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RESEARCH REPORT

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Impacts of Using Salt and Salt Brine for Roadway Deicing

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16. Abstract

Idaho Transportation Department (ITD) uses a variety of methods to help ensure safe travel on the state highway system following winter storm events. These methods include plowing, use of sand to improve traction, and use of salt and chemical compounds for deicing. While the use of salt and salt brines can help keep roads free of snow and ice, improving safety and mobility, questions have been raised about their contribution to wildlife-vehicle collisions (big-game animals may be attracted to salt used on roadways), their environmental impacts, and the corrosive effects on vehicles. To better understand these impacts, ITD requested a review of literature and state practices in each of these three areas of concern.

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Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4		mm	mm	millimeters	0.039	inches	in
ft	feet	0.3048		m	m	meters	3.28	feet	ft
yd	yards	0.914		m	m	meters	1.09	yards	yd
mi	Miles (statute)	1.61		km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g	g	grams	0.0353	Ounces (avdp)	oz
lb	Pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	Pounds (avdp)	lb
T	Short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^{o}F-32)	Celsius temperature	^oC	^oC	Celsius temperature	9/5 ^{o}C+32	Fahrenheit temperature	^oF
		ILLUMINATION					ILLUMINATION		
fc	Foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

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Technical Advisory Committee

Each research project has an advisory committee appointed jointly by the ITD Research Program Manager and ITD Project Manager. The Technical Advisory Committee (TAC) is responsible for assisting the ITD Research Program Manager and Project Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, and oversight of the approved research project. ITD's Research Program Manager appreciates the dedication of the following TAC members in guiding this research study.

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List of Acronyms

BOD	Biochemical oxygen demand
$CaCl_2$	Calcium chloride
CDOT	Colorado Department of Transportation
CMA	Calcium magnesium acetate
CSB	Concentrated sugar beet
DOT	Department of Transportation
EPA	Environmental Protection Agency
GPS	Global Positioning System
IDEQ	Idaho Department of Environmental Quality
ITD	Idaho Transportation Department
kph	Kilometers per hour
MCL	Maximum contaminant level
MDSS	Maintenance Decision Support System
$MgCl_2$	Magnesium chloride
MPY	Mils per year
MS4	Municipal separate storm sewer system
NaCl	Sodium chloride
NPDES	National Pollutant Discharge Elimination System
PNS	Pacific Northwest Snowfighters
ppm	Parts per million
SF	Sodium formate
TAC	Technical Advisory Committee
TAC	Transportation Association of Canada
TMDL	Total Maximum Daily Loads
TRB	Transportation Research Board
TSS	Total suspended solids
WSDOT	Washington State Department of Transportation

Introduction

Background on Salt and Salt Brine Use in Idaho

The Idaho Transportation Department (ITD) uses a variety of methods to help ensure safe travel on the state highway system following winter storm events. These methods include plowing, use of sand to improve traction, and use of granular salts and salt brines (sodium chloride, magnesium chloride and calcium chloride) for deicing. Material application rates (for granular salts, liquid brines, and anti-skid sand) vary by district, based on the severity of the storm, the time between material applications, and the pavement temperature. For a technical discussion of the freezing point of deicing chemical solutions, refer to FHWA's Manual of Practice for an Effective Anti-Icing Program.

ITD's winter maintenance practices have evolved and improved over the years, as research has demonstrated the safety and economic benefits of using various materials, and as new technologies for tracking road conditions and materials usage have supported proactive, streamlined operations. ITD has also taken steps to minimize potential negative impacts associated with salt and salt brine applications, such as the addition of corrosion inhibitors and careful storage of salt stockpiles to avoid runoff. For details about ITD's materials usage, historical winter operations practices, and leadership in winter maintenance materials research and practice, see the overview provided by ITD in Appendix B. ITD also publishes information about how the agency prepares for storms, its use of anti-icing chemicals, and how roads are prioritized for plowing on the ITD Winter Maintenance website.

Purpose of This Report

While the use of salt and salt brines can help keep roads free of snow and ice, improving safety and mobility, questions have been raised about the corrosive effects they have on vehicles, their environmental impacts, and their contribution to wildlife-vehicle collisions (big-game animals may be attracted to salt used on roadways). To better understand these potential impacts, ITD requested a review of literature and state practices in each of these three areas of concern. This investigation also included:

- Face-to-face interviews with ITD stakeholders about their concerns.
- A survey of state departments of transportation (DOTs) regarding their winter maintenance materials and practices.
- A review of federal environmental regulations regarding the use of winter maintenance deicing chemicals.
- Interviews with staff at the Idaho Transportation Department and Idaho Department of Environmental Quality to document any violations or penalties related to ITD's level of compliance with environmental requirements.

ITD will use the findings of this report to inform future practices in winter highway operations in the state.

Overview of Report Parts

Part 1. Deicers, Inhibitors, and Vehicle Corrosion

This section of the report presents completed and in-progress research (both laboratory and field studies) on the corrosive effects of salt and salt brines on vehicle components/parts. The findings include a review of laboratory testing approaches used for winter chemicals, national standards and specifications aimed at minimizing corrosion, and the effectiveness of corrosion inhibiting additives. The report also presents state practices', including Idaho's, related to inhibitor use and other strategies for minimizing corrosion, as shared through survey responses and related documentation. Refer to the Summary of Findings at the beginning of this section for an overview of key findings and conclusions.

Part 2. Environmental Effects of Roadway Deicing

This section presents research and other literature on the environmental impacts of using granular salts (including sodium chloride, calcium chloride, and magnesium chloride), salt brines, sand, and corrosion inhibitors for roadway deicing. The report addresses potential impacts to soil, vegetation, water quality, aquatic life, air quality, and animals (through ingestion). This synthesis also summarizes federal environmental regulations regarding winter maintenance deicing materials used by ITD, including chloride salts and abrasives, and ITD's level of compliance with these regulations. Refer to the Summary of Findings at the beginning of this section for an overview of key findings and conclusions.

Part 3. Road Salt and Wildlife-Vehicle Collisions

This section reviews research and literature regarding the extent to which salt used for deicing may be attracting wildlife to roadways, increasing the likelihood of wildlife-vehicle collisions. The report also discusses strategies for minimizing collisions that might be related to salt and salt brine use, such as using additives to repel animals and draining roadside salt pools. Refer to the Summary of Findings at the beginning of this section for an overview of key findings and conclusions.

Part 4. Appendices – Supplemental Information

In the course of this study, CTC talked with many individuals at ITD and throughout Idaho to gather background information and resources. CTC also conducted a 25-question survey on behalf of ITD aimed at identifying the range of approaches to salt and abrasives use (as well as the use of additives and corrosion inhibitors), the rationale for these approaches, any problems encountered and steps taken to minimize negative impacts. The survey questions were organized around the three focus areas of the research (corrosion, environmental impacts, and wildlife-vehicle collisions) with the goal of identifying trends among the states surveyed, major similarities and differences, and notable practices. See Appendix A for the full survey responses by question. Observations related to the three areas of interest are also included in each of the three report parts. Finally, CTC received several guidance and policy documents from state DOTs related to their use of winter maintenance materials. ITD’s winter maintenance practices are summarized in Appendix B; other states’ guidance documents are available online or from ITD.

Part 1
Deicers, Inhibitors, and Vehicle Corrosion

Executive Summary

Background

The use of chemicals for anti-icing and deicing roads is one of the most common practices in winter maintenance. The materials help agencies improve safety for the traveling public by speeding the process of clearing snow and ice from roads and helping prevent snow and ice build-up. A wide variety of chemicals are available, and each has its advantages and disadvantages. While salt and other chloride-based chemicals are generally effective and relatively inexpensive, they contribute to corrosion in the metals used in vehicles. This corrosion has been estimated to cost billions of dollars per year in the United States. *(Koch et. al. 2002)*

Corrosion - the electrochemical oxidation of metal - can be caused by many factors, including contact between two different types of metals, microbes, or heating in the presence of oxygen. Deicing chemicals are a major cause of corrosion on motor vehicles, however, because the chloride ions in salt and other deicers produce highly electrochemically active solutions when dissolved in water, including the snow they melt.

To mitigate the impact of vehicle corrosion from chlorides, agencies often recommend regular vehicle washing to remove corrosive chemicals from cars and trucks. Some state DOTs also add corrosion inhibitors, many based on agricultural by-products, to their deicing chemicals. Acetate-based deicers have also been developed that contain no chloride and are therefore minimally corrosive, but their cost is significantly higher than chloride-based deicers. ITD's practices include the use of solid salt, salt brine, and magnesium chloride brine with corrosion inhibitors approved by Pacific Northwest Snowfighters, a consortium of transportation agencies that tests deicing and anti-icing chemicals.

While these efforts appear to have had some positive impact, vehicle corrosion remains a problem. Winter maintenance agencies are working to minimize the amount of corrosion through careful selection of chemicals and practices.

For example, ITD has minimized the quantities of salt used, according to a February 2012 Idaho Department of Environmental Quality (IDEQ) report. *(Idaho DEQ 2012, pp. 29-30)* ITD used approximately 100,000 tons of dry salt and 4 million gallons of salt brine in the 2012-13 winter season, according to the 19-state survey conducted as part of this synthesis (see Appendix A). ITD's application rate of around 130 pounds of salt per lane mile, as reported in the IDEQ report, is significantly lower than in other states, particularly in the Midwest, where application rates may be 600 to 1,500 pounds of salt per lane-mile. ITD has also started to use mobile data collectors with GPS to collect data about material application rates to improve practices and minimize chemical usage.

Nevertheless, there are still concerns among some stakeholder groups, both in Idaho and nationally, regarding vehicle corrosion attributed to the use of chloride-based deicers, and particularly road salt (sodium chloride). To address these concerns, ITD requested a synthesis of research on the corrosive effects of deicers, practices and products available to reduce corrosion, and state practices aimed at mitigating the impacts.

Summary of Findings

Vehicle corrosion from all sources has a significant cost—$23.4 billion annually nationwide in corrosion-related depreciation, repairs and maintenance, and engineering and material costs, according to the most recent available FHWA estimates. *(Koch et. al. 2002)* Since deicing chemicals are a major source of vehicle corrosion, agencies have invested considerable resources into trying to quantify the differences in corrosiveness among chemicals and evaluate the impacts of corrosion inhibitors and other strategies to minimize corrosion.

All chloride salts used for deicing - which include sodium chloride, magnesium chloride, and calcium chloride - are corrosive. In laboratory tests, sodium chloride has consistently been among the most corrosive. However, a simple ranking of deicing chemicals' corrosiveness is difficult for several reasons.

There are several widely accepted laboratory tests of corrosiveness. However, these tests do not always produce results that agree with each other or the corrosion performance of deicing chemicals in the field. Environmental conditions are likely important in determining the relative corrosion rates among deicing chemicals, because both magnesium chloride and calcium chloride are hygroscopic (water-attracting). In humid environments, these chemicals stick to metal better than road salt and therefore have more time to cause corrosion.

Several other factors affect the corrosiveness of a chemical. Vehicles contain several different metals, and each metal reacts uniquely to various deicing chemicals. A deicer that is minimally corrosive to steel may cause serious corrosion to aluminum, for example. Climatic conditions, methods of use, and application rates all affect the corrosiveness of a given deicing chemical as well. Corrosion inhibitors further complicate matters, as there are many unique formulations on the market, and their effects also vary based on conditions and the metals they come in contact with.

The difficulty of making a definitive assessment of the corrosiveness of deicing chemicals is illustrated by the experience of the Washington State DOT 2002–2004 Salt Pilot Project, one of the most extensive field studies of deicer corrosiveness to date. Comparing the corrosiveness of salt vs. corrosion-inhibited chemicals on steel, researchers found that the corrosion-reducing effects of inhibited chemicals that were seen in the eastern part of the state were not apparent in the western part of the state. *(Baroga 2005, pp. 43)*

A 19-state survey conducted for this investigation found that state DOTs use a combination of approaches to reduce corrosion to vehicles. These include adding corrosion inhibitors to deicing chemicals, outreach to the public and other stakeholders to encourage regular vehicle washing to remove corrosive chemicals, and adjusting application rates and approaches.

It is also potentially illustrative to examine techniques used to minimize corrosion on winter maintenance equipment, which is naturally exposed to significant quantities of corrosive anti-icing and deicing chemicals. Many agencies make special efforts to mitigate the impact of corrosive chemicals on this equipment, such as by careful material selection, using metal coatings, and modifying maintenance practices, particularly frequent washing. Washington State DOT identified several best practices for mitigating corrosion on DOT equipment, including material selection, improved design, maintenance practices such as vehicle washing, and effective anti-corrosion coatings or salt removers.

Detailed Findings

Chloride-based chemicals, in general, are the most corrosive deicing chemicals. However, tests disagree about which of the three common chlorides (sodium chloride, magnesium chloride, and calcium chloride) is most corrosive. In practice, environmental conditions are likely important in determining relative corrosion rates among these chemicals, because magnesium chloride and calcium chloride are hygroscopic (water-attracting). In humid environments, these chemicals stick to metal better than road salt and therefore have more time to cause corrosion.

Laboratory Testing Approaches

There are several standard laboratory tests used to evaluate deicer chemical corrosiveness. *(Shi and Akin 2010, A-1–A-3)* Briefly, they are:

- **NACE TM 0169-95:** Metal coupons are cyclically submerged in a deicer chemical solution. Their mass is measured before and after the test to determine how much corrosion took place.

- **Pacific Northwest Snowfighters** uses a modification of the NACE test to determine whether to approve corrosion-inhibited product for sale to PNS members. Metal coupons are immersed for 72 hour-long cycles consisting of 10 minutes of immersion followed by 50 minutes of drying. Solutions are compared to distilled water and 3 percent sodium chloride, and corrosion for all solutions is "corrected" by subtracting corrosion due to the distilled water. Products 70 percent less corrosive than the salt solution may be approved.

- **ASTM F483:** This is similar to the NACE test, but exposure is constant.

- **ASTM B117:** Another continuous-spray test.

- **SHRP H-205.7:** This is also an immersion test, but aspiration introduces air into the solution. Inhibitors should be tested at three concentrations, and the test is recommended to be conducted for up to eight weeks.

- **SAE J2334:** This test includes procedures for dip, fog, or spray applications. Metal coupons coated with automotive paint are exposed to a chemical for 15 minutes, followed by 17 hours and 45 minutes of drying, and then 6 hours in a 100 percent humidity environment. The test is run for 80 cycles, with flexible options for weekends and holidays.

- **Electrochemical techniques** measure polarization as an indicator of corrosion rates. (Metal corrosion is an electrochemical redox reaction in which electrons are transferred between different types of atoms to produce new chemical compounds.) These are the most rapid tests available, with evaluations available in under two hours.

Research on Deicers and Corrosion

Laboratory Tests

Most corrosion studies compare deicing chemicals using sodium chloride as an index. While steel is the metal most frequently tested, many studies have evaluated the effect of deicers on multiple metals. In published research, sodium chloride is consistently among the most corrosive chemicals tested; corrosion rates of salt on steel are often in the range of 40 to 50 mils (thousandths of an inch) per year (MPY). Because of differences in test methods, the research studies cited in this synthesis reported rates as low as 1.6 MPY and as high as 130.1 MPY.

While laboratory corrosion tests may offer useful information, their context must be considered. As Iowa Highway Research Board Project TR-471, "Evaluation of Deicing Materials and Corrosion Reducing Treatments for Deicing Salts," notes: "At present there are no data that link specification test performance with field performance." *(Nixon et al. 2009, pp. 17)* It goes on to acknowledge that "while the multi-year salt pilot project in Washington State goes some way toward developing some of the data that [a significant test program] would require, even this field study, extensive as it is, does not provide the information required."

Field Tests

There have been limited field tests of deicer effects on corrosion. Field tests in Washington State and Ontario found that while many corrosion inhibitors reduced corrosion by at least 70 percent in lab tests, they generally failed to meet that standard in the field. *(Baroga 2005, pp. 21–34; Ontario Ministry of Transportation 2009)* Four field tests performed by three agencies are described below.

Washington State DOT Field Test (2002-2004 Salt Pilot Program)

Among the most extensive field tests in the literature, this multi-year test designated 25- to 60-mile sections of highway where specific deicing chemicals—rock salt and salt brine, corrosion-inhibited liquid magnesium chloride, and corrosion-inhibited liquid calcium chloride—were used exclusively. Steel and aluminum coupons were mounted on Washington State DOT maintenance trucks that worked exclusively within one of these highway sections and were therefore exposed only to a single chemical, as well as supervisor trucks that were driven on highways where they might be exposed to multiple types of chemicals. Coupons were also fitted onto fence posts within the project sections to provide controls to measure "background" corrosion due to weather. *(Baroga 2005)*

This test showed mixed results. (*Baroga 2005* pp. 43–44) In the eastern parts of the state, corrosion on truck-mounted steel coupons exposed to inhibited chemicals was significantly less than on those exposed to salt, although these reductions did not meet the commonly cited Pacific Northwest Snowfighters specification of "70 percent less corrosive than salt." These results were not replicated in the western part of the state, although those results may be skewed by a limited quantity of data.

In eastern Washington, guardrail-mounted steel coupons exposed to corrosion-inhibited chemicals suffered more corrosion than those exposed to salt. Researchers did not offer an explanation for this result. This test was not run in the western part of the state.

Corrosion rates on aluminum coupons were particularly varied; in some instances, coupons exposed to salt experienced more corrosion, but in others, corrosion-inhibited chemicals caused more corrosion. Overall corrosion rates on aluminum were significantly less than on steel: The steel coupons lost grams of mass due to corrosion, while aluminum coupons lost tenths of grams.

Ontario Ministry of Transportation Field Test

While not published as a formal research report, the Ontario test was based on steel and aluminum coupons mounted on roadsides where different winter maintenance liquids with varying quantities of corrosion inhibitors were used. Results were inconclusive; the first phase found that inhibitors reduced corrosion in some cases but increased it in others. A second phase, involving more testing sites, was similarly inconclusive; inhibited chemicals that performed well in lab tests led to increased corrosion in the field as the inhibitor concentration increased. *(Ontario Ministry of Transportation 2009)*

Colorado DOT Field Tests

In a 2002 Colorado DOT (CDOT) field test, five metal coupons of varying metals were mounted on Plexiglas plates; these plates were mounted on seven private for-hire trucking company trucks and three CDOT Region 6 maintenance trucks. *(Xi and Xie 2002, pp. 24–25, 33–34)* Differences in corrosion rates could be seen on different trucks, most notably that trucks being driven between Denver and Grand Junction suffered more corrosion than those driven between Denver and Pueblo. Salt application records on the roads where the trucks were driven were not available, however, and no conclusions could be generated.

A 2009 CDOT field test installed mild and galvanized steel coupons at sites in Aspen, Greeley, and Castle Rock for times ranging from 255 to 451 days. *(Shi et al. 2009)* These coupons were exposed to chloride-based deicers, although the specific chemicals were not specified. Mild steel corrosion rates averaged 0.09 MPY, significantly lower than in other tests detailed in this and other reports. This seemingly anomalous result is attributed to two factors: the long test time and the limited deicer exposure. Corrosion rates are greatest at the beginning of the corrosion process, because once corrosion forms it serves as a barrier to further corrosion. Long tests will therefore have a lower overall corrosion rate. Additionally, the metals in this test were exposed to deicing chemicals for only a small percentage of the test time. *(Shi et al. 2009, pp. 214–216, 229)*

Summary of Lab and Field Studies

Sodium chloride is consistently among the most corrosive chemicals tested in available laboratory studies. Corrosion rates of salt on steel are often in the range of 40 to 50 mils (thousandths of an inch) per year (MPY), calculated as the weight loss due to corrosion/(area of tested coupon * time * metal density). Because of differences in test methods, such as the concentration of chemicals used, differences in the method of chemical exposure, and differences in the cycle of exposure and drying (without exposure to the chemical), comparing corrosion rates from different tests may not be valid. Different tests below reported salt's corrosion rate on steel as low as 1.6 MPY and as high as 130.1 MPY. Oxygen is a necessary part of the corrosion process, so tests based on immersion of metal in chemicals produced minimal corrosion. *(Xi and Xie 2002, pp. 32)*

Below is an overview of the key research studies completed on the link between corrosion and salt or deicer use in order of significance.

Table 1. Completed Research on Corrosion and Salt or Deicer Use

Study	Test Method	Results
2002-2004 Salt Pilot Project: Final Report for the Washington State Department of Transportation	Field	The Washington State Department of Transportation 2002–2004 Salt Pilot Project conducted a field evaluation of sodium chloride and corrosion-inhibited snow and ice control chemicals on steel and aluminum. On steel, corrosion rates for coupons exposed to salt were greater than those for inhibited chemicals, although inhibited chemicals did not meet the Pacific Northwest Snowfighters' 70% corrosion reduction standard in the field. Corrosion rates varied widely for the aluminum compounds. Corrosion was significantly less to aluminum, generally measured in tenths of grams relative to grams for steel, and conclusions may therefore not be as valuable. *(Baroga 2005 pp 21–34)*
"Corrosion Inhibitor Tests: The Results Are In"	Field	Ontario Ministry of Transportation conducted laboratory and field testing of corrosion inhibitors on both steel and aluminum in 2006 and 2007. Lab and field tests (in which corrosion coupons were installed on threaded nylon rods installed in patrol areas using different winter maintenance liquids) evaluated NaCl brine, $MgCl_2$ brine, and a brine that blends NaCl, $CaCl_2$, and $MgCl_2$. Each chemical was tested uninhibited and with inhibitors rated to be 50% and 70% less corrosive than sodium chloride brine. Results were mixed. The first phase found that in some cases inhibitors reduced corrosion, but in others inhibitors increased corrosion. A second phase, with a larger number of field sites and coupons tested, was similarly inconclusive. Inhibited chlorides functioned well at reducing corrosion in lab tests, but for many of the tested inhibitors, corrosion levels in field tests increased as the concentration of inhibitor increased. *(Ontario Ministry of Transportation Winter 2009)*
Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers—Phase I	Field	Mild steel and galvanized steel coupons (representing CDOT guardrails) were placed at field locations in Aspen, Greeley, and Castle Rock, Colorado, for exposure times ranging from 255 to 451 days. Corrosion rates on mild steel averaged 0.09 MPY, significantly lower than in any other test, for 2 reasons. Corrosion rates are greatest when the process starts, as once corrosion forms on a metal surface it serves as a barrier to further corrosion. PNS and electrochemical tests measure corrosion rates at the start of the process, while this test evaluated over a long period. Coupons in this test also experienced contact with deicers for a small percent of the test time. These sites used chloride-based deicers, although the specific chemicals used was not specified. *(Shi et al. 2009, pp. 214–216, 229)*

Study	Test Method	Results
Corrosion Effects of Magnesium Chloride and Sodium Chloride on Automobile Components	Multiple	This study evaluated how different corrosion tests, and how chemical concentration, affected the results of corrosion tests of salt brine and liquid inhibited magnesium chloride on several metals commonly used in vehicles. The hygroscopic (water-attracting) nature of $MgCl_2$ had a dramatic impact on corrosion rates; it was more corrosive than salt in humid environments (100% relative humidity in this test), but salt was more corrosive in dry environments or under immersion. *(Xi and Xie 2002,* pp. iii) SAE J2334 indicated that $MgCl_2$ was more corrosive than NaCl on steel, aluminum, and copper. The continuous-spray ASTM B117 test found lower corrosion rates overall than the SAE J23334 test, and that NaCl was more corrosive than $MgCl_2$ on the metals tested *(Xi and Xie 2002*, pp. 38–39). PNS tests found that $MgCl_2$ was significantly less corrosive than NaCl. *(Xi and Xie 2002, pp. 51*).
"Novel Corrosion Inhibitors Derived from Agricultural By-Products: Potential Applications in Water Treatment". (See also "Novel Corrosion Inhibitors Derived from Agricultural Byproducts" in *Materials Performance*, (Kharshan et al. 2012a)*	PNS	This study evaluated a corrosion inhibitor made from corn by-products from ethanol extraction. Three solutions that included the inhibitor (two containing propylene glycol, and one containing calcium chloride) met the PNS standard of being 70% less corrosive than a 3% salt solution on carbon steel. *(Kharshan et al. 2012b, pp. 8)* The calcium chloride was 29.6% as corrosive as salt, while the propylene glycol solutions were both less than 4% as corrosive as salt.
Qualified Product Listing	PNS	This document lists the commercially available deicing products that have been tested under the PNS laboratory test procedures and found to be at least 70% less corrosive than a 3 percent sodium chloride solution and are therefore approved for sale to PNS members. Dozens of products have been approved and are listed with their manufacturer, corrosion rate as measured under the PNS standard, concentration, and approval date for each chemical. *(Pacific Northwest Snowfighters 2013)*
Summary of Evaluation Findings for the Testing of Ice Ban	PNS	The Highway Innovative Technology Evaluation Center evaluated Ice Ban, a collection of $MgCl_2$ and $CaCl_2$ chemicals with agriculturally derived inhibitors. Corrosion rates on steel were between 3 and 18% of the corrosion rate of salt. Uninhibited $MgCl_2$ showed 33% of salt's corrosion rate, while $MgCl_2$ with a borate corrosion inhibitor was 21% as corrosive as salt. *(Highway Innovative Technology Evaluation Center 1999, pp. 24)*

Study	Test Method	Results
Investigation of Materials for the Reduction and Prevention of Corrosion on Highway Maintenance Equipment	Modified PNS	This test evaluated the effect of concentration of several deicer chemicals on corrosion rates. Results varied greatly. Salt brine was roughly as corrosive whether applied in a 1.5%, 3%, or 6% solution. Calcium magnesium acetate, mineral brine, $CaCl_2$, and Caliber M-1000 (a liquid magnesium chloride deicer with a corn-derived inhibitor) became less corrosive as concentration increased, while an Ice Ban/salt brine blend became more corrosive at higher concentrations, and GeoMelt (a beet-derived inhibitor for sodium chloride now known as Beet 55) and potassium acetate showed no correlation between concentration and corrosion. *(Nixon and Xiong 2009, pp. 12–15)*
"Evaluating the Corrosivity of Chemical Deicers: An Electrochemical Technique"	Electrochemical and PNS	This study evaluated an electrochemical test as a rapid alternative to gravimetric (weight-based) corrosion testing. The electrochemical test matched results of the PNS test to a reasonable degree. Both tests found NaCl and $CaCl_2$ to have similar corrosion rates, while $MgCl_2$ and $MgCl_2$-NaCl blends were somewhat less corrosive (although not enough to meet the PNS standard for inhibited chemicals). *(Shi and Song 2005, pp. 4)*
Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers—Phase I	Electrochemical and PNS	While this study focused on the corrosive impact of deicers on concrete and transportation infrastructure, it did include a component that investigated deicer impact on steel coupons. Electrochemical testing found that for 3% solutions of deicers, the impact of sodium acetate, potassium acetate, and sodium formate was small enough to be considered non-corrosive to mild steel. CDOT's magnesium chloride blend, IceBan ($MgCl_2$ and ag-based inhibitor), IceSlicer, and a salt/sand blend were all considered highly corrosive. *(Shi et al. 2009, pp. 211–213)* The PNS test found that Apex Meltdown and IceBan passed the PNS specification of 70% less corrosive than a salt solution, although barely. Uninhibited IceSlicer (salt-based) was the most corrosive chemical, approximately 25% more corrosive than salt. Peak SF (sodium formate), and CDOT's magnesium chloride blend were less corrosive than salt, but not by enough to meet PNS standards.
"Performance and Impacts of Current Deicing and Anti-Icing Products: User Perspective versus Experimental Data"	Electrochemical	Commercially available deicers (which were not identified by name in the report) were tested on A36 mild steel and compared to a blend of salt and sand (10-25% NaCl by weight). One liquid chloride-based deicer was slightly more corrosive than the salt/sand blend, while an ag-based deicer and a second chloride-based deicer were significantly more corrosive. Potassium acetate and sodium acetate were significantly less corrosive. *(Fay et al. 2008), pp. 13)*

Study	Test Method	Results
Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts	Electrochemical	This study tested 15 deicing chemical and inhibitor blends at three concentrations (As-received, 10%, and 1%) on 5 different metals: structural steel, wrought aluminum alloy, cast aluminum alloy, free machining brass, and magnesium alloy. Overall, chloride-based chemicals each showed similar corrosion rates on structural steel at a given concentration. This study suggests that field conditions, particularly related to hygroscopicity, may be a more important factor than chemical composition in determining corrosion rates. The effect of inhibitors varied widely; in some cases they provided no detectable improvement, and in some cases their effectiveness depended on concentration. *(Levelton Consultants 2007, pp. 135–145)*
Effects of Deicing Agents (Magnesium Chloride and Sodium Chloride) on Corrosion of Truck Components	SAE J2334 and ASTM B117	This test evaluated the corrosivity of $MgCl_2$, in both inhibited and uninhibited form, and NaCl on representative metals used in the automobile industry, including stainless steel 410 and 4L, aluminum 2024 and 5086, and coated auto body sheets. The SAE test indicated that $MgCl_2$ is more corrosive than NaCl for each of the metals tested (by as much as 13 times higher for stainless steel 410), although the ASTM B117 test indicated NaCl is more corrosive than $MgCl_2$ on stainless steel 410. A mixture of $MgCl_2$ and NaCl was found to be more corrosive than either chloride alone. Coated auto body panels treated with electroplating or hot-dip alloying strongly resisted corrosion, while coated cold roll sheets were highly corroded. Due to the reduced oxygen concentration in the ASTM B117 test, researchers suggested it may be a less realistic simulation of field conditions than the SAE J23334 test. *(Xi and Olsgard 2000)*
"Assessment of Safecote: New Deicer Product"	Neutral salt spray	This was a UK evaluation of Safecote, a corrosion inhibitor. Rock salt with Safecote was 55% as corrosive as plain rock salt to steel. $CaCl_2$ with Safecote was 34% as corrosive as rock salt, and $MgCl_2$ with Safecote was 18% as corrosive. *(Burtwell 2004, pp. 536)*
Evaluation of Selected Deicers Based on a Review of the Literature)	Multiple	As a literature review, this report did not include original research. It did include references to several older papers that are difficult to acquire today. *(Fischel 2001)* Relevant papers reported included: • Environmental Impact of Road Salting: Sodium chloride causes the greatest corrosion to steel, among deicing products. *(Jones et. al. 1992)* • Report on Laboratory Corrosion Test: $MgCl_2$ produced less corrosion than FreezGard (liquid $MgCl_2$), which in turn was less corrosive than IceSlicer (inhibited NaCl) on mild steel. *(Addo 1995)* • Use of Road Salt for Deicing: Administrative Report Calcium magnesium acetate had the lowest corrosion potential, $MgCl_2$ had moderate corrosion potential, and $CaCl_2$ and NaCl had severe corrosion potential. *(Vancouver City Council 1998)*

Strategies to Minimize Vehicle Corrosion

State DOTs use several approaches to mitigate the impacts of vehicle corrosion from chlorides. Below is a summary of state practices, as shared by the 19 respondents to the state DOT survey conducted for this investigation. Following this summary is additional information regarding each strategy shared, along with information gathered about corrosion prevention efforts on winter maintenance vehicles specifically.

