Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America

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16. Abstract

Winter highway maintenance practices in North America have traditionally been based on reactive strategies (such as *deicing* and *sanding*) where the launch of maintenance operations relied on signs of snow and ice accumulation. In the past decade or so, an improved approach termed *anti-icing* has been adopted by winter maintenance personnel, which is the early application of chemicals to help prevent black ice and prevent or weaken the bond between ice and the roadway surface. While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used. Another innovative practice in winter road maintenance is termed *pre-wetting*, i.e., the addition of a liquid chemical to an abrasive or solid chemical before it is applied to the road. The pre-wetting of solids is performed either at the stockpile or at the spreader.

As improved maintenance strategies, anti-icing and pre-wetting are seeing increased implementation in North America. One of the greatest challenges of implementing these practices has been the misunderstanding of the benefits and outcomes of their use. Members of the general public and organized groups such as trucking associations have been critical of these strategies, which may be a result of insufficient information, limited understanding and speculation. Therefore, research is needed to synthesize the information on these strategies in an objective manner.

Through this project, the authors synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion, costs, etc.

The research indicates that compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates. Anti-icing has been recognized as a pro-active approach to winter driver safety. Pre-wetting has shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required.

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EXECUTIVE SUMMARY

In the northern states and Canada, transportation agencies face a difficult challenge to keep roadways open and safe during heavy snowfall, low visibility, and icy conditions. Each winter, large amounts of solid and liquid chemicals, along with abrasives, are applied onto the roadways to keep roads clear of ice and snow. The widely used chemicals include: sodium chloride, calcium chloride, magnesium chloride, potassium acetate, calcium magnesium acetate, and agricultural byproducts. They can melt ice and snow by lowering the freezing point of the snow-salt mixture.

Winter highway maintenance practices in North America have traditionally been based on reactive strategies where the launch of maintenance operations relied on signs of snow and ice accumulation. After snowfall, the *deicing* process uses granular materials that penetrate accumulated snow and ice in order to break the bond that has formed with the roadway. Once the bond is broken, the layer of snow and ice can be easily removed by mechanical means such as snowplows. In addition, through *sanding* operations, abrasives such as sand are applied onto the roadways to provide temporary traction in slippery conditions. Such reactive strategies are generally reliable and well understood.

One concern regarding reactive maintenance practices is the increased potential for accidents and injuries due to poor road conditions while maintenance crews are being deployed. Another problem with reactive practices is the quantity of materials and labor hours needed to maintain the desired level of service for winter roadways.

In the past decade or so, an improved approach termed *anti-icing* has been adopted by winter maintenance personnel, which is the early application of chemicals to help prevent black ice and prevent or weaken the bond between ice and the roadway surface. While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used. Another innovative practice in winter road maintenance is termed *pre-wetting*, i.e., the addition of a liquid chemical to an abrasive or solid chemical before it is applied to the road. The pre-wetting of solids is performed either at the stockpile or at the spreader.

As improved maintenance strategies, anti-icing and pre-wetting are seeing increased implementation in North America. One of the greatest challenges of the implementation has been the misunderstanding of the benefits and outcomes of their use. Members of the general public and organized groups such as trucking associations have been critical of these strategies, which may be a result of insufficient information, limited understanding and speculation. Therefore, research is needed to synthesize the information on these strategies in an objective manner.

The Pacific Northwest Snowfighters Association (PNS) was formed by technical experts from Idaho, Montana, Oregon, Washington, and British Columbia and later joined by Colorado to address the needs of winter highway maintenance with environmentally-friendly and fiscally-responsible solutions and to develop specifications for winter maintenance chemicals. The mission of PNS is "to serve the traveling public by evaluating and establishing specifications for products used in winter maintenance that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness and performance."

Through this project with PNS, the authors at the Western Transportation Institute at Montana State University (WTI) synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion, costs, etc.

The research indicates that compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates. Anti-icing has been recognized as a pro-active approach to winter driver safety. Pre-wetting has shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required.

The information in this report will benefit maintenance agencies and transportation officials who seek to fully understand the benefits derived from improved winter maintenance technologies, identify areas for improvement within their own jurisdiction, and learn about related experiences from other agencies.

1. INTRODUCTION

1.1 Background

Inclement weather has a major impact on the strategic objectives of transportation agencies, including: safety, mobility, economics, and the environment. In cold-climate regions such as the northern states and Canada, winter maintenance is often the activity of highest priority for transportation agencies. These agencies face a difficult challenge to keep roadways open and safe during heavy snowfall, low visibility, and icy conditions.

During the winter season, large amounts of solid and liquid chemicals along with abrasives are applied onto winter roadways to keep them clear of ice and snow. The most common chemicals include sodium chloride, calcium chloride, magnesium chloride, potassium acetate, calcium magnesium acetate, and agricultural byproducts. These chemicals can melt ice and snow by lowering the freezing point of the snow-salt mixture. Abrasives (such as sand) are applied to increase the traction between the icy road and a vehicle's tires.

With the growing use of chemicals and abrasives for snow and ice control, there have been growing concerns over their environmental impacts and corrosion effects. It has been shown that repeated applications of winter maintenance chemicals and abrasives may adversely affect the surrounding vegetation, water bodies, aquatic biota, and wildlife (Mussato et al., 2003; Buckler and Granato, 1999). Motorists and trucking associations have become wary of winter maintenance chemicals on their vehicles as signs of corrosion, especially to aluminum parts, have been documented. In addition, chemicals may cause corrosion damage to the transportation infrastructure such as paved surfaces, reinforced or pre-stressed concrete structures, and steel bridges (FHWA, 2002).

One study estimates that road salt imposes infrastructure damage costs of at least $615 per ton, vehicular corrosion costs of at least $113 per ton, aesthetic costs of $75 per ton if applied near environmentally sensitive areas, plus uncertain human health costs (Vitaliano, 1992). It should be noted, however, these estimates do not represent the snow and ice control operations in the Pacific Northwest, where stringent requirements have been implemented for winter maintenance chemicals and new chemicals and improved maintenance practices have been continuously sought to minimize their corrosion and environmental impacts.

To address the needs of winter maintenance with environmentally-friendly and fiscally-responsible solutions, transportation agencies within the states of Washington, Oregon, Montana and Idaho and the province of British Columbia formed a committee several years ago to develop specifications for chemicals related to snow and ice control. This committee has evolved to become the Pacific Northwest Snowfighters Association (PNS), later joined by the state of Colorado. The association is comprised of technical experts in the fields of chemistry, environment, maintenance operations and management, insurance law and claims, public affairs and purchasing. The association has developed specifications for nine categories of snow and ice control chemicals, including performance specifications for corrosion inhibitors. Chemical specifications and stringent quality control guidelines help users identify the best products available, and by joining forces, the association hopes to increase product quality and lower costs. The mission of PNS is "to serve the traveling public by evaluating and establishing specifications for products used in winter maintenance that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness and performance”.

This report will review and synthesize information on using anti-icing and pre-wetting methods for winter maintenance with a focus on the PNS states and provinces. The report aims to deliver a better understanding of anti-icing and pre-wetting strategies in terms of benefits and constraints so that the public, maintenance agencies, and organized groups such as trucking associations are more informed about such operations. The ultimate goal is to help transportation agencies maximize traveler safety, improve levels-of-service, mitigate environmental concerns, identify cost savings, and improve public relations.

1.2 Benefits of Winter Highway Maintenance

In the northern states and Canada, snow and ice control operations are crucial to help ensure the safety of traveling motorists on winter highways. Snow and ice control methods allow maintenance agencies to keep the road system safe, mobile, and productive, striving to ensure that:

- Traveler safety is maximized by the reduction of vehicular accidents and associated fatalities and injuries;
- Merchandise and services can arrive to their destinations throughout the winter;
- Emergency service vehicles can continue to provide timely response and assistance;
- Travelers can access winter recreation activities and support the local tourist economy; and
- Daily routines are uninterrupted.

These winter highway maintenance activities offer such direct benefits to the public as fewer accidents, improved mobility, and reduced travel costs. In the state of Washington, it was found that “crash frequency in the presence of snow was five times the rate under clear conditions”. A comparison of crash rates between winter and summer revealed that January had 12 times the accidents as July (Goodwin, 2003). In addition, for Washington State, it was found that 8% of the accidents that resulted in injury or fatality during a five-year period (1991 to 1996) occurred on snowy, icy roads (Boon and Cluett, 2002). In a case study in Iowa, it was found that during severe winter weather events, accidents increased by 1,300 percent and traffic volume decreased by 29 percent on a roadway segment 30 miles long (Knapp et al., 2000). While this 30-mile segment is not representative of all winter roadways, the observations generally arrive at a similar trend of accidents increasing and average daily traffic volumes decreasing in the presence of snow and ice.

Winter storms are also costly to the traveling public in terms of fuel economy. Studies in both Canada and U.S. show that on average, winter driving requires 33% more fuel (Transportation Association of Canada, 2004). Fuel economy decreases with colder temperatures, slick roads, and snow buildup on vehicles, especially around tires. It is estimated that a short winter trip may consume 50% more fuel than the identical trip driven in the summer (Natural Resources of Canada, 2004).

Indirect benefits of snow and ice control operations include: reduction in accident claims, sustained economic productivity, continued emergency services, etc. In one study, it was found that costs associated with accidents decreased by 88 percent after deicing salts were applied (Marquette University, 1992).

Investing in clear roads is essential and beneficial to the public as well as the economy, since the U.S. and Canadian economies cannot afford the risk of shutting down the winter highways. Society has grown accustomed to year-round travel on “bare pavement” conditions, and the economy relies on it. The cost of road closure is far greater than the cost of winter highway maintenance activities. From one economic study, it was found that “failure to get snowplows out and salt on the roads during a single day of a winter storm costs almost three times more in lost wages than the total annual costs for snowfighting” (Salt Institute, 1999). In a recent incident, a winter storm blanketed Oregon from the end of December 2003 into January 2004. Heavy snow accumulation, wind, freezing rain and bitter cold temperatures forced road closures on many state highways and interstates, leaving many motorists stranded and paralyzing the region. As a result, many businesses and schools were closed and major disaster areas were declared for 30 of Oregon’s 36 counties (State of Oregon, 2004). A region paralyzed by winter weather is costly in terms of lost production, sales, and wages. Another example of a winter storm hindering the U.S. economy occurred in 1996 when a blizzard shut down much of the northeastern U.S. for four days. The loss in production was estimated to be approximately $10 billion and the loss in sales was estimated to be $7 billion (Salt Institute, 1999). Even these values do not account for accidents, injuries or other associated costs.

1.3 Costs of Winter Highway Maintenance

Winter highway maintenance is costly, but the traveler safety benefits alone have the potential to dwarf all the direct and indirect costs associated with snow and ice control operations. Overall, the U.S. spends over $2.3 billion dollars annually on snow and ice control operations (FHWA, 2005). The northwestern states of Colorado, Idaho, Montana, Oregon and Washington are part of the PNS association and comprise 5% of this direct cost at $114 million (estimates based on the questionnaire results).

Figure 1 and Figure 2 show the costs of winter maintenance for fifteen states and provinces in the snowbelt region of North America[1]. Figure 1 includes the participating states and provinces in the PNS Association while Figure 2 includes non-participating states and provinces for which data were available.

[1] These values include labor, materials, and equipment costs, but not risk management or litigation costs.

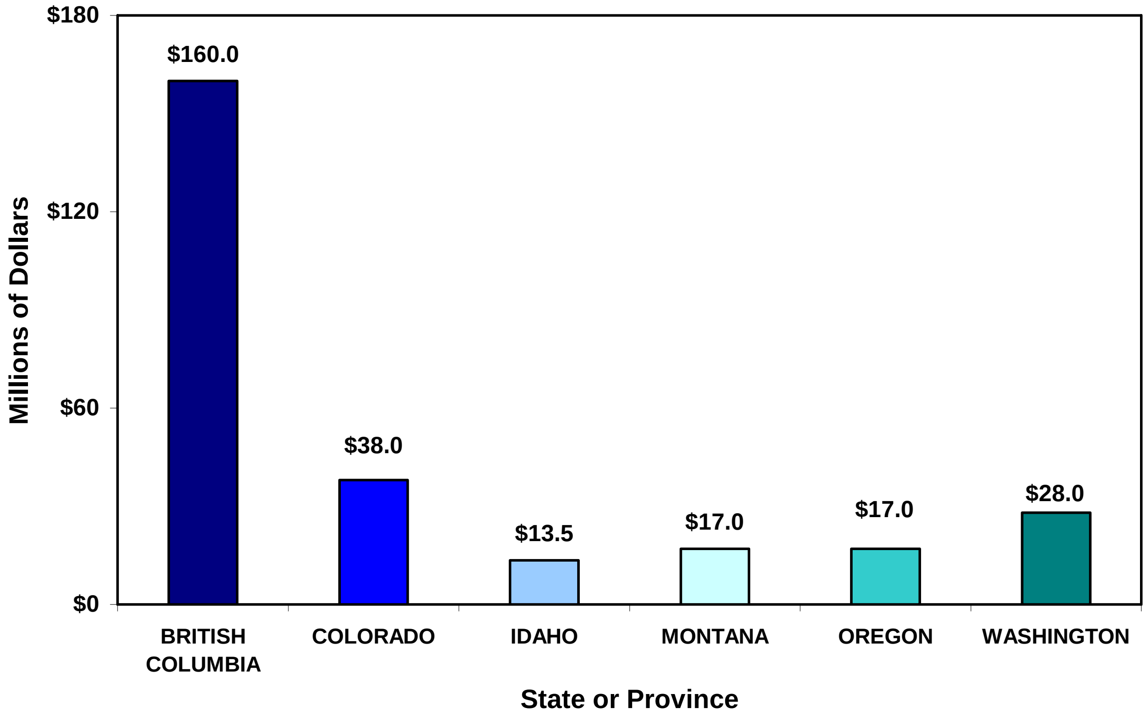

Figure 1: Annual Snow and Ice Control Cost for the Six PNS Participating States or Provinces (in US $, millions)

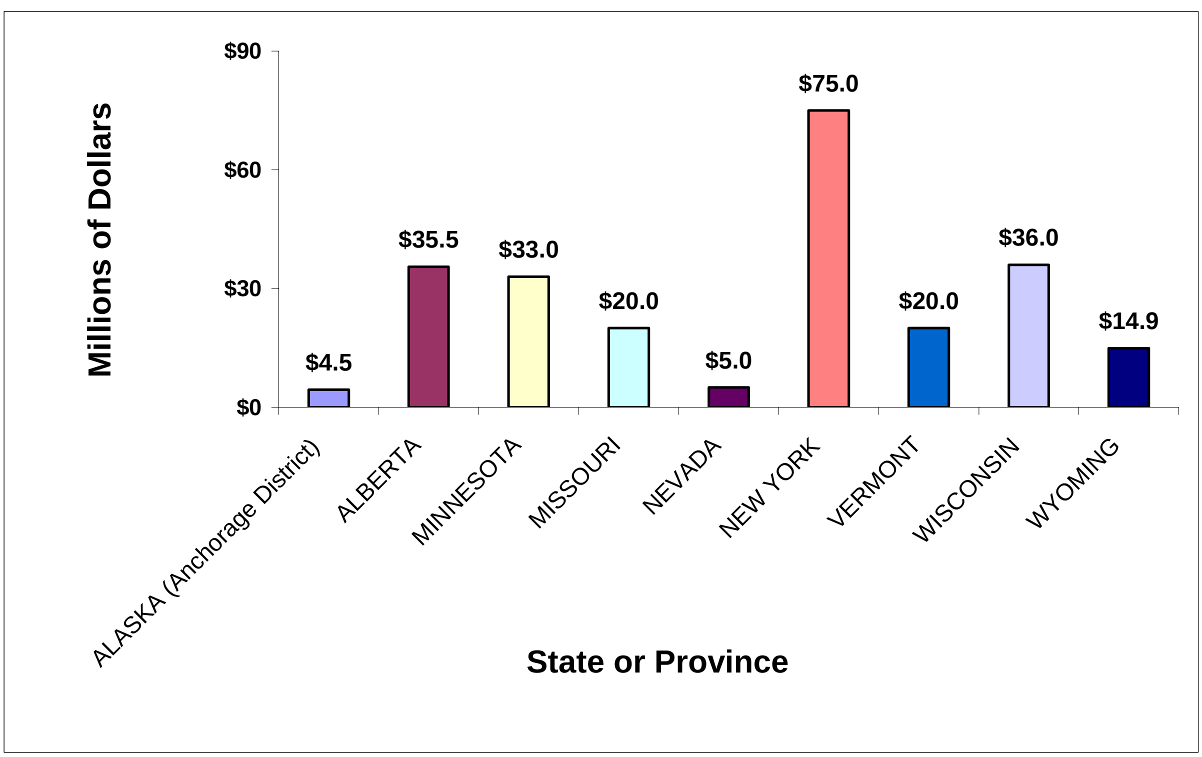

Figure 2: Annual Snow and Ice Control Cost for Nine Non-PNS States or Provinces (in US $, millions)

In addition, the magnitude of hidden costs derived from the corrosion and environmental impacts of snow and ice control operations is significant compared with the direct cost of such operations. It is estimated that when using road salts for snow and ice control the hidden costs are approximately three times as much as the direct cost in labor, materials, and equipment (Shi, 2005).

1.4 Information Offered by This Report

This report synthesized information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and pre-wetting for winter highway maintenance. Concerns discussed include: driver safety, human health, environmental stewardship, corrosion, costs, etc. The report concludes with the viability of these options and offers insight to future advancements.

1.5 How This Report Is Organized

The organization of this report is as follows. Before indulging into the research findings and discussions, the methodology used to gather and synthesize the information is described in the next Chapter. Chapter 3 details general concerns related to winter highway maintenance practices, not limited to anti-icing and pre-wetting. Chapter 4 addresses the concerns from Chapter 3 in terms of anti-icing and pre-wetting, and states advantages or disadvantages in utilizing these tools. Chapter 5 concludes this report. In the end, a sample of the agency survey, a copy of the responses, and the references cited are attached.

2. METHODOLOGY

This report summarizes information gathered through a literature review and phone interviews with maintenance personnel at state departments and provincial ministries of transportation. Both methods were important in gathering the most up-to-date information available regarding the practices of anti-icing and pre-wetting for winter highway maintenance in North America.

2.1 Literature Review

Computerized and manual literature searches were performed to identify if and how anti-icing and pre-wetting were more beneficial than conventional maintenance strategies in terms of traveler safety, roadway level-of-service, toxicity to the environment and human health, corrosion, effects on pavement, and economics. The literature search targeted publications and documents from the Federal Highway Administration, environmental protection agencies, and transportation agencies. Other sources included government documents and manuals, scientific journals, and reliable websites.

A computerized search was performed using the Internet to access the following resources:

- Transportation Research Information Service (TRIS) http://trisonline.bts.gov/sundev/search.cfm
- Transportation Research Board (TRB) http://www.trb.org
- Federal Highway Administration (FHWA) http://www.fhwa.dot.gov/
- State Departments of Transportation (DOT) http://www.fhwa.dot.gov/webstate.htm
- Public Roads http://www.tfhrc.gov/pubrds/pubrds.htm
- Google Scholar http://www.scholar.google.com
- Montana State University Library http://www.lib.montana.edu/
- U.S. Environmental Protection Agency http://www.epa.gov
- Environment Canada http://www.ec.gc.ca

2.2 Interviews

A questionnaire was developed to explore the state-of-practice for winter highway maintenance across the snowbelt regions of North America, and to document any advantages or disadvantages experienced while implementing anti-icing or pre-wetting strategies. It also addressed concerns associated with winter maintenance practices such as driver safety, human health, environmental stewardship, vehicular and infrastructure corrosion, and costs.

The questionnaire was sent as an email attachment to maintenance professionals in eighteen state departments of transportation and two Canadian provincial ministries of transportation, including the six participating PNS states (and provinces) and twelve states involved with the Federal Highway Administration Test and Evaluation Project #28. The contact list was developed by the project's advisory committee, and included maintenance managers, directors, superintendents, and engineers.

Fifteen of the twenty contacted professionals agreed to participate in the questionnaire, including: Alaska, Alberta, British Columbia, Colorado, Idaho, Minnesota, Missouri, Montana, Nevada, New York, Oregon, Vermont, Washington, Wisconsin, and Wyoming. Upon confirmation of participation, maintenance professionals were given a week to review the questionnaire and gather any needed information at which time an interview was scheduled. All interviews and responses to the questionnaire were completed by April 2005. With only one contact per state or province, the results presented herein are reflective upon the opinions of the interviewee, and are not necessarily representative of the entire state or province. A list of professionals who participated as well as their contact information is provided in Table 1.

Table 1: Contact Information for Questionnaire Participants

Name	Organization	Title	Contact Information
Jerry Reed	Alaska Department of Transportation	Anchorage District Superintendent	email: Jerry_Reed@dot.state.ak.us phone: (907) 338-1432
Steve Otto	Alberta Infrastructure and Transportation	Operations Standard Engineer	email: steve.otto@gov.ab.ca phone: (780) 422-9972
Grant Lachmuth*	British Columbia Ministry of Transportation	District Manager, Transportation	email: Grant.Lachmuth@gov.bc.ca phone: (250) 712-3660
Wayne Lupton*	Colorado Department of Transportation	Director of Maintenance and Operations	email: wayne.lupton@dot.state.co.us phone: (303) 273-1840
Dave Jones*	Idaho Transportation Department	Highway Maintenance Engineer	email: Dave.Jones@itd.idaho.gov phone: (208) 332-7893
Norm Ashfeld	Minnesota Department of Transportation	Highway Maintenance Superintendent	email: Norm.ashfeld@dot.state.mn.us phone: (651) 582-1437
Bill Billings	Missouri Department of Transportation	Maintenance Superintendent - District 4	email: Bill.Billings@modot.mo.gov phone: (816) 241-0246
Dan Williams*	Montana Department of Transportation	Winter and Roadside Maintenance Specialist	email: dawilliams@state.mt.us phone: (406) 444-7604
Rick Nelson	Nevada Department of Transportation	Assistant Director, Operations	email: rnelson@dot.state.nv.us phone: (775) 888-7440
Gene Taillie	New York Department of Transportation	RWIS Manager	email: gtaillie@dot.state.ny.us phone: (585) 265-6803
Richard Poecker*	Oregon Department of Transportation	Office of Maintenance, Clean Water Program	email: Richard.A.POECKER@odot.state.or.us phone: (503) 986-4484
Ken Leach	Vermont Department of Transportation	Transportation General Maintenance Supervisor	email: ken.leach@state.vt.us phone: (802) 751-0212
Tom Root*	Washington State Department of	Maintenance/Operations Branch Manager	email: roott@wsdot.wa.gov phone: (360) 705-7857
Tom Martinelli	Wisconsin Department of Transportation	Winter Operations Engineer	email: Thomas.Martinelli@dot.state.wi.us phone: (608) 266-3745
Tim McGary	Wyoming Department of Transportation	District Maintenance Engineer	email: tim.mcgary@dot.state.wy.us phone: (307) 745-2100

* Current PNS Association Participating Members

3. CONCERNS RELATED TO CHEMICALS AND ABRASIVES

Snow and ice control operations call for highway agencies to strike the right balance among their multiple objectives including: traveler safety, environmental stewardship, infrastructure preservation, and economics during winter seasons. For instance, overshooting the application rate of a chemical or an abrasive caused by poor weather forecasting or improper equipment will be costly and undesirable. Yet, apply too little, and maintenance crews face the complaints and liabilities resulting from unsafe roadways.

The ultimate goal of a winter highway maintenance program is *to deliver the right type and amount of materials in the right place at the right time*. Therefore, it is desirable to use the most recent advancements in the application of winter maintenance materials, equipment, and road weather information or other decision support systems (Environment Canada, 2004; Rentch, 2004).

Prevention of future problems requires adopting design practices for corrosion prevention, utilizing non-corrosive, environmentally friendly chemical products, and minimizing material usage while maximizing performance. In order to reduce costs and improve levels-of-service, it is important that individual maintenance agencies improve their snow and ice control strategies and tactics and implement a quality assurance program for snow and ice control products.

This chapter will document findings pertinent to corrosion and environmental concerns derived from the use of snow and ice control materials. It is noteworthy that products and application rates vary greatly across the snowbelt region of North America. Therefore, some of the data reported herein may not be applicable to the Pacific Northwest region.

3.1 Specifications for Winter Maintenance Chemicals

Even in the same state, snow and ice control practices may vary significantly depending on the specific, localized climatic, traffic and site conditions as well as the available resources and the experience, training and perception of maintenance staff. For winter maintenance chemicals, concentrations and application rates are generally specified by maintenance managers, and not all agencies follow strict quality control guidelines to ensure the proper chemicals have been purchased and delivered.

