Maine Winter Roads:
Salt, Safety, Environment and Cost

A Report by the Margaret Chase Smith Policy Center
The University of Maine

February 2010

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Acknowledgements and Disclaimers

This study would not have been possible without the great cooperation of the Maine Department of Transportation. We would like to specifically recognize the following individuals who participated on the MaineDOT Road Salt Risk Assessment Team: Dale Peabody, Bill Thompson, Peter Coughlan, Brian Burne, Joshua Katz, David Bernhardt, Chip Getchell, and Gary Williams. We also thank Joe Payeur, MaineDOT Region 2; Gregory J. Stone, Director of Highway Safety, Maine Turnpike Authority; Patrick Moody, Director, Public Affairs, AAA Northern New England; members of the project's Advisory Committee; and countless others who graciously contributed to this effort.

The views and opinions expressed in this report are solely those of the Margaret Chase Smith Policy Center and the individual authors. They do not represent those of Maine Department of Transportation or any other individual or organization that has provided information or assistance.

Road Salt Project Key Findings and Policy Recommendations

Key Findings

This section summarizes key findings from a yearlong study of the issues and practices in winter maintenance of Maine's roads. Please see the Executive Summary and the full report for additional details. Findings are grouped according to the major sections of the report.

Maine Winter Operations

- We estimate statewide expenditures for winter road maintenance in 2008-09 (state and municipal) at $98 million, or $76 per capita.
- We estimate that 490,000 tons of rock salt were purchased in 2008-09 in Maine. This is roughly 750 pounds for every Maine resident, or 21 tons per road mile.
- Sodium chloride (rock salt) is by far the most widely used chemical for snow and ice control. Significant amounts of sand, calcium chloride, and magnesium chloride are also used.
- Maine has approximately 23,450 miles of public roads which are maintained in winter by MaineDOT (18%) and the Maine Turnpike Authority (1%), as well as 488 municipalities, ten of Maine's counties and three reservations (81%).
- Anti-icing practices (preventing the bond of snow and ice to the road surface) are being widely adopted by state agencies across the U.S., using a variety of materials. MaineDOT, MTA, and some municipalities have incorporated anti-icing practices.
- The cost of municipal winter maintenance per lane mile varies. The municipality with the highest cost has a cost three times greater than that of the municipality with the lowest cost, reflecting differences in geographic conditions, maintenance practices, levels of service, and non-road winter maintenance (e.g., sidewalks and schools).

Corrosion

- All chloride salts contribute to corrosion; none is consistently shown to cause more corrosion than another in actual field conditions.
- No risk ranking of salts is possible. Climatic conditions, methods of use, and application rates may have more influence on corrosion than their chemical composition.
- Corrosion affects different metals and alloys differently and is also influenced by environmental factors such as moisture and temperature.
- Of deicing materials, sodium chloride has the greatest impact on steel in concrete. Calcium and magnesium chlorides chemically interact with cement paste in concrete to degrade it.
- All auto manufacturers have discontinued the use of hexavalent chromium, an effective corrosion preventative coating on brake lines and electrical components.

Mobility and Safety

- Using federal guidelines for the costs of injuries and deaths, Maine accident data show a 10 year average cost of $1.5 billion dollars annually.
- The combination of young drivers and snow-covered roads is hazardous.
    - Drivers ages 16 to 17 are involved in 9% more winter-condition crashes than their share of crashes for other road conditions.
    - Drivers ages 18-19, 20-24 and 25-34 also have higher numbers of winter-condition crashes, but not as many as 16 to 17 year olds.

    - Analysis by road category shows these higher numbers of crashes are concentrated on urban townways. On state highways there are fewer winter-condition crashes involving young drivers than expected.
- Drivers ages 65 to 74 have a smaller share of crashes in winter conditions than their share of crashes under dry conditions.
- Vehicle miles traveled in Maine (except for the last two years) has been steadily increasing.
- Drivers are exposed to fewer road conditions of snow and ice than a decade ago, and this has led to improved mobility.
- There are significantly fewer crashes in Maine than a decade ago, both during winter road conditions (snow, slush, ice) and during non-winter road conditions.
- In winter months (not conditions) between 1989 and 2008, the number of crashes has not been reduced when compared to crashes during the rest of the year. This is true for state highways as well as for all other roads.
- In winter months between 1989 and 2008, there is a significant reduction in the number of fatalities on state highways. This reduction does not occur on town roads and state-aid highways. This is consistent with our finding of a statistically significant decrease in fatalities on state highways since MaineDOT's anti-icing policy was implemented. It is unknown whether the anti-icing policy is the cause of the decrease.
- Colder temperatures with snowfall lead to large increases in daily crash totals. Temperatures below 25 degrees with a daily snowfall greater than one inch contribute to 127 additional crashes beyond the "average" day of 82 crashes.
- There are fewer crashes in extremely low temperatures with snowfall above 5 inches, possibly due to the lower number of drivers in these conditions.
- Data were not available to determine the level of vehicle travel during storm events.

Environment
- All of the chemicals used on roads end up in soil and water.
- Chloride salts degrade water quality, soil quality, and ecosystems. Specific effects vary by location.
- Long-term environmental effects, such as salt-contaminated groundwater wells, continue to be found along Maine's roads.
- Some environmental effects are short term; that is, they are seasonal and largely reversible.
- Although long-term effects of salt contamination in the environment are cumulative, they may be reversible. Recovery will take many years to decades after salt inputs stop.
- New policies are needed to encourage the use of chemicals and technologies that have fewer environmental effects than those of sand and salt.

Stakeholder Input
- Corrosion effects, though not rigorously documented, are real and widely felt in the transportation sector.
- Stakeholders express that roads in Maine are better than they used to be. The people who maintain our roads in Maine do a good job. Some people perceive the level of service to be higher than necessary on some roads.
- Stakeholder groups hold differing viewpoints and focus on issues that concern their group. There is no consensus on the relative importance of the consequences of the use of road salts.

- Stakeholders recognize the need for change and seem willing to work together on this issue. Some recommendations from stakeholders include more driver education for winter conditions, greater public awareness of this issue, and re-examining levels of service priorities except on state highways.

Policy Recommendations

Safe, passable roads in winter are necessary for commerce and mobility. Public works agencies and private contractors maintain our roads. Levels of service (how often and how quickly roads are cleared) are driven by public expectations (as expressed through local and state governments) and by available technologies. Winter road maintenance is funded by taxpayers. Chloride salts are currently the most effective and economical material for maintaining safe, passable winter roads. Salts corrode vehicles, affect infrastructure, and compromise water quality; these are the additional costs of winter mobility and safety. Level of service is a balance of the tradeoffs of safety, environmental impact, and cost.

Our recommendations address safety, water quality, and costs. Not all roads or regions of the state are the same; consequently, no one treatment method or level of service can be applied to all roads or all storms. There are, however, advances in technology and practice which can lead to reduced costs and reduced salt use. These advances should be pursued where feasible. Educating the public about the tradeoffs and costs of winter road maintenance is essential – effective change in policy and practice requires the participation of practitioners, elected officials and the general public. Educating young drivers about the risks of driving in winter storms can save lives.

Materials and Practices
Goal: maintain safety while reducing salt and sand use

- Do not limit the selection of materials available to maintain winter roads.
- Continue to improve practices to reduce salt and sand use.
- Continue, and expand, anti-icing practices at all levels. This includes expanding training for municipalities and private contractors.
- Identify municipal roads that are candidates for anti-icing vs. roads that require sand or special treatment.
- Encourage research and demonstration projects involving new materials, higher road-crown heights, porous asphalt, and other promising innovations for maintaining drivable roads in the face of winter storm conditions.

Budgetary Impact
Goal: identify efficiencies

- Improve record keeping by MaineDOT regions and by municipalities on material use by roadway segment. Enhance sharing of information in order to improve efficiencies statewide.
- Undertake a thorough inventory of municipal practices and accounting to identify possible efficiency gains.
- Investigate private contractor practices and training to identify possible efficiency gains.
- Based on information gathered, expand training at municipal and state levels.

- Investigate whether additional regional cooperation at the municipal level can lower winter maintenance costs, improve service, or both.

Environmental Protection
Goal: reduce salt use

- Reduce overall salt use through improved practices, new materials and equipment, and changes in levels of service.
- Review the levels of service in municipalities to see if some roads can have reduced salt application through lower service priorities, for example residential low-speed-limit neighborhoods.
- Identify state and local roads near sensitive environments which should receive reduced salt.
- Expand monitoring of salt loading in key areas to establish baseline data on water quality.
- Expand monitoring of the environmental impacts of deicing materials in urban areas, particularly parking lots, located near sensitive environments.

Corrosion
Goal: increase public awareness of preventative measures

- Investigate current best practices on corrosion prevention and vehicle maintenance for both fleet and private vehicles.
- Develop a public awareness campaign to encourage these practices across the transport industry and among the general public.

Driver Safety
Goal: increase driver safety

- Expand winter driving education for young drivers.
- Develop public awareness strategies to educate the public on winter road conditions and safe winter driving practices.
- Consider the cost effectiveness of requiring snow tires in winter.
- Incorporate more elements of winter-condition driving into state driver training and testing.

Public Education
Goal: increase public awareness of winter practices, costs, and environmental impacts

- Develop a public-awareness campaign about safe winter driving practices based on the increased risk of crashes in certain weather conditions.
- Develop a model public information campaign that can be used by state and local governments to make the public aware of road treatments, materials, and levels of service, as well as taxpayer and environmental costs.

Executive Summary

This report presents the results of a project by a research team from the University of Maine, in cooperation with the Maine Department of Transportation (MaineDOT), to examine the use of salts, equipment and personnel to control snow and ice on winter roads in Maine. The goal is to develop a common understanding among Maine residents of the relationships of cost, materials, research, policy priorities, and consequences.

In this report, we present background information on winter road maintenance, a description of current practices and policies in Maine, and summaries of the literature on environmental effects and corrosion. We examine winter road practices in other selected states and provinces. We base our analysis of safety, mobility and costs on state- and municipal-level data. To analyze road safety and the relationship between winter weather and crashes, we examined data from all police reported crashes from 1989-2008 in Maine. We used daily weather data from five weather stations throughout the state to measure the effect of precipitation, snow and temperature on road accidents and safety. We held meetings with stakeholders and conducted individual interviews to provide input to the project and for public outreach.

The State of Maine has 23,450 miles of public roadway, more miles per person than any other New England state. As a rural state, we have a relatively high per-resident cost for transportation maintenance and infrastructure. MaineDOT maintains approximately 4150 centerline miles in winter, 18% of the total roadway, which it divides into three categories of priority. The Maine Turnpike Authority maintains 109 centerline miles. The remainder of the mileage is maintained by Maine's municipalities and counties. 488 municipalities, 10 counties, and 3 reservations have winter road maintenance responsibility, and together they maintain approximately 81% of the total road mileage. We estimate that clearing winter roads last year cost Maine (MaineDOT, MTA, municipal governments) $98 million dollars, or $76 per person. Change in winter road maintenance practices may provide an opportunity for cost savings. Any changes will need to be balanced with levels of service that the public has come to expect.

By far the most widely used chemical on winter roads in Maine is rock salt (sodium chloride) due to its cost-effectiveness and ease of handling. The total purchased in the state last year amounts to roughly 750 pounds for every Maine resident, or 21 tons per road mile. The resulting clear roads contribute to high levels of safety and mobility. There are fewer crashes on all roads under all conditions than a decade ago. Still, Maine accident data show a 10-year-average annual cost of $1.5 billion dollars. The youngest drivers have a disproportionately higher share of winter-condition crashes, specifically on urban townways. Elderly drivers have a disproportionately lower share of crashes in the same conditions. The consequences of road salt use show up in water quality, vehicle corrosion, and state and municipal budgets. Environmental data show increasing levels of chloride in fresh water throughout the Northeast. Anecdotal evidence shows that vehicle corrosion is widespread and costly.

Deicing is the winter road maintenance practice familiar to most people -- plowing the roads and applying a mixture of salt and sand to break the bond of ice with the pavement, improve traction and promote melting. Anti-icing is based on prevention -- an approach that requires greater attention to road and weather conditions than deicing. Anti-icing and pre-wetting policies have been shown to result in reduced plowing time, a reduction in abrasives use, a decrease in total

chemical use, and decreased maintenance costs. Anti-icing also means that the road returns to bare pavement faster than with deicing. This reduces time lost through travel delay and damage to cars and equipment due to abrasive use. Anti-icing has been gradually adopted by most northern state transportation agencies, including MaineDOT, the Maine Turnpike Authority and some municipalities in Maine.

There are primarily five types of chemicals available in North America for snow and ice control on roads. They all lower the freezing point of water. These are sodium chloride, or salt (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KA), and calcium magnesium acetate (CMA). Most ice-melting chemicals are based on these primary ingredients. Additives from agricultural processes are used as corrosion inhibitors. Sand is commonly used for traction on roads but it has no ice melting properties.

Each year, state Departments of Transportation in northern regions spend an average of 20% of their budgets on ice and snow removal. These expenses take the form of equipment, chemicals, training, repair, workers, and planning. Maintaining clear roads benefits local businesses, interstate transport, freight carriers, emergency vehicles, and the driving public. The application of road salts is effective at maintaining clear roadways and vehicle safety. It also has consequences for the environment, vehicles, infrastructure and budgets.

We estimate that approximately 490,000 tons of road salt were purchased statewide by all entities in Maine for 2008-09. Calcium chloride has long been used as an additive to road salt at lower temperatures to lower the freezing point. Magnesium chloride shares many performance characteristics with calcium chloride including its ability to retain moisture. MaineDOT uses magnesium chloride; the Maine Turnpike Authority and many municipalities use calcium chloride. Field tests show that performance among these chemicals varies with specific conditions. Chemical choice is often a matter of cost and availability.

Most of the available environmental research on deicers is for the commonly used salt (NaCl). There is ample evidence that salt is increasing in the aquatic environment in both the short term (months) and the long term (years). Winter road maintenance is a significant source of the total chloride loading to fresh waters. Short-term effects are directly related to the seasonality of salt use, with peak levels occurring in spring and fall. Several long-term studies find evidence of an increasing chloride trend. These studies found increases of 240 to 350% over several decades. Although most chloride is exported, some unknown amount accumulates in watersheds over time. Each year ten to twenty private wells in Maine are closed because of chloride. Once contaminated by high chloride levels, surface and ground water can take decades, if not longer, to recover. It will only recover after the source of chloride contamination is eliminated. Maintaining water quality in Maine for the long term will include reducing the amount of chloride that we put into the environment.

Abundant anecdotal evidence in Maine tells us that vehicle corrosion on cars and trucks is more prevalent than a decade ago. It affects family vehicles, commercial fleets, school buses, and government-owned road equipment. Bridges are subject to corrosion from road salts through impacts on exposed steel, concrete and the steel reinforcing within concrete. All deicers increase the number of freeze-thaw cycles, accelerating deterioration of concrete and pavement.

Corrosion causes damage to exposed metals and to vehicles. Of all the consequences of road salt, it is corrosion which elicits the most concern from the public and from industry.

From an extensive review of the published literature we conclude that it is not possible to rank chloride-based (sodium, calcium, magnesium) deicers for their impacts on vehicle corrosion when taking into account real-world conditions. The National Cooperative Highway Research Program (NCHRP) indicates that while all chlorides cause corrosion in laboratory, the variation in field conditions (climate, temperature, road surface, speed, application rates, etc.) may determine differences among the chlorides. All of the common chlorides show high impact through atmospheric corrosion to metal, with calcium and magnesium chlorides higher due to their property of retaining moisture. Modern vehicles are composed of many metals and alloys; each responds differently to different road chemicals under different conditions. At the same time, vehicle manufacturers no longer use hexavalent chromium, a highly effective anti-corrosion coating for brake lines and electrical connectors. Its use has been discontinued because it is a proven carcinogen.

Our examination of crash data in Maine indicates that there are significantly fewer crashes reported during winter road conditions (snow, slush, ice) than a decade ago. In winter months (not conditions), however, the number of crashes has not been reduced compared to crashes during the rest of the year. This is true for state highways as well as for all other roads. For state highways there is even a slightly smaller reduction in winter month crashes compared to the rest of the year. However, if we look at fatalities, there is a significant reduction in the number of people killed on state highways. Town roads and state-aid highways have not seen a similar reduction. The clear-pavement policy means drivers are exposed to fewer conditions of snow and ice, and this has led to improved mobility. People get to their destinations more quickly and they probably cancel fewer winter-time trips because of inclement weather.

Older drivers are clearly underrepresented in crashes on snow- and ice-covered roads, compared to their share of crashes during other road conditions: 65 to74 year old drivers are significantly underrepresented in winter crashes by about 26% and drivers 75 years or older, by about 47%. The reason for this may be that elderly drivers may refrain from driving when roadway conditions are more risky. However, we do not know this with assurance since we lack data on miles driven by age group under different weather conditions.

On the other hand, 16 to 17 year old drivers are significantly overrepresented in winter crashes, by about 9%. This analysis compares their involvement in winter-related crashes to their share of crashes for all road conditions. There are also higher rates of winter crashes for the 18-19, 20-24 and 25-34 age groups. It is clear that the combination of young drivers and snow-covered roads is hazardous. An analysis by roadway category shows that this higher number of crashes is concentrated on urban townways. On state highways, teen drivers are actually underrepresented with respect to winter-road accidents. This may indicate that the MaineDOT is doing a good job maintaining the state highways during snowstorms, making them safer, or that teenagers are less likely to travel on state highways in winter weather conditions.

An analysis of weather parameters that influence the number of wintertime crashes shows that the presence of colder temperatures and snowfall account for the largest increase in daily crash totals but hold a negative relationship with monthly fatality rates. Specifically, temperatures below 25 degrees and a daily snowfall greater than one inch contribute to 127 additional crashes compared to the "average" day of 82 crashes. However, crashes decrease in extremely low temperatures and snowfall above 5 inches, probably due to the decrease in the number of drivers in these conditions. Weekend days, and months with higher traffic volumes, increase the number of crashes by 40%. Regression results show a statistically significant decrease in crashes after MaineDOT's anti-icing policy was implemented but it is unknown whether this policy is the cause of the decrease because we are not able to control factors including the demographic characteristics of drivers, changes in roadways, safety improvements on vehicles (e.g., anti-lock brakes, stability control systems) and changes in rates of impaired driving.

We examined other states' and provinces' winter road maintenance practices to learn from their experience. The State of New Hampshire has a growing population and traffic density in the southern region. During a planned expansion of Interstate 93 the state formed a Salt Reduction Working Group and developed a Salt Reduction Plan for the area. Similar in climate to Maine, but with a larger population, Minnesota takes a more high-tech approach to winter road maintenance. A well-developed network of Road Weather Information Systems and Automatic Vehicle Location Maintenance Decision Support System contribute to Minnesota DOT's liquid anti-icing program.

In 1995 Canada initiated a five-year scientific assessment of road salts. In 2001 it concluded that road salts were affecting freshwater ecosystems, soils, vegetation and wildlife and recommended them for designation as toxic substances under the *Canadian Environmental Protection Act.* A multi-stakeholder working group developed a Code of Practice to guide development of voluntary salt management plans for road authorities using more than 500 metric tons of salts per year or maintaining roads near vulnerable ecosystems. Ontario's Ministry of Transportation uses Road Weather Information Systems and Advanced Vehicle Locator systems that allow monitoring of salt usage and application rates through a computerized mapping system. Quebec became the first province to make winter tires mandatory in 2008 for all passenger vehicles and taxis registered in Quebec.

We have shared research findings with stakeholders in Maine and incorporated their feedback into this report. Stakeholder input comes in the form of interviews, stakeholder meetings and project advisory committee meetings. Although stakeholder groups hold differing viewpoints, all recognize the need for change and appear willing to work together to examine this issue in more detail and to participate in discussions of policy options. Recommendations from stakeholders include enhanced driver education for winter conditions and re-examining levels of service priorities except on state highways. All stakeholders, and the general public, have much to gain from increased public awareness of the issues surrounding road salts in Maine.

Glossary of Terms

A. **Anti-icing** - Anti-icing is a philosophy, not a specific practice. It refers to treatment focused on preventing development of a bond between ice and the roadway, as opposed to removing ice and snow after a storm. Anti-icing requires attention to weather information and road conditions. Anti-icing may include pre-wetting or pre-treating.
B. **Deicing** - The winter road maintenance practice familiar to most people – plowing the roads and applying a mixture of salt and sand to break the bond of ice with the pavement, improve traction and promote melting. Plowing is commonly started after an inch of snow has accumulated on the roads, and a salt and sand mixture is spread. Sanding provides temporary traction while salt melts snow and ice so it can be cleared by plows.
C. **Centerline Miles** - Are the actual length of roadway in one direction of travel. Opposing travel lanes on some state highways are separated by large medians, this can result in the total length of highway differing for each direction.
D. **Lane Mile** – A measurement of roadway distance based on a single lane of travel. For example, one mile of a two lane road would constitute two lane miles.
E. **Pre-treating** - Pre-treating refers to direct application of liquid brine to the road before a storm.
F. **Pre-wetting** - Pre-wetting refers to the wetting of solid salts as they are spread onto the road by the service trucks. Pre-wetting may be performed at the storage area or at the spreader.
G. **State Aid Road** - These roads connect local roads to the State Highway system and generally serve intracounty rather than intrastate traffic movement. With the exception of compact areas, the state aid roads are usually maintained by MaineDOT in the summer and by municipalities in the winter pursuant to State Law 23 MRSA 1003. The State Aid Highway category generally corresponds with the federal 'collector' classification.
H. **State Highway** – A system of connected main highways throughout the state that primarily serve intra- and interstate traffic. With the exception of compact areas, the MaineDOT has responsibility for the year-round maintenance of state highways. The State Highway category generally corresponds with the federal 'arterial' classification.
I. **Toll Road** - In Maine, these are all roads maintained by MTA.
J. **Townway** - These roads are all roads not included in the State Highway or State Aid Highway classifications that are maintained by municipalities or counties. These roads are classified as federal 'local' roads.
K. **Winter Road Chemicals**:
Sodium chloride ($NaCl$), or road salt, is the most widely used chemical for winter road maintenance. It is used in solid form, as rock salt, or liquid form as brine. As brine it is used for pre-treating.
Calcium chloride ($CaCl_2$) is used to lower the working temperature of rock salt.
Magnesium chloride ($MgCl_2$) is used to lower the working temperature of rock salt. It is used in some states to pre-treat roads.
Calcium magnesium acetate (CMA) is used to lower the working temperature of rock salt. Sometimes used in environmentally sensitive areas, it is extremely expensive.
Potassium acetate (KA) can be used to lower the working temperature of rock salt. It is more expensive and less commonly used than chlorides.

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Introduction and Scope

This report presents the results of a fourteen-month effort by a research team from the University of Maine in cooperation with the Maine Department of Transportation (MaineDOT) to conduct research, engage stakeholders, provide information, and foster policy discussion on the use of salts on winter roads in Maine and the consequences of that use.

Background

In November 2007, representatives of MaineDOT contacted the Margaret Chase Smith Policy Center at the University of Maine to inquire what resources the University could assemble to conduct research and help raise awareness about public policy issues related to the use of road salts and winter road maintenance in Maine. The Margaret Chase Smith Policy Center assembled a multidisciplinary team representing the Department of Civil Engineering, Department of Public Administration, Senator George J. Mitchell Center for Environmental and Watershed Research, and the Margaret Chase Smith Policy Center. After considerable discussion with representatives of MaineDOT, the University and MaineDOT developed a state-university cooperative agreement employing resources of MaineDOT and the University of Maine to address many of the issues identified initially by MaineDOT.

Project Goals & Objectives

The overall goal of this project is to develop among all stakeholders a common understanding of the public policy issues and the relationships of funding, current research, levels of service, and risks associated with the use of road salt. To achieve this goal, the project includes both research and public outreach components. The research components of the project are intended to create an expanded knowledge base of information and the public outreach components are intended to ensure widespread availability and dissemination of that information.

Project Activities

The major project activities include creating and actively involving a project advisory committee, collecting and conducting research related to specific topic areas, conducting interviews of selected stakeholder representatives, presenting research findings and soliciting stakeholder feedback at a series of four stakeholder meetings across the state, and preparing this project report.

Research

Research activities included extensive literature reviews, analysis of data from secondary sources, and a brief survey of Maine municipalities. Specific areas of inquiry included automobile crash analysis related to winter road conditions, practices and materials used in winter road maintenance, corrosion related to use of road salts, the environmental effects of road salts, and winter maintenance practices in other states and provinces. Stakeholder input was collected from the Advisory Committee, through selected stakeholder interviews, and from participants in the stakeholder meetings. The references and appendices provide substantial background detail.

Public Outreach
Four Stakeholder Meetings were held across the state in September 2009. Based on recommendations from the Advisory Committee, invitations were sent to individuals representing a variety of stakeholder groups for each of the four meetings. At the Stakeholder Meetings, results of project research activities were presented and discussed with participants. In addition, participants were engaged in activities to allow them to share their issues and perspectives related to the use of road salts and winter road maintenance practices.

The remainder of this report presents the results of project activities. This project was initiated to help inform the policy process. As we have gone through these activities, our efforts have affirmed that this project is not an end – it is part of an on-going process. New studies related to these topics have been published during the course of the project and further research should be conducted. Meetings with stakeholders confirmed to us the resonance of this issue throughout the state and the motivation of stakeholders to pursue a policy solution.

Project Advisory Committee

In cooperation with MaineDOT, the project identified potential stakeholders and stakeholder groups related to the use of road salts in winter road maintenance in Maine. The Advisory Committee was chosen to reflect these stakeholders, and includes representatives of the trucking industry, local officials with responsibility for roads and road maintenance, those concerned with environmental impacts from road salt, those with responsibility for accidents and public safety, other state and federal governmental agencies with related responsibility and the traveling public. See Appendix 1 for a list of members of the Project Advisory Committee.

The Advisory Committee met three times during the course of the project. During the first meeting, they helped define specific project research areas and assisted in identifying sources of information related to the project. During the second meeting, the Advisory Committee reviewed preliminary results and provided guidance in presenting those results at the stakeholder meetings. In addition, Advisory Committee members assisted in identifying individuals who should participate in stakeholder meetings. During the final meeting, Advisory Committee members reviewed and provided comments on a draft of this report.

Limitations

The methods and data used throughout this research project reflect the best information that could practically be obtained or developed within the constraints of time, limited comprehensive data, development of original data, and data analysis. The methods and data are intended to provide breadth rather than depth of knowledge about winter salt usage and attendant risks along with related aspects of winter road conditions and maintenance throughout the State of Maine. In numerous instances, the research team has had to calculate or infer pieces of information (such as in-state lane-miles) – that is, make a calculated assumption – as a step in aligning data sets from disparate sources for further analysis.

The information presented in the report is meant to provide policy makers and the public with a basis for making more fully informed judgments and subsequent decisions regarding the treatment of winter roads in Maine, with its distinct combination of climate, topography, geology, land use, demographics, roadways, and transportation needs. These conditions vary significantly within the State and vary far more beyond Maine's boundaries; consequently, what holds true right now in large parts of Maine may or may not apply throughout the State and may apply even less in other locales.

History, Materials & Current Practices

Background

Each year state Departments of Transportation in northern regions spend an average of 20% of their budgets on ice and snow removal from roads and highways. Nationally, state and local agencies spend more than 2.3 billion dollars on snow and ice control (USDOT, 2008). These expenses take the form of equipment, chemicals, training, repair, workers, and planning. Maintaining clear roads benefits local businesses, interstate transport, freight carriers, emergency vehicles, and the driving public. The preferred chemicals for keeping roads clear are road salts due to their cost, effectiveness and ease of handling. Approximately 23 million tons of road salt (sodium chloride) was used in the U.S. in 2005. In the state of Maine, an estimated 490,000 tons of sodium chloride (NaCl) were used by all sectors in 2008[1]. The application of road salts, while effective at maintaining clear roadways and vehicle safety, has consequences for the environment, vehicles, infrastructure and budgets.

As road networks have grown, private and commercial travel has increased. The public's demand for faster goods and services has translated to expectations of clear road conditions following winter storms. A delay in travel means lost time and money to individuals, businesses, and the state. State and municipal transportation agencies face the challenge of responding to the public and business' demand for clear and safe roads while choosing alternatives with the least harmful impact on the environment and infrastructure -- and still working within the budgetary constraints. There is significant year-to-year variation, but over the last five fiscal years MaineDOT spent an average of $19 million annually to keep roads clear of snow and ice (see Figure 5). Winter maintenance costs constitute a large percent of a municipal budget. Finding the most effective balance among public expectations, road-clearing chemical choice, practices, environmental impact, cost, and public safety is an ongoing challenge.

In this report we address the many issues surrounding the use of road salts in Maine. We provide the background to understanding winter road maintenance policies and describe current practices by the Maine Department of Transportation (MaineDOT), the Maine Turnpike Authority (MTA), and some municipalities in Maine. We describe the experiences and policies of a few other states and provinces. We examine the characteristics of road clearing chemicals, their effect on the environment, and the effect on corrosion of bridges and vehicles. We use data from all police-reported crashes in the

[1] Estimate based on amount supplied into Maine by all vendors of road salt.

state over a 20 year period to examine safety. Finally, we present a summary of the four stakeholder meetings held by the research team.

Deicing with salt and sand

The use of salt (sodium chloride) in winter road maintenance began in America in the 1930s. The New Hampshire State Highway Department was the first to use granular salt on roads, an idea pioneered in 1938 by LeRoy F. Johnson, New Hampshire's maintenance engineer, using a direct windrow application method on the New Hampshire state highway system. This method soon became the standard. Throughout the 1940s and 1950s "bare pavement" policies were gradually adopted by transportation agencies as the standard during winter weather (USEPA, 1999). Salt continues to this day to be the most widely used and cost-effective deicing chemical.

Deicing is the winter road maintenance practice familiar to most people -- plowing the roads and applying a mixture of salt and sand to break the bond of ice with the pavement, improve traction and promote melting. Plowing is commonly started after an inch of snow has accumulated on the roads, and a salt and sand mixture is spread. Sanding provides temporary traction while salt melts snow and ice so it can be cleared by plows. This mix is often followed by more salt to remove ice and snow bonded to the roadway. This reactive strategy is both well-understood and effective.

Concerns with deicing have arisen around the quantity of salts applied and the seasonal accumulation of sand requiring road crews to clear sand from roadways and culverts in the spring. Even when early research showed environmental impacts from salt, the lack of viable alternatives for clearing the roads meant a continuation of deicing. In the mid 1990s snow removal policies began to change in Maine and elsewhere as research focused on finding the best practices with fewer environmental consequences.

Impacts of Salt and Sand

In the 1970s the US Environmental Protection Agency (USEPA) began its first major assessment of the impact of deicing salts on the environment (Field and O'Shea, 1992). Over the next decades studies were conducted of road runoff, water quality of surface and ground waters, and the impact on soils, wildlife and vegetation. It was found that road salt can cause damage across a variety of environmental indicators. Uncovered salt storage areas also were found to be a major source of ground and surface water contamination. Some estimates suggest that improper stockpiling of salt, where rain and runoff can carry salt into soil and nearby bodies of water, contributed as much as 80% of the environmental problems associated with salt use before the issue of storage was addressed. (Salt Institute, 2007).

The impacts from sand and salt are now well documented. The USEPA summarizes these impacts in a brief brochure available on the internet (USEPA, 2005). Sand applied to roadways collects in catch basins and streambeds. It reduces water quality and clarity. It typically has had to be removed from the roadside at the end of each winter season. Sand causes fine dust that impacts air quality and can adversely impact human health. Sand contributes to air pollution as measured in the PM-10 and PM-2.5 standards for particulates; numerous cities and towns have been restricted in their application of sand due to violations of these standards.[2]

Concentrations of salts in highway runoffs have been found to affect vegetation, soils, water supplies and human health. Corrosion results in impacts to roadways, bridges, and vehicles. Corrosion of vehicles and bridges represents both safety concerns and costs to individuals, private companies, and government. Improvements in manufacturing have greatly improved the corrosion resistance of vehicles since the 1970s, yet vehicle corrosion is still a major concern to owners of cars and trucks. More detail on environmental impacts and corrosion will be found later in this report with a discussion of specific chemicals.

Anti-Icing

As the traditional application of sand and salt is called deicing, the alternative practice has come to be known as anti-icing. Anti-icing is based on prevention -- an approach that requires greater attention to road and weather conditions than deicing. As part of a five-year Strategic Highway Research Program begun in 1987, nine states carried out an anti-icing initiative to optimize the effectiveness of anti-icing operations. Six additional states participated in two years of subsequent testing and evaluation of methods. Results of these trials show that chemicals can be used more effectively to prevent bonding of ice or snow to the pavement than in removing the bond once it has formed. Fewer chemicals are needed for the same levels of maintenance, and the need for abrasives is reduced (Chollar, 1996).

The National Highway Cooperative Research Program defines anti-icing as (AASHTO, 2009):

> "…the proactive use of any melting agent to assist melting and resist the formation of a bond between snow and ice and the pavement surface. Highway anti-icing is the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a chemical freezing-point depressant…"

In 1996 The Federal Highway Administration (FHWA) and Strategic Highway Research Program (SHRP) published a manual of practice for implementing an anti-icing strategy. Since its publication these anti-icing guidelines have been gradually adopted by most northern state transportation agencies. There is now a large body of literature and numerous resources to guide decision makers on best practices for anti-icing.

Although in practice some states use pavement pre-treatment in their anti-icing strategy, anti-icing refers to a proactive approach, rather than a strict set of guidelines. AASHTO clarifies the definition: "Anti-icing can involve application to the roadway of liquids, pre-

[2] Denver, Colorado, Seattle, Washington and Presque Isle, Maine (1994) are examples of the many PM-10 nonattainment areas across the country which have been subject to subsequent sanding restrictions.

wetted solid granular materials or dry granular material. Thus, anti-icing is not confined to using liquids (AASHTO, 2009)."

Details of FHWA Recommendations
Anti-icing is a philosophy, not a specific practice. It refers to treatment focused on preventing development of a bond between ice and the roadway, as opposed to removing ice and snow after a storm. Anti-icing requires attention to weather information and road conditions. Treatment is begun as soon as practicable after the onset of a storm, and sometimes before, applying materials to prevent icing. These materials can be liquid, solid salt wetted with liquids, or solid salt. An anti-icing strategy is also intended to reduce the use of sand.

Pre-treating refers to direct application of liquid brine to the road before a storm. The advantages of pre-treating a road with brine are a reduction in the scatter and blowing of salt, allowing consistency of application and less waste. Brine applied to roadways can be effective for up to 3 days before a storm, allowing more efficient use of equipment and personnel. This approach requires judgment in decision making informed by accurate weather reports, and requires timely anticipatory action.

Pre-wetting refers to the wetting of solid salts as they are spread onto the road by the service trucks. Pre-wetting may be performed at the storage area or at the spreader. Liquids used for pre-wetting may be salt brine, liquid calcium chloride, liquid magnesium chloride, or less commonly, liquid acetates. Advantages of pre-wetting are that solids stay on the pavement better, the salt starts acting more quickly, melting can occur at lower temperatures, and less salt overall is needed. A standard liquid application rate is 10 gallons per ton of solids, or 5% (MaineDOT, 2007)

Implementation of an anti-icing policy requires decision making based on accurate weather forecasting, current road condition information, traffic conditions, patrols or visual observation, and assessment of the treatment effectiveness, all of which also requires trained personnel.

Changing Practices

Numerous research efforts have resulted in the publication of recommendations for best practices to minimize salt usage and salt entry into the environment. Most of these recommendations focus on changing practices for winter maintenance. Many state agencies have replaced deicing with anti-icing in winter operations; anti-icing is being adopted by municipalities more slowly. The result for state agencies, as they pay closer attention to weather conditions and use more liquids, has been a decline in the amount of sand used and a more efficient use of salts.

Anti-icing and pre-wetting policies have been shown to result in reduced plowing time, reduction in abrasives use, a decrease in total chemical use, and decreased maintenance costs (O'Keefe and Shi, 2006). Anti-icing also means that the road returns to bare pavement faster than with deicing, thereby reducing accidents, time lost through travel delay, and damage to cars and equipment due to abrasive use (Boselly, 2001). Pre-wetted salt is more effective than dry salt. Applying liquid in pre-wetting accelerates the melting process because salt needs moisture to be effective. The material sticks to the road better, reducing bounce and scatter on the road. Because of the reduced use of sand, anti-icing reduces airborne dust and salt particulates. Assessments show anti-icing to be a more efficient use of material and manpower overall (Boselly, 2001). Pre-treating with liquid yields additional material savings; some estimates suggest that pre-treatment with brine may use one-third to one-fourth of the material used during deicing (Salt Institute, 2007).

Technology and Equipment
Changes in technology and mechanics have the potential to add significant efficiencies to winter maintenance. The standard method for spreading solids is the horizontal spinner. Some studies of current practices show that 30% of the product spread by a horizontal spinner is lost from the pavement (Williams, 2001). While this project does not have the scope to examine road salt spreading equipment or technology, the possibility of gains in efficiency through technology improvement should be considered as a means to reduce chemical use in winter road maintenance while maintaining acceptable levels of service.

Overview of Snow and Ice Control Materials

The following section is a non-technical summary of the materials commonly used for snow and ice control on roads in North America, with specific focus on Maine. We outline the general characteristics of the materials and summarize the current knowledge about their impacts on the environment, infrastructure, and vehicles.

There are primarily five types of chemicals available in North America for snow and ice control on roads. They all function as freeze point depressants, meaning they lower the freezing point of water. These are sodium chloride, or salt (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KA), and calcium magnesium acetate (CMA). Most proprietary blends of chemicals for ice melting, which often contain additional corrosion inhibitors, are based on one of these chlorides or acetates as a primary ingredient. Additives used as corrosion inhibitors are often by-products of agricultural processes, such as the carbohydrate-based solutions from corn, beet or grains. Anti-corrosion additives increase the cost of ice-melting chemicals. One chemical additive currently being promoted is derived from sugar beets and is used as a mixing agent with other chemicals. MaineDOT has tried this product on a trial basis; however, its higher cost precludes using it. Sand is commonly used for traction on roads but it has no ice melting properties. Because it is widely used in winter road maintenance, however, its characteristics are also discussed here. Of these materials, NaCl (solid and in brine), $MgCl_2$, and $CaCl_2$, and sand are most commonly used in Maine.

Salt

By far the most widely used chemical on winter roads is road salt, or sodium chloride. A near record 20.3 million tons[3] of road salt were sold in 2007 in the United States (Salt Institute, 2008). We estimate that statewide approximately 490,000 tons of road salt were purchased in Maine by all entities for 2008-09. In Figure 12 we show an estimated breakdown of salt use by end user.

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[3] Salt is typically reported in tons, while sand is typically reported in cubic yards. A ton is generally equivalent to a cubic yard of sand or salt.

Salt performs best for melting at certain temperatures, generally considered to be above 15 °F. It stops melting altogether at -6°F (see figure below). It is at these lower temperatures (below 15 °F) that other chlorides and acetates are often used to supplement salt for ice-melting as they have a lower freezing point.

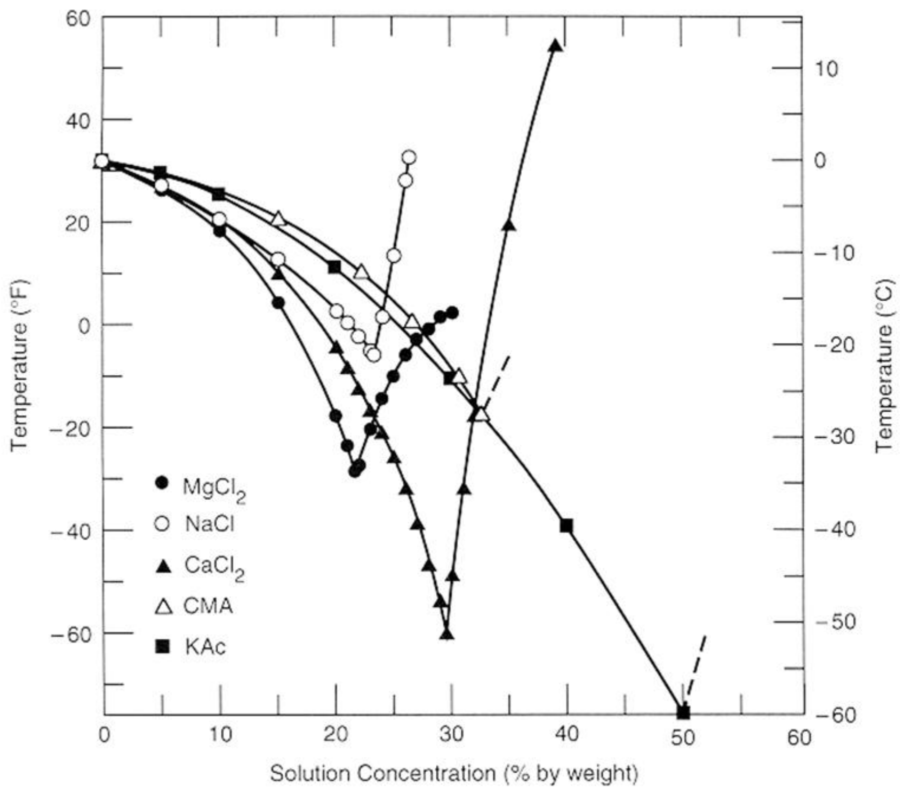

Figure 1: Freezing Point of Common Road Chemicals

Other Chlorides

Calcium chloride has long been used as an additive to salt at lower temperatures due to its ability to lower the freezing point. It is considered to have an advantage over salt in its hygroscopic ability to absorb moisture from the air. This added moisture helps keep the material on the pavement more effectively and longer than salt. This same quality, however, may cause it to adhere to tires and thus be carried away more than salt. Calcium chloride may be applied in flake form as an additive to abrasives or in liquid form directly to the roadway, but is more often used in liquid form for pre-wetting a load of salt. Magnesium chloride is a more recently available material for road maintenance. It shares many performance characteristics with calcium chloride including its ability to retain moisture. Field tests show condition specific variations in performance, and chemical choice is often a matter of cost and availability. It is applied as a liquid to pre-wet a load of salt, and can be applied on its own to the road in liquid form.

Acetates and Carbohydrate-Based Solutions

Acetate-based deicers such as potassium acetate (KA) and calcium magnesium acetate (CMA) are used much less frequently than chlorides, partly due to their extremely high cost. When used, they are used primarily as pre-wetting agents, mixed with salt or sand before application. They can be applied as stand-alone liquids, but tend to be used in specific niche situations.

Carbohydrate-based deicers have recently become more well-known as winter maintenance materials. These are often derived from fermentation of grains or processing of sugars such as cane or beet sugar. These materials are rarely used as stand-alone products, but more often are combined with chlorides or acetates in proprietary mixes. Some of these products claim to have corrosion inhibiting qualities, but these claims are not consistently substantiated in the research.

In addition, there are many proprietary mixes of deicing chemicals used to supplement road salt. The mixes are usually made with a base of $MgCl_2$ or $CaCl_2$, often mixed with a carbohydrate based product with claims of inhibiting corrosion. The deicer currently used by MaineDOT for lower temperature melting, Ice-B-Gone, is a patented formula consisting of a mix of $MgCl_2$ and sugars from byproducts of alcohol distillation or molasses, which also act as a corrosion inhibitor. It has been used in a mixture at 30% with brine although MaineDOT is currently experimenting with blending Ice-B-Gone and salt brine, using different mixing ratios to find the most appropriate balance between cost, effectiveness, and corrosion protection.[4]

According to a 2007 survey, most state Departments of Transportation continue to rely on chloride salts and abrasives (Fay et al., 2008). Acetates were used by a minority of respondents as alternatives to chlorides because their costs are much higher, and their impacts different. According to this survey nationwide sodium chloride is used most, followed by abrasives, magnesium chloride and calcium chloride, followed by other deicers such as acetates and agriculturally derived solutions.

