NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 24

MINIMIZING DEICING CHEMICAL USE

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
MAINTENANCE, GENERAL
CONSTRUCTION AND MAINTENANCE EQUIPMENT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1974

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the advisory committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the advisory committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This report will be of special interest to highway maintenance engineers, maintenance equipment engineers, and others involved in snow- and ice-removal operations. Both rural and urban environments are considered. Detailed information is presented on a variety of techniques, many of which are relatively new, that are being employed by highway agencies in minimizing the use of chemicals in snow and ice removal consistent with maintaining the level of service required by highway users.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—a synthesis being identified as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems. This is the twenty-fourth report in the series.

Although syntheses normally are accomplished entirely with funds from highway sources, by agreement in this instance the support was augmented by funds from the U.S. Army Cold Regions Research and Engineering Laboratory.

The "bare-pavement" policy adopted for winter-storm treatment in recent years has been understandably popular with highway users; so popular, in fact, that deicing chemicals (mostly sodium chloride) have sometimes been used in unnecessary quantities detrimental to nearby soils, vegetation, and water, and harmful to the pavement structures themselves. A general awareness exists among highway officials and in the chemical industry that the use of chemical deicers should be minimized consistent with keeping the traveled surface in a safe condition. This awareness has, especially in recent years, motivated highway agencies to explore and adopt policies and procedures aimed specifically at minimizing the use of deicing chemicals without reducing the over-all effectiveness of snow- and ice-control operations.

This report of the Transportation Research Board describes and reports on the effectiveness of such approaches to minimizing deicing chemical use as: prewetting salt with liquid chemicals; direct application of liquid chemicals; improved spreader calibration techniques; better management control; special training programs; better use of weather forecasts; use of abrasives in lieu of straight chemicals; and improved snowplow operations. Desirable chemical storage practices are also discussed.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from many highway departments and agencies responsible for highway planning, design, construction, operations, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

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ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The principal investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers.

Special appreciation is expressed to L. David Minsk, Research Physical Scientist, Applied Research Branch, U. S. Army Cold Regions Research and Engineering Laboratory, who, as special consultant to the Topic Advisory Panel, was responsible for the collection of data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Advisory Panel, consisting of George M. Briggs, Director, Maintenance Division, New York State Department of Transportation; Paul E. Cunningham, Chief, Maintenance Branch, Construction and Maintenance Division, Office of Highway Operations, Federal Highway Administration; J. Hode Keyser, Chief Engineer, Control and Research Laboratory, Public Works Department, City of Montreal, Quebec, Canada; and John M. Kirtland, Chief, Maintenance Section, Department of Public Works, Hennepin County, Minn.

A. G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the Special Projects staff and the Topic Advisory Panel.

Information on current practice and ongoing research was provided by many highway agencies. Their cooperation and assistance were most helpful.

MINIMIZING DEICING CHEMICAL USE

SUMMARY

Chemicals are applied to highway pavements to accomplish three things: (1) prevent formation of ice, (2) melt ice that has formed, and (3) prevent buildup of snowpack.

Salt (sodium chloride) is the most commonly used deicing chemical because of its relatively low cost. Its melting effectiveness diminishes below 20°F (−6.7°C), and it ceases all melting at −6°F (−21°C). Salt-calcium chloride ($CaCl_2$) mixes can increase melting effectiveness and reduce quantity of salt used. Several agencies are using liquid $CaCl_2$ to prewet salt as it is spread. Prewetting has been estimated to reduce the amount of salt used by up to 40 percent. Aqueous $CaCl_2$ solutions have also been used alone successfully.

Solid chemicals are spread in a wide path or placed in a narrow [1 to 3 ft (0.3 to 0.9 m) wide] windrow at the crown. Windrowing is preferred by many agencies as the more efficient method. Liquid chemicals are sprayed from a distributor bar at the rear of a tank truck or dump truck with slip-in tank.

Optimum application rate depends on level of service required, weather conditions, chemical used, time of application, traffic, topography, and type of road surface. Actual rates for a single application of salt vary from 100 to 800 lb per lane-mile (30 to 230 kg/km) in rural areas and up to 2,000 lb per lane-mile (560 kg/km) on city expressways. Annual use reaches up to 40 tons per lane-mile (23,000 kg/km) on heavily traveled roads in high-frequency snow areas.

