Clear Roads Study

Establishing Effective Salt and Anti-icing Application Rates

Summary Report

Task 2: Update Guidelines

MnDOT Contract No. 02000
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Submitted by

Blackburn and Associates
16545 E. Fairfax Dr.
Fountain Hills, AZ 85268

Preface

The work reported in this document on application rates of traditional and new chemical blends would not have possible without the vision and leadership provided by Duane E. Amsler, Sr. His role in formulating a realistic and simplistic approach toward the development of chemical application rate information for winter maintenance personnel is justly recognized. Without Dewey's help, this work would not have been possible. Dewey passed away unexpectedly on June 18, 2014 from surgery complications. He is deeply missed and the memory of his simplistic approaches toward solving winter maintenance problems will live on for some time.

Summary of Task 2 Findings

1.0 Introduction

This report contains a brief summary of the Task 2 activities and findings for MnDOT Contract No. 02000 dealing with "Establishing Effective Salt and Anti-icing Application Rates." The Task 2 work, identified collectively as the updating of guidelines, involved a number of activities. These included:

1) Assembly and organization of interview results from Task 1 and established research or other documents related to chemicals used for anti-icing and deicing operations;
2) Review of application rate guidelines used by highway agencies for various winter weather event types and pavement conditions;
3) Development of updated application rate guidelines for use of sodium chloride (NaCl) during winter maintenance operations;
4) Development application rate guidelines for use of chemicals other than NaCl; and
5) Investigation of the relative cost of chemicals used during winter maintenance operations as a point of comparison between chemical categories.

The ultimate goal of Task 2 is to refine and expand the recommended application rates in the National Cooperative Highway Research Program (NCHRP) Report #526 with a simple as possible approach considering pavement type, pavement temperature, adjusted dilution potential, and cycle time for a range of chemical types. The influence of weather patterns, storm type or scenarios, and site characteristics are to be treated as classifying elements in the recommended application rate tables.

This summary report is divided into six main sections following this introduction. Section 2 presents an overview of the liquid and solid chemicals used by the surveyed highway agencies. Section 3 provides a review of chemical application rate guidelines used by highway agencies. Section 4 describes the development of the updated application rate guidelines for NaCl. Section 5 describes the development of application rate guidelines for chemicals other than NaCl. Section 6 presents the result of an investigation into the relative cost of chemicals used in winter maintenance operations. Finally, Section 7 provides a summary of the Task 2 activities and findings.

2.0 Liquid and Solid Chemicals Used by Highway Agencies

In Task 1, a total of 37 North American winter maintenance experts were identified for purposes of interviewing them regarding the anti-icing and deicing materials they have used and their experiences with those products. The responses from 32 of the 37 experts provided an insight into the diversification of material used. The summary Report for Task 1 attempted to tabulate, in Appendix D of that report, the liquid and solid material reported. Those data were re-examined and a more complete tabulation was made of the liquid and solid chemicals used by highway agencies during winter maintenance operations. The liquid chemicals used are given in Appendix Table A-1 and solid chemicals are given in Appendix Table A-2 of this report.

The liquid snow and ice control chemicals used by the responding highway agencies are subdivided by: common brine chemicals (e.g. NaCl, $MgCl_2$, $CaCl_2$) without a corrosion inhibitor; other liquid chemicals that are commercially produced without an inhibitor; liquid chemicals that are commercially produced with an inhibitor; liquid chemicals that are blended with an inhibitor by the highway agencies; and commercially produced organic inhibitors that are used by the highway agencies. A “1” placed in an agency row under a particular chemical indicates that agency used the chemical in its snow and ice control operations. Some agencies use a wide variety of liquid chemicals while other highway agencies make use of a limited number of liquid chemicals.

The most common liquid chemical used by the surveyed highway agencies is NaCl brine (see Table A-1). The next three liquid chemicals most commonly used are $MgCl_2$, $CaCl_2$, and KAc. Liquid $MgCl_2$ is extensively used in blends with corrosion inhibitors. The liquid chemicals, both with and without inhibitors, used by the agencies for pre-wetting are also given in Table A-2. Again a “1” placed in an agency row under a particular chemical indicates that agency uses the chemical in its snow and ice control operations.

The solid snow and ice control chemicals used by the responding highway agencies are given in Table A-2 and are subdivided by common solid chemicals without an inhibitor and those solid chemicals that are commercially produced with an inhibitor. The most common solid chemical used by the surveyed highway agencies is rock salt (solid NaCl) as shown in Table A-2. The next two most commonly used solid chemicals are $CaCl_2$ and Ice Slicer, which is predominately NaCl. Solid CMA is used by only one of the surveyed highway agencies.

3.0 Review of Available Chemical Application Rates Guidelines

The responses received from the surveys of the highway agencies and chemical manufacturers/vendors were entered into two separate databases during the Task 1 activities. Each database was searched in Task 2 and subfiles were generated that pertain to:

- ❖ Application rates for specific chemicals used by the highway agencies and rates recommended by the manufacturers for their products;
- ❖ Pavement temperature range recommended by the manufacturers of various liquid and solid chemical products; and
- ❖ Minimum operation pavement temperatures reported by the highway agencies for applying specific solid, prewetted solid, and liquid chemicals.

With the exception of a few responses from the highway agencies, very little specific information was obtained concerning chemical application rate usage for operating conditions. The information was too general for use in modifying the application rates specified in the NCHRP Report #526.

The application rate information provided by the chemical manufacturers was even less specific than that provided by the highway agencies. The manufacturers would only provide a range of liquid and solid chemical application rates for general winter maintenance operations such as anti-icing, deicing, or prewetting without regard to pavement temperature or type of precipitation event. The rates provided by the manufacturers gave the impression it was up to the highway user to find out from trial and error what worked the best. The marketing ads and brochures provided by the chemical manufacturers relied heavily on testimonials of agencies that used their products under non-controlled and ill-defined operating conditions.

Both the highway agencies and chemical manufacturers did have a feel for the minimum pavement temperature, or temperature range, which is appropriate for specific liquid and solid chemicals. The data obtained from both sources regarding the minimum pavement temperature for chemical applications are tabulated in Appendix Tables B-1 and B-2 by specific chemical and reporting source. Table B-1 provides data for liquid chemicals and Table B-2 provides data for solid chemicals. An application frequency tabulation is given in Table B-3 for the minimum pavement temperature reported for applications for NaCl, $MgCl_2$, $CaCl_2$, and KAc brines plus two solid chemicals. It is interesting to note the lack of agreement among the users and vendors on the minimum pavement temperature cutoff for the use of the chemicals identified.

Chemical application rate guidelines provided by some highway agencies as supplements to the returned questionnaire yielded better and more specific information than just the answers to the questions. Many of these guidelines were similar to the format used in the FHWA Manual of Practice. That is, the example guidelines provided specific application rate information for different pavement temperatures and weather conditions (events). In addition, maintenance notes were also provided to aid in the chemical application process. The chemicals considered in these guidelines were restricted to solid NaCl, prewetted solid NaCl, and NaCl brine.

Only one highway agency was found to use the chemical application rate guidance given in the NCHRP Report #526. This sole highway agency was using the guidance in the NCHRP report because the material had been used in a training program provided some time ago by one of the project team members.

4.0 Development of Updated Chemical Application Rate Guidelines

Safe highway travel in cold climates depends on preventing or removing the accumulation of ice and snow on the road surface, and maintenance crews rely on a combination of chemical and mechanical techniques to do so. Experience demonstrates that treatment of the roadway with chemicals before and during the initial stages of a precipitation event facilitates later mechanical clearing of accumulated ice and snow. Even in locales that seldom experience snowfalls, travel can become treacherous when frosting or icing of roadway surfaces occurs with sudden drops in temperature. This section reviews and updates current practice recommendations for chemical applications, especially, the use of sodium chloride, NaCl, used for anti-icing and deicing winter maintenance operations.

During the process of updating the chemical application rate guidance in the NCHRP Report #526, it was decided to pattern the presentation of the material after the approach given in the FHWA Manual of Practice. That approach provided suggested application rates for a range of pavement temperatures during given precipitation or icing events. This type of format appears to the more acceptable to winter maintenance personnel than the application rate format given in the NCHRP report. In addition, it was decided the update development would start with NaCl, the most common chemical used in snow and ice control operations. The extension of the guidance to other snow and ice control chemicals would then be determined relative to that of NaCl application rates and its format of presentation.

An application rate comparison sheet was developed for hand tabulating all the data collected from various sources for solid and prewetted solid NaCl applications. The sheet provided a convenient way of comparing the NCHRP rates and those in the Manual of Practice with current practice rates. The rates were tabulated for a range of winter weather events (light snow, moderate snow, heavy snow, freezing rain, sleet, and frost/black ice) as a function of pavement temperature.

The NCHRP rates for the various winter weather events were computed using the adjusted dilution process described in the NCHRP Report #526. This process adjusts a base application rate for both anti-icing and deicing operations to account for traffic volume, cycle time and road surface conditions.

The application rate comparison approach permitted the use of a common pavement temperature band across the various winter weather events. This feature was not possible in the application rate tables given in the Manual of Practice. The use of a common pavement temperature band across the various winter weather events will greatly benefit the format of simplified cab cards to be developed in Task 3.

Finally, insufficient data were available from various sources to distinguish chemical application rates for different pavement types such as Portland Cement Concrete and asphaltic concrete.

The results of the comparisons showed that the NCHRP rates for solid sodium chloride were in line with current practice. The comparisons also revealed the application rates recommended by the Manual of Practice for light snow events were less than they should be for all pavement temperature bands. There was a strong belief during the development of the FHWA Manual of Practice that an application rate of about 100 lbs/lane-mile should be adequate for anti-icing operations during light snow events, especially in the pavement temperature band of 20 to 32^{o} F. This belief was based primarily on European experience that used close observations of pavement conditions and relatively short maintenance cycle times.

The determination of the chemical application rates for anti-icing and deicing operations using sodium chloride was based on the previous discussion plus some presentation simplification. The recommended application rates for dry, prewetted solid and liquid sodium chloride are given in Tables C-1 through C-6 of Appendix C as a function of pavement temperature bands and various winter weather events. The rates are given for both pretreatment of road surfaces as well as for within-event conditions. The winter weather events considered for pretreatment conditions include;

- Snow
- Frost/Black ice
- Freezing rain
- Sleet

The events considered for within-event treatment conditions include;

- Snow
    - Light
    - Moderate
    - Heavy
- Frost/Black ice
- Freezing rain
    - Light
    - Moderate
    - Heavy
- Sleet
    - Light
    - Moderate
    - Heavy

The pretreatment application rates in Tables C-1 and C-2 are for anti-icing operations and replace the values given in the Manual of Practice under what was called "Initial Operations." These rates were determined from pretreatment experiences of various highway agencies involved with anti-icing operations and do not depend upon the rate of precipitation of the event anticipated.

The application rates for within-events replace the values given in the Manual of Practice under what was called "Subsequent Operations." The rates in Tables C-3 through C-6 are given for both anti-icing and deicing operations. The rates for deicing operations are limited to 525 lbs/lane-mile. The adjusted dilution process described in the NCHRP Report #526 was used to compute the rates for the various winter weather events. The definitions of the various winter weather events in Table C-1 through C-6 are given in Appendix D.

Maintenance action notes are given in each table where appropriate to guide the maintenance field personnel in their anti-icing and deicing operations.

The units of the solid NaCl rates in Table C-1 through C-6 are in lb/lane-mile. The units of the liquid NaCl rates in the tables are in gal/lane-mile. The liquid NaCl rates were determined from the associated solid rates by dividing the weight in pounds by 2.3 lb/gal which is the weight of NaCl in one gallon of solution at 23% concentration.

5.0 Development of Application Rate Guidelines for Chemicals Other NaCl

This section of the report presents the development of application rate guidelines for chemicals other than NaCl. The first subsection provides a chemistry 101 version of the freezing of water and melting of ice. The next subsection deals with interpretation of the phase diagrams of snow and ice control chemicals. The following subsection discusses the application of phase diagram data to winter road maintenance. This is followed by a discussion of other chemicals used for winter road maintenance.

5.1 Chemistry 101 Version of the Freezing of Water and Melting of Ice

It has been known for a long time that the freezing point of water is lowered or depressed when chemicals are dissolved in the water. Similarly, it is common knowledge that solids such as sodium chloride (NaCl or rock salt) spread atop of a layer of ice or snow, and in the presence of moisture, results in melting, even when the road temperature is below 32° F, the normal freezing point of water. These simple observations form the basis for employing chemical treatment of highway surfaces. Over the past decade or so numerous new chemical agents have been introduced to complement, supplement, or replace the traditional salts such as sodium chloride (NaCl), calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). Before selecting a chemical, developing application rates, or evaluating new products, it is helpful to understand how and why *any* chemical treatment can affect freezing of water and melting of ice.

Because water (H_2O) is a substance essential to life that people are accustomed to handling, it is easy to forget that this common chemical has some uncommon properties. For example, the oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2) making up air all have about the same chemical mass as water, yet these materials exist as gases even when cooled to temperatures far below those that humans encounter in nature. The individual molecules of O_2, N_2 and CO_2 all behave as small non-interacting spheres separated by relatively large distances from each other. In contrast, H_2O molecules do interact readily with each other, much like partners in a square dance. This creates a "web" of rapidly forming *and* breaking links between individual molecules (or dancers) that keeps them in close proximity to each other, but moving fluidly. (Chemists refer to these linkings as hydrogen bonds.)

As the temperature of pure water approaches 32°F, the speed at which individual molecules jostle about and exchange "dance partners" slows down greatly. At the freezing point, the individual water molecules become linked together by hydrogen bonds in a hexagonal lattice, and they stop moving about freely: crystals of ice form. When most liquids freeze, the individual molecules pack together more tightly and the solid is more dense than the liquid. But in the case of ice, the H_2O molecules are spaced further apart than in the liquid form—ice is less dense than liquid water and floats on top of the liquid.

This simple model of freezing water helps explain both how dissolved chemicals can change the freezing point and why once ice forms it can be so hard to dislodge it from the pavement. Traditional road chemicals such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), as well as potassium acetate (KAc) and calcium magnesium acetate (CMA) are composed of collections of oppositely charged particles that separate from each other when dissolved in water. Thus, NaCl, $MgCl_2$ and $CaCl_2$ all dissolve in water to release negatively charged ion of Cl^- and a positively charged ion (Na^+, Mg^{2+} or Ca^{2+}). KAc and CMA similarly separate into positive and negative ions.

Water molecules have a high affinity for interaction with ionic particles; cations like Na^+, K^+, Ca^{2+} and Mg^{2+} interact with the oxygen atom of H_2O, while anions such as Cl^- interact more strongly with the hydrogen atoms of water. More important, these interactions between ions and water molecules disrupt the formation of the hexagonal ice crystal lattice at 32°F, and consequently, freezing occurs at a lower temperature. The freezing process creates pure ice (solid water) and a brine (water solution of a chemical). Since melting and freezing occur at the same temperature (but differ in the direction of heat flow), adding chemicals to snow and ice can result in melting even below 32° F.

Similarly, the surfaces of materials containing "charged" groups will be attractive to water—and when the liquid freezes the "ice bond" to the pavement is formed. For this reason, creation of a brine on the roadway surface *before* freezing occurs (anti-icing) makes the later removal of accumulating ice and snow easier.

5.2 Interpreting Phase Diagrams

How much the freezing point is lowered depends on both the identity of the chemical substance and its concentration in the brine formed, as illustrated by the three phase diagrams in Figure 1.

- ❖ The smaller inset graph shows the general appearance of most phase diagrams. The region marked "solution" displays the combinations of temperature and composition over which only liquid brine exists.
- ❖ The lower region at left marked "Solution + ice" describes the temperature-concentration ranges over which both ice and liquid brine exist.
- ❖ The horizontal dotted line falls at the "eutectic temperature"—below this temperature there is no liquid, only mixtures of solid ice and solid salt exist.
- ❖ The area to the right labeled "Solution + Salt" describes temperature-composition combinations at which solid excess salt and liquid brine coexist, with no ice present.

Typically, one "leg" of the V-shaped phase diagram is more relevant for purposes of highway maintenance, and that is the curve dividing the "Solution + ice" region from the "solution" section, on the left of the phase diagrams in Figure 1. The other "leg" involves impractical quantities of chemicals for road treatment, except possibly, for $MgCl_2$.

The phase diagrams for NaCl-H_2O and $CaCl_2$-H_2O mixtures in the major portion of Figure 1 clearly demonstrate that freezing point depression depends upon the specific chemical used. Both salts produce similar freezing point depression behavior over the 32-15° F range. At lower temperatures, additional $CaCl_2$ (% by weight) lowers the freezing point more than NaCl−notice the left curve slopes downward more rapidly for calcium chloride. Very noticeably, the lowest temperature at which a liquid brine of NaCl exists (23% by weight NaCl) is about -6° F compared to the $CaCl_2$ brine (32% $CaCl_2$) that does not freeze until -60° F.

In Figure 2, phase diagrams for the most common chemicals (NaCl, $CaCl_2$, $MgCl_2$, KAc, and CMA) are all plotted on a common axis for easier comparison of their potential effectiveness in lowering the freezing point. It is apparent that:

a) NaCl, $CaCl_2$, and $MgCl_2$ are *approximately* equally effective in lowering freezing point between 32° F and about 15° F;

b) below 15° F both $MgCl_2$ and $CaCl_2$ cause a larger relative freezing point depression than NaCl, with $CaCl_2$ causing the greatest lowering; and

c) KAc and CMA produce a smaller lowering of the freezing point than NaCl, $MgCl_2$, and $CaCl_2$ in the 15°-32° F range.

