed for a 15% reduction in product usage, as the pre-wetted salt exhibited equivalent ice melting performance, better adherence to the road surface, and less loss and scatter (Peter Noehammer, Toronto, personal communication, Mar. 28, 2012). Dahlen and Vaa (2001, p. 34) found that "by using heated materials or adding warm water to the sand it is possible to maintain a friction level above the standard, even after the passage of 2,000 vehicles."

Owing to the diversity in chemical products, pavement surfaces, traffic, and other conditions, there is still a lack of consensus in the appropriate application rate for a specific road weather scenario, which hinders the optimal use of chloride roadway deicers. *NCHRP Report 577* provided guidelines for the selection of snow and ice control materials, including anti-icers, deicers, and abrasives (Levelton Consultants 2007). Depending on the pavement temperature, an anti-icer rate of 65 to 400 pounds per lane mile was recommended. For deicers, an application rate of 200 to 700 pounds per lane mile was recommended. For abrasives (pre-wet, dry, or mixed with road salt), an application rate of 500 to 600 pounds per lane mile was recommended. Such guidance was based on information provided by Blackburn et al. (2004) and Wisconsin Transportation Information Center (1996). FHWA provides guidance on the application rate of anti-icing materials, including liquid chemicals, solids, and pre-wetted solids, in its *Manual of Practice for an Effective Anti-icing Program* (Ketcham 1996). This guidance covers four types of storm events: light snow, light snow with periods of moderate or heavy snow, moderate or heavy snow, and frost or black ice. The suggested application rates (e.g., 100 pounds per lane mile) varied as a function of chemical type, pavement temperature and its trend, and other factors. The Salt Institute (2007) provided guidelines for salt application in *The Snowfighters Handbook: A Practical Guide for Snow and Ice Control*. Depending on weather, road surface and temperature conditions, recommended application rates ranged between 100 and 400 pounds per lane mile. When salt-treated abrasives were employed, a range of 750 to 1,000 pounds per lane mile was recommended.

For anti-icing, the application rate of chemical products may significantly affect the skid resistance on asphalt pavement. In some cases, too high an application rate can lead to a reduction in the coefficient of friction of pavement (Leggett and Sdoutz 2001).

The following are the survey responses from this synthesis work pertinent to operational strategies:

- Increasing costs have resulted in new strategies that include (1) improved targeting of known roadway problem areas, (2) conversion to salt brine, and (3) more pre-wetting in sand applications (Alaska DOT).
- The Ministry of Transport of Ontario uses the TAC Best Management Practices including reduced salt application rates with pre-wet or pre-treated salt, direct liquid application (Ministry of Transport of Ontario, Canada).
- Currently, pre-wet is being used for all of our snowplow trucks to seek to reduce usage. The pre-wet brines help keep the material on the road especially with wind and traffic trying to carry it off the highway (Alberta, Canada).

Additional Resources for Anti-icing, Deicing, and Pre-wetting Practices

Burtwell, M., *Transportation Research Circular Number E-C063: Deicing Trails on UK Roads: Performance of Prewetted Salt Spreading and Dry Salt Spreading*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-063), Spokane, Wash., June 7–9, 2004, pp. 564–584.

CTC & Associates, LLC, *Anti-icing in Winter Maintenance Operations: Examination of Research and Survey of State Practice*, Transportation Research Synthesis 0902,

Minnesota Local Road Research Board, May 2009 [Online]. Available: http://www.lrrb.org/pdf/trs0902.pdf.

Federal Highway Administration (FHWA), *Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel*, FHWA-RD_95-202, June 1996 [Online]. Available: http://www.fhwa.dot.gov/reports/mopeap/eapcov.htm.

Hunt, C.L., G.F. Mitchell, and W. Richardson, *Transportation Research Circular E-C063: Field Persistence of Anti-Icing Sodium Chloride Residuals*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-049), Spokane, Wash., June 7–9, 2004, pp. 609–624.

Luker, C., B. Rokosh, and T. Leggett, *Transportation Research Circular E-C063: Laboratory Melting Performance Comparison: Rock Salt With and Without Prewetting*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-032), Spokane, Wash., June 7–9, 2004, pp. 585–601.

Nixon, W. and A.D. Williams, *A Guide for Selecting Anti-icing Chemicals*, Version 1.0.IIHR, Technical Report No. 420, 2001[Online]. Available: http://dot.alaska.gov/stwddes/research/assets/pdf/anti_icing_guide.pdf.

Nixon, W.A., G. Kochumman, J. Qiu, L. Qiu, and J. Xiong, *Transportation Research Circular E-C063: Role of Performance Specifications in Developing a Quality Control System for Winter Maintenance*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-046), Spokane, Wash., June 7–9, 2004, pp. 555–563.

O'Keefe, K. and X. Shi, *Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America*, Final Report, prepared for the Pacific Northwest Snowfighters Association in Collaboration with the Washington State Department of Transportation, Olympia, Aug. 2005.

Smithson, L.D., *Transportation Research Circular E-C063: Proactive Snow and Ice Control Toolbox*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-061), Spokane, Wash., June 7–9, 2004, pp. 153–157 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.

Strategic Highway Research Program (SHRP), *1999–2000 Technology and Usage Survey Results: Anti-icing Techniques and Road Weather Information System Technology*, Anti-icing/RWIS Lead States Team, Transportation Research Board of the National Academies, Washington, D.C., May 2000.

Thompson, G.E., *Transportation Research Circular E-C063: Anti-Icing and Material Distribution Performance Measures for Achieving Level of Service Through Mobile Data Collection*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-004), Spokane, Wash., June 7–9, 2004, pp. 503–515 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.

WEATHER FORECASTING AND ROAD WEATHER INFORMATION SYSTEMS

Weather observations and forecasts are important inputs for developing more effective and efficient treatment strategies in winter maintenance operations such that the optimal amount of chloride roadway deicers are used and their environmental footprint is minimized. Accurate weather forecasts and data help to minimize the need for chlorides while allowing for the same, or better, level of service to be provided. Weather information may be gathered from a variety of sources such as free weather services, private-sector weather forecast services, RWIS, public-sector weather services (or mesonets), and decision support systems, each providing distinctive levels of detail in weather information. Accurate weather information must be obtained and used to meet winter road maintenance challenges (Ohio DOT 2011). Near-real-time weather and road condition information and customized weather service are valuable to the success of proactive maintenance strategies (Shi et al. 2007a; Ye et al. 2009c). When considering the choice between spatially or temporally improved forecasts, Fu et al. (2009) found that improved spatial resolution of forecast data would provide greater expected benefit to service levels.

Mesonets are regional networks of weather information that integrate observational data from multiple sources to provide a more comprehensive and accurate picture of current weather conditions (Shi 2010). Current mesonets include Washington State's rWeather, University of Utah's MesoWest, Iowa's WeatherView, and California's WeatherShare. Working in partnership with federal, state, and local governments as well as with several Canadian provinces, the *Clarus* Initiative developed a road weather observation network that provides integrated and quality-checked atmospheric and pavement observations from mobile and fixed platforms; after running successfully for several years on a research and development platform, the system in now being transitioned to the National Weather Service where it will be integrated into the Meteorological Assimilation Data Ingest System, where its functionality will be streamlined into an operations environment (Pisano et al. 2005a, b, 2008). These data management systems are expected to maximize availability and utility of road weather observations and facilitate more accurate, route-specific forecasting of road weather conditions.

Shi and colleagues (2007b) examined the labor and materials costs in the 2004–05 season for 77 Utah DOT winter

maintenance sheds and established a neural network model to treat the shed winter maintenance cost as a function of weather service usage, evaluation of DOT weather service, level-of-maintenance, seasonal vehicle-miles traveled, anti-icing level, and winter severity index. The model estimated the value and additional saving potential of the DOT customized weather service to be 11%–25% and 4%–10% of the DOT labor and materials costs for winter maintenance, respectively. The risk of using the worst weather service providers was estimated to be 58%–131% of the DOT labor and materials costs for winter maintenance. The Utah DOT Weather Information Program was estimated to feature a benefit–cost ratio of 11:1.

Ye et al. (2009b, 2009c) conducted case studies to analyze the benefits and costs associated with the use of weather information for winter highway maintenance. The survey of winter maintenance personnel found that free weather information sources, private-sector weather providers, and RWIS were the most widely used weather information sources. Air temperature, wind, and the type and amount of precipitation were primary parameters of current and forecast weather conditions, whereas road weather elements (e.g., pavement temperature, bridge temperature, pavement conditions) were also widely used in winter maintenance. The case studies collectively showed that winter maintenance costs decreased as the use of weather information increased or its accuracy improved. Table 1 summarizes the benefits and costs associated with weather information for winter maintenance. The study (Ye et al. 2009c) recommended the use of weather information to be more focused on the road environment, in order to develop better winter maintenance strategies. In addition, the maintenance agencies should continue to invest in road weather information with high accuracy (such as RWIS and customized weather service) and to ensure high usage of the existing road weather information services.

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. 1993a, b). 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) found that Alaska's benefits from RWIS usage included reduced staff overtime, less misdirected staff time, fewer wasted materials and equipment, and improved roadway LOS. Figure 4 shows an RWIS installed in the Kansas roadway environment.

FIGURE 4 RWIS (*Courtesy*: Kansas DOT).

TABLE 1
CASE STUDIES OF WEATHER INFORMATION OF WINTER HIGHWAY MAINTENANCE

Case Study State	Winter Season	Winter Maintenance Cost ($ 000s)	Benefits ($ 000s)	Weather Information Costs ($ 000s)	Benefit–Cost Ratio	Benefits/ Maintenance Costs (%)
Iowa	2006–07	14,634	814	448	1.8	5.6
Nevada	2006–07	8,924	576	181	3.2	6.5
Michigan	2006–07	31,530	272	7.4	36.7	0.9

Source: Ye et al. (2009c).
Note: The analysis considered agency benefits but excluded benefits to motorists, society, and the environment.

The following are the survey responses from this synthesis work pertinent to weather forecasting and RWIS:

- Currently have 18 RWIS sites with sensors that give the chemical factor and thus help us to avoid the over-application of salt when we do have a winter storm event (South Carolina DOT).
- Currently have 49 fixed road weather stations and more than 140 mobile road weather stations are made available to decision makers. Training sessions were held and more will be held over the coming years so that users can use the devices to their full potential (Quebec, Canada).
- Have reduced chloride use by storm intensity/duration forecasting (Utah DOT).
- Road weather stations were implemented first as tools to help decision makers better plan operations. If the operations are better planned, it is possible to reduce the amount of road salts spread by using other technologies or other materials or simply to spread the right amount at the proper time (Quebec, Canada).

Additional Resources on Weather Forecasting and RWIS

Ballard, L., *Transportation Research Circular E-C063: Analysis of Road Weather Information System Use in California and Montana*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-060), Spokane, Wash., June 7–9, 2004, pp. 190–207.

Conger, S.M., *NCHRP Synthesis 344: Winter Highway Operations*, Transportation Research Board of the National Academies, Washington, D.C., 2005, 74 pp. [Online]. Available: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_344.pdf.

Ericksson, D., *Transportation Research Circular E-C063: Reducing Salt Consumption by Using Road Weather Information System and Mesan Data*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-058), Spokane, Wash., June 7-9, 2004, pp. 278–281.

Ketcham, S.A., et al., *Test and Evaluation Project 28: Anti-icing Technology, Field Evaluation Report*, FHWA Report RD-97-132, Federal Highway Administration, Washington, D.C., Mar. 1998.

Mitchell, G.F., W. Richardson, and A. Russ, *Evaluation of ODOT Roadway/Weather Sensor Systems for Snow & Ice Removal Operations/RWIS Part IV: Optimization of Pretreatment or Anti-icing Protocols*, Final Report, prepared for Ohio Department of Transportation and FHWA, Nov. 2006.

Strategic Highway Research Program (SHRP), *1999–2000 Technology and Usage Survey Results: Anti-icing Techniques and Road Weather Information System Technology*, Anti-icing/RWIS Lead States Team, Transportation Research Board of the National Academies, Washington, D.C., May 2000.

Strong, C. and L. Fay, *RWIS Usage Report*, Final Report prepared for the Alaska Department of Transportation and Public Facilities Division of Program Development, Juneau, Sep. 2007 [Online]. Available: http://www.westerntransportationinstitute.org/documents/reports/4W1526_Final_Report.pdf.

Zwahlen, H.T., A. Russ, and S. Vatan, *Evaluation of ODOT Roadway/Weather Sensor Systems for Snow and Ice Removal Operations Part I*: RWIS, Russ College of Engineering and Technology, Ohio University, Athens, 2003.

SNOWPLOWS

This section presents information on snow and ice control equipment but with a focus on snowplows, whereas dispensing technologies (or road salt/sand equipment) such as vehicle-mounted spreaders are discussed in the next section and integrated technologies are discussed in chapter five. Maintenance agencies have identified and validated advances in equipment and technology that are considered effective practices of winter road maintenance. Advanced equipment technologies can make maintaining winter roadways more efficient, safer, less costly, and environmentally friendly. Additionally, advanced equipment technologies help to minimize the need for chlorides while allowing for the same, or better, LOS to be provided.

The use of advanced winter maintenance equipment and technologies has increased throughout the United States and Canada since the time the SHRP began funding research in new areas of winter maintenance technology (SHRP Project H-207 and SHRP Project H-208) and the International Winter Maintenance Technology Scanning Review was completed in 1998. Highway agencies have been under increasing pressure to conduct timely and environmentally responsible snow removal operations, generally without a corresponding increase in staffing or fiscal resources. Consequently, when a new piece of equipment becomes available, highway agencies should determine whether it can improve their operations, reduce their material usage, or lower their ongoing expenditures. For instance, Figure 5 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). The pre-wetting at approximately 7 to 10 gallons of brine per each ton of salt has been successful.

According to the TAC (2003i, p. 2), “winter maintenance equipment, once optimized, can help an organization meet the 4-R’s of salt management: the Right Material;

FIGURE 5 Ohio DOT pre-wetting equipment.

the Right Amount; the Right Place and the Right Time." Winter maintenance equipment and technology can be categorized into three groups: equipment for mechanical snow/ice control (snowplows, snow removal/disposal equipment); equipment for applying road salts or abrasives (spreaders, electronic spreader control, calibration equipment); and operational support equipment (material usage monitor, materials loading/handling equipment, brine supply equipment). The snow removal/disposal equipment is used to remove the piled snow containing salt or other road pollutants in an appropriate manner. *The Synthesis of Best Practices in Snow Storage and Disposal* (TAC 2003h) provides more information.

Mechanical snow/ice control equipment mainly includes: snowplowing vehicles (trucks, motor graders, loaders, and snowplows with cutting edge), and snow removal/disposal equipment (loading, hauling and dumpling equipment and snow blowers). There are various types of snowplows: front-mounted one-way plows that move the snow to the right only, front mounted reversible plows and "v" shaped plows, wing-plows, underbody plows, and vertical plows, to name a few. Figure 6 shows (a) standard plow truck with front-mount Gull-Wing plow and right-hand mid-body mount wing plow; (b) reversible straight blade snowplow with right- and left- hand wing plows; (c) tandem axle plow truck with front reversible straight blade snowplow and mid-body mount right-hand wing plow; and (d) triple-axle plow truck with 10-cubic-yard spreader and 350-gallon pre-wetting tanks and tow plow in action.

The technologies for snowplows are constantly evolving, ranging from low-tech calibrated spreaders, to multi-purpose trailers (Kroeger and Sinhaa 2004), to high-tech vehicle guidance systems. Lannert (2008) discussed the use of wider front plows to clear one 12-ft lane in one pass in Missouri using a 14-ft-wide plow. The cost of this conversion was less than $400 per foot of plow. The benefits obtained from this practice included a reduction in the number of passes needed, saved fuel, and reduced labor. The use of trailer plows was also discussed, which produced the benefits of one snowplow truck and operator clearing more than 24 feet of lane at high speeds while reducing fuel usage through the elimination of multiple plows. The author noted that tow plows also can reduce an agency's capital investment needs by 20% to 30% and still achieve the same amount of work. Macfarlane (2001) discussed the use of a plow truck equipped with a reversible plow

(a)

(b)

(c)

(d)

FIGURE 6 Various plow trucks (*Courtesy*: Utah DOT).

and wing. Dedicated left-hand cast plows and wings lack flexibility because they are only used on multilane, wide-median highways. A better solution is the use of a reversible plow and switchable wing mounting. The New Brunswick DOT tried this in 1995 and found several benefits, including improved plowing efficiency and equipment versatility, reduced run-up collisions, and operators of plows having improved visibility. Recent work has also quantified visibility improvements from deflectors placed over snowplow blades (Thompson and Nakhla 2002). Additionally, previous work investigating the development of moldboards indicated that energy consumption could be reduced through the effective use of such attachments (Pell 1994). Vehicle guidance and collision avoidance systems have been used to assist snowplow drivers in low visibility conditions. This technology appears to be most beneficial on high-volume roads that experience frequent road closures from winter weather (Cuelho and Kack 2002). It also is possible to couple plowing and spreading such that there is less need to spread chemicals for snow and ice control, thus reducing the salt footprint.

When survey respondents were asked if their state or agency has implemented any tool, techniques, practices, or strategies to reduce the impacts of chloride deicers, many respondents stated that they were working on annual or better calibration of equipment (e.g., adding ground speed controllers to salt trucks), or training on how to calibrate the equipment.

Additional Resources for Snowplows

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Winter Maintenance Equipment and Technologies*, TAC, Ottawa, Ontario, Sep. 2003i [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-9.pdf.

Veneziano, D., L. Fay, Z. Ye, D. Williams, and X. Shi, *Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations*, Final Report, prepared for the Wisconsin Department of Transportation and the Clear Roads Program, Madison, Sep. 2010a.

VEHICLE-MOUNTED SPREADERS

Advances in dispensing technologies (e.g., vehicle-mounted spreaders) may greatly reduce the amount of chloride deicers used for winter maintenance without sacrificing the LOS. To meet diverse user requirements, manufacturers provide different spreader types, which include hopper spreaders (see Figure 7), tailgate spreaders, reverse dumping spreaders, and other new types of spreaders. In the winter road maintenance context, "spreading operations are directed at achieving three specific goals…: anti-icing, deicing, and traction enhancement...the selection of the appropriate spreading operation is based on economics, environmental constraints, climate, level of service, material availability, and application equipment availability" (TAC 2003i).

FIGURE 7 Snowplows with hopper-type spreaders (right lanes) and "all-liquid" truck (center lane) (*Courtesy*: Utah DOT).

According to a recently completed Clear Roads study (Blackburn 2008), "automatic control of material application rates is achieved with ground-speed-oriented controllers… [in this study], actual salt, abrasive, and pre-wetting liquid chemical dispensing rates from spreader trucks with various types of manual and ground-speed-controller units were investigated and documented from both a yard study and in simulated field settings that would be used during winter storm events." Figure 8 shows a spreader controller, which "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, p. 4).

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 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.

FIGURE 8 A spreader controller.

In the third phase of the Highway Maintenance Concept Vehicle (HMCV) project, a decision matrix was developed to automatically control the spreading of chemicals based on the information available (air temperature, pavement temperature, road friction, type and application rate of salt or sand) (McCall and Kroeger 2001). This prompted the fourth phase of the HMCV project that investigated the feasibility of integrating geo-location data, on-board sensor devices, and friction measurements with an automatic material spreader system. It was also mentioned that a rule-based algorithm using the *FHWA Manual of Practice for Snow and Ice Control* guidelines will be coded into an application capable of controlling the material distribution (McCall and Kroeger 2001).

In addition, hoppers configured to allow the snowplow to carry and spread both liquid and granular materials in different amounts are becoming more common, especially in areas sensitive to certain chemicals and materials. As shown in Figure 9, 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 2005).

Another patented technology is a surface condition sensing and treatment system, which includes an electromagnetic radiation transmitter used to determine one or more characteristics of a road surface such as friction, ice or snow, and freezing point temperature as well as depth, density, and composition of the road surface material. The system also comprises a geographic information system (GIS), 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 may be controlled both remotely and locally, and the data may be transmitted, received, and processed. The researcher indicated that the entire system may also have a vehicle-mounted application (Andrle et al. 2002).

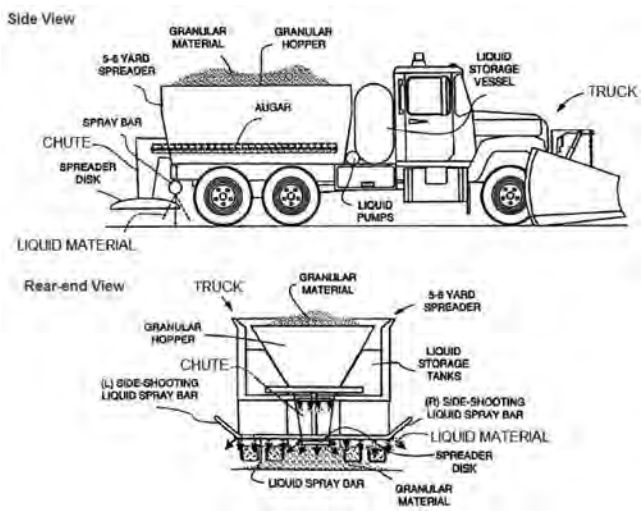

FIGURE 9 A system for synchronized application of a plurality of materials (solid or liquid) (McCall and Kroeger 2001).

In this synthesis work, when survey respondents were asked if their state or agency has made any effort to mitigate or reduce the impacts of chloride deicers, some of the following responses were provided:

- Thru ongoing operator training, equipment calibration, and improved delivery systems focusing on placement and retention of product. Our goal is to apply only the amount of product necessary to meet our needs (Montana DOT).
- Increasing the number of closed loop spreader control systems on our fleet with AVL/GPS. Offering a "Green Incentive" for our winter plow vendors to install similar AVL closed loop spreader controls (Massachusetts DOT).

Additional Resource for Vehicle-Mounted Spreaders

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Winter Maintenance Equipment and Technologies*, TAC, Ottawa, ON, Sep. 2003i [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-9.pdf.

ROADWAY AND PAVEMENT DESIGN

Good roadway design can help reduce the amount of snow and ice accumulated on the pavement, improve the performance of snow and ice control chemical, minimize the chemical usage for the same or better LOS, and thus reduce environmental impacts. Elevated road surfaces are common not only for drainage and visibility but for reducing snow drift. Road cuts are notorious for accumulating blowing snow. Roadway design and snow fences are important tools to consider especially in open and windy areas (Dan Williams, Montana DOT, personal communication, Sep. 6, 2011). According to the TAC (2003e, p. 8), "a good crossfall on any pavement will…keep the chemicals on the road longer…Higher slope percentages tend to shed snow and ice control liquids more quickly, such that a 2% crossfall is preferred to a 3% crossfall. Poor road design and poor crossfall as a result of deterioration of the pavement necessitates broadcast spreading, leading to greater loss of chemicals to the adjacent environment." TAC (2003c) has discussed basic principles to consider in planning and designing of roadway and bridge facilities for minimizing snow and ice buildup.