Material Choice and Decision Making

Choice of winter road materials, particularly for municipalities, can be a function of cost. The average price of salt purchased by MaineDOT for the 2008-09 winter ranges from $66 to $79 per ton. The price paid by most municipalities is comparable. Calcium chloride, available in liquid or solid form, costs approximately $1.37 per gallon or $276 per ton, and the cost of Ice-B-Gone is $1.39 per gallon, approximately $280 per ton[5]. CMA costs are closer to $700 per ton. Salt brine used for pre-treating is a mixture of 23% NaCl in water and costs approximately $40 per ton. In addition to purchase price a cost comparison of winter road materials should, under full accounting, also include costs such as cleanup, environmental cost, and cost of damage to vehicles and infrastructure.

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[4] MaineDOT, Personal communication. March 2009.

[5] One ton is approximately equal to 202 gallons. One cubic yard of salt weighs approximately one ton. Prices for 2008.

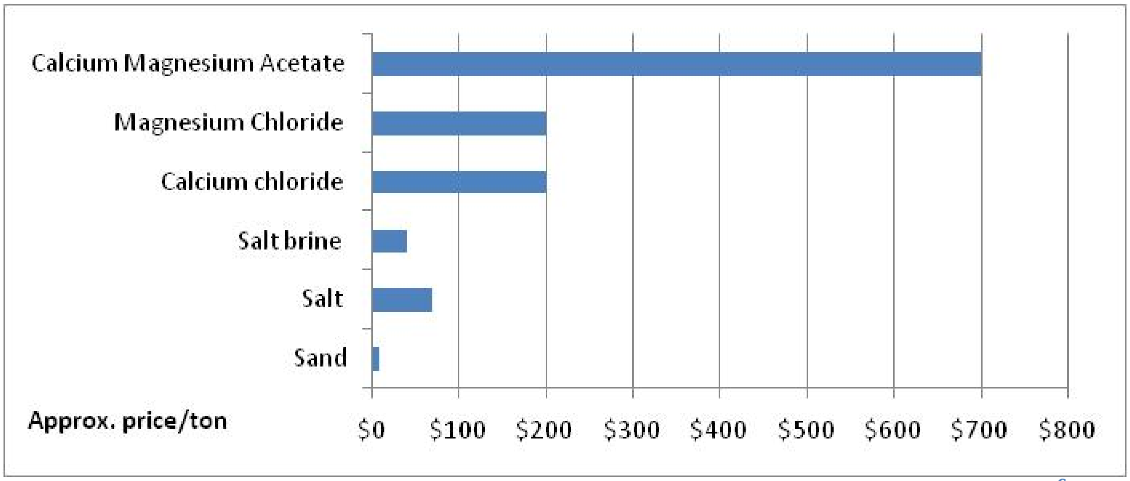

Figure 2: Approximate price per ton of common winter road chemicals.[6]

Each of the chemicals commonly used for road clearing has different attributes, and performance may vary under different road and weather conditions, further complicating the decision of chemical choice. Standard tests methods have been established for evaluating deicers (NCHRP, 2004) and recent research has attempted to develop a deicer composite index which would allow managers to numerically evaluate deicers based on priorities and local needs (Shi, et al., 2009) Guidance is also available on choice of materials for meeting Level of Service goals (NCHRP, 2004). The recent NCHRP Report 577 offers guidelines for selection of materials based on environmental impacts (NCHRP, 2007) and many state Departments of Transportation do their own field tests to compare performance under differing local conditions. The regions of Maine are subject to varied climate, topography, road conditions, and road surfaces, however. Many municipalities choose their winter road materials based on their own specific conditions and experience.

While the decision to use any one deicing product over another is a function of purchase cost, availability, and effectiveness, each chemical also has its own set of impacts. These include effects on the environment, contribution to the corrosion of vehicles, and contribution to the corrosion of infrastructure, particularly bridges. In the following sections we summarize these impacts.

Current Winter Operations in Maine

The state of Maine has 23,450 miles of public roadway and, depending upon location, can expect between 20 and 40 winter storms between November and April (MaineDOT 2009a). With a population of approximately 1.3 million, Maine reported approximately 1.2 million registered motor vehicles in 2008 and approximately one million licensed drivers (Maine Bureau of Motor Vehicles, 2009). As a rural state Maine has more miles of roadway per person than any other New England state leading to a relatively high per-resident cost for transportation maintenance and infrastructure (MaineDOT, 2002). MaineDOT is responsible for maintaining approximately 8,500 (state highway) lane

[6] Sources for this price chart include: MaineDOT (2009), and https://netfiles.uiuc.edu/mcheryan/www/cma.htm (2006).

miles in winter[7], or 18% of this total roadway, which it divides into three categories of priority for winter maintenance (MaineDOT, 2007). The Maine Turnpike Authority maintains 109 centerline miles (632 lane miles). The remainder of the roadway mileage is maintained by 488 of Maine's towns and cities, ten of the sixteen counties, and three reservations. Some unspecified amount of this mileage may be contracted to private contractors for winter maintenance. This section will give an overview of the winter operations of each of these three sectors.

Figure 3: MaineDOT Regions

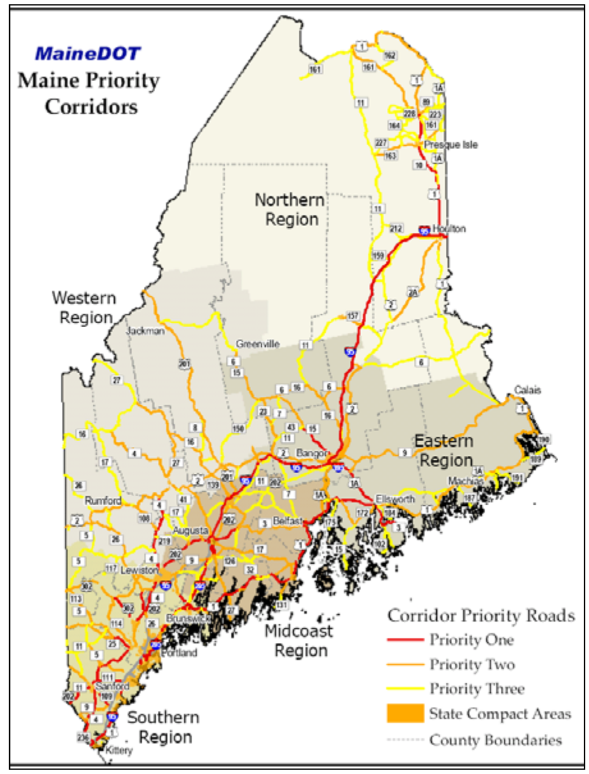

Figure 4: MaineDOT Priority Corridors

Maine Department of Transportation

In 2008-09 MaineDOT spent $28.1 million on winter road maintenance including labor, equipment, and materials (MaineDOT, 2009b). MaineDOT is divided into 5 maintenance regions, with regional headquarters are located in Scarborough, Augusta, Dixfield, Bangor and Presque Isle. Regional offices are governed by policy decisions at the state level in Augusta.

Anti-Icing

Like many other northern states, since the mid-1990s MaineDOT has been progressively adopting the procedures recommended by the Federal Highway Administration for anti-icing. A 2000 press release announced the MaineDOT change to "salt priority" (the term

[7]Maine has 23,450 *centerline* miles of road. The MaineDOT and MTA count road miles by *lane mile* (see glossary of terms), so determining the number of centerline miles requires converting lane miles to centerline miles based on the number of miles of 4 and 6 lane roads.

used by MaineDOT) indicating the associated reduction in the use of sand. MaineDOT currently uses an anti-icing policy on 95% of the roads it manages (MaineDOT 2008a). This practice includes the application of pre-wetted salt in a timely manner designed to prevent ice bonding to the road, and selective pre-treatment on priority roads. By comparison to deicing, treatment usually occurs sooner after the onset of a storm in order to prevent icing on the roadway, and the materials used are pre-wetted salt and some brine, rather than a mixture of salt and sand.

The transition to salt priority has reduced sand use by MaineDOT from a 10-year average (1990-1999) of 455,142 to 24,781 cubic yards for the most recent 5 year period (2004-2009), see Figure 5. This has lead to a reduction in overall material costs from an annual average (1990-1999) of $14.3 million to $8.5 million (2004-2009). Costs are reduced by eliminating sand and its cleanup, freeing up time for other spring and fall road work. In addition, new sand and salt storage buildings can be built much smaller due to the need for less sand, and fewer trucks are needed for winter maintenance due to lower volumes of sand. MaineDOT has eliminated 55 trucks by changing winter policies to anti-icing (MaineDOT, 2009c). Salt use has increased from an average (1990-1999) annual 72 to 110 thousand tons per year (2004-2009).

Pre-Treating

A smaller but expanding piece of the anti-icing plan in Maine is pre-treating the pavement with liquid salt brine. This is done when the road temperature is approximately 15^{o}F or higher. Solid salt is then applied throughout a storm, but the pre-treating provides an effective base to prevent ice from forming on the pavement. Pre-treating relies on accurate localized weather information. On MaineDOT roads no more than 15% of the mileage is pre-treated for any particular storm, and for many storms there is no pre-treatment (MaineDOT, 2008).

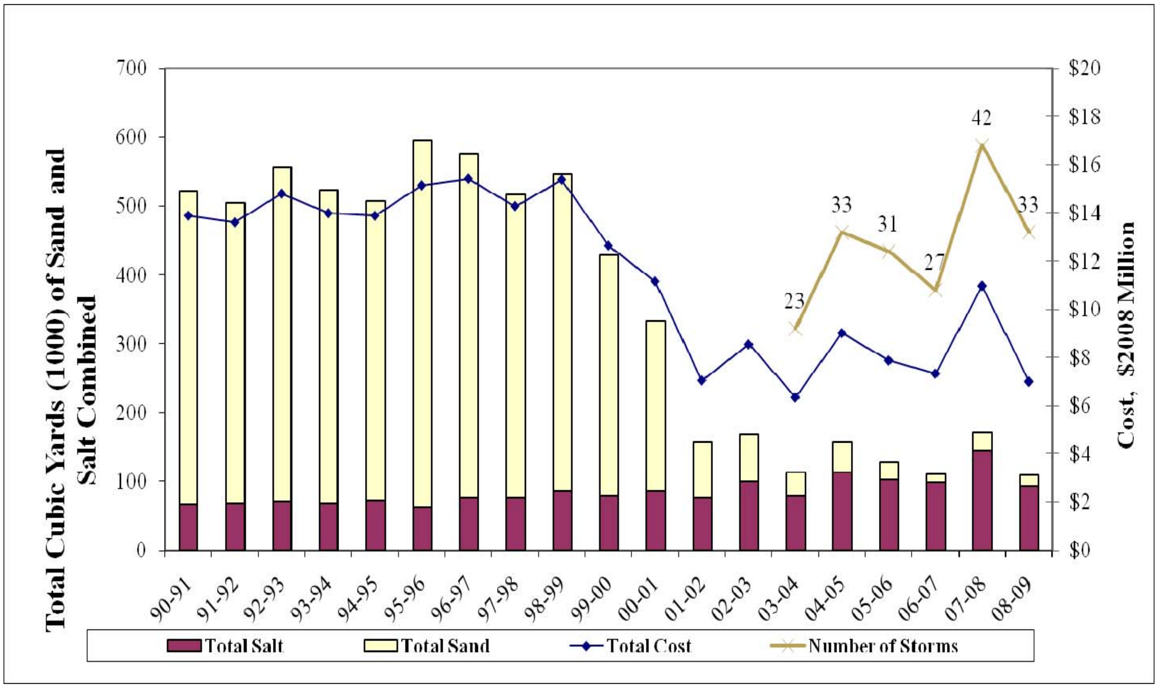

Figure 5: MaineDOT Material Use and Cost

In many states current weather information is provided via Road Weather Information Systems (RWIS) monitoring from road-level weather stations. MaineDOT has nine RWIS stations in the state. Currently these are used for gathering data to understand trends in weather and conditions. To use RWIS stations as a reliable indicator for road conditions, more are needed.

Levels of Service

MaineDOT snow and ice control operations are guided by a policy which classifies the level of service of roadways by priority corridors (MaineDOT, 2007). Each level of service has a defined cycle of service time, plow route length, and prescribed amount of time to return the road to normal winter driving conditions after a storm.

- Priority 1 corridors (26% of total miles) will be treated and bare pavement provided following a storm as soon as practicable, at most within 3-6 daylight hours.
- For Priority 2 corridors (36%) bare pavement will be restored as soon as practicable after Priority 1 corridors, and within 8 daylight hours. Pre-treatment is provided on Priority 1 and 2 corridors to prevent ice from bonding with the road surface.
- Priority 3 corridors (38%) are treated within 24 hours, providing one-third bare pavement in the middle of the road as soon as practicable. For Priority 3 corridor sand routes, roads will be plowed and sand applied, yet the road surface may be snow covered during and following a storm.

Materials

MaineDOT currently uses 392 trucks, based out of regional maintenance centers to cover approximately 8,500 lane miles of Maine roads. Rock salt (sodium chloride) is the primary material used in winter maintenance for the majority of roads. In 2008-09 MaineDOT used 92,932 cubic yards of rock salt. Winter sand mixed with salt is used for providing temporary traction for specific locations. In 2008-09 MaineDOT used 15,443 cubic yards of sand.

Salt brine is a 23% solution of salt in water used either to pre-wet solid materials applied by plow trucks or to pre-treat the roads before a storm. Salt brine applied to the roadway will adhere to the pavement as it dries and can prevent frost formation for up to three days. In 2008-09 MaineDOT used 380,000 gallons of salt brine.

In the northern region temperatures are often below the effective range of salt or brine. Other chlorides can help lower the effective melting temperature of the salt. For pre-wetting solid salt at colder temperatures MaineDOT uses Ice-B-Gone (a patented formula consisting of magnesium chloride and sugars from byproducts of alcohol distillation, also containing a corrosion inhibitor). Its chemical components are described on the manufacturer's website (SEACO, 2009). In 2008-09 MaineDOT used 308,000 gallons of Ice-B-Gone. In past years MaineDOT has used calcium chloride in pre-wetting procedures, but they have not used it since 2005.

Sand

As shown in Figure 5, sand use has been reduced dramatically with the implementation of anti-icing practices by MaineDOT since 2000. This reduction in sand means lower material costs and also reduced need for cleanup of sand at the end of the winter season, an additional savings of time and personnel. Sand is still used in some locations to provide traction on curves, intersections, or grades where chemicals are not effective or available.

In addition to following published guidelines, MaineDOT conducted its own trials in 2003-04 of several deicing chemicals (MaineDOT, 2004). Comparison tests were conducted on Ice-B-Gone (a magnesium chloride mix), a calcium chloride mix, and salt brine. After field testing, MaineDOT found that Ice-B-Gone offers the best balance between environmental considerations, and cost and performance. A wider range of products were compared during the winter of 05-06 (MaineDOT, 2006). Documentation was maintained on performance, application rate, and cost. Material choice is a function of performance, ease of handling, availability and cost. MaineDOT re-evaluates its choice of deicing chemicals as new information becomes available.

Early treatment (anti-icing) has been more cost effective than deicing for MaineDOT; research shows that 25-30% less salt per lane mile is required to return roads to bare pavement condition after a storm using anti-icing strategies. Research also shows that mixing liquid chemicals with the solids (pre-wetting) speeds up the melting process and reduces the bounce and scatter of solid material as it hits the road, reducing waste (MaineDOT, 2003).

Maine Turnpike Authority

The Maine Turnpike Authority (MTA) maintains the 109 centerline miles between Kittery and Augusta. This distance is equivalent to 632 lane miles and includes 176 bridges that carry or cross over the Turnpike. The MTA maintains a high level of service for all miles of the turnpike, clearing all areas of the Turnpike as soon as possible. The MTA employs anti-icing and pre-wetting, and has a policy to reduce the use of winter sand. Since 2006 this policy has included pre-treating with a 23% salt brine solution under certain conditions (MTA, 2008).

Over the winter of 2008-09, MTA used 16,047 tons of salt, 5,959 cubic yards of sand, and 2,955 gallons of calcium chloride. Figure 6 shows winter maintenance budgets and winter road materials for the Maine Turnpike Authority for the past eight winter seasons. The variation in total material use and total costs closely follows the number of storms in each year.

MTA Current Policies

The Maine Turnpike Authority has a bare pavement policy, meaning that the MTA does not consider a snow and ice storm completed until the snow, ice, or slush is removed entirely from the pavement, shoulders and bridges. They state that all areas of the Turnpike should be free of snow and ice as soon as possible. During heavy storms when it is not possible to remove snow and ice simultaneously from the roadway, shoulders, parking areas, crossovers, the following priorities must be adhered to unless otherwise directed (MTA, 2008, p. 31).

First Priority: Mainline pavement, toll plazas, interchanges, service area ramps, and median crossovers.

Second Priority: Shoulders, toll facility parking lots, service area parking lots, and access roads.

Third Priority: Other facilities and parking lots.

Fourth Priority: Final cleanup and snow removal at service areas, parking areas, gores, and bridges.

Since 2006 the Maine Turnpike Authority has been using an anti-icing process by pre-treating the highway with salt brine under certain conditions. A 23% solution of salt brine is applied at a rate of approximately 40 gallons per lane mile using truck-mounted tanks when a storm is imminent in the next 6-12 hours (MTA, 2008).

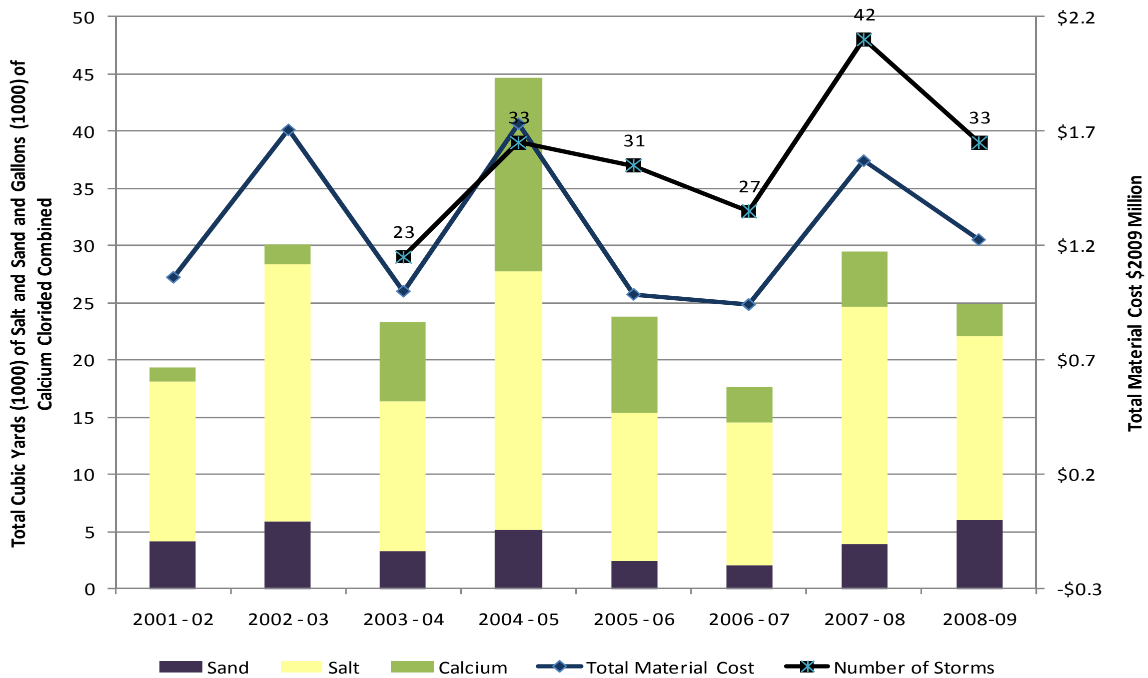

Figure 6: MTA Material Costs 2001-2009

Both Figure 5 and Figure 6 illustrate year-to-year variation that can be significant. Costs and material use depend on the severity of the winter and the severity and characteristics of each storm. These storm-based variations complicate comparison of winters and the identification of trends.

Maine Municipalities and Counties

Maine has 488 municipalities, 10 counties, and 3 reservations that have winter road maintenance responsibility. These municipal governments (town, city, and county and reservation) are responsible for approximately 18,500 centerline miles of road, or approximately 80% of Maine's 22,830 miles of centerline miles. Municipal governments either provide winter maintenance services directly through public works departments or use private contractors.

Municipal winter road maintenance can vary from state-level winter road maintenance in a number of significant ways. Not only are road surface and traffic patterns different, but equipment, training and technology are also more varied. Likewise there is no uniform set of conditions for municipal roads; climate, elevation, and slope all influence local conditions. Municipalities also differ from each other in their budget-keeping, population density, degree of urbanization, and levels of service. Some of the larger cities also provide higher levels of service in their downtown areas, clearing sidewalks, municipal parking lots and schools.

To get an understanding of the costs, diversity of practices, and material used in communities of different size and location, MaineDOT surveyed municipal governments on winter maintenance practices.[8] MaineDOT initially sent a short survey on Maine

[8] See Appendix 5 for the municipal government survey instrument.

Local Roads listserv to members of the Maine Chapter of APWA. Response was small, and the survey was sent again on the listserv in June, 2009. Of the approximately 350 municipalities queried, 129 responded to the survey and were included in our analysis. We also sent requests for information individually to specific municipalities to get adequate representation from larger communities. The total of responses represents 47% of the state population and 37% of the total centerline miles. The responding areas range from the State's largest cities to a number of towns with a population of less than 1,000. The total of road maintenance expenditures reported by the municipal governments that responded with budget numbers is $27.4 million for the 2008-09 winter season.

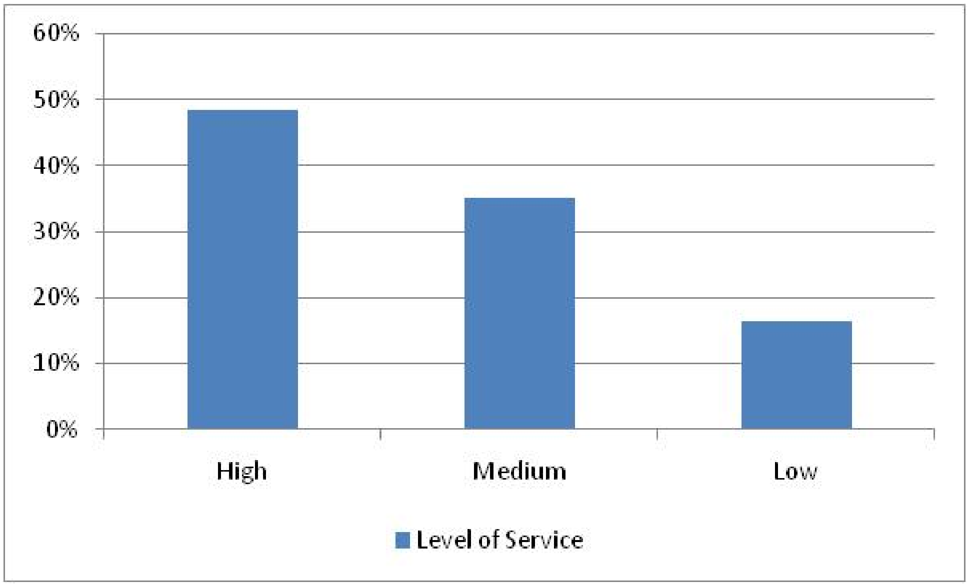

Figure 7: Level of Service on Municipal Roads

Municipal Levels of Service

The municipalities that responded to our survey self-identified their levels of service by ranking high, medium, and low priority. Figure 7 shows the (miles-weighted) level of service reported on municipal roads. We see that municipal governments report that just fewer than 50% of roads receive a high level of service while 35% and 16% of roads receive medium and low levels of service. It is important to note that respondents include large cities like Portland and Bangor, as well as many towns with a population under 5000.

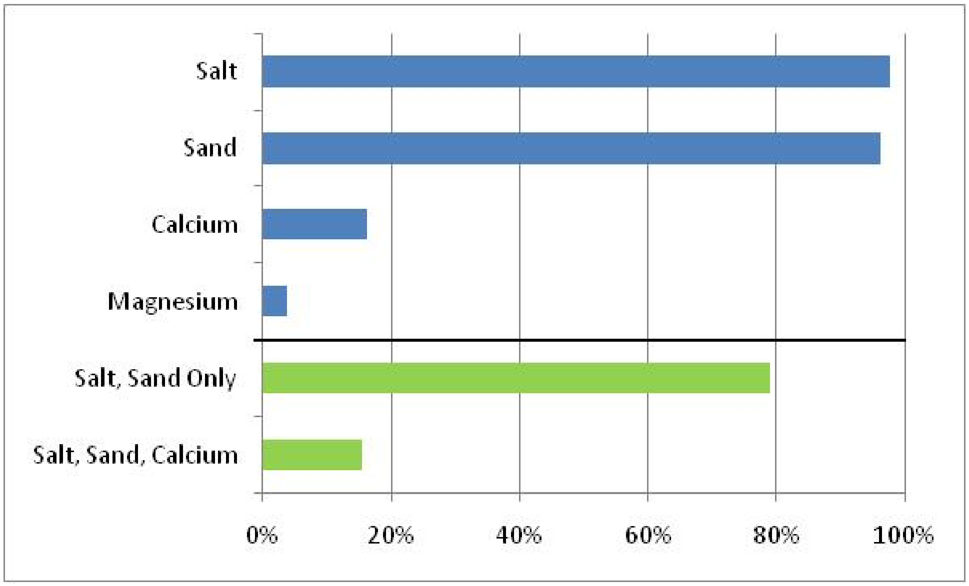

Figure 8: Material Use by Municipal Governments

Material Use by Municipalities

As shown in Figure 8, 98% of municipalities used salt, 96% used sand and 79% used both salt and sand. Additionally, 16% used calcium chloride, 4% used magnesium chloride and 16% used salt, sand and calcium chloride. Our municipal respondents reported using 99 thousand tons of salt and 360 thousand cubic yards of sand. If our respondents are broadly representative of all municipal governments, this means that municipal governments in Maine (for 2008-09) used 266 thousand tons of salt, 967 thousand cubic yards of sand, 210 and 134 thousand gallons of calcium chloride and magnesium chloride solutions, respectively.

What really stands out from this use of winter road maintenance materials is not the volume, which is substantial, but how the mix of materials differs markedly from that of MaineDOT and the MTA. Shown in Figure 9 is the total material use by management type.[9] Clearly, the proportion of sand use to salt is much greater for the municipal governments than for MaineDOT and MTA. This likely reflects MaineDOT's and MTA's switch to anti-icing policies. This has a significant implication for costs.

The following comparison of material totals between these three segments of the state illustrates the overall material totals for the 2008-09 winter.

[9] Gallons of calcium and magnesium liquids are converted to tons by dividing by 250.

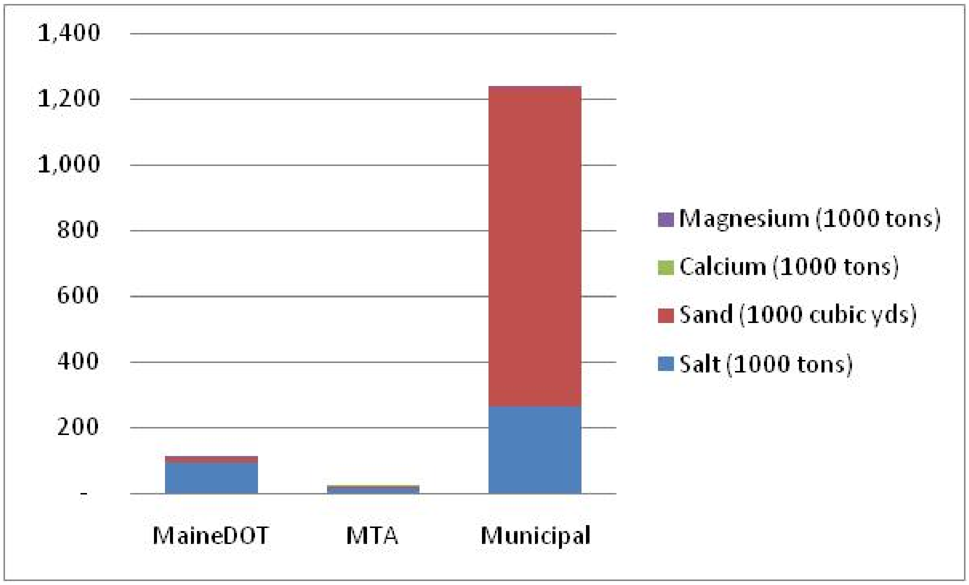

Figure 9: Material Use by Management 2008-09

Municipal Costs

At the municipal level, maintaining winter roads is often one of the largest parts of the budget. Figure 10 shows the cost per centerline mile reported by our survey respondents. They are ordered from smallest to largest cost per centerline mile for each of the municipalities completing the survey. The costs to municipal governments for winter maintenance vary from about \$2,000 to more than \$8,000 per mile. Also seen in this figure is the costs-per-centerline mile divided by the population of their respective municipality.

Notwithstanding a few outlying towns that have very low populations (< 100), there is great uniformity of costs when municipal population levels are taken into account. We suspect, but do not know (since the survey instrument did not ask), that larger municipal areas, with larger tax bases, are choosing to have higher levels of service. The larger municipalities maintain city sidewalks, schools, and city parking lots that may account for the cost differences. This suggests that different municipal governments face different challenges in providing winter maintenance services. It is also reasonable to presume that this large variation in cost-per-centerline mile reflects substantial variation in the levels of service and practices.

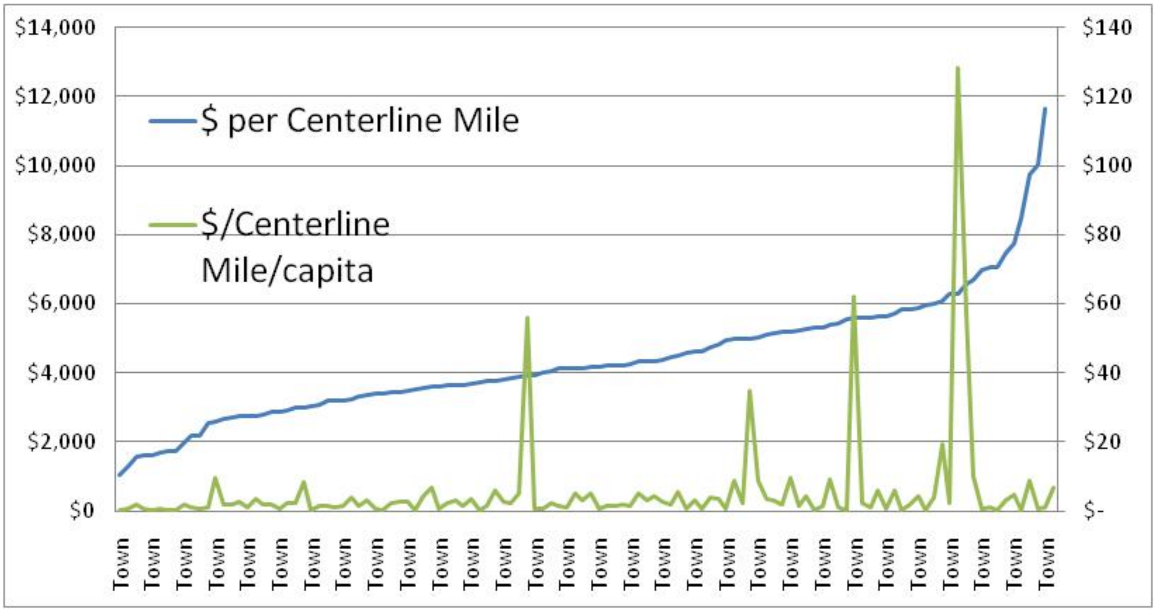

Figure 10: Municipal Costs per Centerline Mile

Material Supply and Use by State as a Whole

In order to determine the total amount of road salt used in the state, we consulted (by phone and email) the companies that supply salt to Maine, and asked them how much they had supplied to all entities in Maine for the season of 2008-09. The companies consulted were Cargill Inc., Morton Salt Co., Eastern Salt Company, Granite State Minerals, Harcros Chemicals, International Salt Co., North American Salt Co., and Mid-Atlantic Salt. Adding these totals gives an approximate amount of salt for the entire state for the 2008-09 winter. There are likely some stockpiles left from the season, so some slightly lesser number would be the amount of salt actually used during that winter. There is also some unknown amount of this total that is not used for winter roads; one company, for example, imports bulk salt to process for bait for the fishing industry, and there may be other smaller uses of bulk salt. From our estimates, the total quantity of bulk salt for 2008-09 was 494,326 tons (see Figure 11). Our understanding is that this constitutes the vast majority of salt in the state, but it does not include smaller amounts that may have been brought in pre-bagged from out-of-state suppliers. This total is a measure of public bulk use; it does not include private use. This amount represents roughly 750 pounds per person for every Maine resident, or 21 tons per road mile in the state.

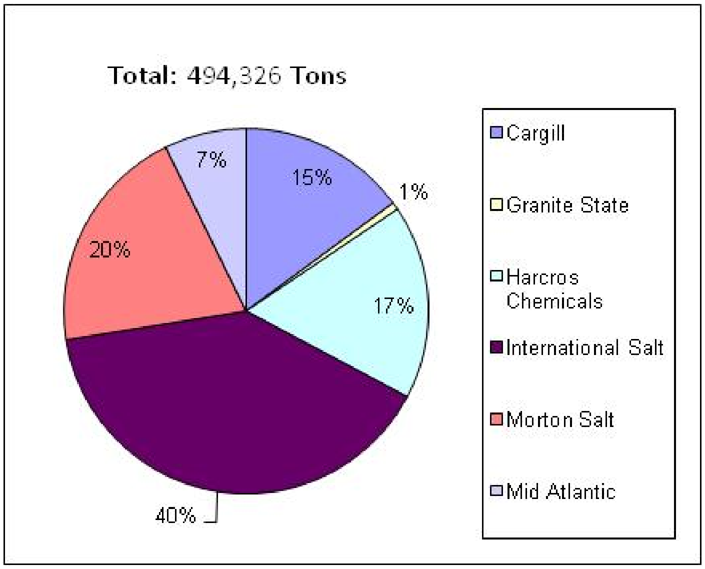

Figure 11: Total Salt Supplied to Maine 2008-09

The actual amount used in any given year is a combination of the stockpiles left from previous years and the current year's use. There may be some left over at the end of each season. Estimating, however, that what was purchased in one year was used in that year, Figure 12 shows the breakdown of salt by user group. Private use, based on a national estimate, is made up of homeowners, private roads and parking lots, airports, colleges, shopping centers and businesses.

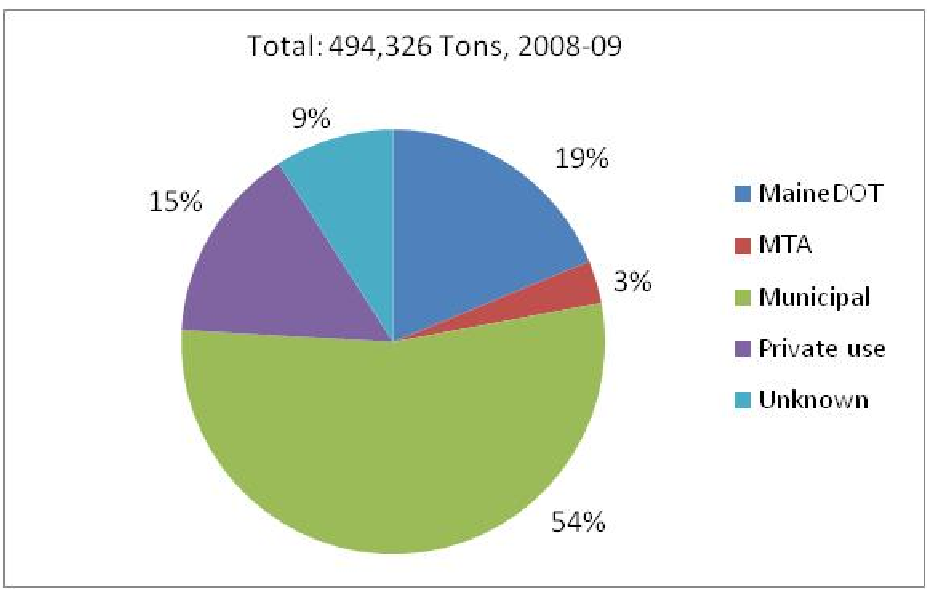

Figure 12: Statewide Salt Use by End User, 2008-09

We then attempted to estimate calcium chloride use in Maine in the same way as bulk salt. We determined, however, that while we may be able to come up with a total number, it is impossible to distinguish winter use from summer use. Calcium chloride is widely used in Maine for dust control on unpaved roads, and farmers also use it on orchard crops; some estimates suggest that up to 90% of the calcium chloride in Maine is used for dust suppression. Quantities of sand used on winter roads in Maine are substantial, but we did not attempt to estimate state-wide totals. Nor did we attempt estimates for other materials such as magnesium chloride.

Environmental Impacts from Winter Maintenance Practices

This summary provides an overview of how road salts affect the environment surrounding roads. More specifically, this section contains research findings dealing with the consequences of road salting to water, plants, and animals that occur near roads. Key questions that we attempt to answer are:

- What is the environmental concentration of salt along roadways?
- What are the sensitive receptors?
- What is the evidence of environmental degradation?
- How are water resources affected?
- Is timing of applications important?
- Are the effects reversible over a short time period (<1 year)? and
- Are there long-term consequences from extended use of road salt?

Information Sources

This summary uses a variety of information sources; unfortunately not all sources are equal in terms of content, presentation, or potential bias. There are only a few studies of road salt that have been conducted in Maine. Scientific papers published in peer-reviewed journals are usually considered to be the most impartial. Summaries and interpretations published by governmental agencies (e.g., US EPA and Environment Canada) also may have been peer-reviewed for content. Focused summaries, or research reports by interest groups typically have very restricted scopes that may deal with only some aspects of a given topic (e.g., Salt Institute and Water Environment Research Foundation). Every effort has been made to interpret these publications carefully in order to develop a balanced summary.

Salt Dispersion in the Environment

Salt applied to roads serves an important function in winter road maintenance. However, once the salt has been delivered to the road surface it starts to disperse into the environment in both solid and liquid form. Salt is extremely water soluble (hydroscopic) and will form solutions using just the moisture in the air (ambient humidity) when the temperature is above -21ºC. Salt moves into the environment through several compartments as depicted schematically in Figure 13.

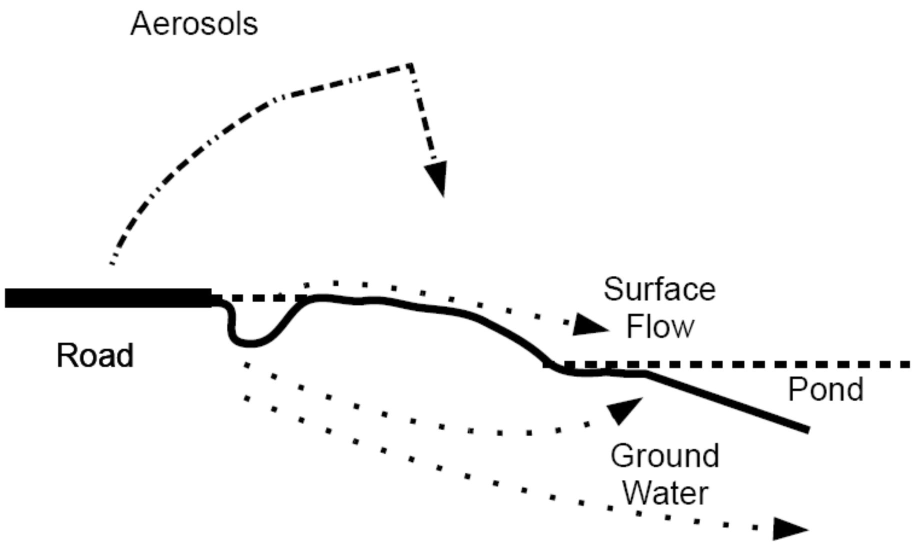

Figure 13: Salt Dispersion in the Environment

Dispersal mechanisms include three modes: solution; solid; and aerosol (solid or liquid). Salt is extremely water soluble (357 g/L, ~3 lbs/gal.) so the dominant transport mechanism is in aqueous solutions. Aqueous solutions will move readily into and along drainage-ways. These solutions will affect surface water and can percolate through the soil and reach groundwater aquifers. Up to 50% of the salt ends up in groundwater. Salty solutions can be detectable for several hundred meters away from a treated road, sometimes further.

Some salt will not be in solution and transport occurs as a solid particle that lodges on or near the roadway. These solids may subsequently dissolve and move as solutions. Solid particles of deicer usually remain on the road surface or get plowed into the adjacent snowbank. Movement laterally from a road surface is typically only a few meters.

Traffic or strong winds will launch a small fraction of salt solution or salt particles into the air as liquid or solid aerosols. These aerosols are distributed by the winds near the roadway and may land in snowbanks or on nearby vegetation. The environmental effects for salt aerosols are limited to a region close to the road, typically less than 100 meters.

The locations in which salt accumulates (sinks) are important because these control the environmental effects. Sinks for road deicers are presented schematically in Figure 14.

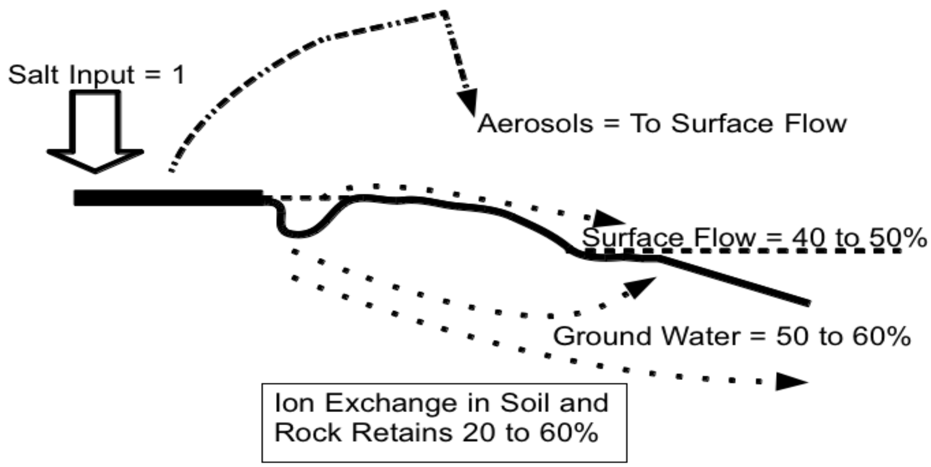

Figure 14: Salt Sinks in the Environment

Aquatic Systems

Most of the available research on deicers is for the commonly used salt (NaCl). Salt in solution breaks into its constituent elements sodium (Na+) and chloride (Cl-) as charged ions. Sodium ions have a positive charge and may become bound to soil particles and participate in ion-exchange reactions that remove sodium from solutions. Chloride has a negative charge and is less likely to become bound to particles. The chemical differences make chloride a better indicator of salt than sodium or the ratio of sodium to chloride. Also, the environmental effects of chloride require the greater scrutiny because this element is able to be transported further from roadways.

There are relevant chloride standards for ambient water quality and for drinking water. Under the Clean Water Act, the US EPA has established general chloride standards for freshwater aquatic ecosystems: criterion maximum concentration (CMC) = 860 mg/L; and criterion continuous concentration (CCC) = 230 mg/L. The CMC value is for short term exposures such as could occur during a large snowmelt event. The CCC value is for continuous exposures such as would occur in a setting with multiple years of accumulated salt dosings.

The US EPA also regulates the occurrence of harmful substances in drinking water provided by community water systems under the Safe Drinking Water Act. Chloride is listed as a secondary standard (= non-enforceable standard) with a maximum concentration of 250 mg/L. Conditions that exceed these concentrations represent degraded water quality.

There is ample evidence that the salt signal is increasing in the aquatic environment in both the short term (months) and the long term (years)[10]. This is particularly noticeable as changes in chloride concentrations over time. Winter road maintenance can be a significant fraction of the total chloride loading to fresh waters.