Table 2. Respondents' Actions to Minimize Corrosive Effects of Salt and Salt Brine on Vehicles

Answer Options	Response Count	Response Percent
Use of corrosion inhibitors	10	53%
Information provided to public on importance of washing vehicles and component parts	9	47%
Reduction in volume of material used and/or frequency of use	8	42%
No steps taken	3	16%

Respondents reported other practices or efforts to address vehicle corrosion.

- Colorado DOT's Maintenance Decision Support System (MDSS) is used in conjunction with the agency's Standard Operating Guide to minimize material usage. A MDSS is an automated system that uses real-time data to assess road and weather conditions and predict changes in conditions, both due to weather and potential road maintenance activities, to aid in decision-making.
- Montana DOT's public outreach has been limited thus far. However, when the agency is presented with a concern, the focus is on educating its customers on the challenges of balancing winter driving safety with the less favorable impacts of the materials used to treat winter roadways.
- Washington State DOT participated in research to determine best practices to prevent corrosion. *(Baroga 2005)*

In addition, automobile manufacturers have sought to minimize the impact of corrosion through engineering and the use of corrosion-resistant materials and metal coatings. *(Koch et. al. 2002, pp. 10)*

Using Corrosion Inhibitors

Types of Inhibitors

In an effort to reduce deicing chemicals' corrosiveness, some state DOTs add corrosion inhibitors to their deicing chemicals. There are many types of corrosion inhibitors available on the market, and a number of winter maintenance chemicals are sold with corrosion inhibitors included. Many inhibitors are derived from agricultural by-products, and most have proprietary formulations, which makes classifying them and drawing broad conclusions about any particular class of inhibitor difficult. In addition, their compositions may not be published and available data may be of limited scientific value. *(Levelton Consultants 2007, pp. 67–68; 74–75)*

NCHRP Report 577, "Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts," identifies three basic types of inhibitors: those that limit the anodic (electrically positive) half-cell of the corrosion reaction, those that limit the cathodic (electrically negative) half-cell of the corrosion reaction, and those that form a physical barrier on metal surfaces to prevent corrosion. *(Levelton Consultants 2007)* Practical anodic inhibitors include phosphates, carbonates, and silicates; they are considered highly efficient at preventing corrosion, but are potentially dangerous because at low concentrations they can accelerate corrosion in localized areas. Cathodic inhibitors include calcium bicarbonate, zinc, polyphosphates, and phosphonates. Most organic inhibitors form protective barriers on metal surfaces.

Most commercial inhibitors don't fall neatly into these categories, however. As the report states:

> "Most commercial inhibitors are organic compounds that cannot be designated as either anodic or cathodic and are known as mixed inhibitors. The effectiveness of organic inhibitors is related to the extent to which they reabsorb and cover the metal surface. Absorption of the organic inhibitor depends on the structure of the inhibitor, on the surface charge of the metal, and on the type of electrolyte. Mixed inhibitors protect the metal in three ways—physical absorption, chemisorption, and film formation."

Specifications and Testing

Pacific Northwest Snowfighters has identified and developed standards for 12 categories of deicing chemicals related to safety, environmental preservation, corrosion, cost-effectiveness and performance. ITD, one of the PNS partner agencies, conducts corrosion testing for PNS in its Boise laboratory. Products that meet these standards can be approved for PNS's Qualified Product Listing. Most of these categories either include inhibitors or are chemicals that are significantly less corrosive than salt even when uninhibited. The categories are:

- Corrosion inhibited liquid magnesium chloride ($MgCl_2$)
- Corrosion inhibited liquid calcium chloride ($CaCl_2$)
- Liquid calcium magnesium acetate (uninhibited) (CMA)
- Corrosion inhibited sodium chloride (NaCl)
- Corrosion inhibited sodium chloride plus 10 percent magnesium chloride ($NaCl/MgCl_2$)
- Corrosion inhibited sodium chloride plus 20 percent magnesium chloride ($NaCl/MgCl_2$)
- Solid calcium magnesium acetate (CMA)
- Non corrosion inhibited solid sodium chloride (NaCl)

- Corrosion inhibited liquid sodium chloride (NaCl)
- Corrosion inhibited liquid sodium chloride plus calcium chloride ($NaCl/MgCl_2$)
- Corrosion inhibited liquid chloride blended brines
- Experimental (for products that do not fit existing categories; it currently includes products with potassium acetate, calcium magnesium acetate/potassium acetate blends, potassium acetate/carbohydrate material, and chloride/carbohydrate blends).

The Qualified Product Listing includes corrosion rates, as measured under the PNS test, for dozens of specific brands of deicing products. As the composition of commercial products with inhibitors is often not specified, this appears to be the only third-party data available for many of the products in it. However, the PNS corrosion tests are laboratory-based, and the results of field tests do not always correspond with lab results.

State Practices

The 19-agency survey conducted as part of this investigation captured details about states' current use of various corrosion inhibitors. A summary of the responses can be found below. Appendix A provides all the responses.

Use of Corrosion Inhibitors in Dry Salt

Three states (16 percent of respondents) reported the use of corrosion inhibitors in dry salt to minimize the corrosive impacts to agency and public vehicles.

- The majority of solid salt or salt/sand used in Montana (75 to 100 percent) is prewetted with an inhibited liquid. The salt used in solid form without prewetting is not inhibited.
- New York State DOT's salt specification requires the use of corrosion inhibitors in all salt.
- In Wisconsin, corrosion inhibitors are used in 10 to 50 percent of the dry salt used. All but a couple of the state's 72 counties prewet their salt, and many are starting to mix corrosion inhibitors into their salt brine.

Washington State DOT had used an inhibited dry salt, but the mixture did not sample consistently for quality and proved to be much more expensive.

Use of Corrosion Inhibitors in Salt Brine

More respondents are using corrosion inhibitors in salt brine than in dry salt. Still, only 8 states (42 percent of respondents) reported the use of corrosion inhibitors in salt brine. (All three states using corrosion inhibitors in dry salt also use inhibitors in salt brine.)

Ohio reports the most limited use, with corrosion inhibitors mixed with less than 10 percent of the salt brine used. In North Dakota and Wisconsin, 10 to 50 percent of the salt brine used is mixed with corrosion inhibitors. In 5 states - Colorado, Montana, New Hampshire, New York and Washington - most or all of the salt brine used (75 to 100 percent) is mixed with corrosion inhibitors. Some respondents provided additional details:

- New Hampshire DOT uses a mix of 20 percent Ice B'Gone with 80 percent salt brine.
- In most cases, New York State DOT makes its own brine using the agency's salt, which contains corrosion inhibitors. The agency does not add additional inhibitors.
- Washington uses corrosion inhibitors with all liquid products.

Three states - Idaho, Michigan and Utah - reported the use of corrosion inhibitors with other types of chlorides. The magnesium chloride used by ITD includes corrosion inhibitors as well.

Corrosion Inhibitors Used by Respondents

Seven respondents provided information, Table 3, about the corrosion inhibitors their agencies use in salt or salt brine. The most commonly used product is ArctiClear (Montana, Washington and Wisconsin).

Table 3. Respondents' Use of Corrosion Inhibitors in Salt or Salt Brine

State	Product	Vendor Website	Reasons for Use
Colorado	Boost	http://www.caclwithboost.com/applications.html	Lab tests, field tests, agency experience
Montana	ArctiClear	http://www.nasalt.com/products-applications/deicing/highway/bulk-specialty/	Lab tests
	Headwaters 40F corrosion inhibitor	http://www.rivertop.com/	Lab tests
New Hampshire	Ice B'Gone	http://ibgmagic.com/	Agency experience
New York	YPS	Not known (YPS could be yellow prussiate of soda, an anti-caking agent used to treat bulk deicing salt to help resist caking and prevent clumping.)	Field tests
North Dakota	Geomelt	http://www.snisolutions.com/antiicing.php (sample distributor site)	Product claims
Washington	ArctiClear	http://www.nasalt.com/products-applications/deicing/highway/bulk-specialty/	Lab tests, field tests, agency experience
	Boost	http://www.caclwithboost.com/applications.html	Lab tests, field tests, agency experience
	Various other inhibitors in small tests	Not known	Field tests
Wisconsin	ArctiClear Gold	http://www.nasalt.com/products-applications/deicing/highway/bulk-specialty/	Product claims
	Bio Melt 64	http://www.snisolutions.com/antiicing.php	Product claims
	FreezGard	http://www.nasalt.com/products-applications/deicing/highway/bulk-specialty/	Product claims
	Geomelt	http://www.snisolutions.com/antiicing.php (sample distributor site)	Product claims
	Ice Ban M80	http://www.scotwoodindustries.com/uploads/94/original/All%20About%20IceBan.pdf	Product claims
	Ice Bite 55	http://www.univar.com/en/Marquee-Ice.aspx	Product claims

Table 4 shows respondents also noted the use of corrosion inhibitors in materials other than salt and salt brine.

Table 4. Respondents' Use of Corrosion Inhibitors with Other Materials

State	Product/Vendor	Reasons for Use
Colorado	Envirotech Services and Desert Mountain Corporation (inhibited magnesium chloride)	Lab test, field tests, agency experience
Idaho	Pacific Northwest Snowfighters-approved corrosion-inhibited magnesium chloride	
Ohio	Pacific Northwest Snowfighters-approved corrosion-inhibited calcium chloride	Lab tests, product claims
Washington	CC&B (inhibited calcium chloride)	Lab tests, field tests, agency experience
	FreezGard Zero Plus (inhibited magnesium chloride)	Lab tests, field tests, agency experience

ITD Corrosion Inhibitor Field Test

In 2013, ITD initiated a field study in District 1 to evaluate how well ArctiClear CI Plus (a PNS-approved inhibitor) reduces the rate of corrosion of mild steel when added to salt brine. This research was initiated following a similar study in South Dakota that found a positive correlation between the use of ArctiClear CI Plus and reduced corrosion rates as compared to the untreated salt brine. *(Wilkening 2014)* The District 1 study is scheduled for completion in the summer of 2014.

Adjusting Application Rates and Approaches

One method of reducing the corrosion caused by chloride-based chemicals is to reduce the quantity of those chemicals that get applied to roadways. ITD has begun using mobile data collectors with GPS to collect information about material application rates, which can ultimately help to minimize material usage.

One completed research project and one project in process, as described below, have investigated the effect of adjustments to application rates.

Research in Progress

Clear Roads Project 12-02, "Establishing Effective Salt and Anti-icing Application Rates, expected to be completed in October 2014, will update guidelines in FHWA TE-28, "Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel," and NCHRP Report 526, "Snow and Ice Control: Guidelines for Materials and Methods," regarding effective application rates for deicing and anti-icing chemicals while minimizing negative impacts.
http://www.clearroads.org/research-projects/12-02-salt-and-antiicing-application-rates.html

Completed Research

The 2010 Clear Roads study on liquid-only plow routes focused on the practice of during-storm direct liquid application of deicing chemicals. Colorado Department of Transportation reported it had reduced the number of complaints about corrosion effects, particularly from the trucking industry, by changing its policies to only apply chemicals to wet roads during or after storms. *(Peterson et al. 2010, pp. 2)*

Outreach Recommending Vehicle Washing

To mitigate the impact of vehicle corrosion from chlorides, agencies frequently recommend regular vehicle washing to remove corrosive chemicals from cars and trucks. Almost half of respondents in the state DOT survey for this investigation reported providing information to the public on the importance of washing vehicles. An ITD brochure entitled "Why does ITD use salt?" lets the public know that frequent vehicle washing helps to minimize corrosion.

Vehicle and truck washing is not always practical, however. Facilities for washing cars and trucks are not universally available, and manual washing is not feasible in winter. Additionally, some in the trucking industry have suggested that this recommendation represents an unreasonable effort for transportation departments to save money by passing winter maintenance costs onto end-users.

Reducing Corrosion on Winter Maintenance Equipment

Winter maintenance equipment can be particularly susceptible to corrosion due to its regular contact with corrosive chemicals. Techniques for mitigating this corrosion include material selection, metal coatings, and maintenance practices, particularly frequent washing.

A 2012 survey of private and government winter maintenance professionals found that the risk of corrosion on winter maintenance equipment was most significant to dump trucks, followed by liquid deicer applicators, hoppers, and front end loaders. *(Shi et al. 2013, pp. 33-35)* Specific equipment components most likely to suffer corrosion were electrical wiring, frames, brackets and supports, brake air cans, fittings, and spreader chutes. Cast iron, carbon steel, and composites were the materials most likely to experience general corrosion.

State Vehicle Washing Practices

Respondents to the state DOT survey conducted for this investigation offered the following about their practices to wash or treat vehicles to minimize corrosion associated with the use of salt and salt brine.

- In Iowa, fleet vehicles are thoroughly washed with salt neutralizing/removal wash.

- Maine treats agency equipment with FluidFilm, a lanolin-based brand of corrosion preventive and lubricant; see http://www.fluid-film.com/ for vendor information. Information about the agency's practices related to corrosion is available at http://www.maine.gov/mdot/winterdriving/corrosion.htm.
- Kansas provides heated, enclosed wash bays to make it easier to wash trucks and equipment.
- In New York, DOT trucks are washed frequently, and the agency uses stainless steel dump bodies to minimize corrosion.
- Washington has a wash policy in place for agency vehicles, and Ohio and Utah wash down trucks after every event.

Mitigation Practices Suggested in the Research

National Research

The final report for NCHRP Project 25-25(04), revised Chapter 8 - Winter Operations and Salt, Sand, and Chemical Management, noted that spreaders are particularly exposed to corrosive materials. It advises:

> *"Spreaders should be manufactured from a material that will resist corrosion. Special chlorinated rubber primers and epoxy-based primers will increase coating life. Stainless and galvanized steel, and fiberglass bodies are available but can be relatively expensive. High strength, low alloy self-coating steel, used with good surface preparation and special primers has been proven to provide a cost effective body life of up to fifteen years. Manufacturers also supply spreader bodies constructed of fiberglass. These bodies are lighter and thus provide increased payload possibilities, but are also more expensive than steel." (Fay et al. 2013, pp. 37)*

State Research

Washington State Department of Transportation Report WA-RD 796.1, "Identification and Laboratory Assessment of Best Practices to Protect DOT Equipment from the Corrosive Effect of Chemical Deicers," identified best practices to minimize corrosion on DOT winter application equipment and vehicles. *(Shi et al. 2013)* The study consisted of a literature review; survey of private and government winter maintenance professionals; a laboratory investigation of the effect of anti-corrosion coatings, spray-on corrosion inhibitors, and salt removers on corrosion of steel caused by salt and magnesium chloride; and a cost-benefit analysis.

Strategies

The literature review found that corrosion on DOT equipment can be mitigated through material selection, improved design, and maintenance practices. For example, a zinc coating on steel substrates provides good anti-corrosion performance. Designs that minimize crevices, eliminate contact between different kinds of metal, and provide easy drainage from exposed surfaces can minimize specific types of corrosion. Frequent washing, with or without salt removers was found to reduce corrosion caused by residual road salts. In most cases, low-pressure washing was effective, although salts that have attached and formed a complex with a metal substrate must be removed with 40,000-psi Ultra High Pressure Water-Jetting. *(Shi et al. 2013, pp. 28–30)*

Product Testing

The survey received 38 responses of coatings, salt removers, and corrosion inhibitors used by agencies to reduce corrosion. The laboratory investigation evaluated the corrosion prevention effectiveness of four anti-corrosion coatings (Zero Rust Red, Zero Rust Black, Rust Bullet, and Lubra-Seal), four spray-on corrosion inhibitors (Krown, Ship-2-Shore, vegetable oil, and Rust Oleum), and six salt removers (MR 35, HoldTight, ChloRid, SaltAway, soap water, and Neutro-Wash). *(Shi et al. 2013, pp. 35–36)*

An initial electrochemical evaluation, involving two hours of immersion in a 30 percent magnesium chloride solution, identified Rust Bullet, Lubra-Seal, Krown, Rust Oleum, HoldTight, and ChloRid as having the best anti-corrosion properties. These products underwent further tests, including two weeks of immersion of steel and aluminum coupons in a 3 percent magnesium chloride solution and wet-dry tests involving 40 minutes of immersion in a 30 percent magnesium chloride solution, followed by 22 hours of air drying and washing. *(Shi et al. 2013*, pp. 38–47) The immersion test found outstanding performance from Rust Bullet, Krown, HoldTight, and ChloRid, while the wet-dry test found significant corrosion resistance benefits from using HoldTight on steel coupons, but not aluminum.

Research in Progress

Clear Roads issued a request for proposals and will soon award a project to develop a best practices guide for the prevention of corrosion on DOT equipment. The guide will be based on Washington State DOT Report 796.1, "Identification and Laboratory Assessment of Best Practices to Protect DOT Equipment from the Corrosive Effect of Chemical Deicers." http://www.clearroads.org/research-projects.html

Part 2
Environmental Effects of Roadway Deicing

Executive Summary

Background

Transportation agencies apply large amounts of winter maintenance materials to roads annually to control snow and ice and to restore friction to winter roads. Using these winter maintenance materials, typically solid or liquid chloride salts, is critical to public mobility and safety. *(TAC 2013)* In winter, applying sodium chloride, magnesium chloride, calcium chloride, and other deicers helps to prevent or break bonds between ice and road surfaces, while applying sand helps to improve traction. *(Shi et al. 2009)* These practices reduce accident rates, improve travel times, and lead to fuel savings. *(TAC 2013)* They also provide significant economic benefits, allowing workers and supplies to reach workplaces, and consumers and finished goods to reach marketplaces. *(TAC 2013)* Winter mobility is also critical to quality of life and the functioning of emergency services. *(TAC 2013)*

Nevertheless, as the use of winter maintenance materials has increased over the last few decades, the winter maintenance community and environmental agencies have become increasingly concerned about the effects of these chemicals on transportation infrastructure, vehicles, and the environment. *(Fay et al 2013; Levelton Consultants 2007)* Deicing salts not only corrode vehicles and infrastructure, they can damage vegetation through chloride uptake and damage soil structure through sodium accumulation. In addition, the presence of deicing materials on roadways has implications for drinking water, air quality, aquatic life, and terrestrial animals. *(Levelton Consultants 2007; TAC 2013)* Besides the estimated costs of winter maintenance, currently $2.3 billion annually in the United States, environmental and corrosion costs are estimated to be at least $5 billion annually. *(Fay et al. 2013, pp. 1)*

Consequently, researchers have been investigating the effects of chloride salts and other winter maintenance materials on the environment since the 1960s. *(Fay and Shi 2012)* Environmental research is critical to helping transportation agencies make the best decisions about the costs and benefits of various deicing practices in given conditions. There is an increasing interest in finding environmentally friendly deicers and engaging in proactive practices (such as prewetting roads with liquid anti-icers) that reduce agency use of winter maintenance materials. (*Levelton Consultants* 2007; Shi et al. 2009) ITD is a founding member of the Pacific Northwest Snowfighters Association (PNS), an organization that established and implemented testing approaches for deicing and anti-icing chemicals. PNS uses these tests to determine which products meet specific criteria related to corrosion, friction, and environmental health. ITD and other agencies around the country use these results to select chemicals that minimize negative impacts.

In Idaho, the Idaho Transportation Department's (ITD's) six districts use a variety of deicing strategies, including plowing, liquid magnesium chloride, sand, and solid sodium chloride. ITD staff reported that the agency has reduced its use of sand/anti-skid, noting that it can contribute to air and water quality problems. ITD has also sought to minimize the amount of road salt it applies, with application rates of from 130 to 300 pounds of rock salt and 22 gallons of salt brine per lane-mile - well below other states. *(IDEQ 2012)* Rates in Midwestern states are as high as 600 to 1,500 pounds of salt per lane-mile. Further, 80 percent of respondents to ITD's 2011 Customer Satisfaction Survey said they were very or somewhat satisfied with ITD's winter maintenance efforts. *(Kane & Foltz 2011)*

Despite these efforts and the overall positive response they have received, Idaho's deicing practices have been a source of concern to some. A number of individuals and interest groups have complained about corrosion to vehicles and raised questions about the environmental impacts of salt use and its role in vehicle-wildlife collisions. The Idaho Department of Environmental Quality has conducted research on the effects of chlorides on the environment, such as needle browning and pine tree die-off in north Idaho and the possibility of elevated sodium and chloride concentrations in streams. *(IDEQ 2008 and 2012)* IDEQ has also investigated the possible negative effects of the use of concentrated sugar beet byproduct, as a corrosion inhibitor, on levels of phosphorus and biochemical oxygen demand in surface waters. Excessive phosphorous and elevated biochemical oxygen demand levels can result in a deprivation of oxygen to some aquatic organisms.

To address these concerns, ITD requested a synthesis of the available information on environmental impacts of the following deicing materials:

- Deicing Salts: sodium chloride, calcium chloride, and magnesium chloride.
- Salt Brine.
- Particulate Abrasives (a mix of sand, crushed rock, and other sediments).
- Corrosion Inhibitors.

Summary of Findings

Introduction

Despite the clear public safety and mobility benefits of using chloride salts and other winter maintenance materials to control ice and snow on winter roads, environmental agencies and the winter maintenance community have become increasingly concerned about these materials' effects on transportation infrastructure, vehicles, and the environment. Although the Idaho Transportation Department has taken steps to minimize the amount of road salt it applies and the environmental effects of deicing in general, and its winter maintenance activities have not resulted in violations of environmental regulations, the agency continues to look for ways to minimize the environmental consequences of its winter maintenance efforts. Consequently, it is interested in better understanding the effects of sodium and chloride on vegetation and water quality, and the effect of concentrated sugar beet byproduct, used as a corrosion inhibitor, on levels of phosphorus and biochemical oxygen demand in surface waters.

We reviewed available literature in the following topic areas:

- Environmental impacts of selected deicing materials.
- Federal environmental regulations applicable to selected deicing materials.
- ITD's level of compliance with environmental regulations.

Environmental Impacts of Selected Deicing Materials

To various degrees, all winter maintenance materials can affect the environment, including soil and soil biota, vegetation, surface waters and ground water, air quality, and animals. According to Levelton Consultants in 2007, of greatest concern are the effects of abrasives on aquatic life and air quality, chloride salts on vegetation, and organic biomass products on aquatic life. *(Levelton Consultants 2007)* There is also moderate concern about the effects of chloride salts on water quality and aquatic life. We reviewed the available literature on the environmental impacts of chloride salts, abrasives, organic biomass products, and salt brine. Overall, the literature seems to suggest that chloride salts are the least environmentally detrimental of the available options. A recent Clear Roads study performed by Barr Engineering, "Determining the Aquatic Toxicity of Deicing Materials," ranked sodium chloride as the least toxic of a number of deicing materials tested for toxicity.

Chloride Salts

The greatest environmental concern for the use of chloride salts is its effect on vegetation, followed by its effects on water quality and aquatic life.

Salts can negatively affect vegetation via contact with foliage and the uptake of chloride and other ions into plants from soils. The effects of direct contact – usually greatest within 10 meters of a roadway – can lead to tissue desiccation, the death of stems and buds on young shoots, delayed and reduced growth, and premature leaf drop in conifers. Uptake of chloride ions can lead to leaf burn, tissue death, plant decline, and reduced growth. The uptake of sodium is less detrimental, but high sodium levels in soils can prevent water and nutrient absorption, leading to reduced growth. The vulnerability of plants to these effects varies widely between species. Most susceptible are younger plants and conifers, while woody trees are fairly tolerant of salts and most grasses are adaptable to high concentrations. As to the other components of salts, plants can tolerate calcium, magnesium, and potassium in high levels.

Using chloride salts for deicing can elevate levels of chloride, sodium, magnesium, and calcium in surface waters and groundwater, with possible consequences for aquatic life (of moderate concern) and human health (of low concern).

Elevated salt levels in surface waters can prevent the mixing of lake strata during the spring and fall, interfering with nutrient release and oxygenation and so harming aquatic life. Chloride can also be directly toxic to aquatic life, with widely varying levels of toxicity for different species. According to Environment Canada, 5 percent of aquatic species are affected at chloride concentrations of 210 mg/L and 10 percent at 240 mg/L. *(Environment Canada 2010)* But overall, the literature suggests that chloride concentrations that can harm fish are seldom caused by highway deicing, and most studies have found no effects on microfauna and invertebrates. Larger bodies of water and streams with greater flow rates are less at risk than smaller bodies because of their capacity to dilute incoming chloride. Further, chloride will not accumulate from year to year if there is enough water to produce runoff, and levels usually surge during winter and thaw periods in affected areas and decline thereafter.

Beyond the aquatic effects of chloride, the other components of deicing salts - sodium, calcium, magnesium, and potassium – are essential nutrients for animals and plants, are common in unpolluted waters, and are consequently highly tolerated by aquatic life.

Studies have also linked deicing activities to elevated chloride concentrations in groundwater, and have shown that chloride can accumulate with time in groundwater, often exceeding the EPA's secondary drinking water standard (250 mg/L). Sodium in groundwater has also been of concern, and the Massachusetts Department of Transportation receives on average 12 complaints per year about sodium levels in drinking water. While the EPA does not regulate sodium in water, there is some concern about its effects on people with hypertension or heart disease. Nevertheless, the levels of sodium due to deicing salts in drinking water are unlikely to contribute significantly to daily sodium intake for human beings.

For soils, the literature shows overall that while chloride-based deicing salts may decrease their permeability and aeration, there is no evidence that it damages soil to a significant degree. Chloride has not been shown to negatively affect soil structure; there are no documented cases of sodium affecting the stability of roadside soils; and calcium and magnesium are thought to benefit soil structure. Further, based on limited available data, it is thought that the use of salts does not significantly harm microbes in roadside soils beyond narrow strips near roads that are already disturbed by the presence of traffic.

Finally, chloride salts are thought to have little effect on air quality and animals. Because they reduce abrasive use, they are thought to be "a net benefit on air quality." *(Levelton Consultants 2007, pp. 60)* And while there are some reports of toxicity to small animals that ingest road salts, "most terrestrial animals have high salt tolerances, especially when adequate drinking water is available." *(Levelton Consultants 2007, pp. 62)*

Abrasives

The primary environmental concerns for abrasives are aquatic life and air quality. Abrasives pose a significant risk to aquatic life either via particles impairing fish habitats by blocking spaces between rocks in the beds of bodies of water (particulate bed load); or particles suspended in water (total suspended solids), which may block sunlight and eventually contribute to particulate bed load. According to Fay in 2013 page 2754, "Abrasives pose significant risk for water quality and may threaten the survivability of aquatic species especially during spring runoff." *(Staples et al. 2004)* Further, a 2001 study found that abrasives are not only worse for the environment than salt, but less economical. *(Schlup and Ruess 2001, pp. 50)*

The use of abrasives can also affect air quality by increasing PM-10 particles in the air, leading to air pollution and threatening human health. Studies have shown that reducing the use of abrasives leads to significant reductions in PM-10 emissions.

Finally, abrasives are thought to have little effect on soils. However, while there is limited data on the effects of abrasives on vegetation, it is thought that in sufficient quantities they can stress and smother it.