To address the corrosion and environmental concerns associated with snow and ice control chemicals, PNS developed specifications that can guide maintenance agencies in the selection of chemicals for snow and ice control. Chemical products have to pass a series of chemical, frictional, toxicological, and corrosion tests before they can be placed onto the PNS Qualified Products List (QPL) and be sold to the PNS highway agencies. For more details, visit the PNS website at http://www.wsdot.wa.gov/partners/pns/.

For maintenance agencies abiding by the PNS specifications, chemical products for snow and ice control must meet environmental and health standards by testing to the specified parts-per-million (ppm) limit or below for all constituents listed in Table 2.

Table 2: Constituent Limits in Parts Per Million (ppm) as Required by PNS

Constituent	Arsenic	Barium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Phosphorus	Cyanide
ppm	5.00	100.00	0.20	1.00	1.00	1.00	0.05	5.00	10.00	2500.00	0.20

PNS also requires the manufacturer to supply the following analyses for information purposes for liquid products or solid products that will be converted into a liquid product for application purposes:

- Ammonia – nitrogen
- Total Kjeldahl nitrogen
- Nitrate and nitrite – nitrogen
- Biological oxygen demand
- Chemical oxygen demand
- Frictional analysis
- Toxicity testing (including: rainbow trout or fathead minnow toxicity test, ceriodaphnia dubia reproductive and survival bioassay, and selenastrum capricornutum algal growth)

Last, but not the least, PNS requires that corrosion-inhibited chemical products for snow and ice control meet the National Association of Corrosion Engineers (NACE) Standard TM0169-95 as modified by PNS and are at least 70 percent less corrosive than sodium chloride, i.e., road salt (Pacific Northwest Snowfighters, 2004).

In addition, PNS requires the following additional analyses for new chemical products being submitted for evaluation:

- Visual inspection and field observations
- Specific gravity
- Gradation
- pH and amount of unreacted base
- Percent total settleable solids and percent solids passing a size-10 sieve
- Moisture content of solid deicer products
- Percent concentration of active ingredient in the liquid
- Corrosion inhibitor presence and concentration

Over the years, PNS has become a recognized pioneer in establishing and standardizing chemical products for snow and ice control. Agencies that have adopted the PNS specifications and use products from the QPL are listed in Table 3, including: Alaska, Alberta, British Columbia, Colorado, Idaho, Montana, Oregon, and Washington. Wyoming is considering adoption of Colorado's specifications and use of PNS guidelines. Agencies that did not comment on their policy for selecting chemical products include Missouri, Nevada and New York. Of the agencies that did not follow PNS specifications, most tested for moisture content and concentration of active ingredient.

Table 3: Compliance with Chemical Specification Guidelines for States and Provinces Interviewed

Agency	Follow Chemical Specification Guidelines	How
AL	Yes	For Liquid MgCl2 specifications mimic PNS. Use QPL, and do a random specific gravity test to ensure it is 29% concentration
AB	Yes	PNS Specifications
BC*	Yes	PNS Specifications
CO*	Yes	PNS Specifications or tighter
ID*	Yes	PNS Specifications
MN	Yes	Product control specifications: Liquid - certain % pure product, Solids - test for moisture content
MO	-	Did not respond
MT*	Yes	PNS Specifications
NV	-	Did not respond
NY	-	Did not respond
OR*	Yes	PNS Specifications
VT	Yes	Test for compliance with gradation and moisture content specifications on salt. Liquid CaCl2 is not tested, but has designated concentration
WA*	Yes	PNS Specifications
WI	Yes	Must be 95% rock salt by weight, no less than 95% NaCl, no more than 2% moisture at the time of delivery, and conform to the ASTM D-632, 5.1.1. Also must be free flowing with non-caking additive
WY	Yes	Use manufacturer's specifications for ordering materials. Also use a propietary product, but will start doing competitive bids for this, at which point, will use a modified CDOT specification (PNS Specification)

* Current PNS Association Participating Members

It can be concluded that PNS-approved chemical products pose no significant damage to human health, vehicles, or the environment, when used correctly. In the following sections, concerns regarding the use of chemical and abrasive products will be discussed. However, effects may differ with the variation in products and application rates.

3.2 Environmental Concerns

While providing improved driving conditions, chemicals and abrasives for snow and ice control have the potential to harm the surrounding environment. In extremely environmentally sensitive areas, the slightest application of such materials may be detrimental to the ecosystem. While most highway segments do not fall in this category, it is important to note the environmental implications of winter maintenance operations so that improvements can be made to minimize future problems.

Through repeated applications and plowings, large amounts of winter maintenance materials are deposited alongside the roadways, which can migrate to the adjacent water bodies by wind, rain, or snowmelt. Highway runoff, originating from salting, sanding, and other maintenance activities, potentially poses threats to water resources (Hanes et al., 1970; Sorensen et al., 1996; Missoula City-County Health Department, 1997; Turner-Fairbank Highway Research Center, 1999), but the damaging impacts depend on site-specific conditions and concentrations of pollutants in the receiving environment. One case study found decreases in the diversity and productivity of aquatic ecosystems at some sites with inflow of highway runoff containing sediment (Buckler and Granato, 1999). In another case study, the physical, chemical, and biological parameters indicated that deicing activities using IceBan (a magnesium chloride-based deicer) and traction sand had no measurable negative impact on the adjacent creek (Yonge and Marcoe, 2001). A study from the Michigan Department of Transportation 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. In addition, groundwater and vulnerable aquifers can be affected by any material applied or spilled on the land, including deicers and sand. However, none of the studied deicers posed widespread adverse environmental threats (Public Sector Consultants, 1993).

In the U.S., environmental issues related to water quality, air quality and wildlife are regulated with the guidance of the Clear Water Act, Clear Air Act, and Federal Endangered Species Act, respectively. These laws also detail the identification and management of environmentally sensitive areas, such as those on the list of impaired streams and the list of PM-10 non-attainment communities.

3.2.1 Impacts of Chemicals

Winter maintenance chemicals may have detrimental effects on the receiving soil, vegetation, and water bodies once the concentration reaches excessive levels. One of the most common chemicals for snow and ice control is sodium chloride (NaCl), or road salt. While it is relatively harmless in small amounts, the quantities applied for winter maintenance may kill vegetation near the roadway and increase chloride concentrations in the waterways. Suggested application rates of NaCl are 100-300 pounds per lane mile (30-90 kg per lane km) of solid material, and 45-165 gallons per lane mile (105-388 liters per lane km) of 23% liquid salt brine (Salt and Highway Deicing, 2005). An application rate of 300 pounds per lane mile of NaCl applied to a layer of ice 0.2 inches (0.5 cm) thick in Milwaukee resulted in an initial salt solution of 69,000-200,000 mg/L during heavy snowmelt. Runoff to surrounding soil and water bodies from this type of application may be in the thousands of mg/L (Sorenson, 1996).

The accumulation of road salt could be detrimental to the surrounding vegetation. For instance, on a 3,700-mile (approximately 6,000 km) stretch of highway in New Hampshire, nearly 14,000 trees died and had to be replaced (Sucoff, 1975). Environment Canada also reported that many woody plant species exposed to road salt had vanished from Canadian roadsides (Environment Canada, 2001). Salt is consisting of a sodium ion (Na^+) and a chloride ion (Cl^-), either ion may be toxic to vegetation when excessive accumulation occurs in the soil. Tolerance to NaCl for some vegetation, specifically pine seedlings, is as low as 67.5 ppm in soils. For seed germination and root growth to occur for grasses and wildflowers, the NaCl concentration in soil should be less then 100 ppm. Some woody and herbaceous species, however, tolerate up to 200 ppm of NaCl (Wegner and Yaggi, 2001). In one study, chloride concentrations in soil near a Canadian highway were taken. It was found that soil in the median had a chloride concentration of 1,050 ppm, and at 33 feet (10 meters) from the highway, the concentration was 890 ppm

(Hofstra and Smith, 1984). Both values are well above the aforementioned thresholds of pine seedlings, grasses and wildflowers.

Another concern regarding sodium ions (Na^+) is that they are highly soluble in water, and can bind to clay soil particles, break down soil structure, and decrease permeability (Public Sector Consultants, 1993). A study performed in Massachusetts evaluated the effects of NaCl on vegetation near roadways. Of the species tested, pines and sumacs had the most widespread, severe damage while grasses, ferns, maples and oaks were tolerant of high salt concentrations. It was found that sodium concentrations in damaged pine needles were about 75 times that of healthy pine needles (Bryson and Barker, 2002).

Compared with sodium chloride, magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) may cause similar effects to vegetation such as growth inhibition, scorched leaves, or even plant death (TRB, 1991; Public Sector Consultants, 1993; Cheng and Guthrie, 1998). Since the chloride ion in salts is what usually causes adverse effects to vegetation, and both $MgCl_2$ and $CaCl_2$ contain a higher concentration of chloride than NaCl by weight, they may be more harmful when applied at the same rates. Magnesium chloride has the highest chloride concentration of 75%, followed by $CaCl_2$ with 64%, and NaCl with 61% (Cheng and Guthrie, 1998). Magnesium and calcium are both crucial for plant growth; however, excess of either nutrient in the soil may result in other deficiencies. For example, excess magnesium may result in calcium deficiencies, and excess calcium may reduce the availability of magnesium and potassium (Cheng and Guthrie, 1998; Bryson and Barker, 2002). Another concern when using magnesium and calcium based products, is that Mg^{2+} and Ca^{2+} are soluble in water and can exchange with heavy metals in soil, potentially releasing them into the environment (Public Sector Consultants, 1993).

Because most chlorides are readily soluble in water and difficult to remove, there have been concerns over their effects on water quality. The U.S. Environmental Protection Agency (EPA) specified that the one-hour average (acute) and four-day average (chronic) concentrations of chloride should not exceed 860 mg/L and 230 mg/L more than once in three years, respectively. These levels were developed for chloride associated with sodium, whereas chloride associated with potassium, magnesium, and calcium would be more toxic to aquatic life, and thus should be managed at lower concentrations (US EPA, 2000).

However, studies have found that chloride concentrations in highway runoff are typically low enough that chloride is quickly diluted in receiving waters. Therefore, the impact of chemical products 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 a WSDOT field evaluation, however, chloride levels in roadside soils, surface water and underlying groundwater were found to be generally low and well below any applicable regulatory standards or guidelines (Baroga, 2005). In Montana, water samples taken from three streams adjacent to highways in 2003 and 2004 indicated that chloride levels do rise in these streams during winter maintenance months, but only spiked to 36 mg/L in one sample, still below EPA regulations. Most chloride levels in these streams during winter months, however, were less than 15 mg/L (Montana DOT, 2003).

In a similar evaluation of water quality in New York, however, elevated chloride concentrations were measured in streams, lakes and groundwater supplies affected by winter maintenance. It was found that during runoff, chloride concentrations spiked to above 1,000 mg/L in Willow Brook, exceeding the EPA's specifications for acute and chronic chloride concentrations. As a result, there has been an increase of mean chloride levels in Otsego Lake by 1.0 mg/L each year. Groundwater samples from wells near the lake were also tested for chloride concentrations. Traditionally, the chloride concentration of these wells would have measured 1-2 mg/L, but they tested at 40-60 mg/L (Albright, 2003). These groundwater samples show increased chloride concentrations; yet, they remain below drinking water regulations set at 250 mg/L by the U.S. Public Health Service (Cohn and Fleming, 1974).

Acetates have been extensively studied as alternatives to chloride-based products for snow and ice control. Environmental impacts are minimal with acetates, but due to funding limitations, the cost makes acetates infeasible for many agencies (Cheng and Guthrie, 1998; Vitaliano, 1992; Wegner and Yaggi, 2001; Fischel, 2001; Keating, 2001). Testing of soil, vegetation, and streams in the North Island of New Zealand where calcium magnesium acetate is used for both anti-icing and deicing has shown no negative impacts; however, the costliness of the product is its principal disadvantage (Burkett and Gurr, 2004).

The two primary acetates used for winter highway maintenance are calcium magnesium acetate (CMA) and potassium acetate (KA). Calcium, magnesium, and potassium are essential plant nutrients, however, all three ions may be problematic if concentrations are too high. Exchangeable calcium in soil is generally between 300-5,000 ppm. For a neutral soil, exchangeable magnesium will be greater than 500 ppm. Potassium is usually present in very high concentrations (20,000 ppm) in soil; however, only 100 ppm of this is available as a plant nutrient (Schulte and Kelling, 2004). As mentioned previously, excess calcium may reduce the availability of potassium and magnesium, and excess magnesium may cause calcium deficiencies (Cheng and Guthrie, 1998). Since acetate is an organic ion, it is also a nutrient for many organisms. Yet, the decomposition of acetate may result in anaerobic soil conditions as well as oxygen depletion in surface waters (Public Sector Consultants, 1993; Fischel, 2001). In two days, acetate concentrations of 100 ppm would completely deplete the dissolved oxygen in water whereas an acetate concentration of 10 ppm would temporarily reduce oxygen supplies (Fischel, 2001).

In recent years, bio-based deicers, often from the fermentation and processing of cane or beet sugar syrup as well as corn, barley and milk, have been added to the list of winter maintenance materials (Albright, 2003; Cheng and Guthrie, 1998; Better Roads, 2001). Often, these products are combined with other winter maintenance materials to act as corrosion inhibitors and increase ice-melting capabilities (Nixon and Williams, 2001). One product thoroughly studied is IceBan, a mix of $MgCl_2$ and agricultural byproduct. In a report evaluating deicers, it was determined that IceBan exceeds PNS specifications for copper, zinc, and sulfate. IceBan has a pH less than 4.0, which could result in acidification of soils and cause leaching of metals into surrounding waters (Fischel, 2001).

Another concern when using bio-based products is oxygen depletion. The organic materials of byproducts when broken down may cause temporary anaerobic soil conditions as well as oxygen depletion in surface waters. Oxygen depletion may also occur in waterways if too much phosphorus is present. Phosphorus is usually introduced into the environment in concentrations of 14-26 ppm from winter maintenance chemicals. However, water quality standards may set a limit lower than this. Michigan, for instance, has set a limit for phosphorus in water at 1 ppm from point discharges (Public Sector Consultants, 1993). Phosphorus spurs the growth of algae, reducing oxygen for other aquatic biota (Fischel, 2001). Algae growth may be spurred by critical levels of dissolved phosphorus as low as 20 ppb (RISE, 2004). In addition, bio-based products often contain high concentrations of nitrates that may contaminate groundwater (Fischel, 2001).

Winter maintenance chemicals are relatively non-toxic to aquatic organisms with some concerns about NaCl and $CaCl_2$ (Cheng and Guthrie, 1998). A Colorado DOT study examined the impacts of $MgCl_2$ on several aquatic organisms and concluded that during the study period in 1997 – 98 $MgCl_2$ had a very limited potential to cause environmental damage more than twenty yards (approximately 18 meters) from the roadway, given a dilution factor of 1:500 of chemicals entering the roadside environment after application on the roadway (Lewis, 1999). Yet, in Michigan, the DOT concluded that winter maintenance chemicals have the potential to be toxic to aquatic organisms in streams with low flows or in wetlands and ponds with long turnover times. It was determined that the most sensitive areas are those where chemical usage is high, and roadway runoff enters small water bodies directly (Public Sector Consultants, 1993).

Despite the potential damaging effects, the use of chemicals for snow and ice control can reduce the need for applying abrasives, and thus pose less threat to the surrounding vegetation, water bodies, aquatic biota, air quality, and wildlife.

3.2.2 Impacts of Abrasives

Abrasives are used in many regions to increase friction on slippery roads. Expert opinions indicate that the detrimental environmental impacts of abrasives generally outweigh those of chemicals (Transportation Association of Canada, 2004; Shi et al., 2005). In addition, the use of abrasives requires at least seven times more material to treat a given distance of roadway, compared with salt (Salt Institute, 2005). As a side benefit, reducing sanding applications (by increasing chemical applications) has contributed to decreasing the claim/count ratio for windshield repair and replacement for Colorado (Chang et al., 2002).

While non-toxic when applied alone, abrasives increase the sediment in waterways, leading to water quality problems. Abrasive materials used for winter maintenance can accumulate on and around low vegetation and cause stress, or settle to stream bottoms and degrade habitat for aquatic organisms (Public Sector Consultants, 1993). In addition to increasing turbidity and depositional loading, the sediment from sanding operations can retain and transport other pollutants to the receiving waters and thus impair water quality (Kirk, 2002). Abrasives from sanding operations may also lead to air quality problems, especially in urban settings.

Particulate matter from sanding operations, especially the finer particles, has a great possibility to adversely impact aquatic systems and downstream habitats (Young et al., 1996). It is agreed that particles less than 6.35 mm (0.25 in) in diameter are detrimental to streams. Many of such small particles naturally occur in the mountainous streams in Pacific Northwest, and these streams typically have sufficient energy to carry them. However, the streams can become overwhelmed when substantial quantities of such small particles are introduced by highway runoff or other sources. Particles less than 2mm (0.08 in) in diameter are especially problematic to aquatic wildlife that lay eggs in streambed gravel. The movement of oxygen into streambed gravels may be blocked by particles of this size, causing asphyxiation of eggs (Montana DOT, 2003). Sand free of much finer particles (ones that pass the #200 sieves, or 0.075mm in diameter) provides better traction and is easier to be captured by many structural BMPs designed to treat highway runoff (Shi et al., 2005).

One study showed that the particle size distribution of traction sand is critical in terms of negative impacts to the productivity of aquatic species. When 10-20 percent (by weight) of a stream's substrate is composed of sediment less than 0.85 mm (0.033 in) in diameter, the salmon egg viability was found to degrade significantly (Reiser and White, 1988).

In the U.S., the Federal Endangered Species Act protects plants, wildlife and fish that have been "depleted to the point of being in danger of or threatened with extinction" (Musgrave et al., 1998). Once a species is placed on the endangered species list, no act should be committed that may endanger the species. In Montana, for example, winter maintenance crews are aware of the sensitivity of the endangered Bull Trout and its habitat; therefore, they are constantly evaluating their use of abrasive materials (Williams, 2003). In New Mexico, it was determined that sedimentation from sanding operations was the likely cause of a reduction of individual invertebrate numbers. During the spring, sediment loadings from traction sand may lead to the asphyxiation of trout eggs (Molles, 1980).

3.3 Health Concerns

While winter maintenance materials increase public safety by improving the driving conditions on winter roadways, they may pose potential threats to sensitive individuals through their negative impacts on water and air quality.

In a study conducted by Levelton Engineering Ltd. in British Columbia, it is noted that chemical products may be harmful to human health if they are ingested, inhaled or come in contact with skin, depending on duration, concentration, frequency, and individual sensitivities to the chemicals. Of the four products tested (salt, CMA, $CaCl_2$, and $MgCl_2$), $CaCl_2$ was the only product that was both irritating to the eyes and skin on contact and toxic if inhaled. Salt and CMA were slight eye irritants, but only CMA was a skin irritant. $MgCl_2$ proved to be the least harmful, being only a slight eye irritant and non-toxic if inhaled (Cheng and Guthrie, 1998). The aforementioned conditions, however, are primarily a concern for winter maintenance personnel.

The most likely way for individuals to ingest chemical products used for winter maintenance is through drinking water. Increased chemical concentrations in public water systems or in private wells may present a health risk to humans if they receive excessive levels of nutrients and minerals. One noted health risk associated with drinking water and the use of roadway salts is hypertension, or high blood pressure. Although it has not been proven that hypertension is a result of salt intake, many doctors advise patients to follow a low salt diet to reduce symptoms of high blood pressure. Research has determined that if drinking water exceeds the maximum sodium levels of 200 mg/L or chloride levels of 250 mg/L, the taste of salt is noticeable (British Columbia Ground Water Association, 2002; New Hampshire Department of Environmental

Sciences, 1998). However, people on a low salt diet or a physician-prescribed "no salt diet" should drink water with sodium levels closer to 20mg/L (Health Canada, 1996; New Hampshire Department of Environmental Sciences, 1998). The U.S. EPA has estimated drinking water to comprise less than 10% of a person daily intake of salt, while Health Canada has estimated it to be even lower (New Hampshire Department of Environmental Sciences, 1998; Health Canada, 1996).

In a synthesis of information prepared by the Utah DOT, a few other health risks related to winter maintenance chemicals entering public water supplies were identified. Besides the risks of hypertension and increased salt intake, it was mentioned that sodium might adversely affect women with toxemia associated with pregnancy, and that high concentrations of sodium sulfate and magnesium sulfate have similar effects as a laxative. However, most water supplies do not test high enough on a regular basis to warrant concern (Sorensen et al., 1996). Table 4 shows different water supply standards.

Table 4: Water Quality Standards for Sodium and Chloride (Sorenson et al., 1996)

Guideline	Material	Use	Information Source
25 mg/L	Sodium	Drinking Water	American Heart Association (Murray and Ulrich 1976)
25 mg/L	Chloride	Desirable Drinking Water	Federal Water Pollution Control Administration (Cohn and Fleming 1974)
50 mg/L	Chloride	Industrial Water	California Water Control Board (Schraufnagel 1967)
250 mg/L	Chloride	Drinking Water	US Public Health Service (Cohn and Fleming 1974)
70-900 mg/L	NaCL	Taste Threshold	(Hanes et al. 1970a)
4,000 mg/d	Sodium	Normal Adult Intake	American Heart Association (Struzeski 1971)

Health risks associated with water quality were also addressed in the *Road Salt and Winter Maintenance for British Columbia Municipalities* report; however, it is stated that "water would become unpalatable to most people before these conditions would arise" (Warrington, 1998).

Poor air quality, on the other hand, is related more to the use of abrasives, even though solid chemicals may also become particulates in the air. Particles smaller than 10 microns (0.01mm) in diameter, known as PM-10, may become suspended in the air and contribute to respiratory problems. Airborne particles lead to air quality issues especially in urban settings, which is one of the concerns regulated by the U.S. Clean Air Act (Williams, 2003). Inhaled particulate matter may increase breathing difficulties for sensitive populations, causing respiratory damage and possibly lung cancer.

U.S. communities with excessive PM-10 particles in the air may surpass limits imposed by the Clean Air Act and be categorized as "non-attainment" areas, where the use of abrasives is only allowed on a limited basis (e.g. Metro Denver and Utah's Wasatch Front). Colorado is one state that has been required to reduce sanding applications and switch to alternative methods of roadway maintenance because of excessive particles suspended in the air. The air quality in Colorado has improved, and since the switch, Colorado has not surpassed the air particulate limit (Chang et al., 2002).

3.4 Corrosion Concerns

Another concern of winter maintenance products is corrosion to both motor vehicles and the highway infrastructure. It is difficult, however, to determine the extent of damage caused by such materials, or to compare the corrosiveness of different products in the field where lots of other variables come into play. While dwarfed by the safety benefits provided by snow and ice control operations, the corrosion effects are still costly and may pose a safety risk.

New products are continually tested and introduced so that agencies can provide safer alternatives for snow and ice control. For example, many transportation agencies have moved toward the use of more advanced chemical products in response to public and environmental concerns about abrasives and salt. Compared with traditional methods of using abrasives and road salt, extensive research has shown these chemical products:

- Do not damage car windshields and paint like abrasives;
- Do not have a negative impact on air quality;
- Do not negatively impact water quality through runoff like abrasives; and
- Are less corrosive to vehicles and infrastructure than salt, especially when blended with corrosion inhibitors.

3.4.1 Vehicular Corrosion

With the increased use of chemical products for winter maintenance, the general public and the trucking industry are increasingly concerned about the corrosion damage that snow and ice control operations may cause to motor vehicles. For motor vehicles, corrosion due to winter maintenance materials is generally cosmetic. However, brake linings, frames, bumpers, and tailpipes may also show signs of corrosion caused by winter maintenance applications.

Corrosion rates of metals are heavily dependent on which test protocol is used and it is extremely difficult to simulate field conditions in a laboratory setting. A study performed in Colorado determined that $MgCl_2$ was potentially more corrosive than NaCl under certain environmental conditions. When these two salts were tested on automobile components, it was determined that "$MgCl_2$ is more corrosive than NaCl under humid environment, and NaCl is more corrosive under immersion and arid environment" (Xi and Xie, 2002). In a recent study using the cyclic immersion-based PNS/NACE corrosion test, it was found plain $MgCl_2$ was the least corrosive among five chemicals tested with chloride concentration of 0.5M (Shi and Song, 2005). The chemicals are representative of five PNS approved deicer categories, including: NaCl, $MgCl_2$, $CaCl_2$, NaCl + 10wt.% $MgCl_2$, and NaCl + 20wt.%$MgCl_2$. The corrosion results, in terms of Percent Corrosion Rate (PCR), are presented in Figure 3. The corrosion test involved cyclic immersion (10 minutes in the solution followed by 50 minutes exposed to air) for 72 hours and the weight loss of steel coupons was translated into PCR, in terms of the solution corrosiveness relative to eutectic salt brine.