A desirable alternative to chemical usage for snow and ice control is pavement layers designed to reduce the bond of ice to pavement or to prevent or treat winter precipitation. These range from antifreezing pavements that rely on physical action, to high-friction in situ anti-icing polymer overlays, to asphalt pavements containing anti-icing additives, to heated pavements. Pavement treatments may be used alone or in combination with other strategies for winter highway maintenance operations. In light of cost considerations, they are most suitable for critical highway locations such as bridge decks, mountain passes, sections prone to frost and/or sensitive to chemicals, and locations featuring drastic changes in road conditions. Relative to the fixed anti-icing spray technology discussed in chapter five, pavement treatments may exhibit higher reliability and incur less capital and maintenance costs. Takeichi et al. (2001) evaluated three types of pavement that provide antifreezing effect through rough surface texture and another eight types through pavement bending. The study found that "the pavement in which grooves were cut and filled with urethane resin…and the pavement with cylindrical or doughnut-shaped rubber embedded at regular intervals in the surface…had particularly high antifreezing effectiveness" (p. 114). These two types of pavement were installed at intersections and exhibited positive performance for pedestrians and automobiles. Textured seal coats for pavements or bridge decks have the potential to prevent dangerous icy or slippery conditions (Adams et al. 1992; Alger 2007; Nixon 2006, 2007). An example of an additive to hot-mix asphalt pavements that is intended to provide anti-icing benefits throughout the life of the pavement is composed of anti-icing chemicals (mostly $CaCl_2$) encapsulated in linseed oil, which is then incorporated in the top course. Several reports are available on the field performance of this product on pavements and, in general, the performance is still inconclusive (Burnett 1985; Maupin 1986; Kiljan 1989; Turgeon 1989). Other anti-icing additives exist that need to be considered (Lu et al. 2009), all of which aim to reduce the usage of deicers and improve the efficiency of mechanical removal.

The heating and cooling rates of pavement vary depending on the pavement type, the time of year, and air and ground temperatures. Concrete pavements, because of the light color and higher thermal mass, generally heat up and cool down more slowly than do asphalt pavements. However, concrete pavement surfaces tend to be less permeable than

aged asphalt ones, and "tend to shed brine more quickly… and may require more frequent application of snow and ice control chemicals or a great quantity based on the pavement temperature trends" (TAC 2003e). Open friction course (OFC) asphalt pavements can be used to reduce noise, improve drainage, and reduce spray, "which can be beneficial in areas that are vulnerable to salt spray" (TAC 2003e).

The TAC (2003d) advises to plan and design proper the road drainage system so as to isolate salt-laden drainage from vulnerable areas, and prevent sudden chloride pulses during spring runoff on the aquatic habitat. Site characteristics must be assessed to minimize the potential impact on "potable water taken from groundwater sources, sensitive aquatic habitats, agricultural lands, wetlands and wildlife" (TAC 2003d, p. 2) and mitigation measures must be implemented as deemed necessary. These may include sheet flow, V-ditch, storm sewer, flat bottom (trapezoidal) ditch, flat bottom (trapezoidal) ditch with storage, dry basin (pond), wet basin (pond), and buffer strip and containment berm, used individually or synergistically.

Pervious concrete has been increasingly used as a powerful tool to mitigate watershed impacts owing to stormwater runoff. It can also help mitigate the urban heat island. Pervious concrete pavements have an open network of pores to allow infiltration through the pavement with a subsequent reduction in the quantity of stormwater runoff and an improvement in water quality (McCain et al. 2010; Brown 2012). A demonstration project in Yakima, Washington (Yakima County 2012) has shown that compared with those from impervious (traditional) asphalt pavement, water samples collected from vaults in pervious concrete pavement had significantly lower biochemical oxygen demand, total suspended solids, copper, lead, zinc, #2 Diesel, and motor oil, respectively. A typical pervious concrete mix design used in the United States consists of cement, single-sized coarse aggregate (between 1″ and the No. 4 sieve), and a water/cement ratio between 0.27 and 0.43. The various mixes can feature a wide range of properties; for example, effective air voids of 14% to 31%, permeability of 35–800 in./h, and compressive strength of 800–3,000 psi (Schaefer et al. 2006). Clogging can reduce the effectiveness of pervious concrete and special maintenance techniques are generally needed to restore performance, such as sweeping and/or vacuuming (McCain et al. 2010). According to the EPA (2012), traction sand should not be applied to pervious concrete pavements, and while pervious concrete does not treat chloride or other deicers, reduced application rates are needed. Several pervious concrete sections were constructed at MnROAD (a Minnesota DOT pavement research facility) between 2006 and 2008 and have not been impacted by any sanding, salting, or plowing operations (Eller and Izevbekhai 2007; Bernard Izevbekhai, MnDOT, personal communication, Mar. 10, 2012).

Additional Resources for Roadway and Pavement Design

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Road and Bridge Design*, TAC, Ottawa, ON, Sep.2003c [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-3.pdf.

Transportation Association of Canada (TAC), *Synthesis of Best Practices, Pavement and Salt Management*, TAC, Ottawa, ON, Sep. 2003e [Online]. Available: http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-5.pdf.

VEGETATION MANAGEMENT

A healthy and mature vegetation zone along the roadway can play an essential role in preserving the soil base adjacent to the pavement and thus slow down the pavement damage. The vegetation near the roadway can inhibit or prevent the soil erosion and loss by wind and rain (Johnson 2000a). However, roadside vegetation, especially salt-vulnerable species, is also subject to the potential negative impacts of the snow and ice control chemicals and abrasives (Fay and Shi 2012). These impacts are most severe within 50 ft of the pavement, and can extend to hundreds of feet away from the roadway depending on the traffic volume and traffic speed, wind direction, and water precipitation near a particular road (Johnson 2000b).

Effective salt management will significantly benefit the vegetation management. Road salts enter the environment mainly through either salt spray or salt-laden runoff. Salt usage monitoring, record keeping, operator training, and wrapping of salt-vulnerable species before the winter are among the most effective methods. Several precautionary measures were proposed in the TAC report (2003f) to mitigate the negative impacts associated with roadway deicers. For example, four approaches were identified to minimize the negative impact when deicers were deployed in the form of the salt spray: optimizing the salt usage, selecting the right plant species, applying deicers at the right locations, and ensuring long-term survival of the vegetation. Four approaches were suggested for mitigating the salt-laden runoff: selecting plant species that are able to tolerate salt-laden runoff, avoiding heavy runoff collection areas, ensuring that the salt-laden roadway runoff is not directed to the plants, and adapting appropriate drainage designs. (More details for drainage design practices can be found in TAC 2003c.)

For effective management of roadside vegetation for local agencies, Johnson (2000a) highlighted seven effective practices identified through research, surveys, and discussion with industry experts.

1. Developing an integrated roadside vegetation management plan
2. Developing a public relations plan
3. Developing a mowing policy and improved procedures
4. Establishing sustainable vegetation
5. Controlling noxious weeds
6. Managing living snow fences
7. Adapting integrated construction and maintenance practices.

The proactive approaches include selecting the right vegetation for specific environmental and road conditions, selecting the right salt-tolerant grasses and sods/ native grasses and wildflowers, establishing effective turf establishment practices and protecting existing vegetation, optimizing deicer usage, and using eco-friendly vegetation products (Johnson 2000b).

A study by the University of Minnesota (Johnson 2000a) has identified a list of critical factors in determining the degree of roadside vegetation damage: temperature, light, humidity, wind, soil water, soil texture and drainage, and precipitation. Other critical factors include the type and condition of the roadside vegetation. Strategies to reduce salt damage should consider such factors; the cost of establishing the soil foundation and the covering turf, and the cost of maintenance and reparation, tend to define the cost-effectiveness of roadside vegetation management.

Another study (Dudley 2011) was focused on the impact of a $MgCl_2$-based deicer, a NaCl-based deicer, and the major salts contained in these deicers on seed germination and seedling growth and the development of 15 species of grasses and forbs native to Colorado. The results suggested that the salt concentration exerted a great impact on the proportions of normal and abnormal seeds and seedlings. Using species with the highest germination rate would provide the best opportunity for establishing plants along highways treated with deicing products. Planting should be done in the fall, and soil should be amended.

Reactive approaches to vegetation management that are usually practiced during or after deicer deployment include irrigation to flush salt from soil, soil treatments, vacuuming and sweeping, rejuvenation of damaged areas, and design and construction strategies. One reactive approach entails treating the soil with gypsum to reverse the effects of salt accumulation. Planting salt-resistant or alkali grass can alleviate the effects of chloride roadway deicer on adjacent soil and vegetation (Johnson 2000b).

Additional Resources for Vegetation Management

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INNOVATIVE SNOW FENCES

A properly designed and placed snow fence can be a cost-effective tool for snow and ice control for highway segments where the abundance of wind leads to blowing and drifting snow on the winter roadways. For such locations, there is a considerable risk of closing the roadways or requiring excessive plowing and chemical usage. The use of primary drift control technique (snow fence) to minimize the amount of snow blowing onto the roadway will provide a number of benefits to the public and landowners. Some of the ben-

efits include reducing blowing/drifting snow on roadways, storing snow at low cost, creating safer travel condition, and reducing the need for snow and ice control chemicals (TAC 2003f). According to Tabler (2005), "total cost for snow fence [is around] $1.39 per square feet of fence frontal area." Data from a Wyoming study shows that "storing snow with snow fences costs three cents a ton over the 25-year life of the fence, [relative] to three dollars a ton for moving it" (Tabler 1991). In the 1970s, the Wyoming DOT reduced snow and ice removal costs by more than one-third on a 45-mile stretch of I-80 where fences were installed. The fences had been effective in preventing drift formation over the 20 years since installation (Tabler 1991).

In 1991, the SHRP developed a Snow Fence Guide to cover essential information for maintenance personnel to design and locate snow fences correctly. This guide provides some helpful tips for snow fence technology. For instance, "a single row of taller fence is always preferable to multiple rows of shorter fence. The taller fence not only traps more snow, but also much more effectively improves driver visibility, costs less, and requires less land. A rule of thumb is that fences are to be at least 8 ft. (2.4 m) tall" (Tabler 1991, p. 41). For temporary fencing, "field installation of prefabricated panels requires approximately three person-hours per 100 ft. (30 m) of fence. It takes less time to install the 8-ft. (2.4-m) fence than to build a series of conventional 4-ft. (1.2-m) fences of the same storage capacity. Material and fabrication costs are comparable to costs for permanent fences." At the state level, the Wyoming DOT has conducted extensive research on snow fence technology for more than 40 years and specifications have been published (Wyoming DOT 2003).

Snow fence technology is being widely used by the state DOTs to effectively trap and control blowing and drifting snow at critical locations. Snow fencing has been proven to be a low-cost mitigation method to prevent blowing snow related accidents. It also helps by reducing maintenance costs and wear-and-tear on the winter maintenance equipment (Wyoming DOT 2009). The Iowa DOT maintains approximately 120 miles of snow fence on Iowa highways (Iowa DOT 2012a). The types of snow fences used by Iowa DOT include temporary fences (4 ft tall and made of wood or plastic), permanent fences (6 ft tall and made of wood or plastic), living snow fences (made of trees, bushes or native grasses), or standing corn snow fences (8–12 rows of corn left standing after harvest). A comparison of all available snow fence types was also given in Table 2 along with their benefits (Iowa DOT 2012b).

Engineered mitigation of blowing and drifting snow through road design and snow fences has been integrated into a software tool, which can reduce maintenance costs and closure times and enhance overall LOS by "improving visibility, preventing drifting on the road, and reducing road icing" (Chen et al. 2009).

TABLE 2
TYPE OF SNOW CONTROL

Type	Description	Advantages	Agreement Length
Structure, Permanent	Six- to eight-foot-tall fence consisting of two wooden posts, lightweight plastic fence, and 2" x 4" supports	Very low maintenance Takes up as little as 1-foot width of land	10-year minimum
Structural, Temporary	Four-foot tall portable plastic fence or wooden fence	Installed after harvest and removed before planting	Fall to Spring
Standing Corn	One section of eight to 16 rows of corn	Can reduce soil erosion Serve as wildlife habitat Public service organizations benefit from picking by hand	Fall to Spring
Living Trees, Shrubs, or Native Grasses	Two or more rows of trees or shrubs, or a combination of both	Wildlife habitat Reduces soil erosion Hunting ground	10-year minimum
CRP Living Snow Fence	Two or more rows of trees or shrubs, or a combination of both with 75- to 100-foot native grass buffer	Wildlife habitat Reduces soil erosion Hunting ground	10–15 years per CRP program guidelines

Source: Iowa DOT (2012b).

An alternative to traditional snow fences can be "living snow fences," which are trees, shrubs, and/or native grasses planted at critical locations along public travel roads or around communities and farmsteads. They are economically feasible and offer an environmentally sound solution for snow management. With living snow fences established, less salt and fewer plow and truck trips are used to keep roadways clear. Such fences can also provide wildlife habitat, control soil erosion, and help improve water quality (Minnesota DOT 2012).

A diagram of the living snow fence is provided as Figure 10 to illustrate the structure of a typical living snow fence used by the Iowa DOT Conservation Research Program (Iowa DOT 2012c). Height, density, length, and plant protection are listed as the key design elements to establish a cost-effective living snow fence. Doubling the height is believed to increase snow storage by four times and should be considered as an important economic factor in species selection. Vegetation with about 50% density will capture and store the greatest amount of snow. Conifers are preferred to plants in light of their appropriate height and year-around foliage and they can be used in combination with many deciduous trees and shrubs (USDA Forest Service 1999). The Minnesota DOT has produced a manual for design, installation, and maintenance of living snow fences, *Catching the Snow with*

FIGURE 10 Diagram of a living snow fence used by the Iowa DOT Conservation Reserve Program (CRP) (Iowa DOT 2012c).

Living Snow Fences (Gullickson et al. 1999). Minnesota also purchases crops such as standing corn to act as temporary living snow fences.

The costs and benefits of living snow fences have been compared with traditional structural snow fences. The U.S. Department of Agriculture (USDA) Forest Service (1999) listed the major advantages of living snow fence over the traditional ones as follows. Service life can be 50 to 75 years for living snow fences versus 5 to 7 years for a slat snow fence (made of wood, metal, or plastic). Slat snow fence installation and maintenance costs are 4 times greater than those for a living snow fence over a 50-year span. For living snow fences, the average cost is $3 per mile per year for each unit of snow trapped, vs. $185 per mile per year for a 4-ft slat fence. Living snow fences provide habitat for wildlife and can be designated to conserve energy for farmsteads, feedlots, and community facilities; however, they have some limitations. It takes 5 to 7 years for living snow fences to provide effective snow control and 20 years to fully mature, and new plantings should be protected from grazing. Living snow fences require more space than slat, and plant establishment is subject to site conditions (USDA Forest Service 1999). Tabler (1991) discussed one more disadvantage of living snow fences: their height and porosity and the resultant drift length and storage capacity could change with time. In a 2012 report (Wyatt et al. 2012), researchers developed a tool to help transportation managers determine the feasibility of installing a living snow fence at snow problem areas in Minnesota. The tool factors in the cost of snow and ice control, the safety benefits from reduced crashes and improved mobility, and the farmer or landowner cost of installing and maintaining a snow fence on private property. A dollar figure for each cost and benefit item is generated to aid in determining the most cost-effective sites for future installation.

Additional Resources for Innovative Snow Fences

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DESIGN AND OPERATIONS OF ROAD MAINTENANCE YARDS

Salt spillage or seepage in the maintenance yard has been a main pathway for chloride deicers entering the groundwater. According to the TAC (2003g), "good (maintenance) yard design and salt handling practices are essential to preventing unnecessary salt loss and the resultant environmental impacts." These include planning, site selection, designing a functional facility, salt storage, site drainage, site operation and maintenance, monitoring, record keeping, and training. Practical considerations include noting the prevailing winter wind direction, positioning building and doors with regard to sheltering loading operations, minimizing snow drifting around doorways, keeping precipitation out of the storage areas, using low permeable surfaces, and avoiding spillage during stockpiling and truck loading (TAC 2003g).

Solid snow and ice control product stockpiles must not be exposed to the rain or snow, and proper storage may entail the use of temporary or permanent sheds, domes, barns, or silos with the roof and exterior made of waterproof material. Solid stockpiles can be stored outside on a low permeable asphalt or concrete pad and covered with a tarp, but this is not recommended and is a short-term, temporary option. Both asphalt and concrete are somewhat permeable and need to be sealed to minimize infiltration, and floors should be inspected periodically for cracks and repaired or resealed as necessary. Containment under and around the sides of the solid stockpiles (e.g., plastic liner) is an effective way to mitigate the long term-loss of solid deicer salts. Where practical, trucks are to be loaded inside storage structures and all spills cleaned up daily (TAC 2003g).

Liquid deicer management involves both storage of liquid products and management of the brine production facility. Many local environmental regulators have specified regulations regarding placement and containment of liquid snow and ice control products, which should be carefully followed. Regardless the ownership of liquid product storage containers by the snow/ice control agency or product suppliers, adequate protection needs to be provided to prevent damages from vehicle impacts and deicer spillage. A secondary containment should be considered, either with double-walled tanks or containment dykes, with containment capacity approximately 110% to 125% of the capacity of the largest tank (TAC 2003g). For brine production facilities, particular caution must be paid to the water supply line, which needs to be insulated to prevent them from freezing damage. Periodic inspection of tanks, pumps, and pipes/hoses needs to be carried out and any leaks repaired immediately (TAC 2003g).

Maintenance yard sites should be chosen such that the drainage can be directed away from the storage areas, any down-gradient groundwater well location, and salt-vulnerable areas. The snow plowed from the site needs to be dealt with similarly to avoid the contamination by the melt water. The salt-laden water should be properly managed, either recycled for brine production or disposed at a sewage treatment facility where permitted (TAC 2003g). The reduction of site drainage can benefit from special regulations designated for the management of road maintenance yards. The recent revision of standards in Alberta, Canada, on the management of highway maintenance yards features two relevant provisions: (1) provision of covered storage for salt and freezeproofed sand and (2) provision of the management of runoff water in contact with chlorides. When designing and developing the yards, consider using an Environmental Management Plan. The yards are subjected to annual monitoring to ensure that the salt is being managed in ways that decrease the environmental impacts from the yard (Hood 2006).

The guidance for the design and operations of road maintenance yards as discussed in this section has been adapted by some road authorities. In this synthesis work, the respondents provided the following feedback:

- New patrol yards and upgrades are designed and built with enhanced environmental protection (City of Ontario, Canada).
- Improved storage of deicers, improved housekeeping at sites. Including controlling runoff from storage sites using paved aprons; loading indoors where possible (Nova Scotia Department of Transportation and Infrastructure Renewal, Canada).
- Storage facilities are designed to divert surface and rain water from entering our salt storage and cleaning up any spilled salt in our facilities (Ohio DOT).
- All of the salt and other chlorides are stored in shelters or tanks and not exposed to the weather (Alberta, Canada).
- Our salt pollution controls are in the storage of salt. We try to cover all stored salt and prevent runoff (Kansas DOT).

Additional Resources for Design and Operations of Road Maintenance Yards

Brinckerhoff, P., *Compendium of Best Management Practices for Environmental Compliance and Stewardship at Highway Transportation Maintenance Facilities*, prepared by EA Engineering, Science and Technology Inc. and

Applied Research Associates, Inc. for AASHTO Standing Committee on the Environment, Nov. 2009 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp25-25%2846%29_FR.pdf.

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Hood, T., "Salt Management in Alberta Highway Maintenance Yards," Annual Conference & Exhibition of the Transportation Association of Canada, Transportation Association of Canada, Ottawa, ON, 2006.

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Michigan Department of Environmental Quality, *Salt and Brine Storage Guidance for Road Agency Maintenance and Other Facilities*, revised Aug. 2007, Lansing [Online]. Available: http://www.michigan.gov/documents/deq/deq-ess-p2tas-bulksaltbrineguidance_267024_7.pdf.

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CHAPTER FOUR

REACTIVE MITIGATION STRATEGIES

This chapter presents information on strategies used to reduce the impacts of chloride deicers once they are in the environment. These are typically defined as structural effective practices; that is, reactive measures implemented along the roadside to physically trap salt-laden stormwater runoff and to allow pollutants to settle out, evaporate, infiltrate, or be absorbed. They are designed to treat both the velocity and the quality of highway stormwater runoff. The basic mechanisms for pollutant removal are gravity settling, infiltration of soluble nutrients through soil or filters, or biological and chemical processes (Turner–Fairbank Highway Research Center 1999).

Reactive strategies used to mitigate the impacts of chloride road deicers on the natural environment identified from the practitioner surveys and literature review and presented here include infiltration trenches and basins, detection/retention/evaporation ponds, wetland and shallow marshes, vegetated swales, and filter strips. Other reactive strategies that could mitigate environmental impacts of chloride roadway deicers, but are not discussed in this synthesis, include strategic use of salt-tolerant plants to buffer roadways and controlled release of highway runoff to mitigate spikes in deicer concentrations. The vast majority of the reactive strategies identified by survey respondents were not originally installed for this purpose; as such, their cost-effectiveness for deicer environmental management is yet to be examined and validated.

Golub et al. (2008) discussed other effective practices that can remove salt from collected runoff, including thermal distillation processes, multistage flash distillation, multiple effect distillation, vapor compression distillation, reverse osmosis, and electro dialysis. However, these will not be covered in this synthesis, as they were not identified as current practices used by the agencies surveyed and their high capital and maintenance costs hinder the implementation by highway agencies.

GENERAL CONSIDERATIONS

Knowledge of the interactions of the precipitation and the pollutants aids in selection of appropriate practices. Understanding the temporal evolution of such interactions can aid in choosing appropriate best management practices (BMPs) for a given site (Oberts 2003). Early in the spring thaw, when flow rates are lower, dissolved pollutants may be transported by lower volumes and lower velocities. At this stage, receiving waters may be more vulnerable to the impacts of these soluble pollutants. Later, suspended pollutants such as sand and chlorides may be carried by runoff with higher velocities and higher volumes that may reduce the efficiency of the reactive mitigation strategy.

For deicer environmental management, the reactive strategies reviewed in this synthesis may vary depending on the specific climate, site, and traffic conditions. The reactive strategies may be used individually or synergistically and consider the potential for contaminated water to recharge into aquifers. Field monitoring of deicer use has allowed for lessons to be learned and for the implementation of site-specific reactive mitigation strategies to be employed. According to Golub et al. (2008), "to select the appropriate structure to install, collaboration of engineering design, installation, field monitoring, analysis of monitored data and assessment of performance and effectiveness are important." Continued research is needed in understanding the fate and transport of pollutants related to snow and ice control activities and in evaluating and improving the efficiency of reactive mitigation strategies used for stormwater management, particularly those in cold regions (Denich and Bradford 2009). Section 5.3 of the *Highway Runoff Manual* provides guidance on how to select the appropriate reactive strategy for your site (WSDOT 2011).