Organic Biomass Products Used as Corrosion Inhibitors

The use of organic biomass produces are of high concern for their effects on aquatic life. Organic matter, such as CSB used as a corrosion inhibitor, can increase biochemical oxygen demand in receiving waters, depriving aquatic life of oxygen. Only one study addressing the environmental effects of using CSB specifically in deicing was located: Clear Roads found that the deicing product Beet 55 led to potentially toxic levels of dissolved oxygen for fathead minnows. *(Clear Roads 2013)* Also relevant is the literature on IceBan, a group of agricultural byproducts patented for use as roadway deicing and anti-icing agents, including the liquid residue of fermented corn byproducts, which has been shown to cause "eutrophication of water, which will result in the proliferation of noxious aquatic plants, especially blue-green algae," reducing water oxygen levels. *(Fischel 2001, pp. 21)* Also used as a corrosion inhibitor, small amounts of phosphorus can dramatically harm aquatic ecosystems.

Salt Brine

No studies were found focusing on the environmental effects of brine specifically as opposed to sodium chloride in general. The use of brine in prewetting roadways is thought to be environmentally beneficial because it leads to less use of salt, although radioactivity can be a concern for brine obtained from groundwater wells associated with oil and gas drilling.

Federal Environmental Regulations Applicable to Selected Deicing Materials

U.S. federal environmental regulations do not specifically address the use of road salt and other winter maintenance materials. However, there are regulations concerning the levels of contaminants in air, soil and water that apply to the components of road salts and other deicing materials. Applicable U. S. federal regulations include: the Clean Water Act, the U.S. Safe Drinking Water Act, the Clean Air Act, and the Endangered Species Act.

For aquatic life, the EPA's *National Recommended Water Quality Criteria* (EPA 2013b) includes recommended surface water thresholds for the protection of aquatic life and human health for about 150 pollutants. These include chronic and acute thresholds for chloride—860 mg/L and 230 mg/L, respectively. EPA regulations (EPA 2013f) also list maximum drinking water levels for various contaminants. Chloride is not regulated, but it is on the secondary drinking water standard list with a limit of 250 mg/L.

Also applicable are the EPA's air quality standards. *(EPA 2012h)* However, the EPA has not yet addressed toxicity in soils. *(Levelton Consultants 2007, pp. 28)* As for regulations related to animal life, when deicing materials are used on roads near endangered species, the Endangered Species Act requires that the threat to species be evaluated. *(U.S. Fish and Wildlife Service 2013)*

ITD's Level of Compliance with Environmental Regulations

ITD's compliance with environmental requirements is monitored at the state level primarily through the Idaho Department of Environmental Quality (IDEQ) and at the federal level through the U.S. EPA. Water quality is monitored by the EPA primarily through National Pollutant Discharge Elimination System (NPDES) permits, which are issued to facilities in urban areas that discharge stormwater runoff, including snow melt runoff, directly to surface water. National Pollutant Discharge Elimination System permits address discharges of runoff through a municipal separate storm sewer system (MS4) involving a relatively small percentage of total ITD highway miles.

Our review did not identify any notices of violation issued to ITD districts, and we identified just one expression of concern regarding use of salt for winter maintenance, in District 1. Further, IDEQ confirmed that salt in northern Idaho waterways does not appear to be a cause for concern at this time, noting that excessive use of sand would be a bigger concern.

In general, federal and state citations of state DOTs for violating environmental requirements due to winter maintenance activities appears to be rare across the country. In the multistate survey conducted as part of this synthesis project, only 4 of the 20 states responding to a survey question on violations indicated any kind of enforcement action.

Detailed Findings

Components of Concern

Levelton Consultants' 2007 *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*, one of the most authoritative and comprehensive sources to date on the environmental effects of snow and ice control materials, defines components of concern for the deicing materials under consideration as follows. *(Levelton Consultants 2007, pp. 29-30)*

Components of concern for chloride salts, which can affect soil and water quality, include:

- Primary Components: Chloride, sodium, magnesium, calcium.
- Possible Byproducts: Heavy metals, cyanide, phosphorus.

Components of concern for abrasives include:

- Air Quality: PM10 and PM2.5 particles.
- Water Quality: sedimentation, including total suspended solids and particulate bed load.
- Possible Byproducts affecting soil and water quality: Heavy metals, phosphorus.

Components of concern for corrosion inhibitors include:

- The possible byproducts of organic matter (complex sugars), derived from agricultural beet processing, which can affect soil and water quality: dissolved oxygen and biochemical oxygen demand.
- Heavy metals, phosphorus, and nitrogen found in other types of corrosion inhibitors.

Snow and ice materials can be discharged into the environment during “transport, storage, or application on roadways.” *(Levelton Consultants 2007, pp. 25)* In particular, during application materials “are deposited on roadside soils from splashing, spraying, gravity drainage, or plowing.” *(Levelton Consultants 2007, pp. 25)* Once on roadside soils, components of snow and ice materials may:

- Directly affect soil structure and soil biota.
- Be taken up via the roots by vegetation (chemicals may also directly splash on vegetation during application or by subsequent traffic).
- Be washed by precipitation into surface waters and groundwater, where they may affect aquatic life and human health.
- Be entrained in the air, causing air pollution.
- Be ingested by animals.

Levelton Consultants on page 26 adapts the following chart from TRB to illustrate the overall relationships between pathways: *(TRB 1991)*

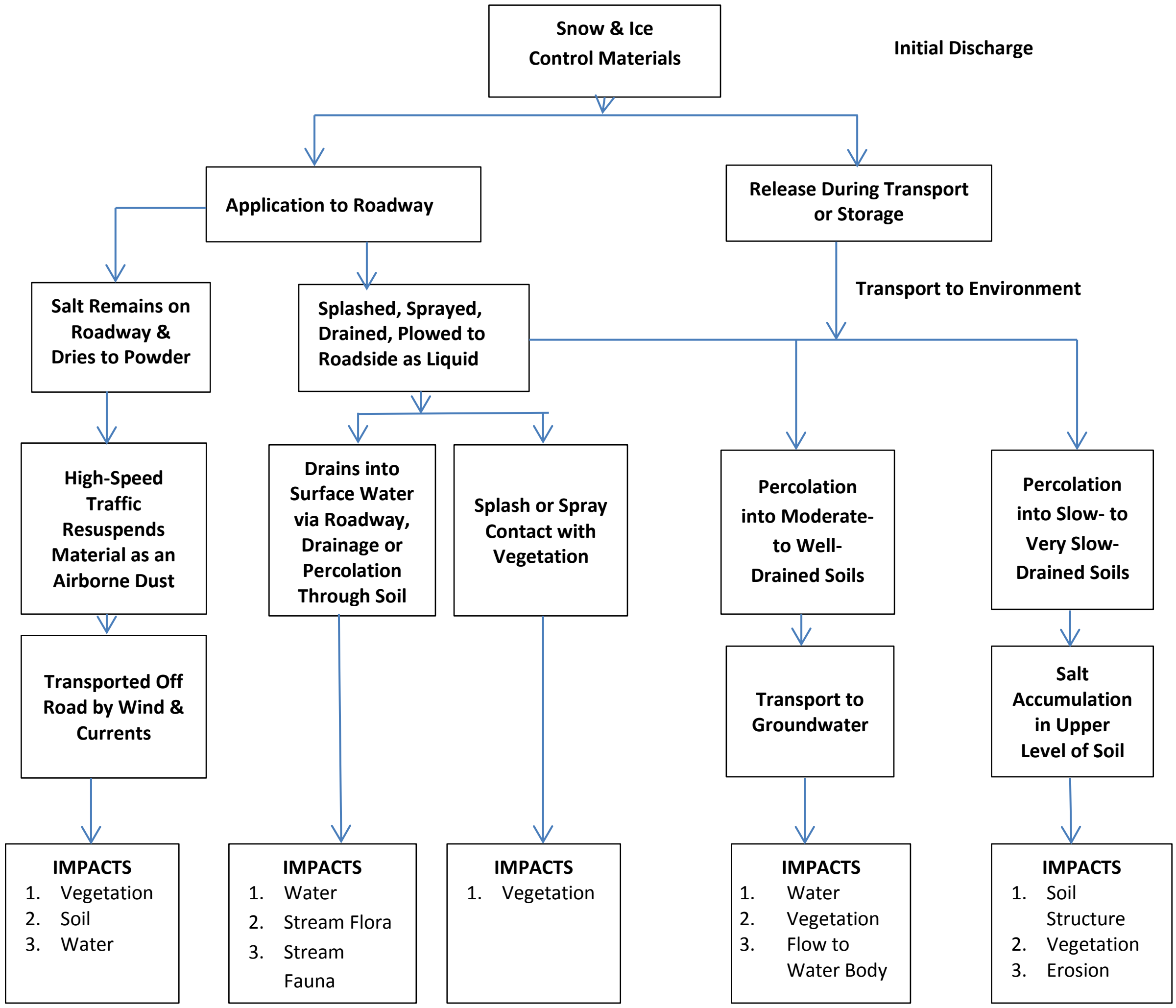

Figure 1. Overall Path of Snow and Ice Control

The literature review that follows is organized by pathway, and where applicable, by component of concern or specific environmental effect.

Effects on Soil

According to the Transportation Association of Canada's (TAC) *Salt Management Guide*, "Salt-laden water from winter roadway maintenance activities can infiltrate soil either directly through the melting of snow banks, salt stockpiles and salt spray and splash, or indirectly through surface runoff in ditches." *(TAC 2013, pp. 56)*

The available literature on the effects of deicing materials on soil is consistent with TAC's conclusion that:

- While salt in soil may decrease its permeability and aeration, with high clay and organic content soils most at risk, there is "no evidence from the literature reviewed that road salting has damage soil structure in highway rights-of-way to any significant degree." *(TAC 2013, pp. 60)*

- Salt in soils may raise PH, decrease soil fertility, "mobilize trace metals in soils … and subsequently affect groundwater and terrestrial organisms," although more research is needed in these areas*. (TAC 2013, pp. 60)*

NCHRP similarly concludes that the direct effects of deicing materials on soils "are generally not a concern, but snow and ice control material can influence soil structure, and the presence of these materials in soil can further affect water systems and vegetation*." (Levelton Consultants 2007, pp. 2) Nevertheless, the literature reviewed below suggests that deicer "migration into soils adjacent to roadways can cause the swelling and compaction of soil, change its electrical conductivity, and lead to loss of soil stability by means of dry-wet cycling, osmotic stress, and mobilization of nutrients. (Environment Canada 2010)*

Chloride Salts

Infiltration and Zone of Influence

Salt concentrations in soil from maintenance activities generally decrease with increasing soil depth and distance from the road. (Levelton Consultants 2007; TAC 2013)

Levelton Consultants in *NCHRP Report 577* cited several reports, sodium and chloride levels in soils adjacent to snow and ice maintenance activities are greatest "within 2 to 3 meters of the pavement edge." *(Prior and Berthouex 1967)* Similarly, TAC 2013 cited another study that found a significant decrease in sodium chloride within 2 meters of roadways. (*Pederson 2000)* However, Levelton Consultants in NCHRP Report 577 cites a study to the effect that higher than normal concentrations can occur "as far as 10 meters from the roadway." *(Hofstra and Smith 1984, pp. 26)* Levelton Consultants cites two other studies that confirm "beyond 10 meters, concentrations of snow and ice control chemicals dropped to background levels" – below 500 ppm (parts per million) for both sodium and chloride. *(Eppard et al. 1992; Cain et al. 2001)* Further, Levelton Consultants cite Novotny's high springtime salt levels disappear in the summer as salt readily leaches. *(Novotny 1999)* A 2002 evaluation of sodium accumulation in soils and plants along Massachusetts roadsides concluded that concentrations ranged from 101 mg/kg at 5 feet to 16 mg/kg at 30 feet from the roadside, with a marked decrease after 15 feet. *(Bryson and Barker 2002)*

Levelton Consultants cite Prior and Berthouex's statement that the depth of infiltration is usually not greater than 1 meter. *(Prior and Berthouex 1967)* TAC cites one study that found that "the highest salt concentrations were in the top 1.3 cm of soil dropping off rapidly thereafter to normal background levels at depths ranging from 102 to 127 cm." *(Hanes et al. 1976)*

Accumulation

Several studies have showed little accumulation over time of deicing salts in soils. A Saskatchewan study in which soil and water sampling was performed at various sites over several years found little accumulation of salts in soils after 10 years:

> … after 10 years of deicing salt application, there is a slight increase of ion levels at the selected site[s]. However, levels have not changed significantly and the environmental impacts are minimal along this highway. The study indicates that although there has been some accumulation of salt in the soil after winter, it is insignificant due to the groundwater flow and the sandy nature of the subsurface. A different set of geological characteristics could have led to an entirely different outcome. The fact that Highway #46 does not have high deicer application rates could also be a reason for this insubstantial impact of deicer application. *(Jin et al. 2006)*

Similarly, Fay cited a 2009 study "soil samples collected in the Lake Tahoe Basin showed no net accumulation of salts, despite the observed damage to trees by deicing salts." *(Munck et al. 2009)*

For chloride in particular, a 2005 Washington State DOT study evaluating the environmental effects of the use of road salt used on four sections along I-90 found that regardless of whether corrosion inhibitors were used, "chloride levels found in roadside soils, surface water, and underlying groundwater were found to be generally low and well below any applicable regulatory standards or guidelines." *(Baroga 2005, pp. 4)*

A 2008 study found that for soils in urban areas of Eastern New York, magnesium chloride ions were more abundant than sodium chloride ions, despite more frequent use of sodium chloride for deicing, suggesting the latter leach more rapidly. *(Cunningham et al. 2008)*

Effects on Soil Structure

Sodium

Deicing salts can affect soils by exchanging sodium cations with the magnesium and calcium cations already in the soil, affecting "structure (permeability and aeration), pH, fertility, vegetation damage and mobilization of trace metals." (TAC 2013, pp. 57) The exchange is higher in clay soils. *(TAC 2013 citing Jones et al. 1986)* Fay (2012) cites further literature to the effect that sodium can displace organic cations in soils, "reducing soil permeability and aeration and increasing overland flow, surface runoff, and erosion." (Public Sector Consultants 1993; Ramakrishna and Viraraghavan 2005)

Fay further notes on page 2757:

> Sodium accumulation can cause increased soil density, reduced permeability, higher alkalinity, moisture retention, and loss of soil fertility, which can reduce plant growth and influence erosion. *(TRB 1991)* Sodium chloride migration through soils can cause soil swelling, increase soil electrical conductivity, cause loss of soil stability from drying and wetting cycles, and cause osmotic stress and mobilization of nutrients and metals impacting the localized environment. *(Ramakrishna and Viraraghavan 2005; Environment Canada 2010)*

Similarly, Levelton Consultants 2007 NCHRP Report 577 concludes that sodium can break down soil structure, reducing permeability by reducing particle sizes and so increasing runoff and erosion and affecting the structural stability of roads. *(Levelton Consultants 2007, pp. 48-49)* But according to the Transportation Association of Canada 2013, for this to happen sodium levels must be "relatively high; i.e. greater than 15% of the soil's exchange capacity is occupied by sodium," at around 3,000 ppm. *(Public Sector Consultants 1993) NCHRP Report 577* found no documented cases of sodium negatively affecting the stability of roadside soils. *(Levelton Consultants 2007, pp. 51)*

Chloride, Magnesium and Calcium

Chloride has not been shown to negatively affect soil structure, although it can increase osmotic pressure by increasing soil conductivity. *(Levelton Consultants 2007, pp. 48)* Levelton Consultants also cited authors that stated both calcium and magnesium "tend to improve soil structure and permeability by increasing aggregation of fine soil particles." *(Novotny 1999; Bohn et al. 1985)*

Fay in 2012 also cites literature by Defourny to the effect that calcium and magnesium improve soil structure: "calcium and magnesium cations have been found to increase soil stability, permeability, and aeration, likely through organic and inorganic particle flocculation." *(Defourny 2000)*

Heavy Metal Mobilization

The various components of road salts, including sodium, chloride, magnesium, and calcium "may displace heavy metals already bound to soil particles in a process commonly referred to as heavy metal mobilization" after which they may, *(Levelton Consultants 2007, pp. 47):*

> … resorb onto other soil sites, interact with soil organic material, form metal acetate pairs, bioaccumulate, or move with the hydraulic gradient in groundwater with eventual discharge to surface water. Mobilized metals are more biologically available than soil-bound metals and pose a greater risk to vegetation, terrestrial organisms, and aquatic life. *(Elliott and Linn, 1987)*

The potential for mobilization is greater when the soil already contains high levels of metals. *(Morin et al. 2000 cited by Levelton Consultants 2007)*

A recent study by Nelson et al. found that immediately after salt application, metals could have concentrations 50 to 1,000 percent greater than normal, with sodium chloride leading to a larger increase in lead and copper than magnesium chloride, and magnesium chloride leading to a larger increase of cadmium. *(Nelson et al. 2009)* TAC 2013 cites another study that showed "a large part of the Pb, Cu and Zn in roadside soils is vulnerable to leaching when exposed to a high NaCL concentration." *(Norrstrom 1998*) TAC 2013 also cited a 2004 study that found increased heavy metal concentrations during the winter at sites where sodium chloride had been used for deicing. *(Backtrom 2004)*

Some laboratory experiments suggest chloride can displace heavy metals from soil to groundwater. *(Amrhein and Strong 1990; Public Sector Consultants 1993; Doner 1978 cited by Levelton Consultants 2007)* However, supporting field evidence is limited, with two studies showing not significant effects. *(Pilon and Howard 1987; Mussato 2001 cited by Levelton Consultants 2007)* One study cited by TAC 2013 on page 63 showed low levels of metals in groundwater with 300 mg/L chloride, "suggesting that these metals were not highly mobilized by elevated chloride levels." *(Howard et al. 1993)*

Similarly, Fay in 2012 on page 2757 cites literature suggesting that the "chloride anion has been shown to mobilize heavy metals from the soil into groundwater," that sodium does so in soils with high clay content, and overall that "salt contamination of soil has been shown to cause nutrient and heavy metal transport from the roadside to receiving waters." *(Sucoff 1975a; TRB 1991; Environment Canada 2010; Defourny 2000)*

Levelton Consultants in 2007 cites several authors stating that calcium and magnesium can also displace heavy metals, but are likely to have less effect in this regard than sodium. *(Winters et al. 1985; Horner 1988; Elliot and Linn 1987; Amrhein et al. 1994)* Despite these concerns, we found not documented cases of significant problems with heavy metal mobilization due to the use of winter maintenance materials, in Idaho or other states.

Abrasives

Abrasives "have few direct effects on soil because they do not chemically react and tend to remain on the surface of the soil." (*Levelton Consultants 2007, pp. 51)* However, some abrasives have high levels of such trace materials as metals.

Organic Products and Corrosion Inhibitors

For organic products, including those used in biomass products used as corrosion inhibitors with salts:

> There is limited specific information detailing the effects of organic products on soil properties, but, based on their organic constitution, it is expected that they would be subject to degradation by soil micro-organisms. Degradation could lead to anaerobic conditions in the soil, which can decrease soil pH and increase the solubility of adsorbed metals. *(Levelton Consultants 2007, pp. 50)*

Effects on Soil Biota

According to NCHRP Report 577:

> High concentrations of salts in the soil can affect soil microbial activity via osmotic stress as well as apparently ion-specific stresses, though the magnitude of the effect is very difficult to gauge. Organisms tend to be highly adaptable and soil characteristics (e.g., pH, ion exchange capacity, ammonium level and fertilization state, and matric water potential) can influence the magnitude of effect. The organisms most likely to be at risk are those in intimate contact with the dissolved solids in the soil water (e.g., protozoa, nematodes, earthworms, and arthropods) ... (*Levelton Consultants 2007, pp. 51)*

Levelton Consultants notes on page 53 that there is not much data on the effects of deicing salts on microbes in soils with the most comprehensive available source of information being Environment Canada's *Priority Substances List Road Salt Assessment*. *(Butler and Addison 2000)* This report makes inferences from studies that do not directly address the effects on soil of snow and ice control materials.

Based on the available research that we review below, NCHRP concludes that "routine snow and ice control practices do not pose a significant risk to roadside microbial populations" outside of narrow strips near roads that are already disturbed. *(Levelton Consultants 2007, pp. 53)*

Chloride Salts

Salts in soils can affect microbes via osmotic stress. *(Levelton Consultants 2007)* Levelton Consultants cite on page 52, the following authors. However, soil strips are narrow, already are disturbed environments with organisms adapted to them, and are likely to return to normal shortly after material application. *(Butler and Addison 1999)* One study showed a temporary decrease in microbial metabolism after sodium chloride runoff. *(Guntner and Wilke 1983)* A 2002 report found that sodium chloride is lethal to 25 percent of soil microbial species at 4,700 mg/kg and has non-lethal effects at 1,200 mg/kg. *(Bright and Addison 2002)* More recently, a 2008 study found that soils in urban areas of Eastern New York had "salt levels high enough to be toxic to terrestrial plants and soil protozoa" due to the use of deicing salts. *(Cunningham et al. 2008, pp. 17)* Magnesium chloride ions were more abundant than sodium chloride ions, suggesting the latter leach more rapidly.

As reported in Levelton Consultants on page 53, field studies found concentrations greater than these thresholds in some cases within 10 meters of roadways, but much lower concentrations at greater than 10 meters. *(Cain et al. 2001)*

Effects on Vegetation

According to NCHRP,

> … most impacts associated with roadside vegetation impairment can be linked to (1) extremely high levels of ions contacting foliage and/or the root zone and (2) ion-specific damage related to chloride ions. As a result, most highway agencies are faced with either accepting some degree of salt-related vegetation damage or modifying operations to reduce the amounts of detrimental materials reaching vegetation. *(Levelton Consultants 2007, pp. 59)*

Damage is of greatest concern within 10 meters of the roadway, with chloride being of greatest concern and sodium having primarily an indirect effect via its potential to degrade soil structure (see **Soils** in this report). *(Levelton Consultants 2007)* Abrasives may also smother roadside vegetation. *(Levelton Consultants 2007)*

Chloride Salts

TAC cited several authors in 2013 finding, deicing salts can reach roadside vegetation "1) through soil where salt concentrations have increased due to airborne salt spray deposition or surface runoff, and 2) through direct salt splash or airborne salt spray deposition upon above-ground tissues," causing a variety of injuries to vegetation, with sensitivity varying widely among plant species. *(Jones and Jeffrey 1986; Smith 1970; Dobson 1991)* These adverse effects, according to NCHRP, are well known and documented, with chloride posing the greatest risk. *(Levelton Consultants 2007, pp.553, 59)*

Zone of Influence

In general, vegetation "damage is of greatest concern within the primary material deposition zone 10 meters from the roadway." *(Levelton Consultants 2007, pp. 59)*

TAC in 2012 cited the following reports. The zone of influence for soil-related effects is usually less than 30 meters from the roadway. *(Jones and Jeffrey 1986; Briggins and Walsh 1989)* For direct splash from passing traffic, one study found the majority is within two meters, although as far as 28 meters for a 50 km/h road. *(McBean and Al-Nassri 1987)*

Airborne deposition has a zone of impact from 40 to 100 meters from the road edge *(Cain et al. 2001* cited in *Levelton Consultants 2007)*, although it can extend as far as 500 meters, *(Jones 1986 in TAC 2013)* and 1 study observed salt damage to White Pine as far as 382 meters from the road. *(Kelsey and Hootman 1992 in TAC 2013)* This zone of influence is greater for roads with steeper slopes. *(TRB 1991)*

Effects of Chloride Salts on Vegetation

Road salts can affect roadside vegetation either through uptake from the soil or direct contact with leaves and stems. *(TAC 2013)* TAC 2013 cites Jones and Jeffrey stating both sodium and chloride can be toxic to plants at high enough concentrations. *(Jones and Jeffrey 1986)* Levelton Consultants cite several authors stating whereas calcium and magnesium are essential nutrients that are not toxic to vegetation even at high concentrations. *(Tisdale 1966; Lewis 1997; Cheng 1998; Bohn et al. 1985)* A 2006 study suggests that it is the concentration rather than the type of anti-icing constituent that is most important to impacts on plants, and that plants are more vulnerable at the end of winter, when they enter their active phase. *(Onoduka et al. 2006)*

NCHRP classifies effects of road salts on vegetation into three groups:

- Aerial deposition.
- Ion uptake and accumulation from soil.
- Osmotic stress. *(Levelton Consultants 2007)*

Aerial Deposition

Aerial deposition of deicing salts can damage leaves. (*Moran 1992; Kelsey and Hootman cited in Levelton Consultants 2007; Hall et al. 1972; Hofstra et al. 1979 cited in TAC 2013)* It can lead to the desiccation of tissues, death of stems and buds on young shoots, delayed and reduced growth, and premature leaf drop in conifers. *(Cain et al. 2001 cited in Levelton Consultants 2007; Barrick and Davidson 1980; Chong 1990 cited in TAC 2013)* Applied directly to plants in the laboratory, both "sodium and calcium chloride severely injure plants." *(Environment Canada 2001 cited by TAC 2013)* Similarly, laboratory tests by Yamamoto et al. showed a tendency for damage when vegetation leaves were sprayed with saline solution. *(Yamamoto et al. 2010)* Degree of vulnerability depends on growth stage and vigor. *(Hanes et al. 1970; Cain et al. 2001 cited in Levelton Consultants 2007)*

Ion Uptake (Chloride)

Levelton Consultants cited several publications. Chloride ions taken up by plants from the soil can lead to "plant decline, reduction of leaf size and plant growth, leaf chlorosis, leaf burn, and tissue death," as well as delay in seed germination. *(Cain et al. 2001)* Sodium is less detrimental , and as essential nutrients, calcium, magnesium, and potassium can be tolerated by plants in high levels*. (Hanes et al. 1970)*

Yamamoto et al. found that after spreading of 2,400g/m^2 of solid sodium chloride over an 8 week period, the damage to vegetation caused by saline soil was temporarily high but well below 0.1 percent. *(Yamamoto et al. 2010)*

Osmotic Stress (Sodium)

Deicing salts also make it "more difficult for most plants to absorb water" by changing the osmotic pressure of water in soil. *(Moore 1982 cited in TAC 2013)* Levelton Consultants cited several reports stating, this can interfere with the uptake of nutrients and damage cells, leading to reduced shoot growth. *(Gidley 1990; Prior and Berthouex 1967; Cain et al. 2001)* High sodium levels in particular in soils can cause osmotic stress, as well as cause further damage to plants by negatively affecting soil structure. *(Levelton Consultants 2007)*

Plant Vulnerability and Other Factors

Vulnerability to salt varies significantly between plant species. See page 70 of TAC's *Salt Management Guide* for a table of thresholds (adapted from *Environment Canada 2000*) for sodium, chloride, and sodium chloride levels in various plants. *(TAC 2013 pp. 70)* In Levelton Consultants see Hanes et al. and Sucoff for lists of various species sensitivities. *(Hanes et al. 1970; Sucoff 1975)* Most susceptible are younger plants and conifers, while woody trees are fairly tolerant of salts and most grasses adaptable to high concentrations. *(Hanes et al. 1970; cited in Levelton Consultants 2007)*

A large number of other variables determine how severely deicing salts affect vegetation, including temperature, light, humidity, wind, soil water, soil texture and drainage, and precipitation; as well as season. *(TRB 1991; OECD 1989; Cain et al. 2001; Hofstra and Smith 1984 cited in Levelton Consultants 2007)*

Cain et al. developed toxicity thresholds for sodium and chloride in soil of 215 to 300 ppm and 300 ppm respectively for roots, and 200 to 650 ppm and 800 to 1650 ppm respectively for plant tissue. *(Cain et al. 2001 as reported in Levelton Consultants 2007)* Another study identifies the threshold for lethal effects by sodium chloride, sodium, and chloride at 840 mg/kg, 275 mg/kg, and 425 mg/kg respectively; and for non-lethal effects, 700 mg/kg, 220 mg/kg, and 440 mg/kg respectively. *(Bright and Addison 2002 cited in Levelton Consultants 2007)*

The Salt Institute advocates "salt-proofing" the roadside environment with salt-tolerant vegetation, especially *Table 3* listing the relative salt tolerance of various species. *(Salt Institute 2004, pp. 17-19)*

Injuries to Trees

TAC 2013 cites several authors regarding injuries to trees by deicing salts, which manifest themselves in the early spring include: *(Hall 1972; Hofstra 1979; Dirr 1976; Sucoff 1975)*

- Coniferous tree species: Browning of needles, premature needle drop, and reduction in growth.
- Deciduous tree species: Desiccation of twigs, death of flower buds and vegetative buds, premature leaf drop, reduction of new growth, and leaf burning.