Analysis by Mullaney et al. (2009) examines river water chemistry data over a period of more than 25 years. They find that the loading of chloride (salt) has steadily increased in 3 rivers in New Jersey, Connecticut, and Illinois. The rate of increase has been noticeably greater since the mid-1980s. Road salt use is suspected as one reason for the increase in chloride in these rivers. In a 2005 study, Kaushal et al. document a consistent rising trend of chloride concentrations in rivers and streams in the northeast over the last 25 years. This is particularly striking for the New Hampshire example where one stream that drains a highway has much more chloride than a nearby stream on a forested hillside. The chloride time trends start to change markedly in the 1980s. Kaushal, et al. also show the concentration of chloride as it relates to development in a watershed (impervious surfaces). Chloride in streams increases in more developed watersheds and even exceeds maximum exposure limits for ecosystems in some instances. Their study indicates that the concentrations have been increasing overall at the sampled locations. The problem of chloride loading to streams and rivers is getting worse with time.

Short Term

Short term effects are directly related to the seasonality of salt use. Spring runoff has been reported to increase chloride concentrations in waters near roads by up to 350% with concentrations up to 1,200 mg/L Cl (Novotny et al., 2008; Mayer et al., 1999). The chloride concentrations remained elevated for up to five months (Mason et al, 1999; Demers and Sage, 1990). Salt can be stored in the watershed and slowly leaks out over many months, maybe years (Madden et al., 2007; Kelly et al., 2008). A secondary salt peak in water has been observed in the fall coincident with fall rains.

Long Term

Several long-term studies find evidence of an increasing chloride trend. These studies found increases of 240 to 350% over several decades (Godwin et al., 2003; Molot and Dillon, 2008). Reported rates of increase were between 1.5 and 4.7 mg/L/yr (Rosfjord et al, 2007; Kelly et al., 2008). Road salt may not be the sole source of chloride in watersheds, and sources such as septic systems and atmospheric deposition of marine salts must be considered (Mayer et al., 1999). A few studies have apportioned the chloride (salt) loadings and estimated that road salt accounted for 35 to 91% of the total quantity exported (Lischeid et al., 2008; Kelly et al., 2008). These studies indicate that although some salt accumulates in watersheds, most is exported. The trend is alarming but the increasing chloride concentrations in water may not reach unsatisfactory concentrations for many more decades; reversal will equally require decades. This means that even if salt loading were stopped today, it would take decades for the salt to be

[10] Appendix 2 contains Table 1 referencing published studies that examined either the direct effects of road salt use or the long-term changes in water chemistry in particular regions. Please refer to Appendix 2 for specific summaries and citations.

purged from watersheds. Preventative and corrective measures will be needed in the near term in order to avoid lasting and perhaps irreversible damage.

On a human scale road salt can contaminate both surface and underground drinking water supplies. Road salting restrictions exist around many surface supplies in the country to protect water quality. The Maine DOT has noted an increase in the number of salt claims for wells since 2001[11]. MaineDOT tests indicate 2-4% of wells in Maine exceeding 250mg/l chloride, a level consistent with the recent USGS study (Mullaney, 2009) finding 1.7% of domestic groundwater wells contaminated with chloride. The numbers vary from year to year but consistently indicate that drinking water wells continue to become contaminated by salt.

The toxic effects (eco-toxicology) of salt signal have been studied in field and laboratory studies[12]. The ecological effects can be grouped into two broad categories: acute and chronic.

Nearly all freshwater aquatic species have an acute toxicity threshold for chloride. Many of these have been compiled by the US EPA and the range is substantial, up to millions of ppm. Terrestrial organisms (plant or animal) have a lower toxic range of 10 to 10,000 ppm (USEPA, 2009). Toxic effects on land and water appear to be very localized. Acute problems from road deicing can be inferred to be rarely observed; stream ecological studies usually are not conducted in the winter. However, acute effects have been documented in association with snow melt runoff; studies in 2008, for example, found seven streams in metropolitan Milwaukee exceeding chloride toxicity standards for biota (Corsi, et al., 2009).

Chronic affects of road salt on ecosystems are more subtle. Runoff containing salt affects various species by making conditions that favor salt-tolerant species. The presence of phragmites is considered a good example of a tolerant invasive plant that is especially common in roadway ditches and constructed wetlands (Richburg et al., 2001). In general, salt forces a reduction in species richness (fewer taxa) and a dominance of salt-tolerant species, even after a salt pulse is gone (Miklovic and Galatowitsch, 2005; Siver et al., 1999).

Certain effects range across the road corridor. Scots pine trees are affected within 30 meters of a treated road (Viskari and Karenlampi, 2000). However, the whole ecological footprint of a four lane highway may extend out 600 meters, including salt runoff (Foreman and Deblinger, 2000). Less obvious effects may be a change in the winter hardiness of woody plants and the survivability of juvenile aquatic species (Berkheimer and Hanson, 2006; Karraker and Ruthing, 2009).

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[11] J. Katz, 2009, personal communication

[12] Table 2 in Appendix 2 contains a summary of selected published studies that examined species or ecosystems. Please refer to Appendix 2 for specific ecological summaries and citations.

Vegetation, Wildlife and Human Health Impacts

Vegetation has been shown to be affected to a distance of 100-650 feet from the roadway, yet species show a wide range of tolerance. Environment Canada (2000) concludes that sodium chloride can cause severe injury to the flowering, seeds, germination, roots, and stems of roadside plant species. Damage occurs when road salt comes into contact with the foliage and the roots of vegetation. Conifers are reportedly most sensitive to salt, with impacts including retarded growth of trees near the roadway and symptoms showing in discoloration of needles. The result is a change in species composition along roadsides with soils impacted by salt. This change can also compromise the beneficial value to groundwater sources of vegetative buffer zones.

Less research has been done on the impacts of the other chlorides on vegetation; however studies report similar impacts to those of sodium chloride. A Colorado study of roadside conifers reported higher damage from $MgCl_2$ than from NaCl, both in the laboratory and in the field (Trahan and Peterson, 2008). Acetate-based deicers, in contrast, do not seem to be harmful to vegetation at concentrations typically used on roads (Fischel, 2001).

Chlorides have relatively low toxicity to fish and invertebrates, but some species can be affected. Research by Santo and Hecnar (2006) concludes that road salts have toxic effects on larval wood frogs at environmentally realistic concentrations. Collins and Russell (2009) report the structure of amphibian communities to be sensitive to chlorides in roadside wetlands through the exclusion of salt intolerant species.

Damage to vegetation can degrade wildlife habitat and thereby impact wildlife populations. Sodium in NaCl is identified as an attractant for wildlife drawn to the roadway, resulting in increased car strikes. Several Canadian studies have noted increased moose kills in areas near roadside pools with increased salt levels, yet few studies have measured the impacts on other wildlife (Environment Canada, 2000). Magnesium and calcium chlorides have not been shown to attract wildlife (NCHRP, 2004). Acetates are also considered to have little impact in drawing wildlife to the roads.

The possibility of road salt in drinking water elicits concern due to the association of dietary sodium and hypertension. Therefore, the US EPA requires that sodium concentrations in drinking water not exceed 20 mg/l and requires public water supplies to be monitored for sodium. The secondary standard for chloride in drinking water is 250 mg/l. Before reaching this level water would have a salty taste and be unpalatable to most people.

Deicing chemicals have varying impacts to the applicator and handler. A comprehensive literature review showed $CaCl_2$ to be the only product of the common deicers that was irritating to the eyes and skin on contact and also toxic if inhaled (Shi et al., 2009). NaCl and CMA were reported to be slight eye irritants, and CMA was also a skin irritant. $MgCl_2$ was shown to be less harmful, being a slight eye irritant and non-toxic if inhaled. Potassium acetate (KA) may cause mild irritation to the respiratory tract upon inhalation.

Chlorides and Long Term Consequences

The use of road salt has long term consequences that must be considered in the development of winter road maintenance policies. The results of repeated salt applications may take years to decades to become observable, and at that point remedial actions may be expensive or impossible. Potential long term outcomes are summarized in the following bullets and can be characterized as the increased likelihood of persistent degradation of ecosystems and contaminated drinking water.

The ecological consequences include changes that will affect the resilience and robustness of ecosystems:

- changes in the structure of communities near roadways;
- cumulative effects of acute dosages of salt on stream biota;
- loss of biological diversity (species);
- survival of invasive species.

The aquatic consequences include changes that will affect the quality of rivers and streams, including:

- changes in the salinity of surface waters;
- changes in acidity;
- increased corrosivity of water;
- degradation of quality standards under the Clean Water Act and Safe Drinking Water Act.

The groundwater consequences include changes that will affect quality:

- contamination of drinking water supplies;
- discharge of salty groundwater into pristine fresh waters;
- modified flow patterns (denser water).

Salt Storage

Regardless of the application levels or methods, improper storage of salt can cause high concentrations of salinity in runoff. It has been estimated that as much as 80% of environmental problems associated with salt use have been due to improper stockpiling of salt, where rain and runoff can carry salt into soil and nearby bodies of water (Salt Institute, 2007). It is now widely understood that salt piles should be properly covered and sited to control runoff, and most states have a mitigation policy for proper storage of salt piles.

The Maine Department of Environmental Protection's Sand and Salt Pile Program has been in place since 1986. The state of Maine requires all private and public salt piles and sand/salt piles to be registered with the state and monitored, and complaints about well contamination are investigated. The program is responsible for mitigating the effects on ground and drinking water from piles of uncovered salt and mixed sand/salt. It provides assistance with the siting of new sand/salt piles and buildings. In 1999 DEP re-registered and re-prioritized them (MaineDOT, 1999). Through this process 674 public and private sand/salt storage areas were registered. One third of these (225) were in buildings, and the remaining 449 were uncovered sites (MaineDOT, 2005). Funding and technical assistance are available to towns for siting and constructing a storage facility by priority of contamination risk.

Acetates and Carbohydrate-Based Products

Acetate-based deicers have environmental effects different from those of chlorides. The primary aquatic impact of acetates is the potential to cause oxygen depletion in soil and water. In this way they can increase the biological oxygen demand in aquatic systems. In terms of being directly harmful, the direct toxicity of CMA to fish and invertebrates is low; potassium acetate (KA) has somewhat higher toxicity to aquatic organisms (Fischel, 2001). However, acetates may be harmful in high concentrations and also can feed excessive microbial growth with secondary effects (Corsi et al., 2009). Other concerns are that CMA in surface waters present the potential for phosphorous enrichment from the decomposition of CMA derived from agricultural products (Wegner and Yaggi, 2001).

Organic corrosion inhibitors (used as additives in proprietary mixes of road chemicals) also have the potential to cause oxygen depletion in streams and ponds. Little is known about the ecological effects of organic-based products because of their relative newness and limited use. The use of substances that can be quickly used by micro-organism may trigger localized blooms in surface waters. Often the content of these proprietary mixes is not fully disclosed. In addition to the active ingredient (agricultural or carbohydrate-based) they may contain small amounts of minerals that can impact the environment.

Sand

Sand, although not a deicer, is commonly used as an abrasive for traction on roads. It has a negative impact on water quality, contributing to turbidity which may cause reduced photosynthesis of aquatic plants and mortality of fish and invertebrates. Sand clogs streams and storm water drains, and can reduce the movement of oxygen within the stream bed.

Application of sand, by increasing particulates, can contribute to reduced air quality as measured in the PM-10 and PM-2.5 standards. Overall concerns about use of sand include poorer air quality, stream sedimentation, and potential to contribute heavy metals to the environment (NCHRP, 2008).

In northern Maine, part of the town of Presque Isle was labeled by the EPA as an Air Quality non-attainment area in 1994 for PM-10 standard under the Clean Air Act, caused in part by application of winter sand. Across the country, many cities and towns continue to be restricted in their use of sand, particularly in denser downtown areas, because of potential air quality impacts.

Environment Summary

Most deicers used on roads by state, municipal, and private agencies are chloride-based salts. The greatest environmental concern from snow removal practices is the effect on aquatic systems. Through applications and plowings, deicers are deposited alongside roadways. Runoff from roadways enters surface waters through roadside drainage ways.

Short term effects include increased Na and Cl in surface waters. These seasonal effects are largely reversible. Long term effects include increased Na and Cl in ground waters, increased salinity of ponds, soil chemistry change through ion exchange and acidification, and storage of chloride in soils with release over time. Elevated chloride levels can contaminate wells used for drinking water. Recent studies show trends of increasing chloride levels in surface waters and groundwater in northern states (Mullany et al., 2009). These chronic effects persist for time periods of months to decades and require years to decades to reverse.

Short term ecosystem consequences include increased attraction of salt-loving species, foliar burning, and loss of salt sensitive plant and animal species. Long term ecosystem effects include a decrease in surface water diversity, dominance by salt-tolerant invasive species, vernal pool decline, and the exceeding of toxic thresholds for sensitive species. The trends are a loss of overall diversity and increases in invasive plant species in an ecological footprint covering 600 meters width from the roadway.

Figure 15 illustrates the trend of increasing chloride in surface waters. Assuming a starting point of 0 mg/L, the trend of 1.5 mg/L/yr would reach the limits of aquatic life in 150 years. Current levels vary by location, but are already higher than zero.

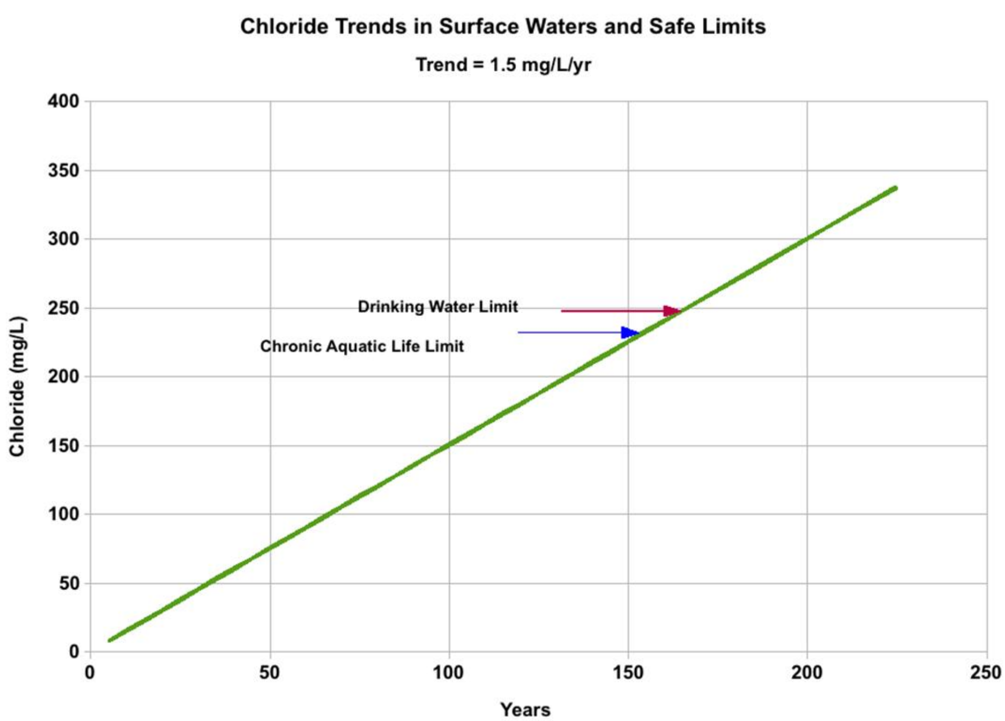

Figure 15: Chloride Trends in Surface Waters

The previous discussion has focused on observed impacts from road salts. The following chart from NCHRP summarizes the major road-clearing chemicals by potential environmental impacts of each.

Table 1: Generalized Potential Environmental Impairment from Snow & Ice Control Materials

Environmental Impact	Road Salt (NaCl)	Calcium Chloride ($CaCl_2$)	Magnesium Chloride ($MgCl_2$)	Acetates (CMA and KA)	Organic Biomass Products	Abrasives
Water Quality/ Aquatic Life (Section 3.4)	Moderate: Excessive chloride loading, metal contaminants; ferrocyanide additives.	Moderate: Excessive chloride loading; heavy metal contamination	Moderate: Excessive chloride loading; heavy metal contamination	High: Organic content leading to oxygen demand	High: Organic matter leading to oxygen demand; nutrient enrichment by phosphorus and nitrogen; heavy metals.	High: Turbidity; increased sedimentation.
Air Quality (Section 3.8)	Low: Leads to reduced abrasive use.	Low: Leads to reduced abrasive use	Low: Leads to reduced abrasive use.	Low: Leads to reduced abrasive use.	Low: Leads to reduced abrasive use.	High: Fine particulate degrades air quality.
Soils (Section 3.5)	Moderate/High: Sodium accumulation breaks down soil structure and decreases permeability and soil stability; potential for metals mobilization.	Low/Moderate: Improves soil structure; increases permeability; potential for metals mobilization.	Low/Moderate: Improves soil structure; increases permeability; potential for metals mobilization.	Low/Moderate: Improves soil structure; increases permeability; potential for metals mobilization.	Low: Probably little or no effect; limited information available.	Low: Probably little or no effect.
Vegetation (Section 3.7)	High: Spray causes foliage damage; osmotic stress harms roots; chloride toxicosis.	High: Spray causes foliage damage; osmotic stress harms roots; chloride toxicosis.	High: Spray causes foliage damage; osmotic stress harms roots; chloride toxicosis.	Low: Little or no adverse effect; osmotic stress at high levels.	Low: Probably little or no effect.	Low: Probably little or no effect.
Animals (Section 3.9)	Low: Sodium linked to salt toxicosis and vehicle kills, magnitude unclear.	Low: Probably little or no effect	Low: Probably little or no effect	Low: Probably little or no effect.	Low: Probably little or no effect; limited toxicity information available.	Low: Probably little or no effect.

Source: Levelton Consultants, 2007: NCHRP Report 577

Corrosion

The United States uses approximately 22 million tons of highway salts per year (Salt Institute, 2008b). While these salts help to keep our roads clear and safe, they also contribute to corrosion of infrastructure and vehicles. Concerns about corrosion caused by road clearing deicers encompass both cost and safety. Infrastructure impacts include the effect on concrete and the effect on the steel reinforcing within concrete. Infrastructure deterioration affects safety and signifies a cost to government. Corrosion of vehicles is largely atmospheric corrosion focusing on the electrical and brake systems. Vehicle corrosion impacts safety and results in costs to individuals, private industry, and government.

A recent NCHRP study identified corrosion to steel rebar as the primary concern with deicer use, followed by effects to vehicles, concrete, structural steel, and roadside structures (Levelton Consultants, 2007).

Infrastructure Impacts

Most concerns about infrastructure focus on concrete structures with particular emphasis on bridges. Snow and ice control chemicals can be detrimental to infrastructure in several ways. They can accelerate corrosion of the steel reinforcing within concrete. They can physically impact cement paste, the extent of deterioration being related to the quality of the concrete. Recent research suggests that magnesium chemically reacts with the cement paste in a process that reduces concrete strength (South Dakota DOT, 2008). All ice control chemicals increase the number of freeze-thaw cycles, accelerating deterioration of concrete. Atmospheric corrosion results in damage to exposed metals and to vehicles. It is this form of general corrosion to vehicles that has elicited the most concern from the public and from industry.

Reinforcing Steel

Currently there are 2,279 bridges in the state of Maine, including interstate and state bridges and city, town, and township bridges. These bridges are inspected every two years. In 2007 28% of Maine's bridges, or 649, were labeled as "structurally deficient or functionally obsolete," the standard terminology for bridges in need of repair. On a national average, about 15% fall into this classification.

It is impossible to accurately measure in the field what percentage of bridge deterioration is caused by road chemicals. Bridges age and deteriorate over time, even in areas without winter road chemicals. The impacts of deicers on bridges cannot be isolated, but rather have to be extrapolated from experimental evidence. It is well documented that when chloride enters concrete structures, it corrodes interior metal or rebar. This is the most common cause of concrete deterioration. Other chlorides, acetates and agricultural products have shorter history of use than salt, and the potential long-term adverse effects remain unclear. Effects from these other chemicals have not been as thoroughly documented as those of salt, but are being investigated in laboratory tests, sometimes with conflicting results.

A recent study ranked all chloride deicers equally high in initiating corrosion of reinforcing steel rebar (NCHRP, 2007). Another study found in laboratory tests that acetate-based deicers were non-corrosive to mild steel, while chloride based deicers were very corrosive. Acetates were, however, comparatively as corrosive to galvanized steel as the chloride-based and agriculture-based deicers (Fay et al., 2008). Calcium magnesium acetate is generally considered non-corrosive to metals (Shi et al., 2009).

A Transportation Research Board study finds that calcium magnesium acetate is significantly less corrosive to steel than chlorides, showing that steel exposed to CMA corrodes at lower rates than steel exposed to chlorides. This study rules out the replacement of salt with CMA on a wide scale, however, due to excessive cost (TRB, 1991).

Two other points stand out regarding corrosion of steel rebar. Claims of effectiveness of corrosion inhibitors are for exposed metals and are not applicable to steel embedded in concrete. The combination of impacts on steel with impacts on the structural Portland cement concrete complicates the ability of laboratory tests to predict field performance.

Deterioration of Concrete
Aside from corrosion of reinforcing steel, deicing chemicals can degrade concrete through either physical deterioration of the concrete surface or by degradation of cement paste through chemical reaction with deicers. Portland cement is the most common type of cement in general use around the world because it is a basic ingredient of concrete. Scaling of concrete occurs during freeze-thaw cycles even without deicer application. The greater the frequency of freezing and thawing, the greater is the potential for scaling. This physical deterioration is directly related to the quality of cement paste. The term "salt-scaling" is used to refer to this process that occurs in conjunction with salt.

Studies have shown little chemical impact to concrete from sodium chloride, suggesting that with use of NaCl it is the physical processes influencing concrete structures. Laboratory tests performed in Iowa on concrete samples with NaCl, $CaCl_2$, $MgCl_2$, and CMA concluded that NaCl was the least deleterious to cement paste (Lee et al., 2000). This study found that CMA caused the most degradation of concrete, and concluded that Mg in any form is damaging to concrete.

A recent study by South Dakota DOT (2008) investigated effects of $MgCl_2$, $CaCl_2$, NaCl, and CMA on Portland cement concrete. This study found "significant evidence that $MgCl_2$ and $CaCl_2$ chemically interact with hardened Portland cement paste in concrete, resulting in expansive cracking, increased permeability, and a significant loss in compressive strength." This study shows that $MgCl_2$ causes more severe deterioration of concrete than do CaCl2 or NaCl because of the reaction of magnesium with the cement paste. The study concludes, "$MgCl_2$ and $CaCl_2$ appear not to be safe for use as a deicing and anti-icing chemical with respect to possible damage to concrete structures. Therefore these chemicals should be used at lowest possible concentrations. Sodium chloride did not show the same effect on cement paste, but NaCl brines show the highest rate of ingress into hardened concrete, significant because of access to embedded steel."

Other laboratory tests found that $CaCl_2$ caused more damage to Portland cement materials than NaCl (Wang, 2006). Wang tested NaCl, $CaCl_2$ (with and without corrosion inhibitor), KA, and an agricultural product for impact on concrete at different rates of penetration, concluding that

$CaCl_2$ caused the most damage. The added corrosion inhibitor delayed damage but ultimately did not reduce it. In this test the agricultural deicing chemical (unnamed) resulted in the least damage of paste and concrete.

Although some laboratory research suggests that $CaCl_2$ causes somewhat more deterioration in concrete structures than NaCl, and less than $MgCl_2$, the most recent NCHRP study concludes that the detrimental effects of $CaCl_2$ to concrete do not appear to be more significant than NaCl (NCHRP, 2007). This research further states that diffusion of chloride in porous materials has also been linked to moisture content, meaning that when concrete remains moist, chloride ions can penetrate faster. A field study by Montana DOT supports these laboratory results, showing that higher chloride diffusion rates associated with $MgCl_2$ (Mends and Carter, 2002). Research has been limited on comparison of chloride diffusion, however, and more studies are needed before making conclusions.

Deicers and Concrete Infrastructure
Current research suggests, then, that among common deicers the chemical reaction from magnesium causes the most deterioration to cement paste. The degree of the physical impact from chlorides is dependent upon moisture content and the quality of the concrete.
All types of snow and ice control chemicals increase the number of freeze-thaw cycles, therefore contributing to the deterioration of concrete and scaling.

There have been conflicting findings regarding impact on concrete. Many researchers note that the lack of clear consistent conclusions indicates that it is problematic to extrapolate results from laboratory mixtures to proprietary chemical mixtures in the field. Difficulty also arises from the testing time frame in the research, as most concrete structures commonly have a lifespan of decades.

Impact to Vehicles and Exposed Steel Infrastructure

Deicing chemicals can impact vehicles and exposed steel through atmospheric corrosion. This may take one of many forms: uniform corrosion, crevice corrosion, poultice corrosion, pitting corrosion, galvanic corrosion, and filiform corrosion (NCHRP, 2007). Corrosion of motor vehicles can be either structural or cosmetic.

In the course of this project we have heard from the trucking industry, auto dealers, fleet transport, and public works departments regarding corrosion to vehicles and the high costs incurred. While evidence of increased corrosion abounds, there is a lack of systematic record keeping that would allow this report to document changes in levels of corrosion in the state of Maine. Therefore, this discussion of vehicle corrosion will focus on the published research.

Impact on Vehicles
Vehicle corrosion from winter road maintenance needs to be put in the context of corrosion that occurs from baseline conditions. Environmental factors that influence corrosion include temperature, humidity, oxygen level, and fluid movement. Chemical factors that influence corrosion are composition, pH, and trace impurities. Corrosion processes are complex, and most studies test for specific conditions. There are many types of metals and metal alloys used in vehicles; each is likely to perform differently in a specific environment. Different test methods are likely to give different results, and few laboratory tests correspond to field conditions.

All of the common chlorides (sodium, calcium, magnesium) show high impact through atmospheric corrosion to metal. The acetates and agricultural based products show lower impact on vehicle corrosion. The following section will summarize the research on vehicle corrosion by deicer type.

Chlorides

Chloride-based salts are all corrosive to motor vehicle components in laboratory tests. Field properties of the hygroscopic chlorides ($MgCl_2$ and $CaCl_2$) contribute to making them somewhat more corrosive than NaCl because they remain wet for longer.

Studies have attempted to rank these three chlorides for corrosion, but the complexity of the corrosion and the variation in laboratory testing versus in-field application have not produced definitive conclusions. A Washington State DOT pilot test found $MgCl_2$ 72% less corrosive than salt in laboratory tests, but only 22% less corrosive in a field test (Nixon, 2007). A Colorado study attempted to compare corrosion from NaCl and $MgCl_2$ (Xi and Xie, 2002). Laboratory tests performed yielded opposite results. They found moisture to be a key condition. Final results showed $MgCl_2$ to be more corrosive than NaCl under a humid environment, and NaCl more corrosive under immersion and in a dry environment.

In recent years, many western states have introduced spraying of liquid treatments on roads for anti-icing. Some western states rely heavily on $MgCl_2$ rather than NaCl. There is a strongly voiced opinion in the western trucking industry that the practice of spraying liquid $MgCl_2$ on roads is contributing to increased vehicle corrosion (TCA, 2009; Weber, 2004). Concerns include corrosion damage in trucking brake systems known as “rust jacking.” A research effort to achieve a more fundamental understanding of the interaction of these chemicals on vehicle materials reported a significant corrosion effect in materials exposed to both $MgCl_2$ and NaCl together, with final research results still pending. As in other studies, corrosion findings varied with type of metal alloy (Shi et al., 2009).

Despite the lack of conclusive and consistent test results, some general assessments can be made. The National Cooperative Highway Research Program findings report that, “…overall, chloride-based snow and ice control materials (NaCl, $CaCl_2$, $MgCl_2$, and blended chlorides) displayed similar corrosion rates for each metal type tested at each concentration level. Field conditions along with other snow and ice control material properties (such as moisture retention) may contribute more to the relative corrosiveness of these materials in the service environment,” (NCHRP, 2007). These findings indicate that while all chlorides cause corrosion in laboratory, the variation in field conditions (climate, temperature, road surface, speed, application rates, etc.) may contribute the factors that determine differences among the chlorides.

Acetates and Corrosion Inhibitors

Acetate-based and organic snow and ice control materials cause less corrosion to vehicles and exposed metals than chloride-based chemicals, but can still accelerate corrosion by increasing the conductivity of the moisture. In laboratory tests, acetates are less corrosive than chlorides to some metals, but more so to others.

Many commercial deicers contain corrosion inhibitors. The composition of most corrosion inhibiting additives is proprietary, although they typically consist of reduced sugar by-products or co-products from agriculture and food industries. Corrosion inhibitors tend to be metal- and environment-specific; no one inhibitor works well for all metals nor for all chemicals. Limited evidence suggests that organic matter from biomass materials used as additives may reduce corrosion rates under field conditions, but more specific testing is needed. The NCHRP concludes that inhibitors are metal-specific and salt-specific, and their effectiveness is poorly quantified (2007). There is also concern over the longevity of corrosion inhibitors and whether they will work effectively after shed storage, exposure to sunlight and dilution. Research on this topic is ongoing.

Corrosion Resistant Coatings

Auto makers typically use corrosion resistant coatings in the manufacture of vehicles. The most common and most effective anti-corrosive coating in the auto industry has been hexavalent chromium, now proven to be a carcinogen. It was banned first by the European Union with a 1993 law as part of the End-of-Life Vehicle Directive, followed by United States enforcement in 2007 (Wing, 2004). Most manufacturers phased out its use gradually prior to the enforcement date: GM between 2003 and 2006; Volkswagen by 2004; Ford, Honda, and Hyundai by 2005; Toyota by 2006; and DaimlerChrysler and Nissan by 2007 (Cookson Elec., 2005). Its use was restricted by other European manufacturers, such as Opel and Volvo, prior to this. Metal finishing in brake systems, fasteners, and electronics have historically used this material. It is now replaced in American manufacturing by a variety of alternative metal coatings such as trivalent chromium. These alternatives do not appear to be as effective in preventing corrosion. The increased corrosion reportedly seen in vehicles, especially in brake lines, in recent years is often blamed on road salts and may be influenced by this change in manufacturing.

Atmospheric corrosion occurs under wet conditions. Factors influencing corrosion are moisture, total time of wetness, and availability of oxygen. The total time of wetness is important because it influences the extent of total corrosion. With regard to inhibitors the NCHRP concludes that no corrosion inhibitors are suitable for all metals and all snow and ice control chemicals (2007). Chloride-based winter road chemicals are corrosive to metals. For a detailed discussion of the types and processes of atmospheric corrosion refer to NCHRP Report 577.

Sand

Sand used as an abrasive on roads has little or no impact on vehicle corrosion and little or no impact on deterioration of rebar or concrete in highway infrastructure. Rarely used alone for snow and ice, sand is almost always mixed with salt. Any impact from sand must also take into account the salt with which it is mixed. Use of sand on roads can also lead to exterior vehicle damage.

Other Infrastructure

There has been limited research on impacts to asphalt pavement. It is generally believed that asphalt pavement is less affected by deicers than Portland cement concrete. Impact to skid resistance appears inconclusive, but the exposure to freeze/thaw cycles and to deicers affects the strength and elasticity of asphalt, resulting in recommendations to follow best practices in mix design and paving and to use high quality materials.

Some research has focused on developing new types of porous pavement that would allow deicer runoff to drain through the pavement into collection areas (UNH Stormwater Center, 2009). This pavement would allow containment of runoff chemicals and keep them from entering the roadside environment. Porous pavement has been tested and considered for low traffic areas such as parking lots and private drives.

Table 2 below gives a summary of the corrosive impact from common winter road maintenance chemicals.

Corrosion Conclusion

Clearing roads of snow and ice is critical to public safety and economic activity in northern climates. Growing use of chemical deicers in cold climate states, exacerbated by a reduction in use of sand due to environmental impact, has prompted concern about deicer impacts on the environment, motor vehicles, and transportation infrastructure.

Damage from atmospheric corrosion incurs costs to private industry such as trucking fleets, costs to individuals in the form of auto repair, and costs to government to repair infrastructure such as steel bridges. There are also costs of corrosion prevention in manufacturing and cost of vehicle depreciation. Some researchers have attempted to quantify these costs from atmospheric corrosion, with estimates varying widely; the problem lies in isolating the amount of corrosion due to snow and ice control materials alone.

For infrastructure, chloride-based deicers can exacerbate scaling and freeze/thaw damage to concrete (Shi et al., 2009). Some deicers may also react with cement paste, reducing concrete strength and integrity. This in turn may allow moisture to enter the concrete, causing rebar corrosion. In relation to vehicles, all of the common chlorides (sodium, calcium, magnesium) show high impact through atmospheric corrosion to metal. The acetates and agricultural based products show lower impact on vehicle corrosion. Additional factors influencing corrosion are moisture, total time of wetness, and availability of oxygen, effectiveness of corrosion-resistant coatings, and effectiveness of chemical inhibitors.

In their 2009 evaluation of alternative deicing compounds for the Colorado DOT, Shi et al. conclude that, “The relative corrosivity of deicers is dependent on many details related to the metal/deicer system. Therefore, no general conclusions should be made when ranking corrosion risks of different deicer products. (...) It is also extremely difficult to relate laboratory test results of corrosion resistance to the actual field performance of metals.[13]

[13] Shi, Xianming, et al. 2009. Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers, Phase 1. Colorado Department of Transportation, February 2009, p.245.

Table 2: Generalized potential corrosion impairment related to common snow and ice control chemicals[14]

Environmental Impact	Road Salt (NaCl)	Calcium Chloride ($CaCl_2$)	Magnesium Chloride ($MgCl_2$)	Acetates (CMA and KA)	Organic Biomass Products	Abrasives
Atmospheric Corrosion to Metals (General)	High: Will initiate and accelerate corrosion.	High: Will initiate and accelerate corrosion; higher potential for corrosion related to hygroscopic properties.	High: Will initiate and accelerate corrosion; higher potential for corrosion related to hydroscopic properties.	Low/moderate: Potential to initiate and accelerate corrosion due to elevated conductivity.	Low: Potential to initiate and accelerate corrosion due to elevated conductivity claims of mitigation of corrosion require further evaluation	Low: Probably little or no effect.
Concrete Matrix (Section 4.1)	Low/Moderate: Will exacerbate scaling; low risk of paste attack.	Low/Moderate: Will exacerbate scaling; low risk of paste attack.	Moderate/High: Will exacerbate scaling; risk of paste deterioration from magnesium reactions.	Moderate/high: Will exacerbate scaling; risk of paste deterioration from magnesium reactions.	Low: Probably little or no effect.	Low: Probably little or no effect.
Concrete Reinforcing (Section 4.1)	High: Will initiate corrosion of rebar.	High: Will initiate corrosion of rebar.	High: Will initiate corrosion of rebar, evidence suggests $MgCl_2$ has highest potential for corrosion of chloride products	Low: Probably little or no effect.	Low: Probably little or no effect; claims of mitigation of corrosion require further evaluation	Low: No effect.

[14]Source: NCHRP Report 577, 2007

Winter Road Maintenance in Other States and Provinces

Maine is only one of many northern U.S. states and Canadian provinces which must address the issue of winter snow and ice control on roadways. While this report examines current practices in the state of Maine at both state and municipal levels, the researchers also looked at practices in other states and Canada. The range of practices varies widely among states, just as states vary in population, income, size, and urbanization. Some states have adopted anti-icing earlier than others; some rely more heavily on liquids and others on solid salt; some seek solutions from innovative technologies and equipment, while others are slower to do so. The following three case descriptions illustrate some of the conditions found outside of the state of Maine by others facing similar issues.

New Hampshire

The state of New Hampshire has a total of 15, 210 miles of public roadway and a population of 1.3 million people. Of these miles, 4,014 (26%) fall under state jurisdiction and the remaining 11,059 (73%) fall under local jurisdiction. There are 2,438 bridges in the state, 744 of which were reported as "structurally deficient or functionally obsolete" or 31% in 2008 (Better Roads, 2008). In 2000 the state had 929,630 licensed drivers and 11,931 million vehicle miles traveled (FHWA 2009).

New Hampshire Department of Transportation (NHDOT) is responsible for 4014 miles of roadway and is organized into 6 district offices around the state. The Well Replacement Program for the investigation and replacement of chloride contaminated private water supplies is administered by the Bureau of Highway Maintenance in NHDOT.

Roadways in the state of New Hampshire include the interstate system, the NH turnpike, high volume state highways and low volume roads. Because of the varied geography of the state wide variations in conditions exist, and no single policy can apply to an entire district. Currently NHDOT uses an anti-icing strategy as much as possible, but continues deicing also. The State highway system consists of four roadway types, defined primarily by volume, which determine priority level of service for winter operations (NHDOT, 2009):

- Type 1A – Interstate and Turnpike and highways with 15,000 vehicles or more daily.
- Type 1B – State highways with 5,000-15,000 vehicles daily.
- Type 2 – State highways with 1000-5000 vehicles daily.
- Type 3 – highways with less than 1000 vehicles daily.

NHDOT has created two additional highway types. Type 4 is a Type 2 state highway by volume for which special requests have been made to establish a low salt section. These roads will receive some salt but mostly sand. Type 5 is a Type 3 road by volume for which requests have been made to establish no salt sections. These roads will receive sand only, and signs will be posted indicating that it is a reduced maintenance highway.

After a pilot project on anti-icing in 1994, NHDOT chose to delay implementation of liquid anti-icing. In the state's approach to implementing an anti-icing strategy (without necessarily using liquids) NH rewrote the FHWA Manual for Anti-Icing, which addressed mainly high speed, high volume highways, to make it apply to low volume, low speed roads. This manual, intended for use by public works managers and crews, facilitated the implementation of anti-icing by interpreting the FHWA guidelines to apply to road conditions more prevalent in the state (UNH, 1996).

Materials currently used in NHDOT winter operations are salt, sand, and calcium chloride. Rock salt is considered the most effective material. Calcium chloride is used in flake form as an additive to sand. Liquid calcium chloride is used in pre-wetting salt. NHDOT experiments with new products as they become available. The use of liquids started in 2005 on a small section of I-93 near Manchester. Most roads are treated with solids and pre-wetted solids. In January 2009 anti-icing with salt brine began with pre-treatment on Interstate 93. The use of brine began over 18 miles of I-93 and sections of 101 in the Manchester area.

New Hampshire currently has 12 Road Weather Information Stations (RWIS) stations around the state, which record observations every 6-10 minutes. Additional sites are planned as funding allows. In its most recent 10-year plan, the state of New Hampshire has cut funding to DOT projects, making it unclear when these RWIS will be expanded.

As in Maine, municipalities in New Hampshire vary in their winter practices. The town of Dover, for example, has chosen to use salt brine (Road Business, 2007). They make their own brine and claim it is less expensive than using salt. Many other municipalities continue to use sand in winter operations.

I-93 Expansion Project

A significant development in New Hampshire for winter road treatment has been the recent plan for expansion of Interstate 93 in the southern part of the state. The expansion project for I93 (planned in 2006) passes through four watersheds in which water bodies have been tested that do not meet water quality standards for chloride concentration. As a result, NH Department of Environmental Services (NHDES) and NHDOT were required to perform a Total Maximum Daily Load study and then develop a comprehensive plan for winter salt use reduction.

A salt-reduction working group was formed to find a solution. In the Beaver Brook watershed in particular, it was determined that 96% of salt imports into the watershed was from deicing activity. The most critical finding of the study was the amount of salt from private surfaces. Approximately 49% of the salt came from private roads or parking lots, another 37% from municipal roads, and 10% from state roads (Taylor and Associates, 2008).

Not only will the expansion of I-93 increase population in southern New Hampshire but, consequently, road salt usage. A steering committee was formed to guide the Salt Reduction Project. A Salt Reduction Workgroup was created and in 2008 their report made recommendations for reducing road salt (Taylor and Associates, 2008). Concluding that there will be no single solution, the workgroup noted possible solutions which cover a range of approaches. These include training of personnel for better treatment practices; equipment and infrastructure upgrades; public behavior change programs (social marketing); lower speed limits during storm events; and mandatory snow tires for the driving public. One of the plans for behavior change involves developing an accounting system to track road salt use in each community. One of the regulatory changes includes creation of specific “no salt” areas.

The increasing levels of chlorides in freshwater is a growing concern in northern states. The NH Department of Environmental Services publishes a monthly newsletter on environmental issues. A recent issue focused on the need to reduce road salt use as the only option for restoring water quality in New Hampshire freshwater and groundwater (NHDES, 2009). Although the state of Maine currently does not have the population and traffic density of southern New Hampshire, the results of the Salt Reduction Working Group and Salt Reduction Plan may hold useful lessons for Maine and other states in addressing the rising levels of salt in freshwater and groundwater.

Research
There has been research at the University of New Hampshire Stormwater Research Center on permeable pavements for control of saltwater runoff. These pavements are designed to allow water to infiltrate into an underlying storage reservoir. They are best suited to residential and low traffic surfaces and parking lots (Ballestero and Briggs, 2009). The Center for the Environment at Plymouth State University has also done research in determining barriers and incentives to reducing salt use in New Hampshire.

Minnesota

Minnesota is a state of 79,610 square miles and a population of 5.2 million people, 3.5 million of whom are concentrated in the Twin Cities area. (US Census Bureau, 2007) There are 141,000 miles (289,500 lane miles) of streets and highways in the state of Minnesota, including 12,000 miles of state highways (MnDOT, 2008a).

The Minnesota Department of Transportation (MnDOT) is responsible for 30,227 lane miles of roadway, 16 percent of which is in the Twin Cities area (MNDOT, 2008b). MnDOT is divided into eight districts. The State has 767 trucks for snow removal and 150 truck stations statewide. It has approximately 1500 snowplow drivers and 224 backup drivers. MnDOT maintains approximately 4700 of the state’s 13,721 bridges. Of this total, 13 percent, or 1760, are classified as structurally deficient or functionally obsolete. The vehicle miles traveled in the state in 2007 was 58 billion miles.

Winter conditions can vary widely in the state due to its size. In 2007-08 the Twin Cities area received 46.8 inches of snow in 34 snowfalls. The northeastern section of the state received 73 inches the same year.

Road salt use by MnDOT statewide is about two-thirds of the overall state total (Stefan, 2008). In the winter of 2006-2007, for example, MnDOT used 182,386 tons of salt, 51,716 tons of sand and 2.5 million gallons of brine statewide. MnDOT also used 2.3 million gallons of salt brine and 191,789 gallons of magnesium chloride (Nixon, 2009). No calcium chloride was used by state agencies. Potassium acetate and liquid corn salt are also used in smaller amounts.

Salt use in recent winters averages 225,000 tons for state highways and 245,000 tons for counties and cities. The State recently joined with counties and cities into a cooperative purchasing agreement to receive better pricing.

Twin Cities Metro Area
The Minneapolis-St. Paul area contains more than half the state's population. The Twin Cities average 54 inches of snow annually in approximately 20 snow events. The MnDOT district encompassing the Twin Cities is the Metro District. Metro District DOT plows 5232 route miles, using 250 trucks. The Metro District used 50,774 tons of salt and 442 tons of sand during the winter of 2006-2007. Considering all entities responsible for road maintenance in the region, however, the material numbers are much larger. In total an average of 349,000 tons of road salt are applied in the Twin Cities Metro Area each year: 76% used by cities, counties, and the state, and 24% by private and commercial users.

An extensive study by the University of Minnesota set out to measure impacts in Twin City area lakes. Increasing chloride concentrations were observed in all 38 lakes analyzed, with lake chloride concentrations increasing on average by 1.4 mg/L/year. Studies indicate that 70% of road salt applied in Twin Cities area is not carried away by the Mississippi River but retained in the watershed. Chloride levels in shallow groundwater wells have also increased. There is a rising trend in urban lake water salinity, and shallow groundwater shows increasing chloride concentrations (Stefan et al., 2008).