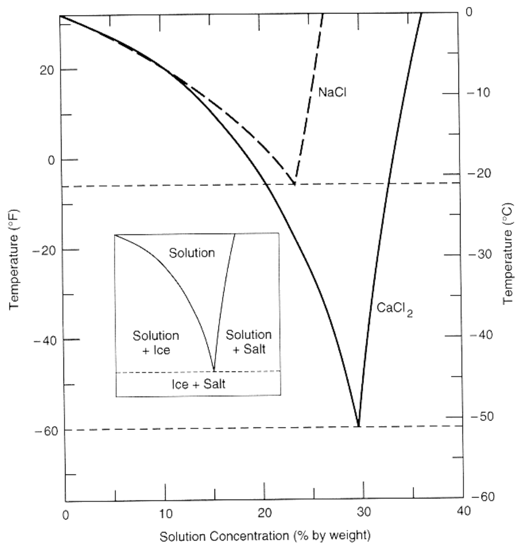

Figure 1: General phase diagram (inset) and curves for NaCl-H_2O, $CaCl_2$- H_2O

Source: Manual of Practice for An Effective Anti-Icing Program, **Publication Number: FHWA-RD-95-202, June 1996.**

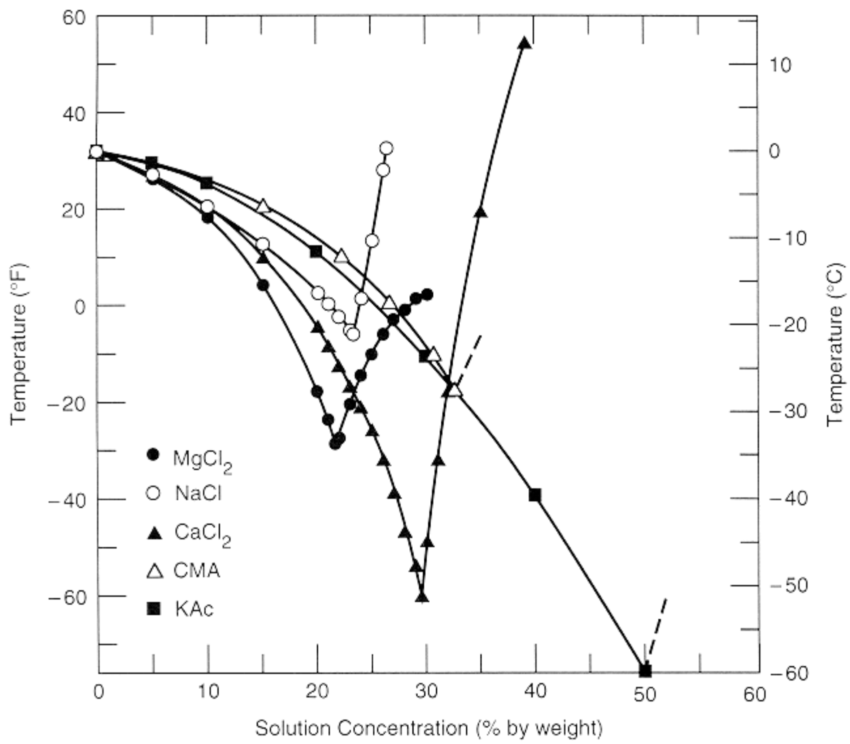

Figure 2: Phase diagram for chemicals used in de-icing and melting

Source: Manual of Practice for An Effective Anti-Icing Program, **Publication Number: FHWA-RD-95-202, June 1996.**

Accessed at http://www.fhwa.dot.gov/publications/research/safety/95202/005.cfm

It is important to understand the meaning and limitations of phase diagrams in order to use them in making choices of chemicals for winter road maintenance. Phase diagrams are obtained in controlled laboratory conditions in which the solid phase (ice) and liquid phase (brine) are mixed thoroughly, maintained at constant temperature, and not subject to further dilution. Unless specified otherwise, the phase diagram is determined for a single substance. It is incorrect to conclude that mixtures containing significant amounts of two or more chemicals behave as predicted by a composite of the individual phase curves.

The composition axis of a phase curve describes the concentration of the brine layer when looking at the "solution + solid" side of the curve (the "left leg" of the curves in Figures 1 and 2). At constant temperature without dilution, the presence of excess solid salt has no influence on the freezing point depression. Indeed, a phase diagram does not indicate how quickly a solid chemical will melt ice or the brine will refreeze. The graph reports only the temperatures at which both solid ice and a liquid brine can coexist without reference to how the brine was formed.

It also may be tempting to compare various chemicals according to their ultimate eutectic temperatures, but with respect to winter road maintenance, the relative downward slope of the curve between 32° F and 0° F better reflects the effectiveness of the chemical in altering freezing point. For example, Figure 2 indicates that KAc forms a brine with a eutectic temperature of almost -70° F; however, the downward slope of the KAc curve is more shallow than for other chemicals, and as a result a much greater amount of chemical must be applied.

5.3 Application of Phase Diagram Data to Winter Road Maintenance

Phase diagrams accurately report the freezing point depression of a brine solution in contact with ice independently of any chemical theory about *how* the chemicals do this. That is, phase diagrams are not theoretical, but practical tools. However, it is also important to recognize that laboratory phase diagrams do not reflect the real-world conditions under which chemicals are applied to the highway surface: the temperature of the road surface and air/precipitation in contact with the road are not consistently the same, nor are the chemicals and ice/snow/brine uniformly mixed as in the laboratory. The road surface contains dust and chemical residues that are also soluble in water that contribute to the overall depression of the freezing point. Environmental conditions on the roadway are changing, unlike those in the lab: dilution occurs from additional precipitation, melting and re-freezing induced by friction from passing vehicles occurs, and any brine that is formed can drain from contact with the road surface or be lost during plowing operations.

In the past, suggested application rates for chemicals have been proposed based on calculations using phase diagram data as in the final report for NCHRP Project 6-13. However, when a comparison was made between the actual in-practice application rates used for NaCl (solid or brine) and those resulting from theoretical approaches, the calculated values were minimally twice as large as those used in the field or even exceeded the amount of chemicals that are ever applied in practice. Thus, application rates based on phase diagram data must be considered "with a grain of salt" (pun intended). Even so, there is merit in considering what can be learned from the graphs.

The approach taken in this project recognizes that workable, field-tested, practical data is often obtained by experience without reference to theory. For that reason, the research team consulted with numerous highway and transportation departments as well as chemical vendors to arrive at what collective wisdom suggests represents current best practice with solid and liquid NaCl under various weather conditions. Sodium chloride remains the most widely available and potentially, cost-effective chemical for winter road maintenance, so the research team focused on determining current best practices for NaCl application rates as the starting point for examining other chemicals.(See Section 4). For several good reasons to be discussed later other chemicals have been found to be useful replacements or supplements for NaCl.

Once application rates for sodium chloride were established, data tables of freezing point versus composition (in weight % or specific gravity) were used to determine equivalent application rates for $CaCl_2$, $MgCl_2$, KAc, and CMA. Based on our survey of highway maintenance units, chemical treatment is usually undertaken within the 32°-0° F range. Accordingly, data from multiple scientific and technical sources were compiled, and plots of composition versus freezing point temperature over 32°-0° F were mathematically fitted to second order polynomial equations. Figure 3 shows the result of such a plot for NaCl, $CaCl_2$, and $MgCl_2$.

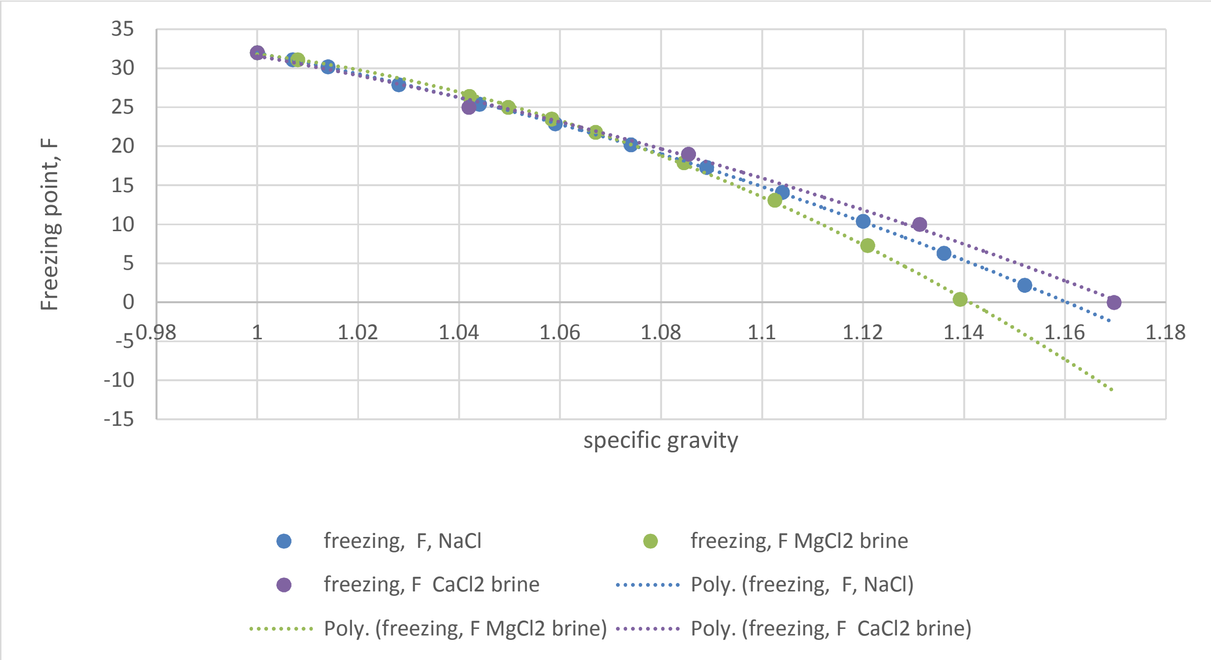

Figure 3: Freezing temperature versus brine concentration at 32°-0° F for three salts

Note: colored dots represent real data points; the dotted lines are the result of fitting the data to a second order polynomial (equations not shown)

For each temperature it was then possible to calculate the associated brine concentration of each salt relative to NaCl. Data for KAc and CMA were treated similarly. This approach makes it possible to compare whether more or less concentrated brine solutions compared to NaCl are needed to achieve a given freezing point depression for a specific chemical. The results are tabulated in Table 1.

Table 1: Application rates for various brine solution expected to give the same freezing point depression as NaCl

Pavement Temperature °F	Solid NaCl, lb/LM	23% NaCl liquid, gal/LM	Solid 90-92% $CaCl_2$, lb/LM	32% $CaCl_2$ liquid, gal/LM	Solid 100% $MgCl_2$, lbs/LM	27% $MgCl_2$ liquid, gal/LM	Solid 100% Kac, lb/LM	50% Kac liquid, gal/LM	Solid 96% CMA, lb/LM	25% CMA liquid, gal/LM
31-32	100	44	110	31	90	32	168	32	170	18
26-30	100	44	110	31	90	32	168	32	170	18
21-25	100	44	110	31	93	33	154	29	160	17
16-20	100	44	107	30	88	32	140	26	150	16
11-15	100	44	103	29	85	30	130	24	150	16
6-10	100	44	103	29	83	29	130	24	140	15
Below 5										

Note: 44 gallons/LM of 23% brine contain the same amount of NaCl as 100 lbs/lane-mile solid NaCl

As explained earlier, the phase diagrams report the composition of the liquid mixture (water + chemical) that is in equilibrium with ice at each temperature. When working with the left "leg" of the phase diagram that describes "ice + solution", only the chemicals which are dissolved at a particular temperature can affect the freezing point. Because solid NaCl has been traditionally the most commonly used chemical for winter road maintenance, it was chosen as the reference. We emphasize that the left leg of the NaCl-ice phase diagram (and for other chemicals presented in the same way) is therefore describing what happens once enough melting has occurred to form a dilute NaCl brine.

In order to construct Table I, the freezing point data for NaCl, $CaCl_2$, $MgCl_2$, KAc and CMA were plotted on a common temperature versus liquid composition curve. Then, a non-linear polynomial equation was used to find the best-fit line connecting each set of data points over the 0°-32° F range. As a result, it was possible to compare the exact liquid solution composition for each chemical at the same temperature.

In the 32°-26° F range, the freezing point depression versus composition (in weight % or specific gravity units) the curves for NaCl, $CaCl_2$ and $MgCl_2$ are nearly identical, with $MgCl_2$ resulting in at most 10% more temperature depression than the other two. Operationally, this implies that the relative effectiveness in lowering the freezing point (NaCl/$CaCl_2$/$MgCl_2$) is close to 1/1/0.9 once the chemical has dissolved. If we further take into account that commercially available $CaCl_2$ is 90-92% by weight, this leads to the assignment of relative application rates in Table I of 100 lbs NaCl = 110 lbs $CaCl_2$ = 90 lbs $MgCl_2$. These dry weight application rates can be converted to liquid application rates delivering the same contained amount of chemical by taking into account the specific gravity (density) and weight percent composition of each substance.

For instance, 100 lbs NaCl x (100 lbs NaCl solution/23 lbs NaCl) x (1 gal NaCl solution/9.79 lbs) = 44 gals of 23% NaCl brine. Also, 100 lbs $CaCl_2$ x (100 lbs $CaCl_2$ solution/32 lbs $CaCl_2$) x (1 gal $CaCl_2$ solution/11 lbs) = 28.4 gals of 32% $CaCl_2$ brine; and conversely, 110 lbs $CaCl_2$ = 31.24 gals of 32% $CaCl_2$ brine.

Finally, 100 lbs $MgCl_2$ x (100 lbs $MgCl_2$ solution/27 lbs $MgCl_2$) x (1 gal $MgCl_2$ solution/10.35 lbs) = 35.8 gals of 27% brine; and conversely, 90 lbs $MgCl_2$ = 32.22 gals of 27% $MgCl_2$ brine.

Turning to KAc and CMA we notice that these track nearly identically to each other in the range 32°-26° F, but result in significantly smaller freezing point depressions than NaCl, $CaCl_2$ or $MgCl_2$. Based on the phase diagrams alone, KAc and CMA thus require about 1.6-1.7 times larger amounts by dry weight than NaCl to achieve the same freezing point depression over 32-26° F. KAc is typically sold as a 50% by weight liquid, while CMA is available for shipping as 96% solid or diluted with water to make a 25% by weight solution.

The following equivalencies were also used: 100 lbs pure KAc = 18.9 gallons of 50% brine, and 100 lbs pure CMA = 104 lbs of 96% CMA = 10.5 gallons of 25% brine.

For each temperature band in Table I similar computations were made among the various chemicals. As indicated by the downward slopes of the respective phase diagrams, the relative effectiveness of the chemicals change as well. Thus, a comparison was made of freezing point versus composition (weight percentage or specific gravity) relative to NaCl. This resulted in the following table of relative factors.

Table 2: Weight Factors for Snow and Ice Control Chemicals
Relative to NaCl = 1 at Various Temperature Bands

Chemical →	90-92% $CaCl_2$	$MgCl_2$	KAc	100%CMA
Temperature band, ° F ↓				
31-32	1.1	0.90	1.68	1.63
26-30	1.1	0.90	1.68	1.63
21-25	1.1	0.93	1.54	1.54
16-20	1.07	0.88	1.40	1.44
11-15	1.03	0.85	1.30	1.44
6-10	1.03	0.83	1.30	1.34

These multipliers convert weight solid NaCl → equivalent weight of other solid chemical.

By way of example, if 100 1bs solid NaCl/LM (lane-mile) is to be used in a particular weather event when the pavement temperature is in the range 16°-20° F, then the equivalent amount of 27% liquid $MgCl_2$ is:

100 lbs NaCl x (0.88 lb $MgCl_2$/lane-mile NaCl) x (35.8 gal liquid $MgCl_2$/100 lbs $MgCl_2$) = 32 gal/lane-mile of 27% liquid $MgCl_2$

Table I is organized to minimize further calculations for end users. For example, if local practice calls for an application rate of 75 lbs solid or pre-wetted NaCl for a pavement temperature of 16-20° F, then the equivalent application of liquid 27% $MgCl_2$ is

75 lbs solid NaCl x (32 gal/lane-mile of 27% $MgCl_2$/100 lbs solid NaCl) = 24 gal/lane-mile of 27% liquid $MgCl_2$.

Some additional commentary on Table 1 is appropriate. Based on the analysis of survey results from highway and transportation departments, the pavement temperature is given in temperature "bands" corresponding to those employed in field treatment guides for road crews. The rates shown are relative to NaCl in units of pounds or gallons of 23% brine per lane-mile. This was done for simplicity in later conversion of specific NaCl application rates in each temperature band. In other words, Table 1 is not recommending absolute application rates, but relative rates that take into account: a) the freezing point depression of each chemical relative to NaCl; b) the change in relative freezing point depression across the temperature bands listed; and c) the percentage composition and density of the brines applied to the road surface.

It should be noted that while 100 lbs solid NaCl contains the same amount of NaCl as 44 gallons of 23% brine, the two forms of salt are not equally effective under all conditions. For example, solid NaCl particles are subject to "bounce and scatter" during spreading operations, leading to a less uniform distribution of rock salt than is achieved by dispersing liquid brine. For this reason, current maintenance practice calls for prewetting solid NaCl to help minimize the bounce and scatter problem when application are made to non-snow covered roadways. The application rates for solids in Table 1 assume the material is prewetted.

The minimum pavement temperature bands for the common snow and ice control chemicals just discussed were used in the construction of the equivalent application rate tables for these chemicals. The minimum pavement temperature bands for each chemical were determined from the information in Section 3.0 and are presented in Tables 3 and 4. Some of the minimum pavement temperature bands for the liquid chemicals were lower than those used for NaCl. The rates in these lower temperature bands were determined by linearly extrapolating the liquid NaCl rates to the lower temperature bands.