Field Studies

A 1996 study cited by Levelton Consultants in 2007, found significant vegetation damage near roadways in Sweden because of a confluence of conditions. *(Backman and Folkeson 1996)* Another study also cited by Levelton Consultants found that 2 main types of damage to trees in the Lake Tahoe basin were caused in part by salt in 15.05 percent of trees. *(Eppard et al. 1992)* Another Lake Tahoe study found deicing salts to "negatively affect at least 19% and up to 55% of the trees in 2006" was cited by Fay in 2012. *(Munck et al. 2009)*

Several other studies have documented road salt damage to vegetation:

- A study of the effect of road salts on cranberry in Massachusetts concluded that irrigation water should not have more than 100 ppm of chloride. *(DeMoranville 2005)*
- Onoduka et al. (2006) found chloride levels well below those that would damage vegetation in roadside soils in Japan. *(Onoduka et al. 2006)*
- An assessment of factors impacting roadside vegetation in Colorado found significant foliar injury and needle loss in roadside conifers compared to off-road counterparts, as well as elevated levels of sodium, magnesium, and chloride. *(Trahan et al. 2008)*

Calcium Chloride and Magnesium Chloride

Because magnesium and calcium are not toxic to vegetation even at high concentrations, the effects of calcium chloride magnesium chloride are attributable primarily to the effects of chloride. (*Levelton Consultants* 2007) *Levelton Consultants also cited two other publications.* Calcium in particular can reduce sodium and chloride uptake from soils. *(Bogemans et al. 1989)* However, high levels of magnesium can lead to nutritional imbalances, for example by producing calcium deficiencies. *(Bohn et al. 1985)*

Levelton Consultants found one study found that the effects of calcium chloride varied among species. *(Paul et al. 1987)* They also found an Environment Canada study in 1984 that found the effects of calcium chloride to be attributable primarily to direct contact rather than soil uptake. *(Environment Canada 1984)* Another study they cite found no effect on roadside vegetation when calcium chloride was applied without splashing leading to direct contact. *(Nairne and Associates 1992)* Mussato concluded that magnesium chloride for anti-icing was unlikely to impact the environment. *(Mussato 2001*) However, Trahan et al. found direct exposure to magnesium chloride was far more damaging to conifer saplings than exposure to sand and salt. *(Trahan et al. 2008)*

Abrasives

According to Levelton Consultants,

> Use of abrasives for snow and ice control can stress and smother roadside vegetation. Small particles can adhere to the stomates and affect the regulation of oxygen, carbon dioxide, and water vapor between the plant and the atmosphere." (Levelton Consultants 2007, pp. 59) Fischel on page 69 cited information from *Audesirk and Audesirk* on page 124 indicating that blocked stomates can also reduce or inhibit photosynthesis and can prevent the plant from adsorbing nutrients from the soil. *(Levelton Consultants 2007, pp. 59)*

Effects on Water Quality and Aquatic Life

Chloride Salts

According to Fay, "chloride salts applied on winter roads can migrate into nearby surface waters and impact them via several pathways," including by elevating salt concentrations in receiving waters and affecting lake stratification. *(Fay 2012, pp. 2754)* Fay also cited that the harm to aquatic life may be insignificant "in large or flowing bodies of water where dilution occurs quickly," and "studies have found that chloride salt concentrations in highway runoff are typically low enough that the chloride salt is quickly diluted in receiving waters." (Jones et al. 1992; Fay 2012, pp. 2755) However, work "by Corsi et al. found road salt to cause detrimental impacts to surface water on local, regional, and national scales, with short- and long-term impacts to streamwater quality and aquatic life" was cited by Fay et al. 2013 on page 8). *(Corsi et al. 2010)* Chloride salts can also affect groundwater and human drinking water supplies. *(TAC 2013)*

Influence of Road Salt on Surface Water Concentrations of Chloride and Sodium

Chloride

Chloride occurs naturally in inland waters with concentrations ranging from 1 to 10 mg/L. *(Waters 1995 cited in Levelton Consultants 2007)* "Where chloride is applied as a main ingredient of snow and ice control materials, substantial augmentation of chloride concentrations in receiving waters is likely." *(Levelton Consultants 2007, pp. 35)* NCHRP cites the example of two Colorado streams in which use of ice materials raised chloride concentrations by a factor of as much as 100. (*Levelton Consultants 2007*, *pp. 35)* TAC 2013 cites D'Itri that these concentrations remained higher than normal into the summer, although spring runoff reduced them from their peak during winter, and they never exceeded EPA aquatic life criteria. In general, larger bodies of water and streams with greater flow rates are less at risk because of their capacity to dilute incoming chloride. *(D'Itri 1992)*

Field Studies of Elevated Sodium and Chloride Levels

There are many documented cases of chloride and sodium concentrations in runoff exceeding aquatic life standards as cited by Levelton Consultants. *(Environment Canada 1999; Butler and Addison 2000)* As Fay in 2012 on page 2755 notes, winter "concentrations following road salting have been recorded as high as 10,000 and 18,000 mg/L." *(TRB 1991; Environment Canada 2010)*

TAC describes numerous studies linking the use of road salt to elevated chloride and sodium levels in surface waters: *(TAC 2013, pp. 43 – 44)*

- Levels of chlorides in Lake Simcoe in Southern Ontario were almost four times higher after four decades of snow and ice maintenance activities nearby, and sodium levels elevated. *(Landre, 2009)*
- Chloride concentrations in five streams in Indiana were correlated with degree of urbanization. *(Gardner and Royer 2010)*
- Between the 1950s and 1990s, levels of sodium and chloride in a river basin in New York rose 130 percent and 243 percent respectively, after use on average of 39 kilograms per square kilometer per day. *(Godwin et al. 2003)*
- Several other studies suggested that elevated chloride and sodium levels in surface waters were due to salt storage or deicing activities in Canada, New York, and Maine, Rhode Island and Massachusetts. *(Perera 2010; Demers 1990; Ohno 1990; Scott and Wylie 1980; Runge 1989; MassDOT 1994)*

Our review found several other studies found elevated sodium chloride levels due to deicing activities:

- A six month evaluation of the effects of a mixture of sand and IceBan on the Peshastin Creek watershed in Washington State found chloride concentrations as high as 3.3 mg/L, significantly higher than the non-impacted average concentration of .62 mg/L (but much lower than EPA limits). *(Yonge et al. 2001)*
- A study of the effects of road salting on a Norway lake showed increased salt concentrations. *(Foeroevig et al. 2005)*
- A study in 45 randomly selected sampling sites near salt storage facilities in Virginia found chloride concentrations that routinely exceeded 2,000 mg/L. *(Fitch et al. 2005)*
- The Idaho Department of Environmental Quality found elevated sodium, chloride, and specific conductivity in streams near I-90 in February and June of 2008 and between 2009 and 2011, although no impacts to aquatic life have been documented. *(IDEQ 2008; IDEQ 2012)*
- Corsi et al. found that 7 of 13 samples taken from Milwaukee area streams during road salt runoff were toxic to two aquatic species. 72 percent of 37 samples taken from a Milwaukee stream from 1996 to 2008 were showed chronic toxicity, and 43 percent acute toxicity, with the maximum chloride concentration 7730 mg/L and in 11 watersheds in Southeastern Wisconsin,

chloride concentrations exceeded EPA acute limits at 55 percent of sites, and chronic limits at 100 percent of sites in November to April. *(Corsi et al. 2010)*

- Exceedences of the EPA water quality standard for chloride were detected in the 4 of 6 New Hampshire watersheds tested, with 91 percent of chloride having its source in road salt. *(Trowbridge et al. 2010)*

However, Denner et al. found that only 20 percent of the chloride load in 3 streams in Vermont was due to deicing, and chloride levels for each stream were below EPA limits. *(Denner et al. 2010)*

A literature review by Evans and Frick concludes that the impacts of salts on surface water are of most concern in urban areas:

> Road salt impacts, defined as increased chloride concentrations, were most pronounced in urban areas and areas located near heavily salted highways. Furthermore, there is some evidence of more gradual increases in chloride concentrations in lakes in these regions, in part a result of road salt application. *(Evans and Frick 2001, pp. 1)*

Retention within the Watershed

In general, according to NCHRP chloride will not accumulate from year to year if there is enough water to produce runoff. *(Levelton Consultants 2007)* Rather, surface water chloride concentrations from road salt usually surge during winter and thaw periods as cited on page 45 by TAC 2013. *(D'Itri 1992; Environment Canada 2010)* However, TAC 2013 on page 45 – 46, found 1 study "elevated CL concentrations after precipitation in spring and summer, suggesting some retention of road salt within the watershed." *(Gardner and Royer 2010)* Similarly, they cite a field study in Minnesota that found that 78 percent of road salt remained in the watershed after application. *(Novotny et al. 2008)*

Several other studies suggest that chloride can accumulate within watersheds:

- A study of the effects of deicing salts on water quality in Minnesota found that about 70 percent of the road salt applied in the Twin Cities Metro Area is not carried away by the Mississippi River, that both sodium and chloride levels are unnaturally high compared to other Midwestern bodies of water, and a rising trend in salinity over 30 years. *(Stefan et al. 2008)*
- Mullaney et al. evaluated 25 years of surface water quality data, and found that chloride had steadily increased in three rivers in New Jersey, Connecticut, and Illinois. Deicing materials were among a number of sources for this increase, which also included landfills, agriculture, and wastewater and water treatment. *(Mullaney et al. 2009)*
- Computer modeling by Shaw et al. suggests that salt concentrations in Fall Creek in central New York can be expected to increase for several decades and that an average residence time of road salt in the watershed is about 50 years. *(Shaw et al. 2012)*

<u>Effect on Lake Strata and Dissolved Oxygen</u>

Levelton Consultants and TAC 2013 cited elevated salt levels can prevent the mixing of lake strata during the spring and fall, interfering with nutrient release and oxygenation and so harming aquatic life. *(Jones and Jeffrey 1986; D'Itri 1992; Judd and Stegall 1982; Ramakrishna and Viraraghavan 2005; Bubeck 1971; Diment 1973)* Reduced oxygen can lead in turn to "higher nutrient loading and subsequently increased algal growth, further depleting" dissolved oxygen. *(TRB 1991 cited by Fay 2012)*

More recently, field measurements by Novotny and Stefan of a lake for two years showed the presence through the summer of a road salt-induced saline layer, which can affect lake quality and ecology. Computer modeling in the same study showed that this layer can prevent dissolved oxygen from reaching lake sediments, negatively affecting microbial communities and fish habitats. *(Novotny & Stefan 2012)*

Heavy Metal Contamination and Mobilization

According to TAC 2013 citation, road salt contains heavy metal contaminants, which can harm aquatic life. (Reinosdotter and Viklander 2007) See Table 3-6 in *NCHRP Report 577* for a table of regulatory aquatic life chronic thresholds for heavy metals most likely to contaminate snow and ice control mixtures. *(<u>Levelton Consultants 2007</u>, pp. 41)* See also **Federal Environmental Regulations** in this report.

Levelton Consultants in 2007 cited that the most likely metals to cause problems are zinc, copper, lead, and cadmium: "All four of these elements tend to become concentrated, probably by evaporation mechanisms, in salt deposits used as sources of magnesium chloride for liquid snow and ice control materials." *(Environment Canada 1999; <u>Lewis 1999</u>; <u>Fischel 2001</u>)*

Road salt can also cause "the release of metals from sediments and suspended particulate matter" in water (TAC 2013, 48, citing Warren and Zimmerman 1994; Gales and Van der Meulen 1992). Levelton Consultants notes that chloride in particular "may liberate mercury bound to wet sediments." (Levelton Consultants, pp. 35, citing Feick et al. 1972)

Effects on Aquatic Organisms

<u>Chloride</u>

The tolerance of aquatic life for chloride is high as cited by Levelton Consultants 2007. *(OECD 1989; <u>Chappelow et al. 1993</u>)* The EPA's freshwater aquatic life criteria are 860 mg/L and 230 mg/L for acute and chronic exposure respectively. *(<u>EPA 2013b</u>)*

According to Environment Canada as cited in TAC 2013, 5 percent of aquatic species are affected at chloride concentrations of 210 mg/L and 10 percent at 240 mg/L and at "lower concentrations, increased chloride concentrations may affect community structure, diversity and productivity."

(TAC 2013, pp. 49) Levelton Consultants also notes that "chloride concentrations exceeding the [EPA] criteria are more likely to change the composition of aquatic communities than to impair all species. *(Jones and Jeffrey 1986; Dickman and Gochnauer 1978)* TAC 2013 cites several reports that similarly notes that "Freshwater organisms differ in their salt tolerance," and even moderate levels of contamination could lead to "the selective elimination of intolerant species," altering the ecosystem other aquatic species and insects. *(Blaustein and Chase 2007)* In fact, aquatic habitats compromised by deicing agents could increase the presence of salt-tolerant insects, including mosquitos. *(Petranka and Doyle 2009;Demers and Sage 1990)* Even in lakes that are large enough to dilute runoff and reduce effects, "saline inflow from road salting may affect benthic invertebrate composition in the bottom waters." *(TAC 2013, pp. 51)*

Microfauna and Invertebrates

According to TAC, sodium chloride is toxic to algae at 1,000 mg/L, various invertebrate species at 1,300 to 7,000 mg/L, and juvenile bivalve species at 200 mg/L. *(TAC 2013)* Elevated chloride levels can cause mutation in bacteria and yeast at 5 to 150 mg/L and behavioral impairment of benthic invertebrates at 1,000 mg/L. *(TAC 2013)* TAC provides toxicity values for a number of invertebrate species. *(TAC 2013)*

A number of field studies have been done to look at potential effects of deicing salts on microfauna and invertebrates. The majority of studies found little to no impact on microfauna and invertebrate populations due to winter maintenance efforts. TAC 2013 cites more specifically:

- A decrease in diversity of aquatic insects downstream from salted highway. *(Demers 1990)* Levels of chloride were 5.23 mg/L, well below toxicity thresholds but 66 times higher than levels upstream.
- Levels of chloride in Indiana waters that were "unlikely to cause direct mortality to aquatic organisms." *(Gardner and Royer 2010)*
- A study of 43 impacted Michigan wetlands showed chloride concentrations ranging from 18 to 2,700 mg/L, with 97 percent having levels less than 334 mg/L, well below macroinvertebrate toxicity values. *(Benbow and Merritt 2004)*
- A six month evaluation of the effects of a mixture of sand and IceBan on the Peshastin Creek watershed in Washington State found no effect on three benthic macro invertebrate fish food organisms. *(Yonge et al. 2001)*

Fish

According to TAC 2013 which cites numerous reports, chlorides can be harmful to fish at concentrations as low as 400 mg/L but many species can tolerate much higher concentrations. For example, the toxicity threshold for small bluegill is 8,100 to 10,500 mg/L, and for rainbow trout is as high as 19,000 mg/L to 52,000 mg/L. *(CH2M Hill Engineering 1993)* D'Itri cites a study that gives an acute chloride toxicity value of 8,500 to 12,000 mg/L for fish and 1,300 to 2,300 mg/L for lower organisms. *(D'Itri 1992)* Larval fish are less tolerant of chlorides than adult fish. *(D'Itri 1992; Hart 1990; Scott and Wylie 1980)* Fish eggs are susceptible to hardening when salinity exceeds 3,000 mg/L. *(OECD 1989)*

Table 5 in Fischel, represented as Table 5 below, gives toxicity thresholds of sodium and chloride to fish of various species: *(Fischel 2001, pp. 39)*

Table 5. Toxicity of Fish and Invertebrates Exposed to Sodium Chloride for 1 to 7 Days

Species	Common Name	NaCl (ppm)	Chloride Ion (ppm)	Response	Exposure	Reference
Lepomis macrochirus	Bluegill	14,000	8,550	LC50[1]	24 hours	*Doudoroff & Katz 1953*
Daphnia magna	Water Flea	7,754	4,704	LC50	24 hours	*Cowgill et al. 1990*
Daphnia pulex	Water Flea	2,724	1,652	LC50	24 hours	*Cowgill et al. 1990*
Ceriodaphnia dubia	Water Flea	2,724	1,652	LC50	24 hours	*Cowgill et al. 1990*
Ceriodaphnia dubia	Water Flea	2,308	1,400	LC50	72 hours	*Cowgill et al. 1990*
Daphnia magna	Water Flea	3,054	1,853	LC50	72 hours	*Anderson 1948*
Chironomus attenatus	Chironomid (Midge)	6,637	4,026	LC50	72 hours	*Thorton & Sauer 1972*
Pimephales promelas	Fathead Minnow	7,650	4,640	LC50	72 hours	*Adelman et al. 1976*
Lepomis macrochirus	Bluegill	9,627	5,840	LC50	72 hours	*Birge et al. 1985*
Oncorhynchus mykiss	Rainbow Trout	11,112	6,743	LC50	72 hours	*Spehar 1987*
Pimephales promelas	Fathead Minnow (embryos, survival)	1,440	874	LC50	7-Day	*Beak 1999*
Ceriodaphnia dubia	Water Flea, mean brood size	1,761	1,068	EC50	7-Day	*Cowgill & Milazzo 1990*
Oncorhynchus mykiss	Rainbow Trout, egg, embryo, survival	2,400	1,456	LC50	7-Day	*Beak 1999*
Daphnia magna	Water Flea, mean brood size	4,040	2,451	LC50	7-Day	*Cowgill & Milazzo 1990*
Pimephales promelas	Fathead Minnow, larvae, growth	4,990	3,029	EC50	7-Day	*Beak 1999*

[1] Concentration that is lethal to 50 percent of the test organisms. A higher LC50 value means Lower toxicity of the chemical.

See also Toxicity Evaluations of Specific Deicing Materials below.

TAC 2013 cites several reports and concludes that "chloride concentrations that are harmful to fish … are rarely generated by highway de-icing. Very high chloride levels exceeding this range have been reported during spring thaws near large snow disposal sites." *(TRB 1991; Scott and Wylie 1980; D'Itri 1992)* Field testing of various water bodies in Canada "supporting a good mixed fish assemblage" suggests that 5 percent have less than 3 mg/L chloride, 50 percent less than 9 mg/L chloride, and 95 percent less than 170 mg/L chloride. *(D'Itri 1992)*

Chloride levels can become high in smaller bodies with limited circulation, or when other factors contribute to its effects:

> …high chloride levels can have a significant effect on aquatic life, in small waterbodies where flow circulation and dilution is limited – effects on larger waterbodies are usually reduced by dilution, although some residual effects on mixing and bottom layers may occur as reviewed earlier. … Overall, harmful effects of salt pollution on aquatic life depend on the oxygen supply in the water, water flows/circulation, size of the waterbody and drainage basin, temperature, length of exposure, rate of salt concentration increase, chemical composition of the water, salting intensity, precipitation, topography and type of highway drainage system. *(TAC 2013, pp. 52, citing TRB 1991; D'Itri 1992)*

Despite the ample data on toxicity from laboratory tests, there seem to be few field studies on the effects of chlorides on fish.

Amphibians

While there is little research, higher concentrations of salt may also be toxic to amphibians. *(Sanzo and Hecnar 2006 in TAC 2013)* Karraker et al. argue that efforts are required to protect the spotted salamander and wood frog from the effects of deicing activities in the Adironack Mountain Region of New York. *(Karraker et al. 2008)* A study of the effects of road salts on Nova Scotia amphibians found that chloride concentrations in 26 roadside ponds caused by the use of deicing salts will exclude salt sensitive species such as spotted salamanders and wood frogs. *(Collins and Russell 2009)*

Sodium, Calcium, Magnesium, and Potassium

Sodium, calcium, magnesium, and potassium are essential nutrients of animals and plants, common in unpolluted waters, and consequently highly tolerated by aquatic life. *(Levelton Consultants 2007)*

Levelton Consultants notes that there are no aquatic life standards for sodium and potassium. *(Levelton Consultants 2007, pp. 35)*

> There are no aquatic life standards or other general use protective upper limits for calcium and magnesium in water, except as related to hardness associated with very high concentrations of Ca and Mg in relation to domestic water supply for maintenance of cleaning performance. Thus, it is unlikely that addition of calcium or magnesium to water would be seen as an environmental threat or a threat to the domestic use of water. *(Levelton Consultants 2007, pp. 36)*

Further: "there is no evidence at present that they cause any biotic responses, given the benign nature of the four major cations within the lower ranges of concentration." *(Levelton Consultants 2007, pp. 37)*

However TAC 2013 notes that Briggins and Walsh stated that sodium can increase the growth of blue-green algae. *(Briggins and Walsh 1989)* A literature review by Evans and Frick found that:

> Magnesium and potassium chloride appear to be more toxic than sodium chloride for all organisms investigated. Plankton and invertebrates appear to be more sensitive to calcium than sodium chloride while the reverse appears to occur for fish. *(Evans and Frick 2001, pp. 1)*

Effects on Groundwater

According to a report cited by TAC 2013 on page 80, "Reports of elevated sodium and chloride levels in drinking water supplies traced to road salting have been documented for more than 30 years in North America." *(TRB 1991)*

Chloride

Chloride is naturally present in groundwater at less than 10 mg/L. *(Fay et al. 2013)* While there is little research on the long term effects of deicing salts on groundwater, it is possible that as chloride accumulates there could be significant deterioration of groundwater quality. *(Howard and Maier 2007; Thunqvist 2004 as cited in Fay and Shi 2012)* It is estimated that 10 to 60 percent of salt applied to roads enters groundwater, and 20 to 45 percent of chloride. *(TAC 2013, pp. 60, citing Jones and Jeffrey 1986)*

Further, Fay and Shi 2012 on page 2755 cites studies that have shown that soils can retain chloride over time, and so serve as a "long-term source of chloride to the groundwater and ultimately to the surface water." *(Kincaid and Findlay 2009; Lax and Peterson 2009)* The migration of chlorides into water from soils can take anywhere from years to decades. *(TAC 2013; Fay and Shi 2012)* According to Fay, it has been shown that sodium chloride in shallow subsurface waters "accumulates until steady-state concentrations are attained." *(citing Environment Canada 2010)* Computer modeling has estimated that application of "24 tonnes sodium chloride per two-lane-kilometre, will result in regional-scale groundwater concentrations greater than 250 mg/L" for high density land use areas and a maximum of 24 mg/L for 40 tonnes of sodium chloride per 2 lane kilometer for low density areas. *(Levelton Consultants 2007, pp. 63, citing Environment Canada 2001)* Jin et al. found that in 3 wells near a highway, chloride concentrations showed a significant upward trend of 0.2 mg/L per year over 10 years, but there was no significant upward trend for sodium concentrations. *(Jin et al. 2006)*

However, a Michigan monitoring study from 1976 to 2006 found that that dilution from precipitation prevents buildup in roadside soils and groundwater. *(Muethel 2007)* Meri, examining the reasons for increased chloride levels in groundwater in areas of Finland, found that it is difficult to distinguish the effects of road salting from that of clay soils, although soil chloride levels were especially high next to a nearby road. *(Meri 2010)*

A number of field studies have linked road salting to elevated chloride levels in groundwater:

- Road salting was a major source of chloride in soils and groundwater near Lindsay, Ontario. *(Howard and Faick 1986 cited in TAC 2013)*
- Pilon found concentrations of 400 mg/L and higher for chloride in shallow subsurface waters near a salted highway. *(Pilon and Howard 1987 cited in TAC 2013)*
- Deicing caused chloride contamination exceeding 1,200 mg/L in a survey of 23 springs in the Toronto area. *(Williams et al. 2000 cited in TAC 2013)*
- A 2002 study found sodium and chloride due to deicing present year round in an aquifer in Indiana, and found that chloride exceeded the "EPA secondary maximum contaminant level of 250 mg/L for drinking water at seven wells down gradient from" a highway. *(Watson et al. 2002 cited on pp. 2756 of Fay and Shi 2012)*
- A study found that during runoff events, chloride concentrations in groundwater due to winter maintenance were 40 to 60 mg/L, as opposed to 1 to 2 mg/L normally. *(Albright 2005 cited in Fay and Shi 2012)*
- Another study found that chloride concentrations are increasing in shallow groundwater in the Minnesota Twin Cities Metropolitan Area. *(Stefan et al. 2008)*
- Testing by the Maine Department of Transportation indicates that two to four percent of its wells exceed 250 mg/L chloride, and concludes that 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)." *(Rubin et al. 2010, pp. 25)*
- According to the Massachusetts Department of Transportation, "MassDEP's 2010 Integrated List of Waters (303(d) and 305(b)) lists four streams in the Wilmington, Tewksbury and Andover area along the I-93 corridor as impaired due to elevated chloride levels based on data collected by EPA-New England during the winter of 2009/10." *(MassDOT 2012, pp. 2-19)*

Finally, a 2000 study showed elevated groundwater concentrations of chloride in New York exceeding EPA limits:

> Water quality analyses of shallow monitoring wells and drinking water supply wells indicated that chloride concentrations exceeded the EPA limit of 250 mg/L in 2.5 percent of shallow wells and 1.7 percent in the drinking water wells. Upward trends in chloride loads were apparent in several watersheds and were attributed to increases in road deicing, wastewater-septic discharges, landfill leachate and salt storage areas. Samples with chloride concentrations greater than 230 mg/L were noted primarily during the months of November through April and were attributed to winter deicing activity. *(Heisig 2000 cited by Jahan et al. 2012)*

Sodium

TAC 2013 cites Jones and Jeffrey that sodium is naturally present in groundwater at concentrations of 6 to 23 mg/L. *(Jones and Jeffrey et al. 1986).* When affected by road salting groundwater concentrations can reach levels as high as 3,100 mg/L. *(Howard 1993)* While not regulated by the EPA either to protect aquatic life or human health, there is some concern that high levels of sodium can affect those on low sodium diets because of hypertension or heart disease (see **Effects on Human Health** below).

The Massachusetts Department of Transportation's *Snow & Ice Control Program 2012 Environmental Status Report* describes a salt remediation program for addressing public concerns about levels of sodium in drinking water from deicing activities, for which it receives about 12 complaints a year. *(MassDOT 2012)* Where MassDOT responds to a complaint, there is a substantial reduction in sodium concentrations. There are 53 reduced salt zones, established to reduce sodium levels in private or public wells after a complaint or a hydro-geological investigation. MassDOT's status report also includes detailed public water supply sodium data. A 2006 analysis of sodium levels for 328 public water supplies in Massachusetts within 0.5 miles of a Massachusetts Department of Transportation roadway showed that 90 percent had sodium concentrations of below the EPA's upper limit of 60mg/L, with 50 percent below 20mg/L: "close proximity to a MassDOT roadway did not seem to be a strong indicator as to which public water supply wells may have elevated sodium levels." *(MassDOT 2012)*

Calcium, Magnesium, and Potassium

Calcium, magnesium, and potassium are essential nutrients of animals and plants, and consequently highly tolerated by human beings and not regulated in groundwater by the EPA. *(Levelton Consultants 2007)* However, high levels of calcium and magnesium can lead to increased water hardness*. (TAC 2013, pp. 61)*

Effects on Human Health

As essential nutrients, alkali and alkaline-earth components of deicing salts (chloride, calcium, magnesium, and potassium) are not regulated by the EPA in drinking water. However, chloride is on the EPA's secondary drinking water standard list (at 250 mg/L) and sodium is on its candidate list because of concerns that water with high sodium levels could affect those on low sodium diets because of hypertension or heart disease (see **EPA Drinking Water Criteria** under **Federal Environmental Regulations** in this report). The EPA also sets an advisory limit of 20 mg/L for sodium in drinking water. *(EPA 2003)* Nevertheless, the levels of sodium due to deicing salts in palatable drinking water are unlikely to contribute significantly to daily sodium intake. *(Levelton Consultants 2007)*

Salt Brine

While there are a number of studies on brine performance, cost-effectiveness, methods of blending and application, and use in prewetting. *(Jahan and Mehta 2012; Druschel 2012; Cloutier and Newbury 2008;*

Pesti and Liu 2003) No studies were found focusing on the environmental effects of brine specifically as opposed to sodium chloride in general. For example, see the brief literature review on the environmental effects of brine in Jahan and Mehan 2012. *(Jahan and Mehan 2012, pp. 1.42-1.44)* Overall, the use of brine in prewetting roadways is thought to be environmentally friendly because it leads to less scatter of salt by vehicles and "much lower levels of chlorides being applied." *(Baroga 2005, pp. 7)* The use of liquid deicers in general can also reduce the effects of dry salt and abrasives on air quality (see **Abrasives** in **Air Quality**).

Abrasives

According to Fay et al. 2013, on page 2754, they cite Staples et al. that "Abrasives pose significant risk for water quality and may threaten the survivability of aquatic species especially during spring runoff." *(Staples et al. 2004)* A 2001 study found that abrasives are not only worse for the environment than salt, but less economical. *(Schlup and Ruess 2001)*

According to page 33 of Levelton Consultants 2007, *NCHRP Report 577*, particulate abrasives (including sand, crushed rock, and other particulate substances) can cause either chemical or physical impairment of surface waters. *(citing Waters 1995)* Determining the chemical impairment of materials requires toxicity testing. Physical impairment can be caused either by (a) particles impairing fish habitats by blocking spaces between rocks in the beds of bodies of water, or particulate bed load; or (b) particles suspended in water (total suspended solids), which may eventually contribute to particulate bed load. *(Levelton Consultants 2007, pp. 34)* Suspended solids can also affect aquatic life by making water cloudy and interfering with the availability of light for photosynthesis. *(Michigan Department of Environmental Quality, accessed 2013)*

Corrosion Inhibitors

Effects of Organics on Biochemical Oxygen Demand and Dissolved Oxygen

Organic matter can increase biochemical oxygen demand in receiving waters, depriving aquatic life of oxygen. *(Levelton Consultants 2007)* NCHRP explains:

> Biochemical oxygen demand is caused by the use of organic substrates by microbes, which oxidize the organic matter using oxygen obtained from the water, thus creating a strong oxygen demand. If the microbial demand is not offset by reaeration processes or by photosynthesis, hypoxia or complete loss of oxygen can be the result. These kinds of adverse effects involving biochemical oxygen demand are most likely in waters that move slowly because such waters have minimal physical exchange of oxygen with the atmosphere (i.e., low reaeration rates). *(Levelton Consultants 2007, pp. 37)*

Natural biochemical oxygen demand in surface water ranges from 3 to 20 mg/L. Snow and ice materials without organic content can have biochemical oxygen demand as high as 5,000 to 10,000 mg/L, but after dilution in receiving waters may have an insignificant effect on the oxygen demand of receiving water; materials with organic content can have a biochemical oxygen demand in excess of 10,000 mg/L, possibly causing major impairment even after dilution. *(Levelton Consultants 2007, pp. 38*) See Biochemical Oxygen Demand and Dissolved Oxygen under EPA Aquatic Life Criteria)

In Idaho, there has been some recent interest in the effects of using concentrated sugar beet byproduct, a waste product from the use of beets to produce sugar, as a corrosion inhibitor. In a letter to the city of Coeur d'Alene in 2009, IDEQ outlined its concerns about the city's use of concentrated sugar beet byproduct based on an analysis of a sample of the city's deicing agent (80 percent brine/20 percent concentrated sugar beet byproduct) by Analytical Laboratories, Inc. *(IDEQ 2009)* The sample contained a large amount of phosphorus (30 mg/L), which "can result in excess aquatic plant growth which can lead to poor swimming conditions and oxygen depletion during plant decomposition in lakes and other bodies of water." Also of concern were "the level of chemical oxygen demand and BOD produced by the mixture, 112,000 mg/L and 51,000 mg/L respectively." IDEQ noted that BOD is 1 mg/L in pristine waters and 600 mg/L in untreated sewage. The sample also contained high amounts of zinc (3.4 mg/L). All of these factors could negatively impact Coeur d'Alene Lake, according to IDEQ. *(IDEQ 2009)* It should be noted that ITD has only used concentrated sugar beet byproduct as a corrosion inhibitor on a very limited basis in Districts 4 (south central Idaho) and 5 (southeastern Idaho) and has not used concentrated sugar beet byproduct in District 1 (northern Idaho) because of concerns about phosphorus emissions in that part of the state.