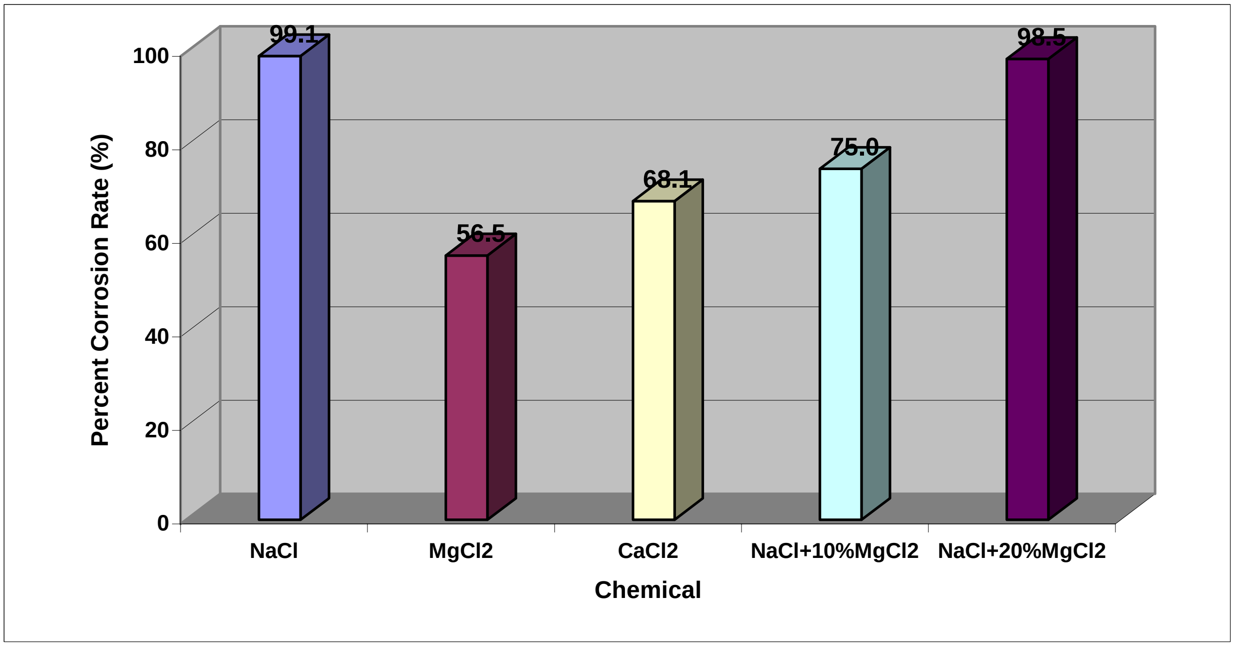

Figure 3: Corrosion Rates of Five Chloride-Based Chemicals with Chloride Concentration of 0.5M

By implementing the PNS/NACE corrosion test in the laboratory, PNS controls the quality of chemical products to ensure that they are 70 percent less corrosive than salt. However, not all products reach this goal in field evaluations as found in Washington State. The pilot project compared the corrosion of steel and aluminum exposed to different WSDOT roadway or roadside environments, where salt or corrosion-inhibited chemicals ($MgCl_2$ or $CaCl_2$) were applied for winter maintenance (Baroga, 2005). In eastern Washington, exposure of steel coupons mounted underneath motor vehicles to corrosion-inhibited chemicals consistently resulted in less corrosion than exposure to salt. These figures ranged as high as 70 percent less corrosive than salt and averaged 43 percent less corrosive than salt. For steel coupons mounted on guardrail posts, more corrosion was found from the exposure to corrosion-inhibited chemicals than from exposure to salt, which may be attributed to the difference in longevity and migration behavior of chlorides and corrosion inhibitors in the field, or to the possible effects of stray currents or galvanic corrosion in the field. Corrosion results for sheet aluminum and cast aluminum were less consistent than those found for steel, possibly because that the weight losses of aluminum coupons were so small that they may be susceptible to experimental errors and interferences in the field.

The following graphs (Figure 4 and Figure 5) show the actual corrosion of inhibited chemicals compared to salt in terms of weight loss in steel. A line is drawn on the bar graph at 70% the corrosion of salt, which is the goal of the PNS specifications, but was not obtained in this field evaluation. The corrosion patterns were consistent between the two years of evaluation.

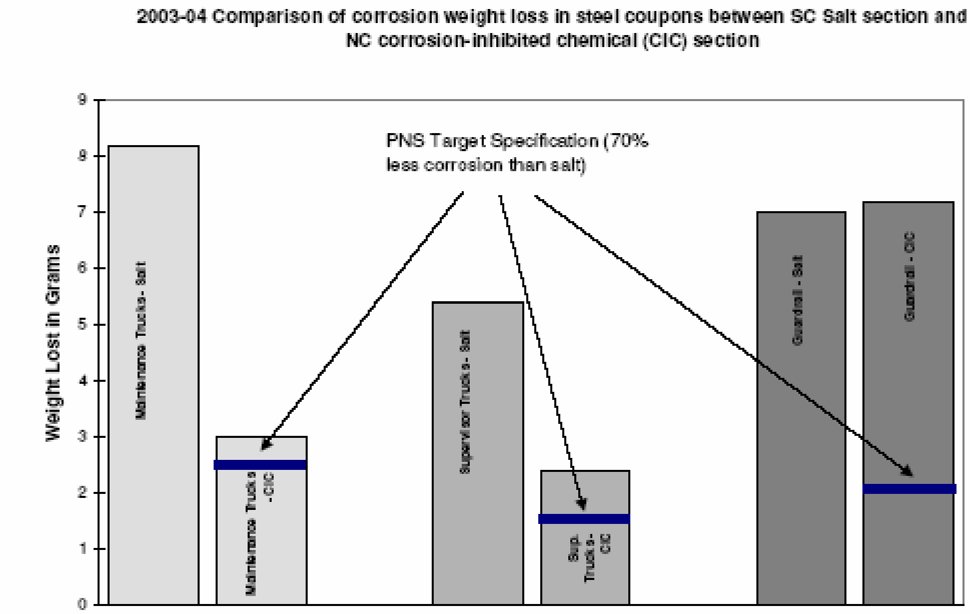

Figure 4: Corrosion of Steel Coupons in Two Test Sections of Washington: the South Central and North Central Region (Baroga, 2005)

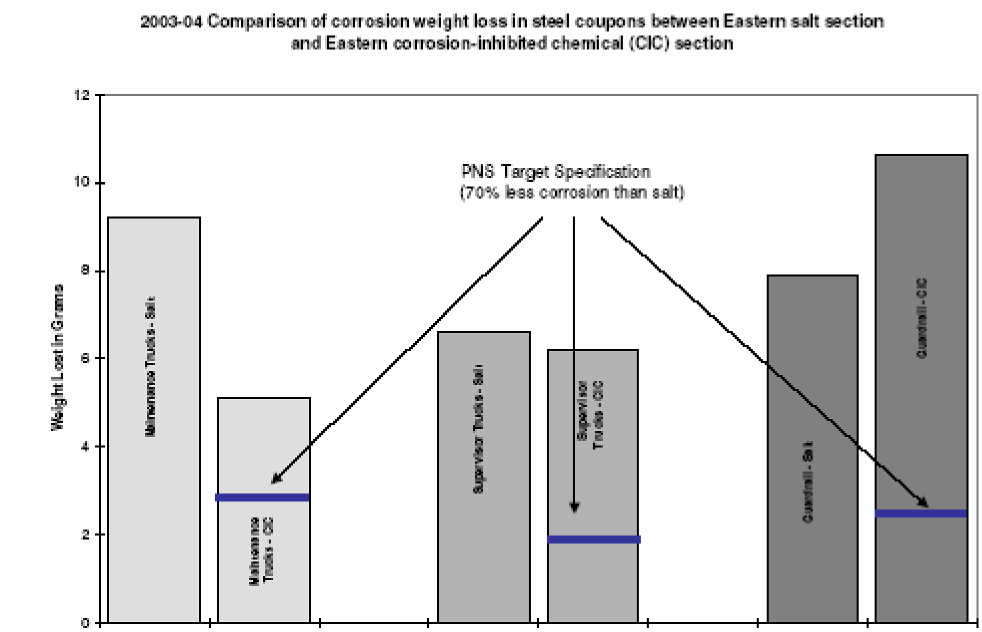

Figure 5: Corrosion of Steel Coupons in Two Eastern Region Test Sections of Washington (Baroga, 2005)

While manufacturers have increased the corrosion resistance of motor vehicles in the last two decades, the annual cost of corrosion in this sector is still substantial. In one study funded by the Federal Highway Administration, the cost of corrosion to vehicles in the U.S. was estimated to be $23.4 billion annually; $2.5 billion was associated with the increased cost of manufacturing corrosion resistant vehicles, $6.5 billion for vehicle repairs and maintenance, and $14.4 billion for vehicle depreciation (Johnson, 2002).

Areas with high corrosion, such as Boston where both road salts and marine conditions exist, saw annual corrosion cost of $141.09/vehicle, compared with $109.11/vehicle in areas with corrosion due to marine conditions only. A difference of $32/vehicle per year is thus attributable to road salts. Another study performed in 1991 found that the cost of corrosion due to road salt was $17/vehicle, which is comparable to $32/vehicle when present day values are considered (Johnson, 2002). It is important to note that this is a generalized estimation for the nation, and the corrosion costs for PNS states and provinces could be much less, as stricter specifications are applied to winter maintenance chemicals used in these regions.

3.4.2 Infrastructure Damage

Snow and ice control operations may cause damage to the highway infrastructure, including: concrete deterioration due to corrosion of the reinforced steel, surface deterioration known as scaling, and degradation of the concrete matrix. Large span supported structures, steel bridges, parking garages and even paved surfaces are susceptible to corrosion derived from winter maintenance chemicals.

First of all, chloride-based chemicals for winter maintenance may result in deterioration of reinforced concrete structures, the major cause of which is the corrosion of steel following the diffusion of chloride ions into concrete (Transportation Association of Canada, 2003). Chloride ingress is one of the major forms of environmental attack for reinforced concrete bridges (Samples and Ramirez, 1999), which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. In addition to marine environments and contaminated mix constituents, road salts are a major source of these aggressive agents. One study found bridge decks prematurely deteriorating due to road salt as well as the contamination of hundreds of parking garages (TRB, 1991). The remediation of concrete bridges in the U.S., undertaken as a direct result of chloride-induced corrosion of the reinforcing steel, would cost the U.S. highway departments $5 billion per year (FHWA, 1999). In the snowbelt region, the synergy of freeze-thaw cycles and corrosion of reinforcing steel can lead to serious problems against reinforced concrete structures.

Secondly, surface deterioration of the concrete, i.e., scaling, is another concern associated with chemical applications (Transportation Association of Canada, 2003; Williams, 2003). Road salts may increase the frequency of freeze-thaw cycles over ambient conditions, thus increasing the potential for scaling (Mussato et al., 2004). The use of properly cured, air-entrained Portland cement concrete will prevent damage by the freeze-thaw cycles. For instance, high quality concrete with 5-7% entrained air is more resistant to freeze-thaw cycles and scaling (Williams, 2003).

Finally, winter maintenance chemicals may chemically react with cement paste or aggregates and cause degradation of the concrete matrix. Laboratory research has shown that $MgCl_2$ reacts with calcium hydroxide, a product of cement hydration, and the “cementitious” calcium-silicate-hydrate (C-S-H) present in the cement paste, to form magnesium hydroxide and “non-cementitious” magnesium-silicate-hydrate (M-S-H). Such reaction degrades concrete strength, and reduces the pore solution pH as well. The latter may result in the loss of passivation of the reinforcing steel and decrease the threshold chloride level to initiate pitting corrosion at the steel surface (Mussato et al., 2004).

A laboratory investigation using concrete samples obtained from existing Iowa highways suggest that magnesium and calcium deicers may accelerate highway concrete deterioration (Cody et al., 1996). Samples were experimentally deteriorated using wet-dry, freeze-thaw, and continuous soak conditions in solutions of magnesium chloride, calcium chloride, sodium chloride, magnesium acetate, magnesium nitrate, and distilled water. Both magnesium and calcium salts were found to severely damage the concrete samples while plain NaCl was the least harmful. In another study, the use of deicers such as salt, potassium acetate, sodium formate, and urea on an airfield strip was found damaging to both aggregates and asphalt mixes (Hassan et al., 2002). An ongoing research project sponsored by the South Dakota DOT is investigating the short and long term effects of high concentrations of salts and other chemical products on pavement and durable Portland cement concrete. The goal of the research is to determine if there is "reduction in performance and service life for pavements and structures" exposed to winter maintenance chemicals (Sutter et al., 2004). However, in a report produced by the Transportation Association of Canada, it is stated that with good pavement design and construction, effects of winter maintenance chemicals may be minimized, and that the pavement may actually assist in the performance of winter maintenance chemicals (Transportation Association of Canada, 2003).

When comparing $MgCl_2$ with NaCl, research has determined that the chloride diffusion coefficients for $MgCl_2$ are two to three times greater than NaCl (Hondo et al., 1974; Deja and Loj, 1999; Mends and Carter, 2002; Mussato et al., 2004), which may reduce the time to corrosion initiation for the concrete embedded reinforcing steel by 10 to 15 years (Mends and Carter, 2002).

Infrastructure damage resulting from winter highway maintenance activities is substantial. Repairing the damage caused by snow and ice control operations costs state and local agencies over $5 billion each year. As of 1999, there were 583,000 bridges in the U.S., approximately 15 percent of which were structurally deficient (FHWA, 2005). The estimated cost of installing corrosion protection measures in new bridges and repairing old bridges in the snowbelt states is between $250 million and $650 million annually (TRB, 1991). Parking garages, pavements, roadside hardware, and non-highway objects near winter maintenance activities are also exposed to the corrosive effects of road salts. Finally, it should be noted that any repairs to the infrastructure translate to costs to the user in terms of construction costs, traffic delays and lost productivity. Indirect costs are estimated to be greater than ten times the cost of corrosion maintenance, repair and rehabilitation (Yunovich et al., 2001). It is important to note that this is a generalized estimation for the nation, and the corrosion costs for PNS states and provinces could be much less, as stricter specifications are applied to winter maintenance chemicals used in these regions.

4. ANTI-ICING AND PRE-WETTING PRACTICES

4.1 Background

Winter highway maintenance practices in North America have traditionally been based on reactive strategies where the launch of maintenance operations relied on signs of snow and ice accumulation. After snowfall, the *deicing* process uses granular materials (such as road salt) that penetrate accumulated snow and ice in order to break the bond that has formed with the roadway. Once the bond is broken, the layer of snow and ice can be easily removed by mechanical means such as snowplows. In addition, through *sanding* operations, abrasives such as sand are applied onto the roadways to provide temporary traction in slippery conditions. Such reactive strategies are generally reliable and well understood.

One concern regarding reactive maintenance practices is the increased potential for accidents and injuries due to poor road conditions while maintenance crews are being deployed. Another problem with reactive practices is the quantity of materials and labor hours needed to maintain the desired level of service for winter roadways.

New advancements in science and engineering, specifically, reliable weather forecasting and new equipment and materials, are making it possible for highway agencies to implement improved snow and ice control strategies that benefit the public and help minimize the effects of winter weather on roadway surfaces.

In the past decade or so, an improved approach termed *anti-icing* has been adopted by winter maintenance personnel, which is the early application of chemicals to help prevent black ice and prevent or weaken the bond between ice and the roadway surface. While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used.

Anti-icing is considered a proactive approach to winter highway maintenance because it treats potential conditions before problems arise, thus giving maintenance crews an advantage when fighting winter storms. The roads remain wet and slushy longer and return to *bare pavement* conditions earlier when anti-iced. As a proactive strategy, successful use of anti-icing chemicals requires application immediately prior to a storm, and thus entails accurate weather forecast. When applied correctly, anti-icing can reduce plowing and decrease the quantity of chemicals used (U.S. EPA, 1999).

Another innovative practice in winter road maintenance is termed *pre-wetting*, i.e., the addition of a liquid chemical to an abrasive or solid chemical before it is applied to the road. The pre-wetting of solids is performed either at the stockpile or at the spreader. The liquid chemical helps accelerate the break-up of the snow/ice pack, and it keeps the material on the roadway longer by preventing losses due to rebound and traffic.

As mentioned previously, chemicals and abrasives help keep roadways clear of snow and ice and improve traveler safety by providing roadway traction. However, there could be corrosion and environmental issues associated with snow and ice control operations, if not properly mitigated. The number one goal of highway agencies has always been human safety on roadways, followed closely by environmental stewardship and economics. It should be noted that accidents also damage the environment and the infrastructure. Furthermore, any cost savings of winter maintenance practices should not be at the price of deteriorated infrastructure, impaired environment, or jeopardized traveler safety. Overall, examining and implementing improved maintenance strategies would result in a better balance of these strategic goals of highway agencies.

As improved maintenance strategies, anti-icing and pre-wetting are seeing increased implementation in North America. One of the greatest challenges of the implementation has been the misunderstanding of the benefits and outcomes of their use. Members of the general public and organized groups such as trucking associations have been critical of these strategies, which may be a result of insufficient information, limited understanding and speculation. Therefore, research is needed to synthesize the information on these strategies in an objective manner.

Anti-icing and pre-wetting are maintenance methods that are improving the way agencies manage roadway surfaces during inclement winter weather. As a snapshot, of all the agencies surveyed, the average experience with pre-wetting and anti-icing was 10 years and 8 years, respectively. The majority of agencies from both PNS and non-PNS states/provinces have had 5-10 years of experience with pre-wetting, whereas the difference in experience with anti-icing was far greater. Fifty percent of PNS states/provinces had more than 10 years of experience with ant-icing, whereas none of the non-PNS states/provinces falls into this category. While PNS states/provinces had an average of 10.3 years of experience in anti-icing, non-PNS states/ provinces surveyed had only 6 years of experience in anti-icing. The differences in experience levels between the two groups of agencies implementing these improved strategies are shown in Figures 6 - 9.

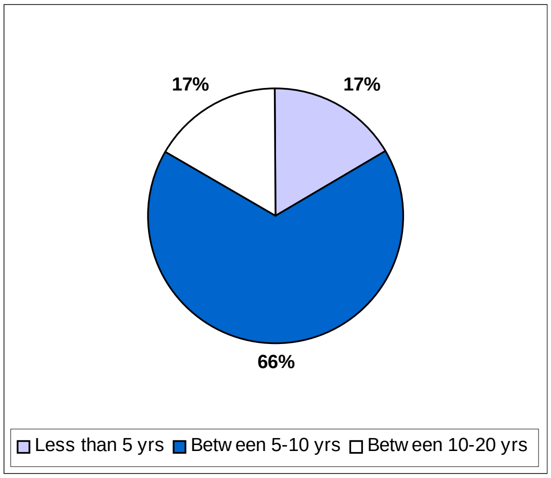

Figure 6: Years of Experience with Pre-wetting – PNS States and Provinces

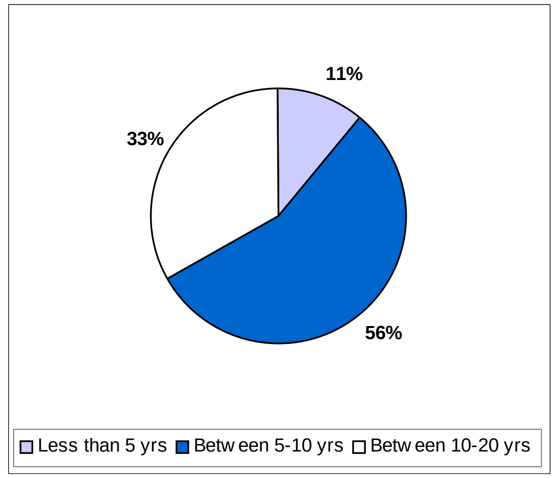

Figure 7: Years of Experience with Pre-wetting – Non-PNS States and Provinces

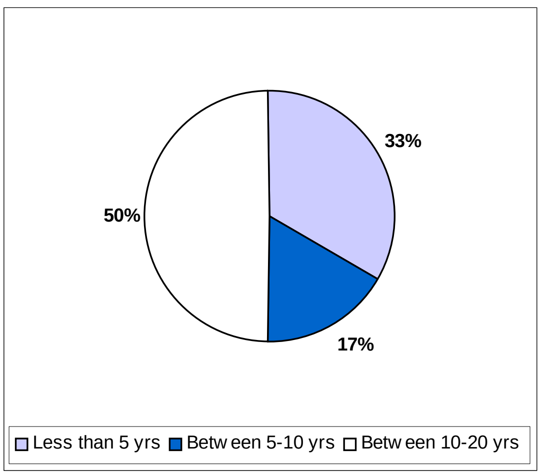

Figure 8: Years of Experience with Anti-icing – PNS States and Provinces

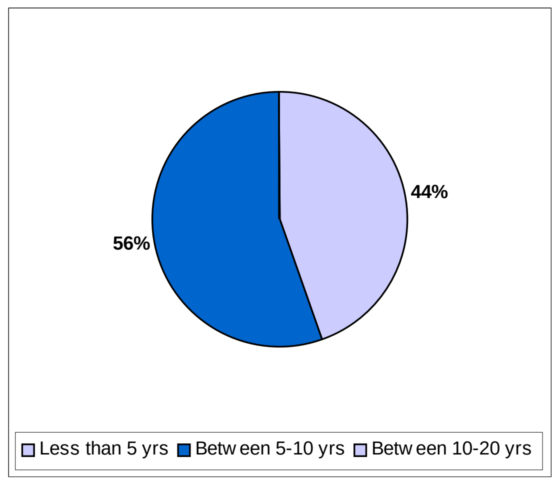

Figure 9: Years of Experience with Anti-icing – Non-PNS States and Provinces

The survey also provided insight and a snapshot into the percentage of roadways across North America using the following maintenance practices: anti-icing, deicing, snowplowing, and sanding. Figures 10- 13 illustrate the percentage of agencies surveyed that use each of these practices, ranging from less than 10% of roadways all the way up to 100% of roadways (in 10% increments). A comparison is shown between PNS states/provinces and non-PNS states/provinces.