Statewide
An area representative of the state outside the Twin Cities is MnDOT District One in the northeastern section of the state. This region has a population of 350,000 and one fifth of the state land area. In this district MnDOT maintains 1600 miles of state highways and 600 state bridges. In an average year they use 34,500 tons of salt, 280,000 gallons of salt brine, 16,000 tons of sand, and 87,000 gallons of $MgCl_2$ in anti-icing. The average cost of state winter maintenance for this region is $7 million, a per capita cost of $20 per year.

MnDOT uses a liquid anti-icing program. In rare instances solids may be used for anti-icing. The anti-icing program is enabled by Road Weather Information Systems (RWIS). There are 93 RWIS sites across the state. These stations include fixed weather sensors and sensors embedded in the roadway. These sensors gather data and feed it to a central computer data base. MnDOT trucks also use pavement temperature sensors to get location-specific measurements.

A statewide committee was formed to introduce liquid anti-icing with magnesium chloride and calcium chloride more broadly to the public in 2001. Anti-icing was begun in the northwest part of the state in 2003, using Geomelt and magnesium chloride. The liquids currently used in pre-treating are magnesium chloride and salt brine.

MDSS-AVL
MnDOT is involved with FHWA research on development of an in-vehicle maintenance decision support system. The Automatic Vehicle Location Maintenance Decision Support System (AVL/MDSS) was first tested in Iowa in 2003. The program was then expanded to a Pooled Fund Study of 10 states, including Minnesota and New Hampshire. MDSS is a technology already in use in some states (Colorado for example) which combines weather and road condition monitoring and input from crews on anti-icing practices and materials to general treatment recommendations for specific routes. It can be used to report pavement conditions, to

deliver information directly to trucks, to provide more efficient dispatch, and to improve consistency of service. This system captures data on each storm which can be used to improve subsequent practices. The project in Minnesota is currently developing a deployment plan for 2010. MnDOT plans to equip 100 plow tricks with the AVL and sensing equipment so that operations can be reported back into the MDSS system. This system has shown that it can reduce fuel use, reduce unnecessary travel, and use the minimum of chemicals to meet level of service.

Specialized Bridge Systems

Automatic anti-icing systems are installed on two Mississippi River bridges in the Twin Cities Area. A bridge spanning the Mississippi River on I-35 near downtown Minneapolis has a computerized system to spray potassium acetate on the bridge deck when RWIS and sensors indicate conditions may become hazardous. The bridge is 1950 ft. long and eight lanes wide, and was the first of its kind in the US to be equipped with an anti-icing system. It was completed in 1999. The bridge had been susceptible to black ice, had a high incidence of traffic accidents in winter, and had high traffic volume. The system's computer checks environmental sensors to determine conditions, activates flashing beacons and begins one of 13 different spray programs, depending on conditions. The chemical used is liquid potassium acetate sprayed through nozzles embedded in the bridge deck. An average spray cycle dispenses 12 gallons per lane mile over ten minutes (MnDOT, 2001). Conventional snow removal strategies are used when slush or snow accumulates. The first year of this system showed a 68-percent decline in winter crashes (MnDOT, 2002).

The I-35E Lexington Bridge over the Mississippi River in St. Paul also uses an automatic anti-icing system which was installed in 2005. Weather stations mounted on the bridge, along with sensors and thermometers in the bridge deck, monitor weather conditions such as dew point, wind speed, air and ground temperatures, wind direction, dampness and freeze point to determine the appropriate pavement treatment. Potassium acetate is sprayed from nozzles in the bridge deck. Bridges in other districts around the state which have high incidence of accidents are also having fixed anti-icing systems installed, such as the I94 bridge over the Red River.

Other Special Programs

Minnesota has numerous innovative programs in winter road maintenance; several others deserve mentioning here. When setting levels of service, MnDOT uses market research to determine how quickly the public expects roads to be cleared. They have also used market research for defining performance measures. An effort in 2007 changed the definition of "bare pavement" from "fully bare" to "bare between the wheel paths". MnDOT has surveyed the public to determine if "bare between the wheel paths" is acceptable. It appears to be acceptable if it is achieved within 3 hours of snowfall.

Private contractors are a segment of the winter maintenance personnel often not reached by state and municipal training programs. Smaller towns may contract their snow clearing to a private contractor, and businesses and suburban parking lots may use private contractors to clear surfaces after a storm. In an example of a suburban watershed with chloride impairment, the Shingle Creek Watershed is estimated to have 7.5% of the salt load coming from private applicators. Recognizing the role of private contractors in winter maintenance, the Minnesota Pollution Control Agency offers a training program for private applicators (those who clear parking lots, walkways, and access roadways) (MPCA, 2008). This program trains contractors and local community staff in the use of Best Management Practices and also has published a maintenance manual for winter parking lots and sidewalks (MPCA, 2006) MnDOT also offers Snowplow Operator Training in best practices, and Snow and Ice Material Application Workshops for MnDOT and local agencies (MNDOT, 2005).

MnDOT, partnering with other Midwestern states, has been involved in research projects to develop a new highway maintenance concept vehicle, integrating GPS, friction readings, surface freeze point information and road surface weather conditions with a chemical application system. Minnesota benefits from the research at the Center for Transportation Studies at the University of Minnesota, including development of pavement materials, new maintenance vehicle design and Road Weather Information Systems.

Other States

Although winter road maintenance practices vary across northern U.S. states, there is a trend toward anti-icing at the state level and a trend toward more liquid use. Some Midwestern (Iowa) and Western (Colorado, Montana) states have moved heavily toward use of liquids. There is no consistent choice of liquid, however. Minnesota and Utah, for example, use brine and some magnesium chloride but no calcium chloride, while Iowa and Missouri use mostly brine, some calcium chloride but no magnesium chloride. Wisconsin and New York use salt, brine, calcium and magnesium chlorides.

Washington State stopped using salt in the late 1980s, based on corrosiveness; now they are doing a pilot project to test brine and salt to determine if other chemicals justify the extra expense given that they all seem to be corrosive. Washington DOT now makes its own anti-icing liquid from brine and de-sugared molasses. They also have invested heavily in weather reporting technology, with more than 400 Road Weather Information Stations (RWIS). Other northern states have been slower to install and use RWIS technology.

States and municipalities also vary in their methods of communicating winter road issues to their citizens. Some have websites which explain in detail their winter maintenance practices, materials, and levels of services; others are much more limited. While some states promote wide scale use of the 511 system for road information, in others it is almost unknown.

Canada

Canada has used road salts (mostly sodium chloride) for ice-melting since the 1940s. Environment Canada estimates that on average five million metric tons are used annually in Canada. With a population of close to 33 million, this translates nationally to 330 pounds per person per year. Measurements of chloride concentrations in groundwater and surface water, especially in areas of heavy use of road salts in southern Ontario, Quebec, and the Maritimes, have been found to be frequently at levels likely to affect biota. These levels have been demonstrated by both field and laboratory studies (CEPA, 1999). Industry estimates show that Ontario and Quebec use the most chlorides, but Nova Scotia has the highest loading per unit area of land. The lowest uses of road salts are in the western provinces (Morin and Perchanok, 2000).

Responding to concerns about impacts on the environment, Canada initiated a five-year scientific assessment of road salts in 1995. The assessment included sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and potassium chloride (KCl), as well as ferrocyanide additives used for anti-caking. In December of 2001 Canada's Environmental Protection Act (CEPA) Priority Substance List Assessment Report was released, concluding that road salts were affecting freshwater ecosystems, soils, vegetation and wildlife (Environment Canada, 2001). The report recommends that road salts -- containing inorganic chloride salts, with or without ferrocyanide salts -- be considered toxic "because of tangible threats of serious or irreversible environmental damage" and be added to list of toxic substances in Schedule 1 under CEPA.

After the report's release, a multi-stakeholder working group led by Environment Canada developed a Code of Practice for the Environmental Management of Road Salts. This Code of Practice, adopted in 2004, is a *voluntary* salt management program for road authorities either using more than 500 metric tons of salts per year, or near vulnerable ecosystems. As a means of risk management it recommended the implementation of salt management plans and the use of best management practices in application, storage and disposal of road salts (Canada Gazette, 2004).

The development of the road salts Code of Practice brought new attention to salt management across Canada and prompted the implementation of better salt management practices in many cases. In spite of the initial recommendation, road salts have yet to be officially added to the Schedule 1 List, making the implementation of salt management plans voluntary. In practice, Salt Management Plans are neither reviewed nor approved by Environment Canada.

All chloride road salts were listed in the assessment because all inorganic chloride salts have broadly similar behavior in the environment. Effects related to the toxicity of chloride depend on the cumulative input of all chloride salts (Health Canada, 2007).

In 2008 Environment Canada did a national evaluation of snow management to determine to what degree best management practices were being followed by the provinces and municipalities. It determined that 90% of salt is adequately stored, 80% of spreaders have electronic controllers, 45% of the fleet is equipped for pre-wetting, and 30% of road authorities have the capacity for anti-icing (Environment Canada, 2008).

Ontario

Ontario is a province of 412,000 square miles with 13 million people and a road network of 45,000 miles. Out of this total mileage, 10,250 miles are maintained by the province's Ministry of Transportation (MTO), and 34,750 miles are maintained by municipalities. The Ministry of Transportation also manages 2,800 bridges and structures, 29 remote airports and eight ferry services.

MTO and municipalities together estimated their road salts use at 2 million metric tons[15] per year for the province of Ontario (Environmental Commissioner of Ontario, 2007). The two biggest

[15] 100 metric tonnes = 110.23 tons

users in Ontario are the MTO and the City of Toronto. The MTO average salt use is 617,000 metric tons annually. In 2004-05 the MTO introduced liquid application, using 31.9 million litres (8.43 million gallons) of brine. The City of Toronto salt use is 135,000 metric tons annually, with 2.2 million litres (580,000 gallons) of brine on 3300 mi. of roads and 4400 mi. of sidewalks.

In Ontario, 83% of the total road length is municipal and 70% of the road salt tonnage is municipal. Similarly, 17% of the total road length is provincial, while 30% of the road salt tonnage is provincial (Environment Canada, 2008).

Current Practice
Ontario implemented its first Fixed Automated Spray Technology (FAST) system in 2000. This was a Road Weather Information System (RWIS) station with pavement sensors and liquid distribution of potassium acetate from nozzles on the road surface. Currently Ontario is operating nine FAST installations on bridges, ramps, and tunnels. These systems are in addition to normal snow removal. The average cost is $2000 (CAN) per meter for a 2 lane structure. A 250 meter structure would be $600,000 (CAN). They have found a reduction in accidents in these locations, but since all of these sites had had numerous weather-related accidents it is possible that some or all of the safety effect was due to normal statistical variation (Daily Commercial News, 2009).

There are 113 Road Weather Information Station (RWIS) sites in southern Ontario with more being installed. This is more than any other province. All Ministry of Transportation salt spreading trucks have electronic spreader controls to control location and amount more efficiently. They are expanding use of pre-wetted salt. Pre-wet equipment has been installed on 140 spreaders. Infrared thermometers on over 200 winter maintenance vehicles assist in planning. Embedded thermometers in the road are read by trucks and data entered into a computerized mapping system Trucks are using high speed spreaders to reduce scatter, bounce and waste. MTO is conducting trials on using rubber snow plow blades which clean the surface better. They are also expanding the use of snow hedge innovations to prevent drifting. Advanced vehicle locator (AVL) systems are present on 240 vehicles, allowing monitoring of salt usage and application rates. There are two automatic bridge deicing systems and three more under construction. Ministry use of salt varies from 500,000 to 600,000 metric tons salt annually.

The City of Toronto has been proactive in its approach to salt management. Some of the highlights of the City of Toronto's Salt Management Plan 2001were their use of electronic spreader controls to prevent excess salting, storage of salts inside buildings to prevent leakage, tarping all delivery trucks; and pre-wetting standard road salt (this uses 10-20% less salt). The city also provided staff training for best management practices. Road Weather Information Systems (RWIS) were installed throughout the city. As a result, the City of Toronto reported $1million in savings in 2001.

Ministry of Transportation Research
The MTO first introduced liquids in 2000. Contractors were concerned it would increase corrosion, so MTO required that liquids be 70% less corrosive than salt, by adding corrosion inhibitors that had been laboratory tested. When direct liquid application (DLA) was implemented in 2001, the level of service increased 50% (measured by hours to bare pavement). There have been clear level-of-service gains from the change to using liquids, but not so clear

salt reduction gains. Since 2005 MTO has used 99% pre-wetting in its vehicle fleet. Pre-wetting has resulted in a salt reduction of 8-30% and a level of service improvement.

The MTO did field studies in 2006 to verify the cost effectiveness of corrosion inhibitors. The results were inconclusive – in some cases corrosion was reduced, in other cases it was increased (Road Talk, 2009a). They continue to perform research to find the best product for winter roads. In the winter of 2009 MTO was testing a new product called Thawrox, which is mix of salt, magnesium chloride, and a viscosity modifier that adheres it to the road. They have also run their first trial of pervious pavement on a parking lot (Road Talk, 2009b).

Environment
Long term monitoring by the Ontario Provincial Water Quality Monitoring Network has shown an increase in chloride concentrations of surface waters since the 1970s, noting highest concentrations in winter and in dense urban settings (Riversides Stewardship Alliance, 2006). The Ministry of Environment's water quality monitoring reveals an upward trend of road salts concentration in Ontario water resources, particularly the Lake Ontario tributary streams in the Greater Toronto area. According to a report by the environmental commissioner of Ontario, approximately 30-45% of all chlorides present in the Great Lakes are a result of winter salt applications (Environmental Commissioner of Ontario, 2007).

Regulatory Issues
Road salts have been addressed at both the federal and provincial level, yet their regulation remains on a voluntary basis. Though recommended for designation as toxic substances under the *Canadian Environmental Protection Act*, there are no regulations which govern roads salts use (CEPA, 1999).

Ontario's Regulation 339 specifically exempts any substance used by a road authority for highway safety in conditions of snow and ice from Ontario's *Environmental Protection Act*. There have been repeated attempts to repeal Regulation 339. Repeal would make management plans mandatory, and bring road salts under the permitting authority of the *Environmental Protection Act*, but it has been turned down each time. They have been recommended for categorizing as toxic substances, but do not have to be restricted or tracked in their handling -- an issue which also has liability implications. More recently there has been pressure from environmental groups to make winter tires mandatory and reduce winter road speeds (Riversides, 2006). The Province of Ontario currently recommends winter tires, but they are not required.

Quebec

The Province of Quebec's has a population of 7.5 million people. Its total road network is 135,000 km (83,885 miles); of these, 28,940 km (20%) are maintained by government and 106,060 km (80%) by municipalities. The Ministère des Transports du Québec (MTQ) manages 31,000 kilometers (19,263 mi.). The MTQ spent $170 million ($155 million USD) on winter maintenance in 2005. Average snowfall is 3.5 meters in Quebec City and 6 meters in the mountains (LeClerc, 2005).

1.43 million tons of road salts are spread on Québec roads every winter, including 771,000 tons on roads managed by the MTQ.

For the Autoroutes and highways in southern Quebec, road conditions are posted on a website 511 system which is continually updating. The road network is divided into 326 segments, each of which is monitored at least twice daily in person and conditions posted (TAC, 2003).

Quebec became the first province to make winter tires mandatory in 2008. From November 15 to April 15, drivers of all passenger vehicles and taxis registered in Quebec must have snow tires. It was estimated that 90% of drivers already have snow tires, but that the 10% who don't are involved in 38% of winter accidents (CBC, 2007). This statement might be interpreted as showing a much higher risk of driving with regular tires; however, it is more likely a reflection of the population who chooses not to buy snow tires.

Safety, Mobility & Costs

If everyone stayed home when roads were snowy or icy, we would know that we have the safest possible roads in winter conditions. Short of this, we have to determine a reasonable balance between mobility and safety. The reasons for clearing roads of snow and ice are to increase mobility, facilitating commerce and industry, and to maintain or improve safety. We measure mobility by vehicle miles driven and vehicle speed. In this analysis we define safety by looking at the total numbers of crashes.

With this in mind, we examine trends over approximately the past 20 years on Maine roads including costs, both in terms of expenditures on winter maintenance and in terms of the cost incurred from crashes. We then conduct a more detailed analysis of crash data looking at the total number of crashes during winter conditions (snow, slush, ice) compared to all conditions. We also consider differential impacts on different age groups. We present age-group results in deviations from the expected crash numbers and examine them by road type.

Output performance measures for safety include the number and rate of highway-related fatalities and injuries (number of crashes per 100 million vehicle miles traveled). Common performance measures for mobility are travel speed, delay, and the quantity of travel (vehicle miles traveled (VMT), and Average Annual Daily Traffic (AADT), together with both variability and reliability indexes (NCHRP, 2003). By focusing personnel and material resources on these output measures, state and municipal agencies can reduce winter season crashes and minimize delays and changes in travel times compared to non-winter conditions. Input performance measures include the amount and cost of resource used (such as types and quantity of material, frequency and types of mechanical removal, labor, equipment)

Generally, the number of crashes during a certain time unit is related to many factors, such as driver behavior, geometric characteristics, e.g., grade and curve radius, weather related variables, interactions between geometrics and weather, etc. (Shankar V., 1995). Other important interactions have been identified in the literature including interactions between weather and traffic volume, holidays and weekly patterning of social activities e.g., weekday travel patterns (Levine et al., 1995).

The Handbook of Road Safety Measures summarizes a large number of studies, many from Europe, on the effects of winter maintenance measure on mobility and safety (HRSM, 2004). Table 3 reproduces a summary table (Table 2.6.2) from the Handbook. This shows how changes in winter maintenance can affect the number and severity of crashes on average over a large number of different geographic areas and time periods. We see that increasing the standard of maintenance by one class level reduces injury and property crashes by 12% and 30%; salting, more rapid deployment of personnel and equipment and sanding also reduce injuries and property crashes.

Table 3: Effects on Accidents of Winter Maintenance Measures[16]

Accident Severity	Best Estimate	Range High	Range Low
Increasing the standard of maintenance by one class throughout the whole winter season			
Injury	-12%	-14%	-10%
Property damage only	-30%	-32%	-29%
Introduction of Salting throughout the winter season			
Injury	-15%	-22%	-7%
Property damage only	-19%	-39%	6%
Cessation of salting throughout the winter season			
Injury	12%	-4%	30%
Property damage only	1%	-15%	21%
Increased preparedness (more rapid deployment)			
unspecified	-8%	-14%	-1%
Salting - effect first 24 hours after measure			
Injury	-24%	-42%	0%
Property damage only	-35%	-59%	3%
Sanding - effect first 24 hours after measure			
unspecified	-62%	-85%	-5%

What this table and the statistical analysis cannot show is how drivers will react to better or worse driving conditions because of winter road maintenance. That is, this information summarizes observed relationships between maintenance measures and crashes, but it would be incorrect to conclude that drivers would not change their behavior (i.e., increase speed or decrease breaking distance) if a particular stretch of road received superior maintenance.

Data

Police Reports

With the assistance from MaineDOT we were given a database of police reports for all automobile crashes in Maine from 1989 to 2008. The data was managed so each row contained a unique report and the columns represented all of the variable fields in the report (e.g., vehicle type, road surface condition).

[16] Source: HRSM, Table 2.6.2

Weather Data
We used daily National Weather Service data to generate daily state averages for temperature, precipitation and snowfall. We collected data from weather stations in Caribou, Farmington, Bangor, Portland and Augusta from 1989 to 2007.

Traffic Volume
We account for monthly and annual traffic volume fluctuations by using estimates of vehicle miles travelled (VMT). Annual estimates help show yearly fluctuations in traffic volume, but monthly VMT data are also needed to correct for monthly variation. To address this need, we estimate monthly VMT by using monthly Average Annual Daily Traffic (AADT) counts reported from traffic counting devices across the state and dividing by the maximum traffic volume per traffic counting site from 2003 to 2009. We then averaged these proportions per month and multiply by an annual VMT to find the average monthly VMT for a given year. Knowing how volumes fluctuate by month is especially important for Maine so that we can control for the rise in VMT during high tourist months.

Except for the most recent year or two, the total number of vehicle miles traveled (VMT) in Maine has been increasing steadily (see Figure 16). In 2008, there were 14.5 billion miles of driving on Maine's roads statewide.

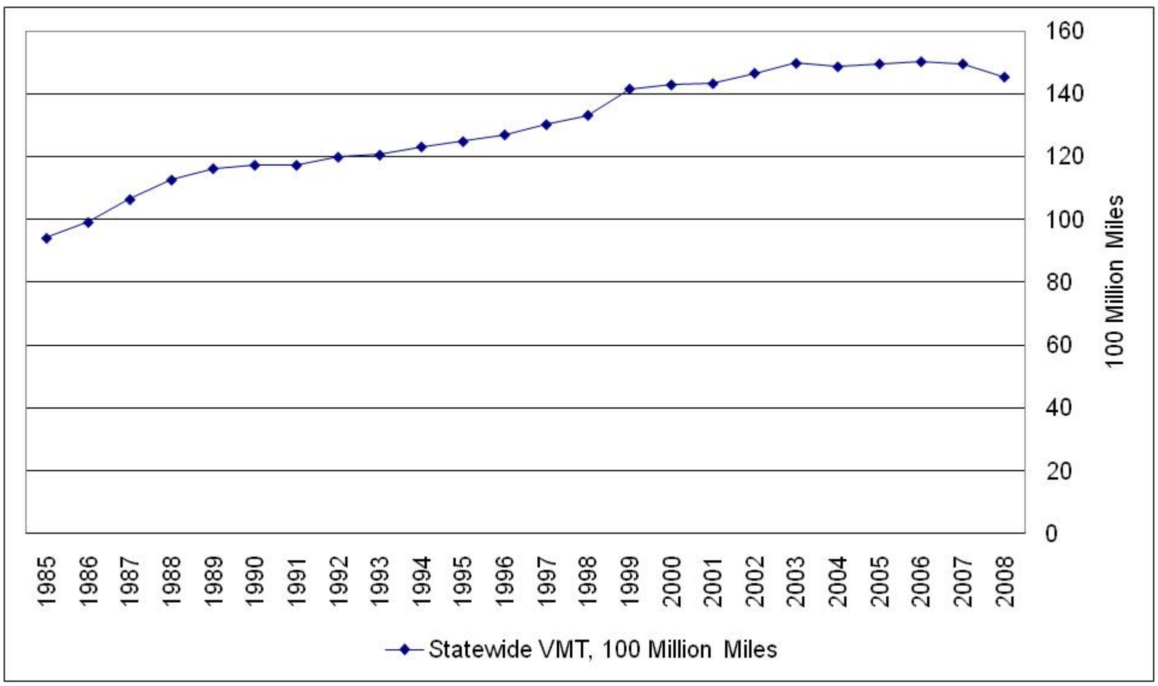

Figure 16: Statewide Vehicle Miles Travelled, 1985 to 2008

Road Safety Trends
To better understand the data, we conducted a trend analysis plotting the distribution of crashes across time, crash severity and road surface condition. Crashes and fatality rates were used whenever possible to control for traffic volume. Overall, crashes occur more often in the colder months but are more severe in the warmer months.

Figure 17 shows the monthly state crash totals from 2000 to 2008. This graph is helpful because it shows how crashes are dispersed throughout each month, as well as how each month varies through time. One thing to notice is the slight bell in the middle of the graph that shows the increase in crashes during the tourist season of April through October.

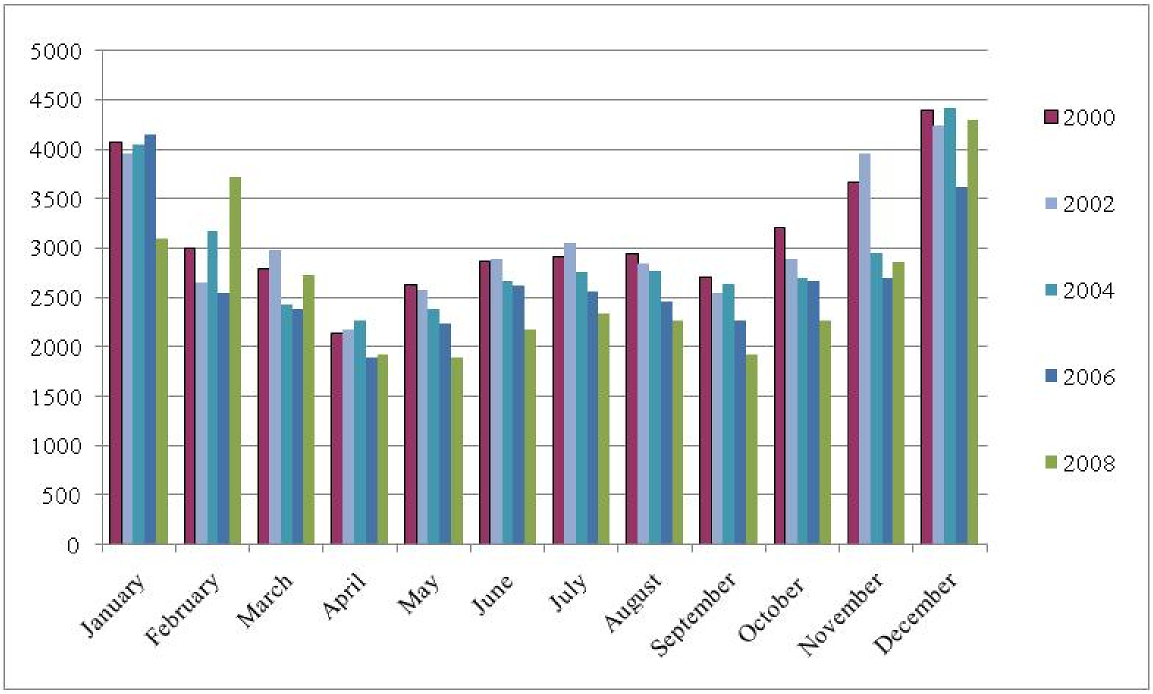

Figure 17: Maine Crash Counts by Year and Month

We can also see that there is a downward trend from year to year for each of these warmer months. When looking at the winter months, a definite trend is not evident and is quite erratic. This volatility could be explained by the difference in severity for each winter and hence the difference in the number of accidents.

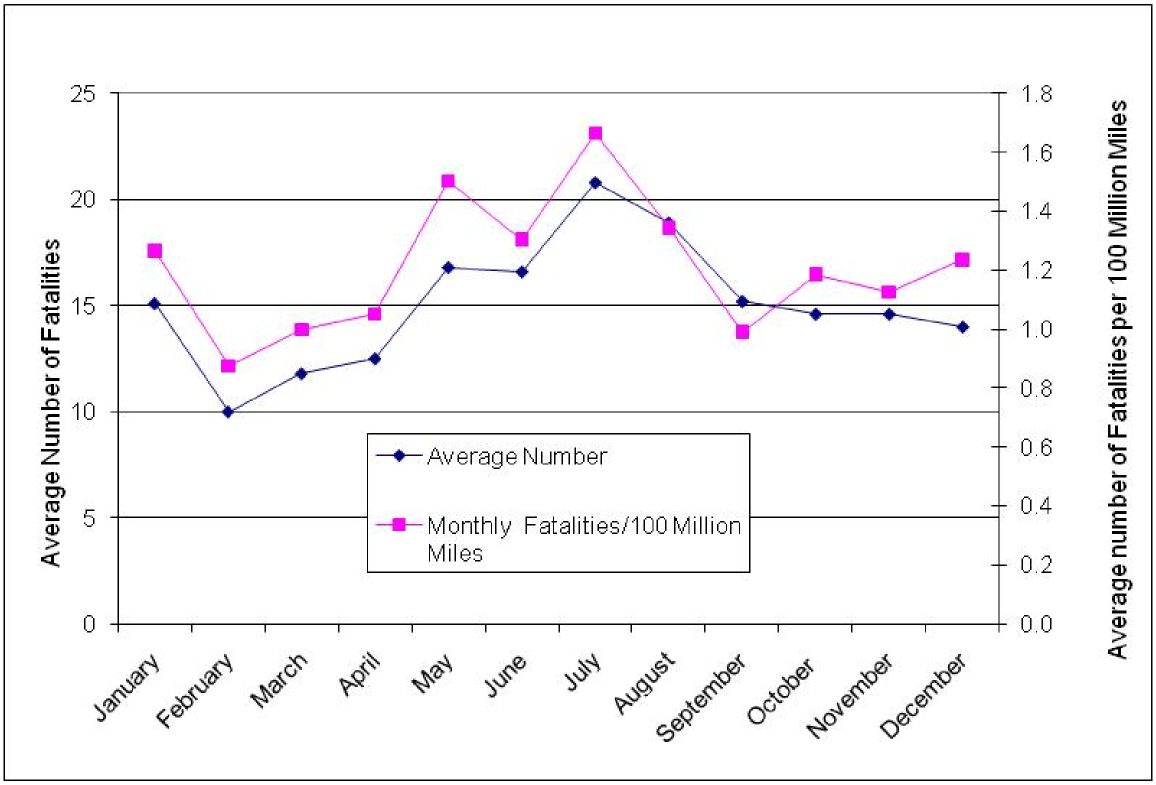

Figure 18: Average Fatalities by Month (1999-2008)

Shown in Figure 18 is the 10-year average (1999-2008) number and rate (fatalities per hundred million vehicle miles) of fatalities in Maine. The monthly average and rate are 15 and 1.2. This figure shows a fair amount of month-to-month variability with the peak occurring in July and the trough in February. This differs substantially from the monthly pattern of crashes which reaches the peak in January and other winter months (Figure 19).

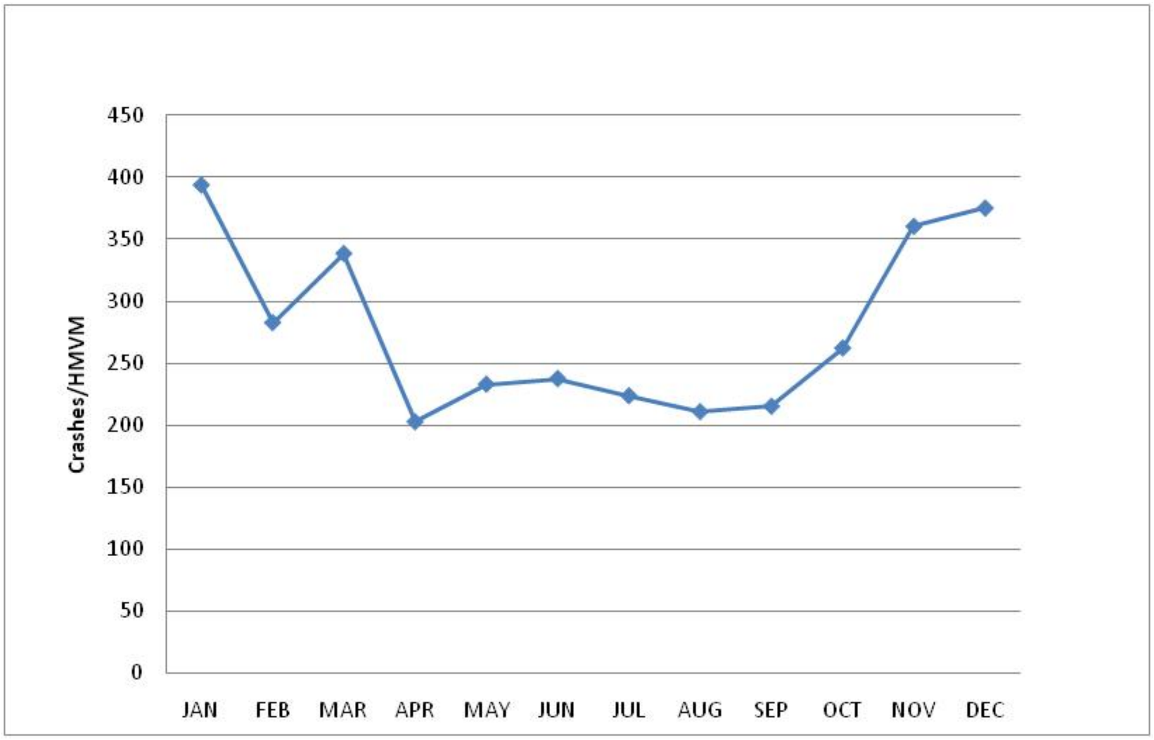

Figure 19: Maine Motor Vehicle Crash Rate by Month, Average 1989-2008

Also interesting is that the crash rate differs substantially by county. Figure 20 shows the crash totals for each county for winter months (October through March) and summer months (April through September) for 1989-2008.

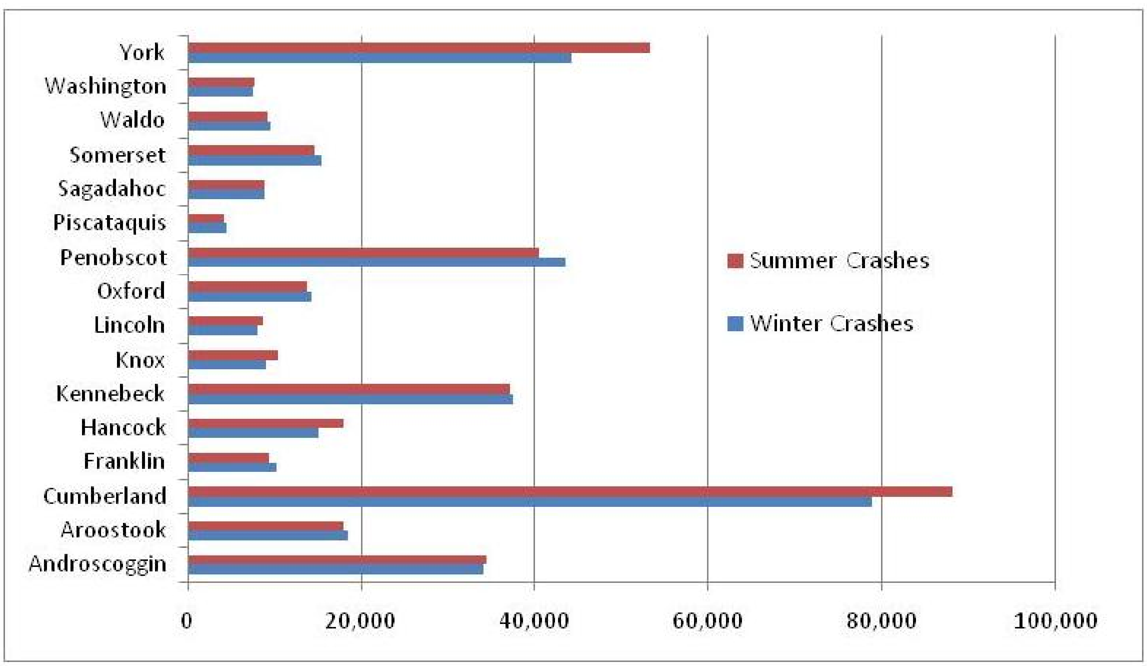

Figure 20: Crashes by County 1989-2008

The end of each bar represents the total crash rate and the two colors show the proportion of crashes for winter and summer months. The two rates were created by splitting up crashes for the two seasons, taking the total number of crashes for each county from the years 1989 to 2008 and then dividing by the hundred million vehicle miles travelled (HMVM) for each county. This shows that for many counties, the crash rates do not vary greatly from summer to winter. For some counties (York, Cumberland, Knox, Hancock), the crash rate (crashes per HMVM) is significantly greater in summer than winter.

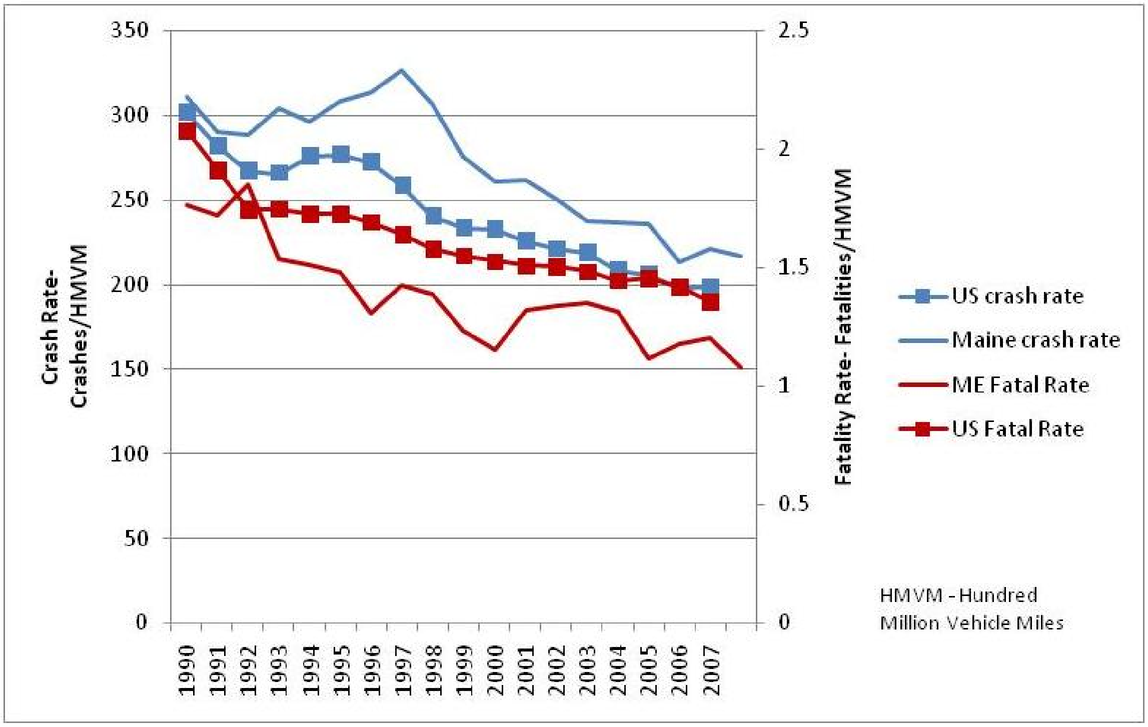

Figure 21: Maine and National Crash Rates 1990 to 2008

Compared to national numbers, Maine has maintained a higher crash rate but a lower fatality rate for the last 19 years (see Figure 21). Although the two rates differ, both the state and the national numbers show a downward trend. This trend can be attributed to many factors, including -- but not limited to -- driver behavior, vehicle technology, roadway improvements and winter road maintenance.

Road Surface Condition

Figure 22 below shows the distribution of crashes across a particular road surface condition. While dry and wet are the two largest categories, it is important to note that those conditions may have resulted from winter road maintenance efforts. That said, in this analysis the phrase "winter conditions" will be referring to the four conditions below with ice, snow or slush (sanded or not). Not evident on this chart is whether road salt and/or any other ice and snow control chemicals were applied before the crash. We don't see these values because the road would hopefully fall into the dry or wet category after the ice or packed snow was melted. This makes the wet category misleading and therefore it is not included in the winter condition analysis.

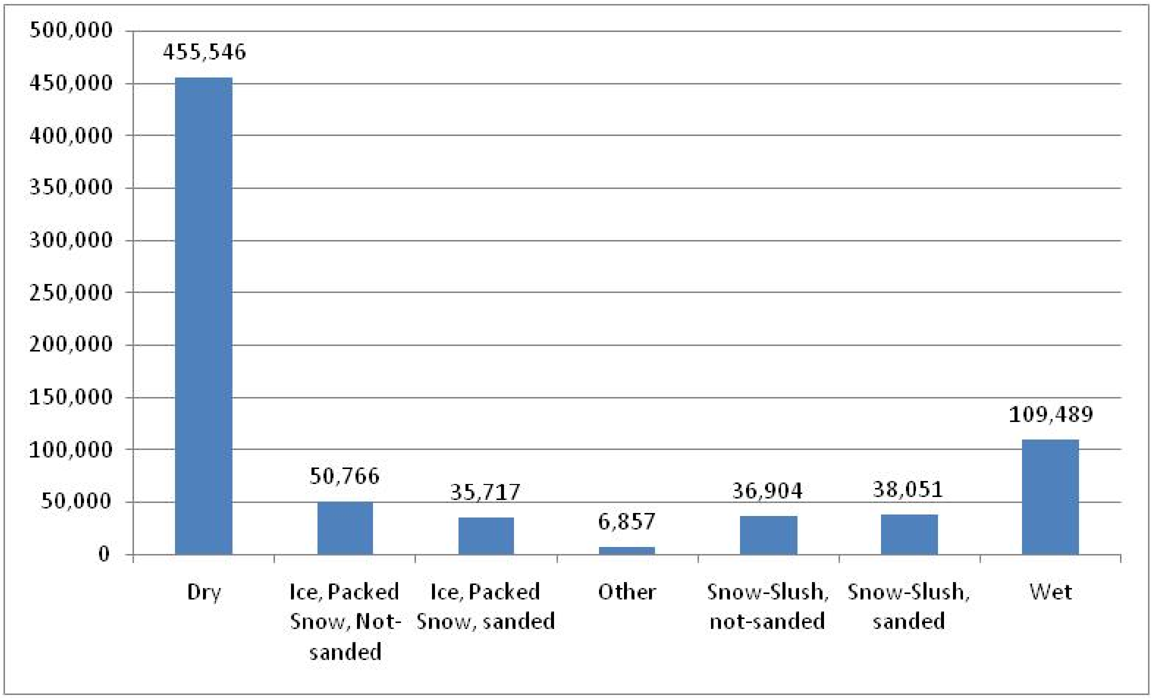

Figure 22: Total Crashes by Road Surface Condition, 1989 to 2008

Winter versus Dry Conditions

As opposed to dividing crashes into winter and summer months, crashes that occurred under winter conditions are compared to those in dry conditions. There are many reasons for doing this, one being that there are many days where roads are completely dry and safe in the winter months, as well as outlier winter storms that may happen in a fringe warm month. Looking at accidents that solely occurred in winter conditions or dry conditions doesn't rely on time of year and therefore doesn't have the same problem.

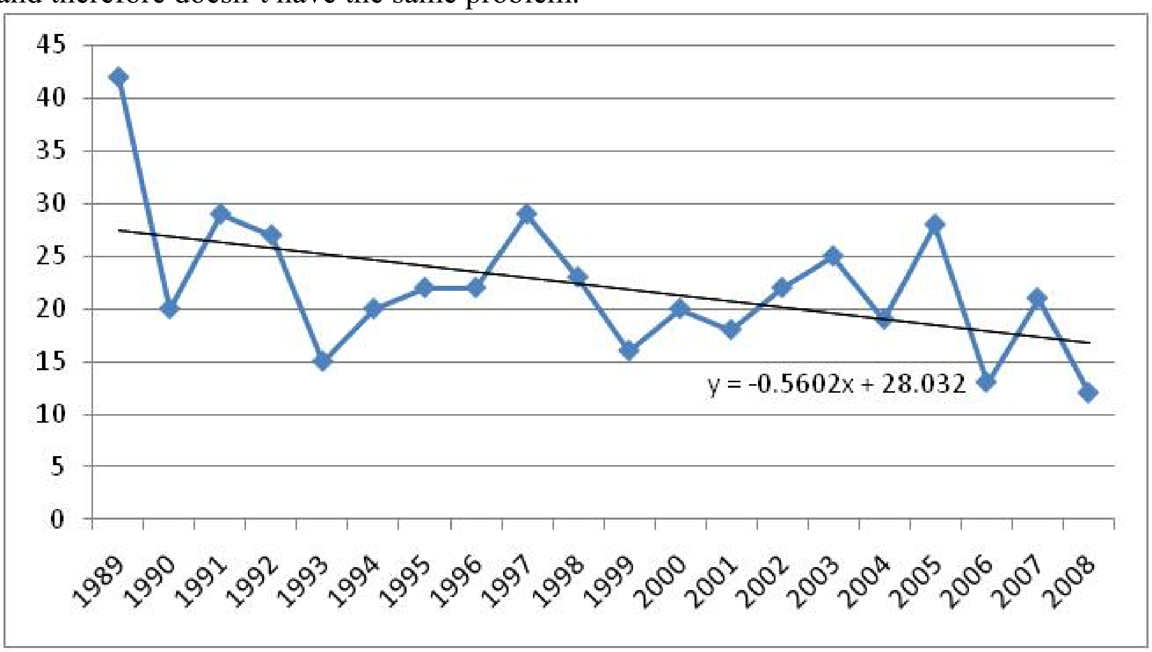

Figure 23: Winter Condition Fatalities

Figure 23 and Figure 24 show fatalities for both dry and winter conditions. We group crashes from all conditions with ice, sand or snow into a "winter" condition category and then filter out all of the crashes that occurred on dry pavement. Annual VMT estimates are then used to correct for traffic volume trends by converting crashes into a rate of fatalities per one-hundred million vehicle miles (HMVM) travelled. The results show that both "dry" and "winter" conditions show an overall downward trend with winter having a slightly steeper trend line (note that the vertical axes have different scales).