Because deicing chemicals are readily soluble in water, it is desirable to prevent their exposure to water. Many agencies store chemicals inside a covered, leakproof shelter. Where a building is not available, chemicals are frequently placed on pads (such as asphaltic concrete) and covered with a waterproof material.

Approaches to minimizing deicing chemical use include:

- *Prewetting salt with liquid chemicals.* The prewetting of salt results in quicker melting, less salt waste because prewetted salt does not bounce and scatter, and a greater temperature range in which salt can be used. A $CaCl_2$ solution is the prewetting liquid most often used.
- *Direct application of liquid chemical.* Salt brine or calcium chloride solutions applied directly result in quicker melting and less use of chemical.
- *Calibration of spreaders.* Calibration is essential for controlling application rates. Various methods can be used, but it is imporant to calibrate each piece of equipment as no two pieces are likely to be the same. Devices to relate spreading directly to ground speed have been credited with reducing chemical use. These devices deliver a preset amount of chemical per unit area regardless of truck speed.
- *Better management control.* Establishment of levels of service, standards for chemical application, and reporting procedures give management better control over use of chemicals.
- *Training.* Many maintenance engineers believe that training of personnel involved with ice and snow control is one of the most important factors in control-

ling chemical use. Comprehensive training programs have been organized by several agencies.

- *Adequate weather forecasts.* The most significant factor in starting snow and ice control operations is adequate warning of an approaching storm. Several agencies have contracts with private weather forecasters and some have experimented with elaborate ice detection systems that use sensors in the pavement.
- *Use of abrasives.* Although abrasives neither prevent nor remove buildup of snowpack, they can be used instead of chemicals in locations where traffic is not heavy enough to remove them rapidly from the road, or where aerodynamic forces will not remove them.
- *Snowplowing.* Truck-mounted underbody blades allow more complete removal of snow from the pavement. Early plowing during moderate to heavy snowfall reduces chemical use.

CHAPTER ONE

INTRODUCTION

Deicing chemicals, principally sodium chloride, have been used in the United States for snow and ice control on pavements since early this century (*1*). Initially little use was made of the application of straight chemical except in cities; salt * was added to abrasives only to keep them free-flowing. In 1941, however, New Hampshire commenced the use of straight sodium chloride as a general policy. A total of 3,865 tons (3.5×10^6 kg) of salt was used the winter of 1941-42, though this figure includes an unspecified quantity mixed with sand. In 1971, the quantity used on a national basis had grown to approximately 9 million tons per year ($8{,}200 \times 10^6$ kg/year). The salt use curve (Fig. 1) started to climb steeply in 1962, but already effects of deicing chemicals on vegetation were beginning to appear. According to Rich (*2*), the earliest report of injury to roadside trees attributed to deicing chemical came from Minnesota in a 1959 publication (*3*). Several publications have appeared during the last several years describing the effects of deicing chemicals on soils, vegetation, and structural materials (*4-23*). Thus, it appears that the cumulative effects of deicing chemicals and the awareness of an environmental problem have followed the salt use curve.

Comparatively few reports have been addressed to the problems faced by the highway maintenance engineer toward reducing the amount of sodium chloride applied to the nation's roads. Nonetheless, a general awareness exists on the part of maintenance engineers and the salt industry that the use of salt should be minimized consistent with keeping the pavement surface in a safe condition. What constitutes a safe pavement surface, and how to achieve it with minimum cost to the public and to the environment, are two questions that demand better answers.

* In this report "salt" refers to sodium chloride; calcium chloride, chemically also a salt, is referred to specifically by name.

SCOPE

Three general sources provided the bulk of the information contained in this synthesis: a questionnaire sent to highway maintenance officials of most of the northern United States, six Canadian provinces, several toll roads, and several large snow-belt cities; personal visits or telephone contacts with officials of selected state highway agencies; and a survey of the literature including Transportation Research Board publications, reports of government agencies, associations, and manufacturers, as well as articles appearing in the industrial and technical press. A literature review of the state of the art of deicing chemicals has been prepared by Keyser (*24*).

It is accepted as a premise that it is desirable to reduce the quantity of deicing chemicals used and, therefore, there is no discussion of the economic consequences of their corrosion of automobiles, scaling of non-air-entrained concrete pavements, damage to vegetation, and intrusion into water supplies, nor of the extent to which these effects can properly be attributed to deicing chemicals.