We found only one study addressing the environmental effects of the use of concentrated sugar beet byproduct specifically in deicing: Clear Roads found that the deicing product Beet 55 led to potentially toxic levels of dissolved oxygen for fathead minnows. For other deicing products tested by Clear Roads, their high chemical oxygen demand did not result in a decline of dissolved oxygen: "This suggests that inhibitor toxicity is not mediated by dissolved oxygen depletion." *(Clear Roads 2013, pp. 17)* This applies to "a range of manufactured materials such as glycol and agricultural byproducts—typically agriculturally derived organic biomass products blended with chloride-based salts as a corrosion inhibitor." Another study examined the potential of a beet-based deicing product to reduce the sodium chloride use. *(Boehm 2011)*

Fischel's *Evaluation of Selected Deicers Based on a Review of the Literature* includes a discussion of several deicers with varying levels of corrosion inhibitors that, like concentrated sugar beet byproduct, are bio-based and agricultural in origin. *(Fischel 2001)* This includes especially IceBan, a group of agricultural byproducts patented for use as roadway deicing and anti-icing agents, including the liquid residue of fermented corn byproducts. Fischel concludes that the biochemical oxygen demand levels of Ice Ban are of concern:

> The chloride deicers, such as sodium chloride (e.g., rock salt and Ice Slicer) have no corrosion inhibitors and have very low biochemical oxygen demand levels. Magnesium chloride deicers (FreezGard Zero and Ice Stop-CI) also have low biochemical oxygen demand levels. Inhibited calcium chloride (Liquidow Armor) has a somewhat higher biochemical oxygen demand. The

> magnesium chloride deicer Caliber M1000, which contains 10% corn derivative as a corrosion inhibitor, has higher biochemical oxygen demand levels and could potentially cause oxygen depletion in small ponds or slow-flowing streams. *(Lewis 2000)* The deicer Ice Ban M50, which contains 50 percent Ice Ban as a corrosion inhibitor, has the highest biochemical oxygen demand D levels of the chloride-based deicers. High biochemical oxygen demand levels are an indication that the deicer can cause significant depletion of oxygen levels in the water.
>
> The organic materials in Caliber and Ice Ban can cause eutrophication of water, which will result in the proliferation of noxious aquatic plants, especially blue-green algae. The increase in algae reduces the oxygen level in the water and often causes the mortality of fish and invertebrates in the lake or stream. Phosphorus and ammonium ion in Caliber and Ice Ban can stimulate growth of aquatic plants. *(Fischel 2001, pp. 21)*

However, a 2005 study found the use of IceBan Magic and Magic Minus Zero reduced “the export of total phosphorus despite elevated phosphorus” in the products themselves. *(Albright 2005)* Another study found that the use of IceBan as a pre-wetter had little negating effect of salt on grass seed germination, freshwater minnow mortality, or roadside vegetation stress.” *(Fitch and Roosevelt 2000 cited by Fay and Shi 2012)* In a six-month evaluation of the effects of a mixture of sand and IceBan on the Peshastin Creek watershed in Washington State, Yonge et al. found no effects on three benthic macro invertebrate fish food organisms or on the spawning locations of three endangered fish species. *(Yonge et al. 2001)*

Small organic molecules such as citrate and triethanolamine may also be used as corrosion inhibitors. *(Levelton Consultants 2007)* Levelton Consultants notes:

> When added at 1 percent to a few percent, small organic substances such as this, although easily biodegraded and thus potentially a source of biochemical oxygen demand in surface waters, may be acceptable because dilution reduces their concentrations rapidly to such a degree that negative effects on oxygen concentrations are unlikely to cause impairment. Impairment is least likely where receiving waters have high energy and where the added organic matter, after dilution on or near the roadway, is near the natural inventory of organic matter in the water (usually 2 to 15 mg/L), and most problematic where runoff enters small bodies of still water and where the added concentrations greatly exceed the natural inventory of dissolved organic matter. *(Levelton Consultants 2007, pp. 38-39, citing Lewis 1997; Weltzel 2001)*

Possibly informative here is the study of the effects of acetates, such as calcium magnesium acetate, which also have organic molecules that can be used by microorganisms as nutrients. *(Levelton Consultants 2007)* A 1988 study found that the “direct effects from acetates are relatively short lived and confined to an area around the roadway.” *(Horner 1988 cited by Levelton Consultants 2007)*

Phosphorus

Also used as a corrosion inhibitor (and present in small amounts in deicing salts and abrasives), phosphorus is "present in only small amounts in unpolluted waters" and "an additive that contains phosphate, even if constituting less than 1 percent of total ingredient mass (e.g., Table 3-3), can increase phosphorus concentrations in the receiving waters to an amount that might be undesirable." *(Levelton Consultants 2007, pp. 38)* Excess phosphorus can lead to undesirably high levels of plant growth, or "eutrophication." *(Levelton Consultants 2007*, pp. 39) Consequently:

> … relatively small amounts of phosphorus can change aquatic ecosystems drastically. Undesirable side effects include excessive organic matter leading to deoxygenation of poorly circulated waters, aesthetic nuisance, harmful algal blooms, and change in the community composition of organisms, including fishes. *(Levelton Consultants 2007, pp. 39, citing Welch and Lindell 1992)*

Sensitivity of receiving waters to phosphorus varies widely. *(Kalff 2001 cited in Levelton Consultants 2007*) While it is not currently regulated by states or the federal government, the EPA is working with states to develop criteria for nutrients in surface waters, especially phosphorus and nitrogen. *(Levelton Consultants 2007*, EPA 2013g; EPA 2013h)

Fay (2013) notes that:

> Phosphorus from deicers is usually introduced into the environment in concentrations of 14 to 26 ppm, and it spurs the growth of algae, thus reducing DO [dissolved oxygen] for other aquatic biota. *(Fischel 2001)* Algae growth may be spurred by critical levels of dissolved phosphorus as low as 20 ppb. *(Staples et al. 2004)* The Colorado DOT has set standards for phosphorus in magnesium-chloride-based deicers at 25 mg/ L or less. Water quality standards may set a limit lower than this. Michigan, for instance, has set a phosphorus limit in water at 1 ppm from point discharges. *(Public Sector Consultants 1993)*

Toxicity Evaluations of Specific Deicing Materials

Levelton Consultants 2007 defines four steps for the evaluation of the environmental effects of deicing materials:

- Dilution analysis, since the harm caused by a material is dependent on its concentration after dilution in receiving waters.
- Toxicity screening, by conducting bioassays of representative organisms using EPA protocols (see **Determining Aquatic Toxicity** under **Federal Environmental Regulations** in this report) to document the percentage of mortality and sub-lethal effects over time.

- Screening for potential to cause eutrophication or oxygen depletion.
- Field monitoring. *(Levelton Consultants 2007)*

The Role of Dilution

In the case of dilution analysis, by examining historical data in one case, Levelton Consultants determined the dilution ratio of magnesium chloride in runoff from roadways as 500:1, and the predicted concentration of chloride in runoff with this ratio to be 400 mg/L, with further dilution in this case of 1:10,000 "within less than a meter from the exit point" (putting target concentrations well below regulatory levels). *(Levelton Consultants 2007, pp. 43)* NCHRP notes that various factors influence dilution, especially the amount of watershed area, making urban areas far more vulnerable than rural areas:

> Concentrations of snow and ice control materials reach their maximum under urban conditions or at other locations where the amount of road structure is very high in relation to the amount of watershed area (e.g., bridges and interchanges). Under such conditions, concentrations of chloride and other soluble constituents, or the augmentation of bedload in the case of abrasives, can far exceed any limits that might be set for the protection of aquatic life (examples given by Environment Canada. *(Levelton Consultants 2007, pp. 43)*

Also important to dilution is the distance, volume, and flushing of receiving waters. *(*Levelton Consultants 2007*, pp. 44)*

Results of Deicing Materials Toxicity Tests

Levelton Consultants tested 42 snow and ice control products, including deicing salts, for various components of environmental concern. It found nitrogen and phosphorus levels in many materials to be a potential environmental concern, and cyanide a concern for solid sodium chloride using iron-cyanide as an anti-caking agent. Metal levels were generally low. *(Levelton Consultants 2007)*

NCHRP conducted aquatic toxicity testing "on 15 snow and ice control products following U.S. EPA standard test methods for chronic exposure to various levels of aquatic biota, including vertebrates, invertebrates, and algae." *(Levelton Consultants 2007, pp. 122)* See tables 9-2 to 9-4 for results. *(Levelton Consultants 2007, pp. 123-125)* NCHRP concludes that dilution of 500:1 in material application would limit aquatic impacts close to the roadway because of further dilution with increasing distance:

> … a dilution to 500:1 would be insufficient to prevent non-lethal chronic effects of most snow and ice control materials on the most sensitive organisms (i.e., Selenastrum and Ceriodaphnia), although other organisms might not be affected at these concentrations (i.e., fathead minnow). Dilution at the margin of a roadway varies, but 500:1 would be close to the amount of dilution for many applications. … a dilution of 500:1 would affect sensitive organisms for a number of snow and ice control materials but not for others. Acute exposure might be the most meaningful

> guide for field applications, given that transport of materials with melt following application probably would not extend for a long period. The suitability of acute or chronic criteria would depend on the location and type of application. Although it appears likely that the most sensitive organisms would be affected in some way at dilutions that could be expected at the margin of a roadway for many snow and ice control materials, it is also true that dilutions greater than 500:1 can be expected within a relatively short distance beyond the roadway. Therefore, the toxicity data suggest that there could be an impact zone relatively close to the roadway, bounded by dilutions that offset acute or chronic toxicities close to the roadway. *(Levelton Consultants 2007, pp. 124)*

Clear Roads has also conducted aquatic toxicity testing of various winter maintenance materials and two corrosion inhibitors, and ranked them by toxicity. *(Pilgrim et al. 2013)* Refer to the figure below from the companion fact sheet produced for this project (available at http://www.clearroads.org/downloads/12_30_13_Final%20Fact%20Sheet.pdf).

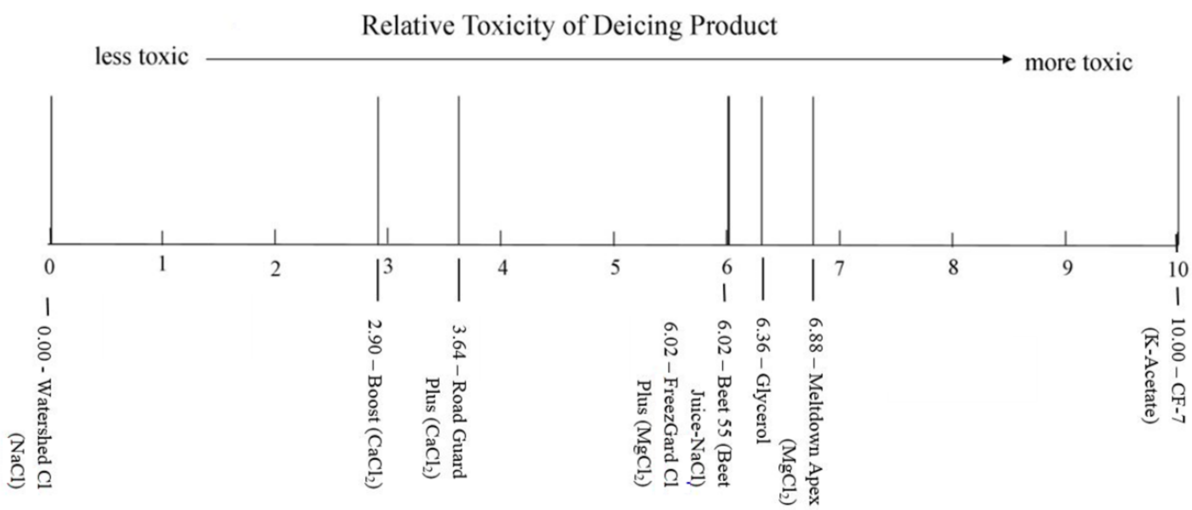

Figure 2. Relative Toxicity of Deicing Products

It concludes generally that:

> Product toxicity with respect to the primary salt could be ranked as follows (from most to least toxic): K > MgCl > CaCl > NaCl." … For an acute exposure period, fathead minnows and *Ceriodaphnia dubia* demonstrated largely equal sensitivity to deicing products. However, *Ceriodaphnia dubia* was more sensitive to chronic exposure periods. *Selenastrum capricornutum* appeared to be less sensitive than fathead minnow but more sensitive than *Ceriodaphnia dubia* to chronic exposure. *(Clear Roads 2013, pp. 15-16)*

ITD uses materials approved by Pacific Northwest Snowfighters. Pacific Northwest Snowfighters has established limits for a number of heavy metals and other constituents, including phosphorus and cyanide. *(Pacific Northwest Snowfighters 2010)* ITD labs conduct testing to ensure that the winter maintenance materials purchased by ITD comply with Pacific Northwest Snowfighters standards.

For more information on toxicity testing, see resources by Pacific Northwest Snowfighters (http://www.pnsassociation.org/), which:

> **…** is an association of transportation agencies dedicated to ensuring the safety of winter maintenance products through structured testing and evaluation. The group established procedures for testing deicing and anti-icing chemicals and maintains specifications that these products must meet to be considered for widespread use. Pacific Northwest Snowfighters has become a nationally recognized leader in establishing and standardizing chemical products for snow and ice control.

See also Table 7 in Fischel, represented as Table 6 below, for toxicity levels of specific deicers on aquatic organisms: *(Fischel 2001, pp. 42)*

Table 6. Acute/Chronic Aquatic Toxicity Test Results for Various Deicers[1]

Chemical	Brand/ Alternative Name	LC50 Rainbow Trout[2] *(Oncorhynchus mykiss)* (ppm) (acute)	LC50 Water Flea *(Ceriodaphnia)*[3] (ppm) (acute)	IC50 Water Flea *(Ceriodaphnia)*[3] (ppm) (chronic)	IC50 Green Algae *(Selenastrum)*[4] (ppm) (growth inhibition)
Chloride-Based Deicers					
Inhibited $MgCl_2$	FreezGard Zero/TEA	3,160	3,668	1,781	6,254
Inhibited $MgCl_2$	Ice-Stop CI	NA	NA	NA	NA
$MgCl_2$ + Caliber Inhibitor[1]	Caliber M1000	6,621	4,950	2,150	631
$MgCl_2$ + Ice Ban	Ice Ban M50	620	585	164	1,090
NaCl (23% Brine)	Salt	68,454	6,583	2,919	9,186
NaCl	Ice Slicer	NA	NA	NA	NA
Inhibited $CaCl_2$	Liquidow Armor	23,452	3,828	2,722	2,422
Acetate-Based Deicers					
Liquid CMA (25%)	CMA	35,000	4,670	1,039	706
Liquid Potassium Acetate (51%)	CF7	2,280	660	240	318
CMA + Potassium Acetate (liquid)	CMAK	14,091	1,918	466	330
Sodium Acetate	NAAC	2,750 mg/l (Fathead Minnow – 24 hr)	2,400 mg/l (*Daphia magna*, 48 hr.)	NA	NA
Sand	Volcanic Cinders, Chipped Rock, Scoria	NA	NA	NA	NA

1. *Mussato & Guthrie 2001*
2. Rainbow Trout 96-hour acute static bioassay (LC50)
3. 7-Day Survival (LC50) and Reproduction (IC50) Bioassay Using *Ceriodaphnia*
4. Growth Inhibition (IC50) bioassay with the Algae *Selenastrum capricornutum*
5. Cryotech MSDS and Product Information Sheets (www.cryotech.com)

NA Not Available

Note: A higher LC50 value means lower toxicity of the chemical tested.

Effects on Air Quality

According to Levelton Consultants, "airborne fine particulate from the entrainment of dried abrasives and salt left on roadways can contribute to local air quality deterioration and may even affect the health of some members of the population" by damaging lungs. *(Levelton Consultants 2007, pp. 59)* The EPA sets air standards for PM-10 and PM 2.5 particulate matter (see **Air** under **Federal Environmental Regulations** in this report for details). In general, air quality is of greater concern in mountainous regions. *(Levelton Consultants 2007)*

Chloride Salts

There is little research on the effects of liquid and dry snow winter maintenance materials on air quality; however, because they reduce abrasive use they are thought to have “a net benefit on air quality.” *(Levelton Consultants 2007, pp. 60)*

Abrasives

PM-10 particles from road dust have “been shown to increase between 50 percent to 90 percent during the 24-hour period following road sanding.” *(Levelton Consultants 2007 citing Fischel 2001)* A 2006 study conducted roadside measurements to assess the impact of abrasives and deicers on ambient particle emissions near Lake Tahoe, and found that 44 to 59 percent of PM-10 emissions were due to sanding and salting, with liquid deicers contributing less to emissions than abrasives. *(Gertler 2006)* Another study found a 75 percent increase in PM-10 emissions 2.5 hours after sanding on dry roads, although emissions returned to pre-sanding levels after 8 hours. *(Kuhns et al. 2003)* To minimize the effects of abrasives, it is best not to use material that “has a high silt fraction (percentage that passes a No. 200 mesh or < 74 µm).” *(Nixon and Williams 2001, pp. 6)*

Reducing the use of abrasives can have “an immediate, and predictable, effect on reduced PM-10 emissions. This applies not only to the period of greatest air quality impact, when the road surface has dried immediately after a winter storm event, but also to the wintertime baseline conditions.” *(Cowherd et al., pp. 101)* ITD reduced abrasives by 83 percent by substituting solid sodium chloride and abrasives with liquid magnesium chloride. *(Breen 2001)* In 1994, Chang noted that according to Denver’s Regional Air Quality Council, “the use of sand as traction aid contributes to 45% of the particulate air pollution (PM sub 10) in the Denver area. *(Chang et al. 1994, pp. 1)* By 2002, the use of liquid deicers instead of sand “has contributed to the high quality of Colorado air,” with Colorado not violating EPA PM-10 emissions within the previous seven winters. *(Chang and Brady 2002, pp. 128)*

Effects on Animals – Ingestion

According to the Levelton Consultants:

> Snow and ice control materials have been linked to reports of salt toxicosis from ingestion and to reports of increases in vehicle-animal collisions. Some information suggests salt toxicosis from ingestion is a concern for small animals such as birds, although most terrestrial animals have high salt tolerances, especially when adequate drinking water is available. *(Levelton Consultants 2007, pp. 62)*

Small Mammal Wildlife

Animals have access to deicing salts via roadside pools and dirt, as well as ponds and livestock drinking water affected by runoff and groundwater. *(TAC 2013)* Beyond attracting large mammals and so causing an increase in collisions with vehicles, and see the companion synthesis report on vehicle collisions with wildlife), salt may sometimes be toxic to small animals: *(Jones and Jeffrey 1986 cited in Levelton Consultants 2007)*

> Investigations of wildlife specimens collected in Wisconsin linked de-icing salts to salt poisoning of smaller wildlife. *(D'Itri 1992)* This was probably an exceptional case – factors in the poisoning were a severe winter, high snowfall, freezing temperatures that reduced available drinking water and increased salting during storm conditions. *(TAC 2013, pp. 76)*

Sodium, while an essential nutrient for animals, can be toxic in excess (Levelton Consultants 2007, pp. 60). But even for small mammals, the ingestion of excess salt should have no adverse effects when there is enough drinking water. *(D'Itri 1992 cited in TAC 2013; Nairne and Associates 1992 cited in Levelton Consultants 2007)* Laboratory tests in rats found that chloride salts are only slightly toxic to rats even at very high levels. *(Hiatt et al. 1988 in* Levelton Consultants 2007*)*

Birds

While salt is not toxic to birds in small doses when drinking water is available, it may sometimes increase "the vulnerability of birds to car strikes as well as directly poisoning some birds", with finches being most susceptible. *(TAC 2013, pp. 77, citing Environment Canada 2001 and Brownlee et al. 2000 cited in Levelton Consultants 2007)* Environment Canada has extensive information on effects of road salts on birds based on a literature review by Brownlee et al. (2000), in which "12 published reports were found associating bird kills with salted roads." *(Levelton Consultants 2007, pp. 61 citing Brownlee et al. 2000)* Increased vulnerability to car strikes is possibly caused by increased fearlessness due to behavioral impairment from elevated brain sodium levels. *(Brownlee et al. 2000 cited in Levelton Consultants 2007)* There is a higher risk of salt poisoning in birds when drinking water is less available during severe winters. *(Jones and Jeffrey 1986 cited in Levelton Consultants 2007)*

Domesticated Animals

Research has not shown salt to be of concern for farm animals or pets. *(TAC 2013)* The tolerance of domesticated animals is much higher than the expected effects of roads salts on water, with for example the tolerance of sheep for sodium chloride ranging from 9,000 to 13,000 mg/L. *(D'Itri 1992 cited in TAC 2013)*

Conclusion: Relative Level of Concern for Environmental Effects of Deicing Materials

Levelton Consultants concludes that "All snow and ice control materials have some potential for affecting the receiving environment," with the magnitude of concern depending on a variety of factors. *(Levelton Consultants 2007, pp. 92)* It notes that the "most significant areas of potential impairment include water quality/aquatic life, air quality, vegetation, soils, and animals" in that order. *(Levelton Consultants 2007, pp. 92)* AASHTO similarly cites a survey of winter maintenance practitioners that "found water quality to be of the greatest concern, with air quality, vegetation, endangered species, and subsurface well contamination" following. *(Fay et al. 2013, pp. 6)*

Table 6.1, represented as Table 7 below, gives further detail on level of concern and effects: *(Levelton Consultants 2007, pp. 93)*

Table 7. Generalized Potential Environmental Impairment Related to Common Snow and Ice Control Chemicals

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.

Conclusions based on the assessment of information reviewed in this study.

Overall, according to Levelton Consultants:

- **Chloride salts** are of high concern for vegetation, moderate concern for water quality/aquatic life, moderate/high (sodium chloride) or low/moderate concern (calcium chloride and magnesium chloride) for soils, and low concern for air quality and animals.

- **Organic biomass products** (including beet byproduct) are of high concern for water quality/aquatic life and low concern for everything else.

- **Abrasives** are of high concern for water quality/aquatic life and air quality and low concern for everything else. *(Levelton Consultants 2007)*

Fay summarizes the effects of various materials on various environmental pathways, as represented in Table 8 below: *(Fay and Shi 2012, pp. 2765)*

Table 8. Summary of the Effects of Materials on Environmental Pathways

	Abrasives	Chlorides	Acetates/formates	Glycols	Urea & agro-based
Soil	Will accumulate.	Cl, Ca, and K can mobilize heavy metals. Na can accumulate in soil and reduce soil permeability, leading to increased soil density. Ca can increase soil permeability and aeration. Mg can increase soil stability and permeability. NaCl can decrease soil fertility, leading to reduced plant growth and increase erosion.	Ca and Mg can mobilize heavy metals, increase soil stability, and permeability. CMA degredation may increase soil pH.	Readily biodegrades. Propylene glycol degredation may reduce hydraulic conductivity in anaerobic soils.	Use of urea can lead to increased nitrate concentrations. Little data are available on agro-based deicers.
Flora	Can accumulate on foliage and in adjacent soils that contact the roots, potentially causing stress.	Cl contact with foliage can cause leaf singe, browning, and senescence. Cl contact can lead to osmotic stress. Salt tolerant species are recommended for us as roadside vegetation where chloride salts are used.	Few effects have been observed. At low concentrations, acts as a fertilizer and, at elevated concentration, reduces seed germination, causing low biomass yield, leaf browning, and senescence.	Can inhibit plant growth.	Little data are available on agro-based deicers.
Surface & ground waters	Can increase turbidity and decrease gravel and rock pore space, leading to limited oxygen supply.	Cl, Na, Ca, and K ions easily go into solution, migrate, and can harden the water. Can cause density stratification in small receiving waters, potentially causing anoxic conditions at depth. K and Ca can mobilize heavy metals in water. K can cause eutrophication of water.	Can leach heavy metals from soil that can transport into water. Has a high BOD and can cause oxygen depletion. Can increase turbidity and hardness of water.	Can increase BOD to a greater extent than any other deicer. Degrades in water faster than additives which can be toxic. Readily biodegrades.	Use of urea can lead to increased nitrate concentrations. Urea additives can be toxic.
Fauna	Can reduce oxygen in stream beds and cause increased turbidity.	Little to no impact when ingested unless extremely elevated concentrations are reached. Direct ingestion of salts by mammals and birds has caused behavior changes and toxicity. Concentrations of 250 mg/L have been shown to cause changes in community structures. Use on roadways may lead to increased wildlife– vehicle collisions.	Can exert a high BOD which may cause anoxic conditions in aquatic environments. KAc and NaAc appear to be more toxic than CMA. Can promote bacteria and algae growth.	Ingestion of concentrated fluid can lead to death. A known endocrine disrupter.	Little data are available on agro-based deicers.
Human	Can cause increased PM-10 and can lead to air quality non-attainment issues. Can reduce stream visibility, alter stream and roadside habitat, and decrease aesthetics.	Skin and eye irritant. Drinking water with sodium concentrations >20 mg/L can lead to hypertension. Can increase Cl, Ca, K, and Na concentrations above recommendations. Anti-caking agents may contain cyanide, a known carcinogen.	Skin and eye irritant. Ca and Mg can increase water hardness.	Ingestion of concentrated fluid can lead to death. A known endocrine disrupter.	Use of urea can increase nitrate levels in water. Little data are available on agro-based deicers.

Federal Environmental Regulations Applicable to Selected Deicing Materials

United States federal environmental regulations do not specifically address the use of road salt and other winter maintenance materials. *(Levelton Consultants 2007, pp. 27)* However, there are regulations concerning the levels of contaminants in air, soil and water that apply to the components of road salts and other deicing materials.

Applicable federal regulations include:

- **The Clean Water Act** which sets requirements for the protection of water quality and aquatic life. (EPA 2012a) Implementation and enforcement in most states occurs largely at the state level. This includes the National Pollutant Discharge Elimination System (NPDES) which requires permits in certain zones for stormwater discharge from municipal stormwater sewers and industrial or construction activity. (EPA 2009) These permits prescribe maximum amounts for regulated substances. The Clean Water Act does not directly regulate the use of snow and ice materials, but NPDES permitting applies to road maintenance and snow and ice control activities in certain areas. Idaho is one of four states that have not assumed implementation and enforcement responsibilities related to the Clean Water Act; the other three are Maine, New Hampshire and New Mexico. EPA Region 10, headquartered in Seattle, Washington, is the NPDES permitting authority for all Idaho stormwater permits, including those issued to ITD. In the section of this synthesis entitled ITD's Compliance with Environmental Requirements we discuss current NPDES permits issued to ITD as they relate to the use of salt and salt brine and other winter maintenance activities. See http://yosemite.epa.gov/r10/water.nsf/NPDES+Permits/Current+ID1319.
- **The U.S. Safe Drinking Water Act**, which protects the quality of drinking water. *(EPA 2012b)*
- **The Clean Air Act**, which sets EPA air quality standards for six pollutants. *(EPA 2013a)*
- **The Endangered Species Act**, which prohibits stressing or increasing the mortality of endangered or threatened species. *(U.S. Fish and Wildlife Service 2013)*

In what follows we review how these regulations apply to components of concern for select snow and ice control materials, as defined by one of the most authoritative and comprehensive sources to date on the environmental effects of snow and ice control materials, *NCHRP 577: Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*. *(Levelton Consultants 2007, pp. 29 - 30)* Covered materials include:

- Sodium Chloride, Magnesium Chloride, and Calcium Chloride.
- Particulate Abrasives (including sand, crushed rock and other sediments).
- Corrosion Inhibitors.