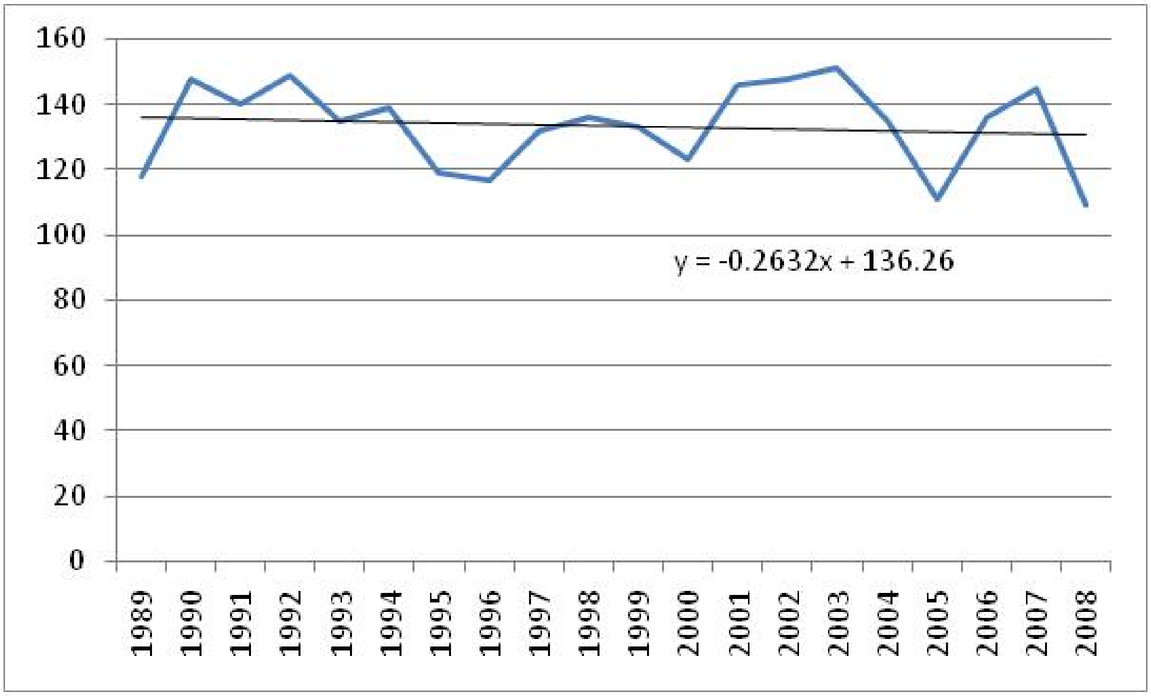

Figure 24: Dry Pavement Fatalities

Winter Maintenance Costs

MaineDOT Expenditures

The MaineDOT has spent an average of $19.3 million dollars over the 2002 – 2008 fiscal years for snow and ice control. These expenditures are for personnel (35%), equipment (37%) and materials (26%). As seen in Figure 5 (p.13). there is a strong relationship between year-to-year material expenditures and the number and severity of winter storms. Personnel and equipment expenditures also rise and fall with the number of storms. Also seen in Figure 5 is that material costs fell sharply in 2000 following MaineDOT's switch to an anti-icing policy that uses much less sand.

Maine Turnpike Authority Winter Maintenance Expenditures

In the 2008-09 winter season, the Maine Turnpike Authority spent a total of $2.9 million on winter maintenance. These expenditures are comprised of $1.2 million for labor (41%), $1.2 million for winter maintenance materials (42%, salt, sand and calcium chloride) and $465 thousand (16%) for equipment.

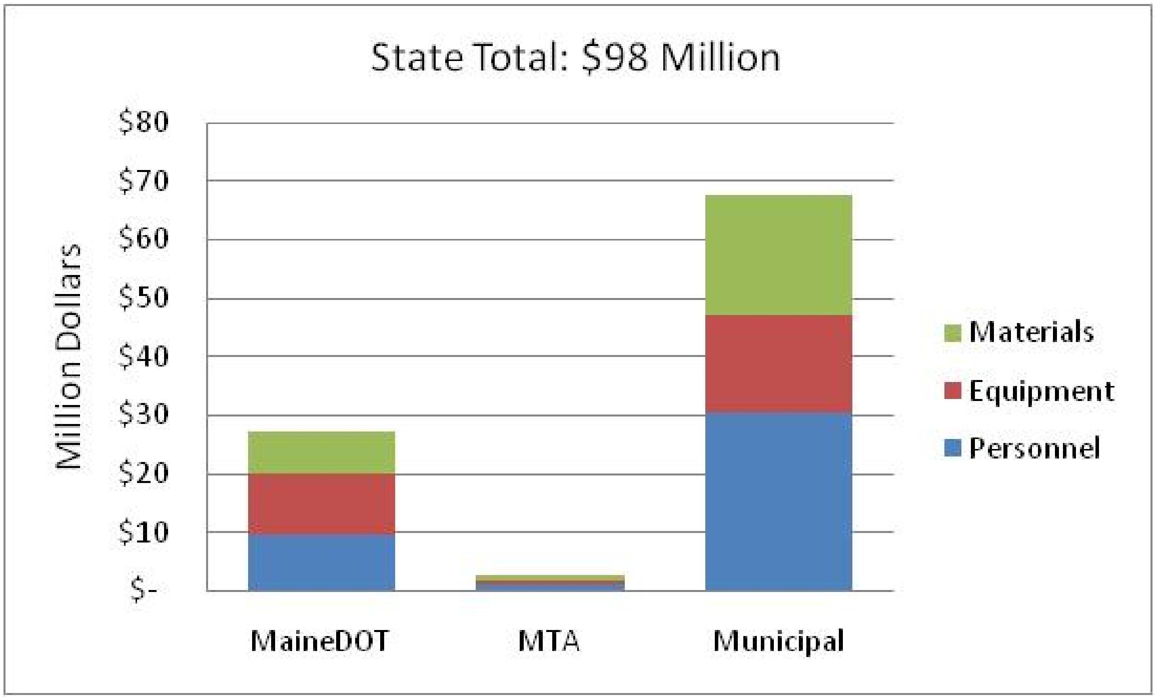

Figure 25: State Total Expenditures on Winter Maintenance 2008-09

Municipal Governments Winter Maintenance Expenditures

From the survey results, the average cost per person for municipal government for winter maintenance expenditures was $51. *If these responding governments are representative of the all municipal governments*, this means that municipal governments spent $68 million on winter road maintenance in the 2008-09 winter season. This average is based on the sum of the population in the municipalities reporting budgets. If, instead, the average is based on the cost per centerline mile in reporting towns, then the cost for municipal governments for the state as a whole is $73 million. These expenditures are composed of personnel, equipment and materials costs representing 45%, 24% and 30%, respectively. A previous survey by the Maine Municipal Association estimates that winter road expenditures comprise 29% of total road expenditures statewide and reported $69.1 million as the total municipal winter expenditures in 2007 (MMA, 2008).

State of Maine Winter Maintenance Expenditures

We estimate that state and local governments together spend $98 million annually on winter road maintenance expenditures. These expenditures are for MaineDOT, MTA and municipal governments, for materials, personnel and equipments. These do not include expenditures by businesses and private residences or the cost of remediating corrosion.

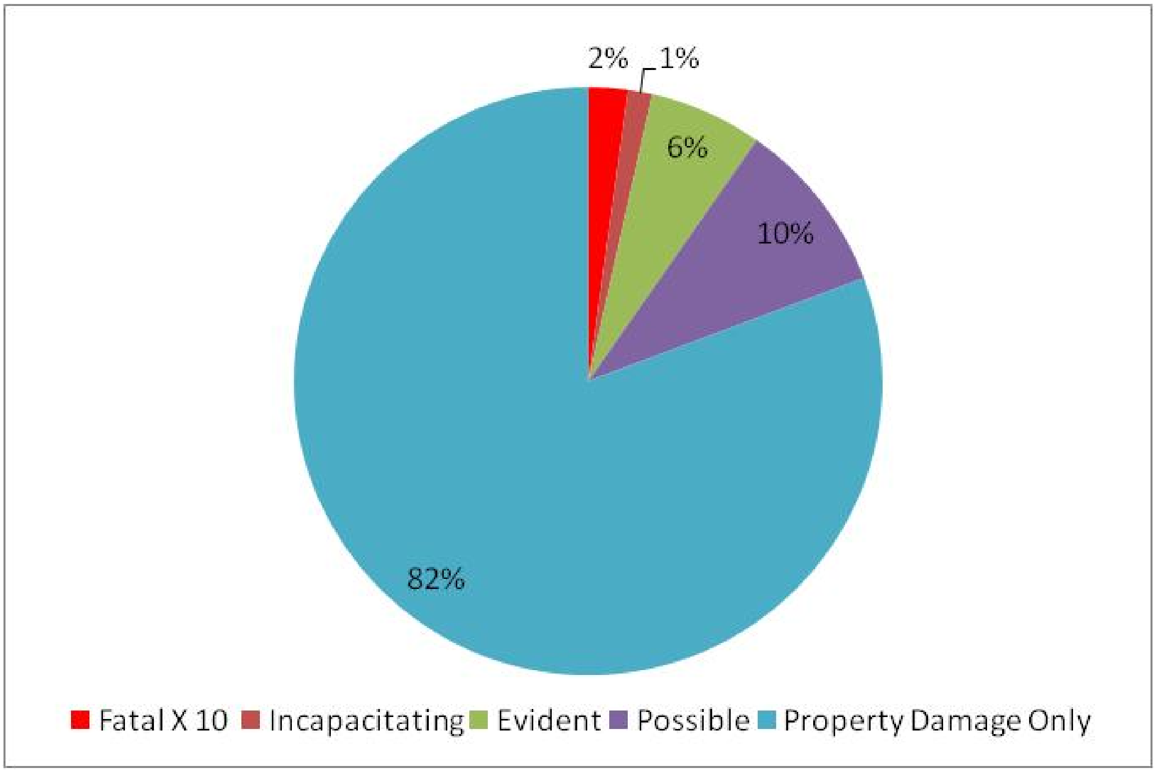

Figure 26: Annual Accidents by Type, Average 1999-2008

Cost of Crashes

The US Department of Transportation provides guidelines on the costs of each type of accident on the KABC scale; these costs are shown below in Table 4 (USDOT, 1994). There is room for disagreement on the appropriateness and accuracy of these costs for any given accident. Their use does provide a basis of comparison over time and across different jurisdictions. They also allow for an economic assessment of the benefits of changing road maintenance and other accident prevention measures.

Table 4: Comprehensive Costs in Police-Reported Crashes K-A-B-C Scale Severity[17]

Severity	Descriptor	Cost Per Injury ($1994)	Cost Per Injury ($2008)[18]
K	Fatal	$2,600,000	$3,509,482
A	Incapacitating	$180,000	$242,964
B	Evident	$36,000	$48,593
C	Possible	$19,000	$25,646
PDO	Property Damage Only	$2,000	$2,700

Using these costs with Maine accident data shows a 10 year average cost of $1.5 billion dollars annually, see Figure 27. Since the cost per accident (by type) is held constant, this reflects a

[17] Source, USDOT, 1994.
[18] Converted to 2008 dollars based on GDP deflator, 2000 base year (GPO, 2008).

decrease in the number of accidents and injuries. The total number of accidents has fallen 26% over the decade or at a simple annual decline of 2.6%. The falling costs reflect average annual decreases of 1.0%, 3.4%, 4.0%, 2.4% and 2.6% for fatal, incapacitating, evident, possible and propery damage only accidents, respectively. The causes of this decrease in accidents is manifold: from better vehicle design, demographic changes, fewer impaired drivers, improved roads, and better winter road maintenance practices.

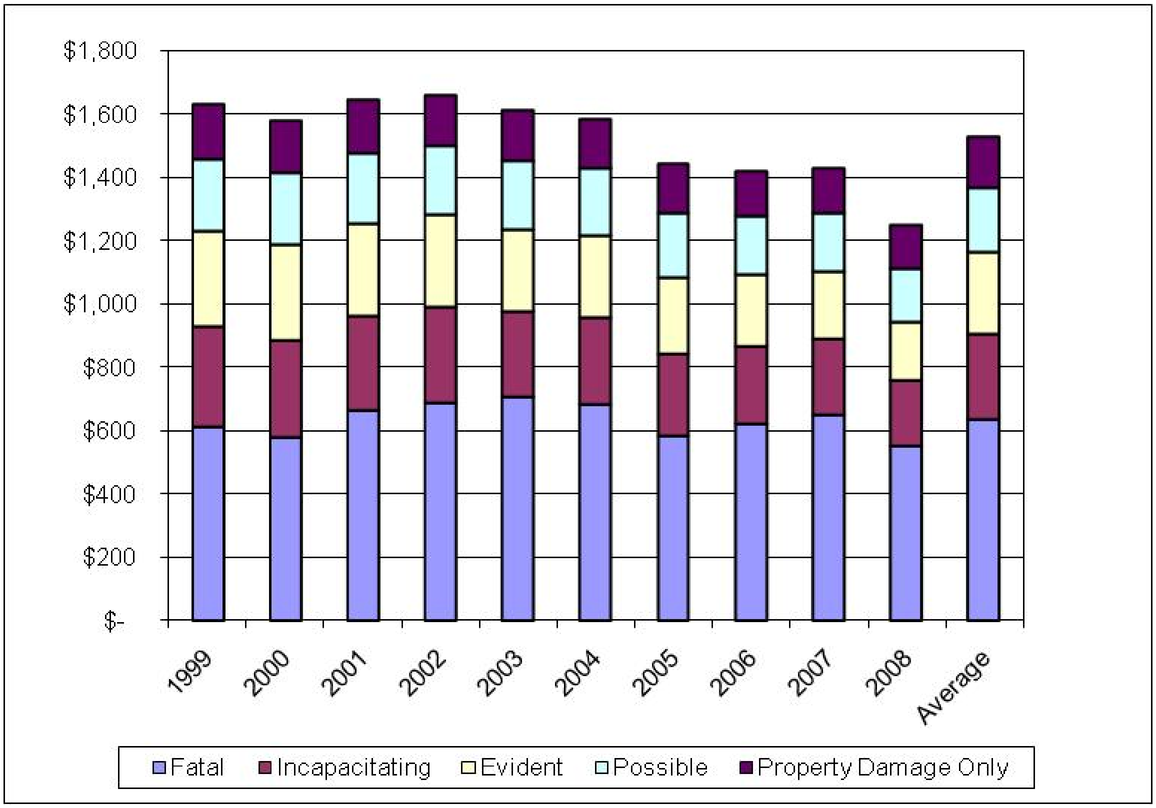

Figure 27: Total Costs of Crashes, $2008 (Millions)

Regression Analysis

We use multiple regression analysis to determine the individual impact of independent factors on crashes.

Statistical Analysis and Limitations

To further investigate winter road safety in Maine we use statistical models to analyze the relationship between winter vehicular crashes and various weather, material and policy variables. We use several linear regression models to analyze crash frequency. The models differ by accident severity, crash aggregation (e.g., monthly, daily) and age group categorization.

One of the limitations to this analysis is that we do not know the actual level of salt and sand on a particular section of roadway during a storm event.[19] We also do not have any information on

[19] In other on-going work we will be looking at data on crashes for the Bangor region where we do have actual levels of salt used during particular storm event for MaineDOT roads.

how many miles are driven by different age groups during storm events. Also, the monthly and daily aggregation levels used do not capture the time of day of a storm event and a crash occurring.

The dependent variables we used in the monthly analysis, "Winter Fatality Rate" (WFR) and "Winter Crash Rate" (WCR) are the monthly total crashes and fatalities for the state of Maine divided by the *estimated* monthly VMT to create a rate or crashes or fatality per one hundred million vehicle miles (HMVM). In this analysis we use rates over number of accidents to control for monthly traffic volume fluctuation, which is especially pertinent in Maine due to seasonality from weather and tourism.

We created weather explanatory variables from daily observations from weather stations in Bangor, Caribou, Farmington, Portland and Augusta. We used observations from all five regions to find daily State averages for minimum temperature, maximum temperature, mean temperature, precipitation (in.) and snowfall (in.). We then used the daily averages to create the monthly variables: days in a month where the minimum temperature was below freezing (TMIN), days in a month where the maximum temperature was below freezing (TMAX), days in a month where the maximum temperature was below freezing and precipitation was noted (PTMX), and total snowfall (SNW).

To analyze the effect on monthly crashes of the anti-icing policy we use an indicator variable that equaled 1 after 1999, the year the policy was first implemented. We also used the annual salt and sand amounts used by MaineDOT and divided them up by the winter months to use as a proxy for state-wide material usage.

Ordinary least squares (OLS) regression was used to estimate the marginal effects of the explanatory variables on monthly fatality and crash rates. The functional forms of the two models are as follows:

$$WFRate = \beta_0 + \beta_1 TMAX + \beta_2 TMIN + \beta_3 SNW + \beta_4 PTMX + \beta_5 PTMN + \beta_6 POLICY + \beta_7 SALT + \beta_8 SAND$$
$$WCRate = \beta_0 + \beta_1 TMAX + \beta_2 TMIN + \beta_3 SNW + \beta_4 PTMX + \beta_5 PTMN + \beta_6 POLICY + \beta_7 SALT + \beta_8 SAND$$

Results
The results of the monthly analysis for both models are inconclusive. We think this lack of results for monthly data is due to our constructed VMT variable. We constructed monthly VMT using monthly sales taxes on motor fuels and annual VMT rates. Unfortunately, monthly tax receipts may be reported 6 weeks after a month. Thus, taxes for March may be reported in April or May.[20]

Daily Data All Maine Roads

To take into account weather events and avoid the need to depend on rates, we constructed a statistical model that tests the relationship between weather, time and other explanatory variables on Maine daily crash totals. We use statewide daily crash totals from January 1, 1989 to May 31,

[20] We are looking at an alternative way to estimate monthly VMT based on a limited number of permanent traffic counters.

2008; in all we have 7,091 observations. Using daily data allows a greater connection between weather and crashes.

After reviewing literature, we determined that temperature and snowfall do not have a linear relationship with crashes. The graphs below show how crashes are distributed for daily average temperatures and snowfall in Maine. We can see that the highest daily crashes are occurring at temperatures below but near 32 degrees. When temperatures fluctuate above and below freezing there is a greater occurrence of ice and slippery road conditions that result in more crashes.

When looking at the average daily snowfall, we can see that the highest incidence of accidents occur at snow depths greater than 1 inch but less than 4. The reduction in crashes after 4 inches is most likely due to a reduction in traffic volume due to the high levels of snow. A snow depth of 1 to 4 inches may still appear safe which would result in more drivers on the road and more crashes in that range.

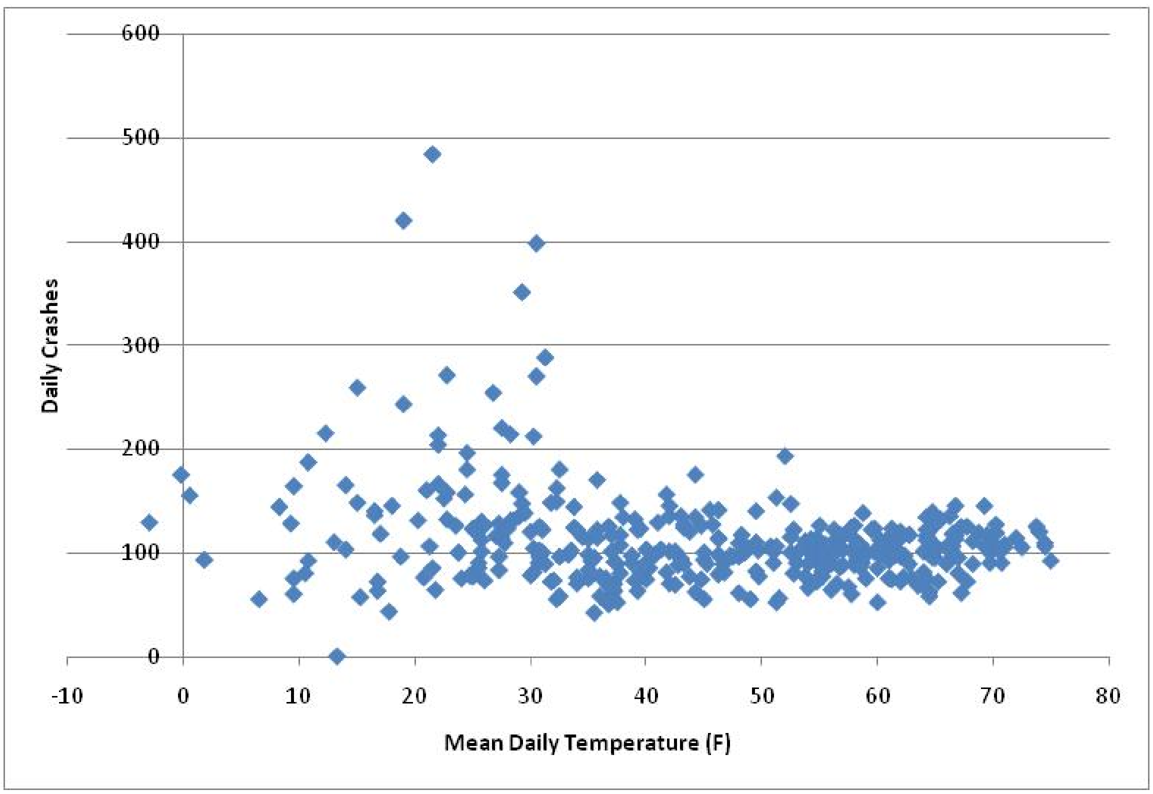

Figure 28: Count of Crashes by Temperature

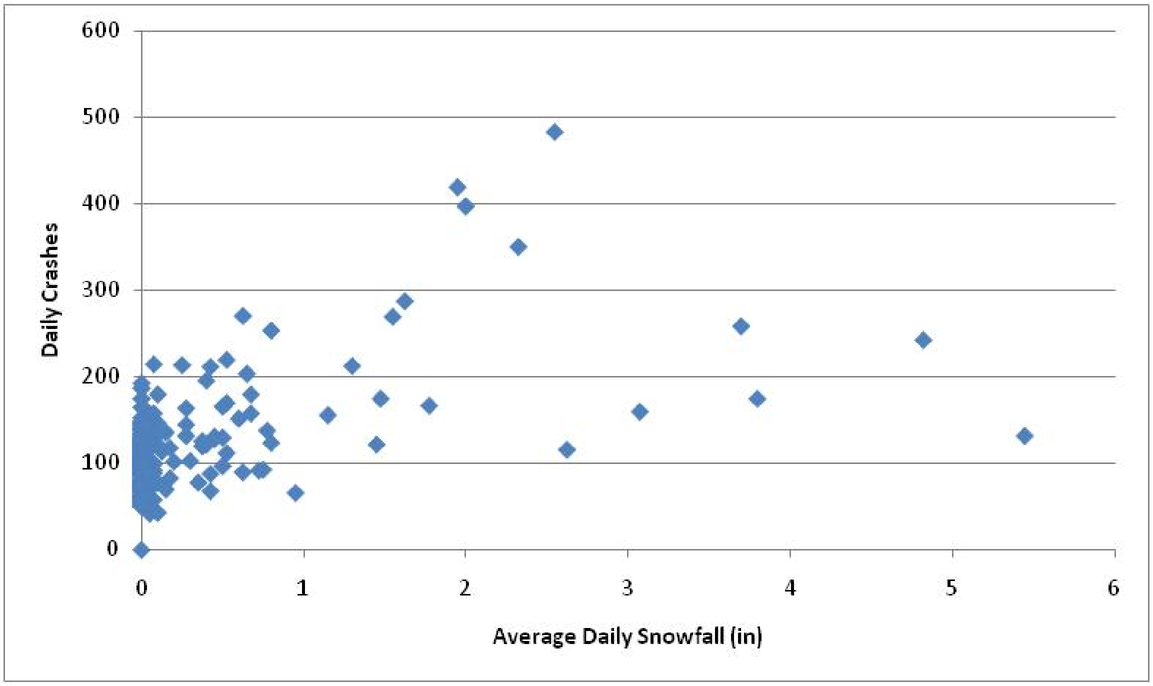

Figure 29: Count of Crashes by Snowfall

In order to account for the varying distributions, we created indicator variables for temperature and snow fall. We set the value of the indicator variable equal 1 when the maximum temp was above freezing and the minimum temperature was below freezing. In addition to "Near32", variables "Maxbelow32", "Maxbelow25", and "Minabove35" were created to capture the different relationships between temperature and crashes. For snowfall, we use five separate indicator variables that are separated based on the daily snow depth starting from 0.01 -0.10 inches and going as high as "greater than 5 inches". A "high volume" indicator variable gives a one if the month is in April - October, noting months with higher traffic volume. When using daily crash totals as the dependent variable we obtained an R squared of 42% and show numerous significant values.[21] The functional form of the model is:

$$Daily \quad Crashes = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Where X_i is a vector with all explanatory variables and ε is a classical error term.

Results and Interpretation

The results below explain the variation in daily crash totals for all ages and for age groups 16-18 and 70+ considered separately. To facilitate interpretation, the beta coefficients for the variables "Minabove32", "Nosnow", and "Wednesday" are set to 0. This allows each coefficient to be interpreted as the increase or decrease of daily crashes compared to a Wednesday with no snow and a mild temperature. For all ages of drivers, the intercept term reflects these normalized conditions and shows that there are approximately 82 crashes per "average" day without any weather, or large variation in traffic volume. The statistically significant coefficients can be interpreted as adding or subtracting from the base value (i.e., the intercept). For example, when

[21] We also examined a Poisson and Negative Binomial models, but show the OLS regressions because of ease of interpretation.

the daily maximum temperature is below freezing, there will be approximately 18 additional accidents statewide, or 96 accidents on average. It is important to note that some variables are structured so that the coefficients show a cumulative effect. For example, when the maximum temperature is below 25 degrees there will be approximately 4 more accidents in addition to the 18 found in the "Maxbelow32" variable (e.g., 100). This is not the case for the snow variables as they are cut off by a specific range and not open-ended like the temperature variables. The R-squared value of 0.43 indicates that the variable we include explains 43% of the variation in daily crashes. Other factors that may be contributing to the variation in crashes but are not included in this analysis are the road type, time of day, and the inclusion of drunk driving. Overall, we conclude that adverse weather, specifically snowfall and colder temperatures, creates unsafe roads and a greater incidence of a crash occurring.

Also, we can see that on days with less traffic on average (Sunday) there are fewer crashes. Traffic volume fluctuations are also found in the "HighVolume" variable showing that in months with higher traffic volume there is a greater risk of a crash occurring.

Table 5: Regression Results Crashes: All Drivers All Roads

Variable	Coefficient	Std. Err.	T	P>t	[95% Conf.	Interval]
Maxbelow32	18.17	2.063	8.81	0	14.13	22.22
Maxbelow25	3.74	2.113346	1.77	0.076	-0.40	7.89
Near32	6.45	1.505597	4.28	0	3.50	9.40
Snow.01-.1	6.62	1.217369	5.44	0	4.24	9.01
Snow.1-1	35.75	1.644809	21.73	0	32.52	38.97
Snow1+	105.13	2.008362	52.35	0	101.19	109.07
Sunday	-26.52	1.61958	-16.37	0	-29.70	-23.35
Monday	0.35	1.619576	0.22	0.829	-2.82	3.53
Tuesday	-0.092	1.619636	-0.06	0.954	-3.27	3.08
Thursday	5.19	1.619779	3.21	0.001	2.02	8.37
Friday	22.63	1.620146	13.97	0	19.46	25.81
Saturday	-2.48	1.620141	-1.53	0.126	-5.66	0.70
HighVolume	10.86	1.449104	7.49	0	8.02	13.70
Time	-6.83	.8777295	-7.78	0	-8.55	-5.11
Constant	82.06	1.821964	45.04	0	78.48	85.63

Number of observations	7091
F(14, 7076)	379.7
P > F	0
R-squared	0.429
Adjusted R-squared	0.4278
Root MSE	36.443

The models that use crash data separated for age groups 16-18, and over 70, also show that weather has an adverse impact on the number of crashes. We see that the 16-18 year-old drivers on an average day can be expected to be involved in 14 crashes. This number increases to 25 with days of heavy snow. For drivers ages 70 and above, the average daily number of expected accidents is 11 and heavy snow increases this to 13. We speculate that the reason for the smaller increase in additional crashes from snow is that older drivers avoid driving on snowy days. The base number of crashes for these age-groups (14 and 11) is less than for all age groups (82) because these age groups are just a sub-set of all drivers. We do not have any information on the proportion of each age group driving the roads on a given day.

The results from all three regressions reflect the hypothesis of the analysis above in that with more snow and colder weather there is a greater incidence of a crash occurring.

Table 6: Regression Results, Drivers Older 70+ , All Roads

Variable	Coefficient	Std. Err.	t	P>t	[95% Conf.	Interval]
Near32	0.47	.1949391	2.44	0.015	0.093	0.86
Maxbelow32	1.69	.2672186	6.34	0	1.17	2.22
Maxbelow25	0.91	.273628	3.33	0.001	0.38	1.45
Snow.01-.1	-0.11	.1576204	-0.71	0.475	-0.42	0.196
Snow.1-1	0.52	.2129636	2.41	0.016	0.096	0.93
Snow1+	1.63	.2600351	6.25	0	1.12	2.14
Sunday	-5.26	.2096971	-25.10	0	-5.68	-4.85
Monday	-0.65	.2096967	-3.10	0.002	-1.06	-0.24
Tuesday	-0.097	.2097044	-0.46	0.645	-0.51	0.31
Thursday	0.02	.2097228	0.10	0.919	-0.39	0.43
Friday	1.57	.2097704	7.51	0	1.16	1.99
Saturday	-2.72	.2097697	-12.96	0	-3.13	-2.31
HighVolume	2.64	.1876245	14.08	0	2.27	3.01
Time	-1.86	.1136451	-16.33	0	-2.08	-1.63
Constant	11.44	.2359011	48.49	0	10.98	11.9

Number of observations	7091
F(14, 7076)	147.03
P > F	0
R-squared	0.2254
Adjusted R-squared	0.2238
Root MSE	4.7186

Table 7: Regression Results: Drivers 16-18, All Roads

crashes	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Near32	0.064	.2844769	0.22	0.823	-0.49	0.62
Maxbelow32	2.32	.3899553	5.96	0	1.56	3.09
Maxbelow25	0.81	.3993087	2.02	0.044	0.02	1.59
Snow011	1.48	.2300173	6.44	0	1.03	1.93
Snow11	4.92	.3107804	15.84	0	4.31	5.53
Snow1	10.99	.3794724	28.96	0	10.25	11.73
Sunday	-3.55	.3060134	-11.61	0	-4.15	-2.95
Monday	-0.47	.3060129	-1.55	0.122	-1.07	0.13
Tuesday	-0.41	.3060242	-1.35	0.178	-1.01	0.19
Thursday	0.60	.3060511	1.97	0.049	0.002	1.20
Friday	5.19	.3061204	16.96	0	4.59	5.79
Saturday	0.95	.3061195	3.10	0.002	0.35	1.55
HighVolume	3.37	.2738027	12.31	0	2.83	3.91
Time	-1.65	.1658437	-9.94	0	-1.97	-1.32
Constant	13.81	.3442533	40.10	0	13.13126	14.48094

Number of obs	7091
F(14, 7076)	163.46
Prob > F	0
R-squared	0.2444
Adj R-squared	0.2429
Root MSE	6.8858

Daily Data State Highway and Turnpike Crashes

Since MaineDOT and MTA use exclusively anti-icing winter maintenance procedures we are interested in a separate analysis of these roads. For state maintained highways and the Maine Turnpike, there were a total of 90,821 reported non-winter-month crashes (April-November) from 1989 through 1999 and 59,377 from 2000 through 2008. There were 51,207 winter-month (December - March) crashes in 1989 -1999. There were 11 years in the “before” period and 9 in the “after” period. So this indicates that the number of non-winter-month crashes per year was reduced by 20.1%. If the winter-month crashes followed the same trend as non-winter-month crashes, we would expect to have 33,478 winter-month crashes (51207 * 59377/90821) in the period 2000-2008. The actual outcome was 33,646. The difference between the two numbers is 168 *more* crashes than expected, or 0.5% more than expected. Unless we consider 0.5% increase to be significant, we conclude that the policy of anti-icing has not had a policy-relevant impact on the total number of crashes. Winter-month crashes are down, but on major highways, slightly less so than during the months when we have no winter weather.

Doing the same analysis for fatalities, we would have expected 89 winter-month crashes in the years 2000-2008. But we only experienced 62. That means that State Highways and the Turnpike saw 27 fewer winter-month fatalities than expected. The 27 "saved lives" on these roads are more than the 24 saved lives in the rest of the state (that we found in the previous analysis). In other words, roads that are maintained by the towns saw no improvement in fatalities in *winter* compared to the summertime (but rather 3 fatalities more than expected) whereas DOT and Turnpike maintained roads did see an improvement in the wintertime.[22] The 27 saved lives amount to a 30.5% reduction in fatalities which is a statistically significant reduction at $p<0.01$. The bare pavement policy is consistent with a statistically significant reduction in fatalities. The estimate of 27 saved lives amounts to $94 million in savings (at $3.51 million per life saved).

In conclusion, looking at the state as a whole, the number of winter-time crashes has been reduced by roughly the same amount as during the summertime months (within one half of one percent). The reduction in crash numbers are probably caused by safer cars and safer roads. The higher-priority roads (State Highways and the Turnpike) have seen a very similar trend. That is that wintertime crashes on these roads are down by 19.7% during the years after 2000 compared to the years 1989-1999. Non-winter months have seen a similar decline (actually fractionally greater at 20.1% reduction). But State Highways and the Turnpike have seen a statistically significant 30.5% reduction in fatalities during the wintertime compared to the reduction during the non-winter months. The gross winter-month fatality reduction was 39.4% whereas the non-winter months saw a 12.6% reduction in fatalities.

Likelihood of Crashes by Age Group

One of the concerns with winter road maintenance practices is differential impacts on sub-populations. Because younger and older drivers are known to have a higher rate of crashes per mile driven, we investigate whether there are weather-specific and winter road maintenance practices that might make one group more or less prone to crashes.

Methodology

We use MaineDOT crash data to analyze all police-reported crashes in from 2004 to 2007. The analysis is based on the number of units involved in crashes, not the number of crashes themselves. Each unit involved in a crash is analyzed with respect to roadway classification, roadway conditions and age of driver. The fields considered and their original database origins are as follows.

[22] Since State-Aid Highways are maintained by DOT in the summer but not in the winter, we here excluded them and included only State Highways, and the Turnpike

From the main accident table:
Accident Year
Accident Date
County #
Segment ID
Road Surface Conditions
Weather Conditions
K Injuries
A Injuries
B Injuries
C Injuries
Crash ID
Crash Cost

From the unit accident table:
Driver's Age
Driver's Sex
Crash ID

From the PART_TIDEYEAR_2008 table:
Segment ID
Jurisdiction
Urban/Rural
Factored AADT

HMVM
Street Name

We separated the data by year, jurisdiction, and urban or rural designation.[23] The crash data within each jurisdiction and designation was then separated by age group, and again by the road conditions during the crash. The jurisdiction categories analyzed were: “Townway”, “State Aid”, “State Highway”, and “Toll”.[24] The age groups studied were based on the police reported driver’s age for each unit involved, and were grouped as follows: 16-17, 18-19, 20-24, 25-34, 35-64, 65-74, and 75+. We omitted crashes involving drivers younger than 16, or where the age is unknown.

We grouped road conditions into “Dry”, “Wet”, “Winter”, and “Other”. The “Winter” designation was given to all crashes that correspond to “Snow, Slush, Sanded”, “Ice, Packed Snow, Sanded”, “Snow Slush, Not Sanded”, and “Ice, Packed Snow, Not Sanded” respectively.

The total number of units involved in crashes was recorded for each jurisdiction and urban or rural designation. The sum of all units involved in crashes classified as occurring with winter road conditions was then divided by the sum of all crash units for that year to determine the percentage of all crash units that had occurred with winter road conditions. This was done for both “rural” and “urban” designations within each jurisdiction category. This percentage was then used as the expected average for that year of units involved in crashes in winter road conditions. The number of crash units involved with winter road conditions in effect within each age category was divided by the total number of crashes within that category, and this number was then compared to the number of expected crash units (based on the percentage) for that category, see Figure 30.

Consistent with the vehicle crash literature (e.g., for count-statistics) we assumed that vehicle crashes have a Poisson distribution. The actual observed number of crash-units involved is

[23] The above fields came from three MaineDOT crash databases; ACCIDENT_YEAR_MAIN, ACCIDENTUNIT, and PART_TIDEYEAR_2008. PART_TIDEYEAR_2008 was used to reference road segment IDs from the main crash reports to the county, road, and jurisdiction the crash occurred, and this year (2008) was used for every year analyzed to maintain consistency in segment locations. The Crash ID is used to reference the individual units involved in crashes to the main accident table.

[24] Federal designations were used for “urban” and “rural” in the event of a discrepancy between state and federal classifications.

compared to the expected number. If there is less than a 5% likelihood that the outcome is a random fluctuation around the expected number, then the outcome is considered significantly deviant. We also note likelihoods between 5% and 10%. After analyzing each of the four years separately, the numbers from 2004 through 2007 were totaled and analyzed in the same way to get four-year averages.

Age-Group Results
Figure 30 shows the results of 2004 – 2007 consisting of 135,661 crashes involving 213,326 vehicles. The results shown in Table 8 are the full set of results.

For the sum of all roadway types, we find that 16-17 and 18-19 year-old drivers are found to be significantly overrepresented in winter crashes, by about 9% and 6%, respectively.[25] This is particularly true for 16-17 year old drivers on urban townways. They were involved in 192 crashes whereas their expected value was 152. This indicates that the age group is 26% over-involved in winter crashes on this roadway type compared to the overall crash-involvement for all road surface conditions for this age group. On the other hand, 16-17 year old drivers are found to be significantly underrepresented in winter crashes on urban and rural State Highways. The differences are around 12% and 13% respectively. The fact that 16-17 year olds are overrepresented in crashes per mile driven in all weather conditions is not analyzed here. This means that winter road conditions are particularly hazardous for young drivers; decision makers may want to take this into account when assigning winter maintenance priorities. It also means that additional driver training on this road type in winter conditions may be warranted.

Additionally, we find that for all roadway types, 20-24 and 25-34 year-old age groups are overrepresented in winter crashes by about 7% - 8%. This is true for most road types (see Table 8). For the next age cohort, 35-64 year old drivers, this age group is overrepresented in winter crashes by only about 1%.

Drivers who are 65-74 years old are significantly underrepresented in winter crashes on all roadway types except for on rural Toll Highways (where numbers are small, and significance is not achieved, though the trend goes towards underrepresentation). Overall, for all roadway types, this age group is underrepresented in winter crashes by about 26%. The oldest cohort, drivers 75 years old or older are significantly underrepresented in winter crashes on all roadway types. Overall, for the sum of all roadway types, this age group is underrepresented in winter crashes by about 47%. The reason these elderly drivers are underrepresented in winter crashes is likely because they refrain from driving when roadway conditions are more risky. However, we do not know this with assurance since we do not have data on miles driven by age cohort under varying weather conditions.