BACKGROUND

The Problem

Snow and ice influence society's highway transportation activity in two major ways: (1) in the increased hazard to

safe travel with the consequent cost of death, injury, and property damage; and (2) in the additional economic penalty on society caused by the delay of traffic and the increased costs of operation. Chemicals are applied to pavements to accomplish three things: (1) to melt ice that has formed on pavement (deicing), (2) to prevent formation of ice (anti-icing), and (3) to prevent the buildup of "pack"—snow compacted by traffic action—which becomes nearly as tightly bonded to pavement as ice, and which is frequently much thicker and more irregular. Both ice and compacted snow have coefficients of friction as low as 0.1. Though friction-improving materials such as sand, slag, or cinders can be and are spread on a slippery surface, certain reasons to be discussed later have discouraged the extensive use of abrasives in many places. The great reliance has been on the use of sodium chloride because of its low cost, ready availability, ease of application, solubility in water, and effectiveness as a melting agent at temperatures near 32°F (0°C). However, these advantages have in turn contributed to the increased use of salt, and part of the problem lies in not knowing how much salt to apply for a known climatic condition nor being able to apply a known, controlled amount.

How Chemicals Melt Ice

Water molecules are continually pulling away from a water surface and flying into the air immediately above. Some of these water molecules return to the surface and rejoin it, and an equilibrium is established giving rise to a fixed vapor pressure dependent primarily on the temperature. This phenomenon is diagrammed in Figure 2 where it can be seen that the vapor pressure for water drops as the temperature drops. At temperatures below T_f, the normal freezing point of water, the vapor pressure for water continues to decrease along path AB. However, under ordinary conditions ice begins to form at T_f, but it has a lower vapor pressure than water and is represented by path AC. This means that more molecules will collect on the ice surface than on the water, and the ice will grow at the expense of the water phase. This reaction can be illustrated by two trays of bees, one in the sun and one in the shade; some of the bees that leave the sunny tray will return and some will fly to the shady tray, which they like better. Bees will also be leaving the shady tray, but more return to it than will fly to the sunny tray, so the shady tray attracts more and more of the bees —eventually all. Similarly, all the water will turn to ice when the heat stored in the water, the heat of fusion, is dissipated.

Addition of salt to water lowers its vapor pressure as shown by the salt solution curve in Figure 2. At T_f the vapor pressure is below that of ice, so the ice will go into solution—in a sense it flows downhill to the lower vapor pressure of the salt solution. Not until point D is reached will the salt solution curve intersect the ice curve, and because at this point the vapor pressures are the same, ice can start to form. ΔT is a measure of the freezing point depression. Substances that dissolve in water will depress the freezing by a known, measurable amount: for the same weight of substance added to the same amount of water. Table 1 gives the freezing point depressions for a number of

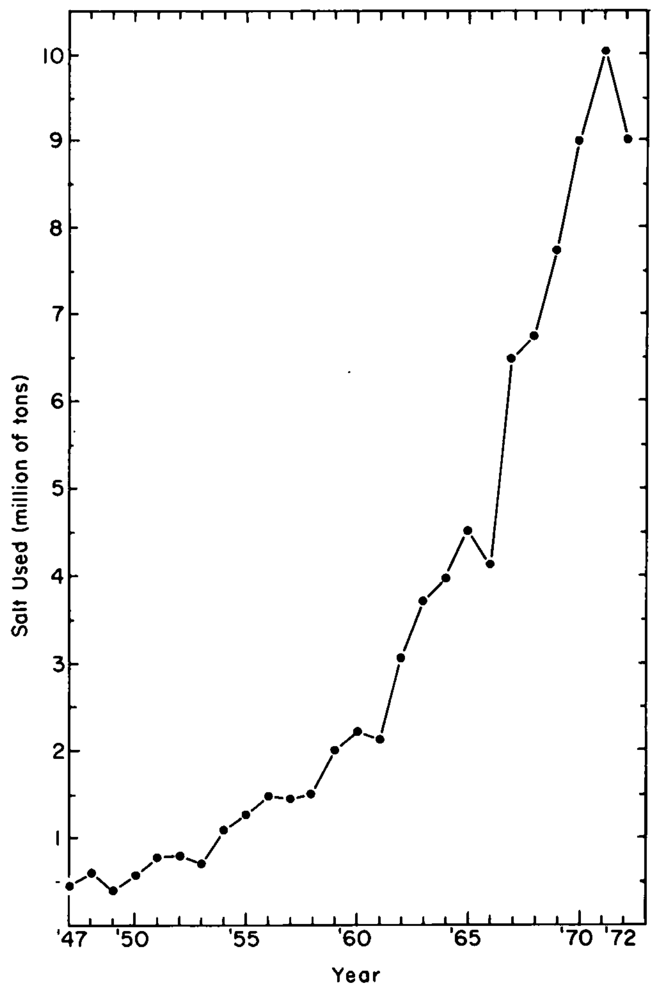


Figure 1. Use of salt for highway deicing, 1947-72.