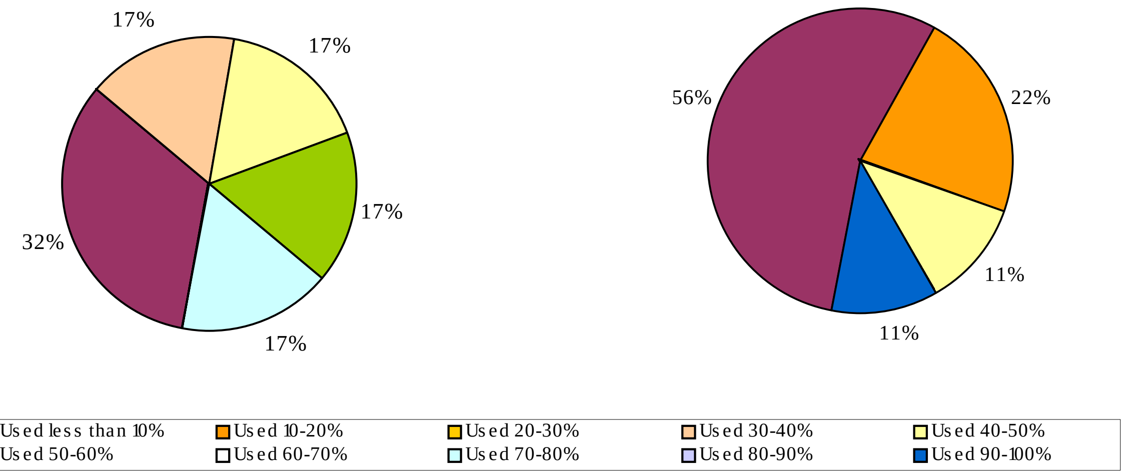

Figure 10: Percent Roadways Using Anti-icing: (left) PNS States and Provinces, (right) Non-PNS States and Provinces

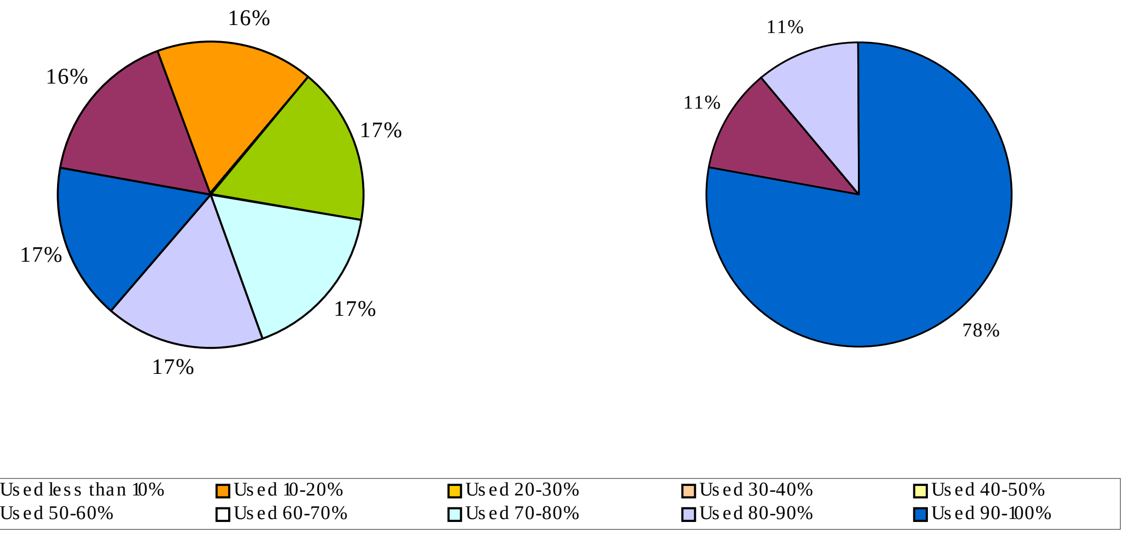

Figure 11: Percent Roadways Using Deicing: (left) PNS States and Provinces, (right) Non-PNS States and Provinces

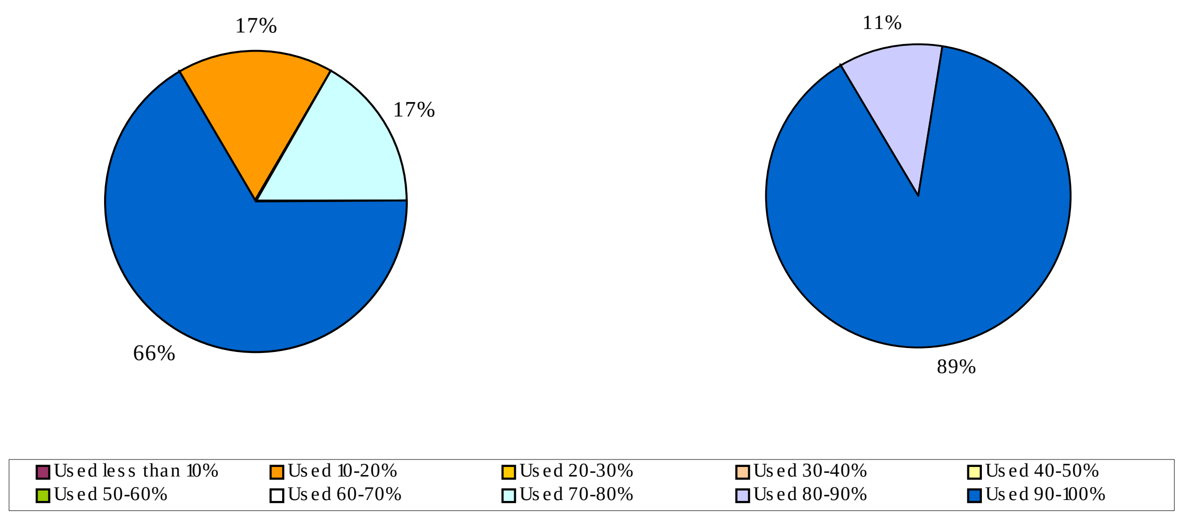

Figure 12: Percent Roadways Using Snowplowing: (left) PNS States and Provinces, (right) Non-PNS States and Provinces

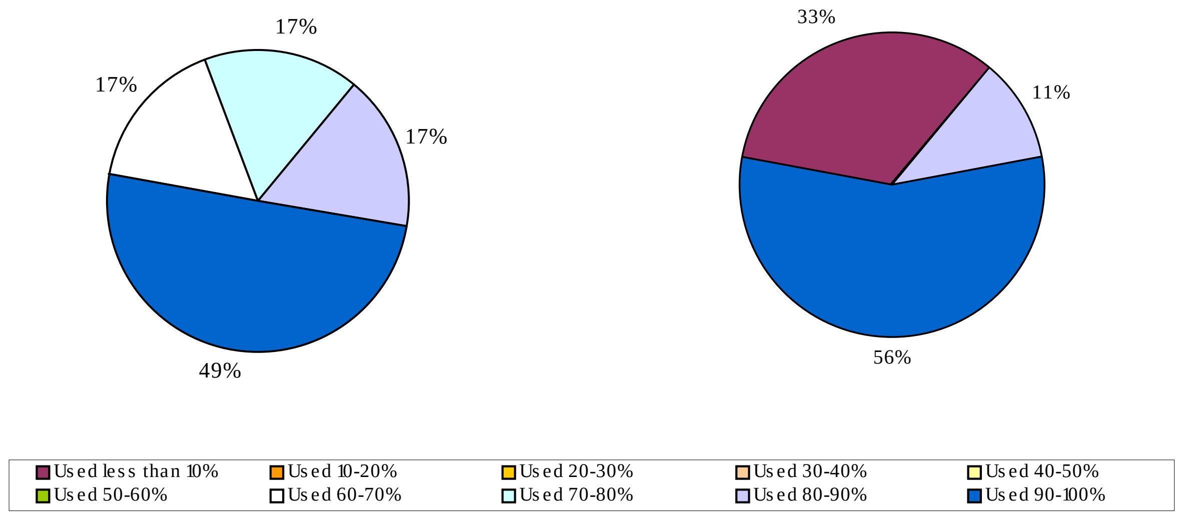

Figure 13: Percent Roadways Using Sanding: (left) PNS States and Provinces, (right) Non-PNS States and Provinces

4.2 Improved Winter Driving Safety

Traditionally, winter highway maintenance was heavily reliant on snowplowing, sanding and deicing. Through this research, it was apparent that these traditional means of snow and ice control are all still heavily utilized today. When asked "What do you see as the best method for maintaining safe winter driving conditions", all respondents stated that the best approach to winter maintenance is to utilize a combination of all tools available. As a follow-up question, professionals were asked "what percentages of your roadway use anti-icing, deicing, snowplowing and sanding". It was found that on average of the fifteen states/provinces, anti-icing was used 29% of the time, deicing – 76% of the time, snowplowing – 92% of the time, and sanding – 75% of the time. Results of the agency survey regarding the usage of anti-icing, deicing, snowplowing and sanding are included in Table 5.

Table 5: The Usage of Various Snow and Ice Control Tools among the Agencies Surveyed

	AL	AB	BC*	CO*	ID*	MN	MO	MT*	NV	NY	OR*	VT	WA*	WI	WY
Anti-icing	10%	1%	3%	33%	50%	15%	15%	10%	50%	100%	75%	0%	60%	10%	2%
Deicing	100%	100%	7%	100%	90%	100%	100%	15%	90%	100%	75%	98%	60%	100%	1%
Snowplowing	100%	100%	20%	100%	100%	100%	100%	100%	90%	100%	75%	100%	100%	100%	100%
Sanding	100%	100%	70%	100%	100%	100%	1%	85%	90%	1%	75%	100%	100%	10%	100%
Best Method	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo	Combo

* Current PNS Association Participating Members

However, when asked if anti-icing and pre-wetting improved roadway safety, the answer was unanimously positive. Field experts agree that roads have increased traction more of the time when anti-icing and pre-wetting have been utilized. Regions implementing anti-icing and pre-wetting practices have been able to achieve higher levels-of-service for winter highways sooner compared with traditional practices.

Research has also shown that pre-wetting and anti-icing are useful strategies in providing the safest roads possible. Conventional theory was that the direct application of abrasives to road surfaces would increase traction for vehicles. However, many studies have proven otherwise. Germany realized, as early as the 1950s that sand did not stick to snow-packed roadways since vehicle traffic would sweep it aside (Nixon, 2001a, Nixon, 2001b). In another study, the New York DOT evaluated the use of sand and sand-salt mixtures for increasing friction. It was found that sand alone was not beneficial and that a sand-salt brine mix was the most effective (Hossain, 1997). In Norway, research proved that sand pre-wetted with hot water can be highly effective. Dry sand may be removed from a roadway by the passage of as few as 50 vehicles, but pre-wetted sand with hot water can remain after the passage of as many as 2,000 vehicles. Using hot water (between 194°F and 203°F) and sand, roads maintained satisfactory friction values for as long as seven days on roads with an average annual daily traffic (AADT) volume of 1,000-1,500 vehicles (Vaa, 2004). These studies indicated that any benefits from abrasives were minimal unless steps were taken to improve material retention on the road.

Pre-wetting solves the problem of material adhesion and allows maintenance crews to fight snow and ice pack more effectively with the addition of chemical brine. Pre-wetted abrasives will refreeze quickly to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50% in cold temperatures (Williams, 2003). If warm, chemicals can accelerate break-up of snow pack while providing a traction aid to the public (Williams, 2003). Overall, maintenance managers are confident that pre-wetting strategies significantly improve material retention and speed up the ice melting process.

Better material retention provides increased friction longer for the traveling public, helping maintain roads safer during inclement weather. In a field evaluation in Michigan, the highway department verified the benefits of pre-wetting by monitoring the placement of dry versus pre-wetted rock salt. It was found that pre-wetted rock salt applied along the centerline in a windrow had 96% material retention compared with 70% of the dry rock salt (Transportation Association of Canada, 2004). In another study, researchers examined the use of pre-wetted abrasives on five different road types, including: high volume paved roads, low volume paved roads, low speed paved roads, unpaved roads, and urban intersections. The only instance where using chemical products to pre-wet abrasives was discouraged was for unpaved roads because it could cause the road to thaw and become unstable. For all other conditions, pre-wetting increased performance and longevity of the abrasive material (Nixon, 2001b).

While pre-wetting is a useful technique in fighting snow and ice pack and for use in areas with high winds, the best way to keep roadways safe is to be proactive and implement anti-icing ahead of a winter storm event. In many conditions, anti-icing eliminates the need for abrasives because it eliminates the cause for slipperiness (Williams, 2003).

The PNS states have seen the benefits of anti-icing. In Washington State, the implementation of anti-icing in the North Central Region has resulted in improved level-of-service at the same cost as previous maintenance practices (Boon and Cluett, 2002). On Washington Pass, maintenance crews had been anti-icing before heavy snowstorms that closed the pass for the season. In the next March, crews were able to cut through the deep snow to find that no ice bond had formed with the pavement (Boselly, 2001).

In Montana, benefits of this proactive strategy were witnessed during a winter storm that hit State Route 200 in December of 2000. The crew responsible for the Plains section used anti-icing techniques whereas the Thompson Falls crew implemented pre-wetting techniques. Of the two sections, the Plains section achieved bare pavement conditions (Figure 14) while the Thompson Falls section remained snow packed (Figure 15), suggesting the success of anti-icing (Williams and Linebarger, 2000).

Figure 14: Montana State Route 200 – Plains Section (Williams and Linebarger, 2000)

Figure 15: Montana State Route 200 – Thompson Falls Section (Williams and Linebarger, 2000)

In Idaho, once anti-icing was implemented on U.S. 12, accidents were reduced by 83% each year compared to years before the start of the pilot program (Breen, 2001). During a twelve-year study involving anti-icing strategies on the interstate system in the Denver metro area, Colorado saw an average of 14% decrease in snow and ice related crashes and a more than 23% increase in traffic volume (Colorado DOT, 2005).

In the central U.S., anti-icing has also been beneficial. In Indiana, spraying liquid chemicals, specifically $MgCl_2$ and IceBan Magic, has helped to reduce accidents. A study monitoring the number of accidents on U.S. 20 during the winter seasons of 1996/1997 when liquid chemicals were first introduced and 1997/1998 when anti-icing became more prevalent showed a drastic decrease in accidents when anti-icing was implemented; results are shown in Figure 16 (HITEC, 1999).

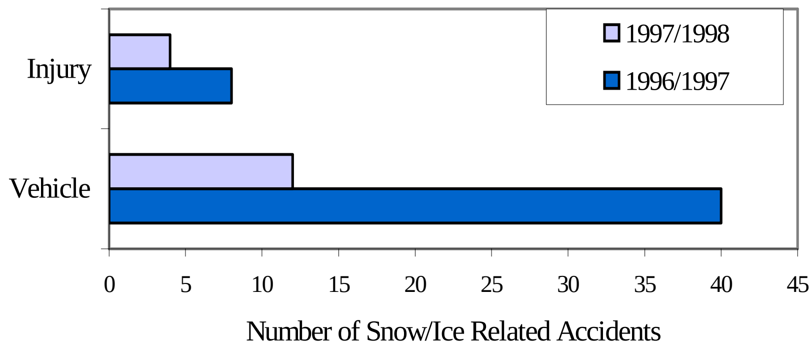

Figure 16: Accident Rates on U.S. 20 in Indiana During the Winters of 96/97 and 97/98 (HITEC, 1999)

Anti-icing has been a topic among maintenance managers and many projects have been deployed to prove its viability. In the Federal Highway Administration Test and Evaluation Project #28, fifteen states implemented and tested anti-icing practices. Overall, it was found that anti-icing could result in reduced chemical usage and improved pavement conditions compared with reactive strategies. While improved pavement conditions can be translated into improved winter travel safety and mobility, reduced chemical usage can be translated into cost savings and less corrosion and environmental damage. For instance, Colorado found that during the course of two storms, the test section that utilized $MgCl_2$ for anti-icing had higher friction values throughout the duration of the storm than the control section that was sanded (Ketchum et al, 1998). For Nevada, anti-icing was used for conditions such as light snowfall, short duration weather events, and temperatures just below freezing, and had been successful in preventing ice bonds during these conditions. Anti-icing has also been successful in Wisconsin where treatments of 100 pounds per lane mile (28 kg/lane km) "caused delays in the reduction in friction, provided higher friction and better traction throughout the periods of heavier snow, and caused faster recovery from the snowpack relative to the conventional operations" (Ketchum et al., 1998). In California, however, results were mixed. The test section consisting of an application of $MgCl_2$, road salt and abrasives, lessened the effects of bonded snow and ice, but did not prevent an ice bond to the pavement. Therefore, the treatment was not effective as a means of anti-icing.

4.3 Reduced Environmental Impacts

The literature review revealed many studies regarding the environmental impacts associated with the use of improved winter maintenance chemicals and abrasives. In Washington State, the impacts of IceBan (37% $CaCl_2$, 63% corn by-product) and traction sand used in pre-wetting applications on State Route 97 near Peshastin Creek were assessed. Peshastin Creek is a habitat for steelhead, Chinook salmon and bull trout, all of which are considered threatened or endangered species. It was determined that sanding operations were not detrimental to the streambed as the sediment loading for this section of the creek was comparable to the non-impacted reach. Chloride levels were measured to determine the introduction of IceBan into the creek. Increased chloride concentration levels were witnessed during spring runoffs; however, even the peak concentrations were far lower than the acute toxicity threshold value of 860 mg/L (Yonge and Marcoe, 2001).

The Montana DOT has also conducted water quality sampling to determine background chloride concentrations and spikes that may be due to highway runoff. In one study, samples were taken from Lolo Creek from May 2003 to September 2004, a region where anti-icing has been implemented. Nine locations were tested, three of which were "background" samples from tributary creeks. Yearly averages, summer averages for both 2003 and 2004, and peak chloride concentrations along with the date they occurred are listed in Table 6. Peak chloride concentrations were well below EPA regulations at all locations. The highest spike was 17 mg/L and was measured at three locations during March of 2004, a month typically associated with high runoff (Montana DOT, 2004).

Table 6: Lolo Creek Water Sample Tests for Chloride Concentration (in mg/L)

Location	Yearly Avg	Summer 2003 Avg	Summer 2004 Avg	Peak	Date of Peak
MDT 1	2.5	2.225	1.33	6.0	7/30/2003
MDT 2	3.0	1.25	2.00	13.0	10/16/2003
MDT 3*	>1	0.25	0.33	2.0	10/16/2003 5/13/2004 6/23/2004
MDT 4*	>1	0.00	0.33	2.0	10/16/2003
MDT 5*	>1	0.00	0.33	2.0	4/14/2004
MDT 6	3.9	3.00	5.67	9.0	9/22/2004
MDT 7	5.6	3.00	4.33	17.0	3/16/2004
MDT 8	4.8	1.25	3.33	17.0	3/16/2004
MDT 9	5.2	3.25	4.00	10.0	3/16/2004

* "Background" samples (Tributary Creeks)

The Missoula Valley of Montana is one area in which excess particulate matter warranted a change in practice. Sanding operations were replaced with alternative liquid chemicals used for anti-icing such as the magnesium chloride based FREEZEGARD. Immediately following the implementation of alternative practices, concerns regarding chloride and heavy metal concentrations were raised, and water quality sampling began. It was found that the use of chemicals increased concentrations of salt and metals in the Clark Fork and Bitterroot Rivers; however, the levels were not high enough to indicate that they would negatively affect water supplies in the future (Missoula City-County Health Department, 1997).

Traditional winter maintenance chemicals along with a few modified products were tested for the Michigan DOT including: sodium chloride, calcium magnesium acetate, calcium chloride, CMS-B (a potassium chloride based product) and CG-90 Surface Saver (salt with corrosion inhibitor). It was determined that none of the products tested are problematic to the environment except in very site-specific instances (Public Sector Consultants, 1993).

In another study, the Colorado DOT evaluated three liquid magnesium chloride based products to determine whether such products could be utilized to help reduce the application of salt and sand mixtures, thus, improving air quality and water quality. The products tested included $MgCl_2$, Caliber M1000, and Caliber M2000 (Caliber products are a mix of $MgCl_2$ and bio-based products). The three products were examined in terms of main ingredients, corrosion inhibitors, and contaminants. It was suggested that Caliber M1000 and Caliber M2000 should not be heavily used without strict guidelines and further testing, as both products exceeded environmental background concentrations of phosphorus and ammonia and both contained large quantities of contaminants, while traditional magnesium chloride was approved (Lewis, 2001).

Environmental impacts from chemical and abrasive applications are highly dependent on quantity applied and a broad range of site-specific characteristics. By using winter maintenance chemicals in a more efficient means, adverse environmental impacts should be lessened, even in environmentally sensitive areas. A number of DOTs have reduced salt usage through new tools and techniques, including improved winter maintenance practices (Rentch, 2004). An evaluation of pre-wetting salt in Canada has shown that fewer chemical applications are needed, resulting in up to 53% less material used (Warrington, 1998). In Nebraska, pre-wetting salt with an M-50 product has reduced salt usage by 35%-40% (Keating, 2001).

Both anti-icing and pre-wetting reduce the total amount of materials used for winter highway maintenance, which helps reduce environmental impacts associated with such materials. Maintenance managers surveyed found anti-icing and pre-wetting beneficial (as shown in Table 7), since such practices helped reduce chloride and sediment levels in waterways and particulate matter in the air. Some indicated a reduction of 20%-30% for sanding applications and about 10% for chemical applications.

Table 7: Survey Responses Regarding Environmental Concerns

Environmental Concerns	**AL**	**AB**	**BC***	**CO***	**ID***	**MN**	**MO**	**MT***	**NV**	**NY**	**OR***	**VT**	**WA***	**WI**	**WY**
Claims	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No
Groundwater Contamination	X	X	X	X						X				X	
Soils and Vegetation		X	X					X	X					X	
Air Particulates				X					X						
Beneficial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

* Current PNS Association Participating Members

4.4 Reduced Human Health Impacts

Concerns regarding human health and the use of chemicals or abrasives on winter roads are generally mild, and most agencies surveyed found anti-icing and pre-wetting practices beneficial in this regard. With the improved maintenance practices, the agencies surveyed were able to reduce material usage, thus, reducing potential health risks. Most agencies surveyed have experienced contamination due to winter maintenance chemicals in some form, but felt that anti-icing and pre-wetting reduced chances of problems reoccurring. Survey responses are included in the following table.

Two reports produced by Levelton Engineering Ltd. examined anti-icing products and their effects on human health. One report evaluated eighteen products for chemical composition and toxicity, and the results were compared with the PNS specifications and the Canadian Drinking

Water Standards. Lead, sodium, and nitrogen found in drinking water may adversely affect human health. All anti-icing products tested met the 1.0 ppm specification for lead, but four products exceeded nitrate levels. Sodium levels are not specified by PNS, but as mentioned in Chapter 3, patients with hypertension are advised to drink water with sodium levels less than 20 mg/L (Mussato and Guthrie, 2000). The other report developed a consensus of any potential impacts associated with these chemicals as well as a comparison between traditional deicers and liquid anti-icing chemicals. It was concluded that most products do not pose serious health risks to humans, and by using liquid chemicals, there is a potential to reduce sanding operations and improve air quality (Cheng and Guthrie, 1998).

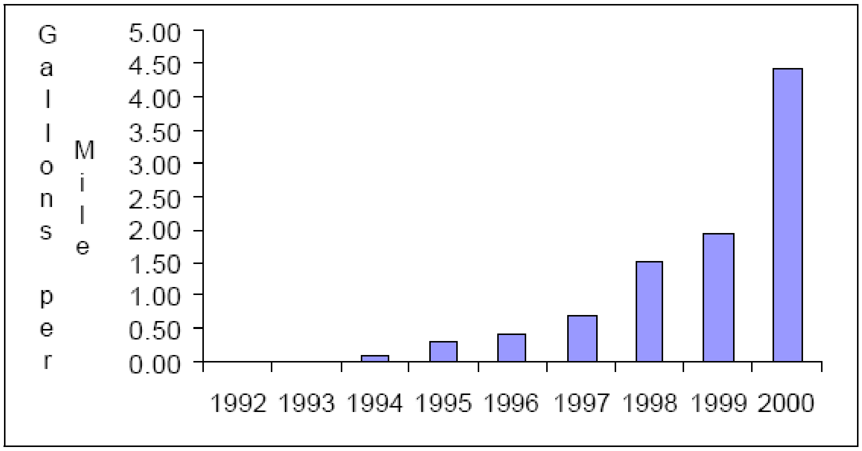

Figure 17: Liquid Chemical Use Per Mile, Denver Metro Region (Chang et al., 2002)

Anti-icing and pre-wetting treat winter roadway conditions with less material and reduce the need for sanding applications, both of which help reduce particulates in the air as well as sediment loadings in waterways. For Colorado, sanding applications were reduced because of the increase in particulate matter. A Colorado DOT report mentioned that once weather cleared, the remaining sand could actually reduce traction and become airborne particulate matter. Before switching maintenance methods, the city of Denver exceeded the PM-10 limit up to three times per month contributing to the brown cloud and causing health concerns. During year 1993 to 2000, sanding applications in the Denver Metro area decreased by 37%, whereas the use of liquid chemicals increased (Chang et al., 2002). Figure 17 shows the increase of liquid chemicals used in the Denver region. It was concluded that the "major benefits of increasing use of liquid chemical deicers include…cleaner air" (Chang et al., 2002). The phrase *chemical deicer*, in this sense, refers to the chemical product applied as a means of anti-icing.

Montana has also faced the issues with exceeding the PM-10 limits, and it has been documented that sanding for winter maintenance is one cause for high particulate matter. A report prepared for the Montana Department of Environmental Quality assessed chemical products and abrasives to determine what options were available to reduce the PM-10 infractions. Improved maintenance practices were first implemented during the 1990/1991winter season, and during the first five years, the use of liquid chemicals for anti-icing increased by 93%. However, the switch to liquid chemicals also posed problems such as increased chloride and trace metal concentrations in surface and ground waters. Despite the increase in chemical applications, it was determined that there has been no "significant negative impact to groundwater, and based on the volume of storm water discharged and the time of discharge, immediate impacts to surface water are probably short-term" (Missoula City-County Health Department, 1997). With this, Missoula's air quality was improved, and therefore posed less of a health risk.

4.5 Reduced Corrosion Effects

As discussed in Chapter 3, there is a great concern for the corrosion effects of winter maintenance chemicals on motor vehicles or the transportation infrastructure. However, most maintenance managers surveyed felt that corrosion from winter maintenance chemicals was minimal with a few complaints of cosmetic corrosion on vehicles. There was one instance where an allegation was made by the power authorities claiming the use of $MgCl_2$ was corroding wires and short-circuiting some of the hydropower lines. Some responded that corrosion to maintenance vehicles used to be high when lots of salt was used, but with the use of liquid chemicals, there was less corrosion to the body of a truck and more on the wiring. Very few agencies, however, linked winter maintenance practices to infrastructure damage.