[25] The calculation is: (2222-2038.0)/2038.0=0.09 and (2678-2525.6)/2525.6=0.06)

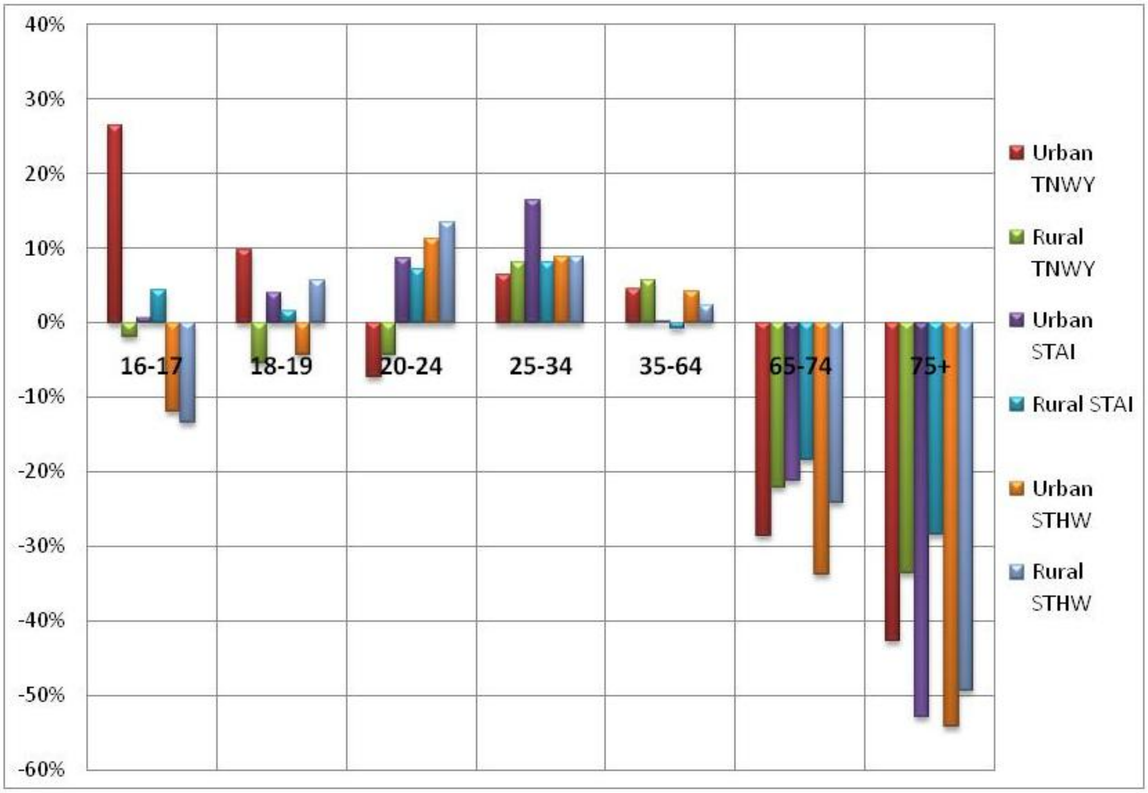

Figure 30: Deviation from Expected Winter Crash Numbers by Age Group 2004-2007

Table 8: Age-Group Crash Results

	# of Crashes						winter % of all	17.3%	
Age Group	**Townway**		**State Aid**		**State Highway**		**Toll**		**Total**
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Units**
All	13204	21158	20792	24183	68827	55601	1489	3162	208416
All Dry RC	8745	11878	14542	14081	49752	37631	989	1913	139531
All Wet RC	1867	2482	3258	2881	12274	7844	231	511	31348
All Winter RC	2496	6209	2920	6977	6640	9756	265	729	35992
All Other RC	96	589	72	244	161	370	4	9	1545
Winter %	0.189034	0.293459	0.140439	0.288508	0.096474	0.175464	0.177972	0.23055	
# Licensed Drivers									
3,984,598									
16-17	803	2223	1238	1779	2933	2744	28	53	11801
16-17 Dry RC	483	1191	840	969	2149	1886	17	35	7570
16-17 Wet RC	113	287	219	248	528	417	5	10	1827
16-17 Winter RC	192	640	175	536	249	417	6	7	2222
16-17 Other RC	15	105	4	26	7	24	0	1	182
mean	151.8	652	174	513	283.0	481.5	5.0	12.2	2038.0
S.D.	12.32047	25.54132	13.18571	22.65517	16.82134	21.94253	2.232311	3.495592	45.14367
Normal Approx. "p" value	0.000635	0.321217	0.480735	0.163093	0.023351	0.001775	0.408461	0.088503	2.39E-05
Poisson "p" value	0.00094	0.323056	0.475712	0.163009	0.021684	0.001459	0.381093	0.080358	2.36E-05
# Licensed Drivers									
66,962									
18-19	872	2046	1500	1889	4423	3656	78	161	14625
18-19 Dry RC	546	1167	1024	1070	3177	2368	42	89	9483

	# of Crashes						winter % of all	17.3%	
Age Group	**Townway**		**State Aid**		**State Highway**		**Toll**		**Total**
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Units**
18-19 Wet RC	134	243	249	234	829	581	16	21	2307
18-19 Winter RC	181	568	219	554	408	678	20	50	2678
18-19 Other RC	11	68	8	31	9	29	0	1	157
mean	164.8373	600.4	210.6579	544.9925	426.7035	641.5	13.9	37.	2525.6
S.D.	12.8389	24.5034	14.51406	23.34507	20.6568	25.32781	3.725829	6.092503	50.25571
Normal Approx. "p" value	0.111244	0.096366	0.294493	0.35777	0.189096	0.077595	0.065789	0.021065	0.001256
Poisson "p" value	0.112347	0.095526	0.2917	0.355466	0.189569	0.078539	0.071778	0.025077	0.001327
# Licensed Drivers									
115,454									
20-24	1845	2934	2630	3211	9542	6549	200	460	27371
20-24 Dry RC	1235	1659	1814	1761	6668	4244	129	245	17755
20-24 Wet RC	278	366	406	414	1824	951	31	83	4353
20-24 Winter RC	323	823	401	992	1024	1304	40	130	5037
20-24 Other RC	9	86	9	44	26	50	0	2	226
mean	348.8	861.0	369.4	926.4	920.6	1149.1	35.6	106.1	4726.8
S.D.	18.7	29.3	19.2	30.4	30.3	33.9	6.0	10.3	68.8
Normal Approx. "p" value	0.088033	0.100579	0.052547	0.016225	0.000346	2.63E-06	0.25635	0.011399	3.32E-06
Poisson "p" value	0.086792	0.099923	0.054007	0.017007	0.000422	4.05E-06	0.251202	0.013365	0
# Licensed Drivers									
310,536									
25-34	2435	3566	3654	4223	12742	9294	298	587	36799
25-34 Dry RC	1581	1909	2464	2377	9094	6126	187	350	24088

	# of Crashes						winter % of all	17.3%	
Age Group	**Townway**		**State Aid**		**State Highway**		**Toll**		**Total**
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Units**
25-34 Wet RC	347	431	579	490	2285	1331	40	90	5593
25-34 Winter RC	490	1131	597	1316	1337	1776	69	146	6862
25-34 Other RC	17	95	14	40	26	61	2	1	256
mean	460.3	1046.5	513.2	1218.4	1229.3	1630.8	53.0	135.3	6354.9
S.D.	21.5	32.3	22.7	34.9	35.1	40.4	7.3	11.6	79.7
Normal Approx. "p" value	0.086731	0.004696	0.000117	0.002696	0.001113	0.000169	0.016857	0.191071	1.05E-10
Poisson "p" value	0.087736	0.005101	0.000164	0.002966	0.001263	0.000202	0.020034	0.190105	0
# Licensed Drivers									
604,329									
35-64	5706	8636	9369	10799	32116	27102	780	1654	96162
35-64 Dry RC	3762	4780	6538	6359	23172	18315	534	1019	64479
35-64 Wet RC	781	967	1482	1263	5640	3738	123	274	14268
35-64 Winter RC	1127	2680	1319	3090	3229	4868	121	357	16791
36-64 Other RC	36	209	30	87	75	181	2	4	624
mean	1078.6	2534.3	1315.8	3115.6	3098.4	4755.4	138.8	381.3	16606.5
S.D.	32.8	50.3	36.3	55.8	55.7	69.0	11.8	19.5	128.9
Normal Approx. "p" value	0.072463	0.001963	0.469998	0.326453	0.00969	0.052078	0.0708	0.11117	0.076682
Poisson "p" value	0.073231	0.002073	0.468181	0.327377	0.009852	0.050629	0.068421	0.110334	0.017367
# Licensed Drivers									
2,251,639									
65-74	667	929	1158	1263	3681	3408	59	147	11312
65-74 Dry RC	488	612	875	829	2827	2516	43	99	8289

	# of Crashes						winter % of all	17.3%	
Age Group	**Townway**		**State Aid**		**State Highway**		**Toll**		**Total**
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**	**Units**
65-74 Wet RC	87	89	150	129	610	424	11	21	1521
65-74 Winter RC	90	212	128	297	235	453	5	27	1447
65-74 Other RC	2	16	5	8	9	15	0	0	55
Mean	126.1	272.6	162.6	364.4	355.1	598.0	10.5	33.9	1953.5
S.D.	11.2	16.5	12.8	19.1	18.8	24.5	3.2	5.8	44.2
Normal Approx. "p" value	0.000764	0.000136	0.003724	0.000229	1.09E-10	1.73E-09	0.061402	0.136148	0
Poisson "p" value	0.000445	7.88E-05	0.002842	0.000152	7.03E-12	3.48E-10	0.050371	0.134453	0
# Licensed Drivers									
345,561									
75+	573	601	1030	848	2812	2499	35	61	8459
75+ Dry RC	433	410	816	587	2234	1915	30	53	6478
75+ Wet RC	75	68	145	79	447	354	4	4	1176
75+ Winter RC	62	117	68	175	124	222	1	4	773
75+ Other RC	3	6	1	7	7	8	0	0	32
Mean	108.3	176.4	144.7	244.7	271.3	438.5	6.2	14.1	1460.8
S.D.	10.4	13.3	12.0	15.6	16.5	20.9	2.5	3.8	38.2
Normal Approx. "p" value	5.36E-06	4.65E-06	1.21E-10	4.91E-06	0	0	0.02906	0.005383	0
Poisson "p" value	9.32E-07	1.25E-06	8.89E-13	1.68E-06	0	0	0.014251	0.001723	0
# Licensed Drivers									
290,117									

Safety Discussion
Crash rates in Maine have declined overall, in both winter and summer months. Numbers of crashes have also declined. We cannot clearly attribute a cause for this trend, however. Many factors may influence a decline in crashes: seat belt laws, improved vehicles, improved roads, winter road maintenance, better speeding enforcement, vehicle attributes such as stability control, driver education, stricter drunk driving laws, and others. If there were a clear influence from winter road clearing practices, we would see a greater decrease in crashes during winter conditions compared to the decrease under all conditions, and this is not the case. Here it is important to distinguish between winter months and winter conditions. Winter month crashes can be either under winter conditions (ice, slush, snow, etc.) or under non-winter conditions (dry, wet, roads that have been plowed and salted). We see the same reduction in crashes during winter and summer *months*, yet there are fewer crashes under winter *conditions*. There are fewer people crashing on ice and snow. It simply means that relative to the total, there are fewer conditions of ice and snow. Road maintenance is keeping the roads clearer -- but not necessarily safer -- in winter, relative to the rest of the year.

We can conclude that mobility has improved over time; there are fewer conditions of ice and snow on roads in the winter than there used to be. There is no evidence that improving mobility has compromised safety on roads in Maine. We can, in fact, say that roads in Maine have become safer over time than they were twenty years ago. We cannot attribute any specific cause to this increased safety. There are fewer crashes, and we see the same reduction in number of crashes in winter and summer months. There is evidence that we have fewer crashes in winter conditions; this does not mean winter conditions are safer, but rather that they are less common.

Stakeholder Input

In addition to compiling research on the topic of road salts, this project has sought input and discussion from those who use, maintain, and depend on Maine’s roads. This input was structured in three ways: a project advisory committee was convened for three meetings at different stages of the project; interviews were held with individuals representing key groups in the State; and meetings were held with invited stakeholders in four different locations around the state. Below we describe the methods of soliciting input and then we summarize the major themes raised from stakeholder input.

Individual interviews
The research team conducted interviews with six individuals offering a spectrum of expertise and perspectives about Maine winter road maintenance. The people interviewed are representatives of the Maine Motor Transport Association, Maine Department of Transportation (geology, engineering), Maine Auto Dealers Association, and Maine State Police and a Maine town manager. The interviews were conducted in person and by telephone. They are based on a common set of questions but range into areas of interest and the expertise relating to each person interviewed. Their observations are incorporated into the description of stakeholder themes and issues below.

Project Advisory Committee
As noted in the introduction, this project has been guided by an Advisory Committee consisting of 21 individuals representing various groups throughout the state that have an interest in the

topic of road salts in Maine. A full list of organizations represented is found in Appendix 1. This group was convened three times during the project. First they were asked for feedback on the structure of the project. An extensive discussion of level of service gave us input on the depth and complexity of this issue. Next, they were asked to review and respond to preliminary research findings. The Advisory Committee was consulted for suggestions on representative individuals to invite to Stakeholder meetings held in four locations in September 2009. In the final meeting the Committee discussed this final report and next steps.

Stakeholder Sessions

With the help of the Advisory Committee and MaineDOT to identify appropriate participants, we invited 318 individuals to attend one of four stakeholder meetings. In September 2009, we held stakeholder meetings in Portland, Belfast, Presque Isle, and Farmington. A total of 88 people attended, from 17 to 30 at each, representing road users, local and state road maintenance, state and municipal officials, truck fleets, public safety, and other interest groups. A list of organizations represented appears below in Table 9. At these meetings the research team presented the information gathered on winter practices, environmental and corrosion impacts, and safety. A second portion of each meeting involved break-out discussion groups to prioritize issues, discuss levels of service, and share perspectives. A transcription of the flipcharts from discussion groups appears in Appendix 3.

Stakeholders were asked to complete an evaluation of the session and issues they consider important; 76 stakeholders responded. The evaluation form and a summary of responses appear in Appendix 6.

Limitations of Stakeholder Input

Comments collected from stakeholders are useful insights but cannot be generalized to the population of all stakeholders because (a) not all groups are represented, (b) individuals who did participate may not reflect the consensus of the group or groups with which they are affiliated, and (c) their comments are from a perspective that may shift based on time, context, and questions asked. With these cautions in mind, their insights nonetheless reflect the opinions of a wide range of experienced, informed professionals who agreed to participate and share their thoughts.

Table 9: Stakeholder Groups Attending Sessions[26]

State Legislature Transportation Committee	Selectmen
Auto and Truck Dealerships	Utility Company
Municipal Government	Conservation Districts
Soil and Water Conservation Districts	Maine Turnpike Authority
County Government	Maine State Legislature
MaineDOT Regional Offices	School Bus Company
Regional Development Councils	Sheriffs
Maine DEP	Water Districts
Trucking Companies	Charter Bus Company
Public Works Directors	Fire Departments
Private Industry Fleet Managers	ME Dept. of Conservation

Stakeholder Groups and Issues

One of the goals of this project is to develop a common understanding among the various stakeholder groups about issues and tradeoffs associated with the use of road salts in Maine. By generalizing somewhat, we can describe the various groups and their stake in the issues of winter road maintenance: transport, auto dealers, public safety, public works, and environmental concerns. These are the primary stakeholders; in addition, private citizens, small business, and public policy makers also have interests in winter road maintenance, but are not so clearly represented by groups.

The transport industry represents commerce in the State. Their primary issue is mobility. They need major roads to be clear and dependable because they need to move their goods to market; delay due to bad weather may mean dollars lost. At the same time, they see their fleet vehicles rusting. The most common issue with trucks is “rust jacking” which is a buildup of rust between the brake shoe and the lining. Stakeholders from this industry brought photos of various types of rust and even rusted vehicle parts to show. There is a perception among some in this industry that the cost of our clear roads is paid by them in the form of vehicle repair cost. One participant described this with the sentiment that we (as a state) are “passing the buck” on the corrosion issue.

Automobile dealerships and repair shops are seeing similar corrosion issues with privately owned vehicles. Dealer service centers report brake lines and electrical connectors rusting in greater numbers than ten years ago. These costs are borne by the individual consumer, and the dealerships must respond to consumer complaints.

Law enforcement, sheriffs, and fire departments represent public safety. The primary issue this group is concerned with is safety on the roads. They must have road conditions that allow them to respond to crashes during a storm. Modification of driver behavior was a topic raised at stakeholder meetings, by more than just public safety officials. Ideally, people should stay off the roads during a storm, drive more slowly, put more space between themselves and other vehicles, properly maintain their car and tires, and put safety as a higher priority. Lowering the speed limit is not an enforceable option because pulling people over in dangerous conditions only creates more hazards on the roads. Discussion in stakeholders meetings touched on what mechanisms

[26] These stakeholders do not necessarily support the findings and viewpoints expressed in this report.

might be employed to get people to slow down, use winter tires, and choose not to drive during a winter storm. This group recognizes the multi-way tradeoff of safety, environment, and level of service with attendant cost considerations.

MaineDOT, municipal public works employees, town managers and selectmen represent public works. This group of people takes their jobs very seriously, including those whose job it is to drive the plow trucks. The perspective of this group is that regardless of policies, they must respond to conditions of each individual storm. They feel the responsibility of keeping the roads safe for their residents. Many expressed the sentiment that perhaps they are actually doing too good a job. Their high levels of maintenance have created expectations of high levels of maintenance on roads. Representatives of local governments are closer to the people they serve, therefore they are more likely to get complaints about road conditions and more likely to respond to these complaints. There is interest in alternative materials and practices; they would like to have more tools in their toolbox and conversely don't want to see any of their tools (materials) taken away. The sentiment we heard from municipal level people is that given the current costs, environmental impacts, corrosion and driver demands, something may have to change. Public education is clearly important, but there is no consensus on exactly what kind of education and by whom.

The environmental sector is represented by soil and water conservation districts and by MaineDEP at the state level. Those in the environmental field appreciate the interests raised by other groups, but in addition to the short-term effects related to safety and commerce they are more concerned with the long-term effects of chlorides in the environment. In some areas the surface waters are much closer to exhibiting those long-term effects.

Themes from Stakeholders

The following section summarizes ideas, concerns, and viewpoints by theme. These were collected in interviews, advisory committee meetings, and stakeholder sessions from representatives encompassing local and state highway maintenance, public safety and law enforcement, trucking, vehicle maintenance, environment, policy makers, and others.

Recurring themes from stakeholder discussions are concerns about safety, costs, corrosion, environmental consequences, level of service, winter road maintenance practices, materials, and education – both for the public at large and for municipal workers and officials.

Safety

The clear consensus among stakeholders is that roads in Maine are better than they used to be. All of the groups we spoke with acknowledge that travel is safer and the roads are clear sooner after a winter storm than they have been in the past. In fact, most stakeholders agreed that the people whose job it is to clear the roads are doing it well. One stakeholder clarified, "Maybe we've done too good a job," because people now expect this level of service and safety.

As one discussion group phrased it, "Safety, that's what we do." Public service workers see safety as the underlying reason for what they do to see that Maine's roads are drivable throughout the winter and as quickly as practical after heavy storms. Many workers measure their work not only by keeping their streets and roads open but also by crashes on their roads, which they take personally.

Safety issues depend not only on weather and anti-icing/deicing practices, but also on temperature, humidity, time of day, topography, road structure, and local environment. Rural roads involve considerably more vehicle interaction because of two-way roads, intersections, sharper curves and limited shoulders, and the like, all of which can make them dangerous. In addition, rural roads often are tree covered and do not get sufficient direct sunlight to help with melting; in these circumstances, tree cutbacks along many state roads help foster melting.

Often, problems come from smaller storms rather than the big ones because people are more likely to stay off roads during large storms. Throughout Maine's winter, driver behavior is a huge factor. The first early-season storms result in a proportionately greater number of crashes as people struggle to relearn safe winter driving patterns. Often the driving public places too much confidence on their vehicles and equipment. One stakeholder observed, "A four-wheel drive car is the first to go off the road, especially in early storms, and next comes a car with bald all-season tires."

Large commercial trucks contribute to safety problems for themselves and others, especially in dry snow and when big rigs travel faster than smaller vehicles traveling the same roadways. However, in responding to perceptions about some trucks traveling too fast on highways during storms, one stakeholder contended this was "a speed limit and law enforcement issue" rather than an issue for the trucking industry itself.

Law enforcement officials face a dilemma in bad-weather situations during which pulling vehicles over creates added hazards for other drivers; at such times, officials concentrate on egregious driving behavior and on responding to crashes. Crash sites can themselves become especially dangerous while public safety, ambulance, wrecker vehicles and their first-responder personnel are on the scene. Officers at times request sand and salt applications near these sites. Maintenance crews try to oblige, but, for many crews, this may involve returning a truck full of salt, dumping it, then reloading with sand.

Stakeholders expressed strong consensus that by far the largest safety risk factor is driving unsafely for a given set of road conditions. Speed, driving experience, driving behaviors, and vehicle readiness (such as studded tires) all contribute to safe or unsafe driving on winter roads. Professional drivers outperform the general public in their ability to judge winter roads and drive sensibly under adverse conditions. Stakeholders were frustrated that poor winter driving habits endanger so many people and those around them. This concern is discussed further in the subsections below on "Level of Service" and "Education."

Costs

Costs were a running theme in stakeholder discussions. The opinion was that cost trends are unsustainable and, as a consequence, will soon force changes in levels of service, storm-related driving expectations and commerce, and, over the longer term, road construction and clearing innovations. The term itself – costs – applied foremost to the direct costs (equipment, material, and personnel) associated with keeping roadways passable in, during, and following adverse winter weather. But stakeholders also used the term “costs” when discussing delayed commerce and lost work-time for the public, environmental and related health impacts (both short- and long-term), and other societal impacts (crash-related injuries, deaths) that have associated direct and indirect costs.

Stakeholders involved in road maintenance cited the ever-rising cost of materials and equipment in the face of increasingly constrained fiscal resources. In terms of materials, “what we’re used to using” and the relative cost of materials tend to determine what anti-icing or deicing agents are applied to the road surface. But from a practical perspective in road maintenance operations, cost is discussed early and late during the season – not during the storm.

As to how increasing costs might be handled, stakeholders had few recommendations. MMTA supported recent proposals for increasing fuel taxes, recognizing the importance of road infrastructure for the trucking industry. Several stakeholders suggested that it would help if the public could be shown the relationship between willingness to accept a given level of taxation and the resulting level of service on their winter roads (see “Education,” below.) Another approach was not on the revenue side; instead, one stakeholder stressed better productivity through best practices, giving an example in which good equipment and a well-laid plan reaped monetary rewards for a nearby town. Others acknowledged cost-savings at MaineDOT when it shifted from deicing using salt and sand to anti-icing using a brine solution, but cautioned that municipalities might not experience the same level of savings –local roads differ in many ways from state and interstate roadways.

Corrosion

Corrosion is a concern foremost in the minds of the trucking industry, auto dealerships, utilities and other industries that operate fleet vehicles. Discussions returned repeatedly to vehicle corrosion as opposed to impact on transportation infrastructure. Questions about damage to bridges surfaced, however, when talking about anti-icing with brine. One town manager noted the rapid corrosion of an iron fence fronting a local park – corrosion had accelerated when the adjacent roadway was widened, bringing it within a few feet of the fence, increasing traffic, and thereby increasing salt and sand applications.

The trucking industry, auto dealers, and auto repair shops offered photographs of damage and strong anecdotal evidence that vehicle corrosion has increased. Managers of trucking fleets discussed the increase in rust jacking. Auto dealers note more frequent replacement of brake lines and couplings in the last four or five years. They also see more corrosion problems with electrical connectors. Dealers say they notice fewer problems in areas where more sand is used (north and west) than in areas using brine, leading them to infer that the liquids keep chlorides on the vehicle longer and thereby exacerbate damage. Public safety vehicles and public works equipment show comparable deterioration, and commercial truckers report that corrosion on trailers stops at a certain height above the roadway. One participant noted that, in his jurisdiction, school buses using state-maintained roads and interstate lanes experienced more corrosion than comparable buses covering rural routes.

Dealers comment that manufacturer warranties expire before brake lines corrode, so it is not a big issue for the manufacturer even though it is for service shops and their customers. Among other factors suggested to affect corrosion – positively or negatively – are garaging, washing vehicle undercarriages, and power washing.

As for steps to prevent or mitigate corrosion, stakeholders hope automakers will improve their manufacturing techniques, materials, and coatings. Truckers say they cannot wait; they need to stop buying high-carbon steel that rusts. Instead, suggests one participant, they should try aluminum or stainless steel for exposed parts, though they are more expensive. Other advice offered was to thoroughly power clean undercarriages for vehicles, but not store the vehicle in a warm, moist garage.

Environment

As with safety, cost, and corrosion, the majority of stakeholders indicated the environment to be an important issue. One group defined environment as the whole ecosystem; another enumerated natural resources, water supply, and wildlife as being sensitive aspects of the environment that we must safeguard from too much salt and other chemicals, notwithstanding our need for safe winter driving. A participant commented that the discussion on environmental hazards paid too little attention to the consequences of using sand to treat winter roads, especially given the extensive use of sand in many localities. One set of stakeholders asked what happens to rusted auto parts; they suggest saving money and helping the environment by using more environmentally friendly materials.

A stakeholder involved in trucking voiced the observation that truckers are among those less likely to be concerned about environmental issues and more likely to see such concerns as impediments to commerce. Other stakeholders suggested that lowering the level of service on most roads could have a positive environmental impact by limiting salt exposure for the natural environment and reducing vehicle corrosion. The consensus, however, especially among those who rely on clear roads for their livelihood, was to use less salt on secondary and local roads but keep major arteries salted and passable. One town manager allowed that municipalities probably could figure out how to put down less material close to lakes and ponds to protect specific areas.

Level of Service

Level of service (LOS) was, in itself, extensively discussed among stakeholders. The broadly held view was that Maine roads are very well maintained for winter driving, at both state and local levels. This enables drivers to move about with reasonable safety very soon after major winter storms. The public takes good mobility for granted. Rather than recognizing that major arteries, local streets, and rural roads do not rate identical treatment priorities, the public – in the view of stakeholders who maintain Maine roads - has come to expect high levels of service across the board.

This expectation has created a dilemma: The bare-pavement target for many roadways has demonstrably saved Maine's driving public from many injuries and deaths (see section on Road Safety Trends), damage to vehicles and property, and cleared the way for commerce and other economic activity – a standard that everyone involved in is proud of and hopes to maintain. But, as discussed earlier in this section, concerns about costs and environmental impacts have mounted to the point that policymakers need to revisit the trade-offs involved between quickly cleared roads, environmental and vehicular damage, and the direct cost associated with maintaining high levels of service.

Stakeholders were concerned that any LOS reduction – whether at the state level, the local level, or both – could adversely affect safety and commerce and would infuriate the driving public. Better training and road treatment practices have the potential to mitigate some cost and environmental concerns while maintaining current levels of service in the short- and mid-term, though the impact would likely be uneven; over the long-term, innovations in materials, practices, and road design may offer promise but are apparently a long way off.

The discussion among stakeholders suggested that a realistic policy could be twofold: first, to keep current LOS practices in force for state roads, which constitute a vital but relatively small segment of Maine's transportation infrastructure; second, to moderate LOS at the municipal level, which handles most roads and accounts for most of the cost outlays for winter road maintenance. How this could be accomplished was unclear, but a most likely force would be the inevitable shrinking of road maintenance budgets in the face of harsh economic conditions.

This shift in LOS would likely lead to adjustments in business and school schedules and would require significant public service announcements; however, many stakeholders felt that a lowered local LOS might nonetheless hold safety constant through reduced driving during and immediately following winter storms.

Practices and Materials

There was some discussion about the differing practices between roads maintained by MaineDOT and municipal roads. MaineDOT has demonstrated cost and material savings by a shift in policy from deicing to anti-icing. Several stakeholders suggested that what works well for state highways is not the same practice that works well for town roads. Pavement conditions differ, traffic volumes differ, and more than a few public works officials indicated that they should not be judged by the same metric. One public works director described his town's experience trying an anti-icing policy. They found it to be unsatisfactory because of slushiness during the storm, and they subsequently returned to deicing with sand and salt.

The issue of pavement condition also entered the discussion, including the concept of addressing winter maintenance issues through improvements in road construction and paving. This issue of differing conditions arose at each stakeholder meeting; any policy changes must acknowledge the broad range of road conditions found at the municipal level and their variation from highway conditions.

Municipalities differ from each other, as well, in road clearing practices. Some towns may have mills with shifts requiring high levels of service around the clock. These municipalities may have higher costs and need to maintain higher service than the average. In other towns, roads might be treated only during daytime hours with little inconvenience from waiting. Cities may have miles of sidewalks and schools to clear, increasing their costs considerably compared to rural municipalities. Effectively addressing the issue of road salts in Maine requires the recognition of the variation in practices and conditions in place and the different constraints placed on municipal and county agencies.

Public Education

The topic of education received a lot of discussion at each stakeholder meeting, adding specifics to the broad idea of education as a solution. One is the suggestion that the public needs to be educated about the risks of winter driving and the consequences of road salting for maintaining high levels of service. They should be better trained and better equipped to drive in winter conditions. They should be educated about the importance of either slowing down or staying home. Suggestions included special courses in drivers' education programs about driving in winter conditions, requiring snow tires on vehicles, and public service announcements about the hazards of driving during poor conditions. One stakeholder suggested a public service/advertising campaign based on the slogan, "Give *yourself* a brake."

Another twist on education is the notion that the public works sector needs to be educated in better practices and using less salt. Our municipal survey shows that most municipalities are using a salt/sand mix and very few are anti-icing. Education about best practices for anti-icing at the municipal level might result in cost and material savings. A reaction to this sentiment was expressed by municipal public works people who sometimes feel they are being criticized for not duplicating MaineDOT practices with respect to anti-icing, when in fact municipal road conditions can be quite different from those of MaineDOT roads. We hope this report will address this concern through developing a common understanding of all the issues at play in the practices of winter road maintenance. The converse to this is that municipal public works should not automatically dismiss practices that are effective and cost saving on state highways because their conditions may vary; there may be gains to implementing anti-icing even though conditions differ.

Yet another call for education is the need to explain to the public at large more of the details of winter road maintenance. Although some of the public is well-educated about winter road clearing practices and materials, for others misconceptions abound. Public works agencies receive many complaints stemming from such misconceptions. In our research into municipal practices we found that towns and cities range widely in the nature and depth of information they provide to the public about their winter road policies. Simply raising the awareness of the general public as to which materials are used, what are municipal and state practices, and what are the consequences of these materials and policies would contribute to a more informed public and therefore better policy making.

Other comments on education deal with trucking. Engaging small trucking operations in events and training is a challenge, especially since many are not part of any formal trucking group or association. "Some cowboys out there," observes one stakeholder, "are difficult to reach and communicate the [safe-driving] message."

As to who ought to step up, fund, and provide serious leadership for winter-driving education efforts, no specific party was named. Discussions seemed to assume two things: first, that the most likely candidates would be MaineDOT, Public Safety, or both, and, second, that this could be an effective initiative costing only a tiny slice of Maine's overall annual winter maintenance budget.

Regulation and Innovation

Laws and regulations, though a minor aspect of stakeholder discussions, nevertheless caught the attention of some stakeholders. Some suggested that winter-driving knowledge and skill be part of driver-license testing. Several stakeholders criticized requirements that studded tires be prohibited after April 15; they held that the road-wear issue was trivial when weighed against public safety, not to mention the direct and indirect costs of early- and late-season crashes. One stakeholder wondered about revisiting the law requiring state and local government to keep roads passable; instead, certain types of roads might close between 10 p.m. and 4 a.m.

Stakeholders advocated ongoing research into chemicals, equipment, and improved practices that would be effective, low cost, and environmentally benign. Some said that manufacturers need to apply better corrosion inhibitors to metal vehicle parts. A town official raised the possibility of segregating treatment protocols in different areas, especially around lakes and ponds. He wondered about putting solar collectors on utility poles and using the energy to help melt snow and ice on the road. Other potentially valuable innovations mentioned were better road crowns, which require less salt to produce dry pavement; more porous asphalt that diminishes road ice by promoting draining; greater tree clearance along roadways to promote melting; and better, clearer, more rapid communication with drivers about road conditions. There is no silver bullet with regard to innovation, however. Several public works representatives noted, "we are stuck where we are, with the materials and technology we have, until something else changes."

Stakeholder Summary

Stakeholders identified several factors that combine to drive change: costs at state and municipal levels; customer demand, expressed directly and through driver behavior; and policies, practices, and regulations, including environmental protections. They are concerned that budget cuts will make current levels of service unsustainable for most categories of roads, they saw public safety as trumping concerns about environmental and economic impacts, and they observe an upward trend in vehicle corrosion.

There is a delicate balance among the contributions of levels of service; of hard work, better technology and training; and of driver expectations to the equation of winter road maintenance in Maine. Municipal and state workers are always trying to get better and yet the public is always expecting more (and for less).

The four meetings held with stakeholders were noteworthy in their collegial atmosphere. Without exception, the tone was non-adversarial; people talked and people listened. Afterwards most said they learned something about each of the major presentation areas at the stakeholder meetings. One person specifically told us that he had come to the meeting with his own strong opinions and left realizing that there were other points of view on the issue he hadn't been aware of. In the group discussions there was consensus about something needing to be done to change the current situation with regard to road salts; no one was advocating that the current conditions were ideal, but rather an imperfect solution. Even though discussion came up short of identifying exactly how to arrive at a better solution the theme of education --for the public, for commercial drivers, and for officials and workers responsible for winter roads – repeatedly emerged as a suggestion for improvement.

Summary and Implications

The reasons for clearing roads of snow and ice are to increase mobility, which facilitates commerce and industry, and to maintain or improve safety. If everyone stayed home when roads were snowy or icy, we would know that we have the safest possible roads in winter conditions. Short of this, we have to determine a reasonable balance between mobility and safety. High levels of safety and mobility come with costs. In this case the costs are in the form of damage to vehicles, infrastructure and environmental systems.

We can say that roads in Maine have become safer over time than they were twenty years ago; there are fewer crashes in both winter and summer months. Causes include improved vehicles, improved roads, and driver behavior. Winter safety, as measured by the number of people killed on MaineDOT and MTA roads during the winter months, has improved. Winter safety, as measured by the number of crashes occurring during the winter months (December through March), has remained relatively constant. In distribution, however, young drivers are overrepresented in winter crashes on urban townways, while older drivers are clearly underrepresented. We conclude that mobility has improved over time; there are fewer conditions of ice and snow on roads in the winter than there used to be. We see fewer crashes in winter conditions; this does not mean winter conditions are safer, but rather that they are less common.

Anecdotal evidence tells us that vehicle corrosion on cars and trucks is more prevalent than ten years ago. It is known that all chlorides contribute to corrosion, but none consistently more than others in real world conditions. Humidity, environmental factors, and manufacturing materials also contribute to corrosion. Corrosion affects family vehicles, commercial fleets, school buses, and government-owned road equipment as well as bridges and other highway infrastructure.

Winter road salts have both short- and long-term environment effects. Short-term effects occur seasonally and are largely reversible. Environmental data measuring long-term effects show increasing levels of chloride in fresh water throughout the Northeast. Once contaminated with elevated chloride levels, surface and ground water can take decades, if not longer, to recover.

We estimate that clearing winter roads in Maine collectively cost the state $98 million dollars last year. Of the road clearing chemicals, salt remains the most readily available and the most economical. More than 490,000 tons of salt was purchased in Maine in the winter of 2008-09. Most of this is destined for use on roads, but some amount is applied to parking lots and other non-road surfaces. This is roughly 750 pounds for every Maine resident, or 21 tons per road mile.

In this report we have described the outcomes of current winter road maintenance practices in Maine and other states and provinces. We know that clearer roads mean that more people will travel because of winter maintenance efforts. This increases mobility and provides economic and social well-being. Yet we also know that chloride levels are increasing in groundwater in the Northeast, and that chlorides are contributing to costly corrosion. State and municipal public works agencies have a variety of materials, equipment and practices at their disposal. At the same time, state and municipal budgets are strained.

The challenge for Maine is to limit the negative effects of winter road clearing without limiting our mobility and safety. As outlined in our policy recommendations, we make a number of recommendations that can potentially save money and limit negative impacts. These include the straightforward: improved record keeping by MaineDOT regions and by municipalities, to more the more challenging – identification of ways to change practices and levels of service where appropriate. There may be room for additional regional cooperation at the municipal level to lower winter maintenance costs, improve service, or both. These are a few of the areas that need further investigation.

We have shared research findings with stakeholders in Maine and incorporated their feedback into this report. Although stakeholder groups disagree about ideal winter road practices, they are in consensus about the need for a public education campaign to foster safer winter driving habits. Further recommendations from stakeholders include enhanced driver education for winter conditions and re-examining levels of service priorities except on state highways. In spite of holding differing viewpoints, stakeholder groups recognize the need for change and appear willing to work together to examine this issue in more detail and to participate in discussions of policy options.

Research Needs

Further research on this topic should address the following areas:

- Water studies in Maine are needed to identify sensitive areas. Water quality monitoring will provide baseline data on chlorides and identify trends.

- An accurate measurement of the full municipal costs of salting is needed, possibly in a select number of communities for a year or two. This could also examine municipal decision making – what role is played by cost, public perception, road conditions, and equipment?

- An accounting of mobility costs from different priority levels is needed in order to determine the cost of changing levels of service. Maine drivers' willingness to accept a different level of service should be determined.

- Better data is needed on driver choice and behavior. There should be special emphasis on young drivers. Public education about risk and expectations requires knowledge about what motivates drivers and what might cause them to change behavior.

- An inventory of municipal roads and conditions could help to determine which would benefit from anti-icing vs. those that require sanding.

- Driver/public education practices should be examined in states that have undertaken such programs. These should be studied to determine what they feature, how they operate, rough cost, and apparent impact.

- More research is needed on winter maintenance practices that can be implemented in Maine. This research should focus on cost savings and material reduction. Given the millions of dollars spent statewide on winter maintenance, savings resulting from improved methods and reduced salt could be significant.

- Research is needed to better understand the material use and practices of private contractors – those employed by municipalities and those who maintain private sector locations such as parking lots and industrial parks.

- Better record keeping is needed for winter road maintenance by state and local entities – for example, how much of which material is applied to which roads and with what frequency.

- More frequent and more widespread measurement of vehicle miles traveled in Maine would lead to more accurate measurements of safety and mobility.

References

American Association of State Highway and Transportation Officials (AASHTO), 2009. NCHRP Project 25-25(04) Final Report. Environmental Stewardship Practices, Procedures, and Policies for Highway Contruction and Maintenance, Online Compendium. Section 8.4.1. http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/8_4.aspx (Accessed 6/5/09).

Ballestero, Roseen, Houle, Briggs. Feb. 2009. Porous Pavements as a Technology for Salt Reduction. A Presentation at the 8th Annual Road Salt Symposium, MN. UNH Stormwater Center. Dept. of Civil Engineering, Univ. Of New Hampshire, http://www.unh.edu/erg/cstev/Presentations/ballestero_porous_pavements_salt_symp.pdf (Accessed 10/5/2009).

Bang, S. S. and D. Johnston. 1998. Environmental Effects of Sodium Acetate/Formate Deicer, Ice Shear™. *Archives of Environmental Contamination and Toxicology* Volume 35, Number 4. November, 1998, 580-587.

Bartosova, & Novotny, 1999. Model of spring runoff quality for urban watersheds. *Water Science and Technology*, *39*, 249-256.

Berkheimer, & Hanson, 2006. Deicing salts reduce cold hardiness and increase glower bud mortality of highbush blueberry. *Journal of the American Society for Horticulture Science*, *131*(1), 11-16.

Bester, Frind, Molson, & Rudolph, 2006. Numerical investigation of road salt impact on an urban wellfield. *Ground Water*, *44*(2), 165-175.

Better Roads Magazine, 2008 Bridge Inventory. http://www.betterroads.com/content/fileadmin/user_upload/issues/pdfs/Bridge_Inventory/bridge2008.pdf (Accessed 5/11/2009).

Blomquist, & Johansson, 1999. Airborn spreading and deposition of de-icing salt - a case study. *The Science of the Total Environment*, *235*(1-3), 161-168.

Boselly, Edward, S., 2001. "Benefit/Cost Study of RWIS and Anti-icing Technologies," Final Report. Prepared for NCHRP, TRB, NRC by S. Edward Boselly Weather Solutions Group. page 24. http://www.transportation.org/sites/sicop/docs/NCHRP20-7%28117%29.pdf (Accessed March, 2009).

Buttle, J.M. and Labadia, C.J., 1999. Deicing salt accumulation and loss in highway snowbanks. *Journal of Environmental Quality*, *28(1)*, 155-164.

Canada Gazette. April 3, 2004. Government Notices, Department of the Environment. Vol. 138, No. 14 http://www.gazette.gc.ca/archives/p1/2004/2004-04-03/html/notice-avis-eng.html#i1 (Accessed 8/20/09)

Canadian Environmental Protection Act, 1999.

CBC News, 2007. "Quebec First Province to Make Winter Tires Mandatory." Thursday, December 20, 2007. www.cbc.ca/consumer/story/2007/12/20/quebec-snowtires.html (Accessed 8/25/09).

Chollar, Brian, 1996. "A Revolution in Winter Maintenance" in Public Roads, FHWA. Winter 1996, vol. 59, no. 3. http://www.tfhrc.gov/pubrds/winter96/p96w2.htm accessed 4/28/09.

Collins, Sara J. and Ronald W. Russell, 2009. "Toxicity of Road Salt to Nova Scotia Amphibians". Environmental Pollution, Volume 157, Issue 1, January 2009. pp. 320-324.

Cookson Electronics, 2005. OEM Elimination Dates for Hexavalent Chromium. http://www.enthone.com/docs/AutomotiveUpdate1-505HexChromeElim.pdf

Corsi, Geis, Bowman, Faily, & Rutter, 2009. Aquatic toxicity of airfield-pavement deicer materials and implications for airport runoff. *Environmental Science and Technology*, *43*(1), 40-46.

Daily Commercial News and Construction Record. 2009 "Ontario's transport ministry laud automatic roadway deicing systems." Feb. 27, 2009. http://dcnonl.com/article/id32825 (Accessed 8/15/09)

Demers, C. L. and Sage, W. R., 1990. Effects of road deicing salt on chloride levels in four Adirondack streams. *Water, Air and Soil Pollution*, *49*, 369-373.

Environment Canada, 2000. Priority Substances List Assessment Report: Road Salts. http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/road_salt_sels_voirie/road_salt_sels_voirie_3_1-eng.php#a35 (accessed 8/20/09).

Environment Canada. 2001. Existing Substances Evaluation: Road Salts. http://www.ec.gc.ca/substances/ese/eng/psap/final/roadsalts.cfm (Accessed 8/20/09)

Environment Canada, 2008. "Update on Measuring and Monitoring Progress for the Environmental Management of Road Salts" Presentation at 2008 Ontario Snow and Ice Colloquium, October, 2008.

Environmental Commissioner of Ontario. 2007. 2006-07 Annual Report Supplement.

Fay, Laura et al., 2008a. Laboratory Evaluation of Alternative Deicers: The Path to Decision Making Based on Science and Agency Priorities. TRB 09-2817.

Fay, Laura, et al., 2008b. Performance and Impacts of Current Deicing and Anti-Icing Products: User Perspective versus Experimental Data. Transportation Research Board. Washington, D.C. TRB 08-1382.

Field, R. and ML O'Shea, 1992. "The USEPA Research Program on the Environmental Impacts and Control of Highway Deicing Salt Pollution." IN: Chemical Deicers and the Environment. Lewis Publishers, Boca Raton, Florida. pp. 117-133.

Fischel, Marion, 2001. Evaluation of selected Deicers Based on a Review of the Literature. The SeaCrest Group. Colorado Department of Transportation and FHWA. Report No. DCOT-DTD-2001-15.

Fraser, David and E.R. Thomas, 1982. Moose Vehicle Accidents in Ontario: Relation to Highway Salt. *Wildlife Society Bulletin*, Vol. 10, No. 3, Autumn, pp. 261-265.

Foos, A. 2003. Spatial distribution of road salt contamination of natural springs and seeps, Cuyahoga Falls, Ohio, USA. *Environmental Geology*, *44*, 14-19.

Foreman, & Deblinger, 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology*, *14*(1), 36-46.

Godwin, K. S., Hafner, S. D. and Buff, M. F., 2003. Long-term trends in sodium and chloride in the Mohawk River, New York: The effect of fifty years of road-salt application. *Environmental Pollution*, *124*(2), 273-281.

Government Printing Office Access, "Budget of the United States Government: Historical Tables Fiscal Year 2009," http://www.gpoaccess.gov/usbudget/fy09/hist.html, Last updated: February 15, 2008.

Green, Machin, & Cresser, 2008. Effects of long-term changes in soil chemistry induced by road salt applications in n-transformations in roadside soils. *Environmental Pollution*, *152*(1), 20-31.

The Handbook of Road Safety Measures, 2004. Elvik, R and Truls Vaa, eds. Elsevier.

Health Canada. 2007. Priority Substances List Assessment Report for Road Salts 2.1.1 Substance characterization. http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/road_salt_sels_voirie/road_salt_sels_voirie_2-eng.php (Accessed 8/20/09)

Hexavalent Chromium phase out:

- http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/8_1.aspx (Accessed 5/5/09).
- ALTERNATIVES to Hexavalent Chromium and Chromium Plating http://findarticles.com/p/articles/mi_m0HRR/is_2000_Winter/ai_75577967
- http://www.allbusiness.com/manufacturing/miscellaneous-manufacturing/557695-1.html

Holden, A., 1961. Concentration of chloride in fresh waters and rain water. *Nature*, *192*, 2.

Interlandi, & Crockett, 2003. Recent water quality trends in the Schuylkill River, Pennsylvania, USA: A preliminary assessment of the relative influences of climate, river discharge and suburban development. *Water Research*, *37*(8), 1737-1749.

Jones & Sroka, Bernae, 1997. Effects of highway deicing chemicals on shallow unconsolidated aquifers in Ohio. *U.S. Geological Survey*. U. S. Geological Survey.

Karraker & Ruthig, 2009. Effect of road deicing salt on the susceptibility of amphibian embryos to infection by water molds. *Environmental Research*, *109*(1), 40-45.

Karraker, Nancy E., James P. Gibbs, James R. Vonesh, 2008. Impacts of Road Deicing Salt on the Demography of Vernal Pool Breeding Amphibians. *Ecological Applications*: Vol. 18, No. 3, pp. 724-734.

Kaushal, Sujay, et al., 2005. Increased salinization of fresh water in the northeastern United States. *PNAS*, *102*, 13517-13520.

Kelly, Lovett, Weaterhs, Findlay, Strayer, Burns, et al., 2008. Long-Term sodium chloride retention in a rural watershed: Legacy effects of road salt on streamwater concentration. *Environmental Science and Technology*, *42*(2), 410-415.

LeClerc, Anne-Marie, 2005. Transports Quebec. Presentation to the World Road Association (PIARC). "Policy for Road Safety in Canada – Quebec." http://publications.piarc.org/ressources/documents/actes-seminaires05/c31-chine05/4-Anne_Marie-Presentation.pdf (Accessed 8/20/09).

Lee, Brook, Dabek-Zlotozynska, & Mabury, 2003. Identification of the major sources contributing to PM sub (2.5) observed in Toronto. *Environmental Science and Technology*, *37*, 4831-4840.

Lee, Hyomin et al. 2000. Effects of Various Deicing Chemicals on Pavement Concrete Deterioration in Mid-Continent Transportation Symposium 2000 Proceedings. http://ntl.bts.gov/lib/9000/9500/9557/Lee.pdf

Levelton Consultants Ltd., 2007: Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts. NCHRP Report 577. National Cooperative Highway Research Program, National Research Council, Washington, D.C.