Table 3
Minimum Pavement Temperature Bands for Liquid Chemical Application Rates

Treatment	Weather Event	Anti-icing/Deicing	Liquid NaCl @ 23% Concentration	Liquid $MgCl_2$ @ 27% Concentration	Liquid $CaCl_2$ @ 32% concentration	Liquid KAc @ 50% Concentration	Liquid CMA @ 25% Concentration
Pre-Treatment	Snow	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	11° - 15° F	11° - 15° F
	Frost/black ice	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	11° - 15° F	11° - 15° F
	Freezing rain	Anti-icing	26° - 30° F	26° - 30° F	26° - 30° F	26° - 30° F	26° - 30° F
	Sleet	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
Within-Event	Light Snow	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Moderate Snow	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Heavy Snow	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F	16° - 20° F
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Frost/black ice	Anti-icing	16° - 20° F	16° - 20° F	16° - 20° F	21° - 25° F	21° - 25° F
		Deicing	21° - 25° F	16° - 20° F	16° - 20° F	21° - 25° F	21° - 25° F
	Light freezing rain	Anti-icing	21° - 25° F	21° - 25° F	21° - 25° F	21° - 25° F	21° - 25° F
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Moderate freezing rain	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Heavy freezing rain	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Light sleet	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Moderate sleet	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
	Heavy sleet	Anti-icing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended
		Deicing	Not Recommended	Not Recommended	Not Recommended	Not Recommended	Not Recommended

Table 4

Minimum Pavement Temperature Bands for Solid Chemical Application Rates

	Weather Event	Operations	Solid NaCl	Solid $CaCl_2$	Ice Slicer	Solid CMA
Pre-Treatment	Snow	Anti-icing	16° - 20° F	6° - 10° F	6° - 10° F	11° - 15° F
	Frost/black ice	Anti-icing	16° - 20° F	6° - 10° F	6° - 10° F	11° - 15° F
	Freezing rain	Anti-icing	16° - 20° F	11° - 15° F	11° - 15° F	16° - 20° F
	Sleet	Anti-icing	16° - 20° F	11° - 15° F	11° - 15° F	16° - 20° F
Within-Event	Light Snow	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	16° - 20° F	16° - 20° F	16° - 20° F	Over 30° F
	Moderate Snow	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	16° - 20° F	21° - 25° F	16° - 20° F	Not Recommended
	Heavy Snow	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	21° - 25° F	21° - 25° F	21° - 25° F	Not Recommended
	Frost/black ice	Anti-icing	16° - 20° F	6° - 10° F	6° - 10° F	6° - 10° F
		Deicing	16° - 20° F	6° - 10° F	6° - 10° F	6° - 10° F
	Light freezing rain	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	16° - 20° F	16° - 20° F	16° - 20° F	Over 30° F
	Moderate freezing rain	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	16° - 20° F	21° - 25° F	16° - 20° F	Over 30° F
	Heavy freezing rain	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	21° - 25° F	21° - 25° F	21° - 25° F	Over 30° F
	Light sleet	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	11° - 15° F
		Deicing	21° - 25° F	21° - 25° F	21° - 25° F	Over 30° F
	Moderate sleet	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	16° - 20° F
		Deicing	21° - 25° F	26° - 30° F	21° - 25° F	Over 30° F
	Heavy sleet	Anti-icing	11° - 15° F	6° - 10° F	6° - 10° F	16° - 20° F
		Deicing	21° - 25° F	26° - 30° F	21° - 25° F	Not Recommended

Equivalent liquid application rates for $MgCl_2$, $CaCl_2$, KAc, and CMA were computed using the results in Table 1 and those in Appendix C for NaCl. The rates were determined as a function of pavement temperature bands and the various winter weather events considered for NaCl. Also the rates were determined for both pretreatment of road surfaces as well as for within-event conditions. The resulting application rates are given in Table 5 along with a similar tabulation of the liquid rates for NaCl taken from Appendix C.

Equivalent solid application rates for $CaCl_2$, Ice Slicer, and CMA were similarity computed using the results in Table 1 and those in Appendix C for NaCl. Those rates are given in Table 6 along with the application rates for solid NaCl taken from Appendix C. The rates for Ice Slicer are based primarily on those for solid NaCl because the material is 90 – 98% solid NaCl plus smaller percentages of solid $MgCl_2$, solid $CaCl_2$, and solid KCl. In addition the manufacturer claims the phase diagram of Ice Slicer is similar to that of NaCl.

Table 5

Liquid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Events

Pavement temperature, °F, at time of application	Liquid NaCl at 23% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	48	44	55	NR	48	57	66	44	98	48	NR	NR	NR	NR	NR
26 to 30	70	57	76	NR	70	76	83	57	109	74	NR	NR	NR	NR	NR
21 to 25	92	70	NR	NR	87	92	96	70	120	87	NR	NR	NR	NR	NR
16 to 20	109	83	NR	NR	100	105	109	83	NR	NR	NR	NR	NR	NR	NR
11 to 15	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6 to 10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, °F, at time of application	Liquid $MgCl_2$ at 27% concentration - gallons per lane mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	35	32	40	NR	35	42	48	32	72	35	NR	NR	NR	NR	NR
26 to 30	51	42	56	NR	51	56	61	42	80	54	NR	NR	NR	NR	NR
21 to 25	69	53	NR	NR	66	69	72	53	90	66	NR	NR	NR	NR	NR
16 to 20	80	61	NR	NR	73	77	80	61	96	NR	NR	NR	NR	NR	NR
11 to 15	NR	NA	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6 to 10	NR	NA	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NA	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

Table 5 (cont)

Liquid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Events

Pavement temperature, ° F, at time of application	Liquid $CaCl_2$ at 32% concentration - gallons per lane - mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	34	31	39	NR	34	41	47	31	69	34	NR	NR	NR	NR	NR
26 to 30	50	40	54	NR	50	54	59	40	77	52	NR	NR	NR	NR	NR
21 to 25	65	49	NR	NR	62	65	68	49	85	61	NR	NR	NR	NR	NR
16 to 20	75	56	NR	NR	69	72	75	56	89	NR	NR	NR	NR	NR	NR
11 to 15	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6 to 10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, ° F, at time of application	Liquid KAc at 50% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	35	32	40	NR	35	42	32	32	72	35	NR	NR	NR	NR	NR
26 to 30	51	42	56	NR	51	56	61	42	80	54	NR	NR	NR	NR	NR
21 to 25	61	47	NR	NR	58	61	63	47	80	58	NR	NR	NR	NR	NR
16 to 20	65	49	NR	NR	60	62	64	NR	NR	NR	NR	NR	NR	NR	NR
11 to 15	72	53	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6 to 10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

Table 5 (cont)

Liquid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Events

Pavement temperature, ° F, at time of application	Liquid CMA at 25% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	20	18	23	NR	20	24	27	18	41	20	NR	NR	NR	NR	NR
26 to 30	29	24	31	NR	29	32	34	24	45	31	NR	NR	NR	NR	NR
21 to 25	36	27	NR	NR	34	36	38	27	47	34	NR	NR	NR	NR	NR
16 to 20	40	30	NR	NR	37	39	40	NR	NR	NR	NR	NR	NR	NR	NR
11 to 15	48	35	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
6 to 10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

Table 6

Solid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Weather Events

Pavement temperature, °F, at time of application	Solid NaCl Application Rates - pounds per lane-mile																							
	Pre-Treatment *				Within-Event **																			
	Snow	Frost/Black Ice	Freezing rain	Sleet	Light Snow		Moderate Snow		Heavy Snow		Frost and Black Ice		Light freezing rain		Moderate freezing rain		Heavy freezing rain		Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	110	100	125	120	110	240	130	265	150	290	100	225	110	240	130	265	150	290	130	265	145	290	165	320
26 to 30	160	130	175	175	160	350	175	375	190	400	130	250	170	350	180	375	190	400	175	385	195	410	210	440
21 to 25	210	160	225	230	200	425	210	450	220	475	160	275	200	425	210	450	220	475	220	465	230	500	240	525
16 to 20	250	190	275	275	230	500	240	525	250	NR	190	300	230	500	240	525	250	NR	250	NR	260	NR	280	NR
11 to 15	NR	NR	NR	NR	260	NR	270	NR	280	NR	NR	NR	260	NR	270	NR	280	NR	285	NR	300	NR	310	NR
6 to 10	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, °F, at time of application	Solid CaCl2 Application Rates - pounds per lane-mile																							
	Pre-Treatment *				Within-Event **																			
	Snow	Frost/Black Ice	Freezing rain	Sleet	Light Snow		Moderate Snow		Heavy Snow		Frost and Black Ice		Light freezing rain		Moderate freezing rain		Heavy freezing rain		Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	121	110	138	132	121	264	143	292	165	319	110	248	121	264	143	292	165	319	143	292	160	319	182	352
26 to 30	176	143	193	193	176	385	193	413	209	440	143	275	187	385	198	413	209	440	193	424	215	451	231	484
21 to 25	231	176	248	253	220	468	231	495	242	523	176	303	220	468	231	495	242	523	242	512	253	NR	264	NR
16 to 20	268	203	294	294	246	535	257	NR	268	NR	203	321	246	535	257	NR	268	NR	268	NR	278	NR	300	NR
11 to 15	309	227	335	340	268	NR	278	NR	288	NR	227	335	268	NR	278	NR	288	NR	294	NR	309	NR	319	NR
6 to 10	357	258	NR	NR	304	NR	319	NR	319	NR	258	361	299	NR	309	NR	319	NR	335	NR	345	NR	355	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: * = For prewetted solid chemical

** = For either dry or prewetted solid chemcial

NR = Not Recommended

Table 6 (cont)

Solid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Weather Events

Pavement temperature, ° F, at time of application	**Solid Ice Slicer Application Rates - pounds per lane-mile**																							
	Pre-Treatment *				**Within-Event ****																			
	Snow	Frost/Black Ice	Freezing rain	Sleet	Light Snow		Moderate Snow		Heavy Snow		Frost and Black Ice		Light freezing rain		Moderate freezing rain		Heavy freezing rain		Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	110	100	125	120	110	240	130	265	150	290	100	225	110	240	130	265	150	290	130	265	145	290	165	320
26 to 30	160	130	175	175	160	350	175	375	190	400	130	250	170	350	180	375	190	400	175	385	195	410	210	440
21 to 25	210	160	225	230	200	425	210	450	220	475	160	275	200	425	210	450	220	475	220	465	230	500	240	525
16 to 20	250	190	275	275	230	500	240	525	250	NR	190	300	230	500	240	525	250	NR	250	NR	260	NR	280	NR
11 to 15	300	220	325	330	260	NR	270	NR	280	NR	220	325	260	NR	270	NR	280	NR	285	NR	300	NR	310	NR
6 to 10	347	250	NR	NR	295	NR	310	NR	310	NR	250	350	290	NR	300	NR	310	NR	325	NR	335	NR	345	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, ° F, at time of application	**Solid CMA Applications - pounds per lane-mile**																							
	Pre-Treatment *				**Within-Event ****																			
	Snow	Frost/Black Ice	Freezing rain	Sleet	Light Snow		Moderate Snow		Heavy Snow		Frost and Black Ice		Light freezing rain		Moderate freezing rain		Heavy freezing rain		Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	187	170	213	204	187	408	221	NR	255	NR	170	383	187	408	221	NR	255	NR	221	NR	247	NR	281	NR
26 to 30	272	221	298	298	272	NR	298	NR	323	NR	221	425	289	NR	306	NR	323	NR	298	NR	332	NR	357	NR
21 to 25	336	256	360	368	320	NR	336	NR	352	NR	256	440	320	NR	336	NR	352	NR	352	NR	368	NR	384	NR
16 to 20	375	285	413	413	345	NR	360	NR	375	NR	285	450	345	NR	360	NR	375	NR	375	NR	390	NR	420	NR
11 to 15	450	330	NR	NR	390	NR	405	NR	420	NR	330	488	390	NR	405	NR	420	NR	428	NR	NR	NR	NR	NR
6 TO 10	NE	NR	NR	NR	NR	NR	NR	NR	NR	NR	375	525	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: * = For prewetted solid chemical
** = For either dry or prewetted solid chemcial
NR = Not Recommended

A word of caution is in order concerning the use of the application rates in Tables 5 and 6 for chemicals other than NaCl. The rates for NaCl were derived from field test data and include the influence of such variables as precipitation types and rate, pavement wheel path conditions, maintenance treatment cycle times, and traffic volume. Even though the equivalent application rates of the other ice control chemicals were based on those of NaCl, the rates were derived, to some extent, from freezing point data of the chemical solutions. As such, the equivalent applications rates for the ice control chemicals other than NaCl should be considered as starting points in determining the appropriate rates for snow and ice control operations. Local experience should refine these values.

5.4 Other Chemicals for Winter Road Maintenance

In recent years increased concern about the corrosive effects and environmental damage caused by use of traditional road salts has led to the introduction of numerous alternative or supplemental chemical substances to the tools available for winter road maintenance. In this section we turn our attention to these materials.

Potassium acetate (KAc) and calcium magnesium acetate (CMA) have already been mentioned as non-halide chemicals for winter maintenance operations. Both substances induce very little corrosion in metal as compared to NaCl, KCl, and $CaCl_2$. Additionally, the acetate ion is biodegradable and substantially less toxic to aquatic life. Unfortunately, these chemicals are considerably more expensive on a weight basis than traditional chemicals, and their phase diagrams (see Figure 2) indicate that they cause a smaller melting point depression in the 15°-32° F range than obtained from common salts. The very low eutectic temperature for KAc (at -76° F) is attractively lower than that for $CaCl_2$, while CMA has its eutectic at approximately -17° F. Even so, much larger amounts of these chemicals are needed to achieve lower temperatures than with $CaCl_2$.

The higher cost and application rates for KAc and CMA make them impractical chemicals for *routine* road treatment, but they do have their niche. The acetates are especially appropriate in environmentally sensitive areas or structures where metal or roadbed corrosion is a concern. In such cases, pre-treatment of the roadway for snow and frost/black ice with liquid KAc and CMA down to pavement temperatures of 11 to 15° F for anti-icing is recommended.

Organic chemicals have received attention in recent years. These materials are usually carbohydrate-based (carbon, hydrogen, oxygen compounds) and may be obtained as a by-product of agricultural operations. United States patents issued to Hartley in 2001, 2002, and 2003 describe the use of aqueous solutions of low molecular weight carbohydrates, an inorganic freezing point depressant (acetate or chloride based), and a thickening agent for de-icing and anti-icing. A plant-derived corrosion inhibitor may also be in the mixture. Similarly, Ossian and co-workers were issued a patent in 2008 for a deicing/anti-icing product based on treated materials remaining after the de-sugaring of beet sugar molasses (also called "raffinate" in the patent). The reported composition is about 1/3 moisture and 2/3 solids carbohydrate and crude protein) that forms a highly viscous liquid relative to water. The patents just cited do not provide phase diagrams for the chemical mixtures, but do include melting rate and/or freezing point depression data to support their claims.

The returned questionnaires from highway agencies identified a wide variety of liquid organic additives that are mixed (with commercially or by the agencies) with brines of conventional snow and ice control chemicals. These liquid mixtures are given in Appendix E subdivided by the base brine chemicals of NaCl, $CaCl_2$, and $MgCl_2$. The highway agencies using many of the chemical blends are also identified in Appendix E. The percent by weight of the additives in the mixtures ranges from less than one percent to almost 20%, depending on the particular chemical mixture.

The discussion of the various blends of common liquid snow and ice control chemicals with organics is divided by the base products beginning with NaCl. But first it is important to provide some general remarks.

In reviewing product literature, it is important to note whether the organic material is being used directly or whether it has been diluted or otherwise blended. ***All*** the agriculturally-based organic products (sugar beet molasses, corn steep liquor, wheat/brewing liquids, lignin-derived chemicals, etc.) by themselves (that is, with no added salts) cause some freezing point depression of water and potentially can be useful components for winter road maintenance. Several points need to be kept in mind:

a) The very low eutectic points reported for many of these products typically are attained when the organic material constitutes about 50% of the solution. The feasibility of directly applying the product will largely rest upon the viscosity of the solution.

b) If the organic products are simply diluted with water, solutions of low concentration will probably be less effective at anti-icing and deicing than traditional salt solutions.

c) The effectiveness of the organic products also depends on whether they are they are employed as prewetting agents for solids, for anti-icing or deicing.

d) Organic additives like the carbohydrates help reduce corrosion of metals to the extent that chloride containing salts are used in lower concentrations. Citric acid is added to some products in low concentration as an anti-corrosion agent.

5.4.1 NaCl Based Products

5.4.1.1 Material Incorporating De-sugared Sugar Beet Molasses

Included in this section are discussions of the following NaCl based products containing de-sugared sugar beet molasses:

- ❖ GEOMELT®55 and pre-mixed blends containing GEOMELT®55,
- ❖ GEOMELT®S, and
- ❖ BEET HEET®

5.4.1.1.1 GEOMELT® 55 and Pre-mixed Blends Containing GEOMELT®55

Assessing commercial products containing organic chemicals is difficult at times because the nature and composition of the products usually is proprietary. Full chemical details about the formulation are typically lacking, and similar products may be distributed under different names. As a specific example, GEOMELT® 55 Anti-icing Fluid is based on “desugared sugar beet molasses” as covered under US Patent 6,080,330 (Bloomer, 2000). [This product was chosen for an example not by way or endorsement or with an aim to refuting manufacturer/distributor claims, but because there is more information readily available than for most other chemicals.] As described in the patent the molasses is approximately 40% moisture and 60% dissolved solids. The "55" apparently refers to the fact that this material is about 55% dissolved solids (32% carbohydrates, 12% protein, with the balance distributed among minor components). The molasses itself has a freezing point that is below -30° F and a high viscosity (150 cps at -30° F). The Bloomer patent covers use of the molasses alone and in mixtures with typical road chemicals such as NaCl and $MgCl_2$ for both anti-icing and deicing.

A cooling curve of the GEOMELT® 55 Anti-icing Fluid obtained by differential scanning calorimetry is shown in Figure 4, along with phase diagrams for NaCl and $CaCl_2$. We assume here that the cooling curve for the GEOMELT® 55 corresponds to dilutions of the product with water alone. Thus, the undiluted product is the material having a eutectic well below -32° F. Over the 32°-20° F range, the cooling curve suggests that dilute solutions of the GEOMELT® 55 provide freezing point depressions comparable to $CaCl_2$ and NaCl. Looking at the curve in Figure 4, below 20° F the downward slope for the calcium and sodium chloride solutions is much greater than for the GEOMELT® 55, implying that significantly higher applications of the diluted product (unmixed with other chemicals) would be needed to achieve similar freezing point lowering.