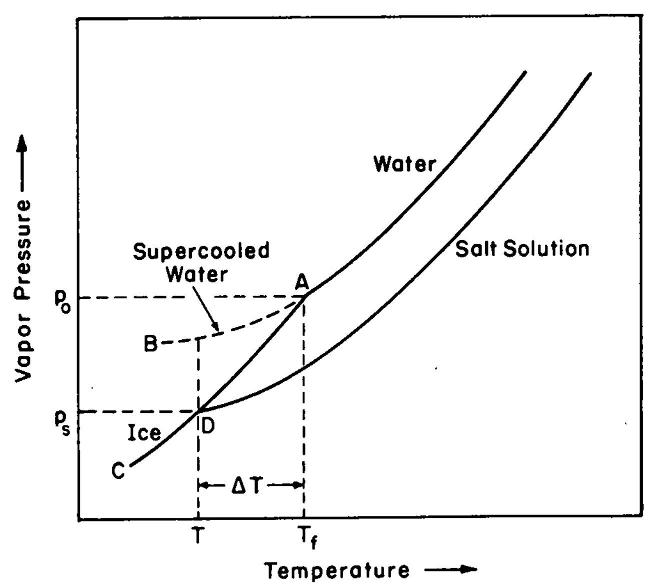


Figure 2. Salt solutions melt ice by depressing the freezing point through the mechanism of reducing the vapor pressure.

TABLE 1

DEPRESSION OF THE FREEZING POINT BY ADDING 2 g OF CHEMICAL (SOLUTE) TO 100 g WATER (SOLVENT) (*25*)

CHEMICAL	ΔT (° C)
Sucrose	0.11
Ethylene glycol	0.60
Urea	0.61
Ethanol	0.81
Calcium chloride	0.88
Magnesium chloride	1.05
Methanol	1.14
Sodium chloride	1.19

common materials. However, because some substances are less soluble than others, adding more material will not depress the freezing point the same amount for all substances. The solubility of sodium chloride is shown in a phase diagram (Fig. 3). Adding salt to the same quantity of water calls for moving to the right along the horizontal axis. As we do so, so drops the freezing point (labeled "solubility curve" because it divides the region where salt is completely in solution from that where ice will form). The freezing point will continue to drop until the salt concentration reaches about 23 percent. Here the freezing point reaches a minimum of −6°F (−21°C) called the eutectic point, and adding more salt only serves to raise the freezing point. If the temperature is lowered below the eutectic point, salt will no longer remain in solution but will solidify outside the ice boundary.

The phase diagram for calcium chloride (Fig. 4) is similar, but at low concentration the curve is flatter; i.e., the freezing point depression is less (see Table 1). The drop in freezing point increases rapidly as the concentration increases and the curve becomes progressively steeper, until the eutectic point is reached at about 30 percent $CaCl_2$ and a freezing point of −67°F (−55°C).

When water freezes it gives up heat in the amount of 80 calories/gram (144 Btu/lb)—the latent heat of fusion. Melting is the inverse process, and heat must be added to ice to melt it. In the case of ice on a pavement, heat can come from the air, from solar radiation, or from the pavement and its heat reservoir. In all cases, however, heat will only flow "downhill;" i.e., from a hot to a cold body. When a deicing chemical is spread on ice and goes into solution, the freezing point is lowered, the vapor pressure is lowered, and additional ice tries to reach the more comfortable state of melting. It will do so only if there is a source of heat available.

In summary, these requirements must be satisfied to melt ice by means of chemicals:

1. Sufficient moisture must be available to dissolve the deicing chemicals.
2. A heat source must be available to provide the energy for melting.
3. The concentration of chemical must not exceed the eutectic composition in order to achieve complete utilization of the chemical.