Madden, Sean S., George R. Robinson, John G. Arnason, 2007. Spatial Variation in Stream Water Quality in Relation to Riparian Buffer Dimensions in a Rural Watershed of Eastern New York State. *Northeastern Naturalist*, 14, (4), 605-618.

Maine Bureau of Motor Vehicles. Total licensed drivers are 1,009,688 and total registered vehicles are 1,548,272 of which a portion are either trailers or farm vehicles. http://www.maine.gov/sos/bmv/stats/reg08.htm (accessed 5/12/2009).

Maine Department of Environmental Protection, 1999. Bureau of Land and Water Quality. 1999 Assessment Prioritization and Environmental Impacts of Uncovered Sand/Salt Piles.

http://www.maine.gov/dep/blwq/docstand/sandsalt/prioritization.htm#Impact%20on%20Private%20Water%20Supplies.
Maine Department of Transportation, 2002. Maine's Transportation System: Status and Trend Indicators of Economic Growth and Quality of Life.
Maine Department of Transportation, 2003. Transportation Research Division. Technical Report. Comparison Tests of Liquid Calcium and Salt Brine: A Controlled Experimental Evaluation of Rock Salt in Pre-Wetting Liquids.
Maine Department of Transportation, 2004. Transportation Research Division. Comparison Tests of Deicing Liquids on Snow Plow Routes in Northern Maine. Technical Report 04-06.
Maine Department of Transportation, 2005. Maine Salt and Sand Pile Program: http://www.maine.gov/dep/blwq/docstand/sandsalt/history.htm
Maine Department of Transportation, 2006. Transportation Research Division, Documentation of Liquid Deicing Agents Utilized During the Winter of 2005-2006. Problem Solving 06-6.
Maine Department of Transportation, 2007. "Snow and Ice Control Policy 10-1-2007".
Maine Department of Transportation, 2008a. Personal communication, November.
Maine Department of Transportation, 2009a. "Public Road Centerline Mileage by County," https://www.maine.gov/mdot/maines-transportation-systems/documents/StateTotal08.pdf , accessed 1/9/09.
Maine Department of Transportation, 2009b, electronic mail, William Thompson, September 08, 2009.
Maine Department of Transportation, 2009c, Personal communication, Feb. 2010.
Maine Municipal Association, 2008. 2007 Fiscal Survey Report. Available online http://www.memun.org/public/local_govt/DATA_tax/fiscalsurvy/2008/2007%20Fiscal%20Survey%20Report.pdf (accessed 9/2009).
Maine Turnpike Authority, 2008. "Snow and Ice Control Policies and Procedures: 2008-09".
Mason, Norton, Fernandez, & Katz, 1999. Deconstruction of the chemical effects of road salt on stream water chemistry. *Journal of Environmental Quality*, *28*, 82-91.
Mayer, T, Snodgrass, & Morin, 1999. Spatial characterization of the occurrence of road salts and their environmental concentration as chlorides in Canadian surface waters and benthic sediments. *Water Quality Resource Journal of Canada*, 34(4), 545-574.
Mends, N. and P. Carter. 2002. "Economic Impact of Magnesium Chloride Anti-Icing on Montana Bridges." p. 739-744, Canadian Society for Civil Engineering,. (Cited in NCHRP Report 577).
Miklovic, & Galatowitsch, 2005. Effect of NaCl on typha augustifolia L. On marsh community establishment: A greenhouse study. *Wetlands*, *25*(2), 420-429.
Mineau, & Brownlee, 2005. Road salts and birds: An assessment of the risk with particular emphasis on winter finch mortality. *Wildlife Society Bulletin*, *33*(3), 835-841.
Minnesota Department of Transportation, 2001. I-35W & Mississippi River Bridge Anti-icing Project. Operational Evaluation Report, July 2001. http://www.dot.state.mn.us/i35wbridgedata/groupwise/September-December-2002/attachments/AntiIcing%20Evaluation%20Report83837249-885b-5905-62e7-96b15b2752c2.doc (Accessed 5/9/09)
Minnesota Department of Transportation, 2002. Anti-icing/Deicing System. http://www.dot.state.mn.us/i35wbridgedata/groupwise/May-August-2002/attachments/MnDOTanti-icingCaseReview0e2a42e8-7c5b-8b23-311f-ba5e82cfd665.doc (Accessed 5/9/09)

Minnesota Department of Transportation, 2004. Guidelines for Anti-icing. http://www.dot.state.mn.us/maint/research/chemical/Guidelines%20for%20Anti-icing%20-Public.pdf (Accessed 5/9/09).
Minnesota Department of Transportation, 2005. Minnesota Snow and Ice Control Field Handbook for Snowplow Operators. Manual 2005-01. http://www.dot.state.mn.us/research/documents/snowicecontrolhandbook.pdf (Accessed 5/9/09)
Minnesota Department of Transportation. 2008a. Statewide Mileage and Land Miles. http://www.dot.state.mn.us/roadway/data/reports/2008/mileage_lanemiles/fzstmccs.xls (Accessed 6/5/09).
Minnesota Department of Transportation. 2008b. Snow and Ice Fact Sheet. Winter 2007-2008 http://www.dot.state.mn.us/i35wbridge/legislative/dec-10-lac/2007-2008snowicefactsheet.doc (Accessed 6/5/09)
Minnesota Pollution Control Agency, 2006. Winter Parking Lot and Sidewalk Maintenance Manual http://www.pca.state.mn.us/publications/parkinglotmanual.pdf (Accessed 5/19/09)
Minnesota Pollution Control Agency. 2008. MPCA Road Salt Education Program. http://www.pca.state.mn.us/programs/roadsalt.html (Accessed 5/19/09)
Molot, & Dillon, 2008. Long-Term trends in catchment export and lake concentration of base cations in the Dorset study area, central Ontario. *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(5), 809-820.
Moore, Niering, Marsicano, & Dowdell, 1999. Vegetation change in created emergent wetlands (1988-1996) in Connecticut. *Wetland Ecology and Management*, *7*, 177-191.
Morin, D. and M. Perchanok. 2000. *Road salt loadings in Canada.* Supporting document for the road salts PSL assessment. Report submitted to the Environment Canada CEPA Priority Substances List Environmental Resource Group on Road Salts, May 2000. Commercial Chemicals Evaluation Branch, Environment Canada, Hull, Quebec. 85 pp.
Mullaney, J.R., Lorenz, D.L., Arntson, A.D., 2009, Chloride in groundwater and surface water in areas underlain by the glacial aquifer system, northern United States: U.S. Geological Survey Scientific Investigations Report 2009–5086, 41 p.
NCHRP, 2004a. Environmental Stewardship Practices, Procedure and Policies for Highway Construction and Maintenance. Center for Environmental Excellence by AASHTO Best Practices, Chapter 8.1.1 NCHRP Project 25-25 (04).
NCHRP, 2004b. Report 526: Snow and Ice Control: Guidelines for Materials and Methods. Transportation Research Board, Washington, D.C.
New Hampshire Department of Environmental Services. February, 2009. "Keeping Our Roads Safe on a Low Salt Diet," GREENWorks: Ideas for a Cleaner Environment. Concord, NH, http://des.nh.gov/organization/commissioner/pip/newsletters/greenworks/documents/09feb.pdf (Accessed 5/11/2009.)
NHDOT. Winter Maintenance Snow Removal and Ice Control Policy. http://www.nh.gov/dot/org/operations/highwaymaintenance/documents/WinterMaintSnowandIcePolicy.pdf (Accessed May 7, 2009).
Nielsen, Brock, Petrie, & Crossle, 2007. The impact of salinity pulses on the emergence of plant and zooplankton from wetland seed and egg banks. *Freshwater Biology*, *52*(5), 784-795.

Nixon, Wilfred et al., 2007 Evaluation of Deicing Materials and Corrosion Reducing Treatments for Deicing Salts. Iowa Highway Research Board Project TR-471.

Nixon, Wilfred. 2009: "National Advances in Winter Maintenance" Presentation at 8th Annual Road Salt Symposium, Feb. 2009. Minnesota.

Novotny, Murphy, & Stefan, 2008. Increase of urban lake salinity by road deicing salt. *Science of the Total Environment*, *406*(1/2), 131-144.

O'Keefe, Katie and Xianming Shi, 2006. "Anti-Icing and Pre-wetting: Improved Methods for Winter Highway Maintenance in North America" TRB 2006 Annual Meeting CD-ROM.

Panno, Hackley, Hwang, Greenberg, Krapac, Landsberger, et al., 2006. Characterization and identification of NaCl sources in ground water. *Ground Water*, *44*(2), 176-187.

Paschka, M. G., Ghosh, R. S. and Dzombak, D. A., 1999. Potential water-quality effects from iron cyanide anti-caking agents in road salt. *Water Environment Research*, *71*, 1235-1239.

Pienitz, Roberge, & Vincent, 2006. Three hundred years of human-induced change in an urban lake: Paleolimnilogical analysis of Lac Saint-Augustin, Quebec City, Canada. *Canadian Journal of Botany*, *84*(2), 303-320.

Pugh et al., 1996. Interactions between peat and salt-contaminated runoff in Alton Bog, Maine, USA. *Journal of Hydrology* Volume 182, Issues 1-4, July 1996, Pages 83-104.

Ramstack, Fritz, & Engstrom, 2004. Twentieth century water quality in Minnesota lakes compared with presettlement variability. *Canadian Journal of Fisheries and Aquatic Sciences*, *61*(4), 561-576.

Reinosdotter, & Viklander, 2007. Road salt influences on pollutant releases from melting urban snow. *Water Quality Research Journal of Canada*, *42*, 153-161.

Rhodes, Newton, & Pufall, 2001. Influences of land use on water quality of a diverse New England watershed. *Environmental Science and Technology*, *35*, 3640-3645.

Richburg, Patterson, & Lowenstein, 2001. Effects of road salt and phragmites australis invasion on the vegetation of a western Massachusetts calcareous lake-basin fen. *Wetlands*, *21*, 247-255.

Riversides Stewardship Alliance and Sierra Legal Defence Fund. 2006. "A Low-Salt Diet for Ontario's Roads and Rivers". February, 2006.

Road Talk. 2009a. "Corrosion Inhibitor Tests: The Results Are In" in Ontario's Transportation Technology Transfer Digest. Vol. 15, Issue 1, Winter 2009. http://www.mto.gov.on.ca/english/transtek/roadtalk/rt15-1/#a2 (Accessed 8/15/09)

Road Talk, 2009b. "MRO's First Pervious Concrete Pavement Trial", in Ontario's Transportation Technology Transfer Digest, Vol. 15, Issue 2, Spring 2009. http://www.mto.gov.on.ca/english/transtek/roadtalk/rt15-2/#a4 (Accessed 8/15/09)

Rosenbury, Bukaveckas, Buso, Likens, Shapiro, & Winter, 1999. Movement of road salt to a small New Hampshire lake. *Water, Air and Soil Pollution*, *109*, 179-206.

Rosfjord, Catherine H., et al., 2007. Anthropogenically Driven Changes in Chloride Complicate Interpretation of Base Cation Trends in Lakes Recovering from Acidic Deposition. *Environmental Science & Technology, 41*(22), 7688-7693.

Salt Institute, 2008a. "Will You Have Enough Salt This Winter?" in Salt & Highway Deicing, vol 45. no. 4, Fall 2008. http://www.saltinstitute.org/content/download/4419/23972 (accessed Feb. 6, 2009).

Salt Institute, 2008b. http://www.saltinstitute.org/Production-industry/Facts-figures/US-production-sales

Salt Institute. 2007. “The Snowfighter’s Handbook: A Practical Guide for Snow and Ice Control.”

Santo and Hecnar, 2006. “Effects of Road Deicing Salt on Larval Wood Frogs (Rana Sylvatica)”. In Environmental Pollution, vol. 140, issue 2, March 2006. 247-256.

Sears Ecological Applications Company, LLC (SEACO), http://www.seaco.com, (accessed 7 October 2009).

Sedransk, K., 1999. Road Salt Dispersal into the Environment. *Ohio Journal of Science.* Vol. 99, no. 1, pp. A-10. Mar 1999.

Siver, Lott, Cash, Moss, & Marsicano, 1999. Century changes in Connecticut, U.S.A, lakes as inferred from siliceous algal remains and their relationship to land-use change. *Limnology and Oceanography*, *44*, 1928-1935.

Shi, Xianming et al., 2009. Inhibitor Longevity and Deicer Performance Study. Western Tranportation Institute

Shi, Xianming, et al., 2009. Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers, Phase 1. Colorado Department of Transportation, February 2009.

South Dakota DOT, 2008 The Deleterious Chemical Effects of Deicing Solutions on Portland Cement Concrete. SD2002-01 Final Report. USDOT FHWA. http://www.state.sd.us/Applications/HR19ResearchProjects/index.htm

Stefan, H., Novotny, E. Sander, A. and Mohseni, O., 2008. Water Quality in the Twin Cities Metropolitan Area, Minnesota. Final Report. University of Minnesota. MNDOT. Sept. 2008.

Taylor & Associates and The Center for the Environment, Plymouth State University, 2008. Potential Solutions for Reducing Road Salt Use in New Hampshire: A Report to the I-93 Salt Reduction Workgroup.

TCA, 2009. Truckload Carriers Association. http://www.truckload.org/members/infocenter/stories/HDT_01_killerchemicals.shtml (accessed Nov. 2008)

Thunqvist, 2004. Regional increase of mean chloride concentration in water due to the application of deicing salt. *Science of the Total Environment*, *325*, 29-37.

Trahan, Nicole and Curt Peterson, 2008. “Impacts of Magnesium Chloride-Based Deicers on Roadside Vegetation.” Transportation Research Circular E-C126. Transportation Research Board. 2008. pp. 171-186.

Transportation Association of Canada. 2003. Syntheses of Best Practices Road Salt Management. “1.0 Salt Management Plans.” September 2003.

Transportation Research Board, 1991. Highway Deicing: Comparing Salt and Calcium Magnesium Acetate. Special Report 235. Transportation Research Board, National Research Council, Washington, D.C. 1991. http://onlinepubs.trb.org/onlinepubs/sr/sr235.html

Transports Quebec. 2008. Road Network Conditions Online. http://www.quebec511.gouv.qc.ca/en/

Trombulak, & Frissell, 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology*, *14*(1), 18-30.

Turtle, Sarah L., 2000. Embryonic Survivorship of the Spotted Salamander (Ambystoma maculatum) in Roadside and Woodland Vernal Pools in Southeastern New Hampshire. *Journal of Herpetology*, Vol. 34, No. 1 pp. 60-67.

U.S. Census Bureau. 2007. "Table 2: Population Estimates for the 100 Most Populous Metropolitan Statistical Areas Based on July 1, 2006 Population Estimates: April 1, 2000 to July 1, 2006". http://www.census.gov/Press-Release/www/releases/archives/cb07-51tbl2.pdf. (Accessed 5/14/2009)

U.S. Department of Transportation, 1994. Federal Highway Administration, Technical Advisory Motor Vehicle Accident Costs, T 7570.2, October 31, 1994

University of New Hampshire. 1996. Manual of Practice for Anti-icing of Local Roads. October, 1996. UNH Technology Transfer Center.

UNH T2 Center, 2007. “Dover NH Salt Brine Research Project.” Road Business. Winter 2007, vol. 22. no.4.

USDOT, 2008, "Highway Statistics Publications, Highway Finance Tables SF-4C and LGF-2," 1997 to 2005, http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm . Cited on FHWA website: http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm, accessed 7 October 2009.

USDOT FHWA Office of Highway Policy Information, 2009. http://www.fhwa.dot.gov/ohim/hbs/nh.htm (Accessed May 7, 2009).

USEPA, 2005. “What you should know about safe winter roads and the environment.” EPA 901-F-05-020, http://www.maine.gov/mdot/iceandsnow/pdf/EPAwinterfacts.pdf

USEPA, 2003. Final Administrative Determination Document on the Question of Whether Ferric Ferrocyanide is one of the "Cyanides" Within the Meaning of the List of Toxic Pollutants Under the Clean Water Act. October 6, 2003

USEPA, 1999. Office of Water, Storm Water Management Fact Sheet: Minimizing Effects from Highway Deicing. Publication EPA 832-F-99-016. September, 1999

Viskari, Eeva-Liisa and Lauri Karenlampi, 2000. Roadside Scots Pine as an Indicator of Deicing Salt Use - a Comparative Study from Two Consecutive Winters. *Water, Air and Soil Pollution*, *122*, 405-419.

Wang, Kejin, 2006, Damaging effects of deicing chemicals on concrete materials. In *Cement and Concrete Composites*, vol. 28, issue 2, Feb 2006, 173-188.

Warren, & Zimmerman, 1994. The influence of temperature and NaCl on cadmium, copper, and zinc partitioning among suspended particulate and dissolved phases in an urban river. *Water Resource Abstracts*, *28*, 1921-1931.

Weber, Rick, 2004. “Corrosion Explosion” Trailer-Body Builders. http://www.trailer-bodybuilders.com/mag/traucks_corrosion_explosion/index.html (accessed 11/2008)

Wegner, William and Marc Yaggi, 2001. “Environmental Impacts of Road Salt Alternatives in the New York City Watershed”. Stormwater May/June 2001.

Werner, & DiPretoro, S., 2009. Rise and fall of road salt contamination of water-supply springs. *Environmental Geology*, *51*(4), 537-543.

Williams, Dudley, Nancy Williams, and Yong Cao, 2000. Road salt contamination of groundwater in a major metropolitan area and development of a biological index to monitor its impact. *Water Research*, *34*(1), 127-138.

Williams, Harvey, 2001. “Gazing into a Crystal Snowball” in Roads & Bridges, September 2001. Vol. 39, no.9.

Wing, Linda, 2004. End of the Road for Hexavalent Chromium. *AEI Material Innovations*, June 2004. p. 43-45.

Xi, Yunping and Zhaohui Xie, 2002. Corrosion Effects of Magnesium Chloride and Sodium Chloride on Automobile Components. Colorado DOT Report CDOT-DTD-R- 2002-4. http://www.dot.state.co.us/publications/PDFFiles/MagAutoCor.pdf

Appendix 1: Members of the Advisory Committee

Tom	Brown	President		Maine Auto Dealers Association	Augusta
Bob	Burns	Public Works Director	MCAPWA	City of Gorham, Public Works Department	Gorham
Phillip A.	Curtis	Road Consultant			Madison
Maurice J.	Dionne	Safety Investigator		Federal Motor Carrier Safety Administration	Augusta
Kate	Dufour			Maine Municipal Association	Augusta
Robert S.	Duschesne	Representative District 13	JS Committee on Natural Resources	Maine State Legislature	Old Town
Perry	Ellsworth	Town Manager, Rangeley		Maine Town & City Management Association	Rangeley
Christopher	Grotton	CO	Traffic Safety Unit	Maine Public Safety	Augusta
Gerry	James	Public Works Director	MCAPWA	City of Presque Isle, Public Works Department	Presque Isle
Erich	Kluck	Environmental Hydrogeology Manager		Maine Department of Environmental Protection	Augusta
Jeff	McEwen	FHWA division office safety engineer		Federal Highway Administration	Augusta
Joe	McNeil	Bus Superintendent	BAT	Maine Transit Association	Bangor
Pat	Moody			AAA	Portland
Brian	Parke	Vice President		Maine Motor Transport Association	Augusta
Ann	Peoples	Representative District 125	Joint Standing Committee on Transportation	Maine State Legislature	Westbrook
Charles	Schalk	Dr.		USGS WRD	Augusta
Ray	Simond			Maine Custom Auto Association	Lewiston
William	St. Michel	President		Maine Fire Chiefs Association	Durham

Gregory J.	Stone	Director of Highway Safety		Maine Turnpike Authority	Portland
Steve	Timpano	Environmental Coordinator		Maine Department of Inland Fisheries and Wildlife	Augusta
Sara	Trafton			Maine Transit Association	Sanford
Dana	Wardwell	Director of Operations	MCAPWA	City of Bangor, Public Works Department	Bangor

Appendix 2: Environment References

Table 1: Water Quality

Environment	Year	Topic/Subject	Key Findings	Reference	I.D.
SW	1990	Streams in Adirondacks (NY)	Chloride increased by a factor of 31; Effects last more than 6 months	Demers & Sage	1
SW	1994	Salt & metal transport	Salt in water increases mobility of cadmium, copper, and zinc	Warren & Zimmerman	2
GW	1995	Roadside ditches (MA)	Significant increases in sodium and chloride by highways	Granato et al.	3
SW	1996	Salt effects on bogs (ME)	Elevated concentrations of sodium and chloride within 100 m of highway; Peat attenuates changes in chemistry	Pugh et al.	4
SW	1997	Salt accumulation or loss in snowbanks (ONT)	Approximately 39 to 65% of road salt applied is lost in runoff; Remainder is stored in snowbanks	Buttle & Labadia	5
SW	1998	Sodium acetate/formate use	Use of acetate and formate can cause dissolved oxygen to decline in surface waters.	Bang & Johnston	31
SW	1999	Long-term study lake (NH)	Stream chloride increased by a factor of 10 in 23 years; Lake chloride increased by a factor of 3	Rosenberry et al.	6
SW	1999	Salt and stream chemistry (ME)	Road salt increases chloride, calcium, potassium, magnesium, and sodium in streams; Effects are reversible but storage in watershed is important; Peak concentrations occur in spring and fall	Mason et al.	7
SW	1999	Spatial chloride patterns (CAN)	Strong chloride in water correlations with developed areas (roads); On average road salt accounts for 40% of all chloride in run-off	Mayer et al.	8
SW	1999	Salt leachate & precipitation effects on lakes (OH)	Amount of precipitation controls migration; Elevated concentrations (4 to 10X) in water persist at least 4 months	Sedransk	9
SW & GW	1999	Iron cyanides in road salt	Effects on water quality are limited in extent (time or space); Not well studied concern	Paschka et al.	10
GW	2000	Springs near Toronto (ONT)	Chloride ranged from <2 to 1200 mg/L in direct relationship to amount of urbanize area	Williams et al.	11
SW	2001	Mill River (MA)	Road salt has acidifying effect on river water	Rhodes et al.	12
SW	2001	Land uses and water quality (MA)	Salt effects associated with development and roads; Year-round effects include elevation sodium and chloride and acidification	Rhodes et al.	13

Environment	Year	Topic/Subject	Key Findings	Reference	I.D.
GW	2003	Springs in Cuyahoga Falls (OH)	Road salt detected in springs; Localized problem by roads	Foos	14
SW	2003	50 years data for Mohawk River (NY)	Chloride increased by 243% while population declined	Godwin et al.	15
SW	2003	Schuylkill River trends (PA)	Increases of sodium and chloride greatest in the winter; Increases noted over several decades	Interlandi & Crockett	16
SW	2004	Basin analysis (Sweden)	Roads contribute 50% of basin loading for sodium and chloride	Thunqvist	17
SW	2004	20^{th} century trends (MN)	Urbanization increases sodium and chloride concentrations	Ramstack et al.	18
GW	2006	Urban well field (ONT)	Wells contaminated by road salt; Model studies indicate decades needed to reduce chloride concentrations	Bester et al.	19
GW	2006	Springs near storage sites (WV)	Chloride in discharge >500 mg/L; Chloride approaches background concentrations in about 5 years	Werner & diPretoro	20
GW	2006	Mapping sources of Na & Cl (IL)	Ground water can be contaminated by sodium and chloride from different sources; Road salt has a unique chemical signature	Panno et al.	21
SW	2007	Riparian buffers (NY)	Forested buffers store and leak salt; Small order streams most likely leak road salt through buffers	Madden et al	22
SW	2007	Long term trends in lakes (northeast)	Significance increase in chloride near urban areas and 18% of rural lakes; Increase = 133 μeq/L (4.7 mg/L) in 20 years.	Rosfjord et al.	23
SW & GW	2008	Catchment Study (Germany)	Road salt accounts for 35% of the variability observed in water chemistry; Relationships are complex; Conclusions from one sample are meaningless	Lischeid et al.	24
SW	2008	20 year catchment study (ONT)	Sodium increased 250 to 350%	Molot & Dillon	25
SW	2008	Nine year watershed study (NY)	Chloride increased 1.5 mg/L/year; Road salt = 91% of annual input, Increases in export linked to storage and release lags	Kelly et al.	26
SW	2008	Urban lake chemistry (MN)	Chloride concentrations are 10 to 25 times background; highest concentrations occur in winter to spring and at depth; salt contamination has stopped turnover in some ponds	Novotny et al.	27
SW	2009	Airport runoff (WI)	Airport deicing runoff can exceeds aquatic life standards for acetates and chloride. Effects measurable up to 5 kilometers downstream.	Corsi et al.	28
SW	2009	Catchment study (England)	Road salt cause a loss of soil dissolved organic carbon.	Green et al.	29
GW & SW	2009	Chloride in water (northern U.S.)	Road density, potential evapotranspiration, and annual rainfall are predictive of chloride concentrations in water.	Mullaney et al.	30

Table 2: Ecological Impact

Organism	Year	Setting	Key Findings	Reference	I.D.
Moose	1982	Roadside pools	Fatalities are greatest near salt affected pools	Fraser & Thomas	28
Biota	1998	Lab Toxicity	Sodium Acetate/Formate deicer relatively harmless to plants and animals.	Bang and Johnston	46
Plants	1999	Constructed wetland (CT)	Runoff with up to 300 ppm chloride favors invasive species	Moore et al.	29
Algae	1999	100 year lake record (CT)	Development in watershed causes species shifts (salt tolerant)	Siver et al.	30
Biota	2000	Toronto wetlands (ONT)	Chloride contamination index (power law); identified salt tolerant species; absence of amphipod Gammarus pseudolimneon and presence of stonefly nymphs indicate high chloride	Williams et al.	31
Scots Pine	2000	Roadside (Finland)	Needles affected 20-30 meters from road; damage caused by aerosols	Viskari & Karenlampi	32
Numerous	2000	Four-lane highway (MA)	The effective ecological footprint including salt for the highways was estimated to be 600 meters wide	Foreman & Deblinger	33
Frogs	2000	Vernal pools	Salt decreases survival of frogs	Turtle	34
Reeds	2001	Fen near road (MA)	Chloride detected in fen at >54 mg/L 300 meters from road; invasive phragmites is salt tolerant; salt decreases species richness	Richburg et al.	35
Macroinvert-ebrates	2001	Wetlands (MI)	Chloride at 18-2700 mg/L affects various species	Batzer et al.	36
Plants	2001	Lab & Field Toxicity Experiments	Sodium- EC25= 200-270 ppm herbaceous/67.5-300 ppm woody Chloride- EC25= 215-1500 ppm herbaceous/215-500 ppm woody	Cain et al.	37
Cattails	2005	Wetland restoration	Cattail is salt tolerant; increased salt concentrations decrease species diversity	Miklovic & Galatowitsch	38
Birds	2005	Winter finch habits (ONT)	Consumption of road salt causes salt toxicity	Mineau & Brownlee	39
Lake Ecology	2006	300 year lake analysis (QUE)	Cultural eutrophication was noted along with transition to salt-tolerant diatoms	Pienitz et al.	40
Blueberries	2006	Roadsides (MI)	Road salt decreases winter hardiness & survival rates	Berkheimer & Hansom	41
Aquatic Biota	2007	Road run-off (Australia)	High salt concentrations persist and decreases ecological richness; short saline pulses impair zooplankton	Nielsen et al.	42
Frogs	2008	Vernal pools	Salt decreases survival of frogs	Karraker	43
Various	2009	US EPA Toxicity tables	Data for terrestrial animal (3) and plant (4) species range over three orders of magnitude (10-1,000's ppm);	US EPA	44

Organism	Year	Setting	Key Findings	Reference	I.D.
			Data for aquatic animal (35) and plant (5) species range over six orders of magnitude (1-1,000,000's ppm).		
Amphibians	2009	Breeding pools	Salt had small effect on survivability; salt increases signs of stress	Karraker & Ruthing	45
Various Biota	2009	Lab & Airport	Runoff may exceed aquatic-life standards.	Corsi et al., 2009	47

Appendix 3: Summary of Stakeholder Comments

This appendix documents stakeholder input from breakout groups at the four stakeholder meetings held in Sept, 2009. Below are the meeting schedule, agenda, instructions for the breakout discussion groups, and transcriptions of flipcharts from each breakout group.

LOCATIONS	***DATES***	***STAKEHOLDERS***
Portland	Wed., Sept. 9	28
Belfast	Fri., Sept. 11	21
Presque Isle	Mon., Sept. 14	17
Farmington	Wed,, Sept. 16	22

MEETING AGENDA 8:30 – 12:00

- Welcome & Introduction
- Presentations (see powerpoint slides, Appendix ___)
  - Road Salt Risk Project Description
  - Road Salt Practices and Materials
  - Road Salts and the Environment
  - Road Salts and Corrosion
  - Road Salts and Safety
- Stakeholder Discussion and Input
  - Breakout Group Idea Development
  - Summary Reporting

BREAKOUT GROUP INSTRUCTIONS AND FLIPCHART NOTES

Stakeholder Meetings
September 2009

Your Thoughts

Your table constitutes a discussion group. As a group, use an available flip chart to summarize your thoughts about winter road maintenance here in Maine: Salt, safety, cost, levels of service, environmental impact, other issues – you name it.

Here are four questions as a framework for your discussion:

1. **Stakeholders.** *Who is at your table*?
   a. Names, if you like (this is optional)
   b. Where everyone works

2. **Oh-oh.** What *three issues or policies are of most concern* to the group? For each item, summarize . . .
   a. What it is
   b. Why it is important
   c. What to do about it

3. **Priorities.** Road crews operate under different levels of service for different types of roadways. The level of service affects accident rates, our ability to travel, and road service budgets. From your own driving experience, *how appropriate are current levels of service* in dealing with winter roads?

4. **Okay**. *What is good* and should stay as it is?
   a. Top example(s)
   b. Consequences if changed

* * *

Before we adjourn today, be ready to report your thoughts to everyone in the room. Thank you for your input.

Flipchart Notes from Each Group

Group A

Stakeholders

Public drinking water
Public works (2)
Soil and water conservation district
MDEP

Oh-Oh

	What	Why Important	What To Do
a.	Winter road maint./corrosion	Cost; safety	Upgrade road conditions so less maint. & salting is needed (can be a touch sell → $); education
b.	Safety	Cost; people's expectations	Better roads; keep improving vehicles, educ., signage; enforcement & educ. on speed limits
c.	Environmental impacts (Cl^- more of an issue) & drinking water (Na^+ more of an issue)	Cost; meeting state regs.; few, if any, BMPs for chloride (difficult to treat)	Need more baseline water quality data around state; porous pavement may prove useful (freezes less), though jury still out; educaton

Group B

Stakeholders

MTA
DOT
MMTA

Oh-Oh

LOS vs. safety vs. cost – Public expectation drives this
Clean up roads as quickly as possible
Environmental costs

Priorities

Current LOS are a good balance

Okay

- Examples
  - Pre-treatment 100#/lane miles
    - Crashes occur at beginning of storm
  - Snow-fighter tools & techniques
    - Newer tech: computerized spreading
- Consequences [if changed]:
  - Decreased LOS
  - Would public slow down?

Group C

Stakeholders

- Trucking
- Trucking Fleet
- Trucking
- MDOT

Oh-Oh

- Corrosion
  - Equipment corrodes
  - Higher maint. costs
  - Frequent repairs due to corrosion
  - Anti-corrosive additives
- Infrastructure
  - Condition of bridges and roadways
  - Continual deterioration with lack of funding
- Increased maintenance costs
  - Increased washing of equip. w/concern of environ. impacts

Priorities

- Maintaining a current level of service on interstate corridors
- Monitor and adjust accordingly for off-corridor roadways
- Enhanced training

Okay

- LOS on interstate corridors

Group D

Stakeholders

- Soil and Water Conservation District
- Municipal Public Works
- MaineDot (2)

Oh-Oh

- Salt impacts to fresh water
- Cost
- Level of service expectations
- Safety
- Triangle: Balance safety, environment, cost/LOS

Priorities

- LOS is good/appropriate
- Expectations too high
- Driver behavior/education

Okay

- Safety improvements/progress
- Environmental considerations
- Using new technologies
- Maintain <u>balance</u>

Group E
Stakeholders
Soil and Water Conservation District
Municipal Public Works
MaineDOT
Oh-Oh
Expectations
Lower service vs. safety/economy (dedicated crew)
Cost analysis
Total & long term
Priorities
Lower expectations [for] level of service
Okay
Continual reevaluation
Growing knowledge of materials

Group F
Stakeholders
Gov't – state & local
Oh-Oh
Finances
Declining revenue
Competing economic & environmental interests
Safety
Public well-being
Education – changing public perceptions and behavior
Taxpayer expectations
LOS
Human nature, education
Priorities
Appropriate
Perhaps on high end
Difficult to maintain (existing) LOS
Okay
LOS – safety standpoint
[If changed,] increased accidents, economic impact

Group G

Stakeholders

- DOT
- Municipal Selectman
- Municipal Public works director
- Municipal Road committee, budget committee

Oh-Oh

- [issues]
  - Veiw 1
    - Amount of material used
    - Corrosion
    - Driver behavior
  - View 2
    - Driver behavior
    - Corrosion
    - Overwork of public works employees
    - Tools
  - View 3
    - Driver behavior
    - Not using enough material in some towns – inconsistency
  - View 4
    - Driver education/behavior
      - Winter maint. practices
      - Maint. education
      - Driver education for winter driving
    - Limit legislation outlawing winter tools (calcium chloride)
- [what to do]
  - Driver behavior/education
    - Ads, flyers, training, town newsletter, web page, town meeting, email
  - Appropriate use of material, tools, & manpower
  - Limit decisions by uneducated people, townspeople, selectmen, legislators (CaCl)

Priorities

- LOS generally appropriate
  - State, interstate – about right
  - Local – excessive; great; excessive/side roads okay; okay with it

Okay

- Level of service is about where it should be
- Plowing may use too much salt (minor)
- Consequences [if changed]: expectations/behavior
  - More phone calls
  - Maybe more accidents
  - Damage to vehicles
  - Unhappy people

Group H

Stakeholders

- Utility Fleet vehicles (equipment corrosion)
- MaineDOT (learn)
- Municipal Fire Dept. (equip. corrosion, safety)
- Trucking (2) (corrosion)

Oh-Oh

- Corrosion
  - Cost: Specialized specs (up arrow)
  - 33% Repairs (up arrow)
  - 15 yrs
  - 10 yrs Longevity (down arrow)
- Environment
  - Natural resources
  - Water supply
  - Wildlife
- Overall cost
  - Operating cost
  - Preventative cost
- What to do about it:
  - Lower level of service – Limits exposure [for] environment, corrosion
  - Legislation – Encourage better public traction
  - Study on studded snow tires
  - Public education

Priorities

- LOS too good
  - Encourages public to drive in dangerous climate condition

Okay

- Clean white roads
- Limited non-use of roads
- Little interruption in commerce
- Consequences [of change]:
  - Poor roads
  - Interruption of commerce

Group I

Stakeholders

- MADA (2)
- Municipal
- Municipal
- MaineDOT

Oh-Oh

- Want ability to continue to use salt
  - Keep roads clear, makes it easier
  - Need to educate public to slow down
- Vehicle corrosion
  - Cost of safety
  - New/better quality steel
  - Rust proofing
- What do we do with rusted parts (environ. concern)
  - Can we save $ by using more environmentally friendly materials and less work on rusted parts

Priorities

- We've spoiled the public, raised their expectations
- To change minds will take increase in costs to taxpayers

Okay

- Roads being clear
- If LOS is reduced, will lead to more complaints and more crashes

Group J

Stakeholders

- Municipal (3)
- Truck dealer
- MaineDOT

Oh-Oh

- Safety – that's what we do
- Corrosion – financial
- Cost – budget

Priorities

- On a scale of 1-10: 8

Okay

- Dedication of public works professionals

Group K

Stakeholders

- Public works (3)
- Engineer
- Automotive

Oh-Oh

- Issues
  - LOS – what is expected of us
  - Cost –
    - To us
    - To the consumer: damages, accidents
  - Safety – Reduce accidents
- What we can do about it
  - Communication (PSA)
  - Manufacturing process
  - Efficiency

Priorities

- LOS – Too high! Affordability
- Base LOS on priority of roadways

Okay

- Provide safe roads
- [if not,] Consumer cost go up/accidents/commerce

Group L

Stakeholders

- Municipal Public works directors (3)
- Planners (2) – NMDC
- MaineDOT (1) – Maine

Oh-Oh

- Maintenance $$ costs
  - Budgets (sand/salt vs. salt/calcium)
  - Search for better options
- Product effectiveness/alternatives
  - Safety/costs/education (driver-related)
  - Search for better options
- Customer Satisfaction
  - Vehicle and property deterioration/safety
  - Search for better options

Priorities

- Satisfied (based on each town/county or MDOT level of priority)

Okay

- Status quo – Continue looking for cost-effective alternatives

Group M

Stakeholders

- Municipal (2)
- State (2)
- Private transportation (1)

Oh-Oh

- Costs, effectiveness, impact
- Consistency of road maintenance, suburbanization
- Societal issues – rush, rush
- Common sense issues – do you need to travel?
- Mindset, slow down, car preparedness
- Educate the public to road issues
- Emergency vehicles – need to travel – minimum service requirements

Priorities

- Emergency vehicles
- Appropriate right now

Okay

- Awareness of all issues
- "Progressive thought process to deal with changing conditions"
- Awareness = $$

Group N

Stakeholders

- Public works directors:
- Legislator
- Town manager:

Oh-Oh

- Safety – Human lives and economic costs
    - Get police to be more proactive in issuing citations for poor tires, etc.
    - Get people to slow down
- Costs vs. public expectations – Costs are high & driven by public expectations
    - Expectations are outrunning revenues
    - Monitor material use (computers)
    - Tailor material to class of roadway and conditions
    - Educate the public
- Environmental concerns – Groundwater contamination
    - Find alternatives (inhibitors)

Priorities

- Cut back on levels of service
- Get public to adjust its expectations
- Current service levels meet expectation <u>but</u> are too high

Okay

- Level of service is excellent
- If changed,
    - The public will be outraged
    - The economy will suffer

Schools will shut down
People will have to change their driving habits, learn to live with less

Group O

Stakeholders

Public works directors (2)
Transportation
MaineDOT (2)
Conservation (2)

Oh-Oh

Resources, safety, education, training
Dictates end results
Education [of workers and officials], training, snow/ice control plan, public educ.

Priorities

Safety, emergency response
Variable depending upon backup [for unavailable public works providers]

Okay

???

Group P

Stakeholders

Auto (2)
MDOT (3)
Municipal (2)
Mainers, outdoors people (?)

Oh-Oh

Issues
Corrosion – cost and safety (vehicles and bridges)
Cost [for] safety – limited $
Environment – whole ecosystem
What to do
<u>Education</u> – vehicle storage, prev. maint., early on and continuous
Less salt – LOS, technology, different products

Priorities

Generally good – Too good; encourages high speeds
People need to lower expectations in storms

Okay

Plowing LOS provided, couldn't be better
(but see [priorities, above])

Appendix 4: Literature Review of Crash, Weather and Winter Maintenance Interactions

Safety and weather

Eisenberg, Daniel PhD, Warner, Kenneth PhD. "Effects of Snowfalls on Motor Vehicle Collisions, Injuries, and Fatalities." American Journal of Public Health 95.1 (2005) : 120-124

Objectives
The purpose of this paper is to advance the literature of state and regional analysis of snowfall and its effect on accidents by conducting the first nationwide analysis that looks at the relationship between snowfall and automobile crashes based on their severity level (property damage only, non-fatal injury, or fatal crashes) from 1975-2000. Eisenberg also wanted to analyze how this relationship changed for the first snowfall of the year, which he defined as the first day of 0.5cm of snow after at least 100 days without such an event. Lastly Eisenberg then compared these results for different age groups to see how the first snowfall affected drivers <18, 30-50, and >65.

Data
Eisenberg used daily snowfall and accident counts for the 48 contiguous states making the unit of analysis to be state-day combination resulting in 429,253 potential observations after accounting for missing data. He used FARS (Fatal Accident Reporting System) to find daily fatal accidents from 1975-2000 for each state. He then used the NHTSA's State Data System for nonfatal-injury and property-damage-only accidents, which he took a subsample of 17 states during the 1990's. For snowfall variables he used the National Climatic Data Center's Cooperative Summary of the Day that collects daily weather measures from over 20,000 monitoring stations around the country. Station data was weighted based on their location to give a statewide daily value. Rain, sleet and dry days were also looked at for controls and as a benchmark.

Method
Bivariate analysis was conducted with chai-squared tests comparing traffic crash rates (although he only has annual state-VMT data that cant account for traffic reduction during a snowstorm) across different categories (dry days, rain days, nonfirst snow days, and first snow days). Multivariate analysis was also conducted using a negative binomial regression, which is a generalized version of the Poisson regression. It is expressed in terms of the Poisson and Gamma distributions in the following way:

$$C_{st} \sim Poisson(\mu_{st}),$$
$$\mu_{st} = e^{(X_{st}\beta + offset_{st} + u_{st})}$$
$$e^{u_{st}} \sim Gamma(\frac{1}{\alpha}, \frac{1}{\alpha})$$

Where C_{st} refers to the crash count for given state and time (days), X is a vector containing indicators of snowfall and non-snow precipitation as well as three indicator variable vectors representing fixed effects for each state, year and month. The fixed effects are used to capture seasonality and trends across geography and to protect against spurious relationships. "Offset" the exposure (traffic volume) for a given observation. Eisenberg notes that he only had annual VMT data for each state so this was a highly aggregated estimate and should affect the results significantly.

Results

Eisenberg reported the results in Incident Risk Ratios (IRR), which is the observed crash rate affected by snow divided by the benchmark crash rate from dry pavement. This table shows the results from the multivariate regression and includes the fixed effect indicator variables that were used to control for confounding variables such as varying level of safe drivers in each state and traffic volume.

	Fatal crashes, IRR (95% CI)	Nonfatal-Injury Crashes, IRR (95% CI)	Property damage only, IRR (95% CI)
Dry days	1.00	1.00	1.00
Rain days relative to dry days	1.06 (1.06,1.07)	1.19 (1.18,1.19)	1.15 (1.14,1.16)
Nonfirst snow days relative to dry days	0.93 (0.90,0.97)	1.23 (1.18,1.29)	1.45 (1.38,1.52)
First snow days relative to nonfirst snow days	1.14 (1.08,1.21)	1.04 (0.98,1.11)	1.01 (0.95,1.08)

As we can see Eisenberg shows a substantial increase in non-fatal accidents but a decrease in fatal accidents for regular snow days. First snow days however show an increase for all severity levels. Eisenberg did further analysis and found that there is a tapering off effect for fatal crashes for the first s snowfalls of the year.

He also compared these numbers to the three different age groups mentioned before and found that for drivers >65 there is a much higher fatal crash rate for the first snowfall but for a regular snowfall the rate is unchanged from dry days. Middle aged drivers ages 30-50 showed the highest fatal crash rates for regular snow days but had the lowest increase in fatalities for the first snowfall. These results are interesting but he mentions that there is the traffic volume used to calculate the rates were annual aggregated VMT and there is no way to account for what age group contributed to the traffic volume. Therefore these numbers shouldn't be looked at seriously.

Problems

In this summary I have noted a few shortfalls in the paper including Eisenberg's use of annual state VMT to calculate crash rates and not controlling for age-specific traffic volumes. In addition, by conducting a nationwide analysis, it would be very difficult to truly control for confounding variables such as regional differences and road type. For example, Northern Maine roads are not only carrying less traffic but they receive a much larger amount of snow than metropolitan Portland, ME. Also, Eisenberg's weather data is reported daily and does not tell the time of snowfall which could drastically alter the results. For example if there was 3 inches of snow reported for a day but it all fell at 2am and was off the roads by 6am, then the daily crash rate will most likely resemble a dry-pavement day and not a snow day. Eisenberg notes that the data is not perfect but cites his large sample size to account for some of the potential flaws.