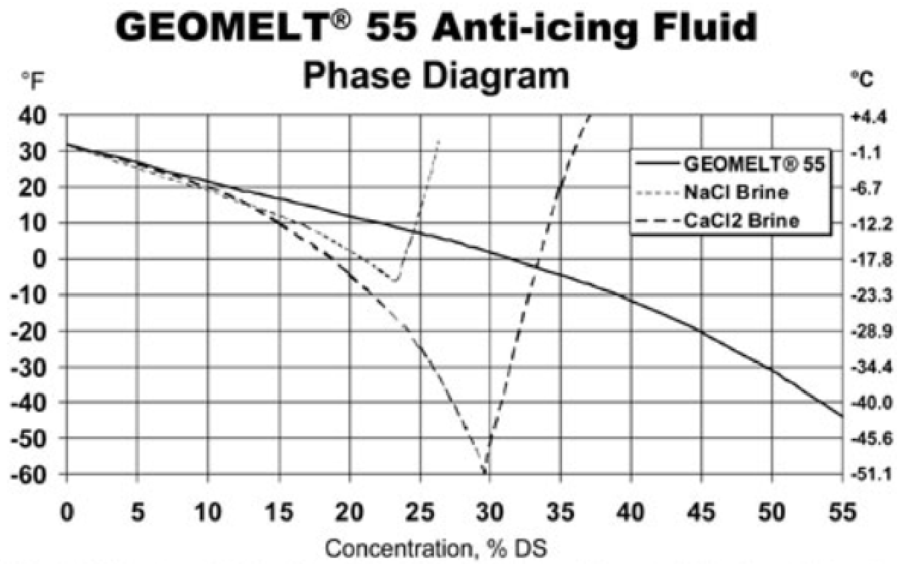

Figure 4: Comparison of GEOMELT® 55 with NaCl and $CaCl_2$ brines

source: http://www.hawkeyereadymix.com/product_geomelt_55.html

As organic materials, "molasses-type" products do not form charged particles like NaCl and other salts, so it is reasonable to wonder how it is possible for them to affect the freezing point of water. Most of us are familiar with adding anti-freeze agents such as ethylene glycol to car radiators. The anti-freeze chemicals are simple organic substances with a molecular structure very much like water. As a result, a molecule of the anti-freeze can compete with water molecules in forming hydrogen bonds, disrupting the formation of the hexagonal ice lattice that pure water forms on freezing. The carbohydrate and proteins in the molasses products are decidedly more complex structures than the ethylene glycol used for anti-freeze but they do incorporate structural units similar to water that are capable of hydrogen bonding.

As a result, the organic chemicals disrupt the formation of the ice-lattice in water, causing the freezing point to fall to lower temperatures.

Another point to consider: the behavior of any material in its "pure, concentrated, or original" composition may be different once it has been blended with other chemicals. For that reason, it is possible to see different effectiveness for the same material depending on whether the material is used for prewetting solid NaCl, anti-icing or deicing. The vendors of GEOMELT® 55 and related products usually recommend blending the product with traditional salt solutions or using it to prewet solid NaCl.

An unimpressive lowering of the freezing point of moisture on the road surface might be expected when products like GEOMELT®55 or their blends with liquid products are used for prewetting solid NaCl prior to being distributed from a spreader truck. In a typical prewetting operation, the solid NaCl might be prewetted with up to 10 – 12 gal/ton of the molasses and liquid NaCl mix. At these rates of application, only about 5 -10% of solids from the molasses are transferred to the solid NaCl. (The molasses itself contains 50 – 60% solids.) This lower concentration of the carbohydrates and the non-uniform mixing of the liquid with solid NaCl results in a very significantly smaller application of the organic chemical to the road surface.

GEOMELT®55 product literature suggests using the undiluted material for treating salt stockpiles at a rate of 5-6 gallons per ton. This gives 2000 lbs NaCl + (6 gallons/ton)x(10.5 lbs/gallon) = 2000 lbs NaCl + 63 lbs GEOMELT® added. This is equivalent to a solid mixture which is 96.9 % NaCl + 3.1% agricultural solids. The product literature further suggests that the application rate for the treated salt can start at about 30% less than that of untreated, dry solid NaCl.

Now suppose that we normally apply 100 lbs NaCl/lane-mile for a given situation. A 30% reduction in application rate of the (NaCl + GEOMELT®) = 70 lbs total weight. Of that 70 lbs, 96.9% or 67.8 lbs is NaCl and 2.2 lbs GEOMELT®. This is equivalent to saying 100-67.8 = 32.2 lbs NaCl have been replaced by the 2.2 lbs GEOMELT®, which lowers the freezing point less than NaCl alone. While the stockpile treatment of the NaCl probably reduces bounce, improves adhesion to the road surface, and may leave an after-melting residue advantageous to the next weather event, it does not seem reasonable to reduce the total weight of salt applied by this much, if any. Disclaimers on the literature read: "Actual field observations may differ" and "The suggested usage levels should be considered as starting points and should be adjusted based on field operator experience, current local conditions and weather expectations."

GEOMELT® 55 is also suggested for blending with liquid solutions of NaCl, $CaCl_2$, or $MgCl_2$ where used for anti-icing and deicing applications. Various pre-mixed blends of GEOMELT® 55 with liquid 23% NaCl are also commercially available, such as GEOMELT® 80/20, 70/30 and as a 85/15 blend (as Ice Bite™). Additional information about the freezing points of blends of GEOMELT® with 23% NaCl solution was obtained by the North Dakota DOT. The data were collected by an independent laboratory using differential scanning calorimetry (see Table 7). Based on this information, a ***blend*** of the GEOMELT® 55 with 23% aqueous NaCl exhibits a *greater freezing point depression than either chemical alone*. This does give support to the possibility of reducing the total amount of NaCl applied for these more concentrated mixtures.

Table 7: Freezing points of various blends of GEOMELT with 23% NaCl solution

GEOMELT®, % by volume in blend	23% NaCl in water, % by volume in blend	Freezing point, °F
10	90	-13
20	80	-18
30	70	-20
50	50	-31

For example, 100 gallons of an 80/20 blend by volume contains approximately 180 lbs NaCl and 11 lbs sugar beet molasses solids and has a freezing point of -18° F as indicated. A simple dilution of 23% NaCl to 80% strength yields an 18.4% NaCl solution with a freezing point of about +6° F, so the added molasses product is playing a significant synergistic role with the NaCl. Notice in Figure 4 that an 11% solution of GEOMELT® 55 alone has a freezing point near 20° F.

5.4.1.1.2 GEOMELT® S

A related product, GEOMELT® S, is sold as an Anti-icing/Deicing Fluid, described as being "an all-natural agricultural product from renewable sources blended with sodium chloride brine" containing 39% dry solids and having a freezing point of -26° F. The material is available in several blends with 23% NaCl solution as a direct replacement for standard 23% NaCl brine. Thus, the "GEOMELT® S 20:80 blend" is 20% by volume GEOMELT® S with 80% by volume being standard 23% NaCl in water. This particular formulation is reported as containing 28-30% dry solids, with a eutectic point of -25° F. The product literature describes using the liquid directly for ant-icing or deicing and prewetting of solid NaCl. [source: www.vanhandels.com/linked/product_data_geo_s_20-80.pdf] A freezing point depression curve for GEOMELT® S is compared to the phase diagram for NaCl-H_2O and $CaCl_2$-H_2O in Figure 5. Note: the exact proportions of GEOMELT® S and 23% NaCl solution were not identified. It is also not clear if the horizontal axis in "% Dissolved Solids" includes the NaCl or merely the diluted solids from the concentrated GEOMELT® S.

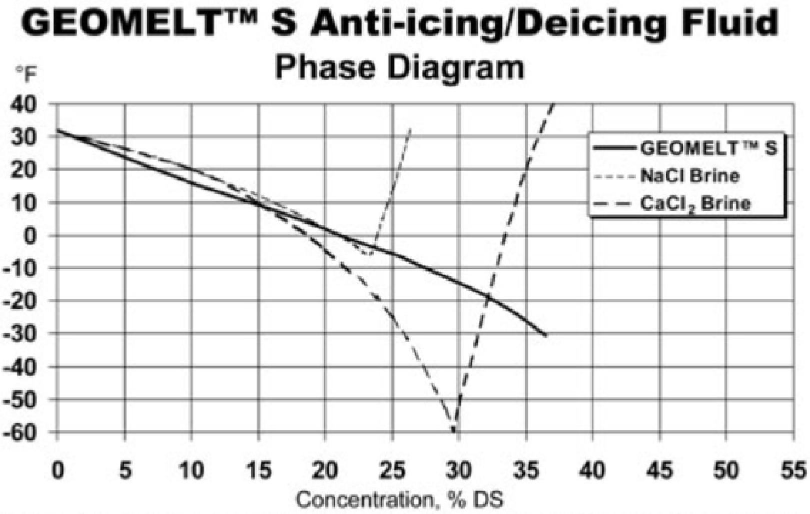

Figure 5: Comparison of freezing points for GEOMELT® S blend with standard brines

Consistent with the findings and calculations above, Figure 5 indicates that the mixture of NaCl and sugar beet molasses product achieves a slightly greater freezing point lowering than 23% NaCl alone throughout the 32°-0° F range. This means that the liquid application rates for GEOMELT® S could be less than the liquid application rates for NaCl in the 32° F to 16° F range to achieve the same freeing point depression as NaCl. This result can be seen more fully in Section 5.4.1.2 when the discussion focuses on the freezing point curves (phase diagrams) of various NaCl based chemicals containing organic additives.

5.4.1.1.3 BEET HEET®

Another product based on sugar beet molasses is BEET HEET® Concentrate, a product of K-Tech Specialty Coatings. Based on the manufacturer's data at http://www.ktechcoatings.com/sites/default/files/docs/BEET%20HEET%20Concentrate%20Technical%20Data%20Sheet.pdf, this concentrate contains NaCl, KCl, $CaCl_2$, $MgCl_2$, and refined sugar beet molasses. The manufacturer claims it may be used directly, for pre-wetting solid NaCl, or blended with liquid 23% NaCl. Specifically, the manufacturer recommends using this concentrate for deicing at an initial application rate of 34-44 gal/LM.

Also supplied is BEET HEET® Severe, a 1:1 (50% by volume) mixture of 23% aqueous NaCl and BEET HEET® Concentrate, recommended for anti-icing application before the temperature falls below 32° F. The analytical data provided indicates that the freezing point of this 1:1 blend is about -11° F. As we noted previously, mixtures containing high proportions of sugar beet molasses mixed with 23% aqueous NaCl appear to be more effective at lowering the freezing point than NaCl alone, though no phase diagram is available for this specific product. The viscous nature of the product undoubtedly affords higher retention on the road surface than NaCl alone, and it most likely functions by preventing the formation of the ice-pavement bond.

Another sugar beet molasses product is sold under the BEET 55™ label, though we have not been able to associate it with a particular patent or formulation. This product is available through Smith Fertilizer and Grain of Iowa. (http://www.sfgiowa.com/beet-55). The vendor reports that this material can be blended with liquid NaCl, $MgCl_2$, and $CaCl_2$, as well as be used for pre-treatment of solid salt, but no further scientific information can be obtained from the vendor.

5.4.1.2 Use of Freezing-point Curves to Estimate Application Rates for Various NaCl Based Products Containing Organic Additives

Very little detailed information was obtained from vendors of organic additives and NaCl based products containing organic additives relative to recommended application rates for the products. The recommendations generally provided to the highway user were based upon a vague starting point or gross ranges of rates which were to be refined over time with local operational experience. Thus, it was up to the highway user to determine what worked best for the highway agency.

The information in the returned questionnaire from highway agencies was not specific enough to formulate recommended application rates for the NaCl based products containing organic additives and the various winter weather events of interest. Therefore, another approach was made to determine liquid chemical application rates for NaCl based products.

The liquid chemical application rates for various organic products that are added to NaCl brines are most conveniently determined relative to those rates developed for NaCl brines. This approach requires the freezing point curves (phase diagrams) of both NaCl brine and the different NaCl based liquid products.

Plots of the freezing point in ^{O} F versus percent total dissolved solids are given in Figure 6 for the following chemicals:

- NaCl = dilutions of NaCl brine only in water;
- GEOMELT® 55 = dilutions of GEOMELT®55 additive without NaCl;
- GEOMELT® S = dilutions of 50% by volume GEOMELT®55 additive plus 50% by volume 23% NaCl in water; and
- TC Econo = dilution of 20% NaCl, 2 – 5% $CaCl_2$, and 8% inhibitor.

TC Econo is a liquid snow and ice control chemical produced by Tiger Calcium Services (Green Touch Systems). The vendor of this product recommends its use for deicing operations and states it can be used in situations colder than are typical for straight NaCl brine. It was not possible to obtain any phase diagrams for any of the other blends of GEOMELT®55 and NaCl brine nor for a product used by McHenry Co., IL that is a County produced mixture.

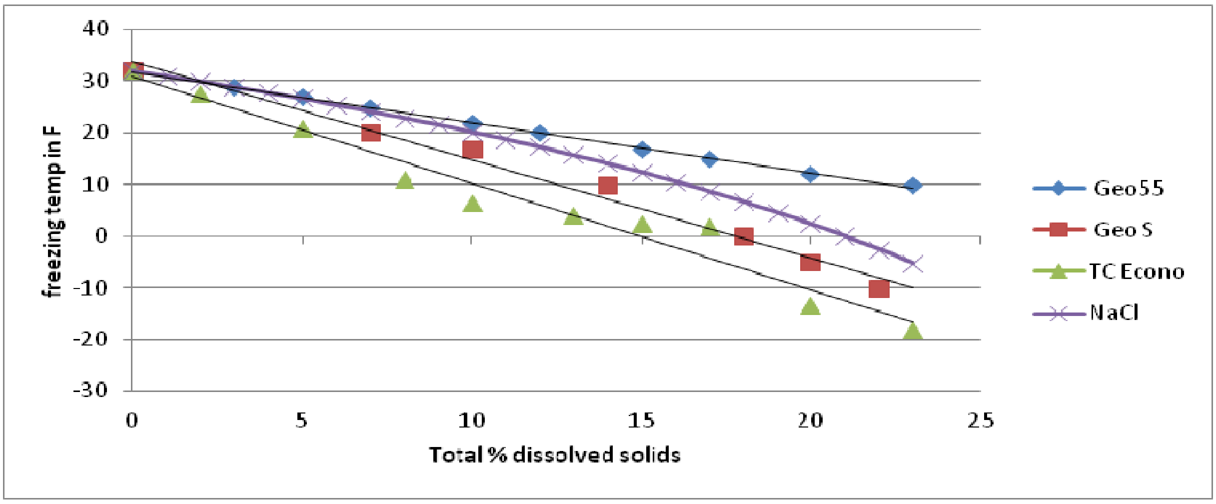

Figure 6 Comparison of Freezing Points for Various Mixtures with GEOMELT® 55

The following conclusions can be drawn from Figure 6:

- ❖ Dilutions of GEOMELT® 55 alone (the concentrated sugar beet molasses material itself) has about same freezing point depression as NaCl down to about 25° F.
- ❖ Below 25° F liquid NaCl provides greater freezing point depression than dilute GEOMELT® 55, but is more corrosive.
- ❖ Dilutions of GEOMELT® S (= 1:1 by volume GEOMELT® 55 + 23% NaCl) give increased freezing point depression compared to NaCl alone, with less corrosive components than NaCl alone.
- ❖ When the plot is examined with finer divisions (which may be smaller than the actual uncertainties in the data itself) the diluted GEOMELT® S shows on average about 10-20% increased efficiency in lowering melting point compared to NaCl alone over 0-20°

F. Above 20° F the improvement in freezing point lowering MAY approach closer to 30%. This is done by comparing the % compositions needed to achieve the same temperature…again note, these are graphical extrapolations with limited data.

- TC Econo does give superior freezing point depression over 0°-30° F compared to NaCl alone, but the performance appears to be variable based on the data available. The data suggests that something crystallizes out of solution around 0° F. What that is or what exactly remains in solution is not obvious. Above 0° F, about 30-40% less TC Econo application rate is needed than NaCl alone to achieve the same freezing point depression.

Some conclusions can be drawn about the effectiveness of 23% NaCl + 5% AMP additive as a snow and ice control chemical. The freezing point data provided by the vendor on the product was reported on the basis of specific gravity and not on the usual total percent dissolved solids. For convenience, the specific gravity data for 23% NaCl + 5% AMP additive is plotted in Figure 7 along with data for NaCl and TC Econo for reference.

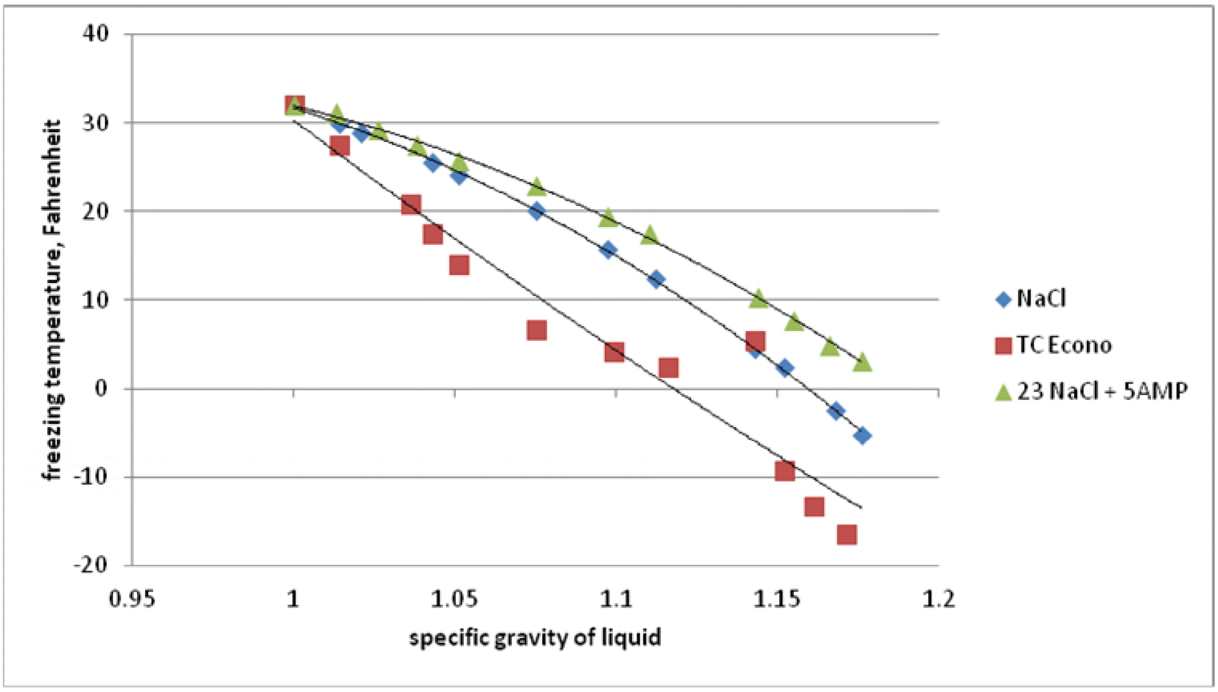

Figure 7 Comparison of freezing points for NaCl and its mixtures.