CHEMICAL APPLICATION

Types of Chemicals

Certain chemicals melt ice by the mechanism previously described. The reaction requires only that the vapor pressure of the chemical solution be lower than that of water, and either the solid state or aqueous solutions of the chemicals can be used. Some chemicals used for deicing purposes are normally liquid at freezing temperatures and above. Thus, the more common deicing chemicals can be divided into three classes:

1. Solid chemicals
   a. Sodium chloride, NaCl
   b. Calcium chloride, $CaCl_2$
   c. Urea, $CO(NH_2)_2$
2. Aqueous solutions of the above solid chemicals
3. Liquid chemicals
   a. Ethylene glycol
   b. Propylene glycol
   c. Alcohol (ethyl, methyl, propyl, isopropyl)

Application Methods

Solid chemicals are distributed on the pavement either by (1) spreading over a wide path (covering parts of two lanes) by means of a spinning disk or a roller extending the width of the truck tailgate, or (2) by windrowing in a narrow path [1 to 3 ft (0.3 to 0.9 m) wide] through a tube or off a dead spinner.

Concentrated spreading of salt, either in a narrow band on two-lane roads or in a 4-ft (1.2 m) wide band spread near the center-line crown or on the high side of superelevations, is favored by many highway maintenance engineers as the most efficient use of chemicals. Here the purpose is to obtain a concentrated brine that will flow under the snow to break the bond, thus enabling traffic and plowing to remove the accumulation. Early exposure to the sun of a portion of the road surface, which may be achieved by concentrated spreading, will also increase the melting rate by absorption of heat.

Liquids are dispensed by conventional nozzle distributor bars attached to the rear of tank trucks or dump trucks carrying a slip-in tank.

SALT APPLICATION RATES

The optimum application rate depends on the:

- Level of service required.
- Weather conditions and their change with time.
- State and characteristics of the chemicals used.
- Time of application.
- Traffic density at time of, and subsequent to, chemical application.
- Topography and the type of road surface.

However, determination of the proper application rate is a matter of judgment and a guess as to weather conditions immediately following the application. If a treatment is made based on the expectation that a storm will continue for several hours but it doesn't, the amount applied will have been excessive. Few maintenance organizations

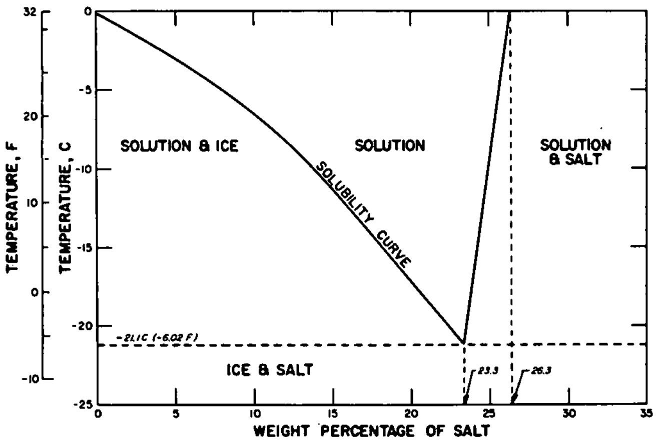


Figure 3. Phase diagram for sodium chloride.

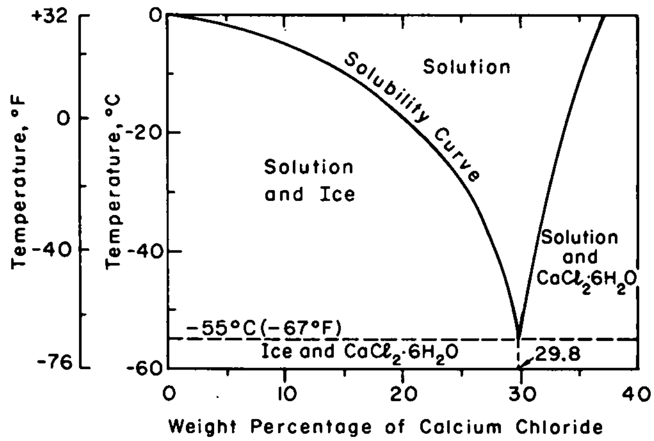


Figure 4. Phase diagram for calcium chloride.

are equipped or staffed to apply a minimum treatment followed by a second treatment should observation indicate the necessity. In some cases, policies call for the treatment of lower-priority roads after the most critical highways are treated; if a second treatment of critical highways is necessary, the lower-priority roads must be left untreated for a longer time. This leads to the practice of operators choosing an application rate that will reasonably cover as many of the unknown future contingencies as possible, even though this results in excessive application when a storm condition unexpectedly moderates. Traffic may soon whip off loose dry chemical or splash off a high-brine-content slush when heavy initial chemical treatments are applied.