Hermans, E, Brijs, T, Stiers, T, Offermans, C. (2006). The Impact of Weather Conditions on Road Safety Investigated on an Hourly Basis, in *Transportation Research Board 85th Annual Meeting,* January 22-26, 2006, Washington D.C.

Objectives
The goal of this paper is to find the best probabilistic model that estimates the effects of various weather variables on the number of road crashes on an hourly basis.

Method
Hermans et al. chose four different regression techniques in this study to test which model was the most accurate. The four he originally chose was a regular Poisson regression, a negative binomial (generalized version of the Poisson that allows for over dispersion), and a Zero-inflated version of each. The Zero-inflated model is described as a dual-state model where an observation passes through one stage to determine if its value is zero and if its not then it goes to a second stage where a Poisson or a negative binomial regression estimates it. All four models are given;

Poisson regression where y is the actual number of crashes and beta is the coefficients on the explanatory variables x:

$$P(Y_i = y) = \frac{e^{-\exp(\beta x_i)} \exp(\beta x_i)^y}{y!}$$

Negative binomial Should be used when the expected mean varies between observations which means that the mean does not equal the variance. Instead the parameter θ is used to measure the potential over-dispersion (this case we use r). If this parameter happens to equal zero then the negative binomial equals the Poisson regression. r, α are said to "shape respectively scale parameter of a gamma distribution with mean $\frac{r}{\alpha}$ and a variance of $\frac{r}{\alpha} + \frac{r}{\alpha^2}$ with the regression looking like:

$$P(Y_i = y) = \frac{\Gamma(r+y)}{\Gamma(r)y!}\left(\frac{\alpha}{\alpha + \exp(\beta x_i)}\right)^r \left(\frac{\exp(\beta x_i)}{\alpha + \exp(\beta x_i)}\right)^y$$

Zero-inflated versions
The Zero-inflated versions of the two models have the mathematical phrase:

$$\delta_{y=0}(\pi)+(1-\pi)$$

Multiplied to the beginning of each model where π and (1-π) equals the probability of the actual number of accidents *y* equaling zero.

Data
Hourly number of crashes and weather measurements from 37 weather stations on the primary Dutch highway system in 2002 were collected. The data was formed into 6 groups of explanatory weather variables: wind, temperature, sunshine, precipitation, weather indicators and visibility. The weather indicators were 6 indicator variables that switched to one if one of the following happened in the last hour: precipitation, fog, snow, hail and black ice.

Results

Best fit model
From the four models tested the negative binomial model best describes the data in most areas. The authors take a careful approach to testing for fit in each model. First the models are put through a stepwise regression where at each step variables are pulled out and the Akaike criterion is calculated. The model with the lowest Akaike value offers the best balance between fit and complexity. Secondly the Likelihood ratio test is performed by taking the difference in the log likelihood for two models and if the value exceeds the chai-squared critical value then the more complex model is chosen.

Weather results
For the snow and ice variables the min, max and median results are reported for their respective coefficients.

	min	med	Max
Snow	1.07	1.25	1.43
ice	.68	.86	1.2

Problems
Although the theoretical approach to this analysis is up-to-date and unique, there are still many shortfalls that could have strengthened it. For example, traffic volume is not in this analysis so there is no way of telling what effect exposure had on the crashes compared to weather. According to Fridstrom, exposure accounts for 70% of the variation in crashes and to not include it is misleading.

Knapp K, Smithson LD, Khattak AJ. "The Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment." *Mid-Continent Transportation Research Symposium Proceedings.* (2000) 67 – 71

Objectives
The two main objectives in this paper were to use several Iowa information management systems to analyze the effects of winter weather on traffic volume and crashes. Citing various sources that have already attempted to find such numbers, Knapp et al. hoped to find more precise

numbers with more detailed data sources. Their goals of this project were to determine the potential impacts of winter weather, support the eventual development of a dynamic winter weather drivability level of service program, and assist with planning preventive and emergency operations.

Data

Knapp used roadway weather information systems (RWIS), automatic traffic recorders (ATR), and a high tech accident database in Iowa for road crashes called ALAS (Accident Location and Analysis System). They also used National Weather Service (NWS) data for certain weather variables. They then chose seven sections of Interstate to monitor weather, traffic volume and accidents for three winters staring in 1995. For a winter event to classify as a measureable storm it had to meet four criteria: 1) precipitation occurring, 2) air temperature below freezing, 3) wet pavement surface and 4) pavement temperature had to be below freezing. Their goal was to limit their research to only significant storms.

Method

Volume analysis

A regression analysis was used to find the relationship between percent traffic volume reduction with the explanatory variables as storm event duration, snowfall intensity and total snowfall, minimum and maximum average wind speed, and maximum gust wind speed.

Safety analysis

A Poisson regression was used to model the relationship between crash frequency during snowstorms and the following explanatory variables: Exposure (length of road segment * vehicle volume), snowstorm duration, snowfall intensity, and maximum wind gust speed.

Results

The results for the volume analysis only showed two significant relationships of percent volume reduction and the explanatory variables of total snowfall and the square of maximum wind speed. Both relationships were positive with the coefficient on snowfall (cm) as 0.90 and wind speed as 0.011. The snowfall result can be as interpreted as with 0.90cm there is a 1% reduction in traffic volume. Out of the 64 winter storm events used, the average reduction was 29%. Out of 54 of those storms the average crash frequency was 5.86 per mvkm compared to a non-storm crash rate of 0.41 per mvkm. The crash regression showed a significant relationship between winter storm event crash frequency, exposure, and snowfall intensity.

Problems

Although this analysis was carefully done it still did not account for the different levels of severity in crashes. By counting just overall crashes you cannot distinguish between costs to society of each crash. Knapp also made a good point when he said that comparing winter crashes with non-winter crashes might produce bias because there could just be a higher-percentage of crashes being reported in the winter due to the fact that the driver would be more likely to need help moving a car out of a ditch or towing.

Fridstrom, L, Ifver, J, Ingebrigsten, S, Kulmala, R, Thomsen, L. "Measuring the Contribution of Randomness, Exposure, Weather, and Daylight to the Variation in Road Accident Counts." Accident Analysis and Prevention 27:1 (1995): 1-20

Objectives

Fridstrom et al. takes a careful statistical approach to measuring how accident reporting, weather and daylight, and pure randomness affect the actual variation in number of accidents. Once measurements are found, these variables can then be controlled for and a risk per unit of exposure can be calculated.

Theoretical Framework

One of the main advantages of this paper is that Fridstrom does a careful job at explaining exactly why and how a Poisson regression is used for accident analysis. He explains that due to the fact that accidents are completely random events with systematic factors that a probabilistic model must be used to estimate the actual observed number which varies around a predicted number which depends on known and unknown conditions. Also he shows the equation for the Poisson distribution for the probability of an observed number of accidents in a given place and time period ($\lambda(r,t)$) as:

$$P[y(r,t) = m] = \frac{[\lambda(r,t)]^m \cdot e^{-\lambda(r,t)}}{m!}$$

Method

Similar to most crash analyses a negative binomial regression is used and is given as:

$$\lambda(r,t) = e^{\sum_j x_j(r,t) B_j}$$

This functional form is chosen so that the expected number of accidents is always a positive number. Taking the log of both sides of the equation the expected number of accidents is a linear regression determined by a set of independent variables *Xj* and its coefficients. In log form the coefficients can be thought of as "crash elasticities" as in the percentage increase in the expected number of accidents following a 1% increase in the independent variables. For indicator variables the coefficients can be interpreted as the percent change in crashes from the indicator changing from 0 to 1. Fridstrom points out that even if there is complete and correct knowledge about each explanatory variable and its coefficients we can still not estimate the expected number of accidents due to the presence of random variation.

Data

Monthly crash counts from Denmark, Norway, Finland and Sweden were collected from approximately 1975-1987 (data availability varies for each country). Gasoline sales were used as a proxy for traffic volume and weather data was collected from weather stations throughout the countries. The dependent variables of accidents were sorted by severity as either injury or fatal and/or number of people killed. This grouping causes some problems because fatal crashes are included in injury crashes.

Results

Exposure

Exposure, measured by a gasoline sales proxy, is reported to have an almost proportional relationship with injury crashes meaning that with a 1% increase in gasoline sales there is a 1% increase in expected injury accidents. The coefficients for fatal accidents are less than one meaning that with a 1% increase in gasoline sales there is less than a 1% increase in expected number of fatal accidents. In other words, with greater traffic volume there is a lower risk of a fatal crash for an individual driver.

Weather
The coefficients on the snowfall variables are negative implying that there is a decrease in the expected number of injury and fatal accidents with increased snowfall.

Explanatory Power
For **injury** accidents it was found that less than 10% of the sample variation can be ascribed to random factors alone but exposure was found to represent 65%-85% of it leaving little room for weather. Randomness in **fatal** accidents on the other hand account for no less than 52% and a max of 80% of the variation. All together randomness, exposure, weather and daylight can explain at least 87% of the variation in expected fatal crashes.

Problems
One of the main issues cited is variation in data availability in the four countries studied and the use of gasoline sales for exposure has the potential to underestimate real traffic volume due to increased fuel efficiency over the years. Also there is noted autocorrelation in the models but this is reported to be small.

Qiu, Lin, "Performance Measurement For Highway Winter Maintenance Operations" (2008) ch. 4, “Synthesis of Weather and Traffic Safety”. *Theses and Dissertations.* Paper 28. http://ir.uiowa.edu/etd/28

Objectives
In this chapter Qui conducts a meta-analysis to create a clearer picture from the conflicting results from various papers on how weather affects accidents. The review hopes to provide the best current (2008) estimates of weather effects on traffic safety as well as reveal areas for future research. Also the analysis attempts to clarify what important factors must be included in any modeling process.

Method
To find comparable results of the different studies a careful analysis was conducted to normalize results. First, to be included the papers had to pass through a screen to make sure studies had the right subject (weather and safety), study design and method (regression, matched pair etc.), outcome measure (crash counts, rates etc.), measures of weather conditions and data. The papers were then organized by study decade, country, study method (matched pair, negative binomial, etc.), sample size, weather category, crash category, percentage change in crash rate. The papers were then ranked and given a validity score based on the study design, type of traffic volume data and levels of aggregation of road segments studied. Different methods were used for the comparison studies and the regression analyses.

Comparison studies
This study converted all results to percent change in accidents due to adverse weather (*P*) with (*i*) weather variables. For results initially reported in a risk ratio or a crash rate, the conversion was:

$$P_i = Risk_i - 1$$
$$P_i = \frac{Rate_i - Rate_{control}}{Rate_{control}}$$

Regression studies
Regression studies were also standardized by a percent change measure (*P).* Negative binomial coefficients (β_i) were converted as so:

$$P_i = \exp(\beta_i) - 1$$

Lastly, if the papers did not correct for the reduction in traffic volume from adverse weather they were corrected based on the following percentage decreases found in empirical research:

Precipitation type	Light Precipitation	Precipitation	Rain	Light Snow	Snow	Heavy Snow
Percent reduction in traffic volume, P_{vi}	1.35%	1.65%	2%	10%	15%	29%

The correction based on the adverse weather type (*i*) is given by:

$$P_{icorrected} = \frac{1}{1 - P_{vi}} * (P_i + 1) - 1$$

This correction is important because the majority of papers that study the effect of adverse weather on safety do not take the volume reduction into account due to lack of data or model specification. As we will see in the results section, this reduction makes a large difference in how weather affects crash rates.

Results
For the comparison studies, heavy snow is said to increase injury crash rates by 420% and light snow increases overall crash rates by 169%. Though these numbers seem high, they are only from a handful of studies. When organized by validity score the more valid studies reported a 45% increase in injury accidents from snow and the less valid studies reported 79%. For the regression studies, it was reported that snow depth had a negative relationship with fatal and injury crashes with coefficients -0.073 and -0.062 respectively.

Strong, C, Shvetsov, Y. "Development of Roadway Weather Severity Index." Transportation Research Record No. 1948 (2006): 161-169

Safety and Maintenance

Qin, X, Noyce, D, Chanyoung, L, Kinar, J. "Snowstorm Event-Based Crash Analysis." Transportation Research Record No. 1948 (2006): 135-141

Objectives

The objective of this paper is to investigate the relationship between snowstorm crashes and snowstorm severity, winter operation, and maintenance costs.

Data

Weather and maintenance data

Data is gathered from "Winter Storm Reports" that are collected for each winter storm event in WI in each county on their state-maintained highway system that explains details of the weather and maintenance data for each storm. Inside each report they can find: Pavement temperature before and after a storm, storm duration, crew work duration, what time the crew started and finished, snow depth (measurement for snow drifts), deicing units used, air temperature, wind speed, salt used, sand used and the chemicals used for pre-wetting sand. The reports also include the observed road surface condition (blowing snow, ice, fog, etc.).

Crash data

The crash data was gathered from police accident reports. From the time of the crash reported, the authors were able to link accidents to certain snowstorms with certain maintenance practices.

Method

Exploratory Data Analysis

Before any regression analysis was conducted an "Exploratory Data Analysis" was performed to test for co-linearity amongst the explanatory variables and to find a measurement for relative crash time. It was found that crashed during a snowstorm follow a normal distribution with the bulk of the crashes happening in the middle of storms and tailing off towards the end.

Negative binomial

A negative binomial regression, similar to most studies, was also run with the following functional form:

$$P(Y_i = y_i; \alpha, d) = \frac{(y_i + d - 1)!}{y_i!(d-1)!} \frac{\alpha_i^{\,y}}{(1+\alpha)^{y_i + 1/d}}$$

Where yi is the number of crashes in a storm (i) and d is the inverse of the dispersion parameter in the NB distribution. Taking the expected value we get:

$$E(Y) = \mu_i = d\alpha = L \cdot \exp(D \cdot \gamma + X \cdot \beta)$$

Where (L) is lane miles (exposure), (D) is a vector of indicator variables such as precipitation and county factors, (γ) is a vector of unknown coefficients of the indicator variables, (X) is a vector of explanatory variables Beta is a vector of their coefficients.

Results
The significant variables are

Variable	estimate
Intercept	-5.402
No freezing rain	0.221
Amount of time crew spent before the storm	-0.045
Storm duration	0.033
Deicing units per lane mile	-0.013
Salt per lane mile	0.001
Speed	0.011
dispersion	0.345

Volume Reduction from Winter Weather
Datla, S, Sharman S. "Impact of Cold and Snow on Temporal and Spatial Variations of Highway traffic volumes." Journal of Transport Geography 16 (2008): 358-372

Objectives
The main objective of this paper is to conduct a detailed analysis of the effect of low temperatures and snowfall on traffic volumes for varying highway types and locations. Datla shows the importance of allowing for traffic reductions to vary within temporal and spatial contexts by comparing data without the variation.

Data

Traffic volume data
Datla uses hourly traffic volume data from 1995-2005 from 350 PTC (permanent traffic counter) sites in the province of Alberta, Canada. He then placed the different road types into the four categories of: commuter, regional commuter, rural long-distance, and recreational roads.

Weather data
Maximum, minimum and mean temperatures, rain, snowfall, precipitation and snow-on-the-ground measurements were taken from 598 weather stations in Alberta and composed in the Environment Canada database.
Method
A very detailed standard regression model was used:

$$VF_{WDYCG} = B_a * EVF_{WDCG} + B_s * S_{WDCG} + \sum B_R * C_{RWDYCG}$$

Where the dependent variable (VF) is the daily volume factor (daily volume divided by average annual daily volume) of a particular day “D” in the week “W” of the year “Y” for the PTC site “C” belongs to road type “G”. EVF is the expected volume factor calculated by taking the average from all available years. S is the total snow and C is a snow indicator variable that switches to one for 10 different cold temperatures in Celcius. The slope coefficient on EVF is interpreted as the deviation from VF on days when there is no snow. B_s is interpreted as the effect on the volume factor from a one cm increase in snow fall.

Results
In words, the results match what was to be expected. The coefficient on EVF is positive and above one for each class of road indicating that traffic volume factors are higher than expected when there is no snow and the temperature is above zero degrees Celsius. The snow coefficient was negative implying that there is indeed a reduction in volume due to snowfall. Also, there are larger negative values for the colder indicator variables showing that there is an increase in volume reduction as the temperature gets colder.

For each model of different road class, there is an Rsquared value of at least 0.99. This good fit is attributed mostly to the EVF variable that explains the majority of the variation in the dependent variable. Datla mentions that although the weather variables do not contribute a major part in explaining this variation, they have a much larger effect on days with winter weather.

Maintenance practices, costs
Hanbali, Rashad M., (1994). “Economic Impact of Winter Road Maintenance on Road Users”, Transportation Research Board Annual Meeting, Washington, D.C. January, 1994

Objectives
This paper analyzes and evaluates the economic impacts of winter road maintenance operations (salting, plowing, and following a bare pavement policy) on road users in three states (New York, Illinois, and Wisconsin) and shows any cost savings per vehicle kilometer of travel (VKT).

Data collection and previous research
Traffic accident data was recorded from the three different states. Winter road maintenance data including the date, operation route, times of salt applications, state of weather and time of day was recorded. The incident of each reported accident was determined by time, severity, location and traffic density. This data was then used to figure out accident rates for twelve hour periods before and after bare pavement was achieved. The reduction in accident rates after bare pavement was found to be statistically significant.

Appendix 5: Survey Instrument for Municipal Winter Operations:

Municipality ____________________

Road miles maintained ___________

Who does your winter maintenance? _____municipal crews/equipment
_____private contractor
_____some of each

About what percentage of winter miles would be 1) highest priority, 2) medium priority, and 3) last priority_____________

How many tons of salt did you use this past winter (08-09)? _______________

How many cubic yards of sand did you use? __________________________

How many gallons of any liquid deicers did you use?_____________
Type?__________________________

Do you pretreat your roads with liquids ______ or prewetted salt____?

What percentage of miles do you pre-treat? _______________

What is your total winter maintenance budget? _____________

If known, how does that break down into personnel costs, equipment, and materials?
____

Are there any other winter practices in your town/city that you care to describe?
____

Appendix 6: Road Salt Stakeholder Meeting Evaluation Summary

Stakeholder Meeting Locations

		Frequency	Percent	Valid %t	Cumulative %
Valid	Belfast	17	22.4	22.4	22.4
	Farmington	20	26.3	26.3	48.7
	Portland	23	30.3	30.3	78.9
	Presque Isle	16	21.1	21.1	100.0
	Total	76	100.0	100.0	

Q1: "1. Please check the stakeholder group you represent: *(check all that apply)"*

Q1 All Respondents

		Responses		% of Cases
		N	Percent	
Q1	Municipal public works	27	31.8%	36.5%
	Elected municipal official	5	5.9%	6.8%
	Elected state official	2	2.4%	2.7%
	State agency staff	20	23.5%	27.0%
	Water conservation district	3	3.5%	4.1%
	Environmental organization	1	1.2%	1.4%
	Public safety	2	2.4%	2.7%
	Regional planning organization	5	5.9%	6.8%
	Trucking/transport	7	8.2%	9.5%
	Water utility company	2	2.4%	2.7%
	Auto dealer/repair	5	5.9%	6.8%
	Municipal administration	3	3.5%	4.1%
	Motor coach/school bus	3	3.5%	4.1%
Total		85	100.0%	114.9%

Belfast Q1 Meeting Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q1	Municipal public works	5	26.3%	31.3%
	Elected municipal official	3	15.8%	18.8%
	Elected state official	1	5.3%	6.3%
	State agency staff	2	10.5%	12.5%
	Public safety	2	10.5%	12.5%
	Trucking/transport	2	10.5%	12.5%
	Water utility company	1	5.3%	6.3%
	Auto dealer/repair	2	10.5%	12.5%
	Municipal administration	1	5.3%	6.3%
Total		19	100.0%	118.8%

Farmington Q1 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q1	Municipal public works	9	45.0%	45.0%
	Elected state official	1	5.0%	5.0%
	State agency staff	5	25.0%	25.0%
	Auto dealer/repair	2	10.0%	10.0%
	Municipal administration	1	5.0%	5.0%
	Motor coach/school bus	2	10.0%	10.0%
Total		20	100.0%	100.0%

Portland Q1 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q1	Municipal public works	5	19.2%	22.7%
	Elected municipal official	1	3.8%	4.5%
	State agency staff	8	30.8%	36.4%
	Water conservation district	3	11.5%	13.6%
	Environmental organization	1	3.8%	4.5%
	Regional planning organization	2	7.7%	9.1%
	Trucking/transport	4	15.4%	18.2%
	Water utility company	1	3.8%	4.5%
	Motor coach/school bus	1	3.8%	4.5%
Total		26	100.0%	118.2%

Presque Isle Q1 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q1Mult Resp(a)	Municipal public works	8	40.0%	50.0%
	Elected municipal official	1	5.0%	6.3%
	State agency staff	5	25.0%	31.3%
	Regional planning organization	3	15.0%	18.8%
	Trucking/transport	1	5.0%	6.3%
	Auto dealer/repair	1	5.0%	6.3%
	Municipal administration	1	5.0%	6.3%
Total		20	100.0%	125.0%

Q2: "2. Which of the following issues related to the current use of road salts on Maine roads are most important to you? *(Check all that apply")*

Q2: All Respondents

		Responses		% of Cases
		N	Percent	
Q2	Environmental impact	49	14.2%	64.5%
	Water quality impact	44	12.7%	57.9%
	Road safety/accidents	49	14.2%	64.5%
	Vehicle corrosion	47	13.6%	61.8%
	Infrastructure corrosion/deterioration	39	11.3%	51.3%
	Cost of road maintenance to municipality	42	12.1%	55.3%
	Cost of road maintenance to state government	35	10.1%	46.1%
	Cost of vehicle maintenance	41	11.8%	53.9%
Total		346	100.0%	455.3%

Belfast Q2 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q2	Environmental impact	9	11.4%	52.9%
	Water quality impact	10	12.7%	58.8%
	Road safety/accidents	11	13.9%	64.7%
	Vehicle corrosion	14	17.7%	82.4%
	Infrastructure corrosion/deterioration	7	8.9%	41.2%
	Cost of road maintenance to municipality	10	12.7%	58.8%
	Cost of road maintenance to state government	6	7.6%	35.3%
	Cost of vehicle maintenance	12	15.2%	70.6%
Total		79	100.0%	464.7%

Farmington Q2 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q2	Environmental impact	15	17.0%	75.0%
	Water quality impact	13	14.8%	65.0%
	Road safety/accidents	12	13.6%	60.0%
	Vehicle corrosion	10	11.4%	50.0%
	Infrastructure corrosion/deterioration	8	9.1%	40.0%
	Cost of road maintenance to municipality	9	10.2%	45.0%
	Cost of road maintenance to state government	9	10.2%	45.0%
	Cost of vehicle maintenance	12	13.6%	60.0%
Total		88	100.0 %	440.0%

Portland Q2 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q2	Environmental impact	17	17.9%	73.9%
	Water quality impact	11	11.6%	47.8%
	Road safety/accidents	12	12.6%	52.2%
	Vehicle corrosion	11	11.6%	47.8%
	Infrastructure corrosion/deterioration	14	14.7%	60.9%
	Cost of road maintenance to municipality	10	10.5%	43.5%
	Cost of road maintenance to state government	11	11.6%	47.8%
	Cost of vehicle maintenance	9	9.5%	39.1%
Total		95	100.0 %	413.0%

Presque Isle Q2 Multiple Response Frequencies

		Responses		% of Cases
		N	Percent	
Q2	Environmental impact	8	9.5%	50.0%
	Water quality impact	10	11.9%	62.5%
	Road safety/accidents	14	16.7%	87.5%
	Vehicle corrosion	12	14.3%	75.0%
	Infrastructure corrosion/deterioration	10	11.9%	62.5%
	Cost of road maintenance to municipality	13	15.5%	81.3%
	Cost of road maintenance to state government	9	10.7%	56.3%
	Cost of vehicle maintenance	8	9.5%	50.0%
Total		84	100.0 %	525.0%

Q3a: Please rate Event Overall

		Frequency	Percent	Valid %	Cumulative %
Valid	Okay	9	11.8	11.8	11.8
	Good	41	53.9	53.9	65.8
	Excellent	26	34.2	34.2	100.0
	Total	76	100.0	100.0	

Q3a: Please rate Event Overall by Meeting Location

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q3a: Event	Okay	Count	1	2	3	3	9
		% within	11.1%	22.2%	33.3%	33.3%	100.0%
		% within	5.9%	10.0%	13.0%	18.8%	11.8%
		% of Total	1.3%	2.6%	3.9%	3.9%	11.8%
	Good	Count	4	11	15	11	41
		% within	9.8%	26.8%	36.6%	26.8%	100.0%
		% within	23.5%	55.0%	65.2%	68.8%	53.9%
		% of Total	5.3%	14.5%	19.7%	14.5%	53.9%
	Excellent	Count	12	7	5	2	26
		% within	46.2%	26.9%	19.2%	7.7%	100.0%
		% within	70.6%	35.0%	21.7%	12.5%	34.2%
		% of Total	15.8%	9.2%	6.6%	2.6%	34.2%
Total		Count	17	20	23	16	76
		% within	22.4%	26.3%	30.3%	21.1%	100.0%
		% within	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.4%	26.3%	30.3%	21.1%	100.0%

Q3b: Please rate Meeting Organization

		Frequency	Percent	Valid %	Cumulative %
Valid	Okay	5	6.6	6.6	6.6
	Good	39	51.3	51.3	57.9
	Excellent	32	42.1	42.1	100.0
	Total	76	100.0	100.0	

Q3b: Please rate Meeting Organization by Meeting Location

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q3b Meeting Org	Okay	Count	0	1	3	1	5
		% within Q3b	.0%	20.0%	60.0%	20.0%	100.0%
		% within Town	.0%	5.0%	13.0%	6.3%	6.6%
		% of Total	.0%	1.3%	3.9%	1.3%	6.6%
	Good	Count	5	10	15	9	39
		% within Q3b	12.8%	25.6%	38.5%	23.1%	100.0%
		% within Town	29.4%	50.0%	65.2%	56.3%	51.3%
		% of Total	6.6%	13.2%	19.7%	11.8%	51.3%
	Excellent	Count	12	9	5	6	32
		% within Q3b	37.5%	28.1%	15.6%	18.8%	100.0%
		% within Town	70.6%	45.0%	21.7%	37.5%	42.1%
		% of Total	15.8%	11.8%	6.6%	7.9%	42.1%
Total		Count	17	20	23	16	76
		% within Q3b	22.4%	26.3%	30.3%	21.1%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.4%	26.3%	30.3%	21.1%	100.0%

Q3c: Please rate Representativeness of participants

		Frequency	Percent	Valid %	Cumulative %
Valid	Okay	11	14.5	14.5	14.5
	Good	36	47.4	47.4	61.8
	Excelle	29	38.2	38.2	100.0
	Total	76	100.0	100.0	

Q3c: Please rate Representativeness of participants by Meeting Location

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q3c	Okay	Count	2	3	5	1	11
		% within	18.2%	27.3%	45.5%	9.1%	100.0%
		% within	11.8%	15.0%	21.7%	6.3%	14.5%
		% of	2.6%	3.9%	6.6%	1.3%	14.5%
	Good	Count	4	8	14	10	36
		% within	11.1%	22.2%	38.9%	27.8%	100.0%
		% within	23.5%	40.0%	60.9%	62.5%	47.4%
		% of	5.3%	10.5%	18.4%	13.2%	47.4%
	Excellent	Count	11	9	4	5	29
		% within	37.9%	31.0%	13.8%	17.2%	100.0%
		% within	64.7%	45.0%	17.4%	31.3%	38.2%
		% of	14.5%	11.8%	5.3%	6.6%	38.2%
Total		Count	17	20	23	16	76
		% within	22.4%	26.3%	30.3%	21.1%	100.0%
		% within	100.0%	100.0%	100.0%	100.0%	100.0%
		% of	22.4%	26.3%	30.3%	21.1%	100.0%

Q3d: Please rate Clarity of Presentations

		Frequency	Percent	Valid %	Cumulative %
Valid	Okay	2	2.6	2.6	2.6
	Good	43	56.6	56.6	59.2
	Excelle	31	40.8	40.8	100.0
	Total	76	100.0	100.0	

Q3d: Please rate Clarity of Presentations by Meeting Location

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q3d:Clarity of	Okay	Count	0	1	1	0	2
		% within	.0%	50.0%	50.0%	.0%	100.0%
		% within	.0%	5.0%	4.3%	.0%	2.6%
		% of	.0%	1.3%	1.3%	.0%	2.6%
	Good	Count	8	10	14	11	43
		% within	18.6%	23.3%	32.6%	25.6%	100.0%
		% within	47.1%	50.0%	60.9%	68.8%	56.6%
		% of	10.5%	13.2%	18.4%	14.5%	56.6%
	Excellent	Count	9	9	8	5	31
		% within	29.0%	29.0%	25.8%	16.1%	100.0%
		% within	52.9%	45.0%	34.8%	31.3%	40.8%
		% of	11.8%	11.8%	10.5%	6.6%	40.8%
Total		Count	17	20	23	16	76
		% within	22.4%	26.3%	30.3%	21.1%	100.0%
		% within	100.0%	100.0%	100.0%	100.0%	100.0%
		% of	22.4%	26.3%	30.3%	21.1%	100.0%

Q3e: Please Rate each of the Following: Relevance of Topics

		Frequency	Percent	Valid %	Cumulative %
Valid	Okay	6	7.9	8.0	8.0
	Good	30	39.5	40.0	48.0
	Excellent	39	51.3	52.0	100.0
	Total	75	98.7	100.0	

Q3e: Please Ate Each of the Following: Relevance of Topics By Meeting Location

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q3e: Relevance of	Okay	Count	2	1	1	2	6
		% within Q3e	33.3%	16.7%	16.7%	33.3%	100.0%
		% within Town	11.8%	5.0%	4.3%	13.3%	8.0%
		% of Total	2.7%	1.3%	1.3%	2.7%	8.0%
	Good	Count	4	7	10	9	30
		% within Q3e	13.3%	23.3%	33.3%	30.0%	100.0%
		% within Town	23.5%	35.0%	43.5%	60.0%	40.0%
		% of Total	5.3%	9.3%	13.3%	12.0%	40.0%
	Excellent	Count	11	12	12	4	39
		% within Q3e	28.2%	30.8%	30.8%	10.3%	100.0%
		% within Town	64.7%	60.0%	52.2%	26.7%	52.0%
		% of Total	14.7%	16.0%	16.0%	5.3%	52.0%
Total		Count	17	20	23	15	75
		% within Q3e	22.7%	26.7%	30.7%	20.0%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.7%	26.7%	30.7%	20.0%	100.0%

Q4a: Please rate the usefulness of the material presented on: winter road practices and materials

		Frequency	Percent	Valid %	Cumulative %
Valid	all new/useful	11	14.5	14.9	14.9
	Some new/useful	44	57.9	59.5	74.3
	I already knew this	19	25.0	25.7	100.0
	Total	74	97.4	100.0	

Q4a: Please rate the usefulness of the material presented on: Winter road practices and materials

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q4a practices	all new/useful	Count	4	2	3	2	11
		% within Q4a	36.4%	18.2%	27.3%	18.2%	100.0%
		% within Town	23.5%	10.0%	14.3%	12.5%	14.9%
		% of Total	5.4%	2.7%	4.1%	2.7%	14.9%
	Some	Count	11	12	12	9	44
		% within Q4a	25.0%	27.3%	27.3%	20.5%	100.0%
		% within Town	64.7%	60.0%	57.1%	56.3%	59.5%
		% of Total	14.9%	16.2%	16.2%	12.2%	59.5%
	already knew	Count	2	6	6	5	19
		% within Q4a	10.5%	31.6%	31.6%	26.3%	100.0%
		% within Town	11.8%	30.0%	28.6%	31.3%	25.7%
		% of Total	2.7%	8.1%	8.1%	6.8%	25.7%
Total		Count	17	20	21	16	74
		% within Q4a	23.0%	27.0%	28.4%	21.6%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	23.0%	27.0%	28.4%	21.6%	100.0%

Q4b: Please rate the usefulness of the material presented on: Corrosion

		Frequency	Percent	Valid %	Cumulative %
Valid	all new/useful	13	17.1	17.3	17.3
	Some new/useful	45	59.2	60.0	77.3
	I already knew this	17	22.4	22.7	100.0
	Total	75	98.7	100.0	

Q4b: Please rate the usefulness of the material presented on: Corrosion

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q4b: Corrosion	all new/useful	Count	7	2	2	2	13
		% within Q4b	53.8%	15.4%	15.4%	15.4%	100.0%
		% within Town	41.2%	10.0%	9.1%	12.5%	17.3%
		% of Total	9.3%	2.7%	2.7%	2.7%	17.3%
	Some new	Count	6	12	18	9	45
		% within Q4b	13.3%	26.7%	40.0%	20.0%	100.0%
		% within Town	35.3%	60.0%	81.8%	56.3%	60.0%
		% of Total	8.0%	16.0%	24.0%	12.0%	60.0%
	already knew	Count	4	6	2	5	17
		% within Q4b	23.5%	35.3%	11.8%	29.4%	100.0%
		% within Town	23.5%	30.0%	9.1%	31.3%	22.7%
		% of Total	5.3%	8.0%	2.7%	6.7%	22.7%
Total		Count	17	20	22	16	75
		% within Q4b	22.7%	26.7%	29.3%	21.3%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.7%	26.7%	29.3%	21.3%	100.0%

Q4c: Please rate the usefulness of the material presented on: Environment

		Frequency	Percent	Valid %	Cumulative %
Valid	all new/useful	10	13.2	13.3	13.3
	Some new/useful	46	60.5	61.3	74.7
	I already knew this	19	25.0	25.3	100.0
	Total	75	98.7	100.0	

Q4c: Please rate the usefulness of the material presented on: Environment

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q4c: Environment	all new/useful	Count	4	2	1	3	10
		% within Q4c	40.0%	20.0%	10.0%	30.0%	100.0%
		% within Town	23.5%	10.0%	4.5%	18.8%	13.3%
		% of Total	5.3%	2.7%	1.3%	4.0%	13.3%
	Some new	Count	9	14	13	10	46
		% within Q4c	19.6%	30.4%	28.3%	21.7%	100.0%
		% within Town	52.9%	70.0%	59.1%	62.5%	61.3%
		% of Total	12.0%	18.7%	17.3%	13.3%	61.3%
	already knew	Count	4	4	8	3	19
		% within Q4c	21.1%	21.1%	42.1%	15.8%	100.0%
		% within Town	23.5%	20.0%	36.4%	18.8%	25.3%
		% of Total	5.3%	5.3%	10.7%	4.0%	25.3%
Total		Count	17	20	22	16	75
		% within Q4c	22.7%	26.7%	29.3%	21.3%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.7%	26.7%	29.3%	21.3%	100.0%

Q4d: Please rate the usefulness of the material presented on: Safety and accidents

		Frequency	Percent	Valid %	Cumulative %
Valid	all new/useful	11	14.5	14.9	14.9
	Some new/useful	51	67.1	68.9	83.8
	I already knew this	12	15.8	16.2	100.0
	Total	74	97.4	100.0	

Q4d: Please rate the usefulness of the material presented on: Safety and accidents

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q4d: Safety	all new/useful	Count	7	1	2	1	11
		% within Q4d	63.6%	9.1%	18.2%	9.1%	100.0%
		% within Town	41.2%	5.3%	9.1%	6.3%	14.9%
		% of Total	9.5%	1.4%	2.7%	1.4%	14.9%
	Some new	Count	7	15	17	12	51
		% within Q4d	13.7%	29.4%	33.3%	23.5%	100.0%
		% within Town	41.2%	78.9%	77.3%	75.0%	68.9%
		% of Total	9.5%	20.3%	23.0%	16.2%	68.9%
	already knew	Count	3	3	3	3	12
		% within Q4d	25.0%	25.0%	25.0%	25.0%	100.0%
		% within Town	17.6%	15.8%	13.6%	18.8%	16.2%
		% of Total	4.1%	4.1%	4.1%	4.1%	16.2%
Total		Count	17	19	22	16	74
		% within Q4d	23.0%	25.7%	29.7%	21.6%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	23.0%	25.7%	29.7%	21.6%	100.0%

Q4e:Please rate the usefulness of the material presented on: Group feedback session

		Frequency	Percent	Valid %	Cumulative %
Valid	all new/useful	19	25.0	26.0	26.0
	Some new/useful	51	67.1	69.9	95.9
	I already knew this	3	3.9	4.1	100.0
	Total	73	96.1	100.0	

Q4e:Please rate the usefulness of the material presented on: Group feedback session

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q4e feedback	all new	Count	9	4	4	2	19
		% within Q4e:	47.4%	21.1%	21.1%	10.5%	100.0%
		% within Town	52.9%	20.0%	19.0%	13.3%	26.0%
		% of Total	12.3%	5.5%	5.5%	2.7%	26.0%
	Some new	Count	7	16	17	11	51
		% within Q4e	13.7%	31.4%	33.3%	21.6%	100.0%
		% within Town	41.2%	80.0%	81.0%	73.3%	69.9%
		% of Total	9.6%	21.9%	23.3%	15.1%	69.9%
	already knew	Count	1	0	0	2	3
		% within Q4e	33.3%	.0%	.0%	66.7%	100.0%
		% within Town	5.9%	.0%	.0%	13.3%	4.1%
		% of Total	1.4%	.0%	.0%	2.7%	4.1%
Total		Count	17	20	21	15	73
		% within Q4e	23.3%	27.4%	28.8%	20.5%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	23.3%	27.4%	28.8%	20.5%	100.0%

Q5: This meeting provided an opportunity for me to share my perspective on issues related to road salts in Maine.

		Frequency	Percent	Valid %	Cumulative %
Valid	Somewhat Disagree	1	1.3	1.3	1.3
	Somewhat Agree	29	38.2	38.7	40.0
	Strongly Agree	45	59.2	60.0	100.0
	Total	75	98.7	100.0	

Q5: This meeting provided an opportunity for me to share my perspective on issues related to road salts in Maine.

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q5: share	Somewhat Disagree	Count	0	1	0	0	1
		% within Q5	.0%	100.0%	.0%	.0%	100.0%
		% within Town	.0%	5.0%	.0%	.0%	1.3%
		% of Total	.0%	1.3%	.0%	.0%	1.3%
	Somewhat Agree	Count	3	8	10	8	29
		% within Q5	10.3%	27.6%	34.5%	27.6%	100.0%
		% within Town	17.6%	40.0%	45.5%	50.0%	38.7%
		% of Total	4.0%	10.7%	13.3%	10.7%	38.7%
	Strongly Agree	Count	14	11	12	8	45
		% within Q5	31.1%	24.4%	26.7%	17.8%	100.0%
		% within Town	82.4%	55.0%	54.5%	50.0%	60.0%
		% of Total	18.7%	14.7%	16.0%	10.7%	60.0%
Total		Count	17	20	22	16	75
		% within Q5	22.7%	26.7%	29.3%	21.3%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	22.7%	26.7%	29.3%	21.3%	100.0%

Q6: I gained information this meeting that I can use to help address issues related to the use of road salts in Maine.

		Frequency	Percent	Valid %	Cumulative %
Valid	Somewhat Disagree	3	3.9	4.1	4.1
	Somewhat Agree	40	52.6	54.1	58.1
	Strongly Agree	31	40.8	41.9	100.0
	Total	74	97.4	100.0	

Q6: I gained information this meeting that I can use to help address issues related to the use of road salts in Maine.

			Town				Total
			Belfast	Farmington	Portland	Presque Isle	
Q6: gained info	Somewhat Disagree	Count	0	0	2	1	3
		% within Q6	.0%	.0%	66.7%	33.3%	100.0%
		% within Town	.0%	.0%	9.1%	6.7%	4.1%
		% of Total	.0%	.0%	2.7%	1.4%	4.1%
	Somewhat Agree	Count	5	10	15	10	40
		% within Q6	12.5%	25.0%	37.5%	25.0%	100.0%
		% within Town	29.4%	50.0%	68.2%	66.7%	54.1%
		% of Total	6.8%	13.5%	20.3%	13.5%	54.1%
	Strongly Agree	Count	12	10	5	4	31
		% within Q6	38.7%	32.3%	16.1%	12.9%	100.0%
		% within Town	70.6%	50.0%	22.7%	26.7%	41.9%
		% of Total	16.2%	13.5%	6.8%	5.4%	41.9%
Total		Count	17	20	22	15	74
		% within Q6	23.0%	27.0%	29.7%	20.3%	100.0%
		% within Town	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	23.0%	27.0%	29.7%	20.3%	100.0%

Q7. Please list below other topics related to road salts that should have been covered during this meeting.

Portland Q7

Closed drainage systems vs. open ditches and the impact on dilution runoff

Costs to infrastructure, need to try to quantify i.e. gate valves, fire hydrants, bridges, etc. due to chemical use. Also the costs/technologies to treat we+ and Cl- contamination issues- drinking water/ storm water

New materials to replace current ones

What is done in other "snow" countries- How might technology change future practices and the associated environmental impact

You hit the key issues

Application process and municipal los

None that I can think of at this time

When Sodium/MNG-Chloride was starting to be used, The costs to vehicles/ bridges etc. vs. adding anti corrosion additive

Labor Maintenance

Discussion of what other options are available and what the consequences may be

Public polling input- what is the expectation and needs of the people in the street

Belfast Q7

Disadvantages of *sand* in the environment session!

Safety with regards to issues due to corroded components of vehicles

How about road sand

Alternatives

Costs for

Presque Isle Q7

Corrosion caused by salt or manufacturing process

More emphasis on corrosion prevention

Alternatives to road salt

Cost to different parts of Maine- Portland vs. Fort Kent

Alternatives

Solutions and alternatives

Safety communication

How much salt to use on roads, and the cost of salt

Farmington Q7

Possible alternatives

More alternative (if they exists)

Damage to in town catch basin systems, lack of dust and clogging of waterways from sand

Group purchasing, ways to minimize salts impacts, locally, and statewide

Maybe in some way demonstrations either in class of on video

More about research on alternatives

Q8. Please list below recommendations for next steps that could be taken in your region to address concerns related to road salts.

Q8 Portland

4 out of the 5 group presenters at the end were from MDOT. Other stakeholders should have a say. *What about public involvement?*

More efficient Use of materials, More investment in roads (Improvement/paving/ road conditions)

MDOT should list "salt" specialist on website, very hard to find the right person there for a subject matter

Education, education. Education

Municipal workshops and discussion groups, MMA policy discussions, and consensus building to come to a common expectation

los expectations

My belief is that municipals should lessen the frequency of salt/ sand application, reducing the expenses.

Properly addressing all of the concerns, and proper training of the operators of PLL snow operators.

Do a presentation at the Maine Water conference, and could have used more reps from the environmental organizations

Education

Explore alternatives to road salting, explore new technology/alternatives, and set timelines by developing new and better practice against scaling down of current practice and imparts

Q8 Belfast

Education of the public, get a T.V station to do a story on the results

Public Education in the effects of salt use to stake holders

Public education on the effects of current level of service, costs as well as environmental effects. People might be willing to accept a lower service level to protect our natural environment.

Possible public invite format

What is the solution/alternative to salt + clear roadways?

Public Education

Public Education

Level of service, and education - expectations of the public use of roads

Public Education

Town committee meetings to reduce the use of material

Q8 Presque Isle

Make sure any information collected is collected state wide, because the weather in Fort Kent is very different than in Bangor

invite salt producers to get input on corrosion, inhibitors, alternatives, etc.

More public knowledge

Not entirely sure what the point of the meeting was. I was hoping that some alternatives would have been discussed

Add emphasis on metal alloys going into vehicles

Alternatives

Q8 Farmington

State level discussions to develop protocol for minimizing school bus corrosion

Public Education

Training for public works employees and education for the general public

Use less road salt

Educate the public

Public informational meetings on winter practices and associated costs and sacrifices as a result of changes

Lower salt usage, educate the public, stay focused on meeting level of service not going above it

Education to the public in state and out of state. Website/ Brochure- Maine allure of tourism i.e. Maine snowmobile, etc. Create links to educate those visiting.

That's your job! No seriously, it takes time to analyze and you have all the data. Alternatives need to be researched it will be cost effective.

Public education is critical