The few complaints from motorists often involve cosmetic corrosion to aluminum parts due to liquid $MgCl_2$. The Salt Pilot Project performed in Washington State found results that would verify this claim, since the corrosion-inhibited $MgCl_2$ product appeared to be more corrosive to sheet and cast aluminum than plain salt (Baroga, 2005).

Concerns from the concrete industry that chemical products "may cause premature surface distress to concrete" prompted the Montana DOT to evaluate the use of liquid $MgCl_2$ for anti-icing. Highways in Montana that have had frequent applications of liquid $MgCl_2$ showed no signs of distress or damage. This was true for both new concrete highways as well as older highways that had been exposed to the chemical for almost ten years. Scaling of bridge decks and spalling from corroded rebar were also evaluated. It was found that bridge decks did not show signs of scaling; however, accumulation of chlorides has resulted in spalling (Williams, 2003).

Another report comparing traditional practices using NaCl to improved practices using liquid $MgCl_2$ for anti-icing or pre-wetting found "no evidence to date suggesting increased deterioration of bridge decks" (Mussato et al., 2004). However, it also stated that future problems might develop since these practices are relatively new. Laboratory results indicate that a reaction of $MgCl_2$ and cement paste degrades structural integrity of concrete, and that $MgCl_2$ may diffuse faster than NaCl into concrete (Mussato et al., 2004). However, $MgCl_2$ is primarily chosen for its ability to melt ice and snow at lower temperatures and in lower quantities than NaCl.

Compared with conventional snow and ice control strategies, both anti-icing and pre-wetting could result in reduced chemical usage, which can be translated into less corrosion effects on motor vehicles and the transportation infrastructure.

4.6 Cost Savings

Both anti-icing and pre-wetting are efficient means of winter maintenance and have been found to decrease maintenance costs while reducing the vulnerability of the highway system to winter weather. In examining economics related to snow and ice control, all costs should be considered such as material costs, labor hours, cleanup and repair, vehicle damage, travel delays associated with winter road closures and construction, human health, and litigation. While some of these numbers are difficult to estimate, all are important in balancing the equation to determine the best management practice.

Materials and labor are two categories that are easily estimated; however, not all agencies separate costs in terms of practice. Instead, they may only report a lump sum, which raises a problem when trying to evaluate whether or not anti-icing and pre-wetting are economical. However, both anti-icing and pre-wetting may reduce labor hours and material usage while providing a safer roadway, leading to the assumption of cost savings.

In one study for cost savings of anti-icing, the difficulty in designating the end use of a product was mentioned. In this study, Colorado, Kansas, Oregon, Washington and the Insurance Corporation of British Columbia (ICBC) were asked to state any cost savings from anti-icing. The following table includes their responses (Table 8). Specifically, Colorado saw an overall cost savings of 52% while Oregon saw a cost savings of 75% for freezing rain events. It was concluded that anti-icing could provide a 10-20% cost savings in snow and ice control budgets, and possibly result in a 50% reduction in cost per lane mile (Boselly, 2001).

Table 8: Cost Savings from Anti-icing (Boselly, 2001)

Agency	Publication Reference	Cost Savings
Colorado DOT	[21]	Sand use has decreased 55 percent. All costs considered, winter operations now cost $2,500 per lane mile versus $5,200 previously.
Kansas DOT	[22]	Saved $12,700 in labor and materials at one location in the first eight responses using anm anti-icing strategy.
Oregon DOT	[23]	Reduced costs for snow and ice control from $96 per lane mile to $24 per lane mile in freezing rain events.
Washington DOT	[24]	Save $7,000 in labor and chemicals for three test locations.
ICBC (Insurance Corporation of British Columbia)	[25]	1. Accident claims reduced 8% on snow days in Kamloops, BC: estimated savings to ICBC $350,000-$750,000 in Kamloops 2. Potential annual savings of up to $6 million with reduced windshield damage.

21: FHWA, 1996a; 22: FHWA, 1996b; 23: FHWA, 1996c; 24: FHWA 1996d; 25: CSHRP, 2000

Similarly, the survey we conducted indicated that agencies saw cost savings when utilizing anti-icing and pre-wetting. Mostly, the professionals felt that they were applying less material and clearing roads faster without the need for overtime with the use of anti-icing or pre-wetting. For instance, one agency reported that "trucks are off and parked 20% faster than the ones not using liquid" (Lupton, 2005). Agencies, however, did not always switch to these practices because of the economic benefits, but rather the improved levels-of-service and safety for the driving public.

On a highway in Idaho, implementing anti-icing reduced accidents by 83% and labor costs by 62% (Breen, 2001). Reducing accidents also translates into an economic savings to the traveling public in terms of vehicle repair, insurance costs, and injuries or fatalities as well as litigation costs. A reduction of accidents by 8% in Canada resulted in savings of over $240,000 (McCormick Rankin Corp and Ecoplans Limited, 2004).

In a large study on the economic benefits of anti-icing, it was found that savings could range "from $1,266 to $30,152 per typical maintenance snowplow truck route per year" while user cost savings in terms of reduced accidents could be as high as $107,312 for 900 storm hours. Table 9 presents cost savings for the U.S. highway network if anti-icing was fully implemented. Total cost savings were estimated to be $1.7 billion (Epps and Ardila-Coulson, 1997).

Table 9: Total Annual Cost Savings with Full Implementation of Anti-icing on the U.S. Highway Network (Epps and Ardila-Coulson, 1997)

Winter Storm Severity						
Storm Hours per Winter	100	300	500	700	900	Total
Storms per Winter	5	12	18	25	30	
U.S. Highway Mileage in Each Category (Percent)	24	12	11	6	3	56
Annual State Agency Cost Savings (Million $)						
Labor	0.63	2.45	4.66	3.61	2.59	13.94
Vehicle Operations	0.59	2.30	4.38	3.39	2.44	13.10
Materials	46.64	71.38	109.93	83.99	54.25	366.19
Equipment	-29.18	-14.59	-13.37	-7.29	-3.65	-68.08
Subtotal	18.68	61.54	105.60	83.70	55.63	325.15
Annual Motorist Accident Cost Savings (Million $)	175.99	263.97	403.29	307.97	197.98	1,349.20
Total Annual Cost Savings with Full Implementation by State Agencies (Million $)	194.67	325.51	508.89	391.67	253.61	1,674.35

In a recent APWA (American Public Works Association) Online Reporter article, five of the most common excuses to not use anti-icing were discussed, one of which is that "it costs too much". In response to this statement, the article quoted the cost savings experienced in Idaho on U.S. 12 as well as the estimated cost savings listed in the SHRP report (see Table 9 above). It was concluded that while anti-icing may cause agencies to initially change management practices, implement more training sessions, and invest in new equipment, in the long run it will save agencies money and improve levels-of-service (APWA, 2003).

By anti-icing or pre-wetting rather than just applying abrasives, cleanup costs in the spring are less (U.S. Roads 1997; Boselly, 2001). For the City of Kamloops, British Columbia, switching to anti-icing and pre-wetting reduced the use of abrasives and resulted in an estimated cost savings of $11,933 per year just from costs associated with roadside cleanup of abrasives (McCormick Rankin Corp and Ecoplans Limited, 2004).

In comparison to pre-wetting, anti-icing further reduces the sand usage and overall cost. In Montana, the 4-year average (1997-2000) centerline mile cost (labor, equipment, materials) for winter maintenance was examined for two sections using different practices to achieve the same level-of-service. Anti-icing the Plains section of State Route 200 resulted in a 37% reduction in costs per lane mile compared with the Thompson Falls section where pre-wetting is used (Goodwin, 2003). Table 10 is the cost analysis of the Montana study.

Table 10: Annual Material Usage and Cost for Montana State Route 200 (Goodwin, 2003)

Montana DOT Winter Maintenance Performance Measures
(Annual Averages)

	Thompson Falls Section	Plains Section	Percent Difference
Sand Quantities	73 cubic yards (56 cubic meters)	43 cubic yards (33 cubic meters)	41%
Sand Costs per lane mile	$724	$407	44%
MgCl Costs per lane mile	$136	$233	N/A
Material Costs per lane mile	$860	$640	26%
Equipment Costs per lane mile	$327	$182	44%
Labor Costs per lane mile	$564	$273	52%
Total Costs per lane mile	**$1,750**	**$1,095**	**37%**

Colorado evaluated the cost of sanding applications in terms of labor, equipment and materials. This helped the Colorado DOT evaluate best practices for winter maintenance and implement changes where necessary. In the last decade or so, Colorado has had one of the highest population growths in U.S. history resulting in increased traffic, insurance claims and insurance costs. The number of windshield replacement claims is cyclical with peaks occurring in the late spring and early summer. Yet, with the increase of liquid chemicals for anti-icing, the number of claims has been following a downward trend, resulting in cost savings to the public (Chang et al., 2002).

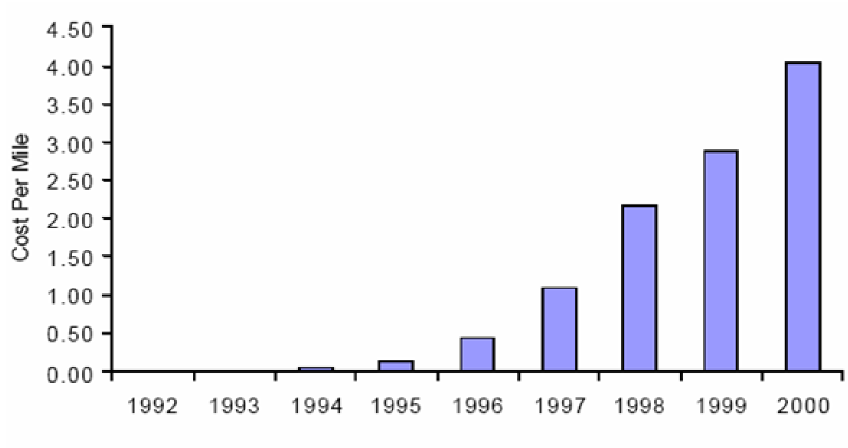

Figure 18: Increased Costs Per Mile of Liquid Chemical for the Colorado DOT From 1992 to 2000 (Chang et al., 2002)

While implementing anti-icing practices has allowed Colorado to meet air quality standards and reduce windshield replacement and repair claims, total costs for winter maintenance are still increasing due to the increasing population. Equipment and labor costs have remained relatively constant with the addition of anti-icing; however, the cost of chemical product per lane mile has increased nearly 400 percent, as shown in Figure 18 (Chang et al., 2002).

4.7 Constraints

Constraints of implementing anti-icing and pre-wetting methods are limited and generally relate to the lack of equipment or training. The cost of implementing these practices may make it difficult for agencies to make the switch, but once an initial investment is made, agencies will generally start to benefit immediately. While most maintenance managers agreed that anti-icing and pre-wetting were extremely beneficial for the driving public and the environment, one commented that it was difficult to implement and execute these practices in a methodical manner. The PNS states and provinces, on the other hand, have gradually overcome these kinds of problems. Some of the common constraints associated with anti-icing and pre-wetting are listed below.

Constraints of anti-icing:

- Training and management
- Equipment costs
- Reliance on accurate weather forecasts
- Casual slipperiness effect
- Material handling, and
- Public perception

Constraints of pre-wetting:

- Training and management

- Equipment costs
- Material handling, and
- Public perception

All of these constraints are intertwined, and cannot be resolved without properly addressing each one. Furthermore, it should be noted that not all conditions warrant the use of anti-icing. Under some climatic conditions such as high wind or very cold temperatures, anti-icing should be avoided (Technology Transfer Center 1996; Ketcham et al., 1996; Blackburn et al, 2004).

The successful implementation of anti-icing and pre-wetting require acceptance and proper training of winter maintenance staff. This requires maintenance managers and crews to understand the fundamental concepts underlying the practices and use them correctly (Smithson, 2004). Proper training and good management would help agencies select the best tools available for the specific combination of site, traffic and climatic conditions, which may include conventional snow and ice control methods. With the addition of new equipment, it is also important that field maintenance crews understand the extent of operations (Smithson, 2004).

Accurate weather forecasts are critical in order to successfully implement anti-icing practices, because such information will guide the timing and amount of chemicals needed for anti-icing operations. To this end, reliable, micro-scale models for the forecasting of localized weather (or road surface temperature) should be established and a network of weather stations should be in place to enable, validate and refine the models. For instance, the Utah DOT features a Weather Operations program that provides reliable, site-specific local weather forecasts for the highway maintenance staff, which promotes the adoption of anti-icing practices by winter maintenance managers and crews (Patterson, 2005). Anti-icing the roads prematurely without accurate weather forecasts may result in biased public opinion that would have to be overcome later. A less desirable option is termed *just-in-time anti-icing*, which is suitable for agencies without access to accurate weather forecasts (such as the Montana DOT). This requires maintenance agencies to watch for visual signs that a weather event is approaching such as moisture and temperature drops, at which time crews will begin deploying anti-icing trucks.

The slipperiness effect of anti-icing is caused by chemical residue remaining on the road, which may draw water to the road surface and cause slippery conditions. There have been a few reported instances of this occurring across the snowbelt region; however, not all cases are traced back to winter maintenance chemicals. In some cases, slipperiness is the perception of the driver and sometimes it is caused by other contaminants on the roadway. In a few instances, it is a result of chemical application, but this only happens when dilution has occurred and refreeze is possible (Leggett, 1999). A few agencies surveyed stressed this issue and stated it as a reason for hesitation when applying liquid chemicals. In one study, a climate-controlled environment was used to test various chemicals and evaluate the potential for slipperiness. It was found that during phase changes of chemicals, slippery conditions could occur; however, more testing would need to be performed on asphalt and concrete samples to determine if the slipperiness effect is a concern for roadway friction (Leggett, 1999).

Handling of liquid chemicals does require additional training; however, most chemicals are the same as used traditionally for deicing applications and are not considered onerous. Table 11 shows precautionary measures taken by each agency surveyed in handling chemical products. This is generalized for all materials, but agencies did state that practices have not changed with the addition of liquid products.

Table 11: Precautionary Measures Taken by Agencies for Handling Winter Maintenance Chemicals

Handling Precautions	**AL**	**AB**	**BC***	**CO***	**ID***	**MN**	**MO**	**MT***	**NV**	**NY**	**OR***	**VT**	**WA***	**WI**	**WY**
MSDS				X	X	X				X	X	X	X		X
Rubber Gloves	X			X	X			X				X			
Eye Protection	X				X		X	X				X			
Rubber Boots				X								X			
Coveralls				X								X			
Operational Guidelines		X	X						X	X				X	
Safety Meetings											X		X		X
Backup Person												X			

* Current PNS Association Participating Members

Public perception is also an issue for maintenance agencies. Members of the public express concerns about the impact of winter maintenance chemicals on the environment, on vehicle corrosion, and even on roadway slipperiness. Yet, they may not yet be adequately informed of the benefits of anti-icing and pre-wetting, such as reduced material usage and improved traveler safety. In general, public perception is relatively preferable for improved maintenance practices such as anti-icing and pre-wetting. Maintenance managers responded that the public attitude towards anti-icing is mixed; however, positive responses outweigh the negative. Table 12 includes information from the agency survey regarding public perception and whether or not the public has been informed about maintenance practices.

Table 12: Community Perception of Anti-icing and Pre-wetting Practices

Community Response	**AL**	**AB**	**BC***	**CO***	**ID***	**MN**	**MO**	**MT***	**NV**	**NY**	**OR***	**VT**	**WA***	**WI**	**WY**
Good	X	X	X			X	X	X	X	X	X	X			
Bad															
Both				X	X								X	X	X
Informed the Public			X		X	X	X				X	X	X	X	X

* Current PNS Association Participating Members

5. CONCLUSIONS

Compared with traditional methods for snow and ice control, anti-icing and pre-wetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates. Anti-icing has been recognized as a pro-active approach to winter driver safety. Pre-wetting has shown to increase the performance of solid chemicals or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required.

Anti-icing and pre-wetting offer many benefits and have great potential in changing the way maintenance agencies approach snow and ice control. Anti-icing and pre-wetting both present a viable option in reducing materials applied to roadways and maintenance costs while providing safer traveling conditions. Both practices also lead to less corrosion and environmental impacts due to snow and ice control operations.

Maintenance managers were asked if anti-icing and pre-wetting improved travel safety, reduced application rates, and were economical. Responses to all three questions were almost universally "Yes," with two agencies stating safety benefits varied, and one agency responding that anti-icing and pre-wetting did not reduce application rates. Yet, the increase in material usage might signify the increase in population and traffic rather than the change in maintenance practices.

Materials chosen for anti-icing and pre-wetting are often similar to those used for deicing (Wyant, 1998). However, improved application techniques should help maintenance agencies achieve safer roadways sooner with fewer applications and lower quantities of materials, thus, decreasing the impact on the surroundings. By implementing anti-icing and pre-wetting strategies for winter highway maintenance, fewer chemicals and abrasives will have the chance to enter soil, waterways and the atmosphere.

5.1 Future Advancements

For anti-icing and pre-wetting, maintenance managers surveyed felt that advancements in the near future would include, but not limited to: better products and equipment for snow and ice control, better weather forecasting, better deployment and utilization of road weather information systems (RWIS), lower costs, and most importantly, better training. Results from the agency survey regarding the trend forecast of anti-icing and pre-wetting can be found in Table 13.

Table 13: Future Advancements in Anti-icing and Pre-wetting, as Envisioned by Maintenance Managers

Future Advancements	AL	AB	BC*	CO*	ID*	MN	MO	MT*	NV	NY	OR*	VT	WA*	WI	WY
Better Products	X				X	X		X			X	X		X	
Better Equipment		X		X		X		X	X	X			X	X	X
Better Forecasting		X		X			X	X				X	X	X	
Widespread use of Anti-icing		X													X
More pre-wetting			X			X				X					X
More RWIS		X	X										X		
Cheaper					X		X								
Better Training								X							X
FAST										X					

* Current PNS Association Participating Members

It is also expected that the use of anti-icing and pre-wetting techniques would become more widespread in the next five to ten years. For anti-icing, its widespread use will be possible with an improved RWIS network and reliable, site-specific local weather forecasts (such as those provided by the Utah DOT Weather Operations Program). Agencies should continue to implement these improved practices for winter highway maintenance and further tailor the techniques to meet their localized needs. A better understanding of these practices is expected in both fundamental science and engineering aspects, as implementation is increased and additional research is performed.

APPENDIX A: BLANK SURVEY

Questionnaire: Anti-icing and Pre-wetting in Snow and Ice Control Operations

1. What do you see as the best method for maintaining safe winter driving conditions?

    Anti-icing

    Deicing

    Snowplowing

    Sanding

    Combo (please explain)

2. What percentage of your roadways use:

    Anti-icing:

    Deicing:

    Snowplowing:

    Sanding:

3. How much do snow and ice control operations cost your state DOT each year?

4. How much does the litigation associated with snow and ice control operations cost your state DOT each year? What *risk management* practices have your DOT adopted?

5. Have you tried *pre-wetting salt or sand* for snow and ice control operations?

If so…

- how long have you used pre-wetting techniques?
- what percentage of your sand or solid salts are pre-wet?
- how do you pre-wet your salt or sand?

    At the stockpile

    In the spreader

    Other (please explain):

6. Based on your experience, is there any technological advantage when using *pre-wetting* versus dry sand or solid salts? Please explain.

7. What experience have you had with anti-icing?

- how long have you used anti-icing techniques?
- during the season, how often does your agency use anti-icing?
- for what road weather scenarios?

8. Based on your experience, is there any technological advantage when using *anti-icing* versus other snow and ice control operations? Please explain.

9. What kind of chemicals does your agency use and what is the cost**:

Deicing	purchase price ($/ton)	estimated cost ($/ton)
Anti-icing	purchase price ($/ton)	estimated cost ($/ton)
Pre-wetting	purchase price ($/ton)	estimated cost ($/ton)

estimated cost accounts for labor and equipment costs as well

10. Have the practices of anti-icing and pre-wetting improved *roadway safety* for your jurisdiction? Please explain.

11. Have the practices of anti-icing and pre-wetting significantly reduced your application rate of chemicals or sand? If so, by what percentages?

12. Compared with conventional snow and ice control operations, do you consider anti-icing and pre-wetting economical? Please explain.

13. For *worker safety*, what precautions does your agency take when handling pre-wetting/anti-icing chemicals? Are the procedures different from those for handling deicing chemicals? Please explain.

14. How does your agency store chemicals? Have you experienced any problems with your storage facilities?

15. Have regions under your supervision experienced detrimental effects to the environment or public health due to the use of road salt or other chemicals, leaks in storage facilities, etc.?

16. In your opinion, are there environmental benefits offered by the practices of anti-icing and pre-wetting, in regard to *human health and toxicity to the environment*? Please explain.

17. Have you experienced or witnessed the corrosion of vehicles, concrete or asphalt pavement, and/or the transportation infrastructure due to pre-wetting/anti-icing chemicals? Is there any difference between these chemicals and deicing chemicals, in terms of corrosive effects?

18. How has the community responded to the anti-icing and pre-wetting practices by your agency?

19. What type of innovation in anti-icing and pre-wetting do you expect in the next five or ten years?

20. Do you have more comments on the practices of anti-icing and pre-wetting?

APPENDIX B: SUMMARY OF SURVEY RESULTS

Questionnaire: Anti-icing and Pre-wetting in Snow and Ice Control Operations

1. What do you see as the best method for maintaining safe winter driving conditions?

Anti-icing

Deicing

Snowplowing

Sanding

Combo (please explain)

Alaska: Combo, there are times when all these strategies have merit.

Alberta: Combo - our climate ranges from dry, warm conditions in the south-east (equivalent to the Montana plains) to cold, moist conditions in our north-east and nearly everything in between. Many of our snowfalls are cold, dry flakes that do not stick to the pavement even during heavy traffic, and the best thing to do is nothing (except for inspections to make sure that things don't change). Other storms, especially in our "shoulder seasons" have sticky snow that turns to ice as soon as it hits the pavement. And, having said all that, we're only starting to experiment with anti-icing, and have only been using pre-wetting (mostly of a mixed sand & salt blend) for the last 3 years.

British Columbia: Combo of snowplowing, sanding and deicing primarily. Anti-icing is used by the minority of maintenance contractors although we promote and encourage anti-icing, we are lacking the technology to make knowledgeable anti-icing decisions, (RWIS stations, sound weather information to base decisions on).

Colorado: Combo - as far as a state goes, you can't do one or the other, you have to use them all. Anti-icing works good, but you get into situations where the snow overwhelms what you can do with anti-icing, so after the storm, you still got deicing to do. Wolf Creek pass in January received 128 inches of snow in 10 days, you have to sand/plow, a little bit of everything.

Idaho: There is no best method for all conditions. Each of these are appropriate for specific environmental, traffic, and roadway conditions on any given segment of roadway and the choice of which method to use depends on the adequate training of the operator or manager.

Minnesota: In terms of maintaining safe winter roadways, anti-icing is the best - can get ahead of the storm and prevent a bond from forming. However, it is probably a combination of anti-icing and deicing the best method, by getting liquid (preferred) and solid (helpful) chemicals on the road.

Missouri: I believe that anti-icing is the key to efficient treatments of the roadway. However, if the anti-icing effort is not successful (as is the case the majority of the time in the Midwest) then the combination of deicing and snowplowing is our next option.

Montana: A combination of those tools is best because winter maintenance is level-of-service driven for different roads and conditions. For example, maintenance on a level-3 road would likely entail plowing only with some sanding at intersections, corners, hills, bridges, and would use liquid chemical to pre-wet the sand. Higher levels of service require adding the use of chemicals for anti-icing and deicing to achieve a bare road more quickly. The use of chemical helps provide a safer winter road with less environmental damage.

Nevada: Combo – there is no single "best method" for maintaining safe winter driving conditions. Effective snow and ice control will always require a combination of the above measures, depending on the weather conditions. For example, anti-icing treatments can be very effective for many storms, while in all cases where snow accumulates on roadways, snowplowing (or blowing) and deicing are the only practical course of action. Our snowplowing is frequently accompanied by salting/sanding to improve traction for the traveling public.

New York: Combination of snowplowing and anti-icing.

Oregon: Combination, depending on the roadway conditions and what the weather forecast is. We look at anti-icing/deicing as one of the tools that can be used for maintenance forces. We look at weather forecast to see what event will occur in the next 12-24 hours, what the traffic is, what the day of the week is, and what kind of crew will be available to be there. Labor availability is critical to any road maintenance action. ODOT gave 16 winter maintenance training classes last October/November, and trained over 500 people on the application of deicers. A big part of the course was a scenario workshop. What actions worked, what actions didn't work were discussed. The crews picked a highway in their area and what situations they ran into, and heard about something that maybe didn't work and make it a learning experience for several crews…Usually a combination, maybe do nothing at all, use a deicer or anti-icer, same chemical but apply it in a different time or rate.