The entire point of this figure is to show that 23% NaCl + 5% AMP is less effective than NaCl over temperatures below 30° F. It is estimated that between 5° - 20° F the 23% NaCl + 5% AMP is only 1 – 2% less effective on a weight basis for depressing the freezing point than NaCl alone. This is reasonable given the low concentration of AMP and its chemical structure.

5.4.2 $CaCl_2$ Based Products

The snow and ice control chemicals identified in the $CaCl_2$ based products include:

- Road Guard Plus™ 8,
- BOOST™ with $CaCl_2$,

- MasterMelt 50,
- Caliber C1000-LS, and
- Caliber C1500.

Road Guard Plus™ 8, is a mixture of $CaCl_2$ (26.5%), $MgCl_2$ (3.1 %), NaCl (1.3 %), KCl (0.9%) and 8% sugar beet molasses-derived materials and other additives.

BOOST™ with $CaCl_2$, is composed of 29-30% $CaCl_2$ with 4.7% additive

MasterMelt 50, contains $CaCl_2$ (15%), NaCl (8.7%), and $MgCl_2$ (3.9%), but there is no mention of an inhibitor component in the product literature.

Caliber C1000-LS is a 10% by volume of about 30% $CaCl_2$ solution mixed with 90% by volume of a corn-based organic material. No phase diagram was available for this product,

Caliber C1500 is 85% by volume of about 30% $CaCl_2$ and 15% by volume of corn-derived additive. No phase diagram was available for this product,

The figure below compares Road Guard Plus™ 8, BOOST™ with $CaCl_2$, and $CaCl_2$ alone. The liquid compositions compare specific gravity of each mixture as a function of temperature in ^{O} F.

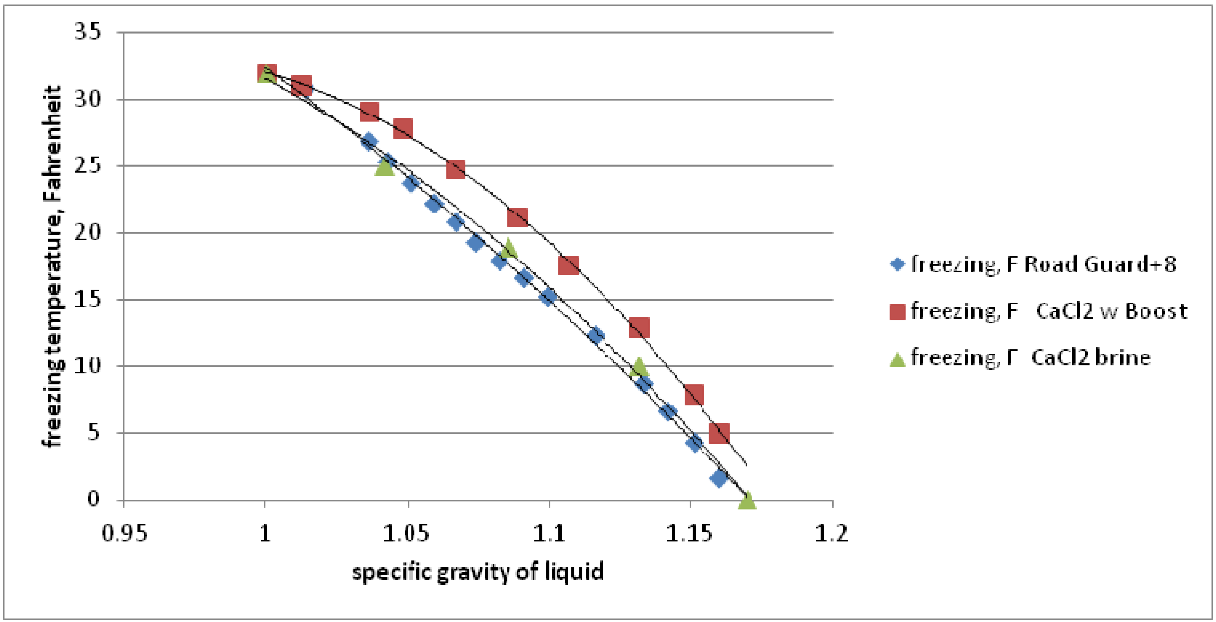

Figure 8 Comparison of freezing points for $CaCl_2$ and its mixtures.

Some general comments can be given relative to the comparison of the two commercial products with $CaCl_2$ brine without any additive.

- The curves for Road Guard Plus™ 8 and $CaCl_2$ brine alone track almost identically. Consequently, the application rates provided earlier in this report for $CaCl_2$ can also be used for Road Guard Plus™ 8 in the operating pavement temperature range of interest.

- ❖ The BOOST™ with $CaCl_2$ product consistently gives less freezing point depressions than $CaCl_2$ alone over the temperature range shown. Based on graphical extrapolation, the BOOST™ with $CaCl_2$ product is about 1–3% less effective than $CaCl_2$ alone considering the amount of material needed to achieve the same freezing point. This means that slightly more BOOST™ with $CaCl_2$ is needed than for $CaCl_2$ liquid alone. Given the uncertainties in the data obtained, this small difference is not likely to be significant. (The plot given above tends to exaggerate apparent differences because of the small horizontal range.) Consequently, the application rates provided earlier in this report for $CaCl_2$ can also be used for BOOST™ with $CaCl_2$ in the operation pavement temperature range of interest.

We now turn our attention to MasterMelt 50. The units for MasterMelt 50 freezing curve are not given in specific gravity terms, but in "% by weight concentration." The corresponding plot compared to data for $CaCl_2$ alone is shown in Figure 9.

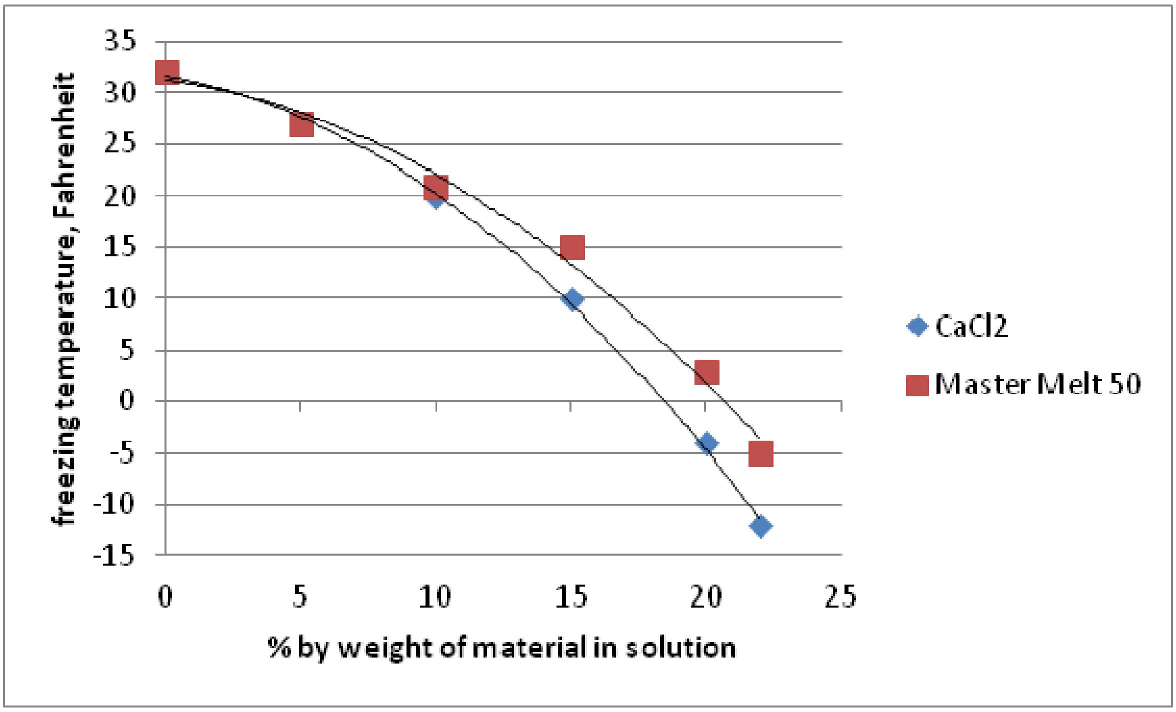

Figure 9 Comparison of freezing points for $CaCl_2$ and MasterMelt 50.

Comparison plots of the phase diagrams of MasterMelt 50 and $CaCl_2$ show that the product does not attain as low a freezing temperature (eutectic temperature) as $CaCl_2$ itself. Below about 27^{O} F, the MasterMelt 50 product has a smaller freezing point depression than $CaCl_2$ alone. Given the crude level of data available, the extrapolated difference between the two chemicals is on the order of only about 1-2%, which is not significant given the uncertainties. Consequently, the application rates provided earlier in this report for $CaCl_2$ can also be used for MasterMelt 50 in the operating pavement temperature range of interest.

5.4.3 Magnesium Chloride Based Products

A large number of commercial $MgCl_2$ based products were identified by the highway agencies surveyed. The snow and ice control chemicals identified in this group include:

- Caliber M1000
- Caliber M2000
- Freezegard CI Plus
- Ice Ban
- Ice Ban Ultra 305
- Ice B'Gone Magic
- MeltDown AP
- MeltDown APEX™
- SOS AP
- Thawrox MG

Caliber M1000 is 90% by volume liquid $MgCl_2$ and 10% by volume of a corn-based additive.

Caliber M2000 is 80% by volume liquid $MgCl_2$ and 20% by volume of a corn-based additive. The supplier of this product recommends its use as a prewetting chemical for only sand and salt mixtures. No phase diagram was available for this product.

Freezegard CI Plus liquid contains 28-30% $MgCl_2$, less than 1 % of a non-sodium brine, and 2% of a corn-based additive. No phase diagram was available for this product.

Ice Ban liquid contains 30% $MgCl_2$ and a very large (16%) component of a corn-based additive. No phase diagram was available for this product.

Ice Ban Ultra 305 is 80-90% liquid of a 30-31% concentration of $MgCl_2$ solution plus 10-20% of a corn-base additive.

Ice B'Gone Magic contains a 30% liquid $MgCl_2$ solution plus a very large (20%) component of a sugar beet based additive. No phase diagram was available for this product.

MeltDown™ AP liquid contains 30% $MgCl_2$ solids plus 0.5% Shield AP which is a sugar beet based additive.

MeltDown™ APEX is a 25-35% $MgCl_2$ liquid containing 0.5% Shield AP corrosion inhibitor plus less than 5% proprietary APEX additive.

SOS AP liquid contains 26% $MgCl_2$ solids plus less than 5% of a proprietary additive as a thickening agent. This product is recommended only for prewetting dry salt or sand. A phase diagram was obtained for this product; however, the diagram shows an eutectic temperature of at least -77^{O} F. It is unlikely that such a small percentage of the additive combined with $MgCl_2$ can produce such a low temperature. The eutectic temperature of $MgCl_2$ is -28^{O} F. Thus, it appears that the phase diagram supplied by the manufacturer is for the additive alone.

Thawrox MG is a 26% $MgCl_2$ liquid containing an unknown percentage of a sugar beet corrosion inhibitor. This product is recommended for stockpile prewetting. No phase diagram was available for this product.

Some general comments can be given regarding a comparison of the phase diagrams of three of the commercial products with $MgCl_2$ brine without any additive. Figure 10 compares the phase diagrams of Caliber M1000, Ice Ban Ultra 305, and MeltDown APEX with $MgCl_2$ alone. The phase diagram for MeltDown AP is not shown for clarity of the figure. If shown, the phase diagram of this product would lie between the one for MeltDown APEX and the one for $MgCl_2$ alone.

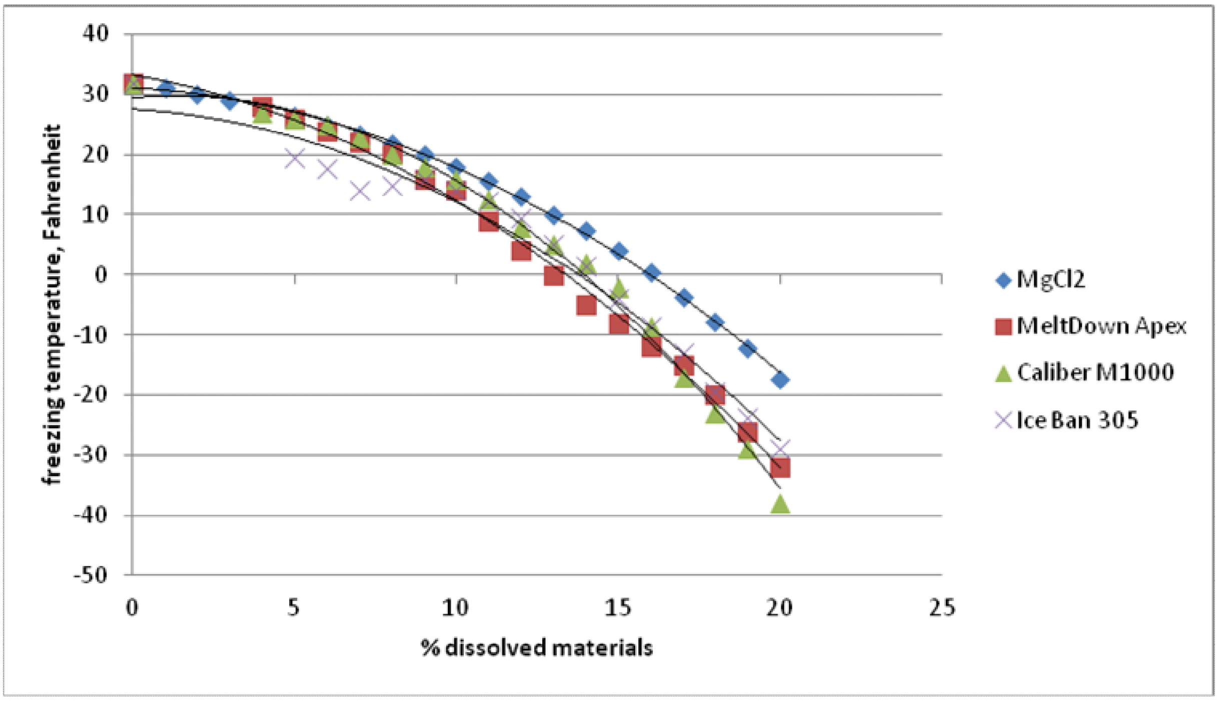

Figure 10 Phase Diagrams for $MgCl_2$ only, MeltDown APEX, Caliber M1000, and Ice Ban 305

- From 32° - 20° F, the performance of MeltDown APEX and Caliber M1000 track very closely, but slightly better, than $MgCl_2$ alone.
- Ice Ban Ultra 305 shows significantly lower freezing point depression than the other products until it appears that some material crystallizes out around 15° F. It is difficult to evaluate the percent reduction in application rate for this product compared to the rate for $MgCl_2$ alone because of the erratic nature of the freezing point curve in the 32° -15° F temperature range.
- Below 20° F, MeltDown APEX, Caliber M1000, and Ice Ban Ultra 305 show enhanced freezing point depression compared to $MgCl_2$ alone, but they do not differ significantly enough to be distinguished among each other.
- By graphical estimation, at 10° F these enhanced products appear to require about 8-15% less application rate than $MgCl_2$ alone.

- Around 0^{o} F, the enhancement in performance of the three products is closer to 20% compared to $MgCl_2$. The difference becomes even larger at lower temperatures.

5.4.4 KAc and CMA

Potassium acetate (KAc) and calcium magnesium acetate (CMA) are known to be intrinsically much less corrosive than chloride salts. As such, there do not appear to be any products based on KAc and CMA that include additional inhibitor agents. These base chemicals themselves are usually regarded as too expensive for general anti-icing and deicing operations except in specific applications, such as treatment of bridge decks and on roads in environmentally sensitive areas.

5.4.5 Additional Comments Concerning the Application Rates of Liquid Chemicals Containing Organic Additives

Any highway agency using liquid chemicals for snow and ice control that contain organic additives should use the manufacturer's/vendor's recommendation regarding application rates. Many times these recommendation rates will be general and non-specific regarding the winter weather event being fought. In this case, the recommended rates should be regarded as "starting points" to be adjusted over time based on local conditions and storm events. This approach will require the agency to record field notes on what worked and what did not work during the variable storm conditions and maintenance actions. These field notes will then be used in "lessons learned" exercises to decide on future application rate amounts. This is a trial and error approach that can work, but it takes a champion to collect and analyze the field notes.

Another approach for determining the application rates of snow and ice control chemicals containing organic additives involves the use of phase diagram information. In this approach, the phase diagram of the chemical with the additive is compared to the phase diagram of the primary base brine chemical. To illustrate this approach, consider Figure 11. At temperature T_1, the percent concentration of the base brine chemical is C_B, and the percent concentration of chemical A containing an organic additive is C_A and the percent concentration of chemical B containing another organic additive is C_C. The base brine chemical can be either NaCl, $CaCl_2$, or $MgCl_2$. The positioning of the three curves is chosen to demonstrate two possibilities. The figure shows the $\frac{C_A - C_B}{C_B}(100)$ percent LESS chemical A needed than he base chemical at temperature T_1 to achieve the same freezing point depression as the base chemical. Conversely, $\frac{C_C - C_B}{C_B}$ (100) percent MORE chemical C is needed than the base chemical at temperature T_1 to achieve the same freezing point depression as the base chemical. Thus, one can determine the application rate of a given chemical with an organic additive for any operating temperature and storm event by applying the decimal percent corrections given above to the values in the application rate tables for the base brine chemical. This procedure demonstrates the importance of obtaining the phase diagram (or freezing point curve) from the manufacturer/vendor of the chemical containing the organic additive. The application rates determined by this approach should be considered as starting rates and should be adjusted either upward or downward as conditions dictate. This approach should take less staff time and resources to arrive at appropriate application rates for the various storm events than the previous method.