The practice of applying chemicals in increments, as needed, represents one of the most useful methods of reducing the quantity of chemicals applied and increasing the amount effectively utilized for deicing or anti-icing.

Observations of the behavior of wet snow under actual traffic conditions by Schaerer (*26*) led him to conclude that snow with a free-water content * less than 15 percent was compacted and formed a hard slippery surface. Snow with a free-water content of 15 to 30 percent was usually not compacted but remained on the road in a soft, loose state. Snow with greater than 30 percent free water was removed by traffic. The British Transport and Road Research Laboratory recommends the application of sodium chloride at a rate of ⅛ lb per inch of new snow per square yard per °F (48 g/mm of snow/m²/°C) below freezing on roads with a traffic density of more than 50 vehicles per hour for removal of the snow by traffic action (*27*). This is equivalent to 1,760 lb per two-lane mile per inch of snow per °F (564 kg/km/mm of snow/°C) below freezing. This quantity of chemical is sufficient to produce between 30 and 40 percent melting. Such high application rates are not common in the United States.

Vermont applies 300 to 800 lb per two-lane mile (85 to 230 kg/km) according to condition (see Fig. 21). The state maintenance engineer must report any application exceeding 800 lb per mile to the State Department of Water Resources within 14 days.

Standard application rate in Maine is 400 lb per two-lane mile (110 kg/km), but it can be raised to 600 lb per mile (170 kg/km) under heavy icing conditions.

Massachusetts has standardized an application rate of 350 lb per lane-mile (100 kg/km) of straight salt for temperatures 25°F (—4°C) and rising, and a 5:1 premix (sodium chloride:calcium chloride) for 25°F and dropping. This rate is not varied; instead, field personnel must justify the number of applications made. The 350-lb rate has been arrived at by experience in achieving a desired margin of safety. Experiments have shown that 200 to 250 lb per lane mile (55 to 70 kg/km) frequently allowed compacted snow to develop. However, experimental applications at the rate of 200 to 250 lb per lane mile of the 5:1 sodium chloride-calcium chloride premix will be made at the warmer temperatures 25°F and rising, in order to reduce chemical quantity. This will consequently increase costs [1972 prices: salt $14.50 per ton ($16/1,000 kg), premix $21.80 per ton ($24/1,000 kg)].

Salt application rates for municipalities run as high as 1,000 to 2,000 lb per two-lane mile (280 to 560 kg/km). New York City used ¼ lb per square yard (140 g/m²) or approximately 3,000 lb per mile (850 kg/km) [20-ft (6.1 m) wide pavement] during the early use of salt in the late 1940's, but now applies salt at the rate of ⅛ lb per square yard (70 g/m²). This is the quantity yielded by the minimum opening of the rear gate on spreaders, and local field tests have shown this is adequate for freezing rain and light snow. Bus routes and federal and state numbered routes always receive treatment; other roads are treated on the basis of ADT, sharp curves, and steep grades. Hazardous intersections are also treated.

During the winter of 1971-72, cities receiving 50 in. (1,270 mm) of snow or more applied salt at an average of 20.6 tons per lane-mile (11,600 kg/km), those receiving 30 to 49 in. (760 to 1,240 mm) snow applied 9.4 tons per lane-mile (5,300 kg/km), and light-snowfall regions (less than 30 in. snow) applied 8.5 tons per lane-mile (4,800 kg/km) (*28*).

Toll road organizations tend to be more generous in their application of deicing chemicals compared to states be-

* Free-water content $= 100 \frac{\text{wt of liquid (water or brine)}}{\text{wt of liquid (water or brine)} + \text{wt of ice}}$

cause they, in effect, are selling a service and don't wish to run the risk of damaging the good will of their customers by permitting road conditions to cause hazards or delays.

Application rates are given along with other information in the tabulation of the responses to a survey on deicing chemical practices (Appendix B). Application rate specifications based on climatic conditions for several organizations are given in Appendix C.