Note that vegetation along roadsides can play a crucial role in the treatment of runoff through chemical and biological processes. Eppard et al. (1992) suggested revegetation with salt-tolerant species. Biotechnical methods suggest using a 70:30 mix of perennial rye-grass, because it shows high resistance to the toxic effects of salt, and fescue-grass when building new roads or reconstructing existing road (Baltrenas and Kazlauskiene 2009).

Additional Resources for General Considerations

Arika, C., D.J. Canelon, and J.L. Neiber, *Impact of Alternative Storm Water Management Approaches on Highway Infrastrcture: Guide for Selection of Best Management Practices—Volume 1*, Final Report prepared for Minnesota Department of Transportation, St. Paul, Feb. 2006 [Online]. Available: http://www.lrrb.org/pdf/200549A.pdf.

Environmental Protection Agency (EPA), *Erosion, Sediment and Runoff Control for Roads and Highways*, US EPA-841-F-95-009d, EPA, Washington, D.C., Dec. 1995 [Online]. Available: http://water.epa.gov/polwaste/nps/runoff.cfm.

Environmental Protection Agency (EPA), *Preliminary Data Summary of Urban Storm Water Best Management Practices*, EPA-821-R-99-012, EPA, Washington, D.C., Aug. 1999 [Online]. Available: http://water.epa.gov/scitech/wastetech/guide/stormwater/.

Golub, E., R. Dresnack, W. Konon, J. Meegoda, and T. Marhaba, *Salt Runoff Collection System*, Final Report, FHWA-NJ-2003-026, New Jersey Institute of Technology, Newark, 2008, 138 pp. [Online]. Available: http://transportation.njit.edu/nctip/final_report/SaltRunoffCollectionSystems.pdf.

Michigan Department of Environmental Quality, *Salt and Brine Storage Guidance for Road Agency Maintenance and Other Facilities*, revised Aug. 2007, Lansing [Online]. Available: http://www.michigan.gov/documents/deq/deq-ess-p2tas-bulksaltbrineguidance_267024_7.pdf.

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Roseen, R.M., et al., "Seasonal Performance Variations for Strom-Water Management Systems in Cold Climate Conditions," *Journal of Environmental Engineering*, Vol. 135, No. 3, 2009, p. 128.

Shi, X., et al., *Evaluation of Alternative Anti-icing and Deicing Compounds using Sodium Chloride and Magnesium Chloride as Baseline Deicers—Phase I*, Final Report No. CDOT-2009-1, Colorado Department of Transportation, Denver, Feb. 2009.

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Urban Storm Drainage, *Criteria Manual Volume 3—Best Management Practices, Urban Drainage and Flood Control Districts*, Denver, Colo., Nov. 2010 [Online]. Available: http://www.udfcd.org/downloads/pdf/critmanual/Volume%203%20PDFs/.

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Washington State Department of Ecology (WSDE), *Stormwater Management in Western Washington, Volume III Hydrologic Analysis and Flow Control Design/BMPs*, Pub. No. 05-10-31, Water Quality Program, WSDE, Olympia, Feb. 2005a [Online]. Available: https://fortress.wa.gov/ecy/publications/publications/0510031.pdf.

Washington State Department of Ecology (WSDE), *Stormwater Management in Western Washington, Volume IV Source Control BMPs*, Pub. No. 05-10-32, Water Quality Program, WSDE, Olympia, Feb. 2005b [Online]. Available: https://fortress.wa.gov/ecy/publications/publications/0510032.pdf.

Wyoming Department of Environmental Quality (WYDEQ), *Urban Best Management Practices for Nonpoint Source Pollution*, Point and Nonpoint Source Programs, Water Quality Division, WYDEQ, Sep. 1999 [Online]. Available: http://deq.state.wy.us/wqd/watershed/Downloads/NPS%20Program/92171.pdf.

INFILTRATION TRENCHES AND BASINS

Infiltration trenches and basins treat runoff and reduce water volume by allowing for water to infiltrate into the surrounding soil (Staples et al. 2004). Infiltration technologies require a pre-settling or pre-treatment to remove suspended solids that otherwise would clog the system and reduce the infiltration capacity. Infiltration systems may have limited potential to treat chlorides in runoff, but have been found to effectively remove fine silts, clays, and phosphorus in the Lake Tahoe region (TIRRS 2001). In Washington State, infiltration technologies including bioinfiltration ponds, ponds, trenches, vaults, and drywells are the preferred methods for flow control and runoff treatment, offering the highest level of pollutant removal (WSDOT 2011). They are preferred partially because of their ability to recharge groundwater and help maintain base stream flow, although it is difficult to successfully utilize this technology if chloride contamination is significant.

Infiltration trenches are excavated trenches filled with stone and lined with filter fabric where runoff is collected and allowed time to percolate into the soil (Staples et al.

2004). Infiltration trenches reduce runoff volume and have moderate to high ability to remove soluble pollutants in the runoff; they are suitable for salt storage facilities. They are also often sited "adjacent to roads where space is limited" (Golub et al. 2003). Figure 11 (*left*) shows a photo of a well-established infiltration trench along a roadside. According to Golub et al. (2003), "the depth of groundwater and soil type limits the use of this option. The maximum drainage area for the system cannot exceed 5 acres and not be used in an area that experiences long and cold winters because freezing of the soil prevents pollution removal." The trenches require regular maintenance (including inspection of the inlet structures), because suspended solids in runoff can clog them and cause them to fail or to require more costly maintenance such as excavation (Hayes et al. 1996).

Infiltration basins function similarly to infiltration trenches, but more closely resemble a dry pond (Staples et al. 2004). Figure 11 (*right*) shows a photo of a typical vegetated infiltration basin. Infiltration basins hold runoff, allowing for longer infiltration times; but unlike dry or wet ponds, they release runoff from storm events. Design considerations (e.g., infiltration rates and site selection) play a crucial role in the effectiveness of an infiltration basin, as regular maintenance may be required. Infiltration basins are not recommended in areas with compacted soil, high groundwater levels, or high levels of sediment in stormwater; dense vegetation, consisting of deep rooted plants at the bottom of the basin, can enhance infiltration capacity and reduce soil erosion. Infiltration basins effectively decrease the runoff volume and reduce downstream flooding, and also can remove sediment, metals, bacteria, and organics.

Additional Resources for Infiltration Trenches and Basins

Barr Engineering Company, *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practices for Cold Climates*, prepared for the Metropolitan Council, July 2001 [Online]. Available: http://www.metrocouncil.org/environment/water/BMP/manual.htm.

Hayes, B.D., T.F. Marhaba, N.W. Angnoli, and D.M. Lackey, *Evaluation of Highway Runoff Pollution Control Devices*, Final Report, NJDOT Task Order #43, Project 7620, 1996.

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DETENTION, RETENTION, AND EVAPORATION PONDS

Dry ponds remove pollutants through sedimentation or settling and can be used to remove suspended solids such as traction sand from the roadway. Dry ponds use a small amount of space and do not increase water temperature, so they can be used in areas where stream temperature will impact aquatic species such as fish (Staples et al. 2004). They

FIGURE 11 An infiltration trench (*left*) and an infiltration basin (*right*) (Photos: www.lowimpactdevelopment.org/greenstreets/practices.htm [*left*] and www.sudswales.com/types/source-control/infiltration-basins [*right*]).

are one of the least expensive runoff treatment practices per unit area, and can perform well in cold climates and remain effective during the winter. Heavy spring runoff storm events can increase the potential for scour and resuspension of accumulated sediment if this possibility is not accounted for with an appropriate forebay (Staples et al. 2004).

Dry settling ponds hold runoff for a given period of time and release it at a controlled rate so that the pond remains dry between storm events (Staples et al. 2004). They provide more volume control than water quality control. For the detention time in the pond, consider the size of the suspended solids to be removed. *Dry extended detention ponds* provide a higher level of water treatment than dry settling ponds, because they are designed to hold runoff for longer periods, which allows more particles to settle out (Staples et al. 2004). Shallower ponds with longer flow lengths tend to show greater sediment removal. Sediment removal rates of up to 60% have been observed for dry pond detention times of up to 24 hours. An additional 28% sediment removal was observed when baffles were added (Shammaa and Zhu 2001).

Wet ponds have high community acceptance, and feature low maintenance and cost requirements (FHWA 2003). They can increase water temperature, which can be detrimental to the ecosystem, but large plants or trees can be used to mitigate this impact (Staples et al. 2004). Figure 12 shows a photo of a typical wet retention pond. Wet ponds can be designed for the treatment of conventional pollutants, or be modified to enhance removal of nutrients or dissolved metals (WSDOT 2011). They generally have higher sediment removal rates than dry ponds and offer effective pollutant removal through mechanisms such as settling, nutrient uptake by plants, and biochemical processes. The effectiveness of wet ponds can be reduced in cold climates, particularly if a surface ice layer forms.

FIGURE 12 Wet retention pond. (Photo: http://rwmwd.org/).

Although only basic maintenance may be needed for a wet pond, regular inspections, particularly during the first few months of the service life, can help ensure proper performance, vegetation growth, and bank stability. Also, incorporating multiple pools of varying depths can help ensure sufficient performance during winter and spring conditions. A sediment forebay also may need to be added.

Wet settling ponds contain water even between storm events and require more area than wet or dry ponds. The permanent pool provides additional treatment of runoff, and is designed to allow runoff from a storm event to displace the volume of water held in the pond from the previous storm (Staples et al. 2004). Hydraulic residence time greatly affects the pollutant removal efficiencies, and studies have demonstrated that approximately 90% of the pollutant removal occurs between rain events. It has been determined that sedimentation removes an estimated two-thirds of trace metals and sediment within 24 hours of a rainfall event (Barr Engineering Company 2001). Wet ponds may require a large contributing watershed of at least 10 acres (Barr Engineering Company 2001). Additionally, depth to groundwater may be considered if groundwater contamination is a concern. Dry and wet settling ponds are among the most cost-effective and commonly used runoff treatment measures (Staples et al. 2004).

Wet extended detention ponds combine the qualities of both wet and dry ponds to treat runoff (Staples et al. 2004). These ponds contain a permanent pool with additional volume to hold and treat additional runoff and provide a higher level of treatment and reduce the velocity of runoff. Removal efficiencies of 60%–80% total suspended solids have been reported for various wet extended detention ponds. (Barr Engineering Company 2001). Wet extended detention ponds generally may need more area than wet or dry ponds. Wet ponds and wet extended detention ponds are not ideally suited for arid climates since greater maintenance may be needed.

According to Golub et al. (2008), "evaporation ponds can be an inexpensive method to separate the dissolved salt. The brine, collected at the maintenance facility, can be directed to an evaporation pond during active periods in the winter… The collected brine can then be evaporated in the summer period or reused on site for brine making." To facilitate the evaporation of brine in the non-winter months, a best practice is to take advantage of site topography and use a cover for the evaporation pond (Hayes et al. 1996). Meegoda et al. (2004) studied the effective practices to mitigate salt water runoff from winter maintenance yards in New Jersey and proposed the use as brine in pre-wetting. Alleman et al. (2004) investigated the reuse of wash water at Indiana DOT locations for brine generation and found that salt truck wash water offers a cost-effective and environmentally friendly option for manufacturing a recycled salt brine solution. Fitch et al. (2004) conducted a study for the Virginia DOT which collected stormwater runoff from loading pads to onsite ponds or collection basins and examined the chloride con-

centrations in the basins. High chloride levels were found in the collection basins, exceeding both state and federal standards. It was found that the DOT would realize significant cost saving by reducing runoff to the collection basins, and the method suggested was to use the runoff water to generate brine that would require no pretreatment. The cost-benefit analysis indicated capital investment associated with the brine production using runoff water at the DOT maintenance locations would be recovered within 2 years for anti-icers produced and 4 years for pre-wetting brine produced. In addition, they reported that low hydraulic retention time and warmer temperatures favored successful brine generation. Another method used by the DOT to reduce the amount of water in stormwater ponds was the practice of applying the brine to gravel roads for dust suppression (Fitch et al. 2004).

According to Golub et al. (2008), "when constructing detention or retention ponds, (one needs to) consider the runoff area (loading pad size), annual average precipitation, and evaporation rates for determining pond area and volume necessary for each site."

When survey respondents were asked if their state or agency has implemented any tools, techniques, practices, or strategies to reduce the impacts of chloride deicers, the following response was provided:

- At storage facilities, we have constructed retention ponds to prevent chloride off site migration (Montana DOT).

Additional Resources for Detention, Retention, and Evaporation Ponds

Alleman, J.E., B.K. Partridge, and L. Yeung, *Innovative Environmental Management of Winter Salt Run-Off Problems at INDOT Yards*, Final Report FHWA/IN/JTRO-2001/27, Indiana Department of Transportation, Indianapolis, 2004 [Online]. Available: http://trid.trb.org/view.aspx?id=787489.

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Washington State Department of Transportation WSDOT, *Highway Runoff Manual*, M31-16.03, Design Office, Environmental and Engineering Program, WSDOT, Olympia, Nov. 2011 [Online]. Available: http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf.

WETLANDS AND SHALLOW MARSHES

Wetlands use the natural processes of adsorption, filtration, sedimentation, and related processes to remove pollutants (Earles 1999). Through the combination of these processes, constructed wetlands can be effective in removing both suspended and dissolved pollutants. Natural wetlands cannot be used for stormwater treatment purposes owing to current wetland protection guidelines. The use of wetlands can be limited in arid regions as a result of evaporation and may be limited in cold regions in light of limited plant growth.

Constructed wetlands use physical and chemical processes of natural wetlands (e.g., adsorption, plant uptake, settling, decomposition) to treat water from runoff and reduce its velocity (Staples et al. 2004). They can provide treatment for dissolved metals through sedimentation and geochemical processes (WSDOT 2011). Similar to wet ponds, they are effective at removing high levels of suspended solids with minimal maintenance (Staples et al. 2004). Stormwater wetlands are designed to store runoff, sustain plant life, and promote microbial growth, which contributes to pollutant removal. They require minimal maintenance and can decrease peak discharges. Design considerations need to be assessed carefully, along with site characteristics. Typical design criteria consist of particle size removal efficiencies and treatment volume (Barr Engineering Company 2001). Limited data are available regarding the use of constructed wetlands for runoff mitigation, and optimal design criteria have not been identified for their use in temperate regions (Earles 1999). Although little information is available for their use in cold regions, constructed wetlands are in use in latitudes as far north as the Arctic Circle. Figure 13 shows a constructed wetland just after completion and after one season, respectively. According to Golub et al. (2008), "constructed wetlands can be used as an effective technique for salt runoff treatment from salt storage facilities and roads…potential problems involved with the system include increased mosquito population, low pollutant remove in winter months, and regulatory problems."

When selecting a site for a wetland, the distance from the runoff source, available land, topography, soil type and permeability, and groundwater and base flow should be considered (Staples et al. 2004). Although wetlands have been estimated to cost 25% more than runoff ponds of equivalent

FIGURE 13 A constructed wetland just after completion (*left*) and after one season of plant installation (*right*) (Photos: http://avery.ces.ncsu.edu/content/BannerElkConstructedStormwaterWetland).

volume (CWP 2003), wetlands and marshes are generally more aesthetically appealing than ponds and offer secondary benefits of creating habitat for wildlife, providing visual screening, and reducing obtrusiveness of drainage facilities (WSDOT 2011). Maintenance can vary depending on the location of the wetland with respect to residential areas. A properly designed forebay, detention pond, or grease/sediment trap that removes sediment and other pollutants can enhance the treatment and limit maintenance to cleaning of the forebay instead of the entire wetland (Golub et al. 2008). Maintenance access for vehicles should be included in the design, and as recommended in several surveys, the forebay or inlet pool could be lined with a hard surface to facilitate cleaning (NYSSMDM 2010).

Vegetation is also an important aspect of a treatment wetland, for example, using plants that can withstand high salt concentrations. Consider monitoring constructed wetland vegetation and hydrologic conditions, especially during the establishment period. Grass infiltration areas also can be utilized to reduce the initial chloride concentration in the runoff before it reaches the wetland, so as to decrease harmful impacts to the wetland vegetation (NYSSMDM 2010).

There are four different configurations: shallow marsh system, pond/wetland system, extended detention wetland system, and pocket wetland system (Barr Engineering Company 2001). Each configuration includes a pool or forebay at the inlet and a pool at the outlet for increased sedimentation of large particles and for enhanced reduction in incoming and outgoing flow velocities. These pools should reduce resuspension of accumulated sediment. A shallow marsh is a type of constructed wetland that is characterized by heavy vegetation and shallow water levels. Although there is standing water within shallow marshes, limited storage volume can create potential complications after larger storms (Staples et al. 2004). Small or perched wetlands that intercept the shallow water table or that are primarily surface water dependent may be most susceptible to chloride-laden runoff, as a result of their small size and reduced dilution potential. With high and prolonged chloride loadings, changes in local plant composition may occur, potentially reducing the overall value and diversity of the wetland (TAC 2003h).

Additional Resources for Wetlands and Shallow Marshes

Federal Highway Administration (FHWA), *New Hampshire Department of Transportation's Route 101 Ecological Protection and Enhancement Features*, Last modified Apr. 22, 2004 [Online]. Available: http://www.fhwa.dot.gov/environment/ecosystems/nh.htm.

Hayes, B.D., T.F. Marhaba, N.W. Angnoli, and D.M. Lackey, *Evaluation of Highway Runoff Pollution Control Devices*, Final Report, NJDOT Task Order #43, Project 7620, 1996.

Metropolitan Council, *Stormwater Wetlands Urban Small Sites Best Management Practice Manual* [Online]. Available: http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm [accessed July 7, 2012].

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Yu, S.L., A. Earles, and G.M. Fitch, "Aspects of Functional Analysis of Mitigated Wetlands Recieving Highway Runoff," *Transportation Research Record: Journal of Transportation Research Board, No. 1626*, Transportation Research Board of the National Academies, Washington, D.C., 1998 [Online]. Available: http://trb.metapress.com/content/86q14308431580g8/.

VEGETATED SWALES AND FILTER STRIPS

Biofiltration is the use of closely grown vegetation to filter runoff. This is achieved by allowing water to flow through the vegetation, which decreases the runoff velocity and allows particles to settle (Staples et al. 2004). Biofiltration systems are generally open channel and are referred to as swales, filter strips, or natural and engineered dispersion. They provide effective removal of pollutants through mechanisms such as adsorption, decomposition, ion exchange, filtration, and volatilization. The effectiveness of biofiltration in colder climates can be limited by the short growing season and cold temperatures as well as by the potential damage of deicers and abrasives to the vegetation. Biofiltration is most effective when combined with other treatment options such as ponds, infiltration trenches, or wetlands (Watson 1994).

Bioinfiltration swales can be dry, grassy, or vegetated channels (Staples et al. 2004; WSDOT 2011). Swales are generally located in naturally low topographic areas of uniform grade such as road ditches (Staples et al. 2004). They treat runoff by reducing its velocity and allowing particles to settle out. Swales are useful for runoff control on highway medians and a main design consideration is the volume of runoff to be treated (Barr Engineering Company 2001). The recommended minimum swale length is 100 ft with the width over designed as opposed to the length, to promote shallow flow, which enhances pollutant removal (Colwell et al. 2000). Where possible, use of salt-tolerant vegetation needs to be considered. The addition of check dams can significantly increase the detention time and therefore sediment removal rate of swales (Yu et al. 2001). *Dry swales* may have check dams to temporarily pond runoff to both increase the removal of suspended solids and reduce the runoff velocity. *Wet swales* vary from dry swales only by having impermeable soils and being located close to the water table (Staples et al. 2004). They frequently have standing water and function similar to a wet pond, where new stormwater runoff replaces the existing volume of water. In addition, wet swales improve water quality through mechanisms such as adsorption, sedimentation, and microbially assisted decomposition of pollutants (Barr Engineering Company 2001).

Vegetated swales require low maintenance other than mowing, clearing, and cleaning out if plugged (Staples et al. 2004). They are generally inexpensive, with costs increasing with maintenance and watering. An initial watering or inclusion of irrigation in dry climates may help ensure the success of the vegetation. In winter months when plants are dormant or covered by snow, this treatment may be less effective (Yu et al. 2001).

Similar to swales, *vegetated filter strips* are densely vegetated areas bordering impervious surfaces that treat runoff by reducing its velocity and allowing particles to settle out. The difference is that the runoff flows perpendicularly across the length of the vegetation, known as sheet flow (Staples et al. 2004). Vegetated filter strips are best located in naturally low-topographic areas of uniform grade, such as roadside ditches or along roadsides. They have shown a wide range of sediment removal rates based on the length (Yu et al. 1995). Vegetated filter strips have been primarily used in an agricultural setting and studies have demonstrated a 50% removal rate of phosphorus, nitrogen, and sediment with a 15-ft grass buffer and a 70% removal rate with a 100-ft grass buffer (Barr Engineering Company 2001). To be effective, vegetated filter strips are to be 15 ft wide and at least 25 ft long for slopes ranging from 2% to 6% and they are not recommended for slopes greater than 10% (Watson 1994; Caraco and Claytor 1997). The strips should be wider for locations with steeper slopes. An accumulation of sediment in the first 30 cm of vegetation should be designed for to avoid blocking of water flow or ponding onto the roadway (Staples et al. 2004). Incorporating native vegetation along with trees and shrubs into filter strips may enhance pollutant removal (Barr Engineering Company 2001).

Vegetated swales and filter strips are low-cost solutions and generally have a life expectancy of 20 to 50 years (Schueler 1987). They can be used for snow storage and allow the meltwater to infiltrate. Vegetated swales and filter strips require minimal maintenance (mainly mowing and sediment/debris removal), which helps to keep their life-cycle cost low. During the winter months, cold weather can impact the vegetation and buildup of sediment and deicers should be monitored. Native grass sod has been shown to effectively work as the vegetation for vegetated swales and filter strips in studies conducted in Montana and California (Dollhopf et al. 2008; Ament et al. 2011). Initial costs may be higher than if seeds were used, but sod has been shown to remove up to 99% of total suspended solids in runoff, much higher than seeding methods (EPA 2002).

Natural and *engineered dispersions* are similar to filter strips, but have a conveyance system that concentrates runoff to the dispersion area, through storm sewer pipe, ditch, or similar (WSDOT 2011). The concentrated flow is then dispersed at the end of the conveyance system to mimic sheet flow. Natural dispersions can be selected based on site topography and soil and vegetation characteristics. Engineered dispersions are enhanced sites by inclusion of compost-amended soils and additional vegetation.