Vermont: Combo - Our methods are driven by VAOT policy, which requires obtaining partial or completely bare roads, depending on type of road, soon after a storm. Salt allows this. Sand generally doesn't. Our types of storms, squalls and freeze-ups don't really allow for ant-icing. Many events begin late in the day and run into, or through the night, when we have very limited manpower available. We have to switch to sand during the night, to provide friction while our crews rest and temperatures often drop. We, then, utilize warmer daytime road temperatures to clean up the roads.

Washington: Combo – each condition has a different solution. Frost – liquid chemical as a pretreatment, freezing drizzle – solid product where liquids would dilute. Depends on climatic zone. For wet snow, use a solid product; in colder regions, maybe use a liquid. Try to pre-treat in all cases, either during or before an event with chemicals and abrasives as needed.

Wisconsin: I'd have to go with the combo choice, we always talk about having a toolbox with different techniques to access…the field people are equipped to do all these maintenance activities you talk about, they will do one or many during any particular storms…Toolbox of different techniques, equipped to do all activities, dependent on temperature, precipitation, type of storm, etc.

Wyoming: No one good method of snow/ice removal, must use a combination methods. Primarily use snowplowing and sanding, deicing for emergencies and anti-icing in Cheyenne (I-25) and Pine Bluffs.

2. What percentage of your roadways use:

Anti-icing:

Deicing:

Snowplowing:

Sanding:

Alaska: Anti-icing 10%, Deicing 100%, Snowplowing 100%, Sanding 100%.

Alberta: Anti-icing <1%, Deicing 100% (80% on a routine basis), Snowplowing 100%, Sanding 100%.

British Columbia: Anti-icing 2-3%. The rest composes the other 97%, with sanding at 20%, deicing at 7%, snowplowing about 70%.

Colorado: Sanding statewide, plowing statewide, anti-icing is used on higher volume traffic areas on I-70 and I-25, air attainment areas, and urban areas, sanding is used statewide.

Idaho: Sanding is used on virtually all roadways as is snowplowing assuming there are winter conditions to warrant them so I would estimate the figure to be 100%. Virtually all of our roadways use deicing (straight salt in limited areas but salt mixed with abrasives in all but a few areas) which I would estimate to be near 90%. Because of the anti-icing program maturing over time, the estimate of how many miles are using this practice is constantly changing, but for now, I would estimate this figure at 50%.

Minnesota: Anti-icing – 10-20% concentrate on critical areas, curves, bridge decks, other historically troubling spots, Deicing – 100%, Plowing – 100%, Sanding – 100%. Northern roads near Canadian border take longer to clear but don't stop working until they are clear.

Missouri: We use anti-icing on our interstate system which carries about 80% of our traffic by volume but makes up less than 15% of our lane miles. Deicing is used on most all of our routes including those that we try to use anti-icing. Snowplowing is used as needed on all routes depending on the type of storm. Sanding is used only on low volume routes with less than 1700 AADT.

Montana: Anti-icing is used in all urban areas primarily in the western part of the state. Some anti-icing is used on rural highways if they lend themselves to that technique - (10%). Deicing is limited to urban areas with PM-10 or high levels of service. If persistent ice conditions exist in critical areas, solid chemical deicing will be used - (15%). Snowplowing – (100%). Sanding will be used in most areas except where prohibited because of air and water quality concerns. – (85%)

Nevada: Anti-icing 50%, deicing 90%, snowplowing 90%, sanding 90%. NDOT is responsible for approximately 5,500 centerline miles of roadways. The only roadways that do not routinely require snow and ice control operations are located in southern Nevada (Las Vegas area), and even in these areas, a rare snow or ice event may occur. Given this, virtually all our roadways may on occasion have snow or ice control operations utilizing some or all of the methods described above. Our anti-icing capability with brine or pre-wetted straight salt is limited to areas that have brine manufacturing, dispense the brine or magnesium chloride. Generally, most anti-icing occurs on our higher volume roadways, while conventional reactive controls are adequate on our rural, low volume roadways.

New York: anti-icing 100%, deicing 100%, snowplowing 100%, sanding – isolated locations.

Oregon: 75% for all, some roadways don’t use it at all because they are right near the coast, used interchangeably. We are likely to use a little less snowplowing and sanding, depending on the year. There is a highway system to cover, but some areas just aren’t prone to freezing. More anti-icing, less sanding, is the trend.

Vermont: anti-icing 0%, deicing 98%, snowplowing 100%, sanding 98% (partial sand) 2% (total sand)

Washington: For all state highways, Anti-icing – 60%, Deicing – 60%, Snowplowing – 100%, Sanding – 100%. This was last year, will try to have all roads at 100% by next year for anti-icing and deicing.

Wisconsin: anti-icing - spotty, hard to measure, do anti-icing on bridge decks and trouble spots, some sections which might anti-ice entire patrol section like a 20 mile stretch, less than 20% maybe even less than 10%, deicing – entire system 100%, snowplowing – entire system 100%, sanding – minimal amount of sanding – less than 10% (areas of the state – hillier areas with lower traffic volumes)

Wyoming: anti-icing 1-2% (Pine Bluffs – only on Bridge decks), deicing – for emergencies only – have only four stations with deicing material, snowplowing – 100%, sanding – 100%.

3. How much do snow and ice control operations cost your state DOT each year?

Alaska: My total budget for the year is $8.54 million dollars and half that or ~$4.47 million is spent during the winter season. Our winter season is 6 months, from October 15th to April 15th. This is strictly for the Anchorage district, not the entire state.

Alberta: Our total winter budget for paved highways (sand, salt, plow hours, snow removal, winging, etc.) is about $Cdn 44 million ($US 35 million) for a network of 30,000 2-lane equivalent kilometers (or about $US 375 per lane mile).

British Columbia: Snow clearing operations, all of the winter maintenance is included as a lumped sum with the maintenance contracts of $Cdn 320 million/year, $Cdn 200 million provincially on snow and ice control operations (or about $US 160 million on snow and ice control operations).

Colorado: 2003 – a little over $38 million, in 2004 - $39.5 million

Idaho: Obviously winter severity and climate have a huge impact on the costs in a given year, but on average the costs including labor, materials and equipment to control winter in a fiscal year average $13.5 million directly with another $3 million for statewide brooming of abrasives. If I were to try to account for the replacement of damaged signs, mailboxes, repairs to guardrail, erosion of striping and pavement markings, tort claims for damage, etc which our winter operations incur, the cost would be higher.

Minnesota: $33 million in 2004 which is fairly average. Can range from $30-50 million

Missouri: In our district (8 counties) we spend about $2 million per year on snow removal. There are 10 districts within the state.

Montana: $15-17 million per year. Roughly 70% is spent on the western third of the state. The costs are split in near equal thirds for labor, equipment and materials.

Nevada: Costs obviously vary widely depending on severity of weather events, but on average the costs are approximately $5 million.

New York: $46 million state forces, $29 million municipal contracts

Oregon: Have costs broken down by fiscal year, anti-icing/deicing last fiscal year cost $2 million dollars, sanding and pre-wetting $8.5 million, snow and ice removal $6.9 million. ~$17 million all together.

Vermont: $20 million on average.

Washington: In the last four years have seen $26, $28, $24, $30 million, so on average, spend $28 million/year.

Wisconsin: Total, typically spend $32-40 million dollars for all winter operations, depends on severity of winter. The winter of 2000/2001 spent $50 million…includes materials, labor, equipment, whole shot. Activity code for anti-icing, last winter (2003-2004), spent about $320,000 on anti-icing (is included in above total estimate). We have two FAST systems in operation (we had a third one, but have given up on that, it wasn't reliable). Both are freezefree systems by Energy Absorption, Inc.

Wyoming: Entire state - $14.9 million budgeted, and on April 8th, had already used 85% of that. This year is not a bad winter and we will still probably exceed our budget. District 1 budget is $3.9 million and have spent 84.9% of that already. For bad winters, usually go over budget by about double, and will have to cancel a construction project.

4. How much does the litigation associated with snow and ice control operations cost your state DOT each year? What risk management practices have your DOT adopted?

Alaska: I don't know the dollar amount but we are self insured. One thing we have done is to pre-screen damage claims by having the claimants stop by our office. We look to see whether the broken or chipped windshields/paint look like they could have been caused by our clean, washed traction sand. We then gather all the pertinent info such as exact location and time of the occurrence and pass that on to risk management.

Alberta: Since we outsourced all maintenance services in 1996, I don't know of any times where the provincial government has been found liable for winter works. Our contractors have been involved in several lawsuits, but we don't know how much this has cost them either in judgments or legal fees.
As the owner/manager, we have contract specifications that clearly outline the respective responsibilities of our own employees and the contractor's employees in winter work. For the most part, the government just audits the contractor's work to ensure that he is providing services in accordance to our standards (and specifications).

British Columbia: See some litigation costs as a ministry, as the government. Part of it is the liability for the maintenance contractors. For our ministry it is probably $2-2.5 million per year. The maintenance contractors are responsible for the delivery of the works and the management as well. Risk management is principally theirs.

Colorado: Litigation – don't know, Risk Management – deny all claims. If a car gets a windshield broken and the rock comes from a tire, deny immediately. If it comes from the truck, will investigate.

Idaho: We have never tallied the litigation costs for winter work at ITD. We don't really have the resources or tools to do that except through a manual and labor intensive effort. An estimated figure would be less than $1 million per year.

Minnesota: Litigation – n/a, Risk Management – n/a, all practice risk management to a degree, but what is good enough. Don't know any specific guidelines followed.

Missouri: I cannot answer the first part of the question, our legal department would have a handle on this, but our risk management practices have changed radically recently. We have snow school that every employee that plows snow will need to attend at least once every three years. This is an intense day long training that includes policy, practice, equipment, and technology. After the September snow school, then we have a day set aside in October that is a hands-on training for new hires that gives them the opportunity to drive the trucks and operate the plows as if we had snow. We also have meetings at each local building that remind the employees before the storm about safe driving practices.

Montana: I don't know of an average litigation cost. Tort claims are numerous for broken windshields from sanding material.

Nevada: NDOT is frequently faced with claims and lawsuits related to snow and ice control operations. The total annual costs of these claims and lawsuits may vary widely depending on the weather events, the number and severity of crashes, and the legal trends regarding such incidents. For 2004, NDOT paid approximately $15,000 in routine snow and ice claims, and we would estimate about $100,000 per year in litigated cases. The litigated cases can be difficult to track, as the complex cases may take years to settle. We do not have any formal risk management practices identified related to snow and ice control, other than a common sense approach to do the best possible job to keep our roadways safe for the traveling public. When the roadways cannot be kept clear, we will close the roads until we can regain the pavements.

New York: Litigation costs vary from year to year and have no measurable pattern. To manage risk, we staff for 24/7 operations by shifting. We have staff ready to go at the beginning of a storm. Also, chemical priority and best practices are considered.

Oregon: Litigation – from winter maintenance training class, went over claims, cost is about an average of $9,000/year. 1/3 are legal costs, the rest are claims paid out, etc. These are deicer claims, doesn't have anything to do with sanding. The claims are generally property damage or vehicle damage…Risk management – annual training classes on deicer applications, based on that, knowing how to use the product, knowing the different conditions where you may/may not apply it.

Vermont: I don't know. Relatively minor costs for broken windshields from winter sand. Some litigation costs. Just recently, VAOT has begun litigating claims for such damages, considering them road hazard damages, rather than paying them automatically. Therefore we may see a further reduction in costs.

Washington: Litigation – no idea. Risk management – looked at and assessed risk based on what we're doing and how we're doing it, developed snow and ice plan to minimize risk, prioritized roadways as to budgetary and response capability, identify primary roads on down to category 5 roads, most of the snow and ice plan was reviewed by the HA and risk assessment team. Also have risk management issues such as broken windshields and corrosion. For broken windshields, if truck was coming at them on two-lane highway, going opposite direction and sander didn't shut-off – valid claim. If they were following or passing plow, or sand was kicked up by another vehicle, claim denied.

Wisconsin: Unique situation, contract all highway maintenance to county maintenance departments, the county inherits the liability responsible, there have been cases that they have been taken to court. Risk management – the DOT is responsible for public service announcements to tell the public what we are doing on the roads and encourage them to drive safely. There is a road condition report. Put out press releases to publicize anti-icing program. Do everything we can to encourage sensible driving.

Wyoming: Litigation, don't know numbers, but see complaints due to chipped windshields and paint, have had a few instances where a car will rear-end the snowplow and file a lawsuit. Sometimes snowplows will sideswipe vehicles. Have had a few head-on collisions due to snowplows crossing the centerline (or being pulled across the centerline due to conditions). When the blade is set at an angle, trying to break through the ice and it hits a slushy part, it may throw the truck across the centerline. Have also had one instance were a rabbit was frozen on the road and when the plow hit it, it sent the truck into the right of way. For broken windshields and chipped paint, the DOT will say too bad. Risk Management – have a snowplow defensive driving course – try to get 1/3 of people through it every year, talk about do's and don'ts, scenarios. Have maintenance equipment training academy – would like to have a simulator to train drivers in, would be very helpful. Usually send an experience man with "green guy" for a few rides for on the job training.

5. Have you tried pre-wetting salt or sand for snow and ice control operations?

If so…

- how long have you used pre-wetting techniques?

- what percentage of your sand or solid salts are pre-wet?

- how do you pre-wet your salt or sand?

At the stockpile

In the spreader

Other (please explain):

Alaska: Probably for 10 years or so, aiming for 100% of pre-wet sand done at the spinner

Alberta: Approximately 20% of the fleet has had pre-wetting equipment since 2002. Probably about 15-20% of material is pre-wet. The material is sprayed as it comes out of the hopper, mostly in the discharge chute, but a few units spray at the spinner.

British Columbia: Maintenance contractors pre-wet mostly sand, not as much salt. Pre-wet abrasives for traction control and braking. Have been pre-wetting for about 5-6 years.

NaCl is pre-wet, but mainly sand. Probably about 30% of sand is pre-wet. Pre-wetting is done on the truck at the spinner.

Colorado: Pre-wet sand for about 4 to 5 years. 10% of sand is pre-wet. Been experimenting with it for about 12 years. Have saddle tanks on trucks, so pre-wet as going down the road. Storage tanks with spray system so after you load the sand you can spray it right on the sand before you leave the yard (Denver area)

Idaho: We do pre-wet at the back of our sanding units on our trucks and have done so since 1996. We started getting saddle tanks on our sanders around 1993, but never really used them or knew what they were for until around 1996. Even today, we are still ramping up our pre-wet program because of our lack of a comprehensive training program for our maintenance technicians. It's all word of mouth, on the job training, and trail-and-error.

Minnesota: Yes, pre-wetting since the 1980's, nearly 20 years, became full blown in the 1990's. Pre-wet both salt and sand, but use very little sand anymore. In the metro district, used only 1000 tons in the last year, and statewide only 25,000 tons. All solid materials are pre-wet (100% solid salts and sand). Pre-wet material both in the auger and in the spinner, as well as at the stockpile. The metro district pre-wets 40% of their stockpiles.

Missouri: Yes, for 10 years. 50% of materials are pre-wet, all done in the spreader.

Montana: Yes, varying quantities of salt have been used in sand for a long time. 6-8 years using liquids in saddle tanks, about 15-25% material pre-wet, primarily use saddle tanks. At the stockpile, a specific quantity of material is pulled aside, and a known quantity of liquid is added to create a "hot pile" which may already have salt but may be adding $MgCl_2$. On the Spreader, we apply about 7 gallons per ton of abrasives, no straight salt piles, trying to use 1 ton/mile of pre-wet material.

Nevada: Yes, both salt/sand mixtures and straight salt (typically only for anti-icing). Have been doing this for approximately 6-7 years and approximately 10% of total salt/sand used is pre-wet. Pre-wet at the spreader. Our newer trucks in the fleet, and those currently being procured for the heavier snow regions include a sander/spreader unit which has brine tanks that wet the sand/salts on the conveyor just prior to the "spinner" that spreads the material on the roadways.

New York: Yes, since the 1980's. Pre-wet about 40% of material at the spreader. Also use treated salts from various manufacturers.

Oregon: Used more each year, with mountain pass areas using this more. Have been using for 5 years, some crews ask for advice on how to do it. Of the sand used, ¼ to 1/3 is pre-wet. Have pre-wet sand both at the stockpile and in the spreader, but we are going more towards applying at the spreader. At the stockpile, pre-wet so it doesn't freeze, some of the colder locations will tend to pre-wet at the stockpile. There is a disadvantage of placing the pre-wet sanding material in the truck at the stockpile as this introduces the deicer into the hopper resulting in corrosion. An alternative to this is to have deicer tank on the truck with the sand. Have deicer come out right where sand comes out, minimized the amount of corrosion on the sand hoppers on the truck. This also helps the sand stay on the road.

Vermont: Have been pre-wetting for about 8 years. Only salt is pre-wet – about 20%. Pre-wet both at the stockpile (20%) and in the spreader (80%).

Washington: Have been pre-wetting for 10 years, 30% of material is pre-wet because of equipment constraints, otherwise would pre-wet 100%. Pre-wet at the spreader as material drops to the roadway.

Wisconsin: Pre-wetting for a number of years dating back to the mid 80's. Amount of material pre-wet varies on storm conditions, varies with pavement temperature and amount of moisture in the snow, on a statewide basis, 70% of county highway departments have onboard pre-wetting equipment. Pre-wetting is done onboard, still a few locations with a spray bar at the salt shed, 60% of the trucks have ability to do this onboard.

Wyoming: Pre-wetting was the first thing we tried before anti-icing, had old saddle tanks, but have moved away from that method since pumps weren't adequate. That was about 7 years ago. Now we pre-wet at the stockpile or as the trucks are leaving. Have homemade equipment (shower systems) similar to what Colorado uses.

6. Based on your experience, is there any technological advantage when using pre-wetting versus dry sand or solid salts? Please explain.

Alaska: Certainly, the pre-wetted sand tends to "stick" to the road better due to the fact that the individual sand particles get seated into any existing snow or ice by way of melting.

Alberta: Yes. In our experience, there are two major advantages: Faster deicing brine formation (especially at low temperatures, -15 to -20^{o} C), and Significantly better material retention in traffic – every operator that I've talked to has remarked that they don't need to go back as often after spreading a pre-wet material.

British Columbia: Yes, that is why we pre-wet our winter abrasives. They seem to stick to the compound snow surface, have seen less blow off from heavy trucks, better adherence of the products, less reapplications.

Colorado: Yes, if you have dry sand, as traffic goes by, especially trucks, it blows off of the road. If you pre-wet it, it starts melting once it hits the road. If your application rate is correct it will freeze and embed itself in the snow pack and will stay on the road.

Idaho: I have seen research, attended training seminars and conferences, and heard our maintenance technicians tell me that the practice works if used appropriately. If a person doubts it, have them stick their tongue on an ice cold metal pole outside on a cold winter day and then ask them if they think pre-wetting makes sense. If they can enunciate with their face stuck to the pole, you'll find you have a convert to the philosophy.

Minnesota: Yes, pre-wetting helps because the liquid helps to jumpstart the process, and helps the material to land on the road and stick. Right now using on average 15-20 gallons/ton of salt, but want to move higher to almost a slurry consistency similar to what Europe has been doing.

Missouri: Depending on the storm the value of pre-wetting is either very advantageous or simply not a factor. We have some storms that will come in very wet at first then dry out as the temps drop. If the storm is dry, most of the rural areas prefer not to use material that will cause the snow to stick to the pavement. Being close to Kansas, we usually get some wind with the dry snows so it simply blows across the pavement. In the urban area we have the lane barriers that modify the mirco-climate and stifles the action of the wind so most of our east/west routes tend to accumulate snows next to the median barrier. We usually like to pre-wet in most urban instances of winter weather action.

Montana: Yes – pre-wetting is limited by availability of equipment. 3 reasons why: increase performance of abrasives/salt, stays on snow pack/ice better, refreezes to make sandpaper, improves storage/performance in stock piles.

Nevada: Pre-wetting salt or salt/sand mixture activates the salt quicker, makes it more effective when it hits the road (especially on snowpack). Another significant advantage of pre-wetting is the material sticks to the road better (instead of bouncing or blowing away). On packed snow for example, pre-wetted material is immediately effective and "bites" into the compacted snow, where un-wetted materials may be blown away by the winds. Pre-wetting also gives salt/sand more "staying power," may increase the amount of time the material remaining on the road is effective. We use brine (22% salt) for the pre-wetting.

New York: Drivers maintain control of when salt is pre-wetted during salting operations

Oregon: Yes, based on the feedback from crews, if it's pre-wet when it comes out of the hopper on the truck and goes down onto the road, the sand/gravel adheres better to the road and tends to work into the pack that may be on the road (ice/snow). Also, have gone and applied sand on a road and gone over and applied deicer on top of it. Sand gets an application of deicer right on it. Use quite a bit on ramps.

Vermont: Sure. Pre-wetting with liquid calcium chloride provides a "jump-start" to our salt, when utilized at otherwise inefficient salting road temperatures of below 20 degrees.

Washington: Yes, pre-wetting sticks salt into lane better (embeds into snow/ice), also sticks to road and doesn't blow off. Enhances salt/sand with liquid deicer.

Wisconsin: Haven't done a study ourselves, rely on study done in Michigan back in the 1980's that shows you can keep 30% more of your salt on the road when you pre-wet, in the training we always refer to that. Highway maintenance guys that do it religiously say they lower their application rates and they eventually they use less material.

Wyoming: On aggregates, guys can tell the difference when applying, on I-80, traffic is 60% trucks, so material would blow off after 3rd truck went by, and sand would be blown off without pre-wetting. It also helps to cutoff ice as the material starts to melt the ice/snow pack.

7. What experience have you had with anti-icing?

- how long have you used anti-icing techniques?

- during the season, how often does your agency use anti-icing?

- for what road weather scenarios?

Alaska: Have used anti-icing techniques for over 10 years as conditions warrant. We use anti-icing in major intersections in our urban sections. At an intersection with 2 through lanes, 2 left turn lanes, and maybe another right turn lane the plows never get the intersection plowed full width on the first pass and consequently the turn lanes get packed down by traffic. The idea is to anti-ice these intersections to prevent the hard bond from occurring in those areas. We also use anti-icing in lieu of sand when conditions warrant to cut down on the total amount of sand we use.

Alberta: Almost no experience, just started rigging up for a couple of pilot projects and haven't even trained the operators yet.

British Columbia: Anti-icing for about 5 years, used only for 2-3% of the time. Currently working on increasing our technology base with the installation of significantly greater numbers of RWIS stations which as the network increases, it will allow us to make better and more timely and accurate weather decisions on what type of weather patterns there are. Use anti-icing for the anticipation of incoming weather patterns of snow accumulation patterns where the road surface temperatures are not expected to drop below 6C.

Colorado: Part of the FHWA TE #28 in 94/95, working with federal highways and pooled fund agencies ever since. About 13 years. Anti-icing all winter long, change materials, change techniques depending on what the weather is doing. Follow guidelines, wait until storm starts and precipitation is on the road and the pavement temperature starts to drop.

Idaho: We have been anti-icing since 1977. The initial years were more experimental than production oriented, but the program started to take off in 1993. How often we anti-ice depends on the weather conditions, but I would hazard a guess that in the belly of winter, we are anti-icing somewhere in Idaho every work day. Our ideal scenario for anti-icing is based on a forecasted weather or frost event as a proactive and preventive treatment, but often times the maintenance technicians are using their professional judgment.

Minnesota: Yes, have been anti-icing for 10 years, came to forefront in the last 5 years. For anti-icing, we have a program that goes out twice a week on Tuesdays and Friday mornings to apply material to the curves, bridge decks, and other critical areas. Use for frost and for critical areas at the beginning of a snowstorm.

Missouri: Personally, I worked with the SHARP program in the late 80's and early 90's identifying the skid resistance of anti-icing techniques. We used both the car mounted traction measurement device and the pogo stick device to run tests during winter weather. We didn't embrace the technology full until the later part of the 90's. We try to use it as often as the appropriate storms approach as we do a lot of pre-treatment with brine. We will not use anti-icing if the storm is going to be rain turning to ice or snow.

Montana: Montana began in 1988 in the Missoula area, and Montana has state of the art equipment. Anti-icing is level of service driven and is an important tool in areas of environmental concerns. Anti-icing is used 100% of the time in the western part of the state. Anti-icing is used in all conditions except rain/wind, cold temperatures below 10F, and when there is solid snow pack requiring deicing.