STORAGE OF CHEMICALS

Runoff Loss from Storage

Because deicing chemicals are readily soluble in water, it clearly is desirable to prevent their exposure to water during storage. Though a crust will form on the surface of uncovered sodium chloride and calcium chloride stockpiles, some leaching will take place during rainfall or when accumulated snow melts.

Rain falling on an uncovered salt pile generates about 625 gal of brine per inch of rainfall per 1,000 sq ft (1.0 l/mm of rain/m²) of stockpile (*29*). The brine flowing from the base is nearly a saturated solution. On large stockpiles the loss per year is on the order of ⅛ percent of the initial weight of the pile for each inch (0.005 percent/mm) of rainfall (*30*). British opinion is that the current cost of covering a salt stockpile becomes economical when the annual rainfall exceeds 24 in. (610 mm), though this apparently does not consider such factors as public opinion and replacement of vegetation (*30*).

Storage Methods

For the most positive protection, many highway agencies store salt inside a covered, leakproof shelter. When not stored within a building, the chemical frequently is placed on an impervious pad (such as asphaltic concrete) and covered with a tarpaulin. Because it is difficult to prevent all leaks by this method, and impossible to keep out all sources of water when loading operations take place during storms, the impervious pad is sometimes pitched to or surrounded by drainage channels that can carry the dissolved salt to a collection basin or a diversion channel. Sand treated with salt as freezeproofing is also stored with the same precautions.

A manual on storage and handling of deicing chemicals is being prepared for the Environmental Protection Agency (*31*).

A Minnesota study (*29*) on controlling loss of deicing materials recommends the following four-step approach:

Step 1. Identify those measures that can be taken with present facilities to eliminate or minimize the cause of stockpile runoff.

(a) Eliminate or relocate the site.
(b) Rearrange the site.
(c) Reduce amount stored at the site.
(d) Keep surface water from entering base of stockpile.
(e) Maximize the use of covered buildings during the rainy season.
(f) Mix treated sand as late as possible.
(g) Minimize sand-chemical ratio in treated sand piles.
(h) Dispose of leftover treated sand.
(i) Cover outside, bulk salt piles with waterproof material at all times.
(j) Avoid spillage during loading operations.

Step 2. Identify those measures that can be taken with present facilities to minimize the effects of stockpile runoff.

(a) Dilute salt brine runoff.
(b) Control direction of runoff flow.
(c) Settle-out sand carried in suspension.
(d) Stir the edge of treated sand storage piles to avoid an unsightly white residue.

Step 3. Identify and cost-out additional facilities that could be constructed to eliminate or minimize the cause of stockpile runoff.

(a) Construct covered buildings with paved floors.
(b) Add doors to existing buildings to prevent water from entering the stockpiles.
(c) Construct pads for outdoor stockpiles.

Step 4. Identify and evaluate additional facilities that could be constructed to eliminate or minimize the effects of stockpile runoff.

(a) Channel the runoff into a collection basin or pond.
(b) Dispose of the collected brine.

Collection facilities should be considered as a last resort. Time, effort, and money can be better spent on avoiding or minimizing the formation of salt brine.

A collecting and settling basin has been designed by the Pennsylvania Department of Transportation to catch runoff and hold it for subsequent disposal (*32*). The design is shown in Figure 5, and the basin under construction in Figure 6. The brine is pumped onto sand stockpiles, and any remaining salt crystallizing out is removed during the summer.

The standard salt shed in Massachusetts is 40 × 84 ft (12 × 26 m) in plan and holds 1,200 tons (1.1 × 10⁶ kg). Buttress walls are 8 ft (2.4 m) high, and clear height to trusses is 18 ft (5.5 m). It is built on an asphalt pad. The state is switching from an 8-mil (0.2 mm) black polyethylene cover to an 8-mil copolymer (EPDM) sheet, and an 8-mil nylon-reinforced polyethylene to reduce the instances of ripping. Altogether 165,000 tons (150 × 10⁶ kg) of deicing chemicals are stockpiled, 20 percent in inside storage (38 sheds). One of the most critical needs to reduce salt loss is more inside storage. A contractor-built shed costs $25,000 for the standard 1,200-ton unit, and funds have been obtained to build 12 more in 1973-74.

Vermont has some outdoor salt storage under waterproof covers, but only where there are sheds nearby. When a shed is emptied, a pile is uncovered and the salt is transferred to inside storage. All chemicals are placed on asphalt pads.