Additional Resources for Vegetated Swales and Filter Strips

Ament, R., S. Jennings and P. Blicker, *Steep Cut Slope Composting: Field Trials and Evaluation*, Final Report, FHWA/MT-10-008/8196, prepared for Montana Department of Transportation, Helena, Apr. 2011 [Online]. Available: http://www.ewu.edu/Documents/CBPA/NWTTAP/Newsletter/Publications/FHWA_MT_10_008_8196.pdf.

Anchorage (Alaska), *Guidance for Design of Biofiltration Facilities for Stream Water Quality Control*, Watershed Management Program, Montgomery Watson (Firm), 1994.

Dollhopf, D., et al., *Using Reinforced Native Grass Sod for Biostrips, Bioswales, and Sediment Control*, California Department of Transportation, Sacramento, Dec. 2008 [Online]. Available: http://www.dot.ca.gov/hq/LandArch/research/docs/Montana_State_Native_Grass_Sod_For_Biostrips_Bioswales_Sediment_Control.pdf.

Staples, J.M., L. Gamradt, O. Stein, and X. Shi, *Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water*, FHWA/MT-04-008/8117-19, Montana Department of Transportation. Helena, Dec. 2004 [Online]. Available: http://www.mdt.mt.gov/other/research/external/docs/research_proj/traction/final_report.pdf.

Washington State Department of Transportation (WSDOT), *Highway Runoff Manual*, M31-16.03, Design Office, Environmental and Engineering Program, WSDOT, Olympia, Nov. 2011 [Online]. Available: http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf.

Watson, M., *Guidance for Design of Biofiltration Facilities for Stream Water Quality Control*, Municipality of Anchorage Watershed Management Program Document No. CPg96002, 1994.

OVERVIEW OF REACTIVE STRATEGIES

A combination of reactive strategies is recommended to enhance overall performance, increase service life, and preserve downstream water bodies. This is achieved by utilizing a series of treatment methods that each focus on one aspect of water treatment. An integrated treatment method may incorporate a vegetated filter strip with swales, an infiltration basin and finally a pond system. Specific design criteria in each system should be considered to ensure that suitable design requirements are attained (Barr Engineering Company 2001).

Table 3 presents the average removal efficiencies (± the 67% confidence interval) of various best practices reported by Weiss et al. (2007). Removal efficiencies for total suspended solids and phosphorus were analyzed over a 20-year period as a function of the pollutant load and water quality volume, which is defined as the volume of runoff that the effective practice is designed to store or treat. It was determined that infiltration trenches and bioretention filters are the most effective treatment techniques for removing total suspended solids. The results suggest that constructed wetlands are a cost-effective stormwater treatment method if sufficient land area is available (Weiss et. al. 2007). The most efficient BMP must be identified during the design stage, in light of the target water quality volume, cost, and other constraints. Note that "removal" in this context is truly removal from surface water by means of diversion and dilution.

TABLE 3
AVERAGE REMOVAL EFFICIENCIES OF VARIOUS BEST PRACTICES

Best management practices	Total suspended solids removal (%)	Total suspended solids (67% CI)	Total phosphorus removal (%)	Total phosphorus (67% CI)
Dry extended detention pond	53	±28	25	±15
Wet basins	65	±32	52	±23
Storm-water wetland	68	±25	42	±26
Bioretention filter	85*	±10*	72	±11
Sand filter	82	±14	46	±31
Infiltration trench	95*	±5*	65*	±35

Note: * = assumed value.
Source: Weiss et al. (2007).

Great care must be exercised to ensure that the implemented practices function effectively in cold regions, especially during the winter and spring months. Roseen et al. (2008) evaluated bioretention systems, a wetlands system, and a sand filtration system throughout winter seasons, and concluded that the winter months had no effect on overall performance of these systems. Nonetheless, they acknowledge the potential risk posed by the winter in cold regions. Traditional design guidelines developed in temperate regions may need adjustment. If necessary, modifications to design features could be made to accommodate site-specific needs. Such modifications can be explored in six categories: feasibility, conveyance, pretreatment, treatment, maintenance, and landscaping (Caraco and Claytor 1997).

Staples et al. (2004) summarized the reactive strategies for mitigating highway runoff, with a focus on cold regions and rural transportation, and discussed their applicability, site criteria, engineering characteristics, maintenance issues, cost, effectiveness, efficiency, and the like. Despite the challenges of winter conditions, reactive strategies such as ponds, wetlands, and vegetated swales and filter strips can still remove high levels of sediment from runoff if they are designed, sited, installed, and maintained properly. In contrast, dissolved pollutants from chloride roadway deicers are difficult to remove. Table 4 provides a summary of selection criteria for reactive mitigation strategies, with a focus on the removal of suspended solids or dissolved pollutants, the characteristics of the strategy, and their applicability in cold regions.

The importance of proper maintenance of reactive mitigation strategies cannot be overestimated. Time and budget commitments for maintenance for all these reactive strategies will aid in their continued function and success. Many of them fail because of the lack of continued support for maintaining the installed facilities.

TABLE 4
SUMMARY OF SELECTION CRITERIA FOR REACTIVE STRATEGIES

Structural BMP	Removal of Suspended Solids	Removal of Dissolved Pollutants	Relative Costs	Relative Maintenance	Difficulty of Use in Cold Climates	Other Requirements and Concerns
Dry Pond	Medium/High	N/A	Low	Low	Low	-
Wet Pond	High	Low	Low/Medium	Low	Low/Medium	Needs year round water
Wet Extended Detention Pond	High	Medium	Low/Medium	Low	Low/Medium	Needs year round water
Wet Vault	Medium	N/A	Medium/High	High	Medium	Needs regular cleaning
Sand Can	Low	N/A	Low	Medium	Low	Primary use as pretreatment
Proprietary Wet Vaults	Medium/High	N/A	High	Medium	Variable	Can be expensive
Constructed Wetland	High	Medium/High	Medium	Low/Medium	Medium	Monitor development of vegetation
Submerged Gravel Wetland	N/A	High	High	Medium	High	Needs pretreatment
Infiltration	N/A	High	Medium	Medium	High	Needs pretreatment
Porous Pavement	N/A	High	High	Medium	Medium	Cannot use traction sand
Bioretention	N/A	High	High	Medium	High	Needs pretreatment
Filtration	N/A	High	High	High	High	Needs pretreatment
Vegetated Swale	Medium	Low	Low	Low	Low	Check dams improve performance
Vegetated Filter Strip	Medium	Low	Low	Low	Low	Ensure sheet flow

Source: Staples and Shi (2004).

CHAPTER FIVE

NEW AND EMERGING TECHNOLOGIES

This chapter presents information on new and emerging technologies utilized to mitigate the impacts of chloride roadway deicers on the natural environment. New and emerging technologies presented in this chapter, identified from the practitioner survey and literature review, includes synchronizing vehicle location and other sensor technologies, MDSS, FAST, and thermal deicing methods. Other emerging technologies that could reduce chloride deicer usage, such as advances in the research and development of non-chloride roadway deicers, are not discussed in this synthesis. Note that a guide for implementation of emerging technologies can found in the *Highway Runoff Manual* 5.3.5.2 (WSDOT 2011). The majority of mitigation strategies identified by the practitioner surveys were proactive practices (see chapter four); this chapter also focuses on recent advances in pro-active deicer environmental management. Although there are recent advances in reactive strategies (see chapter five) as well, they generally are not aimed at enhancing the removal of pollutants associated with chloride roadway deicers.

In this work, survey respondents were asked to provide an example of a new technology, tool, or methods they are using to reduce the impacts of chlorides on the natural environment. Figure 14 reveals that the top three technologies being implemented for deicer environmental management include (1) advanced material controllers or ground speed controllers, (2) liquid anti-icing or pre-wetting, and (3) automatic vehicle location (AVL)/global positioning system (GPS). They are followed by environmentally friendly deicers/anti-icers/additives, MDSS, FAST, salt brine making, living snow fences, clearing vegetation from right-of-way, training, environmental monitoring, plowing techniques, slurry technology, and 14-ft tow plows. The vast majority of these technologies (except the final two) have been available and in practice for more than a decade. Many of them (especially the top three, MDSS, and FAST) also have been extensively researched and show desirable benefit–cost ratios.

Five new and emerging technologies identified through the literature review and the practitioner surveys are synchronizing vehicle location and other sensor technologies, MDSS, FAST, thermal deicing methods, and innovative snow fences. Other emerging technologies could reduce chloride deicer usage, such as advances in the research and development of non-chloride roadway deicers. An emerging technology implementation guide can be found in the *Highway Runoff Manual* 5.3.5.2 (WSDOT 2011).

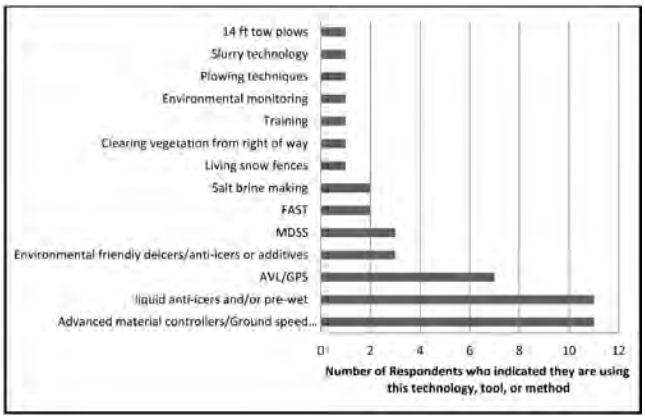

FIGURE 14 New and emerging technologies implemented by survey respondents to mitigate the impacts of chlorides on the natural environment.

SYNCHRONIZING VEHICLE LOCATION AND OTHER SENSOR TECHNOLOGIES

Numerous equipment technologies support winter road maintenance by helping manage the operations with timely, useful data or by supporting the service delivery itself. Advanced vehicle-based sensor technologies, including AVL, mobile RWIS technologies (surface temperature sensors, on-board freezing point and ice-presence sensors, and salinity sensors), visual and multispectral sensors, and millimeter wavelength radar sensors, have been developed in the past decade or so to achieve improvements in winter maintenance efficiency and safety. Among them, Shi and colleagues (2007) found AVL systems and road surface temperature sensors to be the only ones that had matured and became fully operational, whereas the remainders were still in the development and testing phases.

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, as illustrated in Figure 15 (Allen 2006). Other than GPS information, real-time information may include type of applied material, application rate, position of plow blade, and pavement temperature (Vonderohe

2004). AVL can assist in storm response, guide storm event planning by providing previous storm event histories, and help agencies simplify tracking and reporting requirements, thus decreasing the paperwork and time required to manage winter maintenance activities (Ye et al. 2012).

FIGURE 15 Schematic diagram of AVL system (Allen 2006).

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). The incorporation of other mobile data collection (e.g., pavement temperature) with AVL is anticipated to further optimize the usage of roadway deicers for snow and ice control. In 1999, the Missouri DOT (2009) conducted a research project to evaluate the benefits of a temperature detection system. The project included a laboratory test as well as a field evaluation of 50 such mirror-mounted pavement temperature sensors distributed throughout the state. The laboratory test shows good sensor accuracy. A material savings of $185,119 during the winter of 1998–99 was estimated excluding the savings from personnel and equipment. Assuming 1 year as the life of the sensors, the project team calculated the benefit–cost ratio to be 9.49.

There is a rich repository of documented experience on lessons learned and best practices for use of AVL in winter maintenance operations. Some of the major themes include the need for thoughtful integration of AVL into an existing vehicle fleet in light of the variety of expected users and sensor packages, and the need to consider the communications requirements of the various technologies. Through several years of demonstration and evaluation, many problems that plagued earlier AVL deployments, such as sensor protection, communications availability, and GPS accuracy, have been addressed. The level of support from the vendor community has improved as AVL vendors have become flexible, adapting and customizing systems to meet specific customer requirements. Vendors also provide customized maps, statistical analysis, and reports as requested by the customer.

There are a few overall trends regarding the future use of vehicle-based technologies for snow and ice control. First of all, integration was an underlying goal in several U.S. winter maintenance vehicle-based technology projects. The HMCV under the sponsorship of several state DOTs have incorporated some of the latest technologies, including temperature sensors, friction sensors, freezing-point sensors, high intensity lights, GPS/AVL, ground speed spreaders, pre-wetting equipment, liquid spreaders, power boosters, and underbody plows (Kroeger and Sinhaa 2004). Agency snowplow specifications are increasingly requiring vendors to allow greater levels of technology integration with road condition sensors, spreader controllers, and other vehicle equipment. Second, there is a trend toward increased automation of snowplow operations. This trend recognizes the complexity associated with executing winter maintenance tasks during storm events, when such tasks are most critical. In the future, two-way AVL could allow a maintenance manager to select application rates without needing to involve the vehicle operator. Finally, while many of the vehicle-based sensor technologies hold great promise in assisting in the winter maintenance process, technological and other barriers currently impede their greater implementation.

In this synthesis work, when survey respondents were asked if their state or agency has made any effort to mitigate or reduce the impacts of chloride deicers, the following response was provided:

- Increasing the number of closed loop spreader control systems on our fleet with AVL/GPRS. Offering a “Green Incentive” for our winter plow vendors to install similar AVL closed loop spreader controls (Rhode Island DOT).

Additional Resources for Synchronizing Vehicle Location and Other Sensor Technologies

Andrey, J., J. Li and B. Mills, “A Winter Index for Benchmarking Winter Road Maintenance Operations on Ontario Highways,” presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 2001.

Meyer, E., “Benefit-cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance,” presented at the 2003 Mid-Continent Transportation Research Symposium. Ames, Iowa, 2003.

Shi, X., et al., *Vehicle-Based Technologies for Winter Maintenance: The State of the Practice*, Final Report, NCHRP 20-02/200, Transportation Research Board of the National Academies, Washington, D.C., 2006 [Online]. Available: http://maintenance.transportation.org/Documents/Final%20Report%202007%20Task%20200.pdf.

Strong, C., N. El Ferradi, and X. Shi, "State-of-the-Practice of Automatic Vehicle Location for Winter Maintenance Operations," presented at the 86th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 21–25, 2007.

Veneziano, D. and C. Strong, "Pilot Test of Automatic Vehicle Location on Snow Plows Technical Memorandum 2: Pre-Pilot Test Results," Western Transportation Institute. Helena, Mont., July 2007.

Veneziano, D., L. Fay, Z. Ye, D. Williams, X. Shi, and L. Ballard, *Development of a Toolkit for Cost-Benefit Analysis of Specific Water Maintenance Practices, Equipment and Operations: Final Report*, WisDOT 0092-09-08, Western Transportation Institute, Bozeman, Mont., Nov. 2010b.

Washington State Department of Transportation (WSDOT), *Highway Runoff Manual*, M31-16.03, Design Office, Environmental and Engineering Program, WSDOT, Nov. 2011 [Online] Available: http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf.

MAINTENANCE DECISIONS SUPPORT SYSTEM

An MDSS is a software application that integrates information from a variety of sources, such as fixed RWIS, weather service forecasts and others observations, to assist managers in making appropriate winter maintenance decisions. The goal is to best utilize resources for effective snow and ice control. It has been proven to be a powerful management tool that facilitates proactive (vs. reactive) winter road maintenance operations. The global essential function of the MDSS is fulfilled as two interrelated applications:

- Application 1: Predict and portray how road conditions will change owing to the forecast weather and the application of several candidate road maintenance treatments, based on an assessment of current road and weather conditions and time- and location-specific weather forecasts along transportation routes. This may be termed a "real-time assessment of current and future conditions."
- Application 2: Suggest optimal maintenance treatments that can be achieved within available staffing, equipment, and materials resources. This may be termed "real-time maintenance recommendations."

Application 1 involves the integration of information on recent and current road and weather conditions, along with reports of winter maintenance actions, from a variety of sources. Application 2 interprets that information and produces recommendations for future action (Ye et al. 2009a). A transportation agency may choose to implement the MDSS in various ways, with diversity in forecasting services, feedback mechanism, treatment recommendations module, and In-vehicle Graphical User Interface (Ye et al. 2009a).

MDSS was proven to be an effective system when it was implemented statewide by the Indiana DOT. For the fiscal year 2009 ice and snow season, MDSS helped INDOT to save $12,108,910 (228,470 tons) in salt usage. When normalized for varying winter conditions, INDOT still realized savings of $9,978,536 (188,274 tons) in salt usage (McClellan et al. 2009). A case study in Maine (Cluett and Jenq 2007) tracked 12 winter storm events that required response in order to characterize the use of the MDSS as a maintenance tool, versus not using a MDSS. The results of the MDSS system were positive and strongly support the future implementation of a MDSS for winter maintenance operations. It was also cautioned that receiving too many alerts may be distracting at times and can be misleading during important warnings. Overall, MDSS was considered beneficial for the environment, safety, and cost reduction. Ye et al. (2009a) established a methodology for analyzing the tangible benefits of the Pooled-Fund version MDSS. The methodology entails the use of a baseline data module and a simulation module and benefits considered included reduced material usage (agency benefit), improved traffic safety (user benefit), and reduced traffic delay (user benefit). The methodology was applied to three case study states with diversity in climatological conditions. The analysis results indicated that the use of MDSS could bring much more benefits than costs.

Integration is also a key consideration with the MDSS, which will make more appropriate roadway treatment recommendations as the quality of information (inputs) improves. The AVL/MDSS system was developed and implemented by Minnesota DOT to provide better information to operators to optimize chemical use and service level, and provide better information for supervisors and managers to enhance scheduling, dispatch, and safety (Hille and Starr 2008). In Japan, Makino and colleagues (2012) reported the development of a system similar to MDSS coupled with AVL, which "enables flexible shifting of snow removal sections." Such flexibility can be valuable in fighting extremely severe winter storms and optimizing the use of resources including roadway deicers.

When survey respondents were asked if their state or agency has made any effort to mitigate or reduce the impacts of chloride deicers, some of the following responses were provided:

- Using MDSS to suggest the most effective treatment types, application rates and timing (South Dakota DOT).
- Implemented MDSS statewide in 2009 with the hopes that it would reduce application rates (Wisconsin DOT).

When survey respondents were asked if their state or agency has implemented any tools, techniques, practices, or strategies to reduce the impacts of chloride deicers, the following response was provided:

- We are using a program MDSS as a tool to give our employees a scientific approach to removing snow and ice in an effort to prevent over-applications (Indiana DOT).

Additional Resources for MDSS

Cluett, C. and J. Jenq, *A Cast Study of the Maintenance Decision Support System* (*MDSS*) *in Maine*, Best Practices for Road Weather Management Version 2.0, FHWA-JPO-08-001, 2007 [Online]. Available: http://ntl.bts.gov/lib/30000/30200/30234/14387.htm.

Ye, Z.R., C. Strong, X. Shi, and S. Conger, *Analysis of Maintenance Decision Support System (MDSS) Benefits and Costs*, Study SD2006-10, 2009a [Online]. Available: http://www.meridian-enviro.com/mdss/pfs/files/WTI-4W1408_Final_Report.pdf.

FIXED AUTOMATED SPRAY TECHNOLOGY

Sensitive structures and critical segments of roadway network need to be freed of snow and ice in a timely manner, before maintenance vehicles can even travel to the site and treat them. For instance, bridge decks or shaded areas may feature hazardous driving conditions in wintery weather, such as frequent frost and black ice. In high-risk areas far from maintenance sheds or areas that experience a high traffic volume, anti-icing chemicals should be applied just prior to the frosting or icing event.

Fixed Automated Spray Technology (FAST) systems aim to deliver anti-icing chemicals to key locations in a controlled manner, using pumps, piping, valves, and nozzles or discs (Zhang et al. 2009). They can reduce usage of chloride roadway deicers through effective and uniform application and through better management of problem areas in the roadway network. As an anti-icing strategy, it reduces the chemical usage by applying the chemical "just in time" (Pinet et al. 2001). Ideally, the application should be fully automated, using pre-programmed logic and real-time input from a number of atmospheric and pavement sensors on-site. Once the sensors detect ice presence or an imminent frost or icing event, the nozzles will be automatically triggered to spray the liquid chemical at predetermined rate and pattern, as shown in Figure 16. FAST has emerged as an important tool to enable proactive winter maintenance and to supplement mobile operations by providing effective service delivery to high-risk locations. It aims to reduce crashes resulting from icy pavement and reduce the amount of labor and materials needed through timely prevention of ice formation/bonding or snow packing, with indirect benefits such as reduced corrosion and environmental impacts and reduced traveler delay and stress. The anticipated benefits from FAST systems are site-specific, as a function of winter weather severity, traffic density, accident history, and distance from maintenance yards, among other factors (Ye et al. 2013).

FIGURE 16 A FAST system on a bridge in action (Pinet et al. 2001).

In principle, FAST systems are to be deployed at locations that are remote, feature high traffic density and significant congestion, or are a considerable safety risk during wintery weather (Ye et al. 2013). FAST is not a solution for the entire road network, but rather for the following key locations where it can derive the maximum benefits (Pinet et al. 2001):

- A new structure with a history of accidents.
- High vehicle volume and/or key route.
- High speed ramp of rural freeway.
- Prevailing winds at most time ran across structure.
- Remote location of structure relative to dispatch location, not in same micro-climate.
- Structure prone to icing earlier and more often than interconnecting segments.

Experience with FAST systems in North America and Europe has revealed a mixed picture. Since the mid-1980s, hundreds of automated anti-icing systems have been used throughout Europe as an established tool to battle snow and ice conditions on highways, bridges, and airports. In North America, FAST is a relatively new technology that has gained popularity since the late 1990s (SICOP 2004). Several studies have indicated reductions in mobile operations costs and significant reductions in crash frequency, resulting in favorable benefit–cost ratios. Yet activation frequency, system maintenance and training problems have been reported. On balance, North American transportation agencies consider FAST to be an evolving technology (Ye et al. 2013). The success of the FAST systems has to do with the appropriate choice of location, having a knowledgeable and dedicated staff, monitoring, and conducting maintenance. As of 2003,

23 states either had FAST systems or were planning to install them (Zwahlen et al. 2003). A survey conducted by Shi and colleagues, however, revealed that transportation agencies in North America were not planning to expand their number of FAST installations (2007a).

Research conducted by Birst and Smadi (2009) for the North Dakota DOT documented how its two installed FAST systems performed relative to other bridge deck treatments and analyzed the benefits and costs of the systems. Both FAST systems were installed in the Fargo District and it was found that they required a steep learning curve. For this reason, vendor support was critical during the first winter season. The users favored the FAST system, especially under frost conditions (which often occur outside of normal operating hours), and are satisfied with the systems' ability to treat freezing conditions. The FAST systems were estimated be 95% reliable for spraying at the appropriate time with the proper application rate and system pressure. The averaged crash reduction for the two FAST sites was 50%, and the FAST implementation allowed one site to be removed from a high-crash location list (with site crash reduction rate of 66%). The benefit-cost analysis for both FAST sites were favorable with ratios of 4.3 ($1,257,869 net benefit) and 1.3 ($675,184 net benefit), respectively. A FAST system installed by the Maryland DOT in the 1998–99 winter season, which sprayed a mixture of calcium magnesium acetate and potassium acetate, was considered a major success, as it reduced accidents on the bridge by approximately 40% and led to cost savings of $16,000 resulting from avoided mobile operations (Lipnick 2001). For three remotely activated FAST systems installed at various sites in the Minnesota DOT roadway network, the number of winter weather-related accidents dropped 82% from the 18 to 24 months before the FAST installations to a similar period after (Keranen 2000).