If for some reason, a phase diagram cannot be obtained from the manufacturer/vendor then a starting point for application rate determination would be the rates listed for the base brine chemical. At operating pavement temperatures from 28° to 32° F, the application rate estimations from the rate tables for the base brine chemicals should be adequate. However, as the temperature drops below this range, the percent difference between the rate required for

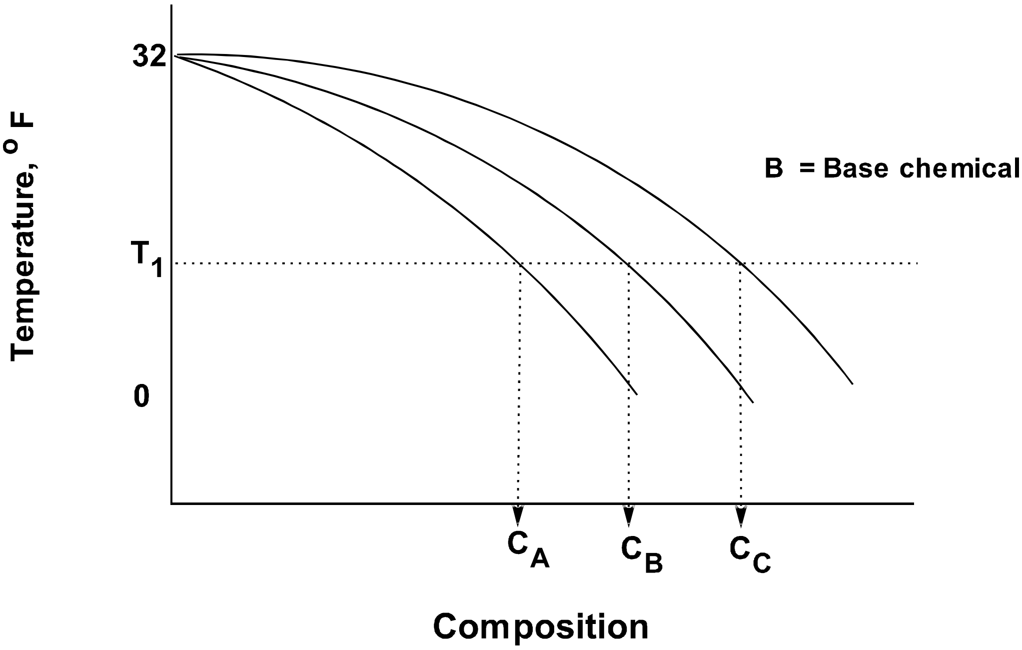

Figure 11 Typical phase diagram curves for determining application rates.

the chemical with the organic additive and the base brine chemical could be as much as ±20% depending on the minimum operating temperature.

One final comment is worth noting regarding the application rates of a solid snow and ice control chemicals, like rock salt, that is prewetted on a distributor truck with a liquid organic additive before application to the pavement. Some of the manufacturers/vendors of these additives will claim that up to 20 to 30% reduced application rate of the solid chemical can be achieved through use of their product. These claims have to be interpreted in terms of proper comparisons. It is true that 20 to 30% more prewetted salt can be retained on a dry or pare pavement compared to an application of dry salt. The prewetting action, if done correctly, reduces the bounce and scatter of the dry salt. This result was demonstrated in a December 1990 report by the Michigan Highway Department, long before the development of organic additives used a liquid prewetting agent for dry salt. Thus, the reduction achieved in application rate of a dry solid applied to a bare or dry pavement can be obtained with a prewetting liquid like a chloride brine just as well as a liquid containing an organic additive. The advantage that the prewetting liquid containing an organic additive has over another liquid is that the tackiness, or stickiness, of the organic based liquid might have a longer lasting effect on the pavement than an ordinary chloride brine. This could possibly help increase the cycle time required between subsequent applications because of the carry-over effect. These possibilities could not be verified with any of the application rate data obtained from either the highway agencies or manufacturers/vendors of the organic additives. These possibilities remain for future field investigations that are well controlled and documented.

6.0 Investigation Into the Relative Cost of Chemicals Used in Winter Maintenance Operations

Part of the contractual obligation of the Task 2 work included the desire to collect and organize the relative cost of chemicals used in winter maintenance operations. This cost information was to be categorized as low, medium, or high to serve as a point of comparison between chemical categories. In addition, material prices needed to be determined from the point of manufacturer and not include transportation cost elements, since these items can vary greatly for different highway agencies.

Chemical cost data were sought in the questionnaires sent in Task 1 to highway agencies and manufacturers/vendors of winter maintenance chemicals sold to those users. In both questionnaires, it was requested the cost data provided did not include transportation related cost elements. The cost data obtained are tabulated in Appendix F by three sources. The first source deals with chemical cost data reported by the highway agencies in their responses to our questionnaire. These data are general and almost always included transportation costs, with a few exceptions. The second source of chemical cost information came from the manufacturers/vendors in their response to our questionnaire. These data provided very limited information because the companies did not want to reveal what they were charging one highway agency versus another. Finally, the third set of chemical cost information came from Clear Roads states as a result of an appeal in Task 2 for addition cost information. Liquid chemical cost data are given in $/gal units and the solid chemical cost data are given in $/ton units.

It is easily seen from the cost information received from the highway agencies that the material costs vary widely due mainly to haul distances from the material source (salt mines in Kansas, Louisiana, Chile, Israel etc.) to the destination. This was to be expected. Similar considerations would likely apply to other winter maintenance chemicals as sources are widely dispersed (Great Salt Lake in Utah, brine wells in Ohio, etc.) in the U. S. It can also be seem that the material suppliers provided little useful chemical cost data due likely to supplier competitiveness concerns.

At first glance, one could look at the tabulated material cost data in Appendix F and make the following assumptions. Most of the chloride brines and organic inhibited liquids make up the lowest cost material, the solids such as rock salt and $CaCl_2$ and the liquid acetates make up the broad middle class cost material, and the solid acetates (CAM) make up the highest cost class. However, this approach is not completely correct. Some of the liquids are used individually while other liquids are used in combinations with solids as prewetting agents. In addition, the liquid costs are on a different basis ($/gal) than the solids ($/ton). Thus, one needs to determine a way of normalizing the costs of the different products. This normalization can be achieved if we look at the material costs on a per lane-mile application basis. Following this approach, it is possible to get a simplistic "feel" for some comparison of chemical cost using the limited delivered material cost data provided by several highway agencies.

For example, one can compare the delivered chemical costs in a region to the various application rates for specific storm event scenarios and established operation temperature ranges. To illustrate this point, consider the following liquid and solid chemical cost data from a MnDOT maintenance area. These data were obtained external to the agency's returned questionnaire.

The known delivered cost of dry salt to a truck station in the Minneapolis-St. Paul Metro area is approximately $75.00 per ton or $0.04 per pound. Given a per gallon cost of say, RoadGuard-8 ® (principally $CaCl_2$) of $1.53 per gallon (per pound cost of $0.133) and a salt-RoadGuard® mix ratio of 90/10, the per pound mix cost of pre-wet salt will be $0.049 per pound. From these unit per pound values, the respective costs for pre-treating one lane-mile of pavement ahead of a forecasted snow storm event with minimum pavement temperatures of 16 to 20 degrees F will be $10.00 and $12.25 respectively. Per lane-mile treatment costs for other regions can be similarly computed once the local material costs are known. However, state-reported pre-wetting benefits exceeding 30% resulting from better adhesion of salt to the pavement, less bounce and scatter and faster melting action more than offset the example's 22.5% increase in cost due to prewetting.

Similar calculations can be made for other snow and ice control chemicals such as $MgCl_2$, $CaCl_2$, KAc, and CMA. These in turn will enable an approximate comparison of treatment costs for various chemicals. To illustrate, one upper Midwestern state agency noted that they typically perform anti-icing operations with liquids at an application rate of 25 to 30 gallons per lane mile. With their $CaCl_2$ (RoadGuard8) , $MgCl_2$ (Freezeguard) and CF-7 delivered costs of $1.50, $1.03, and $4.00 per gallon, respectively, and a mid-range 27.5 gallon per lane-mile application rate for an unspecified range of storm conditions, application costs per lane-mile would be roughly $41.25, $28.33, and $110.00, respectively. The distinct lack of data on related storm and temperature conditions for this example precludes any definitive cost estimates for any other specific pre-storm conditions at this time. Thus it can be seen from these examples of material cost comparisons, one needs to consider the material costs in a geographical region together with the application rates used in that region for the various storm event types expected.

7.0 Summary of Task 2 Findings

This report documents the findings from the Task 2 activities associated with updating the chemical application rate guidelines in NCHRP Report #526. The updating includes information on a wide range of snow and ice control chemicals currently used in winter maintenance operations. A summary of the Task 2 activities and findings follows:

- ❖ The update development started with NaCl, the most common chemical used in snow and ice control operations.
- ❖ The presentation of the application rates for NaCl is patterned after the approach given in the FHWA Manual of Practice. That is, suggested application rates are given for a range of pavement temperatures during given precipitation or icing events.
- ❖ Application rates for dry, prewetted solid, and liquid sodium chloride are given for both pretreatment of road surfaces as well as for within-event conditions. Events considered for pretreatment conditions include snow, frost/black ice, freezing rain, and sleet. Rates for expanded levels of precipitation are given for within-event conditions along with considerations for anti-icing and deicing operations.

- Freezing point versus composition (in weight % or specific gravity) were used to determine equivalent application rates for $CaCl_2$, $MgCl_2$, KAc, and CMA relative to that determined for NaCl in the pavement temperature range of 6° to 32° F.
- Tables of application rates for liquid NaCl, $CaCl_2$, $MgCl_2$, KAc, and CMA plus solid NaCl, $CaCl_2$, Ice Slicer, and CMA were developed for both pretreatment of road surface as well as for within-event conditions. Events considered for both pretreatment as well as within-event conditions are the same as those described for NaCl above.
- An approach was developed for determining the application rates of liquid snow and ice control chemicals containing organic additives. This approach involves comparing the phase diagram information of the chemical with the additive to the phase diagram of the primary base brine chemical of either NaCl, $CaCl_2$, or $MgCl_2$ that is combined with the additive. Thus, the application rate of a given liquid chemical with an organic additive can be determined for any operating pavement temperature and storm event by applying a decimal percent correction to the values in the application rate table for the base brine chemicals.
- Phase diagrams or freezing curves can provide useful information about the potential utility of a chemical agent in winter road maintenance for freezing point depression.
- Phase diagrams alone cannot predict the performance of a particular chemical mixture for deicing, anti-icing, or pre-treatment of stockpile salts.
- The phase diagrams themselves do not provide information about melting rates or refreeze rates, but do indicate at what temperature a diluted product will be likely to refreeze.
- We have shown that it is possible to use phase diagrams of single compounds to generate equivalent application rates based upon the relative concentrations of the liquid phases needed to achieve a particular freezing point.
- There are an increasing number of products sold as “enhancers” or “corrosion reducers,” available from an expanding list of suppliers, and it can be difficult or impossible to discern from trade literature the exact composition and nature of the material being described.
- The agricultural derivatives are not single chemical substances, but complex mixtures of proteins, simple and complex sugars, and other agents naturally present or added during their manufacture and processing.
- Modern agricultural additives based on corn, sugar beet molasses, wheat or other grains by themselves *can* function as deicing agents when undiluted, but they may not be appropriate for direct application to roadways if high viscosity impedes normal spray dispersal at a given temperature.
- Some blends of the corn and sugar beet molasses products with chloride salt solutions do exhibit lower freezing points than the pure salt solution alone, but how much lowering of freezing point is achieved depends on the specific additive, its concentration, and the type of application.
- The residue of agriculturally-derived additives remaining on the road after melting occurs might be expected to confer some anti-icing advantage before the next application is applied. This result could not be validated by information obtained from highway agencies experiences.

- It was difficult to get chemical cost information from all but one highway agency (Colorado) that did not include transportation cost elements.
- Very little chemical cost information was obtained from the material suppliers because of competitiveness concerns.

APPENDICES

FOR

TASK 2: UPDATE GUIDELINES

APPENDIX A

Liquid and Solid Snow and Ice Control Chemicals Used by Surveyed Highway Agencies

Table A - 1
Liquid Snow and Ice Control Chemicals Used by Surveyed Highway Agencies

Highway Agency	Common Snow and Ice Control Brine Chemicals w/o Inhibitor				Liquid Snow and Ice Control Chemicals w/o Inhibitor Commercially Produced		
	NaCl	**$CaCl_2$**	**$MgCl_2$**	**KAc**	**Apogee**	**Alpine Ice Melt**	**CF-7**
Brine Chemical(s)	Na	Ca	Mg	KAc	Ac	KAc	KAc
Phase Diagram Available	X	X	X	X	X	X	X
Agencies							
Colorado DOT	1		1		1		
Idaho DOT	1			1			1
Illinois DOT	1	1					
Iowa DOT	1	1					
Kansas DOT	1		1				
Maine DOT	1						
Massachusetts DOT							
Michigan DOT	1		1	1			1
Minnesota DOT	1	1	1	1		1	1
Missouri DOT	1	1					
Montana DOT	1		1				
Nebraska DOT	1			1			1
New York DOT	1						
North Dakota DOT	1						
Ohio DOT	1	1					
Rhode Island DOT	1	1	1				
Utah DOT	1			1			1
Vermont DOT							
Virginia DOT							
Washington State DOT				1			1
West Virginia DOT	1	1					
Wisconsin DOT	1	1					
Wyoming DOT	1						
Subtotal	19	8	6	6	1	1	6

Table A - 1 (cont)
Liquid Snow and Ice Control Chemicals Used by Surveyed Highway Agencies

Highway Agency	Liquid Snow and Ice Control Chemicals Commercially Produced w/Inhibitor														
	NaCl Products Like:		$CaCl_2$ Products Like:				$MgCl_2$ Products Like:								
	Liquid Corn Salt	Unidentified Blend	$CaCl_2$ w/ BOOST	Freeze Fighter Hi-Cal 50	Master Melt 50	Road Guard Plus 8	Caliber M1000	Caliber M2000	Freezegard CI Plus	Ice Ban Ultra 305	Ice B'Gone Magic	Meltdown AP	Meltdown APEX	Thawrox MG	Unidentified Blend
Brine Chemical(s)	Na	Na	Ca	Ca, Na, Mg	Ca, Na, Mg	Ca,Na,Mg,K	Mg		Mg	Mg	Mg	Mg	Mg	Mg	Mg
Phase Diagram Available						X	X		X	X		X	X		
Agencies															
Colorado DOT							1			1		1	1		
Idaho DOT															
Illinois DOT															
Iowa DOT															
Kansas DOT															
Maine DOT											1				
Massachusetts DOT															
Michigan DOT															
Minnesota DOT	1					1			1	1			1	1	
Missouri DOT															
Montana DOT		1							1						1
Nebraska DOT													1		
New York DOT			1				1	1		1			1		
North Dakota DOT															
Ohio DOT															
Rhode Island DOT															
Utah DOT															
Vermont DOT															
Virginia DOT															
Washington State DOT	1		1						1						
West Virginia DOT															
Wisconsin DOT															
Wyoming DOT															
Subtotal	2	1	2	0	0	1	2	1	3	3	1	1	4	1	1

Table A - 1 (cont)

Liquid Snow and Ice Control Chemicals Used by Surveyed Highway Agencies

Highway Agency	Common Snow and Ice Control Brine Chemicals w/o Inhibitor				Liquid Snow and Ice Control Chemicals w/o		
	NaCl	$CaCl_2$	$MgCl_2$	KAc	Apogee	Alpine Ice Melt	CF-7
Brine Chemical(s)	Na	Ca	Mg	KAc	Ac	KAc	KAc
Alberta, DOT	1	1	1				
Manitoba, MIT	1						
New Brunswick, DOT	1						
Nova Scotia	1						
Ontario, MTO	1	1	1	1			
Quebec. DOT							
Saskatchewan, DOT	1						
Subtotal	6	2	2	1	0	0	0
City of Calgary							
City of Denver			1				
City of Toronto	1						
Lake St. Louis	1						
McHenry Co, IL	1	1	1				
NY Throughway Auth.	1						
West Des Moines	1	1					
Subtotal	5	2	2	0	0	0	0

Table A - 1 (cont)
Liquid Snow and Ice Control Chemicals Used by Surveyed Highway Agencies

Highway Agency	Liquid Snow and Ice Control Chemicals Commercially Produced w/Inhibitor														
	NaCl Products Like:		$CaCl_2$ Products Like:				$MgCl_2$ Products Like:								
	Liquid Corn Salt	Unidentified Blend	$CaCl_2$ w/ BOOST	Freeze Fighter Hi-Cal 50	Master Melt 50	Road Guard Plus 8	Caliber M1000	Caliber M2000	Freezegard Cl Plus	Ice Ban Ultra 305	Ice B'Gone Magic	Meltdown AP	Meltdown APEX	Thawrox MG	Unidentified Blend
Brine Chemical(s)	Na	Na	Ca	Ca, Na, Mg	Ca, Na, Mg	Ca, Na, Mg, KCl	Mg		Mg	Mg	Mg	Mg	Mg	Mg	Mg
Alberta, DOT							1			1					
Manitoba, MIT										1					
New Brunswick, DOT															
Nova Scotia															
Ontario, MTO				1	1										
Quebec. DOT															
Saskatchewan, DOT							1			1					
Subtotal	**0**	**0**	**0**	**1**	**1**	**0**	**2**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**
City of Calgary															
City of Denver															
City of Toronto							1								
Lake St. Louis															
McHenry Co. IL															
NY Throughway Auth.															
West Des Moines															
Subtotal	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table A-2

Solid Snow and Ice Control Chemicals with their Prewetting Agents of Surveyed Highway Agencies

Highway Agency	Common Snow and Ice Control Solid Chemicals w/o Inhibitor					Solid Snow and Ice Control Chemicals Commercially Produced w/ inhibitor						
	Rock Salt	Solar Salt	$CaCl_2$	Ice Slicer	CMA	ClearLane enhanced	Blue Magic Salt	Ultra Magic Salt	SWP Treated	Thawrox	Rapid Thaw	Quick Salt
Brine Chemical(s)	Na	Na	Ca	Na,Mg, Ca		Na	Na	Na	Na	Na	Na	Na
Phase Diagram Available	X		X		X							
Agencies												
Colorado DOT	1	1		1							1	1
Idaho DOT	1			1								
Illinois DOT	1		1									
Iowa DOT	1		1									
Kansas DOT	1											
Maine DOT	1											
Massachusetts DOT												
Michigan DOT	1		1		1							
Minnesota DOT	1									1		
Missouri DOT	1		1									
Montana DOT												
Nebraska DOT	1			1								
New York DOT	1					1	1	1	1			
North Dakota DOT	1											
Ohio DOT	1											
Rhode Island DOT	1											
Utah DOT	1	1		1								
Vermont DOT												
Virginia DOT												
Washington State DOT	1	1										
West Virginia DOT	1		1									
Wisconsin DOT	1											
Wyoming DOT	1											
Subtotal	19	3	5	4	1	1	1	1	1	1	1	1

Table A -2 (cont.)