Nevada: Anti-icing approximately 7 years. Depends on weather events, but where we have this capability it is used when deemed appropriate by the maintenance crews. In advance of anticipated heavy snow/ice storms to provide improved traction/prevent freezing, and help keep the road free from build-up of snow/ice. If the roads are dry and we expect "dry" snow or potential "black ice" conditions, the crews might pre-treat using only a brine solution. If a "wet" storm is expected, pre-treatment with brine alone could get washed away, which is obviously ineffective. Where the roads are wet, and heavy wet snow or freezing rains are expected, the anti-icing pre-treatment would probably be done using pre-wetted straight salt.

New York: Minimal experience with anti-icing, 5-10 years. Use as needed in advance of storms, dependent on humidity, temp, etc. Use on certain bridges, black ice/frost locations and trouble spots.

Oregon: Department has used anti-icing for about 5 years. This winter had hardly any precipitation. We have deicer sampling program, and did receive more samples than last winter. Last winter was pretty severe. Samples – following PNS specifications, any time a maintenance yard gets a delivery of a product, must take a sample and send it the Office of Maintenance, where the QA/QC is managed. Samples are sent to the lab, and the results are documented and tracked by the Office of Maintenance. This helps the regulators to know the trace metal concentrations, having ODOT meet the PNS specs. Generally, as an anti-icer, if precipitation is going to move in and temperature is to drop below freezing, will be proactive.

Vermont: None

Washington: In some areas, for 10 years. Use anti-icing about 60% of the time in Washington, would anti-ice all year if weather conditions allowed. Always use anti-icing for frost, can get 8-10 days out of one application. Also anti-ice for freezing rain/snow, but may use solid deicer for pretreatment.

Wisconsin: Started some test section for two winters 97/98 and 98/99 and went full-bore with anti-icing in 2000/2001, didn't actually mandate it, again because of our relationship with the counties, we try to do things as a partnership, maybe 40/72 counties participated in the first winter (2000-2001), now 80% of the counties have the equipment and do anti-icing

Bridge decks and trouble spots, frost control and black ice, use under light snow condition…it might snow for a length of time but we don't get a very big quantity of snow and we can keep roads wet by anti-icing

Wyoming: Have been experimenting with anti-icing for about 5 years, use three trucks right now with tanks in back, single axle with spray bar, and apply about 25-27 gal/lane mile. Would like to get trucks with ground speed controls, have a few bigger tanks in tandem trucks. Are currently bidding on three trucks.

8. Based on your experience, is there any technological advantage when using anti-icing versus other snow and ice control operations? Please explain.

Alaska: Yes, anti-icing can prevent the hard bond of snow/ice to the pavement.

Alberta: n/a

British Columbia: Definitely, the experiences we've had with liquid $MgCl_2$ and $CaCl_2$, we've seen the benefits of anti-icing preventing the bonding of the compact snow to the road surface as well as the lower effective temperature ranges of liquid $MgCl_2$ and $CaCl_2$. We have had some negative experiences with anti-icing. With liquid $MgCl_2$, the slipperiness effect. Also, feedback from the trucking associations about their perception of corrosion on the aluminums products on their trucks being caused by liquid $MgCl_2$. Have also had allegations from power authority that liquid $MgCl_2$ has been causing some electrical problems with the power lines and the controllers.

Colorado: Yes, in high volume areas, will stay wet through rush hour. When storm is over, get snow pack off road a lot easier if you've used anti-icing. By using it on Vail Pass, cut our chain law and closures in half.

Idaho: The way the anti-freeze in a car radiator operates to alter the boiling point of water is the exact same physics that the anti-icing chemical uses to alter the freezing point of water. I'm not a chemist or physicist and neither are our maintenance technicians, but most of us have accepted this research, testimonials and have experimented with the process enough to accept that it works.

Minnesota: Yes, excellent, prior to anti-icing, had lots of people sanding bridges at 4-5 a.m., we don't have that anymore. Has also prevented numerous accidents.

Missouri: When it can be used it usually provides easier removal of frozen precipitation, giving us an economic advantage as well as quicker return to normal conditions. It is easier to break any bonding of ice to the pavement if a coat of salt or brine is applied ahead of the storm.

Montana: Yes – more bare roads at the beginning of the storm and more quickly achieving bare road at the end of the storm. Reduce overtime labor with faster removal, spending more money for anti-icing at the beginning of the storm, but saves money in the end.

Nevada: Anti-icing can be very effective under certain circumstances to prevent freezing/black ice conditions on highways, and it also greatly helps to reduce snow and ice build-up or pavement bonding (under wheel track compaction). Snow plowing or blowing roads pre-treated with anti-icing is often far more effective and results in a much cleaner roadway. This is a significant benefit, which helps reduce total chemical usage, and time spent in snow and ice control operations, and also reduces later sweeping operations.

New York: Helps to reduce accidents; provides a head start on snow and ice control at relatively low cost.

Oregon: Very successful, heard from the crews that the accident rates have gone down, they like it because they don't put down sand, eliminating need for cleanup afterwards. Advantages environmentally over sanding include improvement in air quality (particulate, PM10), and minimize water quality sediment problems with runoff to streams.

Vermont: I can understand how anti-icing can be effective at warmer temperatures when icing, packing and/or re-freeze is not likely. I'd think that it could buy valuable time in some circumstances, allowing plow trucks to get on the roads before they became slick from traffic. In our relatively low-traffic area, however, we often wait for snow to get to plowable depth, before we send the trucks out to plow and/or apply any material.

Washington: Maintains roadway in bare/wet condition for longer, makes roadway safer for longer with limitations. Temp drops to 26F, anti-icing is successful, roads won't ice up, but if temp drops to 25F or below, may have ice form, and anti-icing becomes prohibitive.

Wisconsin: Pro-active, buy yourself some time at the beginning of the storm event, have already made your application the day before so don't have to have people out early in the morning. Once you have your anti-icing application, it is easier to plow any snow that has accumulated ontop of your application. Even after we have done an anti-icing application, we will sometimes also put down pre-wetted salt on accumulated snow to assist the plowing operation.

Wyoming: Cheyenne and Pine Bluffs areas both use anti-icing. Have 1 crew for I-25 and will anti-ice ~12 hours ahead of forecasted storm. Both Pine Bluffs and Cheyenne sections are believers of anti-icing and they get upset if we consider stopping the program, but they haven't had any bad experiences. In Laramie, tried anti-icing in canyon between Laramie and Cheyenne, had a few instances where conditions were dry and sunny, but in areas near cliff walls which receive no sun, chemical was keeping roadway moist and slick. Had about 3 accidents, and quit using anti-icing in canyon. In Cheyenne, on I-25, believes accidents have been reduced by 50%, Pine Bluffs believes that it has helped reduce accidents on bridges.

9. What kind of chemicals does your agency use and what is the cost**:

Deicing	***purchase price ($/ton)***	***estimated cost ($/ton)***
Anti-icing	***purchase price ($/ton)***	***estimated cost ($/ton)***
Pre-wetting	***purchase price ($/ton)***	***estimated cost ($/ton)***

*****estimated cost accounts for labor and equipment costs as well*****

Alaska: We only use liquid magnesium chloride. Our delivered price is $0.98/gallon. This year we only used about 65,000 gallons.

Alberta: Deicing – NaCl (solid) $45/ton, anti-icing – n/a, pre-wetting – NaCl (23% brine) $110/ton, $CaCl_2$ (32% brine) $335/ton, $MgCl_2$ (22% proprietary mix) $375/ton

British Columbia: Don't have costs available. Most deicing done with NaCl solid, our pre-wetting and anti-icing have been done with liquid $CaCl_2$, some liquid $MgCl_2$, and within the last 18 months, maintenance contractors have been experimenting with NaCl brine. The advantage with NaCl brine is that they can batch it themselves at a significantly lower cost than they can buy.

Colorado: Majority of liquids are $MgCl_2$, also use $MgCl_2$ with agricultural enhancement additives – corn based. $MgCl_2$ ($0.34/gallon), for $MgCl_2$ with agricultural additives ($0.60/gallon). $MgCl_2$ comes from Utah, $MgCl_2$ with agricultural additives comes from Minnesota. Also use IceSlicer for deicing which also comes from Utah. Use $MgCl_2$ for all three practices.

Idaho: Winter chemical costs vary widely across the state primarily due to freight and the PNS specifications we have adopted. Liquid $MgCl_2$ can range from $52/ton near the Utah-Idaho border to as much as $98/ton near the Canadian border. Liquid CaCl is approximately $132/ton in northern Idaho transitioning to around $100/ton in southeast Idaho. Solid salt follows a similar pricing trend with costs in southeast Idaho around $30/ton ranging to $50/ton in the panhandle.

Minnesota: Deicing – NaCl ($32-37/ton), anti-icing – $MgCl_2$ and Sodium Acetate (ranging from $0.06-0.80/gal), $MgCl_2$ is in the area of $0.55-0.80/gal, pre-wetting – NaCl and sodium acetate ($0.06-0.15/gal). Make NaCl but not sodium acetate.

Missouri: Deicing – NaCl ($34/ton), Liquid $CaCl_2$ ($15-20/ton), Anti-icing – NaCl ($34/ton), Pre-wetting – Brine ($0.10-0.15/gallon)

Montana: Deicing – solid salts (PNS Category 4 salts $180/ton, Anti-icing – $MgCl_2$ at $75/ton, $CaCl_2$ at $110 a ton, Pre-wetting – $MgCl_2$ at $75/ton

Nevada: Salt costs about $30/ton, which is the major chemical we use. We also use bulk salt to make our brine solution at several locations across the state. The brine is basically 2 pounds of salt per gallon of water. Sand costs about $10/ton. Application rates for salt/sand are typically 200 pounds per lane mile, but this can vary from 50 to 500 depending on the circumstances. We typically use salt/sand mixed 5 parts sand to 1 part sand (by weight). A truck driver typically earns about $20.00/hr, and the operating costs for a plow/sander truck are approximately $45.00/hr. In some parts of the state, we also use magnesium chloride instead of salt, and it costs about $45/ton.

New York: Deicing ($40.00/ton), anti-icing ($1.00/ton), pre-wetting ($1.00/ton)

Oregon: Purchase price, don't break down between anti-icing, deicing, pre-wetting. Purchase price, use primarily $MgCl_2$, $71-97/ton. Mag chloride has corrosion inhibitors in it. Price varies according to where the delivery is, quoted prices in contract according to where delivery is. Use $MgCl_2$ for all three, using it for several years. Use a small amount of CMA, 30% concentration by weight. Use in limited area, running about $2/gallon. This product is delivered as a liquid product.

Vermont: Deicing – salt at $42.89/ton, pre-wetting – liquid $CaCl_2$ at $0.85/gallon

Washington: Straight, solid salt - $88.6/ton, salt brine - $0.20/gallon, sand - $17.2/cubic yard, solid deicers, inhibited salt - $153/ton, liquid $MgCl_2$/$CaCl_2$ - $0.48/gallon

Wisconsin: Deicing – salt ($30/ton), Anti-icing – salt brine or $MgCl_2$, to make salt brine in-house costs 5-10 cents/gallon, $MgCl_2$ costs 65 cents to $1 per gallon (higher cost due to rust inhibitor), pre-wetting – $CaCl_2$ or $MgCl_2$ or Salt brine $CaCl_2$ costs about 30 cents/gallon and more expensive with corrosion inhibitor (purchase price = $0.60-0.70/gal). Have been moving away from the use of $CaCl_2$ (in the last 7-8 years) because of problems with handling, very corrosive, no skin contact – will burn your skin, eats clothing…

$30/ton is a statewide average, used for budgeting, but varies between counties

Wyoming: Deicing – IceSlicer from Salt Lake $50-60/ton, Anti-icing – Caliber M1000 from Riverton $0.65/gal, Salt - $30/ton. Have been using Caliber as deicer to shower/spray top of load in bigger areas.

10. Have the practices of anti-icing and pre-wetting improved roadway safety for your jurisdiction? Please explain.

Alaska: Yes, when we use mag in lieu of sand, it provides better traction by melting

Alberta: Yes, although we'd be had put to document it. Our ability to de-ice at low temperatures has improved with the use of pre-wetting (although part of that may just be from using a calcium or $MgCl_2$ liquid chemical with our sand/salt blend).

British Columbia: Definitely, our experiences here at BC, we've seen great benefits of pre-wetting, particularly of our winter abrasives. We are getting the abrasives staying on the roads longer with improved traction, friction, braking on our road surfaces. The limited experiences that we've had with anti-icing certainly suggest that there are benefits to be had, especially as we move more into anti-icing technology in the future.

Colorado: Yes, keeps the road wet longer, reduces the amount of time there is ice and snow pack on the road.

Idaho: We have done a survey using our Safety and Maintenance management systems on several segments of roadway. In some cases, the results were favorable, in many cases, the results were marginal and in a few cases, they showed increased accidents. Trying to get statistically reliable results with widely varying winters, changes in traffic volumes, construction changes to the road surfaces and alignments, changes in chemicals and application equipment, turnover and training issues, etc. renders these results as "interesting" but not absolutely useful.

Minnesota: Yes, without a doubt. Anti-icing has eliminated frost problems. With pre-wetting, have seen a distinct drop of chlorides, amount of NaCl used, up to 30% less and achieve the same results.

Missouri: I think we get the higher volume routes cleared quicker using anti-icing and pre-wetting.

Montana: Yes, more traction more of the time because of more bare roads.

Nevada: Detailed data is not available to quantify this (documentation of lower crash rates), but based on the effectiveness of the practices and common sense we are extremely confident that anti-icing and pre-wetting practices help improve safety for the traveling public. As discussed previously, these practices can defiantly help improve the effectiveness of snow and ice control measures.

New York: Anti-icing provides a head start in snow and ice control storm operations. Pre-wetting allows salt to be effective at lower temperatures. This helps to maintain safe roadways.

Oregon: Yes, we've seen a vast improvement, good comments from the public. The crews overall like it and it has helped out in a lot of problem areas.

Vermont: Yes. Pre-wetting have us allowed to de-ice during and sooner after storms at lower temperatures than we would have dared try without it. Salt applications would have had to be greater than policy allows in order to de-ice without pre-wetting. Deicing is certainly safer than trying to provide traction with abrasives (sand) once the roads have formed a hard ice surface.

Washington: Keep pavement bare/wet longer in colder temperatures than historically possible without deicers. Believed it has reduced accidents, more normal flow of traffic.

Wisconsin: I'd like to believe that it does, no in-depth data analysis, I do keep track of winter crashes every season. The problem with winter data is you got so many variables, we do calculate a winter severity index, sometimes I use this to normalize, also the amount of lane miles is always changing, about +400-500 lane miles per year. Looking at our winter crash data going back 8 years, when I calculate the number of crashes per lane mile per severity index there has been a decrease. The base year was 96/97 which was a bad winter, had a high severity index. Just looking at the raw numbers, the number of reportable crashes has gone down. That's basically tied in with the anti-icing, doing pre-wetting a lot longer…give most of the credit to the anti-icing efforts.

Wyoming: Good experiences out weigh the bad. Have had some incidents, but have also been able to prevent accidents and improve road conditions sooner.

11. Have the practices of anti-icing and pre-wetting significantly reduced your application rate of chemicals or sand? If so, by what percentages?

Alaska: It has very slightly reduced our use of traction sand

Alberta: We are in the process of working on a winter weather benchmark so that we can compare material use over different storm patterns. But some limited work done when we started doing pre-wetting indicated that were using about 20% less material, mostly from a reduction in re-applications.

British Columbia: Definitely, the pre-wetting of winter abrasives has reduced our applications of winter abrasives. I think our experiences with anti-icing are probably limited at this point so it is difficult to say what reduction of chlorides we'd see. We are expecting to see a reduction of salts used on the roads with effective anti-icing.

Colorado: Reduced sand probably 20%, reduced chlorides by 10%. Pretty much eliminated sand in the Denver area – FY 04 used 12,000 tons in the Denver Metro area.

Idaho: No, use of abrasives in Idaho have steadily increased since before I was born up until the present although the trend is not linear. Credit some of that to poor or reduced quantities of equipment in the past being replaced by more and better equipment, increasing lane miles, and a strong desire to raise the level of service on all of our routes. Any other conclusions are speculation.

Minnesota: Yes, anti-icing 10-30% less material, pre-wetting, up to 30% less material.

Missouri: We have moved to a standard application rate of 100-200 lb/lane mile. We used to be at 400 lb/lane mile.

Montana: Anti-icing has reduced the need for sand by resulting in more bare roads. I don't have a percent for you. Pre-wetting of sand results in 33% less from back of truck because it is placed rather than applied. A 50% reduction overall on road in areas that are actively anti-icing. Chemicals are being increased so sand use and costs are beginning to decrease.

Nevada: Detailed data is not available, but we are extremely confident believe that both practices have the potential to significantly reduce total quantities of chemicals and sand. Anti-icing allows getting "ahead" of a storm event and helps to keep the roads clear at the onset, so less total chemical usage is required to meet the safety needs of the motorists. Pre-wetting allows material to be more effectively applied to the road (with less waste), and makes the material more immediately effective, which can obviously reduce the total amount of material needed.

New York: Treated salt/pre-wetting allows for a 20% reduction in salt application rates. Areas treated with liquid prior to the storm receive standard salt application rates during the storm.

Oregon: Yes, reduced application rate of sand, depending on location and roadway conditions. One of the districts has reduced sand by about 50%.

Vermont: Pre-wetting has probably reduced our yearly amount of sand use. Since it is used only at cold temperatures, it has not affected application rates at warmer temperatures. Since it has allowed us to salt at reasonable rates at colder road temperatures, it has actually increased the number of times we salt at higher rates during or immediately after storms. This is probably balanced out by a reduced amount of salt required to remove hardened snow or ice pack caused by deferred deicing.

Washington: Have reduced the use of sand: 2000-2001 – used 244,000 cubic yards, 2001-2002 – used 191,000 cubic yards, 2002-2003 – used 113,000 cubic yards, 2003-2004 – used 188,000 cubic yards, and 2004-2005 – used 60,000 cubic yards. So there has been a reduction of sand usage, but this last year may be a little low because of the mild winter.

Wisconsin: Data on total tons used per winter per lane mile…on a statewide basis, numbers indicate that salt usage has gone down since starting anti-icing, anywhere from 15-25% less salt usage when you normalize it for the severity. We don't have a policy where we say we're going to lower our salt usage by a certain percentage, got into anti-icing because of the pro-active feature, we could provide safer road conditions sooner, the majority of accidents will happen in the first hour of the event…anti-icing helps us do that. Raised the level of service early in the storm, cost savings is a side benefit.

Wyoming: Amount has been reduced, but isn't quantifiable, but the guys are convinced.

12. Compared with conventional snow and ice control operations, do you consider anti-icing and pre-wetting economical? Please explain.

Alaska: Yes, pre-wetting in particular allows us to use less sand because more sand stays where we want it to.

Alberta: We started using pre-wetting, and we're getting into anti-icing, as an improvement in our service, not for economic reasons.

British Columbia: Certainly pre-wetting has proven to be very economical for us. For anti-icing, the economics will depend on the products used. Liquid $MgCl_2$ and $CaCl_2$ are quite expensive and with the negative feedback we've been receiving regarding the use of $MgCl_2$ makes us apprehensive to use $MgCl_2$, however, with our experimentation with NaCl brine would suggest that the economics are there. And if we can prove out the effectiveness of anti-icing with liquid brine, then the economics are there.

Colorado: Yes, pre-wetting makes it so more of the material you put down stays on the road and you don't have to apply materials as often. Anti-icing – using liquids ahead of the storm, trucks are off and parked 20% faster than ones not using liquid.

Idaho: Yes, each tool has a unique condition where it is most effective. Adding anti-icing and pre-wetting to our approaches to winter weather has allowed us to perform better in conditions which we would otherwise have not been able to.

Minnesota: Yes, helps get a jumpstart on the storm, get out in front of it, prevent bonding. We have a bare lane policy, so we have clean roads. Costs 10 times more after bond has been created to clear the roads. It is cheaper to get chemical on the road ahead of a storm, less money is spent on equipment and labor hours.

Missouri: I believe we clean the roads faster, using less material if we get the pavement pretreated.

Montana: Yes. Bare roads results in parking the truck, reduced overtime and less sand.

Nevada: Yes, it is economical for several reasons, the most important factor being reduced (society) costs due to improved safety. It is also economical as the practices can reduce the amount of time spent in snow and ice control operations, as well as reducing the amount of materials used. Reducing the materials used also has a very important secondary benefit, which is a reduction in post storm event sweeping and the associated air quality/dust problems.

New York: Over a season, we would anticipate a reduction in salt consumption when using treated salt.

Oregon: Yes, saved some crew time. We are able to keep the roads in better shape for longer periods of time. The crews are familiar with what application rates to use and what sections of the road to use it on. May have increased the use of the product, as applicators are feeling a more comfortable using it.

Vermont: Yes. I believe pre-wetting, when used judiciously, is economical, if not a cost saving technique. Most of the benefit derived, though is improved safety by obtaining bare roads in a more timely manner.

Washington: Yes, believe by using correct amount of solid/liquid deicers, and reduction of sand, reduce sand cleanup costs, more environmentally friendly. Also with proper calibration, in the long term, reduce fleet size and maybe even labor and equipment by applying the deicers and holding the roadway longer between applications or what were historical applications of sand or reapplications of sand as it blows of road. Moving that direction, but it’s a slow move. New calibrated equipment, ground speed controls, thermometers, etc.

Wisconsin: From a standpoint of the amount of salt we’ve used, there’s been economical saving. Looking at the labor hours, there seems to be a general downward trend, decrease in overtime hours because anti-icing operations done during regular hours, now that we are doing anti-icing, we don’t do any frost runs (send out a couple trucks early in the morning to look for ice/frost, so they were on overtime), don’t spend money there. See savings in labor/equipment costs…Besides salt usage, keep track of total maintenance costs per lane mile, everything. Cost per lane mile per severity index for last 8 winters, there has been a decrease. Less then 10%, probably 7-8% decrease. When you consider your labor rates and equipment rates are going up, that’s a positive savings

Wyoming: Pre-wetting is economical, when nothing else works, aggregate sticks better. Anti-icing is economical in it reduces accidents

13. For worker safety, what precautions does your agency take when handling pre-wetting/anti-icing chemicals? Are the procedures different from those for handling deicing chemicals? Please explain.

Alaska: Rubber gloves and eye goggles are provided but liquid magnesium chloride is not very onerous

Alberta: Worker safety is the contractor’s responsibility. But as far as I know, our contractors aren’t doing anything beyond the legislated requirements for handling and storing either liquid or solid chemicals.

British Columbia: In the maintenance contracts that we've tendered, all of the maintenance contractors have to provide salt safety guidelines for how they handle and work with the chloride products both in handling and in storage. No difference in handling practices because the products are generally the same, other than they are stored differently.

Colorado: Follow MSDS sheets, don't wear leather, the product will suck all the moisture out of leather. Wear rubber boots and rubber gloves, most have coveralls.

Idaho: We require MSDS sheets for all chemicals. It is up to the employees to use the appropriate gloves and protective equipment necessary for the task.

Minnesota: Worker safety, follow MSDS sheets, have had no problems when comparing dry with liquid chemicals. We train on how to load and transfer liquid chemicals.

Missouri: We use protective eye wear when handling salt.

Montana: No worker safety issues. When handling liquids – we suggest eye protection and rubber gloves.

Nevada: Standard precautions apply, we use the same brine solution for anti-icing and pre-wetting.

New York: Worker safety guidance is provided by MSDS and operational guidelines.

Oregon: All of the products are non-hazardous. We make sure the MSDS sheets are on site. The crew is supposed to get a MSDS with every delivery. The crews have regular safety meetings.

Vermont: Yes. We have a safety protocol, which requires protective eyewear and clothing when applying pre-wetting agent to bulk salt, as well as an additional person to act as back-up or first responder in case of any incident.

Washington: MSDS sheets – follow recommendations, provide any safety equipment needed, training on calibration and safety concerns related to liquids or solids. Used to have nasty chemicals 15-20 years ago, but now are pretty stable, organic chemicals.

Wisconsin: I don't get involved with safety issues within the counties, have county rules or operation manuals address that.

Wyoming: Nothing special, caution workers, warn them about leather boots/gloves being exposed to the products, follow MSDS sheets, but don't find it necessary to require bibs, etc. It's a strong salt, but its not harmful.

14. How does your agency store chemicals? Have you experienced any problems with your storage facilities?

Alaska: We have (2) 15,000 gallon bladders and, (1) 6,000 gallon polyethylene tank, and (1) 10,000 steel tank with an interior coating. No problems with storage to speak of.

Alberta: Again, the contractors are responsible to store our chemicals. But I haven’t heard of any big problems beyond ‘housekeeping’ habits. All of our solid salt is under cover, we’re in the process of specifying covered storage for sand/salt blends, and any liquids are in tanks with a containment system.

British Columbia: Liquids are stored either in railcars or on sight in plastic storage tanks in maintenance yards, solid chemicals are stored undercover with an asphalt pad and brine tanks for any stowage. We haven’t experienced any problems with storage facilities across the province.