Components of concern for chloride salts, which can affect soil and water quality, include:

- Primary Components: Chloride, sodium, magnesium, calcium.
- Possible Byproducts: Heavy metals, cyanide, phosphorus.

Components of concern for abrasives include:

- Air Quality: PM10 and PM2.5 particles.
- Water Quality: Sedimentation, including total suspended solids (TSS) and particulate bed load.
- Possible Byproducts Affecting Soil and Water Quality: Heavy metals, phosphorus.

Components of concern for corrosion inhibitors include:

- The Possible Byproducts of Organic Matter (complex sugars), Derived from Agricultural Beet Processing, which can affect soil and water quality: dissolved oxygen and biochemical oxygen demand.

- Heavy Metals, Phosphorus, and Nitrogen Found in Other Types of Corrosion Inhibitors.

Water

The EPA's *National Recommended Water Quality Criteria* includes recommended surface water thresholds for the protection of aquatic life and human health for about 150 pollutants (detailed in two tables: the *Aquatic Life Criteria Table* and *Human Health Criteria Table*). *(EPA 2013b)* These criteria provide guidance to states and tribes to use in adopting water quality standards, as per Section 304(a) of the Clean Water Act.

EPA Aquatic Life Criteria

The EPA's Aquatic life criteria table includes values for the acute exposure (1 hour) and chronic exposure (96 hours or more) of aquatic life to various pollutants. *(EPA 2013b)* Below are the freshwater values for pollutants relevant to snow and ice control.

Chloride

The acute limit for chloride is 860 mg/L and the chronic limit is 230 mg/L. Background chloride concentrations in surface water are one to 10 mg/L, and the tolerance by aquatic life of chloride is high. *(Levelton Consultants 2007, pp. 35)* However, 10 percent of freshwater aquatic species are adversely affected by chronic chloride concentrations above 240 mg/L, and for *Ceriodaphnia dubia* a 50 percent mortality rate occurs at 1,400 mg/L. *(Davis 2004, pp. 309)* Where road salt use is heavy and regular, concentrations of chloride in runoff can be as high as 18,000 mg/L. *(Davis 2004, pp. 309)*

Nutrients

EPA aquatic life criteria do not regulate sodium, magnesium, potassium or calcium, and tolerance for them by aquatic life is high. *(Levelton Consultants 2007, pp. 36)* The EPA publishes ecoregional criteria documents for some nutrients. *(EPA 2013c)* These set limits that vary by region and type of water on phosphorus (which can limit plant growth in inland waters, nitrogen, chlorophyll a, and turbidity/secchi. *(Levelton Consultants 2007, pp. 39)*

Nutrient pollution from nitrogen and phosphorus can cause algae overgrowth, harming water quality, food resources and habitats for aquatic life, and reducing dissolved oxygen. *(EPA 2013e)*

Biochemical Oxygen Demand and Dissolved Oxygen

The oxidation of organic matter by microbes in receiving waters can deplete them of the oxygen required by fish and other aquatic life.

For dissolved oxygen criteria, see *Table 1* in the EPA's *Quality Criteria for Water. (EPA 1986, pp. 211)* Values are as follows:

- Coldwater
    - Early Life Stages: 7 day mean of 9.5 mg/L, 1 day minimum of 8 mg/L.
    - Other Life Stages: 30 day mean of 6.5 mg/L, 7 day mean minimum of 5 mg/L, 1 day minimum of 4 mg/L.
- Warm water
    - Early Life Stages: 7 day mean of 6 mg/L, 1 day minimum of 5 mg/L.
    - Other Life Stages: 30 day mean of 5.5 mg/L, 7 day mean minimum of 4 mg/L, 1 day minimum of 3 mg/L.

Most warm water fish need dissolved oxygen in excess of 2mg/L; trout require 8 mg/L, and striped bass 5 mg/L. *(Northeast Georgia Regional Development Center 2001, B-1)*

There are no fixed limits for biochemical oxygen demand, but levels for biochemical oxygen demand must typically be set and tested on a case-by-case basis as part of NPDES permits. The EPA provides guidance for collecting and analyzing water samples for dissolved oxygen and biochemical oxygen demand. *(EPA 2012c)*

Heavy Metals and Cyanide

Chronic limits for cyanide are 22 mg/L, and acute 5.2 mg/L. The Aquatic Life Criteria table includes several heavy metals, including zinc (120 mg/L acute and chronic). *(EPA 2013d)*

Total Suspended Solids

Particles suspended in surface water (total suspended solids) can affect aquatic life by making water cloudy and interfering with the availability of light for photosynthesis. *(Michigan Department of Environmental Quality undated)* Particles can also impair fish habitats by blocking spaces between rocks in the beds of bodies of water (particulate bed load).

The EPA does not establish a single national numeric limit for total suspended solids. *(EPA 2004a, 8-1)* But the turbidity/secchi standards under *Nutrients* in this document are an indirect measure of total suspended solids. The Clean Water Act also requires that Total Maximum Daily Loads for total suspended solids be developed in some cases for NPDES permits, to ensure that turbidity/secchi standards are met.

In general, water seems clear with TSS concentrations of less than 20 mg/L, cloudy between 40 and 80 mg/L, and dirty over 150 mg/L, depending on the types of particles suspended. *(Michigan Department of Environmental Quality)*

There are currently no regulations on particulate bed load.

See also:

- The EPA's Web page *Suspended and Bedded Sediments. (EPA 2012d)*
- *Sediment-Related Criteria for Surface Water Quality. (EPA 2004b)*
- *Guide to Selection of Sediment Targets for Use in Idaho TMDLs. (Rowe et al. 2003)*

EPA Drinking Water Criteria

Under the U.S. Safe Drinking Water Act, the EPA's drinking water regulations list maximum levels for various contaminants (MCLs). *(EPA 2013f)* These also include a table of non-enforceable secondary drinking water standards that affect water cosmetically or aesthetically. Finally, the EPA keeps a list of candidate contaminants that may require regulation in the future and has established a monitoring program for unregulated contaminants. *(EPA 2012e; EPA 2012f)*

Values for pollutants of relevance to snow and ice control are as follows:

- Chloride is not regulated, but it is on the secondary drinking water standard list with a limit of 250 mg/L.

- Nutrients: Sodium, magnesium, calcium, potassium, and phosphorus are not regulated, but sodium is on the candidate list because of concerns that high-sodium water could affect those who have heart disease or are on low sodium diets. *(EPA 2012g)* The EPA also has an advisory limit for sodium in drinking water of 20 mg/L () that is non-enforceable and based on a recommendation by the American Heart Association that the EPA believes to be too restrictive. *(EPA 2003 cited in Levelton Consultants, pp. 36)* Many groundwater systems have in excess of 120 mg/L of sodium. The EPA is currently working with states to develop numeric drinking water criteria for phosphorus and nitrogen. *(EPA 2013g; EPA 2013h)*
- Zinc is not regulated, but it is on the secondary drinking water standard list: 5 mg/L. Other heavy metals are regulated.
- Cyanide (0.2 mg/L).
- For drinking water, the EPA does not regulate total suspended solids or biochemical oxygen demand.

Air

Fine particles in the air from dried abrasives and salt on roads can cause respiratory damage in human beings. *(Levelton Consultants 2007, pp. 59)* The EPA's air quality standards set primary standards (for public health protection) and secondary standards (for public welfare protection). *(EPA 2012h)* The standard (both primary and secondary) for PM-10 is an annual average of 50 µg/m3 and a daily average of 150 µg/m3. *(EPA 2012i)* The standard (both primary and secondary) for PM-2.5 is a daily average of 35 µg/m3; the primary annual average is 12 µg/m3 and secondary annual average 15 µg/m3.

Soil

The EPA has not yet addressed toxicity in soils. *(Levelton Consultants 2007, pp. 28)*

Animal Life

The Endangered Species Act prohibits stressing or increasing the mortality of endangered or threatened species. *(U.S. Fish and Wildlife Service 2013)* When snow and ice control materials are used on roads near endangered species, it is required that the threat to species be evaluated. Road salts may be toxic to some birds and small mammals and dangerous for animals that seek them out on roads. *(Levelton Consultants 2007, pp. 60-62)*

Related Guidance

EPA Deicing Guidance

While the EPA does not directly regulate snow and ice control materials, it has published guidance on best practices for minimizing their environmental effects, including:

- *Manual for Deicing Chemicals: Application Practices*, which defines supervisory aspects of proper chemical usage and discusses elements of proper decision making, equipment calibration and legal requirements. *(EPA 1974a)*
- *Manual for Deicing Chemicals: Storage and Handling*, which recommends covered storage of salt and other deicing chemicals, preferably in permanent structures. *(EPA 1974b)* Guidelines are given for site selection and design of foundations, paved working areas and site drainage. Best practices are given for handling of salt and other deicing chemicals.
- *Storm Water Management Fact Sheet – Minimizing Effects from Highway Deicing*, which "summarizes research addressing water pollution and associated effects from deicing chemicals, and describes the methods used to control snow and ice on roadways while minimizing impacts on the environment." *(EPA 1999)* Recommendations include improved operational practices, alternative deicing chemicals (such as calcium magnesium acetate), road weather information systems, pretreatment, and mechanical and structural approaches.
- *Road Salt Application and Storage*, a brief fact sheet recommended proper storage and calibrated application. *(EPA 2006)*
- *Managing Highway Deicing to Prevent Contamination of Drinking Water*, which covers alternative deicing chemicals, road weather information systems, maintenance decision support systems, pretreatment, amount and timing of application, equipment and employee training, prewetting, storage and ground water quality monitoring. *(EPA 2010b)*

Pacific Northwest Snowfighters Snow and Ice Control Chemical Products Specifications and Test Protocols

The Pacific Northwest Snowfighters (of which the ITD is a member) curates a widely used list of environmental specifications for qualification of snow and ice materials. *(Pacific Northwest Snowfighters 2010)* These include:

- Limits on material constituents, including phosphorus, cyanide and heavy metals.
- Testing requirements (including but not limited to nitrogen, biochemical oxygen demand and aquatic life toxicity).

Determining Aquatic Toxicity

The EPA details methods for assessing toxicity to aquatic organisms:

- *Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organisms. (EPA 2002a)*
- *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Freshwater Organisms. (EPA 2002b)*

Two recent studies apply these methods to a number of deicing products (see **Toxicity Evaluations of Specific Deicing Materials** under **Environmental Impacts**):

- *NCHRP Report 577* evaluated the aquatic toxicity of 15 deicing products (see tables 9-2 to 9-4 in the report for a summary of results). *(Levelton Consultants 2007, pp. 123-125)*
- A 2013 Clear Roads study conducted toxicity testing for a number of deicing chemicals and two corrosion inhibitors. *(Clear Roads 2013)*

ITD's Level of Compliance with Environmental Regulations

ITD's compliance with environmental requirements is monitored at the state level primarily through the Idaho Department of Environmental Quality (IDEQ) and at the federal level through the U.S. EPA. The previous section of this synthesis outlines the various federal laws aimed at protecting the quality of air, water, soil, and animal life. In this section we focus specifically on compliance issues directly related to the use of salt, salt brine, and abrasives for deicing and anti-icing. In addition to reviewing documents, we spoke with officials at ITD, IDEQ, and U.S. EPA Region 10.

Water quality is monitored by the EPA primarily through National Pollutant Discharge Elimination System permits, which are issued to facilities that discharge stormwater runoff, including snow melt runoff, directly to surface water. Urbanized areas are of most concern because of the large concentrations of impervious surfaces that have been constructed as a result of development. Stormwater flowing over the impervious surfaces collect pollutants such as debris, chemicals, and sediment (sand). National Pollutant Discharge Elimination System permits address discharges of runoff through a municipal separate storm sewer system involving a relatively small percentage of total ITD highway miles.

ITD Districts' Stormwater Permits

According to U.S. EPA Region 10, National Pollutant Discharge Elimination System permits have been issued to ITD Districts 1, 3, 5, and 6, covering primarily the state highways in larger cities in those geographical areas. District 4's population is not large enough to require a stormwater permit. District 2's stormwater permit is currently in the draft stage. ITD District 3 is a co-permittee with the city of

Boise, Garden City, the Ada County Highway District, Drainage District 3, and Boise State University. ITD District 6 is a co-permittee with the city of Idaho Falls. See these and other current National Pollutant Discharge Elimination System permits in Idaho at http://yosemite.epa.gov/r10/water.nsf/NPDES+Permits/Current+ID1319. Also see ITD's information on its District stormwater permits, including annual reports on progress and key issues, at http://itd.idaho.gov/enviro/Stormwater/Overview/MS4/default.htm.

ITD Compliance

Based on a review of ITD District annual reports to EPA, we found no notices of violation. We were only able to identify the following expression of concern regarding use of salt for winter maintenance:

- In a March 14, 2012, letter to ITD District 1, EPA noted a lack of information in ITD's compliance file to demonstrate how ITD is addressing potential negative impacts from the use of salt in deicing operations. In response, District 1 reported in an April 13, 2012, letter that collaborative monitoring of salt content in highway stormwater drainage had been undertaken with IDEQ. District 1 also responded to EPA that it will resume conducting chloride testing as part of water sampling within the MS4 area covered by the stormwater permit. District 1 stated: "To date the chloride levels that have been detected in highway stormwater drainage do not appear to cause a water quality problem or otherwise exceed any known threshold of concern for chloride." See ITD District 1's annual report at http://itd.idaho.gov/enviro/Stormwater/Overview/MS4/MS4-Annual_Reports/D1_2012_Annual_Report.pdf.

- On the basis of the collaborative chloride testing referenced above, the IDEQ Water Quality division administrator stated in an interview that salt in northern Idaho waterways does not appear to be a cause for concern at this time. He said he would be more concerned with use of excessive quantities of sand for winter maintenance, since the resulting sediment loading in the streams could lead to an interference with fish spawning.

IDEQ further indicated that the agency has not identified ITD as being subject to a "total maximum daily load" allocation for either sediment or salt in any of the waterways for which it is responsible. The TMDL is the maximum amount of pollutant that a body of water can receive while still meeting water quality standards. The fact that a TMDL has not been issued appears to indicate a relatively low level of concern.

ITD Headquarters Environmental staff indicated there have been no other violations of environmental regulations related to the use of salt and salt brine for winter maintenance activities. However, staff did call our attention to a 2001 consent order between ITD and IDEQ requiring mitigation of sodium chloride contamination of ground water in Cambridge, located in ITD District 3. This is the only consent order between the two agencies. Relevant details are:

- Around 1999 ITD removed the underground fuel tanks at the maintenance yard it owned in Cambridge in preparation for selling the property. Subsequent testing also found high levels of sodium chloride in the groundwater near the site, possibly originating from salt/sand piles stored in the yard for winter maintenance.

- In April 2001 ITD voluntarily entered into the consent order with IDEQ to address the sodium chloride contamination without the issuance of a notice of violation. Among other actions ITD developed a Remedial Action Plan to map the presence of sodium chloride in the groundwater and monitor contaminant levels using approximately 15 wells.

- Sodium chloride levels have declined steadily over the ensuing years, and the number of monitoring wells has been reduced to four, two of which show sodium chloride levels above the 250 mg/L maximum for drinking water as of an October 2013 report to IDEQ.

- None of the homes or businesses in Cambridge obtain drinking water from wells.

- ITD has constructed covered storage facilities in all its Districts for sand and salt used for winter maintenance to prevent leaching of sodium chloride into the groundwater.

Survey Results

Federal or state citation of state DOTs for violating environmental requirements due to winter maintenance activities appears to be rare across the country. In a multistate survey conducted as part of this synthesis project, only 4 of the 20 states responding to a survey question on violations indicated any kind of enforcement action. (See complete survey results in Appendix A.)

The survey question (#21) was: Has any practice by your agency related to the use of deicing materials led to or contributed to the violation of a state or federal environmental regulation, such as water quality or air quality?

The four affirmative responses follow:

- **Iowa.** Salt content from some garages' wastewater was too high. Installed wastewater brine recyclers to keep salt out of sewer flow.
- **Maine.** Maine state law requires the replacement of any wells that are damaged by salt contamination caused by us. We have replaced several.
- **Montana.** Improper storage of solid salt has caused several contaminated well claims.
- **New Hampshire.** Currently involved in U.S. Environmental Protection Agency total maximum daily load issue in the widening of the southern section of I-93 from the Massachusetts border to Manchester, NH. Sodium chloride is the culprit.

Part 3
Road Salt and Wildlife-Vehicle Collisions

Executive Summary

Background

Sodium is a biological necessity for all animals. In northern climates, however, naturally occurring sources of sodium are difficult to find, particularly in winter. Many animals face sodium deficiencies in the winter, and seek natural or artificial salt licks to meet their needs. Road salt, which is commonly applied as a deicer or anti-icer on road surfaces, is a viable source of sodium for animals, either on the roadway where it is applied or nearby in areas of runoff.

This attraction of animals to any source of salt has prompted concerns about the use of salt in winter maintenance operations. If animals are drawn to or near roadways, they may be in greater danger of being struck by vehicles. Vehicle collisions with wildlife, particularly larger species such as deer, moose and elk, can cause significant human, animal, and economic damage. In Idaho in 2012, more than 1,000 collisions between animals and vehicles were reported, causing 3 human fatalities and, based on U.S. Department of Transportation average collision costs, approximately $19 million in total costs. *(Idaho Transportation Department 2013)*

It is not clear, however, what role winter maintenance chemicals play in wildlife-vehicle collisions. ITD maintains a database of animals killed on state highways, and research is under way to bring together data from various sources to create a comprehensive GIS-based data file that can be used to prioritize mitigation efforts. To explore the possible correlation between the presence of road salt and wildlife-vehicle collisions, ITD requested this synthesis of research on the use of salt and salt brines and wildlife-vehicle collisions, along with a review of state practices aimed at mitigating these crashes.

Summary of Findings

Because salt is biologically necessary but scarce in many northern regions, road salt applied for deicing and anti-icing purposes is undoubtedly an attractant to many animals. A number of photos have appeared in news reports showing deer or moose licking winter roads or vehicles coated in salt or salt residue. *(Stensland 2011)* That many animals are attracted to road salt does not necessarily mean, however, that road salt is a primary cause for wildlife-vehicle collisions.

Although the link between the use of road salt and wildlife-vehicle collisions is frequently asserted, few studies have sought to establish this link conclusively. The limited research that has been conducted generally supports the idea that road deicers contribute in some way to wildlife-vehicle collisions. For example, moose have been found to travel long distances and visit places they typically avoid to reach roadside salt pools when they were sodium deficient. *(Laurian et al. 2008; Miller and Litvaitis 1992)*

Research in the Laurentides Wildlife Reserve in Quebec, Canada, found that the presence of roadside salt pools doubled the number of collisions between moose and vehicles. This study also found that salt pools with higher sodium and calcium levels received increased moose visitation. *(Grenier 1973)* Another study found that road segments with at least one brackish pool nearby had an 80 percent increase in moose-vehicle collisions. This study, however, found enough other factors influencing accident rates (such as time of year and slope of the terrain surrounding the roadway) that the impact of brackish pools should not be overemphasized. *(Dussault et al. 2006)*

Without the benefit of more extensive research, it is not possible to draw conclusions regarding the extent to which salt or deicer use increases the number of wildlife-vehicle collisions. Many other factors, including migration patterns, breeding behaviors, and highways as convenient transit corridors for wildlife movement, may also contribute to these collisions.

Among those participating in the survey of state practices conducted for this investigation, two respondents explicitly reported not finding a correlation between wildlife-vehicle collisions and salt use. Montana DOT reported that no significant evidence tied collisions to the use of salt or salt brine on roadways. Utah DOT tracks all animal carcass removal from its roadways, and data has shown no correlation with salt use or distribution.

One approach to analyzing the connection between wildlife-vehicle collisions and the use of winter maintenance chemicals is to consider the peak months when these collisions occur. However, published research is mixed on the peak months for wildlife-vehicle strikes. While some sources have found that animal-collision rates peak as sodium needs are highest, others have found that collision rates with moose peak in mid-November or midwinter, as the animals seek feeding sites that have little snow cover, often near roads. In addition, even though salt and salt brines are only applied during the winter months, these materials are still present after winter in roadside water due to runoff. Deer may be attracted to these salt pools in the early spring when natural sources of sodium are difficult to find.

Dozens of techniques for mitigating wildlife-vehicle collisions have been proposed, including building fences or crossing structures, reducing speeds, and educating the public. While many techniques have been studied, those directly related to deicer usage and management has been the subject of relatively few published studies. The use of deicers other than sodium chloride is possibly the most recommended of these techniques, although some biologists have suggested that magnesium chloride and calcium chloride both attract wildlife as much or more than sodium chloride. Few deicer additives or repellants sprayed on roadside vegetation have been conducted, although lithium chloride has shown promise in repelling caribou in a controlled test. *(Baird 2010)* Deactivating roadside salt pools by draining them and then filling with rocks has shown promise at reducing moose visitations in both computer models and field tests.

Detailed Findings

Background on Wildlife-Vehicle Collisions

Scope of the Problem

Wildlife-vehicle collisions can cause injury or death to humans and animals (with attendant ecological damage), as well as significant property damage. There are several estimates of the costs of wildlife-vehicle collisions in specific jurisdictions and, in some instances, for specific animals. ITD's annual crash report reported 1,058 wildlife-vehicle collisions in 2012. *(Idaho Transportation Department 2013)* Of these, 3 caused human fatalities, 13 caused serious injury, 43 caused visible injuries, and 63 caused potential human injury. Based on U.S. Department of Transportation estimated average costs by crash type, these collisions had a total cost of approximately $19 million. *(Huijser et al. 2008, Chapter 3)*

A National Cooperative Highway Research Program/U.S. Geological Survey study evaluating the costs of deer-vehicle collisions in Utah determined an average cost of $3,470 per collision, with a total cost of more than $45 million over 6 years. *(Bissonette et al. 2008)* These costs were primarily human fatalities (53 percent) and vehicle damage (39 percent), but loss of deer made up 6 percent of costs and human injuries made up 2 percent.

Insurer State Farm, meanwhile, noted that the nationwide average claim for deer-vehicle collisions between July 1, 2011, and June 30, 2012, was $3,305. *(Insurance Advocate 2012)* Average cost per claim grew 4.4 percent over the prior year, and the number of deer-related claims increased by 7.9 percent over 4 years. The Insurance Institute for Highway Safety estimated that deer-vehicle collisions in the United States are responsible for about 200 human fatalities per year.

Animal Attraction to Salt on Roads

Many herbivorous animals naturally seek salt (sodium chloride) to supplement their diets. Sodium is necessary for physiological functions, including muscular contraction, reproduction, lactation, growth, hair production, maintenance of body mass and appetite, intercellular exchange, neural transmission, and acid-base equilibrium (Laurian et al. 2008, pp. 1094). In northern climates, wildlife may travel great distances to get the salt they need. Moose, elk, deer, bighorn sheep, woodchucks, snowshoe hares, porcupines, cottontail rabbits, and several species of birds have been observed feeding on roadside salt. *(Environment Canada and Health Canada 2001, Section 3.6.1; Luers 2013; Stensland 2011)*

Moose, for example, typically lose weight in winter and need increased sodium in spring and early summer to help regain weight and energy, grow antlers, and begin lactation. The terrestrial vegetation available to moose in winter has a sodium concentration of only 10 ppm and provides only 6 percent of moose's annual requirements. Better natural sources of sodium that moose utilize in spring include aquatic vegetation (with a concentration of 150 to 700 ppm) and brackish water at mineral springs (with a concentration of 23 ppm to 200 ppm). *(Laurian et al. 2008)* But availability of these sources is limited: aquatic vegetation is not fully developed in spring and early summer when moose need its sodium most, and mineral springs have limited geographic availability.

Melted snow from roadways mixed with deicing chemicals can produce artificial roadside salt pools. With a high sodium concentration (greater than 500 ppm), these pools can provide the sodium that moose and other animals need in winter. They also offer an easy-to-consume source of sodium, relative to aquatic plants that provide low net energy content and may have high levels of toxic heavy metals. *(Leblond et al. 2007)*

Completed Research

Potential Link: Wildlife-Vehicle Collisions and Road Salt

Many agencies have hypothesized a link between deicing chemicals and wildlife-vehicle collisions. Montana Fish, Wildlife, and Parks attributed road salt (along with driver inattention, grass near the highway that greens faster than other vegetation at that altitude, and lion predation) for a rapid decline in the bighorn sheep population near Highway 200 at Thompson Falls. *(Sakariassen 2012)* According to a Western Transportation Institute report, “The presence of bighorn sheep along Highway 3 [in southern British Columbia and Alberta] is frequently due to their attraction to salt that they lick off the roads.” *(Clevenger 2010)*

While assertions of the link between deicer use and wildlife-vehicle collisions are commonplace, research that directly connects the two is more difficult to find. A survey of winter maintenance practices among state DOTs conducted for this synthesis found few respondents who had evaluated the connection between salt and wildlife-vehicle collision.

Below is an overview of those studies that did find a likely connection between the use of road salt and deicers and an increased presence of animals on or near roadways.

Behavioral Adaptations of Moose to Roadside Salt Pools

A moose-tracking program in the Laurentides Wildlife Reserve in Quebec, Canada, quantified the use of roadside salt pools by moose. In the study, researchers monitored 47 moose fitted with GPS collars for 2 to 36 months. These collars collected location data every two hours, totaling nearly 200,000 location readings between January 2003 and April 2006. During this period, more than 100 metric tons of deicing salts were applied per kilometer of highway each winter, creating 86 roadside salt pools in the study area. There were also 23 compensation salt pools—man-made salt pools managed by the Quebec Ministry of Transportation and located 100 to 1,500 meters away from highways to attract moose away from roads.

Moose visited salt pools relatively rarely, with only 0.12 percent of readings recorded at salt pools. These visits occurred from May to September, peaking in June. However, moose traveled large distances to reach salt pools when they did visit. The distance between successive locations averaged 150 meters for all readings, but 300 to 500 meters when a moose was accessing a salt pool. Additionally, salt pools were often located at the edge of a moose's home range in areas that moose typically avoided. Based on this data, researchers hypothesized that moose made intentional journeys to visit salt pools when they were sodium-deficient, filled their needs rapidly, and moved on. *(Laurian et al. 2008)*

Temporal and Spatial Distribution of Moose-Vehicle Accidents in the Laurentides Wildlife Reserve, Quebec, Canada

In a Quebec Ministry of Transportation study, researchers evaluated 13 years of accident data in the Laurentides Wildlife Reserve from 1990 to 2002 and found that the number of collisions between vehicles and moose increased by 80 percent on road segments that had at least one brackish pool nearby. Other factors contributing to accidents were time of year (collisions were most common from mid-May to late August, peaking in the second half of June); the presence of valleys across the road that allowed moose to travel without expending extra energy on steep slopes, which increased collisions by 120 percent; and the average slope of the terrain surrounding the roadway (collisions increased as the mean slope increased).

Multiple brackish pools in an area after the first did not increase the likelihood of collisions. Other factors that did not impact accident rates were distance to food or water availability, altitude, range in slope of the surrounding terrain, and twisting or undulation of the roadway.

Even the factors that did have a notable impact on accident rates do not offer a full explanation, however. The authors assert that the variables explain less than 25 percent of the spatial variation in accidents, suggesting that there are other variables that affect accident rates. *(Dussault et al. 2006)*

Moose Killed on the Highway in the Laurentides Park, Quebec, 1962 to 1972

Research on the 189-kilometer-long Talbot Boulevard in the Laurentides Wildlife Reserve found that the presence of roadside salt pools doubled the number of collisions between moose and vehicles. This study also found that salt pools with higher sodium and calcium levels received increased moose visitation. It did not, however, find any link between the chemical composition of ponds and moose mortality. *(Grenier 1973)*

Moose-Vehicle Accidents in Ontario: Relation to Highway Salt

Researchers examined crash data on Highway 17 in Ontario, Canada, to evaluate the quantitative impacts of deicers on wildlife-vehicle collisions and concluded that moose were attracted to roadside salt pools. They found that 43 percent of moose-vehicle collisions occurred within 100 meters of a saltwater pool. This figure is higher than what would be randomly expected. *(Huijser et al. 2007; Huijser et al. 2008)* Additionally, the peak period for collisions corresponded with moose's peak sodium deficiency rather than a period of maximum traffic. *(Fraser and Thomas 1982)*

However, a 2005 TRB paper questioned this conclusion's validity after observing that the same number of moose-vehicle crashes took place more than 300 meters from saltwater pools. *(Knapp 2005)* Researchers also questioned the original research's assumption that all locations would have an equal chance for a collision if roadside salt pools were not present and noted that the original research made no assertion of the number of crashes that could have been prevented if the salt pools were removed. (This and other dissenting perspectives are discussed in the section below—**Questioning the Link: Wildlife-Vehicle Collisions and Salt**.)

Use of Roadside Salt Licks by Moose (Alces alces) in Northern New Hampshire

Researchers tracked 14 moose by radio collar and found that most (11 out of 14) extended and elongated their home ranges specifically to include salty roadside pools. *(Miller and Litvaitis 1992)*

Environmental Impact of Road Salting - State of the Art

A 1982 Ontario Ministry of Transportation technical report stated that deer and moose that drink salty water are prone to bolting, which can sometimes take them into the path of a vehicle rather than moving away from it as they normally would. *(Jones and Jeffrey 1986, cited in Environment Canada and Health Canada 2001, Section 3.6.1)*

Questioning the Link: Wildlife-Vehicle Collisions and Salt

Research suggests that a link between roadside salt pools and wildlife-vehicle collisions is not universally accepted. Among those participating in the survey of state practices conducted for this investigation, two respondents explicitly reported not finding a correlation between wildlife-vehicle collisions and salt use. Montana DOT reported that no significant evidence tied collisions to the use of salt or salt brine on roadways. Utah DOT tracks all animal carcass removal from its roadways, and data has shown no correlation with salt use or distribution.