FAST is not an "off-the-shelf" system that can be purchased and installed right away at any given site. Customized design of the installation (e.g., spray logic) at each site after studying the site specifics and conditions is suggested (CERF 2005). The FAST systems have been found to not spray when wind speed is greater than 15 mph and when pavement temperature drops below 12°F (Birst and Smadi 2009). Previous studies have documented preventive maintenance requirements for FAST, and these cover before-season, during-season, and after-season inspection and services needed for the FAST system to work properly (Barrett and Pigman 2001; Roosevelt 2004).

Additional Resources for FAST

Barrett, M.L. and J.G. Pigman, *Evaluation of Automated Bridge Deck Anti-icing System*, Kentucky Transportation Cabinet Research Report #KTC-01-26/KH36-97-1F, Frankfort, 2001.

Bell, G.T., W.A. Nixon, and R.D. Stowe, *A Synthesis to Improve the Design and Construction of Colorado's Bridge Anti-Icing Systems*, Final Report No. CDOT-DTD-R-2005-19, Colorado Department of Transportation, Denver. 2006 [Online]. Available: http://www.coloradodot.info/programs/research/pdfs/2005/fast.pdf/view.

Birst, S., and M. Smadi, *Evlauation of North Dakota's Fixed Automated Spray Technology Systems*, Upper Great Plains Transportation Institute, North Dakota State University, Fargo, Oct. 2009 [Online]. Available: http://www.ugpti.org/pubs/pdf/DP219.pdf.

Decker, R., *Automated Bridge Deck Anti- and Deicing System*, NCHRP IDEA Project 27 Final Report, Transportation Research Board, National Research Council, Washington, D.C., 1998 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/NCHRP027_Final_Report.pdf.

Friar, S. and R. Decker, "Evaluation of a Fixed Anti-icing Spray System," *Transportation Research Record 1672*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 34–41.

Johnson, C., *I-35W and Mississippi River Bridge Anti-icing Project: Operational Evaluation Report*, Report # 2001-22, Office of Metro Maintenance Operations, Minnesota Department of Transportation, St. Paul, 2001.

Snow and Ice Pooled Fund Cooperative Program (SICOP), *Fixed, Automated Anti-icing Spraying Systems*, SICOP, AASHTO, Washington, D.C., 2004.

Waldman, J.R., *Transportation Research Circular E-C063: State-of-the-Art Fixed Automated Spray Technology*, Sixth International Symposium on Snow Removal and Ice Control Technology (04-001), Spokane, Wash., June 7–9, 2004, pp. 379–390 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.

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THERMAL DEICING METHODS

Thermal deicing methods, also known as heated pavement technologies, aim to prevent ice formation or to facilitate snow and ice removal. They can reduce usage of chloride roadway deicers and contribute to better management of problem areas in the roadway network. Depending on the relative location of heating source to the pavement, they can be classified as internal heating [e.g., geothermal heat pumps (Seo et al. 2011),

electrical resistive heating (Yehia and Tuan 1998; Yehia et al. 2000; Chang et al. 2009; Yang et al. 2011)] and external heating (e.g., microwave and infrared heating). Infrared heat lamps and insulating bridge deck with urethane foam were attempted but found to be ineffective (Axon and Couch 1963; Zenewitz 1977).

Geothermal Heating

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 the shallow ground and its auxiliary solar energy in the summer; when it was first installed in Ninohe, Iwate Prefecture in 1996, it was found to be effective in snow/ice melting and environmentally benign even under low temperatures for the month of January [averaging −8.3°C (17°F)]. Yasukawa (Institute for Geo-Resources and Environment 2007) summarized the advantages of geothermal heat pump application of Gaia System: reduced consumption of fossil fuels (and thus less CO_2 emission), reduced consumption of electricity with higher coefficient of performance, and reduced urban heat island effect with heat exhaust into underground.

Hiroshi (1998) reported the implementation of a snow melting technology utilizing tunnel spring water and hot spring water on a highway through the Abo Pass, where the average minimum temperature is around −18°C (−0.4°F) during the previous 5 years with average annual accumulated snowfall depth of 500 cm (16.5 ft).They concluded that such systems present a practical method to melt snow where sufficient thermal energy and a large site are available. This is based on their higher construction costs (1.15 to 1.24 times the cost of conventional, electric-powered road heating) and lower operating costs (22% to 46% of the conventional systems).

Electrical Conductive Concrete

As detailed in Table 5, a comparison of conductive concrete technology against other deicing technologies in the literature revealed its potential to become the most cost-effective approach in the future (Kiljan 1989). Electrically conductive concrete is made by adding electrically conductive components to a regular concrete mix to attain stable electrical conductivity of the concrete. A thin layer of conductive concrete can generate enough heat because of its electrical resistance, and can be utilized to prevent ice formation on the pavement surface when connected to a power source. The conductive concrete includes two types: (1) conductive fiber-reinforced concrete and (2) concrete containing conductive aggregates. Each type has its own advantages and limitations. Recent advances in this field include electric roadway deicing systems featuring the use of carbon nanofiber paper (Zhou et al. 2012) or carbon/glass fiber hybrid textile (Song 2012). These new materials have yet to be field evaluated but claim to offer enhanced electrical conductivity, improved heating capacity at low voltage, uniform and rapid heating, reliable performance, low cost, and/or improved service life.

TABLE 5
COMPARISON OF DIFFERENT DEICING SYSTEMS

Deicing System	Initial Cost*	Annual Operating Cost*	Power Consumption
Automated Spray System, 2004	$600,000	$12,000	Not applicable
Electric heating cable, 1961	$54/m^2	$4.8/m^2	323–430 W/m^2
Hot water, 1993	$161/m^2	$250/storm [76 mm snow]	473 W/m^2
Heated gas, 1996	$378/m^2	$2.1/m^2	Not available
Conductive concrete, 2003	$635/m^2	$0.80/m^2/storm	350 W/m^2

Source: Kiljian (1989).
*Cost figures were quoted directly from literature, and conversion to present worth was not attempted.

A bridge deicing system implemented with conductive concrete deck was under evaluation from 2003 to 2008. Carbon and graphite products (instead of steel shavings) were used in the conductive concrete mix design. In the storm events, an average of 500 W/m^2 (46 W/ft^2) was used to raise the slab temperature 16°F above the ambient temperature by the conductive concrete. The total construction cost of the bridge deicing system was $193,175. The cost per unit surface area of the conductive concrete inlay was $59/ft^2. The operating cost of the deicing system was about $250 per major snow storm (Tuan 2008). The author stated that "the most challenging task in the mix design was to achieve the long-term stability of the electrical conductivity… The use of high voltage and high current causes a safety concern."

The conductive concrete pavement technology has also found its application to airport runways. One such system was installed and operated at O'Hare International Airport (Der-

win et al. 2003). The electrically conductive asphalt pavement used a unique blend of graphite, asphalt, and electricity to heat the runway surface and break the ice bond to pavement. It was installed and operated at the airport for 4 years since November 1994. The installation costs were at $15/ft^2. The conductive asphalt showed similar durability as regular asphalt concrete and "consistently melted snow in all but the most severe conditions." It was able to increase the pavement temperature 3°F to 5°F per hour as designed. The system was effective even when temperatures went down to –10°F in one of the winter seasons. Its ability to increase the pavement temperature 22°F confirmed its effectiveness in the extremely cold weather.

Alternative Heating (Solar, Wind, Microwave, and Infrared)

To further reduce the energy consumption by snow removal equipment and to overcome the problems associate with other methods, snow melting systems using natural energy have been under development in Japan. Many renewable heat sources can be used to heat the pavement such as solar energy and wind energy. Hiroshi (1998) outlined a number of snow melting systems using natural heat sources in Japan. The approaches include utilizing underground water sources or steam, storing heat underground and circulating it under pavements, and using electricity produced by wind power. Relative to electrical resistive heating systems, such systems entail relatively high capital cost, the savings are expected from reduced maintenance cost (energy savings) as well as environmental conservation.

For microwave and infrared heating, limited technical information is available in the published domain and the knowledge is still lacking on their performance and cost-effectiveness (Long 1995; Hopstock and Zanko 2005). The infrared heaters can be mounted on a truck or on the bridge-side structures to provide heat from the lamps to melt the snow and ice on the pavement or bridge deck. Switzenbaum et al. (2001) described its application on aircraft. Microwave heating shares the similarities in the installation of infrared heaters and can be mounted on a truck or on the bridge-side structures (Johnson 2006).

Additional Resources for Thermal Deicing Methods

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CHAPTER SIX

CONCLUSIONS

CONCLUSIONS

This synthesis presented information on environments at risk of impacts from chloride roadway deicers, and mitigation techniques used to reduce the impacts of chloride roadway deicers on the natural environment including the surrounding soil and vegetation, water bodies, aquatic biota, and wildlife. Many of the identified techniques could also apply to mitigating the impacts of abrasives and non-chloride-based roadway deicers. Information was presented on proactive strategies, reactive strategies, and new and emerging technologies. The survey responses and the literature identified reactive mitigation strategies used to reduce the effects of chloride once it reaches the environment. Many of these strategies were designed for and are frequently used in stormwater management and to transport chlorides from sensitive areas to non-sensitive areas for treatment, as it is difficult to truly treat chlorides or remove chlorides from the environment.

Proactive mitigation strategies are currently the most commonly used methods for reducing the footprint of chloride roadway deicers. Proactive strategies entail preventative measures designed to reduce the amount of chloride deicers entering the environment, which can reduce the need for or dependence on reactive strategies. Table 6 summarizes the information on the proactive strategies presented and major pros and cons for each, based on information gathered from the literature review and survey. The following effective practices were identified in the practitioner surveys: salt management plans, staff training, monitoring and record keeping, anti-icing/deicing/pre-wetting practices, weather forecasting and Road Weather Information Systems, equipment technologies, vehicle-mounted spreaders, roadway design, vegetation management, and road maintenance yard design and operations. These practices contribute to the ultimate goal of facilitating or enabling effective and efficient use of resources so as to apply the right type and amount of materials in the right place at the right time for snow and ice control. Most methods, techniques, and tools can be used alone, paired in a series, or integrated to form a proactive mitigation effort.

Reactive strategies aim to reduce the impacts of chloride deicers once they are in the environment. They are typically implemented along the roadside to physically trap salt-laden stormwater runoff and to allow pollutants to settle out, evaporate, infiltrate, or be absorbed. Table 7 summarizes the information on the reactive strategies presented and major pros and cons for each. The following effective practices were identified in the literature review and confirmed by practitioner surveys: infiltration trenches and basins, detection/retention/evaporation ponds, wetland and shallow marshes, vegetated swales, and filter strips. All were designed to reduce velocity and improve the quality of the highway stormwater runoff. The vast majority of the reactive strategies identified were not originally installed for this purpose, and their cost-effectiveness for deicer environmental management is yet to be examined and validated. For deicer environmental management, reactive strategies may vary, and they need to be designed, sited, installed, and maintained properly. The reactive strategies may be used individually or synergistically, and a combination of reactive strategies is suggested to enhance overall performance, increase service life, and preserve downstream water bodies. Great care must be exercised to ensure their effective function in cold regions, especially during the winter and spring months. If necessary, the design could be modified to accommodate site-specific needs.

This synthesis also presented information on recent advances in methods, techniques, or tools used to mitigate the impacts of chloride roadway deicers on the natural environment, with a focus on proactive strategies. Five new and emerging technologies were identified through the literature review and the practitioner surveys: synchronizing vehicle location and other sensor technologies, maintenance decision support systems (MDSS), fixed automated spray technology, thermal deicing methods, and innovative snow fences. Most technologies presented here are not “new” to winter maintenance but instead have been recently implemented.

Interviews with selected survey respondents provided information on identified effective practices. These were made into case examples on the following topics: closed loop controllers, needle browning, snow disposal and melting, and making salt brine from recycled vehicle wash bay water. Case examples can be found in Appendix B.

SUGGESTIONS FOR FUTURE RESEARCH

A significant body of information about proactive and reactive tools, techniques, and methods used to mitigate the impacts of

TABLE 6
SUMMARY TABLE OF IDENTIFIED PROACTIVE STRATEGIES WITH PROS AND CONS

Proactive Mitigation Strategies	Pros	Cons
Salt Management Plan	A guidance document that can define effective practices and strategies.	Implementation at all levels is critical to the effectiveness of SMPs, as well as contractor and vendor buy in to new practices and strategies.
Staff Training	Provides staff with the same knowledge base and allows for transfer of knowledge from those with on-the-job experience.	Follow-up may be required to assess how much information has been assimilating into daily operations and what needs to covered again.
Monitoring and Record Keeping	A tool that can highlight effective practices and inefficiencies. The collected data can be used at all levels to encourage specific practices, provide management with real world data, etc.	The collected data should be used once collected. Data collection systems may need to be upgraded periodically to manage all the incoming information.
Anti-icing, Deicing and Pre-wetting	Anti-icing - when used appropriately can lead to a reduction in the amount of product used. Deicing - when coupled with appropriate information application rates of products can be reduced while still maintaining the same LOS. Pre-wetting - of grit or product can reduce the amount of product needed to provide necessary friction or deicing, can reduce product loss from bounce and scatter. Overall reduction of product application rates means there is less product available to reach the environment adjacent to the road.	Different equipment and specific training is necessary for anti-icing, deicing and pre-wetting.
Weather Forecasting and RWIS	Use of accurate weather forecasts and real-time data can allow for cost and material savings, and reduced environmental impacts.	Use of inaccurate weather forecasts can increase winter maintenance costs and environmental impacts due to over application of products and time treating the roads.
Snow Plows and Blades	Snow plow blades and plowing techniques can be used to reduce the number of the vehicles passes, and therefore increase efficiency across the board.	To improve plowing techniques, new blades and or training may be necessary.
Vehicle-Mounted Spreaders	Through integration of vehicle-mounted spreaders with available environmental data, product application rates can be automatically adjusted without relying on the vehicle driver. This can reduce product application due from over application and user error.	Integration of the vehicle-mounted spreaders with environmental data may require capital investment. Driver buy-in is important.
Roadway and Pavement Design	Design of road shape, path, and drainage can reduce the quantity of product needed to treat a road. Pavement overlays can provide longer lasting anti-icing than using product.	Road design can be difficult and costly to alter. Many pavement overlay options are still being field tested.
Proactive Vegetation Management	Using appropriate vegetation and management techniques can reduce the impacts of chlorides on environment adjacent to the road.	Appropriate management of vegetation may include increase maintenance efforts including mowing and noxious weed management.
Innovative Snow Fences	Constructed snow fences and living snow fences can reduce maintenance and product application for roadways.	Maintenance agency may need to work with local land owners for permission to place snow fences or plant living snow fences. Living snow fences may require 5-7 years to establish and reach their necessary height.
Design and Operations of Road Maintenance Yards	Appropriate management of maintenance yards can led to reduced product loss and less product leaving the site and entering the adjacent environment.	Restructuring of site procedures may be necessary. Financial investment in buildings, equipment and storm water collection systems may be necessary.

chloride roadway deicers on the natural environment is available in the literature and in practitioner experience. There are still significant knowledge gaps where additional research or development is needed. For instance, there is an apparent need for further research in the design options, performance, and cost-effectiveness of reactive strategies for managing the footprint of chloride roadway deicers.

There is also a lack of knowledge regarding the fate and transport of relevant pollutants (e.g., deicers, anti-icers, additives) in soil, vegetation, or water bodies, whereas such knowledge is much needed to guide the design, monitoring, and evaluation of reactive strategies in treating chloride-laden roadway runoff and minimizing potential damage to the receiving environment. Existing studies focused on dynamics in either a laboratory setting or an actual field setting; however, the former lack the field variables and the latter produce only site-specific results with limited transferability. Such research should be conducted in a controlled field environment where a comprehensive test program can be formulated to examine selected processes or to test significant hypotheses.

TABLE 7
SUMMARY TABLE OF IDENTIFIED REACTIVE STRATEGIES WITH PROS AND CONS

Reactive Mitigation Strategies	Pros	Cons
Infiltration Trenches and Basins	Treat runoff and reduce water volume. Recharge ground water. Trenches require only a small amount of space.	Can clog from grit or sand. Have limited potential to treat chloride in runoff. May require maintenance or cleaning out to remove build up of suspended solids and chlorides.
Detention, Retention and Evaporation Ponds	Allow suspended solids to settle out of the runoff. Inexpensive. Can perform well in cold climates. Wet ponds are aesthetically pleasing.	May require maintenance or cleaning out to remove build up of suspended solids and chlorides.
Wetlands and Shallow Marshes	Remove suspended solids and pollutants from runoff. Aesthetically pleasing.	May not work as effectively in arid and or cold climates. Natural wetlands cannot be used to treat storm water runoff. May require maintenance or cleaning out to remove build up of suspended solids and chlorides.
Vegetated Swales and Filter Strips	Decreases runoff velocity. Require only a small amount of space. Can be used for snow storage in Winter months.	Biofiltration can be limited in colder climates due to short growing season or damage to plants from deicers. In winter months may not work as effectively. May require maintenance or cleaning out to remove build up of suspended solids and chlorides.
Reactive Vegetation Management	Salt tolerant plants adjacent to roadways and in constructed reactive mitigation strategies aid in biofiltration, can reduce runoff velocities and can be aesthetically pleasing.	Establishment may require watering or weeding to remove unwanted plant species.

The synthesis identified some knowledge gaps. Research recommended to fill those knowledge gaps includes the following:

Fundamentals

- Investigate the negative impacts of abrasives on air quality, waterways, and the need for chlorides, etc.
- Investigate the benefits and risks of using liquids for anti-icing and deicing.
- Investigate how the presence of natural sunlight (vs. shaded areas) on a roadway affects needed salt applications, and how removing trees along a road may let in more sunlight and reduce the need for deicers.
- Investigate the cost-effectiveness of various chemicals used for pre-wetting.
- Investigate the cost-effectiveness of products based on agricultural derivatives and whether they can reduce environmental impacts.

Monitoring

- Develop a mobile salinity meter to assess residual chloride left on the pavement (from previous applications) to mitigate the need to place more material down during a storm.
- Determine how salt-tolerant vegetative species establish in areas of high salt use and monitor plant species and salt concentrations over time.
- Investigate chloride loading in roadside soils by proximity to the paved surface and how far the impact of chloride loading extends in roadside soils as a function of average annual usage of deicers.
- Monitor salt levels in soils around patrol yards.
- Monitor the effectiveness of salt management plans in protecting and preserving the natural environment (watercourses, groundwater, vegetation, etc.).

Strategies

- Update the FHWA guidelines for anti-icing and deicing so as to establish appropriate application rates to achieve an acceptable level of service (LOS) (e.g., measured by friction coefficients).
- Investigate the concept, feasibility, and implementation of incentive programs for more efficient winter maintenance practices or technologies that reduce chloride deicer usage. An example involved the Massachusetts Department of Transportation (DOT) rewriting specifications on equipment and providing a financial incentive to private contractors that complied with the new specification before it became mandatory.
- Determine the minimum amount of chloride needed to maintain critical interstate highways at an extremely high LOS, including at a “wet” condition throughout light to moderate snowfall. This would be based on current and future weather and pavement conditions, the data of which can be available in a MDSS-type application.
- Develop a written guide to the efficient use of road salt and chloride brines.
- Research the use of plants that can absorb salt from the roadside and be used as wildlife cover or harvested for use as a biofuel, and balance that with the potential risk of attracting wildlife to roadways.
- Identify performance measures for environmental and nonenvironmental winter maintenance operations that are feasible to measure and quantify.

Technology

- Develop an affordable pavement friction course that prevents bonding of snow and ice without the use of chemicals.
- Develop an MDSS-type weather service that monitors pavement conditions and recommends accurate material rates based on those conditions.
- Research better chemical products, as new technologies of modified salts would reduce the amount needed for performance and may be made of less corrosive chemicals.

- Develop improved sensors that measure parameters relevant to winter maintenance (e.g., pavement temperature, relative humidity, dew point, salinity).
- Develop a performance standard and winter severity index for MDSS.
- Investigate the effectiveness of spreading technologies.
- Improve thermal road mapping to simulate road temperature characteristics and assist highway supervisors in coordinating deployment of staff and materials.

In light of the literature review, continued research and monitoring are necessary before the short- and long-term environmental impacts of many deicers can be better understood and mitigated. Performance parameters for both proactive and reactive strategies can be easily defined, but are more difficult to measure. Further investigation into measurement methods for performance parameters is warranted. Currently, results-based standards are common practice for many DOTs and highlight the success of many programs. To develop results-based standards, reliable data are needed from record-keeping and other sources. Many DOTs would benefit from the development of a streamlined data collection and record-keeping system, which would enable the winter maintenance managers to assess the effectiveness of given strategies or practices in deicer environmental management and to help implement results-based standards. Accountability of salt use is an issue that some DOTs have taken on indirectly, as a result of tightening budgets. Another way in which DOTs have incorporated accountability into their programs is through the use of truck sensors and automatic vehicle location technology to track salt usage. This is an example of utilizing results-based standards to modify the approach to winter road maintenance practices.

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GLOSSARY

°C – degrees Celsius

°F – degrees Fahrenheit

AVL – automatic vehicle location

ARWIS – Advanced Road Weather Information Systems

BMP – best management practice

BOD_5 – Biological Oxygen Demand, the amount of dissolved oxygen consumed in 5 days by biological processes breaking down organic matter.

$CaCl_2$ – calcium chloride

DLA – direct liquid application

DOT – department of transportation

FAST – fixed automated spray technology

GIS – geographic information system

GPS – global positioning system

HMCV – Highway Maintenance Concept Vehicle

mph – miles per hour

LOS – level of service

MDSS – maintenance decision support systems

$MgCl_2$ – magnesium chloride

MOA – Municipality of Anchorage

MTO – Ministry of Transportation, Ontario

NaCl – sodium chloride

NYSSMDM – *New York State Stormwater Management Design Manual*

OFC – open friction course

PNSA – Pacific Northwest Snowfighters Association

RWIS – Road Weather Information Systems

SHRP – Strategic Highway Research Program

SMP – salt management plan

TAC – Transportation Association of Canada

APPENDIX A

Survey and Responses

SURVEY QUESTIONNAIRE

Please enter the date: _____

Please enter your contact information: _____

First and Last Name_____

Title _____

Agency/Organization_____

Street Address _____

Suite _____

City_____

State _____

Zip Code_____

Country _____

E-mail Address _____

Phone Number _____

1. Has your state or agency made any effort to mitigate or reduce the impacts of chloride deicers, either through reduced chloride deicer use of by reducing the impacts of the chlorides to the natural environment?