Colorado: All straight salt and IceSlicer under covered storage. Liquids – in the process of building containment facilities, use plastic and metal tanks. Sand mixes are on impervious pads with retention ponds. Some problems have occurred such as operators back into doors, put a whole in the wall, and overfill trucks. No problems with metal tanks.

Idaho: Liquids are stored in plastic or poly type tanks. Many have containment around them but some do not. Over the years we have experienced many problems with storage and have learned from them to improve on our practices. The PNS specifications provide a significant protection to many problems, but mechanical issues arise.

Minnesota: Liquids – 5,000 gallon upright, double-walled, plastic tanks. Dry salt – under cover in a shed – may be a concrete, wood or new material shed, but all dry material is under a roof.

Missouri: $CaCl_2$ in tanks and the NaCl in storage buildings. No problems.

Montana: Liquids – 10,000 gallon polypropylene tank – level bedded, isolated from trucks by guardrail so no trucks run into tank, Solid – closed sheds, Salt/Sand – usually in the open. Looking into tents (design has been improved). We do secondary containment when needed. Sand berm around salt/sand piles when stored outside to prevent leaching.)

Nevada: Brine solution is stored in PVC tanks. Salt/sand mixtures are stored in a variety of locations/methods, ranging from dedicated storage buildings to outside storage in piles. Outside storage has created some concerns with potential salt infiltration into the surrounding environment, so at most outdoor sites the piles are placed on an asphalt pad. Outdoor pile storage has also created problems with caking and deterioration of the salts. Eventually, NDOT would like to have covered storage for all our stockpiles, but this will take time given budgetary constraints.

New York: Salt domes, sheds, barns, bins. DOT recently completed a dome overhaul and replacement project. Liquids are stored in tanks.

Oregon: We store them on site after delivery in storage tanks on site, plastic (polypropylene). Solid CMA pellets are stored high and dry, remain covered. As with the storage of any chemicals, we encourage regular tank inspections and inspect all the hoses and valves. Encourage secondary containment where storage tanks are located near creeks or water features.

Vermont: Liquid calcium chloride is stored in 3000 gallon poly tanks. We have experienced corroded fittings in application wands and loss of material in two instances in our District, due to failure to properly close shut-off.

Washington: Solid deicer – 3 sided building, open faced, with roof, on impervious floor with leach containment. Liquids – 5,000-15,000 gallon storage tanks probably have 50-60 throughout the state, plastic or fiberglass. Haven't had any problems with storage. A couple facilities are placed where there may be some environmental risk, so all liquid storage tanks have concrete containment around them so if they were to rupture, material would be contained. Solid deicers also have some containment.

Wisconsin: State law which governs the storage of salt, has to be under an enclosed facility on a impermeable pad, the DOT is responsible for inspecting all salt storage facilities in the state. All salt is stored in buildings/sheds with a bituminous pad for a floor. We have guidelines called 'housekeeping' – expected to keep area outside the shed clean so we don't have any salt runoff from that area. Liquids – all stored in plastic (polypropylene) tanks, some stored outdoors, some stored inside the salt shed. There is an annual inspection done of all those facilities and if there is an issue, it gets addressed…storing, no huge problems, some isolated incidents.

Wyoming: Liquids are stored in 6,000 gallon plastic tanks, also have some smaller 2,000 gallon tanks. Sand is stored out in the open, some piles have membranes to capture salt runoff which may be used later as a salt brine (but no known concentration), have applied 7% salt to piles to keep from freezing. In Laramie, have a 15,000 ton pile, in Cheyenne have 17,000 ton pile, and at Elk Mountain, have 18,000 ton pile. District 1 has seen as much sand as 93,000 tons in given season.

15. Have regions under your supervision experienced detrimental effects to the environment or public health due to the use of road salt or other chemicals, leaks in storage facilities, etc.?

Alaska: Total chloride in storm waters has been an issue due to our NPDES permit in Anchorage. We haven't had any problems due to leaks.

Alberta: Limited problems with soils and crops affected by salt loss, usually at storage facilities. We are only now seeing groundwater contamination outside our property line in a couple of locations, but we know that we've got salt contaminated groundwater at just about all of our stockpile sites.

British Columbia: Not with our current storage facilities, previously, our solid NaCl was stored in stockpile, and we experienced groundwater contamination from leakage into the ground, but since we've moved to covered stockpiles with asphalt pads, we haven't had any recent environmental problems with the storage of road salts. And we haven't had any reports of problems with our liquid storage. We've had allegations brought to our ministry about vegetation kill of trees along the roadway in about 1-2 areas of the province over the last 3-4 years. It has been alleged that the solid NaCl has caused the death of roadside vegetation in a few instances. No water quality problems.

Colorado: People complain about it, but have done quite a few studies and don't see where we are causing any health hazards. Have met with department of public health, and come to the conclusion that what we're doing now is better than what we were doing before. When we were putting all the sand out, we were having particulate problems. The department of public health is happy that we are using liquids to get rid of air particulates. No problems with private wells with liquids. 8-10 years ago, before salt was under storage, had runoff off property contaminating wells.

Idaho: We have had environmental issues associated with winter maintenance chemicals. Our PNS specifications protect us from most environmental problems, but misuse and improper storage practices have resulted in occasional environmental damage.

Minnesota: Haven't had any problems yet. The only problem was with an automated deicing system on a bridge. Potassium acetate was used which is environmentally friendly for that area, but doesn't mix with galvanized steel, so had some problems with the storage facility.

Missouri: Yes, we have had some environmental concerns and claims due to run-off and leaks.

Montana: Some adjacent vegetation has browned in some areas and some tree mortality in isolated spots. Nothing major and nothing really to point to as the source or reason.

Nevada: The Lake Tahoe basin is environmentally very sensitive, and we have research underway to determine if salt usage affects pine trees and other receptors in the environment. We know of no significant issues related to public/human health, other than post storm event issues with air quality related to dust from the sands. We are aware of the potential for environmental impacts, so for this reason (and to reduce costs) we attempt to use the least amount of chemicals consistent with meeting public safety needs. Because of PM 10 requirements, the gradation and degradation requirements of the abrasive used in these areas have been changed to reduce sand particles in the air.

New York: There is some litigation pending for alleged salt contamination in wells.

Oregon: Have had a couple of leaks, one was from where the drain/valve comes out of the tank. There was a heavy metal valve where the weight was inadequately supported. Over time, this worked its way loose and started damaging tank. Lost 2,000 to 3,000 gallons of deicer, but didn't leak into any waterway. Communicated statewide on ways to provide better support for fittings and pipes.

Vermont: Not to my knowledge.

Washington: No – we are very careful, and try to minimize use. We do random sampling along roads, and haven't found any alarming numbers for ppm values, so we have no reason to believe our chemicals are causing problems. Have investigated a few instances of vegetation dying, but found it wasn't related to roadway chemicals.

Wisconsin: (County highway department sees the lawsuit, the DOT provides support, pays portion of liability insurance premium, provide technical support, if necessary will testify, give depositions to support the county)

Incidents where nearby private well was contaminated, located close to a salt shed, probably due to poor housekeeping. The salt sheds were built on the edge of town but are now surrounded by subdivisions that aren't always on city water. Have paid to replace private wells, maybe 5-6 times since he's been there. Have been sued over salt spray damage to apple/cherry orchards. Not storage, but on the road usage of salt. Lost court cases, where they have been able to prove salt spray damage to orchard. (In heavily maintained roadway, one situation was a heavily used winter recreation area)

Wyoming: No, not yet. Liquids – no leaks, had one valve fail and material flowed into an area where it couldn't leave and couldn't enter the groundwater because of the clay in the area. In Cheyenne, there has been salt runoff into the Air Force Base.

16. In your opinion, are there environmental benefits offered by the practices of anti-icing and pre-wetting, in regard to human health and toxicity to the environment? Please explain.

Alaska: Yes, there is an opportunity to use less sand by using liquids.

Alberta: We expect to need reduced quantities of deicing chemicals once we have the experience to use pre-wetting and anti-icing properly, but we haven't seen this benefit yet.

British Columbia: Certainly, we expect and hope that by moving to anti-icing, and certainly with our experience with pre-wetting, that ultimately, we are using less chlorides on the highways by moving to these new technologies. Our expectation is that pre-wetting and anti-icing is going to allow us to use less product on the road in the future, therefore, less chlorides going into the environment.

Colorado: We know that the use of liquids reduces air particulates, improves air quality. We know that by using liquids that we've reduced overall chloride usage during the storm. Have done about $1 million in studies, see what we're doing now is better than what we were doing. Starting another study to see what alternative chemicals there are to $MgCl_2$ and NaCl.

Idaho: Yes. The PNS specifications have been tested and researched to the point that I have no qualms about using the products.

Minnesota: Basically, more is kept on the road where it belongs, so there are fewer chlorides on the ground surface to cause problems.

Missouri: Only if the materials are not over applied or misused.

Montana: Yes, better air quality/water quality. Air – PM-10 not exceeded since we changed to using chemicals. Water quality – has seen lower sediment loading.

Nevada: As discussed above, our primary goal is to use the least amount of chemicals, consistent with meeting public safety needs. These practices (we believe) help reduce total chemical usage, and thereby may reduce any human health/toxicity impacts related to the chemicals.

New York: Using salt reduces the need for using sand. Sand is a very temporary traction provider and does nothing to melt snow and ice. It also requires very heavy application rates. Unlike salt, sand tends to clog fish spawning areas, plugs drainage structures resulting in erosion problems, and roadway cleanup may result in air quality issues. An anti-icing program as a whole requires less material which reduces the amount of chemical exposure to the environment.

Oregon: Haven't had any major instances. Benefits, yes, on the environment, less sediment entering the waterways compared to sanding, less particulate matter, air pollution.

Vermont: Not aware of any.

Washington: Yes, beneficial because there is a reduction of sediment loading for Salmon bearing streams. Also, have lowered the PM-10 levels by moving away from sanding applications, so better for human health as well. Believe chemical program is safer for the environment and people, human health.

Wisconsin: No WisDOT in depth studies to show either benefits or costs to environment…refer to report from the Colorado DOT in 2001 costs/benefits of NaCl/$CaCl_2$, and other products, a literature search and survey done in snowbelt states –
www.dot.state.co.us/publications/researchreports.htm#deicers
Look for report that makes reference to the environmental effects of salts Oct 2001
Human health – not been a huge issue, not a big organized effort to challenge WisDOT on that.

Wyoming: Helps to keep people on roadways, less crashes, so safer. Have more trouble with the EPA in terms of sand and sediment loadings/particulate matter than chemicals. The EPA would rather see less sand and more chemicals.

17. Have you experienced or witnessed the corrosion of vehicles, concrete or asphalt pavement, and/or the transportation infrastructure due to pre-wetting/anti-icing chemicals? Is there any difference between these chemicals and deicing chemicals, in terms of corrosive effects?

Alaska: There has probably been a slight increase in corrosion on our sanders due to the use of magnesium chloride for pre-wetting but it has not been very much or even noticeable.

Alberta: Is there any difference between these chemicals and deicing chemicals, in terms of corrosive effects? We haven't noticed any increased corrosion from the increased use of liquid de-icers, and haven't had a problem in the past with solid sodium chloride. Some of our bridge engineers are starting to look for corrosion problems with magnesium chlorides, but we don't have any clear evidence yet.

British Columbia: We have had allegations brought to our ministry regarding corrosion of vehicles, primarily commercial transport trucks with aluminum and Mg products. We haven't experienced any corrosion problems with concrete/asphalt. However, we have had allegations from the power authorities that liquid $MgCl_2$ is causing corrosion and short-circuiting on some of the hydro-power line infrastructure.

Colorado: We see corrosion of vehicles, when used lots of salt, corrosion was significant on trucks. With the use of liquids, see less corrosion to trucks, but more to the wiring on the truck. Bridge decks/concrete – no. Materials engineer is looking into potassium acetate because at the Colorado Springs airport, runways are deteriorating. The concrete companies are blaming the chemical supplier, and the chemical supplier is blaming the concrete company.

Idaho: Yes. All winter maintenance chemicals containing chlorides will corrode metal unless the chlorides are removed. The PNS specifications require corrosion inhibitors, but even those don't offer complete protection. As for damage to concrete or asphalt or other infrastructure, there is no evidence that our liquids have done any damage over and above what decades of salt usage does. Washington DOT and Montana DOT are looking into this and may have found certain chemicals have effects to roadside infrastructure, but the evidence is inconclusive at this writing. If the chemicals have the added protection of the PNS specifications and the using agency employs a quality assurance program for their use and trains their personnel on how to properly handle and apply the chemicals, I don't believe there is a significant difference in regards to corrosion to using just salt or salt brine all the time.

Minnesota: Not sure, new chemicals have anti-corrosive inhibitors and new vehicles are also more resistant, so its hard to compare new chemicals to older chemicals. Road construction uses coated rebar, so that is not a problem. Have seen corrosion in trucks, but the biggest problem with pre-wetting is that with too much liquid, the material cakes in the sander.

Missouri: Salt and brine will cause corrosion but not as bad as $CaCl_2$ used in deicing.

Montana: Yes to all except asphalt pavement. Salt on bridge decks/approach pads has caused concrete spalling. I'm not sure about steel structures. All chemicals, except for road salt have corrosion inhibitors.

Nevada: Salt unquestionably contributes to corrosion of vehicles, and it can also reduce pavement life (especially in concrete with inadequate rebar protection). We primarily use salt brine for both pre-wetting and anti-icing, and do not have detailed data regarding the corrosive effects of these practices. However, since we believe total salt usage can be reduced by these practices, we would obviously expect less corrosive impacts.

New York: Chemicals do cause corrosion. NYSDOT spec's call for corrosion inhibitors. Our technical services group is studying the effects of $MgCl_2$ on concrete bridge decks.

Oregon: Careful about application rates, part of training, encouraging the use of the right application rates to save money. Don't want to overapply and waste product, want to apply enough to keep the LOS up, but don't want to apply more than needed into the environment. Handful of complaints regarding corrosion of vehicles associated with MgCl, most of the complaints have been in regards to wheel damage. Much of these are after market products, aluminum. Complain about pitting and discoloration. Minimize problems by washing vehicles particularly after going over mountain passes and not tailgating deicing application trucks. Believe our bridge section has some monitoring going on regarding corrosion.

Vermont: I have seen some possibly accelerated corrosion only on the application end of our own plow trucks. However, the corrosion related to being continually coated with road salt is so significant that it's difficult to discern any true difference.

Washington: Yes, there is a number of complaints each year, even though using inhibited deicers, they are still corrosive. A lot of complaints for soft metals, aluminums, copper wiring. May have effect on rebar, but no conclusive studies that bring it back to the application of deicers by maintenance. But haven't moved away from inhibited salts, still using 70% less corrosive salts, with exception of a few test areas. Seeing some corrosion on equipment.

Wisconsin: No WisDOT in depth studies on corrosion issues, one story, about 3-4 winters ago, had an over the road trucker call and say the $MgCl_2$ they were using was corroding his rims and discoloring his aluminum, went out to visit with him, saw cosmetic things, amounts to needing to wash truck more often now. Didn't really see any evidence of corrosion. Travels from Pennsylvania to West coast, traveling through a number of states, using a number of chemicals. He had probably heard the stories from the truckers in Colorado and trying to make an issue of it here. We have always encouraged people to wash their vehicles in the winter time, wash off the salt. He also showed that the wiring inside the running lights on the side of his trailer had corroded. Haven't done any study on the county maintenance equipment, has seen when only using NaCl and $CaCl_2$ could see lots of corrosion on the trucks, but now they say that since they have gone to $MgCl_2$ with rust inhibitors have had less corrosion of maintenance equipment. Haven't done any documentation – bridge maintenance thought there was a potential of corroding their bridges faster, but explained by using anti-icing, application rates are lower. Was in a research unit in the 1970's testing the bridge decks to determine the salt content and were finding pretty high salt content, so changed some things with the bridge design in the 80's went to epoxy coated rebar, had more concrete cover over the top of the rebar, also went to different painting systems on exposed steel

Wyoming: You can tell in the sanders that more salt/IceSlicer is used – should clean equipment after every storm because chains and other parts in the sander start to show signs of corrosion. We can tell that the material is more harmful than 10 years ago. As we use more salt, find that we have to clean delineators and other signs more often as they are coated with salt and are not effective any more.

18. How has the community responded to the anti-icing and pre-wetting practices by your agency?

Alaska: There was an initial little uproar but that quickly subsided.

Alberta: Limited approval, but we really haven't tried to publicize the use of this newer technology yet – we want to make sure that we know what we're doing before we start drawing attention to it!

British Columbia: It's been generally very well received. I don't know that they notice pre-wetting since we're pre-wetting abrasives as it goes down. Certainly, we've had questions from the public regarding anti-icing, however when we explain to them what we are doing and what it is, they seem very perceptive because we are doing something proactive rather than reactive, and they like that concept.

Colorado: At first, they were very apprehensive about applying liquids on roads that were about to freeze. A lot of areas like it, and in some areas, like Aspen/Vail, they don't like it. They would rather have snow pack all winter long.

Idaho: There are skeptics and concern over corrosion mostly. Not a lot in Idaho, but it does come up from time to time. Fortunately, we present the facts and attempt to keep innuendo and speculation on the part of the misinformed to a minimum.

Minnesota: At first, the public didn't know what we were doing, and they were taken aback. They were worried that it was sunny out and we had trucks applying chemicals. Have put up signs on the road and on the back of trucks regarding the use of anti-icing liquid. Now there are hardly any comments, and the process has been accepted.

Missouri: Usually they only care about getting the roads back to normal. We have tried to educate the community on the use of each practice, but usually they don't care as long as the road is back to normal as soon as possible.

Montana: It's human nature to call about complaints and not for good service. Some communities have signed petitions to stop the use of magnesium chloride. The vast majority of Montanans are very satisfied with the level of service they are being provided.

Nevada: The local community probably does not fully understand these practices, nor the benefits of these practices. However, the public strongly supports and appreciates the DOT in conducting effective snow and ice control, and wants to have the roads safe for travel throughout winter storm events.

New York: Mostly positive responses.

Oregon: Mostly good. Most are favorable responses, thank you for keeping our roads in such good condition. Have a leaflet put out last year, 2004, an information sheet, answering common questions.

Vermont: I've heard nothing much negative. The press has been accepting.

Washington: Most of the state doesn't understand liquid or solid deicers, and they don't care for the most part. There are a few people that care about the corrosion, and there are a few people that appreciate the safer roads. Right now, have mixed approval and denial. Have a fairly aggressive public outreach, in some places, didn't forewarn public and then moved into active PR campaign to tell public what we were doing on roadways. For Washington, see maybe 20 complaints/year.

Wisconsin: One thing we have done, we've done customer surveys, 1-2 questions relate to winter maintenance, really broad, such as what type of job are we doing maintaining the roads in the winter, on a scale of 0-10, come in at 7-8 which means ¾ of people seem to be satisfied, not related specifically to anti-icing/pre-wetting

Every other spring survey state patrol troopers because they are out on the road a lot, ask questions related to the winter season, the first question is to rate the your overall impression of how the counties did this past winter, usually in 7.4-7.5

Asked some specific questions, have you noticed the county out doing anti-icing maintenance, have you noticed it helping…get varied responses, some say have never seen county operations, some say yes, it has been helpful especially on bridge decks. Have done press releases explaining what we are doing out there, have also placed signs on the back of trucks saying anti-icing operation stay back 200 ft.

Wyoming: Most people don't realize what we are doing. On I-25, when we first started, had people call in and wonder why we were applying "water" on roads. We did a press release. Cheyenne city uses straight IceSlicer, the public doesn't realize that chemicals are on the roads, they just wonder why there is slush when its 0°F.

19. What type of innovation in anti-icing and pre-wetting do you expect in the next five or ten years?

Alaska: Better chemicals that work at wider ranges and colder temperatures.

Alberta: - Automated vehicle locating systems on all plow trucks, within the next two years. This will give us better records of where the deicing chemicals are being applied. Widespread use of anti-icing, starting in 4 or 5 years once our RWIS system is on-line. Within ten years, but no time in the near future, I expect to see automated application control based on RWIS data and real-time pavement friction and temperature measurements.

British Columbia: I don't know that much is going to change other than for our ministry we expect to see our contractors pre-wet more of the abrasives as well as some of the solid NaCl. We will probably see some of our contractors use the NaCl brine for anti-icing. As we implement and put into place more RWIS, we will be able to move more confidently into anti-icing technologies.

Colorado: Working with the MDSS – federal highway and pooled fund sponsored studies. Fine tuned weather forecast, recommendation for treatment types. Get the information to and from the truck. 20 of the trucks have GIS/GPS. Can tell us what application rates being used are and what they are doing. Look at storm system, get updated recommendations. Can see what people are doing and make sure they are doing what they are supposed to do.

Idaho: A wonder product you only apply once in the fall that lasts all winter, costs about the same as water, and guarantees to keep roads bare all winter. Oh yeah, and it has no corrosive or environmentally objectionable properties.

Minnesota: Except to see larger volume of pre-wetting, we are now using about 15-20 gal/ton of salt, but maybe see 50-60-70 gal/ton more like a slurry used in Europe. Pre-wetting helps keep dry chemical on the road, but where trucks go 70-80 mph, the material still blows off the road. Improvements in equipment/nozzles and chemicals. Chemicals are constantly changing, new product or more byproducts. Minnesota has a program to evaluate the chemicals.

Missouri: We will probably improve our techniques of storm forecasting but in general we are looking for ways to do things better, faster, and cheaper.

Montana: Better materials, less corrosive materials, better application techniques, better forecasting, ability to handle materials better through more advanced equipment, and better training.

Nevada: We expect technological improvements in the equipment, which will allow more precision in the application rates of chemicals. For example, our current plow trucks have relatively primitive pre-wetting technology, which does not adjust the wetting rate to the application rate of the salt/sand materials.

New York: “FAST” bridge systems, more liquid applicator trucks, use more treated salt.

Oregon: More innovation and more research into alternative products. Some of the non-chlorides. Any time you have a chloride you’re going to have some corrosion even with inhibitors. Look at non-chlorides which work well and are cost effective.

Vermont: I expect to see some new products that work. VAOT is also going in the direction of installing sensing / transmitting devices which will provide early warning of weather and/or temperatures which might cause icing. This might be followed by a call for trying anti-icing techniques under some circumstances.

Washington: Precision calibration equipment, GPS, data logging and tracking, document application rates, time, locations for a given storm at a given time. All placed in computer data base. Also, have RWIS deployed more to allow additional information on humidity and calcium content. Better decisions on application rates, better weather forecasting.

Wisconsin: Improvements in application equipment and controls…more of an electronic control, tied into the pavement temperature. We use pavement temperature now to help us decide when to salt and how much to use…
Materials…always looking for the miracle product, experimenting with different mixtures/rust inhibitors

Wyoming: Catch up with Colorado and Montana on Equipment, would like to get a truck with ground speed control for spreading materials

20. Do you have more comments on the practices of anti-icing and pre-wetting?

Alaska: It’s hard to implement and due in a systematic way. We are looking forward to running all of our maintenance foreman through the AASHTO Anti-icing/RWIS Training CD.

Alberta: No

British Columbia: No

Colorado: No

Idaho: No

Minnesota: Definitely a huge benefit for driving public and the environment.

Missouri: No

Montana: No

Nevada: No

New York: No

Oregon: Good program, good tool to use.

Vermont: No

Washington: No

Wisconsin: Slipperiness issue with anti-icing, there have been some instances with people putting down liquids and causing slipperiness on pavement for a short period of time. There has been a lot of research done by a lab in Canada. We have had a couple in Wisconsin. We looked at all the data and facts, and feel comfortable about anti-icing. There are a few rare instances where you have the right combination of humidity and pavement temperatures…the studies have talked about, these situations usually occur early in the season, if you have gone for a period of time in the fall without precipitation, there is oil, rubber particles collecting on the pavement, when any type of liquid is applied on top of this, they don't mix….same thing happens in the summer, get a down pour on top of pollutants. Have had lots of accidents due to this in the summer…Advised maintenance crews to monitor weather conditions, and first time or two use a lower application rate, and minimize the opportunity for this to happen…State of WA has had a number of lawsuits filed against them, none have gone against the state (other conditions, driving too fast, tailgating, under the influence). Maintenance people aware of slipperiness issue.

Wyoming: IceSlicer (Deicing) is an emergency, supplemental thing, we order about 8 loads of 20 tons for the season. Also, truckers in Colorado complain about corrosion to Aluminum wheels, but should just wash more often, especially with the amounts of chemical Colorado uses. People even care extra gallons of washer fluid in their cars in Colorado because they go through it so fast with the increase of chemical products being used.

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