In a 2004 report, the Salt Institute argued "[t]here is little scientific information about vehicle-wildlife collisions related to the presence of highway salt along the roadside." *(Salt Institute 2004, Section 4.1)* To support its claim, the institute cites Wisconsin DOT data suggesting crashes between vehicles and deer peak in October and November, during deer breeding season. *(Wisconsin DOT 2001)* October and

November accounted for 41.1 percent of all deer-vehicle crashes in Wisconsin in 2001. A much smaller secondary peak—15.7 percent of crashes—occurred in May and June. The Salt Institute suggested that those May and June collisions are unrelated to deicers, since road salt is generally not needed that late in the year. This assertion, however, ignores the fact that salt remains on or near the roadway after winter.

Published research is mixed on the peak months for wildlife-vehicle strikes. Some sources (including research in Quebec, Ontario, Newfoundland, and southern Sweden) have found that animal-collision rates peak as sodium needs are highest. Many others (including research in British Columbia, Alaska, Norway, Finland, and northern Sweden) have found that collision rates with moose peak in mid-November or midwinter. At these times, animals seek feeding sites that have little snow cover, which are often available in valleys near roads. *(Dussault et al. 2006)*

These reports suggest that in some areas and for some animal species, mating or migration behaviors are a more pertinent cause of wildlife-vehicle collisions than road salt. A Montana DOT study of deer-vehicle collisions suggests additional contributing factors that attracted white-tailed deer to high-collision sections of Highway 83 in the Seeley-Swan Valley. *(Huijser, Gunson, and Abrams 2006, pp. 65)* These factors included: road salt, land management practices, the public's provision of food and salt licks, temporary food sources created by logging, and hay in nearby horse pastures.

As described earlier in this report, the conclusions of a 1982 Ontario study linking roadside salt pools to wildlife-vehicle collisions have been questioned because the study made no attempt to determine how many crashes would have occurred if roadside saltwater pools were eliminated or reduced. *(Knapp 2005)* Knapp found no other studies that linked wildlife-vehicle collisions to the use of road salt (although research conducted after 2005 has found stronger links).

Wildlife-Vehicle Crash Mitigation: Focusing on Deicers

Numerous techniques have been identified to reduce the number of collisions between animals and vehicles. These can be classified into four broad categories: reducing the animal population near the roadway, reducing the number of vehicles on a roadway, modifying animal behavior, and modifying motorist behavior. *(Mastro et al. 2008)* A Montana DOT report details 39 mitigation techniques that have demonstrated varying levels of effectiveness for deer-size and larger animals. *(Huijser et al. 2007)* Additionally, a 2005 Transportation Research Board paper evaluates the state of research into many often-suggested techniques for mitigating deer-vehicle collisions (Knapp 2005).

While many mitigation techniques have been tested, there is relatively little research available about the effect of deicer-related solutions such as alternate deicers, additives, roadside salt pool management, and compensatory salt sources. These specific wildlife-vehicle collision reduction techniques are described below.

Alternate Deicers

Many sources recommend the use of alternate deicers to reduce the number of wildlife-vehicle collisions, but these recommendations are not generally supported by research. *(Laurian et al. 2008; Hedlund et al. 2003; Huijser et al. 2007; Watson and Klingel 2000; Clevenger et al. 2010)* A Federal Highway Administration report listed "investigate deicing alternatives" as one of many mitigations that may be promising. *(Huijser et al. 2008)*

Washington DOT wildlife biologists have reported anecdotal observations that calcium chloride and magnesium chloride seem even more attractive to wildlife than road salt. *(Luers 2013)* These observations were supported by an informal experiment in which biologists sprayed feeding barrels at a bighorn sheep winter feeding site with either commercially available magnesium chloride solutions or dissolved table salt. In all three tests, sheep licked the magnesium chloride-coated barrels first. The magnesium chloride solutions contained proprietary corrosion inhibitors, and it is unknown which specific components attracted the animals in this experiment.

Colorado Parks and Wildlife biologists have also cited magnesium chloride as an attractant for bighorn sheep. *(Vieira 2012)* The report notes that "[b]ighorn seem invariably attracted to the magnesium chloride applied to the roads, which increases their vulnerability to being hit by vehicles particularly under poor driving conditions." *(Vieira 2012, pp. 32)*

In Jasper Park, Alberta, Canada, calcium chloride was specifically tested and failed to deter animals from the road. *(Bertwistle 1997, cited in Huijser et al. 2008)*

Additives

Several deicer additives have been tested for their ability to repel animals. Lithium chloride, a gastrointestinal toxicant, was the most effective additive in a test of 14 caribou in Alberta. *(Brown 2000, cited in Baird 2010)* The caribou rejected nearly all of the food treated with lithium chloride that they were offered over a five-day test period. In the same test, the caribou were initially repelled by Deer Away Big Game Repellent, an olfactory and taste repellent, but feeding time and food intake returned to near baseline levels by the end of the test period. Wolfin, which simulates the scent of wolf urine, had no impact on the caribou. It must be noted that this test was conducted under controlled circumstances rather than in the field.

Montana DOT and Montana Fish, Wildlife, and Parks tested GameAway as a deicer additive on Highway 200 to reduce vehicle collisions with bighorn sheep. *(Bragg 2012)* This research produced inconclusive results, however. *(Justun Juelfs, personal correspondence)* Photographic data found that bighorn sheep were on or near the road more often during GameAway treatment periods than at other times, but observational data found the opposite. Additionally, study results are considered compromised because GameAway was almost always applied with a salt/sand mixture on the road rather than independently.

Several tests of deer repellents on roadside vegetation have been ineffective at reducing collisions. *(Mastro et al. 2008)* A prior synthesis of repellent studies suggested that natural predator and putrescent egg scents had the most potential as area-based repellants. *(Knapp 2005)* The synthesis noted that area-based repellents needed to be field-tested and that it was unlikely for a single repellent to be functional for all animals. A Montana DOT report concluded that olfactory or chemical repellents likely have limited effectiveness. *(Huijser et al. 2007)*

Roadside Salt Pool Deactivation

In a three-year study of roadside salt pool deactivation in the Laurentides Wildlife Reserve, where pools were drained and filled with rocks, researchers noted significantly reduced moose visits, visit duration, and frequency of night visits. *(Leblond et al. 2007)* Researchers concluded that reduced visitation rates would reduce the risk of collision, although this was not specifically tested. Another field test of roadside salt pool deactivation is under way in John Prince Research Forest in British Columbia, but results are not yet available. *(Rea and Rea 2005)*

A Maine DOT report recommended a similar approach: concentrating salt runoff in a specific location and then identifying that location to the driving public. *(Maine Interagency Work Group on Wildlife/Motor Vehicle Collisions 2001*) This report, however, offered no details about implementing this approach.

Agent-based modeling (a model that simulates the actions and interactions of individuals within a larger population) of moose behavior in the Laurentides Wildlife Reserve also suggested that salt pool removal would reduce the number of road crossings by moose. *(Grosman et al. 2009)* The model indicated that 100 percent roadside salt pool removal could reduce road crossings by 49 percent, if no compensatory salt pools (salt pools created as a mineral source some distance from the roadway) were created, or by 18 percent if compensatory salt pools were created. Removing two-thirds of roadside salt pools reduced road crossings by 16 percent, regardless of whether compensatory salt pools were created. Another study that used agent-based modeling found that removing roadside salt pools reduced road crossings by 22 percent to 79 percent. *(Grosman et al. 2011)* Compensation pools, if used, should be located as far as possible from the roads, at least 500 meters.

Compensatory Salt Pools

As indicated above, models suggest that compensatory salt pools may reduce the effectiveness of salt pool removal. An unintentional form of compensatory feeding—a compound salt shed—has been observed as an attractant to bighorn sheep near Radium Hot Springs in British Columbia. *(Dibb 2006*) The author expressed concern about this shed potentially spreading saliva-borne disease or contamination of the salt with toxic substances, but observed that there has been no evidence of these problems actually occurring.

Salt and Water Reduction Near Roadways

As part of its response to the survey of state DOTs for this synthesis (see Appendix A), Utah DOT offered suggestions for reducing salt build-up near roadways. These suggestions included minimizing salt use, reducing salt scatter and bounce, and eliminating standing water where possible along roadsides within the right-of-way to minimize the potential for wildlife-vehicle collisions.

Wildlife-Vehicle Crash Mitigation: Beyond Deicers

While this synthesis focuses on mitigation techniques related to deicer usage, several other prominently used techniques warrant brief overviews, including:

- **Fences.** Several studies have found that properly maintained fences, combined with wildlife crossings, are the most effective method for reducing collisions between deer and vehicles. *(Mastro et al. 2008)* Fences are also credited with reducing collisions with bighorn sheep in north central Washington, even as the herd size is growing. *(Mehaffey 2012)*

- **Speed reductions.** A test of speed reductions from 90 to 70 kilometers per hour on 3 sections of the Yellowhead Highway in Jasper National Park, Alberta, Canada, produced mixed results. *(Bertwistle 1999)* During the test period, there was a 33 percent decrease in bighorn sheep-vehicle collisions in 90 kph zones, but a slight increase in zones that were changed to 70 kph. Speed reductions were affiliated with a different impact on elk: Collisions increased by 84 percent in 90 kph zones, but a much lower 24 percent in 70 kph zones.

- **Crossing structures.** Banff National Park, Alberta, Canada, uses crossing structures in conjunction with fences to reduce wildlife-vehicle collisions on the Trans-Canada Highways. These crossing structures are expensive but effective. *(Alan Dibb, personal correspondence)* In addition, two states noted activities related to wildlife crossings in the state DOT survey conducted for this investigation:
    - Washington is constructing wildlife bridges. (http://i90wildlifebridges.org/bridging-futures-2013) In 2014, a student design will be finalized for construction of Washington's first wildlife overcrossing.

    - Wyoming DOT has installed several wildlife crossing structures. (Refer to the survey responses for this synthesis report in Appendix A.) These large box culverts allow wildlife to pass under the roadway in locations identified by the Wyoming Game & Fish Department as migration routes or problem areas. The agency has noted success with adding game fencing to the right-of-way to channel wildlife toward the crossings.

- **Public education.** Few respondents of the state DOT survey conducted for this synthesis reported taking any steps to minimize wildlife-vehicle collisions thought to be caused by salt or salt brine use. Public education was the only method used by a significant percentage of respondents (21 percent).

Research in Progress

Several projects currently under way have implications for the state of knowledge of deicers' role in wildlife-vehicle collisions. This research includes:

- An ITD project that seeks to determine where mitigation measures are needed to reduce wildlife-vehicle collisions and the most cost-effective options. A GIS tool will identify high-risk corridors. The project is scheduled for completion in June 2014. *(Cramer, in progress)*
- The Deer-Vehicle Crash Information and Research Center pooled fund website, established in 2001, has not been maintained or updated since 2009. A current project will incorporate research into the website that has been completed since then. *(Knapp, in progress)*
- A field test of roadside salt pool deactivation is under way in John Prince Research Forest in British Columbia, but results are not yet available. *(Rea and Rea, 2005)* While originally scheduled to be completed in 2008, personal correspondence with the researcher revealed that the project is still under way and no results could be shared yet.

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Appendix A
Survey of States:
Use and Impacts of Salt and Salt Brine

Introduction

On August 27, 2013, CTC announced the availability of a 25-question survey distributed on behalf of Idaho Transportation Department to gather information on the use of salt and salt brine for roadway deicing. The survey addressed the impacts of these materials on vehicle corrosion, environmental contamination, and wildlife-vehicle collisions.

Potential respondents included the Technical Advisory Committee members from the 26 participating states in the Clear Roads research program: California, Colorado, Idaho, Illinois, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Virginia, Washington, West Virginia, Wisconsin, and Wyoming. Clear Roads is an ongoing pooled fund research project aimed at rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews. Representatives from Nevada and South Dakota DOTs also received the survey however not response was received.

We received responses from DOTs in 19 states, as listed below and shown in the map:

- Colorado
- Idaho
- Iowa
- Kansas
- Maine
- Michigan
- Montana
- New Hampshire
- New York
- North Dakota
- Ohio
- Pennsylvania
- South Dakota
- Utah
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

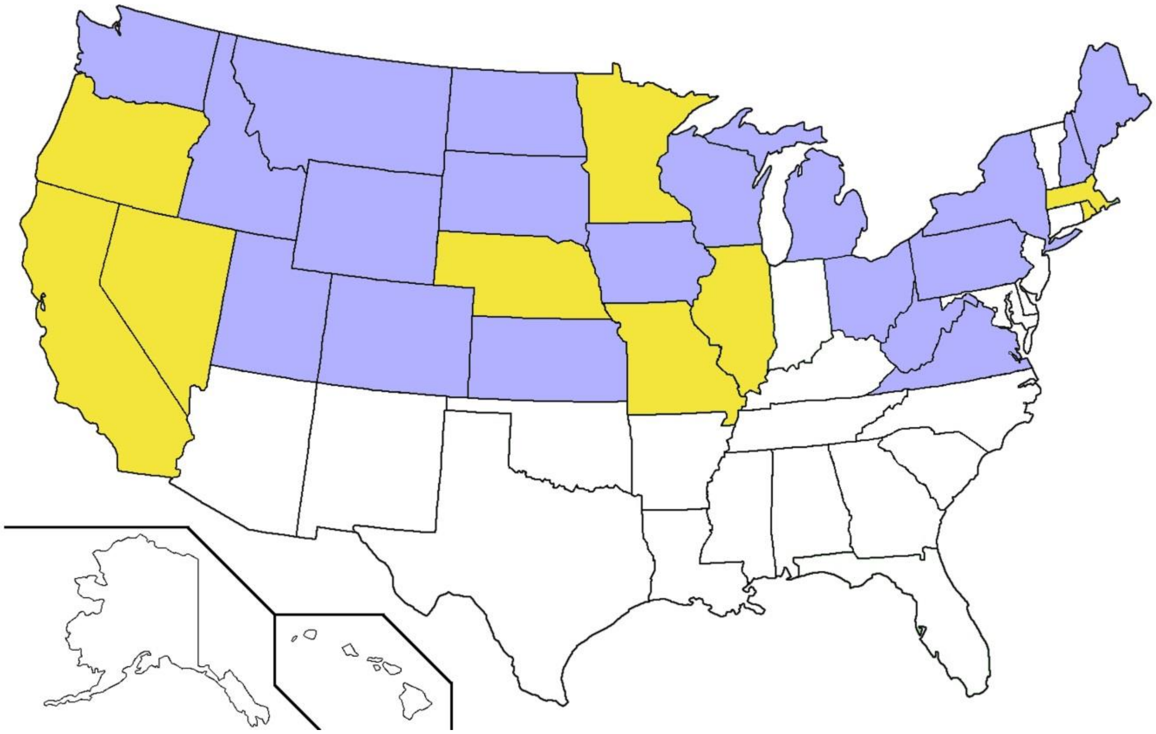

Figure 3. States Participating in the Survey
(purple = states responding; yellow = states not responding)

Oregon DOT did not complete the survey but indicated that its salt use is limited to a five-year pilot project that began in the 2012-2013 winter season. Oregon's experience with this pilot so far is described on the next page.

Survey Results by Question

1. **Does your agency currently use any amount of either salt (sodium chloride) or salt brine for winter highway maintenance?**

Colorado	Yes	Ohio	Yes
Idaho	Yes	Oregon	Yes (two pilot areas only)
Iowa	Yes	Pennsylvania	Yes
Kansas	Yes	South Dakota	Yes
Maine	Yes	Utah	Yes
Michigan	Yes	Virginia	Yes
Montana	Yes	Washington	Yes
New Hampshire	Yes	West Virginia	Yes
New York	Yes	Wisconsin	Yes
North Dakota	Yes	Wyoming	Yes

Oregon DOT (ODOT) was the only respondent to indicate that salt and salt brine are not used as part of an agency's standard winter maintenance practices.

Due to environmental concerns (solid sodium chloride has been shown to contaminate ground and surface water supplies), and because liquid magnesium chloride has been effective, ODOT has not adopted the use of sodium chloride as a statewide practice. With research indicating that salt can be effective at low application rates and with perhaps low environmental impacts when used in conjunction with best management practices, ODOT is piloting the responsible use of salt in two locations.

In a five-year pilot that began with the 2012-2013 winter season, ODOT is using solid sodium chloride as a road deicer in two pilot locations to determine if solid salt can fill an operational gap where current tools are unable to reach and maintain level of service (LOS) standards. The pilot locations:

- U.S. 95, a two-lane highway with passing lanes in the southeastern corner of Oregon, runs about 120 miles between Nevada and Idaho (both states use salt). ODOT is experimenting with using salt in limited situations on this highway except in an area near a city water supply. This section of roadway is classified as LOS B, which means that snow may be encountered using a winter storm but ODOT crews work to achieve bare pavement within a few hours after the storm.

- I-5 over the Siskiyou Pass connects Oregon with California, which already uses salt on the Interstate. ODOT is experimenting with using salt in limited situations on 11 miles of this six-lane Interstate with truck climbing lanes and a chain-up area. This section of roadway is classified as

LOS A, which means that ODOT crews work to maintain bare pavement throughout the winter months.

Goals of the pilot are to:

- Provide a consistent level of service between Oregon and adjoining states.
- Provide a greater level of safety for the traveling public.
- Reduce temporary holds and delays for the freight industry and public in the I-5 pilot area.

2. How many lane miles of highway is your state agency responsible for maintaining in the winter?

Lane Miles	States	Comments
10,000 or less	Maine, New Hampshire, North Dakota, West Virginia	*ND* - We are 1 of 8 districts in the state. Our district lane miles are 2,100.
10,001 to 20,000	Idaho, South Dakota	
20,001 to 30,000	Colorado, Iowa, Kansas, Michigan, Montana, Utah, Washington, Wyoming	
30,001 to 40,000	Wisconsin	
40,001 to 50,000	New York, Ohio	*NY* - 43,350 lane miles total. Of this total, 7,350 lane miles are handled through municipal contracts with towns, counties and villages.
50,001 or more	Pennsylvania, Virginia	*PA* - 86,000+ lane miles.

3. How many tons of salt (dry sodium chloride) were used in the 2012-2013 winter season?

Tons of Dry Salt	States	Comments
10,000 or less	Colorado, North Dakota, Wyoming	*CO* - Used 4,000 tons of NaCl. Used 45,953.253 tons of Ice Melt and Ice Slicer, both $MgCl_2$ products.
10,001 to 100,000	Idaho, Kansas, Montana, South Dakota, Washington, West Virginia	*ID* - 39,690 tons were purchased for and during the 2012-13 winter season. Some salt was still in inventory. *KS* - 91,000 tons.
100,001 to 200,000	Iowa, Maine, New Hampshire	*ME* - 101,710 tons.
200,001 to 300,000	Utah	
300,001 to 400,000	Virginia	*VA* - May use between 100,000 and 500,000 tons of salt depending on the winter weather severity.
400,001 or more	Michigan, New York, Ohio, Pennsylvania, Wisconsin	*PA* - 892,000 tons. *WI* - 621,000 tons rock salt.

4. What percentage of the total dry materials (including abrasives) used for winter maintenance in 2012-2013 does salt represent?

Salt as Percentage of Dry Materials	States	Comments
Less than 5%	Colorado, North Dakota	
5% to 25%	Michigan, Montana, Wyoming	
25% to 50%	Idaho	*ID* - Most applications are either straight salt, 2:1 or 3:1 sand to salt.
50% to 75%	Kansas, Pennsylvania, Washington, West Virginia, Wisconsin	*WI* - Only used 19,000 yd^3 of sand statewide.
75% or more	Iowa, Maine, New Hampshire, New York, Ohio, South Dakota, Utah, Virginia	*ME* - Salt accounts for 89% of the agency's dry material use.

5. How many gallons of liquid sodium chloride (brine) were used in the 2012-2013 winter season?

Liquid NaCl Salt Brine (gallons)	States	Comments
100,000 or less	Washington, West Virginia, Wyoming	
100,001 to 500,000	Montana, New Hampshire, North Dakota, Virginia	*NH* - Just over 100,000.
500,001 to 1,000,000	Colorado, Maine	*CO* - Used 910,565 gallons of corrosion-inhibited salt brine that we made. Also used 13,853,818.980 gallons of liquid $MgCl_2$. *ME* - 650,500 gallons.
1,000,001 to 2,000,000	New York, South Dakota, Utah, Wisconsin	*WI* - 1.1 million gallons of salt brine for anti-icing; 12,000 gallons of salt brine for prewetting sand; and 1.8 million gallons of salt brine for prewetting salt.
2,000,001 to 4,000,000	Idaho, Michigan (all liquids, not just salt brine), Ohio	
4,000,001 or more	Iowa, Kansas, Pennsylvania	*IA* - About 18,000,000 gallons. *KS* - 4,150,000 gallons. *PA* - 9.3 million gallons.

6. What percentage of the total liquid materials used in 2012-2013 does salt brine represent?

Salt Brine as Percentage of Liquid Materials	States	Comments
Less than 5%	Wyoming	
5% to 25%	Colorado, Michigan	*CO* - 6.57% salt brine.
25% to 50%	Virginia, Washington	
50% to 75%	Idaho, Montana, Ohio	*ID* - 73% salt brine, 27% $MgCl_2$.
75% or more	Iowa, Kansas, Maine, New Hampshire, New York, North Dakota, Pennsylvania, South Dakota, Utah, West Virginia, Wisconsin	*KS* - Use a little $MgCl_2$ brine in our metro Kansas City and Topeka areas.

7. Considering the total lane miles for which your state is responsible, on what percentage of these does your agency use either salt or salt brine?

Percentage of Lane Miles	States	Comments
Less than 5%	Colorado, Wyoming	*CO* - Use salt brine in two locations where the climatic conditions warrant it.
5% to 25%	New Hampshire	
25% to 50%	Montana	
50% to 75%	Virginia, West Virginia	
75% or more	Idaho, Iowa, Kansas, Maine, Michigan, New York, North Dakota, Ohio, Pennsylvania, South Dakota, Utah, Washington, Wisconsin	*KS* - 100%. *WI* - There are 72 counties in the state. All but 16 counties prewet with salt brine. Every county uses rock salt.

8. During the past 10 years what has been the trend for your agency's use of dry salt?

Trend	States	Reasons for the Trend
About the Same	Iowa, Kansas, Maine, Pennsylvania, Virginia	None provided.
Slight Decrease	New Hampshire, West Virginia	*NH* - Better training, calibration, environmental concerns.
Moderate Decrease	New York, Ohio, Utah	*NY* - Some light winters resulted in lower salt use. Also, better management of salt application rates as well as modifying our guidelines to lower initial application rates have resulted in lower salt use.
Substantial Decrease	Colorado, Michigan	*CO* - We moved to a predominately liquid-based strategy. *MI* - We used approximately 16,183 less salt for 2012-2013 season versus our five-year average.
Slight Increase	Idaho, Washington, Wyoming	*WY* - Our maintenance operators are learning that the salt in their sand mixture is really what is clearing the roads. They believed the aggregate was clearing the roadway.
Moderate Increase	Montana, North Dakota	*MT* - Level of service; environmental considerations related to sand.
Substantial Increase	South Dakota, Wisconsin	*SD* - Our organization went away from using salt and sand mixed to using straight salt in most conditions.

9. During the past 10 years what has been the trend for your agency's use of salt brine?

Trend	States	Reasons for the Trend
About the Same	Maine, Ohio, Virginia, Washington	*ME* - Depends on the winter and number of storm events, but in 04-05 and 05-06 we had about the same number of storms as 12-13 and salt usage was the same in each of those years.
Slight Decrease	No responses.	
Moderate Decrease	No responses.	
Substantial Decrease	No responses.	
Slight Increase	Colorado, West Virginia	*CO* - Only two facilities manufacture and use brine. They are located in the extreme SW corner of the state in basically desert conditions. The climatic conditions, elevation, temperatures and wind preclude its use in other parts of the state.
Moderate Increase	Idaho, New Hampshire, Wyoming	*NH* - Increased use on Interstates in the southern section of the state. *WY* - Forces have been purchasing more equipment to apply liquids.
Substantial Increase	Iowa, Kansas, Michigan, Montana, New York, North Dakota, Pennsylvania, South Dakota, Utah, Wisconsin	*IA* - More people think it is effective and are comfortable using it in more situations. Brine making and application capabilities have also increased. *MI* - Industrywide trends and practices along with change in management. *MT* - Level of service; cost. *NY* - Increased the use of salt brine for pre-storm anti-icing of pavement surfaces. *PA* - All trucks are now prewet-capable by policy. We also use prewet salt as a means to reduce the amount of slat that is lost due to bounce and scatter.

10. Does your agency have a winter maintenance policy addressing the use of winter maintenance materials (which materials to use in which situations)?

Nine states—Kansas, Montana, North Dakota, Ohio, Utah, Virginia, West Virginia, Wisconsin and Wyoming—do not have a winter maintenance policy addressing the use of winter maintenance materials. While not a policy, Kansas notes its practice of using salt, salt/sand mixes and brine for snow and ice control on all of its state routes.

Washington State DOT uses the 1996 FHWA application guidelines (Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel) in its snow and ice plans, pending the publication of new and improved application guidelines resulting from a Clear Roads research project. For more information about Clear Roads' research project, Establishing Effective Salt and Anti-icing Application Rates.

See below for winter maintenance guidance provided by respondents that are available online or from ITD.

Colorado

Standard Operating Guide (SOG) for Winter Maintenance and Operations. Denver, CO: Colorado Department of Transportation, August 2010.
This guide recommends procedures for the application of anti-icers/deicers, and abrasives, calibration of sprayers, logs to be used for recording information about the specific applications and information/testing on the products themselves.

Idaho

Section 330.00, Winter Maintenance Guidelines, Maintenance Manual. Boise, ID: Idaho Transportation Department, July 2013.
http://itd.idaho.gov/manuals/Manual%20Production/Maintenance/maintenance%20printable.htm
See page 143 of the document for the beginning of the section on winter maintenance.

Iowa

Chemicals and Abrasives, Snow and Ice Control, Instructional Memorandum No. 8.400. Ames, IA: Iowa Department of Transportation, June 12, 2012.
This memorandum provides guidance to field personnel regarding procedural guidelines for using chemicals and abrasives in the snow and ice removal program.

Maine

Level-of-Service Goals, Snow & Ice Control (Activity 412 & 413). Augusta, ME: Maine Department of Transportation, January 12, 2012.
From the document: The purpose of this document is to define the Department's approach to snow and ice control. It defines the levels of service goals that the Bureau of Maintenance and Operations will strive to provide in order to achieve the safest roadway conditions that are reasonably possible with the available resources. Since storms vary dramatically and occur over a variety of roadway and traffic conditions, this is intended to be flexible to accommodate the variety of conditions that are encountered.

Michigan

Best Practices for Applying Deicing Materials, Maintenance Advisory MA 2013-01. Lansing, MI: Michigan Department of Transportation, August 27, 2013.
This document provides the guidelines used for applying deicing material beginning with the 2013-2014 season.

MDOT Winter Maintenance Application Rates (Solids). Lansing, MI: Michigan Department of Transportation, August 2013.

These guidelines address air temperature, pavement temperature, weather condition, amount applied per lane mile, and the actions and application recommended.

New Hampshire

Winter Maintenance Snow Removal and Ice Control Policy. Montpelier, NH: New Hampshire Department of Transportation, revised October 15, 2001.
http://www.nh.gov/dot/org/operations/highwaymaintenance/documents/FinalWinterMaintSnowandIcePolicy.pdf
This 13-page publication describes recommended snow and ice treatments, recommended spreading practices and details of the agency's plowing operations.

New York

Chapter 5, Snow and Ice Control, Highway Maintenance Guidelines. Albany, NY: New York State Department of Transportation, revised January 2012.
https://www.dot.ny.gov/divisions/operating/oom/transportation-maintenance/repository/HMG%20Section5.pdf
The guidelines address preparing for snow and ice control, stockpiling, passive snow and ice control, and application rates; references are also included.

Pennsylvania

Chapter 4, Winter Services, Maintenance Manual, Publication 23. Harrisburg, PA: Pennsylvania Department of Transportation, updated April 2013.
ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2023/Pub%2023-Chapter%204%20.pdf
From the manual: This chapter discusses all phases of ice and snow control operations. As nearly as possible, it chronologically lists all winter-related activities starting with those performed in the spring, continuing with summer and fall activities, and concluding with the winter season.

South Dakota

Deicing Guidelines, South Dakota Department of Transportation, undated.
These guidelines address pavement temperature, weather condition, maintenance action and amount of material applied.

11. Which of the following winter maintenance materials are used by your agency? Please complete all that apply by indicating the approximate statewide percentage as a percentage of all materials used.