   ☐ Yes

   ☐ No

Please explain:

2. Does your state or agency have defined application guidelines or performance specifications for (please check all that apply)?

   ☐ Use of chlorides for winter maintenance practices (e.g., pounds/gallons per lane-mile)

   ☐ Tools or methods to determine the effectiveness of chlorides used in winter maintenance practices (e.g., success toward bare pavement)

   ☐ Tools or methods to quantify the environmental impacts of chlorides used in winter maintenance practices (e.g., monitoring browning trees, contaminated wells, etc.)

   ☐ Other (please explain):

3. If your state or agency has defined application guidelines or performance specifications for any of the items checked above will you be willing to provide these to the researchers?

   ☐ Yes

   ☐ No

   Upload files here (please provide a descriptive name for each file)

   Choose file Upload

4. Have you or your agency made any efforts in the last 5 years to reduce the amount of chloride deicers applied during winter maintenance operations?

   ☐ Yes

   ☐ No

   If yes or no, please explain.

5. If you answered yes to the previous question, do you have records and/or data on the implemented strategy that was designed to reduce chloride deicer use during winter maintenance operations (e.g., how many miles of highway implemented on, how many patrol yards implemented in, how many tons of chlorides saved)? If so can you provide these data?

   Chose File Upload

6. Has your agency made any official or unofficial policy changes to mitigate or encourage a reduction of impacts of chlorides from winter maintenance operations on the natural environment? (For example, incentive programs for reducing the amount of deicer applied, or once applied capturing the deicers.)

   ☐ Yes

   ☐ No

Please explain if yes or no, and label whether it is an official or unofficial policy.

7. Have you or your agency implemented any tools, techniques, practices, or strategies to reduce the impacts of chlorides on the natural environment?

   ☐ Yes

   ☐ No

If yes or no, please explain.

8. Please check all techniques, tools, or methods you/or your agency have used to reduce chloride roadway deicer use or the impacts of chlorides on the natural environment.

   ☐ Salt management plan

   ☐ Non-chloride-based chemical alternatives

   ☐ Staff training

   ☐ Monitoring/keep records on usage

   ☐ Road design

   ☐ Vegetation management

   ☐ Design and operations of maintenance yards

   ☐ Equipment and/or technology

   ☐ Anti-icing/deicing practices

   ☐ Snow storage and disposal

   ☐ Infiltration technologies (trenches, basins, etc.)

   ☐ Detention and retention ponds

   ☐ Wetlands and/or shallow marshes

   ☐ Vegetated swales and/or filter strips

   ☐ Filtering systems

   ☐ Other (please explain):

9. The survey asks specifically if you have experience using techniques, tools, and methods to reduce the impacts of chloride deicers on the natural environment. For any of the answers you provided within the questionnaire, were the techniques, tools, or methods originally put in place for reasons other than reducing the impacts of chlorides on the natural environment? (If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of reducing the impacts of chlorides on the natural environment.)

   ☐ Yes

   ☐ No

If yes, please explain.

10. Can you provide an example of a new technique or technology that you are using that reduces chloride deicer use or reduces the impacts of chloride deicers on the natural environment?

   ☐ Yes

   ☐ No

If yes, please explain to what degree the technique and/or technology has been implemented.

11. Can you please provide one example of a recommended research project that would benefit the field of winter maintenance, specifically in the area of mitigation of the effects of chloride roadway deicers on the natural environment?

12. Do you have a potential case study project that you would be willing to share detailed information about to illustrate important current and effective practices or lessons-learned by your organization?

   ☐ Yes

   ☐ No

If you responded yes to the above question please provide:

1. The name/location of the project?

1. Please describe what was done, the benefits and/or lessons-learned?

Thank you!

Thank you for taking our survey. Your response is very important to us. If you have any questions or comments, please feel free to contact Laura Fay at:

E-mail: laura.fay@coe.montana.edu

Phone: 406-600-5777

Mailing Address: PO Box 174250, Bozeman, MT 59717-4250

SUMMARY OF SURVEY RESULTS

The survey was sent to all state DOTs and to Canadian provincial transportation agencies. A total of 40 state DOTs responded with a response rate of 80%, and 12 Canadian provincial transportation agencies responded with a response rate of 100%. Figures A1 and A2 are maps with the location of responding states or provinces.

FIGURE A1 Map of the United States, showing where survey responses came from by state.

FIGURE A2 Map of Canada, showing where survey responses came from by province.

Responses to the survey are provided below.

Question 1. Has your state or agency made any effort to mitigate or reduce the impacts of chloride deicers, either through reduced chloride deicer use of by reducing the impacts of the chlorides to the natural environment? (yes, no, or other, please specify)

Of the 52 survey responses to this question, 88% responded yes, including all Canadian responses. Additional comments provided with survey responses are provided in Table A1 summary of comments to Question 1.

TABLE A1

SUMMARY OF SURVEY RESPONDENTS COMMENTS FOR QUESTION

Organization	Has your state or agency made any effort to mitigate or reduce the impacts of chloride deicers, either through reduced chloride deicer use or by reducing the impacts of chlorides to the natural environment? Please explain	
Alaska DOT & Public Facilities	Yes	The colder parts of the state from Anchorage to Fairbanks use chloride deicers (Mag chloride) that comes with an inhibitor. As for the wetter parts of the state like Juneau and Prince William Sound, use an additive at a rate of up to 30%.
Amarillo District - Texas DOT	Yes	Nothing formal, just trying to get by with less salt.
Arizona DOT	Yes	Calibrate our spreaders annually, educate our operators, developed a Winter Storm Management Operations Manual to try to determine the most effective application rates, and initiated a research study to try to correlate application rates with soil salinity, etc. Best Management practice is to use the least amount of product necessary.
California DOT	Yes	Expanding the use of Salt Brine and reducing the amount of rock salt being applied. (Use mag sometimes, states broken-up into 12 districts, district 2 near Redding uses mag chloride and have had good luck with it. Rest of state uses brine or salt. Have such a small area that use salt, only mountain passes. Storm levels 3000ft and above, or 5000 to 6000 ft and above. Use much less salt than back east. East side of California uses most material. Use rock salt because it holds up better. Are pushing to use more brine.
City of Calgary	Yes	Have had continual research into environmentally friendly chlorides that can reduce the amount of chloride applied and are organic in nature.
City of Toronto, Transportation Services	Yes	Salt Management Plan which speaks to staff training, equipment upgrades, salt storage practices, handling practices, application rates, use of liquids, etc. In use since 2002.
Colorado DOT	Yes	Yes, in my region of Colorado, use MDSS to suggest the most effective treatment types, application rates and timing. We have also reduced the amount of salt in our traction material and we increased our training to educate the operators.
Connecticut DOT	Yes	Apply chlorides under strict guidance and in accordance with our snow and ice guidelines which dictate application rates based on road temperatures. Also employee anti-icing techniques which helps reduce overall chloride usage.
Delaware DOT	Yes	Ground speed control, salt storage procedures, brine usage.
Government of Newfoundland and Labrador, Transportation Branch	Yes	Prewetting, Computerized spreader controls, RWIS sites, Training of managers and operators. localized forecasting specific to road networks, more salt storage coverage, mixing pads, etc.
Idaho Transportation Department	Yes	All liquid and granular chloride deicers purchased are required to meet PNS specifications. However, our internally manufactured liquid salt brine, NaCl is not corrosion inhibited.
Illinois DOT	Yes	Have implemented ground speed controls on all our trucks, provide training to employees on sensible salting and provide MDSS services to decision makers in our field staff.
Indiana DOT	Yes	Conducting a study on the application of liquid routes using salt brine as a deicer and not just as anti-ice. Using considerably less salt with this practice.
Kansas DOT	No	Have tried to reduce the impact of chlorides on our bridges. Using polymer overlays and different seal coats.
Kentucky Department of Highways	Yes	This year, have focused on reducing dry salt application rates primarily for overuse and monetary reasons.
Louisiana DOT	Yes	Louisiana has very limited need for deicing compared to the northern states. Exploring the use of non-chloride deicers and currently have procurement specifications allowing districts to use them.
Manitoba Infrastructure & Transportation	Yes	By using automated spreading systems and presenting our material we are able to use less product.
Maryland State Highway Administration	Yes	MDSHA focuses its efforts on training, equipment improvements, anti-icing, and improved data collection. It is piloting a MDSS program that should lead to salt reductions. Finally, it prepared a Statewide Salt Management Plan that serves as a Best Practices document for use by all highway agencies in Maryland.
Massachusetts DOT	Yes	Requiring Pre-wetting on all applications of solid deicer, converting our material spreaders to closed loop, and requiring all material spreaders to be calibrated.
Ministry of Transportation, Ontario	Yes	MTO has developed a Salt Management Plan as per the Environment Canada Code of Practice. MTO also continues to experiment with new technologies, methods and products reduce the impact of salt on the environment

Table A1 continued on p. 72

Table A1 continued from p. 71

Organization	Has your state or agency made any effort to mitigate or reduce the impacts of chloride deicers, either through reduced	
Ministry of Transport of Quebec	Yes	Since 2008, the MTQ has taken action to reduce the impacts of chlorides to the environment. Each year, actions are targeted, gathered together in a road salt management plan and implemented.
Minnesota DOT	Yes	MnDOT provides education, technology and research to its snow fighters. MnDOT is deploying MDSS technology to provide snowfighters with a recommended application rate that is based on the road condition and weather forecast. MnDOT uses alternative chemicals carefully while considering the merits and limitations of any new product. Public and legislative pressures.
Missouri DOT	Yes	Have continued to reduce our chloride use through lower application rates and addition of beet juice to keep more of the salt on the roadway.
Montana DOT	Yes	Impacts are reduced thru ongoing efforts to reduce usage.
Nebraska Department of Roads	Yes	Using other deicers.
New Brunswick Department of Transportation	Yes	Salt Management Plan in place Regular Salt Management training of staff Established guidelines for applications. Regular reports on salt use. Auditing of salt usage.
New Hampshire DOT	Yes	Have deployed RWIS, pre wet systems, training and new technologies.
New Mexico DOT	No	There has not been an interest to reduce chloride deicers or reduce the impacts of chlorides to the natural environment.
New York State DOT	Yes	Covered salt storage. Use ground speed controllers & annual equipment calibration. Use salt brine for pre-storm anti-icing. Limit truck speeds to 35 mph. Reduced initial salt application rates by 10%. Piloting MDSS on selected routes. Partnered with universities and other entities to study chloride reduction.
Nova Scotia Department of Transportation & Infrastructure Renewal	Yes	Developed a Salt Management Plan.
Nova Scotia Transportation and Infrastructure Renewal	Yes	Use brine to pre-wet salt when appropriate.
Ohio DOT	Yes	Monitor salt use so that only the minimum amount needed is used. The department has also developed a Material Application Guideline that provides use rates to managers and drivers.
Oregon DOT	Yes	OR DOT uses liquid magnesium chloride as an anti-icer for winter maintenance. Using liquid mag chloride has proven effective in limited quantities. Further, the ODOT Environmental Management System provides bmps for storage such as when to provide secondary containment.
Pennsylvania DOT	Yes	Reductions of salt use through using more salt brine for anti-icing and prewetting. Also through annual training which highlights applying the right amount at the right time.
Prince Edward Island Department of Transportation and Infrastructure Renewal	Yes	Pre-wetting salt (brine), monitoring application rates and staff training.
Rhode Island DOT	Yes	Increasing the number of closed loop spreader control systems on our fleet with AVL/GPRS. Offering a ""Green Incentive"" for our winter plow vendors to install similar AVL closed loop spreader controls. Continuing to construct enclosed salt storage structures. Implement proper application rates for sodium chloride use.
Saskatchewan Ministry of Highways and Infrastructure	Yes	Snowplow trucks equipped with electronic spreader controls to apply appropriate amount of deicers products. Improve the effectiveness of salts and sand applied on the road by using pre-wetting system.
South Carolina DOT	No	Don't have many winter storm events and often go years without significant snow fall.
Tennessee DOT	Yes	Adding Ground Speed Controllers to Salt Trucks.
Utah DOT	Yes	Have reduced chloride use by calibrating spreaders, using ground speed controllers, prewetting, anti-icing, and storm intensity/duration forecasting.
Vermont Agency of Transportation	Yes	Have a brine program that reduces the amount of chemicals used.
Virginia DOT	Yes	Stressing spreader calibrations, implementing an anti-icing program and stressing the need to follow application guidelines.
Volker Stevin Contracting Ltd.	Yes	All chlorides are stored in covered structures, including sand/salt mixtures. Operators are all given training in Salt Smart principles.
Washington DOT	Yes	Have experienced roadside vegetation impacts in high usage areas such as mountain passes. The browning of needles and leaves on certain tree species led to public and media inquiries about chloride use.
West Virginia Highways	Yes	Reduced application rates for road salt statewide starting in winter 2008.
Wyoming DOT	No	WY is an abrasive user and just getting into the chemicals for ice and snow control.

Question 2. Does your state or agency have defined application guidelines or performance specifications for: (please check all that apply) Use of chlorides for winter maintenance practices (e.g., pounds/gallons per lane-mile), tools or methods to determine the effectiveness of chlorides used in winter maintenance practices (e.g., success toward bare pavement), and tools or methods to quantify the environmental impacts of chlorides used in winter maintenance practices [e.g., monitoring browning trees, contaminated wells, etc.), or other (please explain).

Figure A3 shows states and agencies more frequently have defined application guidelines or performance specifications for use of chlorides in winter maintenance practices (95% United States and 91% Canada), than for tools or methods to determine the effectiveness of chlorides in winter maintenance practices (48% United States and 58% Canada), or tools or methods to quantify the environmental impacts of chlorides used in winter maintenance practices (28% United States and 33% Canada).

This clearly shows that there is a need to improve or create tools or methods to quantify the environmental impacts of chlorides used in winter maintenance practices.

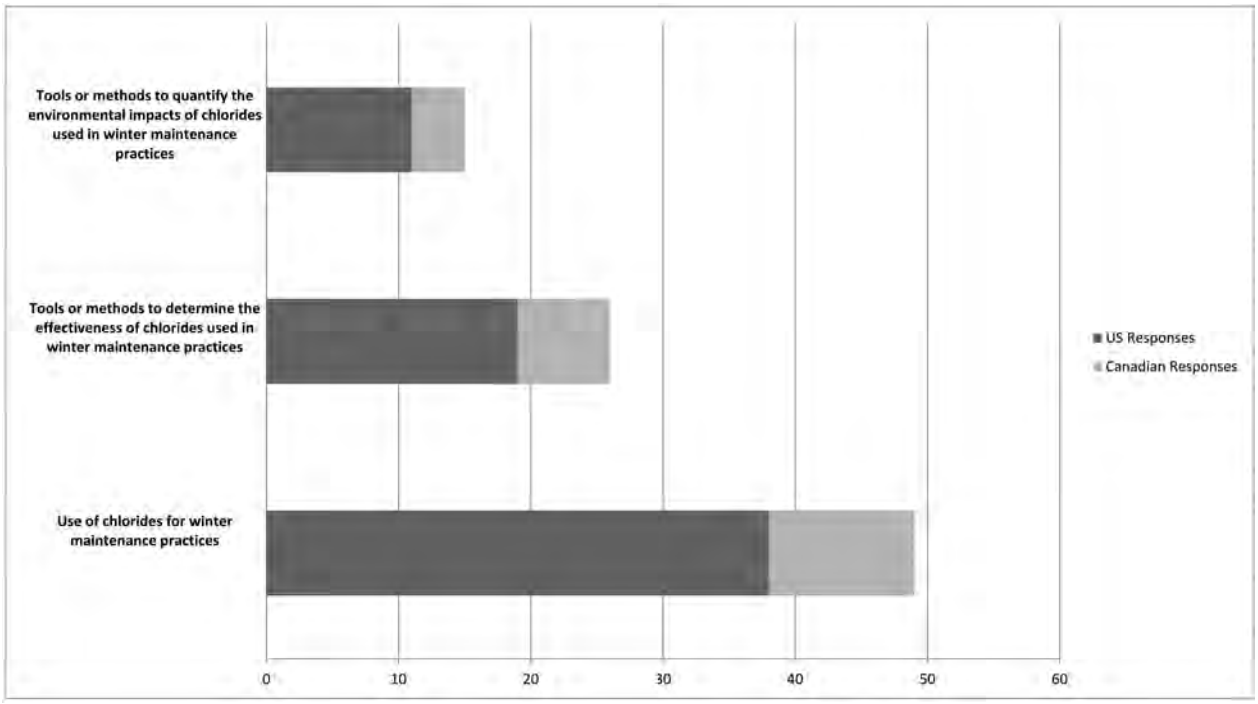

FIGURE A3 Summary of responses when asked if their state or agency has defined application guidelines or performance specifications for the use of chlorides for winter maintenance practices, tools, or methods to determine the effectiveness of chlorides used in winter maintenance practices, tools, or methods to quantify the environmental impacts of chlorides used in winter maintenance practice.

Respondents were asked to provide additional information in the Other category, and those comments can be found in Table A2.

TABLE A2
SUMMARY OF SURVEY RESPONDENTS COMMENTS FOR QUESTION 2

Organization	Other, please explain.
Alaska DOT & Public Facilities	Increasing costs have resulted in new strategies that include: 1) Improved targeting of known roadway problem areas 2) Conversion to salt brine 3) More pre-wetting in sand applications
Amarillo District - Texas DOT	Basic average application rates per lane mile as provided by suppliers.
Colorado DOT	Have guidance in our SOG for winter operations. We use MDSS to achieve our bare regain time LOS.
Idaho Transportation Department	Currently working on developing chloride application matrixes that will become part of our defined winter maintenance guidelines. Have developed a winter maintenance storm index and corresponding performance measure that is based on pavement grip from our RWIS sensors.
Illinois DOT	Have guidelines for salt application rates. Have a statewide RWIS system as a tool to determine effectiveness of chlorides.
Kansas DOT	Use the FHWA Manual of Practice for guidance on chemical application amounts.
Louisiana DOT	Use manufacturers recommendations to determine rates.
Ministry of Transportation, Ontario	MTO has a number of standard salt application rates depending on precipitation and temperature. Also have a bare pavement report and are working on a Winter Severity Index. Have a couple of projects starting to track chlorides in the water and mitigation opportunities
Ministry of Transport of Quebec	There are no defined application guidelines or performance specifications. There are only deadlines specified in contracts regarding snow removal and de-icing.
Montana DOT	Application rates are dependent on pavement temperature and precipitation as well as performance of the product applied. Operators have the latitude to determine appropriate application rates.
New Brunswick Department of Transportation	Granular salt
New Mexico DOT	There are general guidelines used to determine application rates.
Oregon DOT	ODOT does recommend standard application rates based on experience and manufacturers recommendations. In terms of determining effectiveness, currently fairly anecdotal. ODOT does have a level of service document that outlines level of service requirements. All tools are intended to help maintenance meet LOS requirements and standards.
Rhode Island DOT	RIDOT has a drinking water well contamination program administered by the Division of Highway & Bridge Maintenance. We use the FHWA/USACOE Manual of Practice for An Effective Anti-Icing Program as a guide for application rates. Make use of RWIS sensors to determine field data such as pavement temperatures.
Saskatchewan Ministry of Highways and Infrastructure	General guidelines are in place for salt applications but field staff use their discretion depending on the conditions encountered on the road. Various materials are recommended for use based on air temperature ranges.
South Carolina DOT	Tend to use the rates described in the snow fighters hand book. We do have 18 RWIS sites with sensors that give the chemical factor and thus help us to avoid the over application of salt when we do have a winter storm event
Vermont Agency of Transportation	Ground speed spreader controls are used along with daily operator log reports. Materials are closely monitored by supervisors and management. GPS tracking devise are used.
Volker Stevin Contracting Ltd.	The guidelines apply to ""typical"" storms. There are Level of Service guidelines for achieving ""good winter driving conditions"" based on ""typical"" storms. Have monitoring wells at each maintenance facility and an Environmental Management Plan for chlorides.
Washington DOT	Monitor over 100 sites statewide for chloride loading every spring and fall.
West Virginia Highways	pounds per lane mile.

Question 4. Have you or your agency made any efforts in the last 5 years to reduce the amount of chloride deicers applied during winter maintenance operations? (yes, no, or If yes or no, please explain)

Ninety- one percent (91%) (n total = 47, *n* = 35 in United States, *n* = 12 in Canada) responded yes, while 9% (*n* = 5 in United States) responded no. Survey respondents were then asked to explain a yes or no response, these comments can be found in Table A3.

TABLE A3
SUMMARY OF SURVEY RESPONDENTS COMMENTS FOR QUESTION 4

Organization	Have you or your agency made any efforts in the last 5 years to reduce the amount of chloride deicers applied during winter maintenance operations? If yes or no, please explain.
Amarillo District - Texas DOT	Basically use as little deicer as possible.
California DOT	By expanding our brine making capabilities, are using less sodium chloride than before. 1 ton of Bulk Salt makes 1000 gallons of brine. Normally apply 50 gallons of brine per lane mile as opposed to 200 pds of salt per lane mile.
City of Calgary	Looking into new products that are more organic less corrosive more effective at deicing. Looking into new machinery that are more efficient and less wasteful.
City of Toronto, Transportation Services	Greater use of liquids for anti-icing roadways and pilot testing non-chloride based deicers for specific conditions.
Colorado DOT	Reduction of salt in our sand, increased operators training and utilization of MDSS.
Connecticut DOT	Reduced salt usage through anti-icing methods and by monitoring application rates stated in our snow and ice guidelines.
Delaware DOT	Improved ground speed control, monitoring of salt usage, avl, brine anti-icing, pre-wetting.
Idaho Transportation Department	Actually seeing a slight increase in the use of chloride deicers as we transition from anti-skid material to deicing practices utilizing chlorides.
Illinois DOT	Operator and manager training.
Indiana DOT	On going studies to lower salt usage through various application practices and alternative products.
Kansas DOT	Have participated in the PFS MDSS since 2005. Have had a difficult time quantifying the success of this program.
Kentucky Department of Highways	Not until this current season. Last season, salt usage had reached an all time high with bad winter. Excessive salt usage drove annual costs very high.
Louisiana DOT	We have developed material specifications for non-chloride deicers and allow districts to purchase.
Manitoba Infrastructure & Transportation	By training our staff / Salt Smart training and providing automated equipment that is pre calibrated to provide a range of product applied which is capped at a maximum amount (kgs/km)
Maryland State Highway Administration	Produced Statewide Salt Management Plan, capture salt usage data by shop, snow route and truck in effort to identify both champions and excessive salt users, intensified Best Practices training for shop managers and front-line forces, joined MDSS Pooled Fund Study, perform post storm reviews, increased anti-icing and pre-wetting.
Massachusetts DOT	Yearly training for our personnel.
Ministry of Transportation, Ontario	MTO uses the Transportation Association of Canada Best Management Practices including reduced salt application rates with pre-wet or pre-treated salt, direct liquid application, electronic spreader controls, Road Weather Information Stations, Fixed Automated Spray Systems and Automated Vehicle Location and operation.
Ministry of Transport of Quebec	For example, 49 fixed road weather stations and more than 140 mobile road weather stations are made available to decision makers. Training sessions were held and others will be held again over the coming years so that users can use the devices to their full potential.
Missouri DOT	Primarily to reduce costs of winter operations.
Montana DOT	Thru ongoing operator training, equipment calibration, and improved delivery systems focusing on placement and retention of product. Our goal is to apply only the amount of product necessary to meet our needs.