Solid Snow and Ice Control Chemicals with their Prewetting Agents of Surveyed Highway Agencies

Highway Agency	Liquid Chemicals Used for Pre-wetting												
	with Inhibitors										with out Inhibitors		
	Caliber M-2000	Ice B'Gone Magic	Ice Ban	GeoMelt 55	MC 95	Arctic Clear Gold	BOOST	Liquid Corn Salt	Thawrox MG	Meltdown APEX	Salt Brine	$MgCl_2$ Brine	$CaCl_2$ Brine
Brine Chemical(s)	Mg		Mg		Ca,Mg,Na,				Mg	Mg	Na	Mg	Ca
Phase Diagram Available			X	X						X	X	X	X
Agencies													
Colorado DOT	1									1	1		
Idaho DOT											1		
Illinois DOT											1		
Iowa DOT											1		
Kansas DOT											1	1	
Maine DOT		1									1		
Massachusetts DOT													
Michigan DOT							1				1		
Minnesota DOT								1	1		1		
Missouri DOT				1							1		
Montana DOT				1									
Nebraska DOT				1							1		
New York DOT	1	1								1	1		
North Dakota DOT				1							1		
Ohio DOT		1		1							1		
Rhode Island DOT											1		
Utah DOT											1		
Vermont DOT													
Virginia DOT													
Washington State DOT											1		
West Virginia DOT											1		1
Wisconsin DOT					1	1					1		1
Wyoming DOT				1							1		
Subtotal	2	3	0	6	1	1	1	1	1	2	19	1	2

Table A-2 (cont)

Solid Snow and Ice Control Chemicals with their Prewetting Agents of Surveyed Highway Agencies

Highway Agency	Common Snow and Ice Control Solid Chemicals w/o Inhibitor					Solid Snow and Ice Control Chemicals Commercially Produced w/ inhibitor						
	Rock Salt	Solar Salt	$CaCl_2$	Ice Slicer	CMA	ClearLane enhanced	Blue Magic Salt	Ultra Magic Salt	SWP Treated	Thawrox	Rapid Thaw	Quick Salt
Alberta, DOT	1											
Manitoba, MIT	1											
New Brunswick, DOT	1											
Nova Scotia	1											
Ontario, MTO	1											
Quebec. DOT												
Saskatchewan, DOT	1											
Subtotal	6	0	0	0	0	0	0	0	0	0	0	0
City of Calgary												
City of Denver				1								
City of Toronto	1											
Lake St. Louis	1											
McHenry Co, IL										1		
NY Throughway Auth.	1					1						
West Des Moines	1											
Subtotal	4	0	0	1	0	1	0	0	0	1	0	0

Table A -2 (cont.)

Solid Snow and Ice Control Chemicals with their Prewetting Agents of Surveyed Highway Agencies

Highway Agency	Liquid Chemicals Used for Pre-wetting												
	with Inhibitors										with out Inhibitors		
	Caliber M-2000	Ice B'Gone Magic	Ice Ban	GeoMelt 55	MC 95	Arctic Clear Gold	BOOST	Liquid Corn Salt	Thawrox MG	Meltdown APEX	Salt Brine	$MgCl_2$ Brine	$CaCl_2$ Brine
	Mg		Mg		Ca,Mg,Na,				Mg	Mg	Na	Mg	Ca
Alberta, DOT											1		1
Manitoba, MIT	1		1	1									
New Brunswick, DOT											1		
Nova Scotia											1		
Ontario, MTO											1		
Quebec. DOT													
Saskatchewan, DOT											1		
Subtotal	1	0	1	1	0	0	0	0	0	0	5	0	1
City of Calgary													
City of Denver										1			
City of Toronto											1		
Lake St. Louis				1							1		
McHenry Co, IL													
NY Throughway Auth.				1							1	1	
West Des Moines				1							1		
Subtotal	0	0	0	3	0	0	0	0	0	1	4	1	0

APPENDIX B

Minimum Pavement Temperatures Recommendations

Table B - 1
Minimum Pavewment Temperatures Recommended for Liquid Chemicals

	Chemical	Colorado DOT	Idaho DOT	Illinois DOT	Iowa DOT	Kansas DOT	Maine DOT	Massachusetts DOT	Michigan DOT	Minnesota DOT	Missouri DOT	Montana DOT	Nebraska DOT	New York DOT	North Dakota DOT	Ohio DOT	Rhode Island DOT	Utah DOT	Vermont DOT	Virginia DOT	Washington State DOT	West Virginia DOT	Wisconsin DOT	Wyoming DOT
		Data obtained from questionnaires returned by highway DOTs																						
Liquids	Apogee																							
	Alpine Ice Melt																							
	BEET 55																							
	BEET HEET																							
	BOOST 55																							
	Calcium Chloride																							
	$CaCl_2$ w/ BOOST																				15°F			
	Caliber M1000	5 - 17 °F																						
	Caliber M2000																							
	BEET HEET Concentrate																							
	Clear Guard																							
	Cryotech CF7																	10°F						
	Freeze Fighter HiCal 50																							
	Freezgard																							
	Freezgard Zero CCI																				15°F			
	Fusion 55																							
	GeoMelt 55																							
	GeoMelt +NaCl														15°F									18°F
	Headwaters - Inhiviroea																							
	Ice Ban 305																							
	Ice B'Grone Magic																							
	Liquid Corn Salt																							
	Magnesium Chloride	16-32°F	15°F							No Minimum		10°F						10°F						
	Master Melt 50																							
	Meltdown AP																							
	Meltdown APEX	O - 17 °F																						0°F
	Road Guard Plus																							
	Salt brine	16-32°F	20°F	15°F	15°F	15°F	10°F			No Minimum	20°F	10°F	5°F	15°F	15°F	20°F	25°F	18°F			20°F	15°F		18°F
	Salt brine (23%) +AMP (5%)																							
	SOS																							
	TC Econo																							
	Thawrox MG																							

Table B - 1 (cont)
Minimum Pavement Temperature Recommended for Liquid Chemicals

	Chemical	Data obtained from local agencies					Data obtained from questionnaires returned by vendors													
		City of Lake Saint Louis	City of Denver	McHenry Co	NYS Thruway Authority	West Des Moines	Smith Fertilize & Grain	American West Environmental	Cargill Deicing Technology	Cryotech Deicing Technology	EnviroTech Services Inc.	K-Tech Specialty Coatings	Naturalawn of America	North American Salt Co.	Northern Salt Inc	Redmond Minerals Inc.	Rivertop Rebewabke	Sears	Redmond Minerals Inc.	Northern Salt Inc.
Liquids	Apogee																			
	Alpine Ice Melt																			
	BEET 55																			
	BEET HEET																			
	BOOST 55																			
	Calcium Chloride																			
	$CaCl_2$ w/ BOOST							Mid. 30's and falling												
	Caliber M1000																			
	Caliber M2000																			
	BEET HEET Concentrate																			
	Clear Guard																			
	Cryotech CF7																			
	Freeze Fighter HiCal 50																			
	Freezgard													5° - 30°F						
	Freezgard Zero CCI																			
	Fusion 55																			
	GeoMelt 55																			
	GeoMelt +NaCl																			
	Headwaters - Inhiviroea																			
	Ice Ban 305																			
	Ice B'Grone Magic																	-15°F		
	Liquid Corn Salt																			
	Magnesium Chloride																			
	Master Melt 50																			
	Meltdown AP										$> 4^{\circ}$F									
	Meltdown APEX										$> -8^{\circ}$F									
	Road Guard Plus																			
	Salt brine	No Mim	15°F	15°F	19°F	10°F														
	Salt brine (23%) +AMP (5%)																			
	SOS										$> 5 - 10^{\circ}$F									
	TC Econo																			
	Thawrox MG																			

Table B - 2

Minimum Pavement Temperature Recommended for Solid Chemicals

	Chemical	Colorado DOT	Idaho DOT	Illinois DOT	Iowa DOT	Kansas DOT	Maine DOT	Massachusetts DOT	Michigan DOT	Minnesota DOT	Missouri DOT	Montana DOT	Nebraska DOT	New York DOT	North Dakota DOT	Ohio DOT	Rhode Island DOT	Utah DOT	Vermont DOT	Virginia DOT	Washington State DOT	West Virginia DOT	Wisconsin DOT	Wyoming DOT
		Data obtained from questionnaires returned by highway DOTs																						
Solids	AMP																							
	Anti-Corrosion Super Salt																							
	ClearLane enhanced																							
	Cryotech NAAC																							
	Cryotech CMA																							
	Cryotech CMA40																							
	Flake Calcium Chloride																							
	Ice Slicer												<5^{o}F					5^{o}F						
	Natural Alternative Ice Melt																							
	North Pro																							
	Rapid Thaw	17^{o}																						
	Rock Salt	No Mim	15^{o}F		15^{o}F	15^{o}F	5-15^{o}F		5-10^{o}F		10^{o}F	10^{o}F	>5^{o}F	15^{o}F	>10^{o}F	20^{o}F	15^{o}F				15^{o}F	No Mim		
	Solar Quicksalt	17^{o}																18^{o}F						
	Salt Blend-$CaCl_2$ Enhanced															0^{o}F								
	Thawrox																							
	Tiger Salt																							

Table B - 2 (cont)

Minimum Pavement Temperature Recommended for Solid Chemicals

Chemical		Data obtained from local agencies					Data obtained from questionnaires returned by vendors													
		City of Lake Saint Louis	City of Denver	McHenry Co	NYS Thruway Authority	West Des Moines	Smith Fertilize & Grain	American West Environmental	Cargill Deicing Technology	Cryotech Deicing Technology	EnviroTech Services Inc.	K-Tech Specialty Coatings	Naturalawn of America	North American Salt Co.	Northern Salt Inc	Redmond Minerals Inc.	Rivertop Rebewabke	Sears	Redmond Minerals Inc.	Northern Salt Inc.
Solids	AMP										> 10°F									
	Anti-Corrosion Super Salt																			
	ClearLane enhanced								25°F-0°F											
	Cryotech NAAC																			
	Cryotech CMA																			
	Cryotech CMA40																			
	Flake Calcium Chloride																			
	Ice Slicer										> 0 - 10°F					0° - 32°F				
	Natural Alternative Ice Melt																			
	North Pro																			
	Rapid Thaw																			
	Rock Salt	None	None	0°F		10°F								10° - 32°F	> 10°F					
	Solar Quicksalt																			
	Salt Blend-$CaCl_2$ Enhanced																			
	Thawrox													5° - 32°F						
	Tiger Salt																			

Table B - 3

Temperature Limitations Histogram Study

Minimum Pavement Temperature Listed for Liquid Chemical Application and Solids

Min Temp	NaCl Brine				$MgCl_2$ Brine				$CaCl_2$ Brine				KAc Brine			
	Reported by Highway DOT	Reported by Local Agencies	Reported by Vendors	Total	Reported by Highway DOT	Reported by Local Agencies	Reported by Vendors	Total	Reported by Highway DOT	Reported by Local Agencies	Reported by Vendors	Total	Reported by Highway DOT	Reported by Local Agencies	Reported by Vendors	Total
25° F	1			1												
20° F	4			4												
18° F	2	1		3												
15° F	7	2		9	3		1	4	1			1				
10°	2	1		3	2		1	3	1			1				
5° F	1			1			3	3								
0°					2			2								

Min Temp	Rock Salt			
	Reported by Highway DOT	Reported by Local Agencies	Reported by Vendors	Total
25° F				0
20° F				0
18° F				0
15° F				0
10°				0
5° F				0
0°				

APPENDIX C

Recommendations for Application Rates for Prewetted Solid Salt and Liquid Salt (Sodium Chloride)

Table C-1

PRETREATMENT OF ROAD SURFACES FOR SNOW AND FFROST/BLACK ICE EVENTS				
Pavement temperature, ^{O} F, at time of precipitation onset	APPLICATION RATES FOR PREWETTED SOLID SALT AND LIQUID SALT (SODIUM CHLORIDE)			
	Anticipated Event Type			
	Snow		Frost/Black ice	
	Solid, lb/lane-mi	Liquid, gal/lane-mi	Prewetted solid NaCl, lb/lane-mi	Liquid NaCl, gal/lane-mi
Over 30	110	48	100	44
26 to 30	160	70	130	57
21 to 25	210	92	160	70
16 to 20	250	109	190	83
Below 15	PA	NR	AA	NR

PA = Plow and Apply Abrasives as Needed AA = Apply Abrasives as Needed

NR = Not Recommended

MAINTENANCE ACTION NOTES:

1. Dry (non-prewet) salt should **only** be used as a pretreatment on low speed, low volume roads.
2. Other Liquid chemicals – Application rates and advisability will vary with chemical type, concentration, road temperature and relative humidity at the time of application.
3. Dry and prewet solid salt should be distributed in 3 to 4 foot bands, near the high side of each travel lane.
4. Some highway agencies have found that by prewetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.

Table C-2

PRETREATMENT OF ROAD SURFACES FOR FREEZING RAIN AND SLEET EVENTS				
Pavement temperature, °F, at time of precipitation onset	APPLICATION RATES FOR PREWETTED SOLID SALT AND LIQUID SALT (SODIUM CHLORIDE)			
	Anticipated Event Type			
	Freezing rain		Sleet	
	Solid, lb/lane-mi	Liquid NaCl, gal/lane-mi	Prewetted solid NaCl, lb/lane-mi	Liquid NaCl, gal/lane-mi
Over 30	125	55	120	NR
26 to 30	175	76	175	NR
21 to 25	225	NR	230	NR
16 to 20	275	NR	275	NR
Below 15	AA	NR	PA	NR

AA = Apply Abrasives as Needed PA = Plow and Apply Abrasives as Needed

NR = Not Recommended

MAINTENANCE ACTION NOTES:

1. Dry (non-prewet) salt should **only** be used as a pretreatment on low speed, low volume roads.
2. Other Liquid chemicals – Application rates and advisability will vary with chemical type, concentration, road temperature and relative humidity at the time of application.
3. Dry and prewet solid salt should be distributed in 3 to 4 foot bands, near the high side of each travel lane.
4. Some highway agencies have found that by prewetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.
5. Liquid chemicals should be used to pretreat for **Light Freezing Rain** events **only.**

6. A. Sleet usually does not bond to the road readily. Try plowing only as the initial treatment and apply chemicals only if bonded.

Table C-3

SNOW Within-Event Application Rates for Dry Salt, Prewetted Salt and Liquid Salt Brine (Sodium Chloride)						
Pavement temperature, °F, at time of application	APPLICATION RATE Pounds per Lane-Mile (Gallons per Lane-Mile)					
	Snow Event Type					
	Light snow		Moderate snow		Heavy snow	
	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	110 (48)	240 (NR)	130 (57)	265 (NR)	150 (66)	290 (NR)
26 to 30	160 (70)	350 (NR)	175 (76)	375 (NR)	190 (83)	400 (NR)
21 to 25	200 (87)	425 (NR)	210 (92)	450 (NR)	220 (96)	475 (NR)
16 to 20	230 (100)	500 (NR)	240 (105)	525 (NR)	250 (109)	PA (NR)
11 to 15	260 (NR)	PA (NR)	270 (NR)	PA (NR)	280 (NR)	PA (NR)
Below 10	PA (NR)	PA (NR)	PA (NR)	PA (NR)	PA (NR)	PA (NR)

NR = Not Recommended PA = Plow and Apply Abrasives as Needed

MAINTENANCE ACTION NOTES:

1. Application rates may be increased by 25% for cycle time greater than 3 hours.
2. For maximum effectiveness, salt should be placed in 3ft. to 4ft. bands on the high side of each travel lane. As pavement temperature becomes lower and /or the event intensity becomes very heavy, the spread pattern should be further narrowed.

3. For pavement temperatures over 32°F and likely to remain at that level, try plowing without spreading salt, especially, if the snow is not bonded to the pavement.

4. It may be uneconomical and operationally impossible to use application rates in excess of 500 pounds per lane-mile. Many agencies choose to use sand/salt mixtures in lower pavement temperature situations until warmer pavement temperature conditions are present.

5. Some highway agencies have found that by prewetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.

Table C-4

FROST AND BLACK ICE Within-Event Application Rates for Dry Salt, Prewetted Salt and Liquid Salt Brine (Sodium Chloride)				
Pavement temperature, °F, at time of application	APPLICATION RATE			
	Anti-icing		Deicing	
	Dry and pre-wet dry salt (lb/lane-mi)	Salt brine (gal/lane-mi)	Dry and pre-wet dry salt (lb/lane-mi)	Salt brine (gal/lane-mi)
Over 30	100	44	225	98
26 to 30	130	57	250	109
21 to 25	160	70	275	120
16 to 20	190	83	300	NR
Below 15	AB	NR	AB	NR

NR = Not Recommended AB = Apply Abrasives as Needed

Maintenance Action Notes:

1. If possible, dry salt should **not** be used, due to the high potential for bounce and scatter and traffic displacement.
2. Material should be spread reasonably uniformly across the travel lanes.
3. Some highway agencies have found that by prewetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.