State	Abrasives (percentage)	Sodium Chloride (percentage)	Magnesium Chloride (percentage)	Potassium Chloride (percentage)
Colorado	4.0	<1	95.0	0
Idaho	58.0	41	1.0	0
Iowa	14.0	86	0.0	0
Kansas	44.0	54	~2.0	0
Maine	7.0	92	1.0	0
Michigan	20.0	79	1.0	0
Montana	75.0	15	10.0	0
New Hampshire	20.0	80	1.0	0
New York	1.0	99	*	0
North Dakota	10.0	90	0.0	0
Ohio	0.0	100	0.0	0
Pennsylvania	42.0	58	0.0	0
South Dakota	20.0	75	5.0	0
Utah	5.0	90	5.0	0
Virginia**	20.0	80	**	0
Washington	30.0	45 (solid & liquid)	24.0 (includes $CaCl_2$)	1
West Virginia	40.0	60	0.0	0
Wisconsin	0.5	99	0.5	0
Wyoming***	90.0	8	2.0	0

* New York State DOT used 176,000 gallons of magnesium chloride (liquid only) to prewet dry salt, with an application rate of approximately 8 gallons per ton (this converts to treating 22,000 tons of the dry salt). Magnesium chloride is rarely, if ever, used as a direct application on pavement.

** The percentages provided are for dry materials only. Virginia DOT reports the use of liquid deicers, including sodium chloride, calcium chloride and magnesium chloride, but data on specific quantities used is not available.

*** All of Wyoming DOT's maintenance shops use abrasives with an approximate 90% sand/10% salt mix. When spreading the sand/salt mix, operators apply either sodium chloride or magnesium chloride using an application rate of 6-10 gallons per ton of mix. The percentages provided above are an estimate based on these practices.

Two states make significant use of abrasives as a percentage of overall winter material use: Wyoming (90 percent) and Montana (75 percent). Five states - Colorado, New York, Ohio, Utah and Wisconsin - reported the lowest concentration of abrasives in overall winter material use (5 percent or less).

For 11 states (58 percent of respondents), sodium chloride makes up 75 percent or more of their winter material arsenal. The following states reported the highest levels of sodium chloride use:

- Ohio - 100 percent
- New York and Wisconsin - 99 percent
- Maine - 92 percent
- North Dakota and Utah - 90 percent

Colorado is the heaviest user of magnesium chloride, reporting that its use constitutes 95 percent of all winter maintenance materials. Idaho and Washington reported the next highest percentages, at 26 percent (of all liquids) and 24 percent (including calcium chloride), respectively. Five states—Iowa, North Dakota, Ohio, Pennsylvania and West Virginia—do not use magnesium chloride.

Washington is the only state reporting the use of potassium chloride, and it represents 1 percent of the agency's overall winter materials.

12. Please indicate the reasons your agency uses salt (dry) for winter highway maintenance rather than other materials.

State	More Effective in Deicing the Roadway	Easier to Handle and Store	More Available	Costs Less	Has Fewer Environmental Impacts
Colorado	No Response				
Idaho	X				
Iowa	X	X	X	X	X
Kansas			X	X	
Maine	X	X	X	X	
Michigan	X	X	X	X	X
Montana	X	X	X	X	X
New Hampshire	X	X	X	X	
New York		X	X	X	X
North Dakota	X		X	X	
Ohio	X		X	X	
Pennsylvania		X		X	X
South Dakota		X		X	
Utah	X				
Virginia		X		X	
Washington	X	X	X	X	X
West Virginia			X		
Wisconsin	X	X	X		
Wyoming	No Response				

Agencies’ Other Reasons to Use Dry Salt

State	Reason(s)
Colorado	The vast majority of our road salt use occurs in the Eisenhower Johnson Memorial Tunnels complex. The salt is purchased in 50 lb. bags and distributed by hand onto the roadway for the first 100 or so feet of the tunnels.
Idaho	Chemicals are required to prevent ice buildup and ice melting. For this reason, chemicals such as salt are used to reduce/eliminate ice for better safety and mobility.
Iowa	We can’t use magnesium chloride because it attacks our local aggregates. Calcium chloride is used in small amounts but is more expensive and has more problems in humidity than salt. Sand is not effective in most situations and is usually not used except when very cold.
Maine	Doesn’t chip paint on vehicles, allowed us to extend plow routes (compared to using winter sand), which, in turn, allowed us to downsize people and trucks and refocus millions to paving, allowed us to eliminate numerous outdoor sand/salt piles (which has caused a reduction in our well claims), eliminated windshield claims and doesn’t plug our drainage systems.
New York	Most effective for anti-icing. Our goal is to prevent hard pack to avoid deicing operations.
Utah	We prewet all dry materials applied to the road.
West Virginia	Our state is in the beginning stages of getting into brine treatment. There were only a few vehicles we possessed to deliver brine as a direct application.
Wisconsin	We’re testing a liquid-only deicing strategy in one county. They’re using salt brine.
Wyoming	Mix in our sand at 10% and more brine making is taking place. Solid salt is not used as a direct application material to our roadways.

13. Please indicate the reasons your agency applies salt brine for winter highway maintenance rather than other materials.

State	More Effective in Deicing the Roadway	Easier to Handle and Store	More Available	Costs Less	Has Fewer Environmental Impacts
Colorado				X	
Idaho	X			X	
Iowa	X				X
Kansas			X	X	
Maine				X	
Michigan				X	X
Montana				X	
New Hampshire	X				X
New York				X	
North Dakota	X			X	
Ohio			X	X	X
Pennsylvania		X		X	X
South Dakota	No Response				
Utah			X	X	X
Virginia				X	
Washington				X	
West Virginia	X			X	X
Wisconsin		X	X	X	
Wyoming	X				

Agencies' Other Reasons to Use Salt Brine

State	Reason(s)
Colorado	Our salt brine usage is less than 5% of our program.
Iowa	Helps keep dry salt on the pavement when used as a prewetting agent. Faster acting than dry salt.
Kansas	More effective in anti-icing the roadway.
Maine	Other types of salts ($MgCl_2$ and CaCl) used in a direct liquid application can become slippery under certain conditions. Salt brine is more forgiving in this regard.
Montana	We can produce it with state forces as needed.
New Hampshire	Use is prior to the storm to provide a greater level of service and provide crews time to respond.
New York	Pre-storm anti-icing direct liquid application to road surface. Also used for prewetting salt.
South Dakota	We use salt brine along with dry salt to activate the salt and speed up the melting process. We also use it in certain conditions when the dry salt isn't as effective.
Utah	Works faster than dry chemicals; breaks the bond between ice and pavement faster.
Virginia	Brine is used for anti-icing (pre-event) applications.
Washington	We use salt brine in drier climates like eastern Washington where it is less likely to be diluted out.

14. Has your agency ever been directed NOT to use salt or salt brine?

The three affirmative responses appear below.

New Hampshire	We have a few low-volume roads where a town can petition for a low- or no-salt area based on water supply protection, typically. Needs approval of public safety officials/schools/hospitals within the town. See policy for info.
North Dakota	We can no longer use salt brine from oil field sources.
Washington	Many years ago when corrosion was a larger issue and questions about environmental impacts persisted.

15. What steps does your agency take to minimize the corrosive effects of salt and salt brine on agency vehicles and on cars and trucks driven by the public?

State	No Steps Taken	Reduction in Volume of Material Used and/or Frequency of Use	Information Provided to Public on Importance of Washing Vehicles and Component Parts	Use of Corrosion Inhibitors	Comments
Colorado		X	X	X	Utilize a Maintenance Decision Support System in conjunction with our Standard Operating Guide to minimize material usage.
ID			X		
Iowa		X			Fleet vehicles are thoroughly washed with salt neutralizing/removal wash.
Kansas			X		Provide enclosed wash bays with heat to make it easier to wash the trucks and equipment.
Maine		X	X	X	We treat agency equipment with FluidFilm. Corrosion info is at http://www.maine.gov/mdot/winterdriving/corrosion.htm. The corrosion inhibitors we use are only in the Ice B'Gone product that we use, not the salt brine.
Michigan			X		
Montana				X	Public outreach has been limited so far but when we have a concern we focus on educating our customers on the balance we are faced with.
New Hampshire				X	Use corrosion inhibitor as the additive for the salt brines (Ice B'Gone).
New York				X	Wash DOT trucks frequently. Use stainless steel dump bodies.
North Dakota				X	Geomelt is added to the brine.
Ohio				X	Washing down trucks after each event.
Pennsylvania	X		X		
South Dakota		X			
Utah		X	X	X	Wash our trucks and snow equipment after EVERY storm. The work is not finished until the equipment is washed thoroughly.
Virginia	X				
Washington		X	X	X	Participated in research to determine best practices to prevent corrosion. Wash policy in place for DOT vehicles.
West Virginia	X	X			
Wisconsin		X		X	Many counties are beginning to make custom brine solutions using inhibitors.
Wyoming			X		

16. Does your agency use corrosion inhibitors in salt (dry) to minimize the corrosive impacts to agency and public vehicles?

The three affirmative responses appear below**.**

Montana Yes, in 75 to 100 percent of the material used. The majority of solid salt or salt/sand is prewetted with an inhibited liquid. The salt in solid form by itself is not inhibited.

New York Yes, in 75 to 100 percent of the material used. Salt specification requires corrosion inhibitors.

Wisconsin Yes, in 10 to 50 percent of the material used. All but a couple counties prewet their salt. Many are starting to mix corrosion inhibitors into their salt brine.

Washington State DOT reports that the agency used to use an inhibited dry salt, but it did not sample consistently for quality and was much more expensive.

17. Does your agency use corrosion inhibitors in salt brine to minimize the corrosive impacts to agency and public vehicles?

Extent of Corrosion Inhibitor Use	State	Comments
No Use of Corrosion Inhibitors	Idaho, Iowa, Kansas, Maine, Michigan, Pennsylvania, South Dakota, Utah, Virginia, West Virginia, Wyoming	*MI* - We do with other chlorides. *UT* - We use inhibitors in $MgCl_2$ and $CaCl_2$ brines.
Less Than 10 Percent of the Material Used	Ohio	Corrosive-inhibited products are being mixed with salt brine in some areas.
10 to 50 Percent of the Material Used	North Dakota, Wisconsin	
75 to 100 Percent of the Material Used	Colorado, Montana, New Hampshire, New York, Washington	*NH* - Ice B'Gone 20%/salt brine 80%. *NY* - We make our own brine in most cases using our salt that contains corrosion inhibitors. We do not add additional inhibitors. *WA* - We inhibit all liquid products.

18. If your agency uses corrosion inhibitors in salt or salt brine, please list the primary types of inhibitors used (with brand name if applicable) and the reason for the choice.

State	Product	Reasons for Use			
		Lab Tests	Field Tests	Agency Experience	Product Claims
Colorado	Boost	X	X	X	
	Envirotech Services and Desert Mountain Corporation (inhibited $MgCl_2$)	X	X	X	
Montana	ArctiClear	X			
	Headwaters 40°F corrosion inhibitor	X			
New Hampshire	Ice B'Gone			X	
New York	YPS		X		
North Dakota	Geomelt				X
Ohio	Pacific Northwest Snowfighters-approved corrosion-inhibited $CaCl_2$	X			X
Washington	ArctiClear	X	X	X	
	Boost	X	X	X	
	Various other inhibitors in small tests		X		
	CC&B (inhibited $CaCl_2$)	X	X	X	
	FreezGard Zero Plus (inhibited $MgCl_2$)	X	X	X	
Wisconsin	ArctiClear Gold				X
	Bio Melt 64				X
	FreezGard				X
	Geomelt				X
	Ice Ban M80				X
	Ice Bite 55				X

19. Has your agency seen a correlation between use of specific winter maintenance materials or techniques and the increase or decrease in complaints about vehicle and truck corrosion?

The five affirmative responses appear below.

Colorado	Initial complaints about corrosion of brake parts and chrome on trucks from the public. Communication regarding the need to wash vehicles after storms has helped.
Idaho	In northern Idaho, inhibited magnesium chloride was used with great complaints. Upon switching to noninhibited brine, complaints decreased initially, but have now increased again in specific areas.
Montana	We experienced some negative public comment after increased chloride usage in northwest Montana.
Utah	When we started widespread use of salt brine the complaints went up. We met with Utah Trucking Association and AGC [Associated General Contractors] and showed them our corrosion data. They quieted down when they figured out that washing their equipment made sense. We also ran some stories on TV and radio explaining what we were doing to the public advising them to wash their cars and undercarriage frequently during the winter. We get very few complaints today.
Washington	The use of inhibited materials and improved vehicle components has resulted in far fewer complaints about corrosion. Also, the traveling public recognizes the correlation between the use of chloride materials and safer driving surfaces.

20. Please indicate the practices employed by your agency to minimize environmental impacts and comply with state and federal regulations regarding the use of salt and salt brine.

State	Use of Appropriate Storage Facilities and Tanks, Including Regular Inspection and Maintenance	Training of Operators in Storage and Application Procedures	Use of Calibrated Application Equipment	Identification of Environmentally Sensitive Roadways and Rights of Way	Soil, Air and Water Testing to Determine Any Negative Effects	Sweeping of Residual Salt on the Roadways and Rights of Way at the End of the Winter Season	Limiting the Amounts or Types of Materials Used	Comments
CO	X	X	X	X		X	X	We utilize a Maintenance Decision Support System in conjunction with our Standard Operating Guide to minimize material usage.
ID	X	X	X		X			
IA	X	X	X					Truck wash recycled into brine so the salt does not get wasted down the drain.
KS	X		X					
ME	X	X	X		X	X	X	We try to minimize salt usage on all roads, so we don't identify isolated segments that get treated differently. We simply don't buy the materials that we feel are more harmful to the environment.
MI	X	X	X	X		X		
MT	X	X	X	X				
NH	X	X	X	X				
NY	X	X	X	X				
ND	X	X	X					
OH	X	X	X	X			X	Guidelines to minimize excessive salt
PA	X	X	X	X				
SD			X			X		
UT	X	X	X	X	X		X	Sweep up all grit applied. All storage facilities have an impermeable retention pond that catches ALL maintenance station yard and storage area runoff. Have zero offsite discharge from our yards. Use oil-water separators also.
VA	X	X	X			X		
WA	X	X	X	X	X	X	X	Limited use of abrasives where fish bearing streams are adjacent to highways. Use all of the above. I don't believe there are any state or federal regulations regarding the use of salt and salt brine, except that EPA publishes clean water standards which include chloride limits. Let me know if you hear differently.
WV	X	X	X					
WI	X	X	X			X		
WY	X		X					

21. Has any practice by your agency related to the use of deicing materials led to or contributed to the violation of a state or federal environmental regulation, such as water quality or air quality?

The four affirmative responses appear below.

Iowa	Salt content from some garages' wastewater was too high. Installed wastewater brine recyclers to keep salt out of sewer flow.
Maine	Maine state law requires the replacement of any wells that are damaged by salt contamination caused by us. We have replaced several.
Montana	Improper storage of solid salt has caused several contaminated well claims.
New Hampshire	Currently involved in U.S. Environmental Protection Agency TMDL [total maximum daily load] issue in the widening of the southern section of I-93 from the Massachusetts border to Manchester, NH. Sodium chloride is the culprit.

22. Does your agency have a claims process for handling complaints it receives regarding negative impacts of winter maintenance materials on personal or commercial property (for example, damage to windshields from abrasives, pollution of well water from salt, corrosion of vehicles, etc.)?

State	Claims Process (Yes/No)	Additional Information
Colorado	Yes	All claims are referred to the State Risk Management department.
Idaho	Yes	We have a process by which tort claims can be filed.
Iowa	No Response.	
Kansas	Yes	Only related to broken windshields.
Maine	Yes	We just have them contact our Environmental office if it's a well claim or our Legal office if it's a windshield claim. Forms are not online. Corrosion is not something for which a person can submit a claim since it is a known by-product of the winter LOS standards we have chosen as a state, is highly dependent on other variables (different road jurisdictions, type of vehicle purchased, ocean water exposure (i.e., Maine lobstermen, clam diggers, etc.), and corrosion can also be mitigated with some simple routine preventative maintenance.
Michigan	Yes	http://www.michigan.gov/mdot/0,4616,7-151-9615_30883-93194--,00.html
Montana	Yes	http://www.mdt.mt.gov/publications/docs/forms/citizen_incident.pdf
New Hampshire	Yes	We have a salted well program where if a well tests at a higher that acceptable level for 12 months straight they will have a well replaced by the department.
New York	Yes	https://www.dot.ny.gov/divisions/legal-services-division/smallclaims
North Dakota	Yes	We have a Risk Management division which handles all claims.
Ohio	Yes	www.dot.state.oh.us/damagereport/Pages/default.aspx
Pennsylvania	No	
South Dakota	No	
Utah	Yes	Same process as used for other claims and torts.
Virginia	Yes	http://www.virginiadot.org/vtrc/main/online_reports/pdf/04-r30.pdf
Washington	Yes	http://des.wa.gov/services/Risk/claims/Pages/standardTortClaims.aspx
West Virginia	Yes	http://www.legis.state.wv.us/Joint/Court/claim_instructions.pdf
Wisconsin	No	
Wyoming	Yes	Contact WY State Risk Management.

23. Has your agency detected an increase in wildlife-vehicle collisions due to the use of salt or salt brine on roadways?

23a. If you answered Yes to question 23, please indicate the approximate percentage increase in wildlife-vehicle collisions and the time frame during which the change was detected.

23b. If you answered Yes to question 23, please indicate the wildlife species involved (one or more).

The two affirmative responses appear below**.**

Maine While we recognize that wildlife like and need salt, our crash data shows that moose collisions are at their highest levels in May and June and deer collisions are highest in November. The winter months tend to have the lowest number of crashes.

Washington The percentage increase in wildlife-vehicle collisions is unknown. The species involved are birds (mostly finches), and bighorn sheep.

Other comments:

Montana We have lots of animal hits but there isn't significant evidence to tie them to using salt.

Utah We track all carcass removal and it does not correlate with salt use or distribution.

Wyoming Did not respond.

24. What steps has your agency taken to minimize the potential for increased wildlife-vehicle collisions due to use of salt and salt brine on roadways?

State	We Have Not Taken Any Specific Steps	Public Education	Draining of Roadside Brine Pools	Use of Additive to Reduce Attractiveness of Salt and Salt Brine to Wildlife
Colorado		X		
Idaho	X			
Iowa	X			
Kansas	X			
Maine				
Michigan		X		
Montana				X
New Hampshire	X			
New York	X			
North Dakota	X			
Ohio	X			
Pennsylvania	X			
South Dakota	X			
Utah		X		
Virginia	X			
Washington		X		
West Virginia	X			
Wisconsin	X			
Wyoming				

Comments related to the use of additives:

Montana GameAway pilot project with North American Salt Company. The results were inconclusive.

Other practices to minimize the potential for wildlife-vehicle collisions:

Maine We've undertaken numerous efforts and safety projects to reduce collisions with wildlife, but they've been focused on the larger issues of wildlife getting into the roadway unseen, as opposed to assuming that salt is a significant cause.

Utah Minimizing salt use, reducing scatter and bounce, eliminating standing water where possible along roadsides within our right of way in environmentally legal ways.

Washington Wildlife bridges in new construction; see http://i90wildlifebridges.org/bridging-futures-2013.

Wyoming WYDOT has installed several wildlife crossing structures. Very large box culverts that allow wildlife to pass under the roadway in location identified by WY Game & Fish as migration routes or problem areas. Added game fencing to the right of way to channel wildlife toward the crossings. Very successful.

25. Does your agency have any completed or in-progress research regarding corrosion from winter maintenance materials, the effectiveness of corrosion inhibitors, the environmental impacts of winter maintenance materials (short- versus long-term impacts, vulnerability of specific habitat types, etc.), or the impact of winter maintenance material usage (not just salt, but also magnesium chloride and corrosion inhibitors) on wildlife-vehicle collisions (including changes in migratory patterns and mortality)?

Colorado All our completed research can be accessed at this link: http://www.coloradodot.info/programs/research.

Maine Those that we fund in part through Clear Roads (www.clearroads.org) and a recent study through the University of Maine (http://mcspolicycenter.umaine.edu/2010/02/19/winterroadmaintfinal/).

Ohio Snow Removal Wastewater Disposal Alternatives; Evaluation and Analysis of Liquid Deicers for Winter Maintenance; Evaluation of the Effectiveness of Salt Neutralizers for Washing Snow and Ice Equipment. Contact Jill Martindale (http://pnsassociation.org/) of the Office of Statewide Planning and Research.

Utah We participate in PNS [Pacific Northwest Snowfighters] studies and support Clear Roads research projects.

Washington See Clear Roads [http://clearroads.org/research-projects.html] and PNS [http://pnsassociation.org/] websites for related research.

Appendix B
Idaho Transportation Department
Winter Information and Research on Deicers

2012/2103 Winter Information

Data from ITD's Transportation Asset Management System (TAMS) showed the following material usage for winter storm maintenance on a statewide basis:

Abrasive Use	Sodium Chloride Use (Liquid & Granular)	Magnesium Chloride Use (Liquid Only)	Calcium Chloride or Potassium Acetate Use
89,070 Tons	62,700 Tons	5,201 Tons	0 Tons
58%	41%	1%	0%

This breakdown of material usage on a District by District basis is as follows:

District	Granular Salt (Tons)	Liquid Sodium Chloride Brine (Gallons)	Liquid Magnesium Chloride (Tons)	Anti-Skid/Salt Added (Tons)	Anti-Skid (Tons)
D1 – Coeur d'Alene	12,128	1,210,329	0	415	695
D2 – Lewiston	884	0	3,315	6,034	15,785
D3 – Boise	8,503	0	1,858	14,950	14,550
D4 – Shoshone	2,206	34,534	27	24,879	3,248
D5 – Pocatello	17,815	1,055,092	0	934	1,838
D6 – Rigby	1,152	726,634	0	18,436	3,715

As with the geographical location of the Districts and their respective climates, application rates also vary by District and within the District depending upon the severity of the storm and the timing of the application. In general terms, application rates for granular salt are 125 to 150 lbs/lane mile. However, depending upon the storm severity and the predicted amount of snowfall, application rates as low as 50 lbs/lane mile have been used and as high as 300 lbs/lane mile in areas forecasted for heavy snow. The application rate is dependent upon the lap time associated with the particular route and geographical location. Lap time refers to the amount of time that passes between applications during the storm event. In more urban areas, shorter lap times are present while in more rural areas, lap times increase and the application rate will increase accordingly.

Liquid chemical application rates are not as variable on a statewide basis. Our typical rate for both sodium chloride and magnesium chloride is 20 to 25 gallons/lane mile. Again, this rate is variable based on the predicted storm event and lap time associated with the particular route. ITD trucks have the ability to apply liquid chemicals as high as 50 gallons/lane mile, but reviewing automated snowplow data has shown that this does not occur except in very rare occasions.

Anti-skid application rates are most dependent upon the anti-skid to salt ratio chosen by the District as this also varies. Districts 1, 4, and 5 use a typical 1:1 ratio blend of anti-skid and salt. Districts 3 and 6 use a 3:1 ratio and the District 2 ratio averages out to 4:1. Since salt is the active ingredient for melting snow and ice in a anti-skid/salt added product, the application rate for this product is dependent upon the ratio and desired amount of salt on the roadway. As stated above, typical application rates for granular salt are targeted at 150 lbs/lane mile, so at a 1:1 ratio, the typical application rate is 275 to 300 lbs/lane mile. As the ratio of salt is reduced within the blend, the application rate of the product goes up. Application rates for straight anti-skid vary depending upon the circumstances in which the product is used. However, for curves, hills, and shady spots, an application rate of 800 lbs/lane mile are normal.

ITD has implemented various technologies to allow us to evaluate the success our of our winter maintenance processes as well as the effort associated. Based on these technologies and the data that is generated, the products selected for use is shifting. Several years ago, the use of anti-skid with vary small quantities of salt added was standard. In the late 90's the use of chemicals was implemented in certain areas of the state to address specific safety issues. As we learned the value of chemicals and evaluated the results of their use, we have been transitioning from the use of anti-skid to a greater use of chloride chemicals for our winter maintenance operations and have found that the use of liquid sodium chloride brine is a more efficient product than granular salt in terms of reducing ice. The transition is expected to continue, however, changing weather patterns will also require us to evaluate our product selection. As an example, in District 1, recent cold weather events have rendered chlorides ineffective, resulting in the need to anti-skid abrasives to address safety concerns.

The first liquid chemical product used by ITD was corrosion inhibited magnesium chloride. Although this product worked well, the high unit cost of $0.95/gallon required ITD to look at other alternatives for liquid deicers. Based on the experience of many other states, ITD began manufacturing and using liquid sodium chloride brine in areas of the state in which winter temperatures made this a useable product. The transition to sodium chloride brine has proven beneficial as well as economical as ITD can manufacture and deliver this product for approximately $0.25/gallon. The low cost and effective results of this product have contributed to the increased use of this product statewide.

The use of liquid materials, both magnesium chloride and sodium chloride, has allowed ITD to be more proactive in responding to winter storms. Experience has shown that by using chlorides and applying them just before a storm, ice and snow accumulation can be significantly reduced and often eliminated. During more severe storms, this practice of pre-treating has resulted in reduced ice duration on roadways as the chloride reduces the ability of the ice to bond with the roadway.

Another benefit of liquid chemicals is the reduced time for the chemical to react and begin melting ice. For this reason, ITD employs a practice of pre-wetting granular material with either liquid magnesium chloride or sodium chloride. The wetted granular material will cause an immediate melt reaction trapping the granular material in a solution or refreezing on the roadway allowing the product to continue to work and provide safety benefits. Prior to the use of this pre-wetting strategy, granular materials were easily blown from the roadway, rendering them ineffective at providing improved safety.

ITD has seen a dramatic shift in the manner in which we respond to winter storm events. Historical practices were reactionary in nature and only included plowing and applying anti-skid materials. Current response efforts are now proactive and include the various materials discussed here. In addition to these efforts, ITD is also utilizing technology to improve our winter response procedures. We have an extensive Road Weather Information System (RWIS) that provides information and pictures regarding the condition of roadways at 100 sites within the state. We are now leveraging the data from these sites to provide information regarding the results of our winter response efforts. This has led ITD to better understand how the procedures and products we use provide for safer highways. The next phase of this technology based response is the automated collection of spreader data from our snowplow/spreader/deicing trucks. We are in the beginning phase of deploying mobile data collectors on trucks coupled with GPS data to better understand how and where we are distributing products. The combination of these two technologies allows us to know what we did to a highway in response to storms as well as the results achieved. Through the evaluation of the data this technology is providing, ITD will become more efficient in the use of various winter products and the expected results of these products.

ITD has taken the necessary precautions to insure that the products used for winter response are stored in the appropriate manner. All stockpiles of salt are covered to insure that run off from the salt pile does not contain the chloride product. The majority of anti-skid products, including those containing salt, are also covered. For those few stockpiles that are not covered, the appropriate precautions have been taken to insure that run off from these sites does not leave ITD property nor leach into the ground upon which the pile is stored.

ITD Research on Deicers and Corrosion Inhibitors

ITD has been at the forefront of specification development for chemical product deicers and corrosion inhibitors since the early 1990’s. Idaho along with other key northwest states and Canadian provinces founded the Pacific Northwest Snowfighters (PNS). The PNS established specifications for individual product categories and corrosion inhibitors, and developed a Qualified Products List (QPL). The heart of the PNS mission is to evaluate products for their use in winter maintenance practices that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness and performance.

Idaho has only purchased chemical deicer products for the statewide winter maintenance program from the QPL of the PNS since the group formed. Additionally, ITD routinely samples product deliveries and test them to the chemical specification requirements which include not only chemical product specific characteristics but also environmental impact parameters. Products that are not compliant to the specifications receive a price adjustment or are rejected based on the severity of the product deviation.

Liquid corrosion inhibited products are purchased according to a Best Buy program. The PNS standard for an acceptable corrosion inhibited product is that the product will be at least 70 percent less corrosive than salt. The program established a cost per ton based on the highest concentration of liquid salt in the material, and awards points for products that provide better corrosion inhibitor protection.

The end goal is to purchase a product that will provide the best chemical performance and also provide the best corrosion protection.

ITD working with the Idaho Trucking Association pinpointed the need to address more corrosion protection with the use of magnesium chloride over ten years ago. In agreement between both parties ITD agreed to contract for magnesium chloride that contained a corrosion inhibitor that was at least 75 percent less corrosive than straight salt. Currently, the corrosion inhibited magnesium chloride product purchased by ITD is more than 85% less corrosive than straight salt and has a product concentration of 30 percent.

The PNS continues to develop corrosion inhibitor categories based on types of salt brine based deicing materials and types of corrosion inhibitors. ITD is currently in the process of conducting a research study in northern Idaho using a corrosion inhibitor that maintains a high concentration of salt brine for performance, and is also one of the most environmentally acceptable. The 2013-2014 winter season will provide preliminary results to the effectiveness of the product to provide corrosion inhibition in the field, and also provide data regarding the performance of the product regarding chemical performance.

Idaho is a current member of the Clear Roads, which consist of 27 states across the US. The group directs research pool fund studies regarding winter highway maintenance. The PNS and Clear Roads have joined forces to provide the best information back to state agencies regarding chemical selection, practices, environmental impacts, cost benefit analysis, and many more items. Idaho is committed to achieving the departmental strategies of safety, mobility and economic opportunity.