Table A3 continued on p. 76

Table A3 continued from p. 75

Organization	Have you or your agency made any efforts in the last 5 years to reduce the amount of chloride deicers applied during winter maintenance operations? If yes or no, please explain.
Nebraska Department of Roads	Using other deicers
New Brunswick Department of Transportation	Updated Salt Management Plan Engaged industry experts in Plan update and training sessions. Reinforced benefits of salt management within the Snowfighters Training Program for operators Auditing of salt usage.
New Hampshire DOT	Along the I-93 corridor in southern NH, efforts to widen this section of roadway is being held up until the chlorides in 4 watersheds along the route are mitigated.
New Mexico DOT	There has not been an interest to reduce the amount of chloride deicers used during winter maintenance operations.
New York State DOT	Review and modify application guidelines and increased the use of salt brine for prestorm anti-icing. Ensure close salt application monitoring by management.
Nova Scotia Department of Transportation & Infrastructure Renewal	More attention paid to our Levels of Service. Make use of pre-wetting
Nova Scotia Transportation and Infrastructure Renewal	Through use of brine to pre-wet salt, review roads to ensure service provided is to our level of service and further expansion of RWIS sites.
Ohio Dot	Through educating our operators, using brine, increasing the amount of grits (crushed stone) in our salt and grits mix, and be reducing the maximum pounds of salt to be used on a roadway down to 400 lbs./lane mile.
Oregon DOT	Annual training made available by maintenance environmental section. Otherwise, no.
Pennsylvania DOT	Continue to reduce salt usage through monitoring and educational efforts.
Prince Edward Island Department of Transportation and Infrastructure Renewal	Began pre-wetting this year which allowed us to reduce application rates by 10%.
Saskatchewan Ministry of Highways and Infrastructure	Salt Management Plan was developed in 2005 to comply with applicable federal and provincial legislation regarding the use and storage of snow and ice control products. Application rates and methods of applications were described in the plan.
South Carolina DOT	Have looked into the use of automated controls for our spreaders to ensure that we are applying chemical at the desired rate.
Tennessee DOT	Adding Ground Speed Controllers to Salt Trucks and increased use of liquid salt brine instead of dry salt.
Utah DOT	Yes, have calibrated spreaders, begun using ground speed controllers, prewetting, anti-icing, and storm intensity/duration forecasting Compiling data for salt reduction would take some time as it would have to be mined from different sources. Only reported net salt usage reduction.
Vermont Agency of Transportation	By using many tools and materials such as brine to enhance the salt, grd speed controllers, pavement temp. RWIS stations we use Ice-Be Gone to enhance the salt in colder temperatures.
Virginia DOT	Implementation of state-wide anti-icing program.
Volker Stevin Contracting Ltd.	Currently using pre-wet for all of our snowplow trucks to seek to reduce usage. The pre-wet brines help keep the material on the road especially with wind and traffic trying to carry it off the highway.
Washington DOT	It is WSDOT policy to utilize the minimum amount of material necessary to achieve the desired outcome (LOS).
West Virginia Highways	Reduced application rates for road salt statewide.
Wisconsin DOT	Sort of, implemented MDSS statewide in 2009 with the hopes that it would reduce application rates.

Question 6. Has your agency made any official or unofficial policy changes to mitigate or encourage a reduction of impacts of chlorides from winter maintenance operations on the natural environment? (For example, incentive programs for reducing the amount of deicer applied, or once applied capturing the deicers.) (yes, no, and please explain if yes or no, and label whether it is an official or unofficial policy)

Fourteen responded yes (8 Canadian, 6 United States), and their comments can be found in Table A4.

TABLE A4
SUMMARY OF SURVEY RESPONDENTS COMMENTS FOR QUESTION 6

Organization	Has your agency made any official or unofficial policy changes to mitigate or encourage a reduction of impacts of chlorides from winter maintenance operations on the natural environment? (For example, incentive programs for reducing the amount of deicers applied, or once applied capturing the deicers.) Please explain if yes or no, and label whether it is an official or unofficial policy.	
City of Calgary	Yes	There has been both official and unofficial policies to control the amount of chlorides into the environment. Regulating applications rates such that there is no over application.
City of Toronto, Transportation Services	Yes	Council endorsed winter maintenance policies.
Idaho Transportation Department	No	However investigating and plan to implement policies and procedures to require the use of inhibitors in our internally manufactured salt brine (NaCl).
Kansas DOT	No	Use abrasive mixes widely across the state.
Louisiana DOT	No	Have no policies.
Manitoba Infrastructure & Transportation	No	Concentrating on training and equipment to reduce amounts used.
Ministry of Transportation, Ontario	Yes	A new Maintenance Best Practice was created with reduced salt application rates used in conjunction with pre-wet or pre-treated liquids. MTO's contracts have changed to requiring electronic spreader controls. New patrol yards and upgrades are designed and built with enhanced environmental protection
Ministry of Transport of Quebec	Yes	The MTQ provides the leadership of the Quebecer Strategy for an Environmental Road Salt Management. The strategy invites public administrations, as cities and municipalities, to do a better management of road salt by implementing a road salt management plan. The MTQ has also implemented a road salt management plan.
New Brunswick Department of Transportation	Yes	Currently implementing a pilot project to integrate salt use via gps tracking hardware/software. Implementation of an audit program.
New Hampshire DOT	No	No change in policy, just practices
New Mexico DOT	No	No official or unofficial policy changes have been made.
New York State DOT	Yes	Reduction in initial application rates for snow events (official). Use of MDSS on selected routes (interim policy). Ensure materials used meet established specifications (official)
Nova Scotia Department of Transportation & Infrastructure Renewal	Yes	Improved storage of deicers, improved house keeping at sites.

Table A4 continued on p. 78

Table A4 continued from p. 77

Organization	Has your agency made any official or unofficial policy changes to mitigate or encourage a reduction of impacts of chlorides from winter maintenance operations on the natural environment? (For example, incentive programs for reducing the amount of deicers applied, or once applied capturing the deicers.) Please explain if yes or no, and label whether it is an official or unofficial policy.	
Ohio DOT	No	We don't have a policy.
Oregon DOT	No	ODOT uses liquid mag chloride, at fairly low rates. No adverse impacts to the natural environment of significance have been noted, nor have complaints as such been received.
Pennsylvania DOT	No	Our treatment guidelines are just that, they are guidelines. Our operators face very different and diverse conditions across the state and there is no ""one size fits all"" solution.
Rhode Island DOT	Yes	RIDOT has a drinking water well contamination program administered by the Division of Highway & Bridge Maintenance. We use the FHWA/USACOE Manual of Practice for An Effective Anti-Icing Program as a guide for application rates. Make use of RWIS sensors to determine field data such as pavement temperatures.
Saskatchewan Ministry of Highways and Infrastructure	Yes	Providing salt smart training to staff, calibration of electronic spreader system, managing salt delivery and storage facilities to minimize impact on environment.
South Carolina DOT	No	Don't have many snow and ice events and often, can go years without a major event. Therefore, the use of road salt has had a minimal impact on our environment.
South Dakota DOT	Yes	Use of MDSS (Maintenance Decision Support System) for application rates and timing. Defined Level of Service for different road types.
Utah DOT	No	No policy to mitigate or encourage a reduction of impacts of chlorides from winter maintenance operations on the natural environment.
Vermont Agency of Transportation	No	Still working to establish this.
Virginia DOT	No	Have annual training for spreader calibration to assure application rates are as required and we encourage limiting application rate to others recommended by Best Practices Manual and national guidelines.
Volker Stevin Contracting Ltd.	Yes	Our contract has a ""footprint"" calculation which results in a payment from us if the quantities exceed the footprint value (running average) or a payment to us if the quantities are less than the footprint. Use of the footprint has to be balanced against potential winter maintenance liability issues.
Washington DOT	No	There is no policy specific to chloride reduction. Rather, it is policy to apply materials in an efficient and cost effective manner.

Question 7. Have you or your agency implemented any tools, techniques, practices, or strategies to reduce the impacts of chlorides on the natural environment? (yes, no, and If yes or no, please explain)

Sixty nine percent (69%) replied yes, while 31% replied no. Survey respondents that provided comments can be found in Table A5.

TABLE A5
SUMMARY OF SURVEY RESPONDENTS COMMENTS FOR QUESTION 7

Organization	Have you or your agency implemented any tools, techniques, practices, or strategies to reduce the impacts of chlorides on the natural environment? If yes or no, please explain.
Amarillo District - Texas DOT	Better calibration of equipment.
Arizona DOT	Basically the calibration of equipment and education of operators. Also selective removal of trees to reduce shading on highway.
City of Calgary	New sanders that can better place and regulate amount of chlorides being applied.
Colorado DOT	MDSS, increased training and reduction of salt in our traction sand.
Connecticut DOT	Reduced salt usage through anti-icing methods and by monitoring application rates stated in our snow and ice guidelines.
Illinois DOT	Supervisor and operator training on sensible salting.
Indiana DOT	Using a program MDSS as a tool to give our employees a scientific approach to remove snow & ice in an effort to prevent over application.
Kansas DOT	Our salt pollution controls are in the storage of salt. We try to cover all stored salt and prevent run off.
Kentucky DOT	In an effort to monitor salt usage rates, have installed AVL equipment on a sample of 20 trucks, participating in the MDSS Pooled Fund Study and adapted the Application Guidelines attached earlier to survey.
Louisiana DOT	Do not allow chloride deicers on certain structures over water bodies used for drinking water.
Manitoba Infrastructure & Transportation	Have developed a Salt Management. Plan for the province as well as a Salt Smart training program. This is also coupled with automated spreader systems.
Maryland State Highway Administration	Produced Statewide Salt Management Plan, capture salt usage data by shop, snow route and truck in effort to identify both champions and excessive salt users, intensified Best Practices training for shop managers and front-line forces, joined MDSS Pooled Fund Study, perform post storm reviews, increased anti-icing and pre-wetting.
Massachusetts DOT	Have reduced the amount of chlorides. Pre-treatment has also helped.
Ministry of Transport of Quebec	Road salt management plans -Mobile and fixed Road weather systems -Quality Assurance Guide for Road salt -Best Practices Guide for salt Storage Sites -Evaluation grid to analyze all the components of each Storage site and determine whether or not they comply with Best Practices -Training on different topics -Pilot projects - Information campaigns: meetings with police forces.
Missouri DOT	The reduction of chloride use.
Montana DOT	Thru ongoing operator training, equipment calibration, and improved delivery systems focusing on placement of product our goal is to apply only the amount of product necessary to meet our needs. At storage facilities we have constructed retention ponds to prevent chloride off site migration.
Nebraska Department of Roads	Using other deicers
New Brunswick Department of Transportation	Pilot project of integration of spreader distribution with gps tracking.

Table A5 continued on p. 80

Table A5 continued from p. 79

Organization	Have you or your agency implemented any tools, techniques, practices, or strategies to reduce the impacts of chlorides on the natural environment? If yes or no, please explain.
New Hampshire DOT	Training, training, training. Increased awareness and recordkeeping (spreader calibration, etc.).
New Mexico DOT	There has not been an interest in reducing the impacts of chlorides on the natural environment.
New York State DOT	Increase salt brine anti-icing. Modern and calibrated equipment. Maintenance management accounting system to monitor materials use and application rates. Annual operator training and ""snow universities"".
Nova Scotia Department of Transportation & Infrastructure Renewal	Controlling run off from storage sites using paved aprons, loading indoors where possible.
Nova Scotia Transportation and Infrastructure Renewal	Pre-wet salt; sand only in salt sensitive areas.
Ohio DOT	Yes, monitor our salt storage sites. Our goal is to reduce rain and surface water contact with salt storage piles. Storage facilities are designed to divert surface and rain water from entering our salt storage and cleaning up any spilled salt in our facilities.
Oregon DOT	Use of liquid magnesium chloride. Environmental Management System for source control at maintenance yards. We tried calcium magnesium acetate in the past, it did not work.
Pennsylvania DOT	The use of prewetting and anti-icing techniques have grown considerably in the last few years. Part of this is due to education and the other may be due to the rising cost of materials.
Prince Edward Island Department of Transportation and Infrastructure Renewal	Pre wetting and operator training.
South Carolina DOT	None other than looking into automatic controls for spreaders to ensure consistent application rates.
South Dakota DOT	MDSS
Tennessee DOT	Decreased dry salt use and increase in liquid salt brine.
Utah DOT	Yes - but a result of reducing salt operationally used not a result of natural environment policy initiative.
Vermont Agency of Transportation	We have limits of salt application rate at 800 lb per application.
Virginia DOT	We have several research projects ongoing but have not moved into implementation.
Volker Stevin Contracting Ltd.	All of our salt and other chlorides are in shelters or tanks and not exposed to the weather. There are procedures for delivery and unloading of salt and the handling of the sand/salt mixtures for winter operations.
Wisconsin DOT	AVL-GPS with MDSS
Wyoming DOT	WYDOT currently is just getting set up to apply Chlorides, so do not have any policies, practices, guidelines or equipment that would impact the natural environment.

Question 8. Please check all techniques, tools, or methods you/or your agency have used to reduce chloride roadway deicer use or the impacts of chlorides on the natural environment.

Figure A4 shows that staff training, anti-icing and deicing practices, monitoring or keeping records of material usage, and equipment and technology are most commonly used, followed by design and operation of maintenance yards and salt management plants. Almost all Canadian respondents mentioned that they use these techniques, tools, or methods, most of which can be classified as proactive measures to mitigate the impacts of chloride on the natural environment. Although the technologies that are considered reactive, mitigating the impacts of chlorides once they have reached the environment adjacent to the road, vegetated swales, filter strips, wetlands, shallow marshes, detention or retention ponds, etc., are mostly used in the United States and only by a few respondents. Additional comments are provided in Table A6.

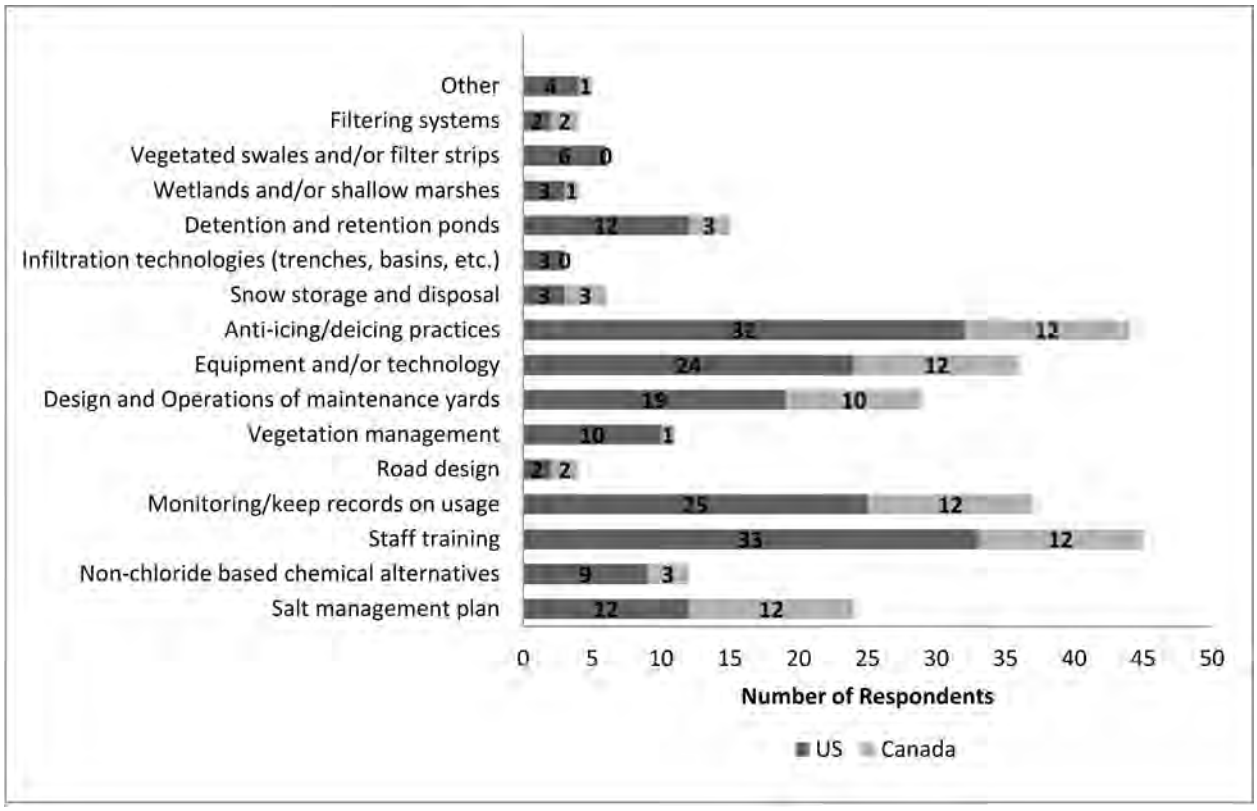

FIGURE A4 Summary of techniques, tools, and methods used by survey respondents to reduce chloride roadway deicer use or the impacts of chlorides on the natural environment.

TABLE A6
SUMMARY OF SURVEY RESPONDENT COMMENTS FOR QUESTION 8

Organization	Other, please explain.
City of Toronto, Transportation Services	Vehicle wash bay and wastewater recovery for brine production.
Idaho Transportation Department	Trying to implement an application matrix geared toward the correct application rate effectively reducing our use. Have always tracked usage of chlorides and continue to improve and implement our application equipment.
Indiana DOT	Constructed several fully contained material storage facilities for salt and liquids all one under roof.
New York State DOT	Living snow fence training for design and installations (vegetation management).
Washington DOT	Many of the above named mitigation features are in place for storm water treatment and are not specific to chloride intrusion, although they could conceivably serve that purpose.

Question 9. The survey asks specifically if you have experience using techniques, tools, and methods to reduce the impacts of chloride deicers on the natural environment. For any of the answers you provided within the questionnaire, were the techniques, tools, or methods originally put in place for reasons other than reducing the impacts of chlorides on the natural environment? (If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of reducing the impacts of chlorides on the natural environment.) (yes, no, and If yes please explain)

Of those that responded, 63% (United States *n* = 21, Canada *n* = 9) responded yes and 38% (United States *n* = 15, Canada *n* = 3) responded no. Comments provided can be found in Table A7.

TABLE A7
SUMMARY OF SURVEY RESPONDENTS COMMENTS TO QUESTION 9

Organization	This survey asks specifically if you have experience using techniques, tools, and methods to reduce the impacts of chloride deicers on the natural environment. For any of the answers you provided within this questionnaire, were the techniques, tools or methods originally put in place for reasons other than reducing the impacts of chlorides on the natural environment? (If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of reducing the impacts of chlorides on the natural environment.) If yes please explain.
Amarillo District - Texas DOT	Cost savings and providing operators training to better understand what and why they are using and the proper rates necessary.
Arizona DOT	Some were simply for cost savings.
Arkansas Highway & Transportation Department	Economics
City of Calgary	Streamline operations, reduce costs, and environmental impacts.
City of Toronto, Transportation Services	Financial savings with less salt use.
Colorado DOT	MS$ requirements and water quality in general.
Delaware DOT	Fiscal and operational pressures.
Government of Newfoundland and Labrador, Transportation Branch	Reducing salt means reducing cost of winter maintenance.
Idaho Transportation Department	The majority of the practices being implemented are efficiency driven which equates to a higher level of customer service while at the same time trying to reduce our overall expenditures associated with winter maintenance.
Indiana DOT	Lower operational cost.
Kentucky Department of Highways	Primarily to lower materials costs.
Manitoba Infrastructure & Transportation	Reducing the cost of winter maintenance by reducing the amount of material purchased.
MassDOT	Cost of materials increased and allowed MassDOT to push towards efficiency
Ministry of Transportation, Ontario	Many of the Best Management Practices, i.e. AVL, good housekeeping, etc. are good business management techniques which also have the added benefit of reducing environmental impacts.
Ministry of Transport of Quebec	Road weather stations were implemented first as tools to help decision makers to better plan operations. If the operations are better planned, it is possible to reduce the amount of road salts spread by using other technologies, other materials or simply to spread the right amount at the proper time.

Organization	This survey asks specifically if you have experience using techniques, tools, and methods to reduce the impacts of chloride deicers on the natural environment. For any of the answers you provided within this questionnaire, were the techniques, tools or methods originally put in place for reasons other than reducing the impacts of chlorides on the natural environment? (If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of reducing the impacts of chlorides on the natural environment.) If yes please explain.
Missouri DOT	The reduction of chloride use was to primarily reduce costs by using only the amount necessary to clear the roads. This reduction does have an impact on the natural environment.
Montana DOT	Our primary objective was to reduce sediment loading to adjacent watersheds.
New Brunswick Department of Transportation	Road Weather Information Stations on major highways that provide climatic characteristics, local area forecasts and web camera views to staff. Stations include road temperature sensors.
New Hampshire DOT	Monetary. Salt also costs a lot of money.
New York State DOT	In addition to environmental awareness and stewardship, a key consideration is cost reductions to compensate for significant budget cuts. New techniques and monitoring to reduce salt usage helps reduce costs in materials, operations and fuel use.
Ohio DOT	ODOT reduced the use of deicers to also save costs. The vegetative swales, retention detention ponds and other vegetative practices were installed.
Pennsylvania DOT	Many of the efforts were geared towards cost savings and the efficient use of materials.
Prince Edward Island Department of Transportation and Infrastructure Renewal	Reductions in budget and improved road safety.
South Dakota DOT	Cost savings thru reduced chloride use was the original intent. Environmental benefits
Tennessee DOT	Decrease in cost.
Utah DOT	Implemented salt reduction strategies to reduce operating costs.
Volker Stevin Contracting Ltd.	Apart from environmental impacts, cost is also a consideration to seek to reduce the overall cost of winter maintenance.
West Virginia Highways	Reduction of operating costs.
Wisconsin DOT	Our main effort has been to reduce the costs of chlorides by using them more wisely, by prewetting, and by implementing MDSS with AVL-GPS. The environmental aspects are a side affect and not the driving force.

Question 10. Can you provide an example of a new technique or technology that you are using that reduces chloride deicer use or reduces the impacts of chloride deicers on the natural environment? (yes, no, and If yes, please explain to what degree the technique and/or technology has been implemented.)