Table C-5

FREEZING RAIN Within-Event Application Rates for Dry Salt, Prewetted Salt and Liquid Salt Brine (Sodium Chloride)						
Pavement temperature, ^{O} F, at time of application	APPLICATION RATE Pounds per Lane-Mile (Gallons per Lane-Mile)					
	Freezing Rain Event Type					
	Light freezing rain		Moderate freezing rain		Heavy freezing rain	
	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	110 (48)	240 (NR)	130 (NR)	265 (NR)	150 (NR)	290 (NR)
26 to 30	170 (74)	350 (NR)	180 (NR)	375 (NR)	190 (NR)	400 (NR)
21 to 25	200 (87)	425 (NR)	210 (NR)	450 (NR)	220 (NR)	475 (NR)
16 to 20	230 (NR)	500 (NR)	240 (NR)	525 (NR)	250 (NR)	AA (NR)
11 to 15	260 (NR)	AA (NR)	270 (NR)	AA (NR)	280 (NR)	AA (NR)
Below 10	AA (NR)	AA (NR)	AA (NR)	AA (NR)	AA (NR)	AA (NR)

NR = Not Recommended AA = Apply Abrasives as Needed

maintenance ACTION NOTES:

1. Application rates may be increased by 25% for treatment cycle time greater than 3 hours.

2. For maximum effectiveness, salt should be placed in 3ft. to 4ft. bands on the high side of each travel lane. In the case of heavy freezing rain or thick ice on the pavement, a very narrow band of salt should be placed on the high side wheel path of each travel lane.

3. For frost/black ice/light freezing rain, a more general distribution pattern across the travel lanes is recommended.

4. It may be uneconomical and operationally impossible to use application rates in excess of 500 pounds per lane-mile. Many agencies choose to use sand/salt mixtures in lower pavement temperature situations until warmer pavement temperature conditions are present.

5. Some highway agencies have found that by pre-wetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.

Table C-6

SLEET Within-Event Application Rates for Dry Salt, Prewetted Salt and Liquid Salt Brine (Sodium Chloride)						
Pavement temperature, °F, at time of application	APPLICATION RATE Pounds per Lane-Mile (Gallons per Lane-Mile)					
	Sleet Event Type					
	Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	120 (NR)	265 (NR)	145 (NR)	290 (NR)	165 (NR)	320 (NR)
26 to 30	175 (NR)	385 (NR)	195 (NR)	410 (NR)	210 (NR)	440 (NR)
21 to 25	220 (NR)	465 (NR)	230 (NR)	500 (NR)	240 (NR)	525 (NR)
16 to 20	250 (NR)	PA (NR)	260 (NR)	PA (NR)	280 (NR)	PA (NR)
11 to 15	285 (NR)	PA (NR)	300 (NR)	PA (NR)	310 (NR)	PA (NR)
Below 10	PA (NR)	PA (NR)	PA (NR)	PA (NR)	PA (NR)	PA (NR)

NR = Not Recommended   PA = Plow and Apply Abrasives as Needed

MAINTENANCE ACTION NOTES:

1A. Sleet usually does not bond to the road readily. Try plowing only as the initial treatment and apply chemicals only if bonded.

1B. The ice component of sleet is very high and will quickly overwhelm the limited amount of chemical that liquids are capable of delivering to the road surface.

2. Application rates may be increased by 25% for cycle time greater than 3 hours.

3. For maximum effectiveness, salt should be placed in 3ft. to 4ft. bands on the high side of each travel lane. As pavement temperature becomes lower and /or the event intensity becomes very heavy, the spread pattern should be further narrowed.

4. It may be uneconomical and operationally impossible to use application rates in excess of 500 pounds per lane-mile. Many agencies choose to use sand/salt mixtures in lower pavement temperature situations until warmer pavement temperature conditions are present.

5. Some highway agencies have found that by prewetting dry salt with a chloride based chemical, or prewetting dry salt with a chloride based chemical mixed with an organic/carbohydrate additive, the application rate of the dry salt component can be reduced from that given in the table above.

APPENDIX D

Meteorological Definitions of Winter Weather Events

Glossary of Meteorological Terms

- **Black ice**. Popular term for a very thin coating of clear, bubble-free, homogeneous ice which forms on a pavement with a temperature at or slightly above 32° F when the temperature of the air in contact with the ground is below the freezing-point of water and small slightly supercooled water droplets deposit on the surface and coalesce (flow together) before freezing.

- **Freezing rain.** Supercooled droplets of liquid precipitation falling on a surface whose temperature is below or slightly above freezing, resulting in a hard, slick, generally thick coating of ice commonly called glaze or clear ice. Non-supercooled raindrops falling on a surface whose temperature is well below freezing will also result in glaze.

- **Light freezing rain.** Small supercooled liquid droplets falling at a rate such that individual drops are easily detectable.

- **Moderate freezing rain.** Small supercooled liquid droplets that are not clearly identifiable when falling. Some sprays from the falling drops are observable just above the pavement or other hard surfaces and a slow accumulation is observed on vegetation and hard surfaces.

- **Heavy freezing rain.** Small supercooled liquid droplets that seemingly fall in sheets. Individual drops are not identifiable. A rapid accumulation of ice is observed on vegetation and hard surfaces.

- **Sleet (ice Pellets).** Precipitation of transparent or translucent pellets of ice, that are round or irregular in shape.

- **Light sleet.** Scattered pellets that do not completely cover an exposed surface regardless of duration. Visibility is not affected.

- **Moderate sleet.** Slow accumulation of ice pellets on the pavement and ground. Visibility is by the falling pellets to less than 7 miles.

- **Heavy sleet.** Rapid accumulation on the pavement and ground. Visibility is reduced by the ice pellets to less than 3 miles.

- **Light snow.** Snow alone is falling at a rate of less than ½ inch per hour and the visibility is greater than ½ mile.

- **Moderate snow.** Snow alone is falling at a rate of ½ inch per hour or greater. The visibility is greater than ¼ mile but less than or equal to ½ mile.

- **Heavy snow**. Snow alone is falling at a rate of 1 inch per hour or greater. The visibility is less than or equal to ¼ mile.

APPENDIX E

Projected Application Rates for Other Common Snow and Ice Control Chemicals

Table E-1
Projected Liquid Application Rates for Common Snow and Ice Control Chemicals

Pavement temperature, °F, at time of application	Liquid NaCl at 23% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	48	44	55	NR	48	57	66	44	98	48	57	66	NR	NR	NR
26 to 30	70	57	76	NR	70	76	83	57	109	74	79	83	NR	NR	NR
21 to 25	92	70	99	NR	87	92	96	70	120	87	92	96	NR	NR	NR
16 to 20	109	83	121	NR	100	105	109	83	132	100	105	109	NR	NR	NR
11 to 15	132	97	143	NR	113	118	122	97	143	113	118	122	NR	NR	NR
6 to 10	153	110	165	NR	129	135	135	110	154	126	131	135	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, °F, at time of application	Liquid MgCl2 at 27% concentration - gallons per lane mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	35	32	40	NR	35	42	48	32	72	35	41	48	NR	NR	NR
26 to 30	51	42	56	NR	51	56	61	42	80	54	57	60	NR	NR	NR
21 to 25	69	53	74	NR	66	69	72	53	90	65	69	72	NR	NR	NR
16 to 20	80	61	88	NR	73	76	80	61	95	73	76	79	NR	NR	NR
11 to 15	90	66	98	NR	77	80	83	66	98	77	80	83	NR	NR	NR
6 to 10	101	73	109	NR	85	89	89	73	102	83	86	89	NR	NR	NR
Below 5	NR	NA	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

Table E-1 (cont)

Projected Liquid Application Rates for Common Snow and Ice Control Chemicals

Pavement temperature, ^{o}F, at time of application	Liquid CaCl2 at 32% concentration - gallons per lane - mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	34	31	39	NR	34	41	47	31	69	34	40	47	NR	NR	NR
26 to 30	49	40	54	NR	50	54	59	40	77	52	56	58	NR	NR	NR
21 to 25	65	49	70	NR	62	65	68	49	85	61	65	68	NR	NR	NR
16 to 20	74	56	83	NR	69	72	75	56	89	68	72	74	NR	NR	NR
11 to 15	87	64	94	NR	75	77	81	64	94	74	78	80	NR	NR	NR
6 to 10	101	73	109	NR	85	89	89	73	102	83	86	89	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Pavement temperature, ^{o}F, at time of application	Liquid KAc at 50% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	35	32	40	NR	35	42	32	32	72	35	NR	NR	NR	NR	NR
26 to 30	51	42	56	NR	51	56	61	42	80	54	NR	NR	NR	NR	NR
21 to 25	61	47	65	NR	58	61	63	47	80	58	NR	NR	NR	NR	NR
16 to 20	65	49	72	NR	60	62	64	49	77	59	NR	NR	NR	NR	NR
11 to 15	72	53	78	NR	62	64	67	53	78	62	NR	NR	NR	NR	NR
6 to 10	83	60	90	NR	70	74	74	60	84	69	NR	NR	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

Table E-1 (cont)

Projected Liquid Application Rates for Common Snow and Ice Control Chemicals

Pavement temperature, °F, at time of application	Liquid CMA at 25% concentration - gallons per lane-mile														
	Pre-Treatment				Within-Event										
	Snow	Frost/black Ice	Freezing rain	Sleet	Light Snow	Moderate Snow	Heavy Snow	Frost and Black Ice		Light freezing rain	Moderate freezing rain	Heavy freezing rain	Light sleet	Moderate sleet	Heavy sleet
	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Deicing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing	Anti-icing
Over 30	20	18	23	NR	20	24	27	18	41	20	24	27	NR	NR	NR
26 to 30	29	24	31	NR	29	32	34	24	45	31	33	34	NR	NR	NR
21 to 25	36	27	38	NR	34	36	37	27	47	34	36	37	NR	NR	NR
16 to 20	40	30	44	NR	37	39	40	30	48	37	39	40	NR	NR	NR
11 to 15	48	35	52	NR	41	43	45	36	52	41	43	45	NR	NR	NR
6 to 10	52	38	56	NR	44	46	46	38	53	43	45	46	NR	NR	NR
Below 5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR = Not Recommended

APPENDIX F

Cost Information on Chemicals Used in Winter Operations

Table F-1

Cost Information on Chemicals Used in Winter Maintenance Operation

	Chemical	Costs Obtained from Questionnaire from Highway DOTs																						
		Colorado DOT	Idaho DOT	Illinois DOT	Iowa DOT	Kansas DOT	Maine DOT	Massachusetts DOT	Michigan DOT	Minnesota DOT	Missouri DOT	Montana DOT	Nebraska DOT	New York DOT	North Dakota DOT	Ohio DOT	Rhode Island DOT	Utah DOT	Vermont DOT	Virginia DOT	Washington State DOT	West Virginia DOT	Wisconsin DOT	Wyoming DOT
Liquids	Apogee																							
	Alpine Ice Melt																							
	BEET 55										$1.10 - $1.25													
	BEET HEET															$1.26								
	BOOST 55																							
	Calcium Chloride									$1.23	$0.65-$0.90			$1.15		$0.62	$1.35					$0.84	$0.90	
	$CaCl_2$ w/ BOOST																	$1.05			$1.20			
	Caliber M1000	$0.82												$0.93-$1.05										
	Caliber M2000	$1.37																						
	BEET HEET Concentrate																							
	Clear Guard																							
	Cryotech CF7									$6.85								$6.45						
	Freeze Fighter HiCal 50																							
	Freezgard																						$0.88	
	Freezgard Zero CCI																				$1.00			
	Fusion 55																							
	GeoMelt 55														$1.28	$1.45							$1.55-$2.30	
	GeoMelt +NaCl														$0.33									$0.85
	Headwaters - Inhiviroea																							
	Ice Ban 305	$0.74																						
	Ice B'Grone Magic						$1.50																	
	Liquid Corn Salt									$2.56														
	Magnesium Chloride					$0.92				$1.18				$0.94			$1.35						$1.07	
	Master Melt 50																							
	Meltdown AP																	$0.58						
	Meltdown APEX	$0.81	$0.81									$0.85		$0.73-$0.91										$1.65
	Road Guard Plus																							
	Salt brine	$0.53	.08-.10	$0.10	$0.11		$0.20			$0.35	$0.15			$0.05- $0.10		$0.07	$0.20	$0.09			$0.50	$0.13	$0.10-$0.28	$0.20
	Salt brine (23%) +AMP (5%)											$0.30												
	SOS																							
	TC Econo																							
	Thawrox MG																							

Table F-1 (cont)

Cost Information on Chemicals Used in Winter Maintenance Operations

	Chemical	Cost Obtained from Local Agencies					Costs Obtained from Vendors									Costs from Clear Roads							
		City of Lake Saint Louis	City of Denver	McHenry Co	NYS Thruway Authority	West Des Moines	Smith Fertilize & Grain	American West Environmer	Cryotech Deicing Technolog	K-Tech Specialty Coatings	Naturalawn of America	Rivertop Rebewabke	Sears	Redmond Minerals Inc.	Northern Salt Inc.	Colorado DOT (Delivered)	Colorado DOT (Pick-up)	Kansas DOT Delivered)	Kansas DOT (pick-up)	North Dakota DOT	Pennsylvania DOT	Iowa DOT	Missouri DOT
Liquids	Apogee																						
	Alpine Ice Melt																						
	BEET 55	$1.25			$1.63		$1.30																
	BEET HEET																						
	BOOST 55																						
	Calcium Chloride			$0.56		$0.60																	
	$CaCl_2$ w/ BOOST							$0.91															
	Caliber M1000																						
	Caliber M2000																						
	BEET HEET Concentrate									$1.14													
	Clear Guard																						
	Cryotech CF7								$6.12 - $7.92														
	Freeze Fighter HiCal 50																						
	Freezgard																						
	Freezgard Zero CCI															$0.76	$0.66						
	Fusion 55																						
	GeoMelt 55			$1.03		$1.20														$0.61			
	GeoMelt +NaCl																						
	Headwaters - Inhiviroea											$3.43											
	Ice Ban 305															$0.83	$0.76						
	Ice B'Grone Magic												≤$1.00										
	Liquid Corn Salt																						
	Magnesium Chloride			$0.51	$0.34																		
	Master Melt 50																						
	Meltdown AP															$0.79	$0.65						
	Meltdown APEX		$1.00													$0.87	$0.93	$0.93					
	Road Guard Plus																						
	Salt brine			$0.09	$0.11	$0.06																	
	Salt brine (23%) +AMP (5%)																						
	SOS																						
	TC Econo																						
	Thawrox MG																						

Note: Cost for Liquids is $ per gallon and Solids is $ per ton

Table F-2
Cost Information on Chemicals Used in Winter Maintenance Operation

	Chemical	Colorado DOT	Idaho DOT	Illinois DOT	Iowa DOT	Kansas DOT	Maine DOT	Massachusetts DOT	Michigan DOT	Minnesota DOT	Missouri DOT	Montana DOT	Nebraska DOT	New York DOT	North Dakota DOT	Ohio DOT	Rhode Island DOT	Utah DOT	Vermont DOT	Virginia DOT	Washington State DOT	West Virginia DOT	Wisconsin DOT	Wyoming DOT
		Costs Obtained from Questionnaire from Highway DOTs																						
Solids	AMP																							
	Anti-Corrosion Super Salt																							
	ClearLane enhanced																							
	Cryotech NAAC																							
	Cryotech CMA																							
	Cryotech CMA40																							
	Flake Calcium Chloride				$278.00						$400.00-$450.00					$389.32						$340.00		
	Ice Slicer	$96.85																						
	Natural Alternative Ice Melt																							
	North Pro																							
	Rapid Thaw	$111.36																						
	Rock Salt	$117.61	$61.58	$60.00	$68.33	$40.63	$59.00-$74.00		$55.00	$71.00	$61.00	$85.00		$49.00	$65.00	$51.79	$52.00	$29.25			$112.00-$150.00	$65.00		$35.00
	Solar Quicksalt	$86.67																$27.75						
	Salt Blend-$CaCl_2$ Enhanced																							
	Thawrox									$100.00				$65.00										
	Tiger Salt																							

Table F-2 (cont)
Cost Information on Chemicals Used in Winter Maintenance Operations

	Chemical	Cost Obtained from Local Agencies					Costs Obtained from Vendors									Costs from Clear Roads							
		City of Lake Saint Louis	City of Denver	McHenry Co	NYS Thruway Authority	West Des Moines	Smith Fertilize & Grain	American West Environmental	Cryotech Deicing Technology	K-Tech Specialty Coatings	Naturalawn of America	Rivertop Rebewabke	Sears	Redmond Minerals Inc.	Northern Salt Inc.	Colorado DOT (Delivered)	Colorado DOT (Pick-up)	Kansas DOT Delivered)	Kansas DOT (pick-up)	North Dakota DOT	Pennsylvania DOT	Iowa DOT	Missouri DOT
Solids	AMP																						
	Anti-Corrosion Super Salt																						
	ClearLane enhanced																						
	Cryotech NAAC								$2,192.73														
	Cryotech CMA								$2,183.60														
	Cryotech CMA 40								$990.91														
	Flake Calcium Chloride																						
	Ice Slicer		$87.00											$12.00									
	Natural Alternative Ice Melt										$310.00												
	North Pro														$93.00								
	Rapid Thaw																						
	Rock Salt	$46.00		$61.00	$55.00	$60.00												$46.00	$30.00		$10.00-$55.00	$58.33-$66.33	$35.00-$40.00
	Solar Quicksalt																						
	Salt Blend-$CaCl_2$ Enhanced																						
	Thawrox			$75.30																			
	Tiger Salt																						

Note: Cost for Liquids is $ per gallon and Solids is $ per ton