Figure A5 shows that the top three technologies, tools, or methods being implemented to mitigate the impacts of chlorides on the natural environment include (1) advanced material or ground speed controllers, (2) liquid anti-icing or pre-wetting, and (3) AVL/GPS. All three of these technologies, tools, and methods have been available and on the market for a number of years, and have had extensive research conducted and show positive cost/benefit correlations. Table A8 presents a summary of survey comments.

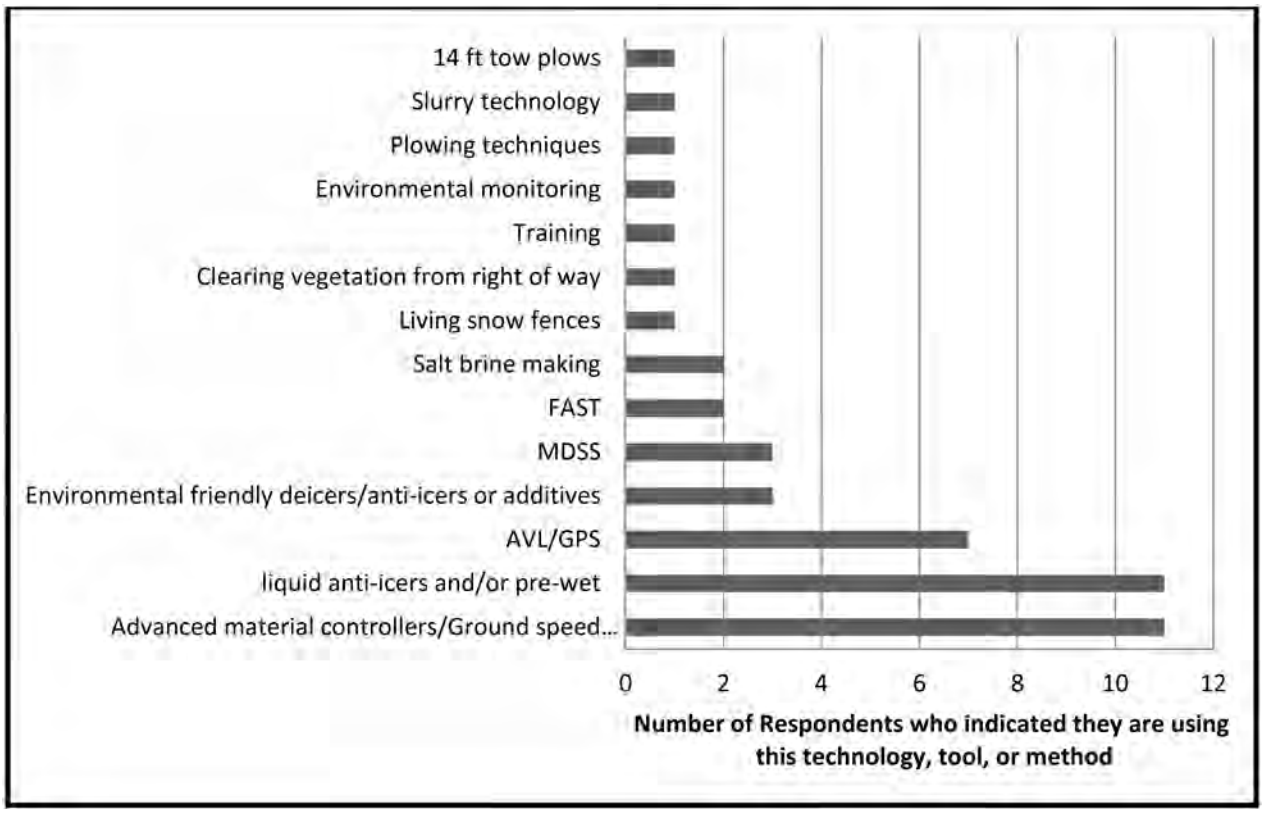

FIGURE A5 Summary of technology, tools, and methods newly implemented by survey respondents to mitigate the impacts of chlorides on the natural environment.

TABLE A8
SUMMARY OF SURVEY RESPONDENTS COMMENTS TO QUESTION 10

Organization	Can you provide an example of a new technique or technology that you are using that reduces chloride deicer use or reduces the impacts of chloride deicers on the natural environment? If yes, please explain to what degree the technique and/or technology has been implemented.	
Arizona DOT	Yes	Clearing of vegetation to daylight the roadway surface
City of Calgary	Yes	Looking into organic salt enhancer that reduces use of calcium chloride. Better sanders to maintain material application rates to keep efficiency. Monitoring and assessment to ensure environmental safety.
City of Toronto, Transportation Services	Yes	Use of liquids for pre-wetting and anti-icing; computerized spreader controllers
Colorado DOT	Yes	The use of the Maintenance Decision Support System, 14' plows and towplows to reduce the amount of times we cycle a road and therefore reduce treatment frequency of the road.
Connecticut DOT	Yes	In the past few years have been relying more on anti-icing practices; such as pre-treating selective roads and bridges with salt brine before the snow flies. This helps prevent the snow/ice pavement bond and in the long run helps us use less salt.
Delaware DOT	Yes	Anti-icing before snow events
Idaho Transportation Department	Yes	Have developed some ""Pilot"" application matrix.
Illinois DOT	Yes	Experimented with agricultural derivatives that can be added to salt brine or used to pretreat salt.
INDOT	Yes	Liquid/granular routes less salt used.
Kentucky Department of Highways	Yes	AVL equipment is showing a wide variance in application rates between trucks for the same event. Being able to adjust excessive rates would save a considerable amount of material.
Manitoba Infrastructure & Transportation	Yes	The use of automated spreading equipment. These units are calibrated every fall to ensure the parameters are correct. These units display the amount of material that is being applied and is speed compensated.
Maryland State Highway Administration	Yes	While SHA has been capturing salt usage at the shop level for years, it's in its 2nd year of data collection at the snow route and truck levels. It anticipates intensifying the collection through AVL/MDC. The goal is to identify excessive usage and correct it through using ""champions"".
Massachusetts DOT	Yes	Pre-Treatment with environmentally friendly deicer. Statewide. Pro-active approach to winter operations
Ministry of Transport of Quebec	Yes	The implementation of an alternative maintenance method which consists in reducing, in partnership with the authorities concerned, the quantities of salt spread (giving priority to abrasive spreading and intensifying snow scraping) to reduce the impact of de-icing salts on sensitive areas, while ensuring the safety of road users.
New Brunswick Department of Transportation	Yes	Currently digitizing plow routes and starting a pilot project with regards to integrating individual truck spreader with gps modules on individual trucks. Information will be tracked via a real time we portal.
New Hampshire DOT	Yes	By utilizing the suite of technologies and training, have been able to reduce chloride application, as compared to winter severity, by approximately 20%.

Table A8 continued on p. 86

Table A8 continued from p. 85

Organization	Can you provide an example of a new technique or technology that you are using that reduces chloride deicer use or reduces the impacts of chloride deicers on the natural environment? If yes, please explain to what degree the technique and/or technology has been implemented.	
New York State DOT	Yes	Piloting the use of MDSS on selected routes. If the anticipated benefits are achieved, hope to implement MDSS statewide. Investing in salt brine makers to expand the cost savings and environmental benefits of this technology. Use of living snow fence.
Nova Scotia Department of Transportation & Infrastructure Renewal	Yes	Piloting the use of anti-icing (application of salt brine) before a storm event.
Ohio DOT	Yes	Pre-wetting of rock salt at the spinner with salt brine reduces the bounce and scatter effect. As a result, more rock salt stays where it is needed. This results in the need for additional salt to be applied.
Rhode Island DOT	Yes	Closed loop spreader control systems equipped with Automatic Vehicle Location (AVL) which provides stricter control of application rates, location of applications, etc. was implemented in 2010-2011 and expanded in 2011-2012. This program is intended to reduce application rates at least 50% for the trucks equipped.
Saskatchewan Ministry of Highways and Infrastructure	Yes	Currently have pilot project under way using a system to apply deicer to salt prior to applying the salt to the road surface. Allows more of the salt to stay on the road surface lowering the application rates needed to be effective.
South Dakota DOT	Yes	MDSS
Tennessee DOT	Yes	Implementation of Ground Speed Controllers on Salt Trucks. Plan to have 90 percent installed before 2012/2013 winter.
Utah DOT	Yes	Using ground speed controllers to apply only the amounts of salt needed rather than all the salt the spreader can dump.
Vermont Agency of Transportation	Yes	Brine maker/machine
Volker Stevin Contracting Ltd.	No	Pre-wet is the newest technology being used. There is some discussion about using MDSS systems for assisting foremen with their winter maintenance decisions.
Washington DOT	Yes	Using a variety of technological tools which reduce chloride deicers impacts. Among these are AVL/GPS components to track material applications and results, advanced material controllers to efficiently apply materials, slurry technology, use of inhibited liquid anti-icers when and where appropriate.
West Virginia Highways	Yes	In the early stages of using brine for anti-icing, deicing, and pretreatment.
Wisconsin DOT	Yes	Not all of the counties prewet or have ground speed controllers. In the process of implementing AVL-GPS statewide and updating all trucks to closed loop ground speed controllers and working towards getting more operators to prewet their salt.

APPENDIX B

Case Examples

The information presented in the following four case examples—closed loop controllers, vegetation management, snow disposal and melting, and making salt brine from recycled vehicle wash bay water—is based on information gained from interviews of survey respondents that suggested the these or related topics. The case studies presented were selected because they represent a wide variety of proactive strategies that are being used currently.

CLOSED LOOP CONTROLLERS

Massachusetts Department of Transportation (MassDOT) provided information on the use of *closed loop controllers* and how implementing this technology reduced application rates of granular salt, providing savings of approximately 200,000 tons of salt equating to $10 million in cost savings. Estimated values for material savings come from measurement of buckets of materials used, material purchased and frequent calibration of controllers. Estimated cost savings was done by comparing similar winters using a winter severity index (for this analysis the winters of 2003 and 2011 were compared), past performance, and material usage. The 2011 data represents approximately 20% more roads than the 2003 data, while showing less material used.

Closed loop controllers monitor both vehicle speed and the belt or auger speed and adjusts how much material is released by the control valve so that a constant application rate of material can be achieved (Blackburn et al. 2008). Figure B1 is an example of one of the many closed loop controllers available on the market. MassDOT has experience using closed loop controllers from many different manufacturers.

FIGURE B1 A ground-based closed-loop spreader control (Photo: www.forceamerica.com).

The switch from open loop controllers that require drivers to alter the application rate of material based on their vehicle speed, to closed loop controllers allowed MassDOT to achieve its goal of applying 240 lb/l-m of salt. When using the open loop controllers, up to 500 lb/l-m of salt or salt-sand (50:50) was typically applied. The technology switch from open to closed loop controllers allowed for material used to be cut in half. One reason the application rates were higher when the open loop controllers were being used was over-application by the drivers, or the human factor part of this equation. The drivers were more comfortable with more material out on the road. By switching to the closed loop controllers and observing the performance of the 240 lb/l-m application rate of granular salt, the human factor was removed from the equation.

Another step that MassDOT took to reduce salt use was to evaluate whether the use of salt-sand (50:50, only used in designated Reduced Salt Zones) or granular salt was more effective based on current application rates. Results from interviews of MassDOT drivers found that salt-sand (50:50) was likely being applied on every pass, resulting in excess application of material, whereas granular salt was being applied less frequently. Therefore, more salt was actually being applied when the trucks were loaded with salt-sand (50:50). MassDOT is currently conducting a pilot study at select Reduced Salt Zone locations to change from salt-sand (50:50) to salt-sand (3:1) in an effort to reduce the amount of sand and salt used. MassDOT will continue to monitor closed loop controllers to see if it can continue to improve the efficiency and effectiveness of material application. If MassDOT can document these results with quantitative data, its goal then would be to go to using only granular salt.

MassDOT was able to invest in the closed loop controller technology as a result of rising material costs and a need to find savings wherever possible. Although the material and cost savings have been significant, having accountability and being able to report usage numbers to inquiring stakeholders is one of the driving forces behind incorporating the GPS/AVL component of the this technology.

Specifically at issue are the approximately 10 miles of 10-lane highway that go through the Cambridge, Massachusetts, watershed that is the water supply. The Cambridge watershed is considered environmentally sensitive. Extensive ongoing testing by the U.S. Geological Survey has found that sodium levels, while elevated, have not increased overtime.

As mentioned in the effective practices section, MassDOT developed a financial incentive program for contractors that were willing to switch to the new closed loop controller technology in the first 3 years it was specified. The incentive was an additional $16 per hour for each truck with the new technology installed. After 3 years, MassDOT required all contractors to have this technology in their trucks, at which time the incentive ends. The amount of the financial incentive was calculated and based on cost-savings related to implementation of the new technology.

A report will be developed for MassDOT within the next 2 years that will document the challenges, issues, and recommendations for statewide implementation of the closed loop controllers and the addition of the GPS/AVL system.

Additional Resources

Blackburn, R.R., E.J. Fleege, and D.E. Amseler (Blackburn and Associates), *Calibration Accuracy of Manual and Ground-Speed-Controlled Salters*, ClearRoads Final Report, CR2005-02/0092-06-21, Feb. 2008 [Online]. Available: http://www.clearroads.org/files/06-21CalibrationFinalReport.pdf.

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VEGETATION MANAGEMENT

The Maintenance Operations Branch Manager for Washington Department of Transportation (WSDOT) provided information on browning of conifers along mountain passes in the state of Washington. A constituent brought the issue to the attention of WSDOT. WSDOT, with the help of a forest pathologist, investigated the issue and found that chloride-based deicers were causing some needle and tree browning along narrow mountain passes under severe weather conditions (Figure B2, *a* and *b*).

FIGURE B2 (a and b) Needle browning caused in part by chloride-based deicers, Blewett Pass, Washington (Photos: M. Mills, WSDOT).

It was speculated that deicers applied to the mountain pass roads were being sprayed and or plowed off the road onto adjacent trees. To address the constituents concerns WSDOT initiated an investigation that took place over 1 year in which a forest pathologist and WSDOT employees surveyed mountain passes for tree browning, collected soil and water samples, and looked for bark beetle infestations. The needle browning and tree death issues were confined to specific mountain passes where the largest quantities of chloride-based deicers were being used, and was more visible on the narrow passes where trees had encroached into the highway right-of-way. WSDOT observed some grand fir and douglas fir tree deaths and theorized that these may have been due in part to root uptake of chlorides. It was determined that road spray, including chlorides from deicers, was ballooning out into the surrounding environment. Other contributing factors to the conifer browning included bark beetles, parasites, and unique climactic conditions (e.g., severe winters, drought conditions).

Based on the report findings, trees were being damaged by applied chloride-based deicers in part as a result of the trees being too close to the roadway. From this finding, WSDOT began a tree removal program to the clear the right-of-way adjacent to the mountain passes. Weakening of the trees owing to bug infestation and disease made the trees more vulnerable to chloride impacts. Most chloride impacts to vegetation were temporary, such that the needles were regenerating over the summer with the exception of some smaller trees. WSDOT now monitors 45 sites state-wide for chloride loading in the spring and fall collecting soil and water samples.

WSDOT clearly stated that safety of the road user is there primary focus, while also working to minimize chloride loading in the adjacent environment. To accomplish this, it uses a variety of chloride-based deicers (sodium, calcium and magnesium chlorides), pretreating roads (anti-icing) in advance of freezing temperatures and snow events in order to apply less deicer, training operators in effective practices, improving equipment calibration, and gathering and tracking data on deicer applications.

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SNOW DISPOSAL AND MELTING

The Director of the City of Toronto Transportation Services provided information on the snow removal, disposal and melting program they have in place. The city of Toronto has an active winter maintenance program every winter, but every few years when they have storms with heavy snowfall they have to pick up snow and take it off-site to designated snow disposal and melting areas. As the snow piles melt, the city of Toronto is tasked with cleaning up the remaining debris and trash and uses appropriate stormwater treatment techniques, or BMPs, to filter debris and sediment out of the snow melt. This snow can be contaminated with deicers, oil, grease or heavy metals, litter and debris, or dirt and other airborne pollutants (TAC 2003h). Currently, there is no practical or economical way of removing chlorides from roadway deicers found in the snow (TAC 2003h).

Recently, owing to development pressures within the city of Toronto, Transportation Services has lost some of the designated snow storage and melting sites and for this reason has moved in the direction of more limited snow stockpiling and using snow melters at only a few strategic snow stockpiling sites (Figure B3). The city of Toronto is currently working to develop a new and updated snow disposal and storage strategy that will meet the snow stockpile and melting needs but also have all of the required environmental approvals.

FIGURE B3 (*left*) A snow melter in use by the city of Toronto staff during the winter of 2007/2008; (*right*) another snow melter in use by the city of Toronto staff during the winter of 2010/2011 (Photos: City of Toronto, Canada).

The city of Toronto currently uses three large stationary snow melters that were purchased in the past 3 years, and two mobile snow melters that were purchased in the 1970s. The city has four main snow disposal sites, and a smaller fifth site for one of the snow melters. The city of Toronto does not use the snow melters every year; it only uses the snow melters when it runs out of capacity to store the snow until it can melt on its own.

Important issues that the city has dealt with include—

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

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 with a snow melter (TAC 2003h). When choosing a location to operate 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.
- Managing 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 2003h).

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 (TAC 2003h). This can be done using onsite monitoring equipment or samples 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 2003h).

The Municipality of Anchorage (MOA) conducted a 4-year study (1998–2001) of snow disposal sites and found three factors that related to how pollutants are released during snow melting:

- The initial source of hauled snow,
- The melt processes of stored snowfall, and
- The shape of the snow storage areas and the snow fills (Wheaton and Rice 2003).

The 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.

Members of Environment Canada and the Road Salt Working Group formed a working group to assemble the first *Synthesis of Best Practices, Snow Storage and Disposal* manual of current and effective practices used internationally. It provides local municipalities with basic guidelines that can then be tailored to fit site-specific needs. The Transportation Association of Canada (TAC) is currently working to update this manual.

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MAKING SALT BRINE FROM RECYCLED VEHICLE WASH BAY WATER

Water from the cleaning of snow and ice control equipment may have a wide range of contaminants, including oil and other hydrocarbons, metals, detergents, road salts, and grit. When contaminants are discharged into surface waters, they can have negative impacts on water quality and aquatic life (Venner Consulting and Parsons Brinckerhoff 2004). "As such, it is important to collect, reuse, or properly manage vehicle wash water and salt-impacted site drainage so as to comply with local water quality regulations and protect surface and groundwater resources" (TAC 2003g). In order to minimize material wastage and environmental impacts, TAC (2003g) provided a list of practices to follow for vehicle wash water.

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 may be decreased from this practice.

The city of Toronto installed a dual-lane flow-through washbay facility for its salt trucks, which removes chloride residue left on the trucks or chassis (Figure B4). The wash water is collected, cleaned by removing the oil and grit using separators, pumped into a tank(s) to settle out any solids, and finally pumped into holding tanks to make salt brine (Figure B5). The city of Toronto has found that it is important to measure the chloride concentration of the recovered vehicle wash water so that it can accurately make a batch of salt brine with the recycled water.

FIGURE B4 A tandem-axel salt truck being washed off following a salt spreading operation. Washwater is then 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 alternative product (*Courtesy*: City of Toronto).

FIGURE B5 The interior of a brine making facility which houses six 5,000-gallon storage tanks, a mixing vessel that holds up to 3 tons of rock salt, and a valve control panel (*Courtesy*: City of Toronto).

The equipment used for making brine solution from recycled truck wash water includes an oil-water separator with an accompanying overflow diversion box and pump, retention tank for wash water collection, brine making tank, storage tank(s), and pumps (Alleman et al. 2004). Plumbing can be set up in a way that recirculation of brine can be done in both the brine making tank and the storage tank. Flexible hose with appropriate couplings can be attached to the storage tank for transfer of brine to the truck saddle tanks. A hydrometer can be used to measure salt content. The salt brine solution should be stored at no less than the eutectic percentage between 23% and 24%. Because of the corrosive nature of salt brine, all containers, equipment, and plumbing in contact with wastewater and brine solution may need to be made of corrosion resistant materials. Consider cleaning and flushing pumps with fresh water at the end of the winter season to extend the life of the pump.

Also, consider housing the brine making operation indoors at or near the wash bays to facilitate operations and prevent freezing of salt brine (Alleman et al. 2004). Ideally, the brine storage tanks can be placed indoors if cold enough temperatures are present. The brine-making system and storage tanks can be placed on concrete or other nonpermeable pads. A secondary containment dike is suggested and may be required by local regulations to contain spills.

Other examples of using recycled vehicle wash water to make salt brine include the efforts of Colorado, Virginia, and Indiana DOTs presented here.

In 2009, maintenance section staff at Colorado DOT (CDOT), 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 floor 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.

Virginia DOT (VDOT) 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 using recycled runoff with the option of hauling away the runoff. Using only those savings, Craver et al. (2008) found that recycling was determined to be feasible, with all capital costs recovered within 2 to 4 years depending on the severity of winters and the average amount of salt used. Based on these findings, VDOT is moving toward a goal of recycling its entire collected runoff, an estimated 60 million gallons (Salt Institute 2010). In average years, this amount will supply the entire water content for all the brine the agency will make, an added environmental and cost-savings bonus.

INDOT 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. INDOT had a 750-gallon brine manufacturing tank, a 2,200-gallon brine storage tank, and the capability to make 1,000 gallons of brine per hour. From 2000 to 2001, approximately 3,600 gallons of salt brine were produced for pre-wetting. Initially, on-board strainers on the truck pre-wetting systems became clogged by solids from the brine made with truck wash water. To correct this, a finer mesh (100) strainer was added to the brine storage tank delivery line and solved the problem. Starting in 2003, the brine from truck wash water also started to be used for anti-icing. The Monticello Sub-District Unit, found that the oil and grease separator was not efficient at removing the oil and grease. No solution was provided for this. By 2004, 6 of the 33 brine-making facilities established by INDOT were set up to use truck wash water to make brine.

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CASE EXAMPLE QUESTIONNAIRE

Date/Time: _____

Name of Interviewee: _____

Agency: _____

Title: _____

Name and quick overview, description of case study/example

Would you say this is an example of as best practice or a lesson-learned?

The details

State/Province: _____

Site location(s) _____

Issue at hand _____

Tools, technology, strategy implemented _____

Cost/Benefit data _____

Level of implementation and time it took to implement _____

Photos/Reports/Publications _____

Additional Comments _____

Can we thank you formally in the final report? Yes/No _____

Thank you for your time.

Cast Example Interviewees

Colorado Department of Transportation (CDOT)

Rhode Island Department of Transportation (RIDOT)

Massachusetts Department of Transportation (MassDOT)

California Department of Transportation (Caltrans)

Washington Department of Transportation (WSDOT)

City of Toronto Transportation Services

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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