A dome structure based on a grain storage building was designed by Fitzpatrick of the Ontario Department of Transportation (*33, 34*). This uses panels of 2 × 6 framing covered with plywood to form a conical shape corresponding to the angle of repose of sand or salt. Commercial units are now available with slopes to accommodate 38° and 45°

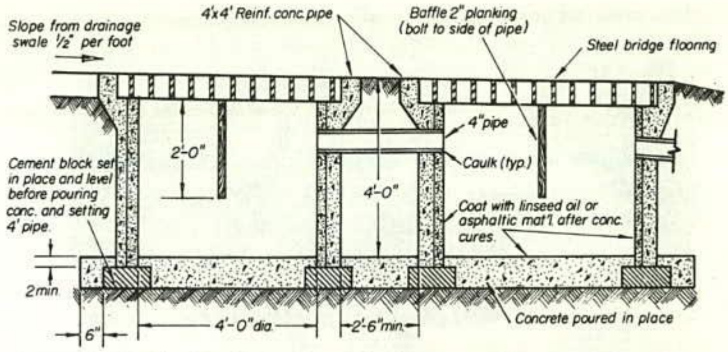


Figure 5. Collecting basin for salt brine runoff (Pennsylvania).

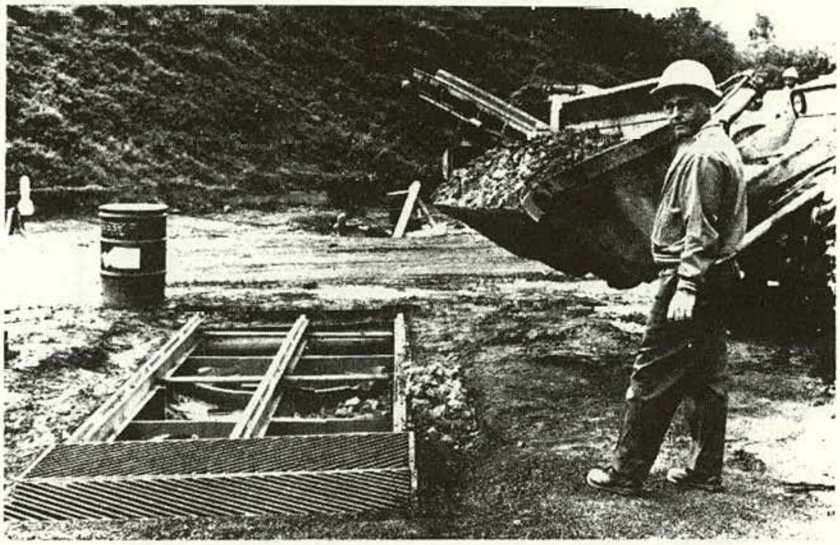


Figure 6. Construction of collecting basin: backfilling around the 4-ft diameter, vertical concrete pipe sections (Pennsylvania).

angles and, in addition to the "beehive" shape (Fig. 7), can be built in a stretched version. Walls do not have to be designed to withstand high lateral pressures because the material stored is freestanding, contacting only a base retaining ring.

RELATION OF SALT USE TO ACCIDENTS

No data are known that indicate unequivocally the influence of deicing salts on accident rates, because so many interrelated and unseparated factors are present in statistics taken from reported studies. For example, a comprehensive study of accident frequency as related to weather condition was conducted for the 1963-64 winter in Chicago (*35*). For snow conditions, it was estimated that there would be nearly 12,600 additional accidents, amounting to approximately $4 million in damage costs, over what would be expected in clear weather. However, this estimate does not separate the effects of plowing, chemical control, or no action at the time of accident. A post-storm, accident carryover analysis comparing rain and snow conditions (Table 2) eliminates the effect of wetted roads; however, it may include the effect of remnant slipperiness because of uncompleted or delayed snow and ice removal and may also include a detrimental effect from the presence of salt as it affects visibility through windshields. The evidence here is inconclusive on the role snow removal or chemical ice control plays in reducing accidents.

Ann Arbor, Michigan, has compiled accident records before and after it commenced using salt for deicing. In 1967, the last year prior to general use of salt, 315 accidents were recorded. In 1968, the number of accidents dropped to 196, and in 1969, to 186 (*36*).

A 1972 survey of cities in the snowbelt states (*37*) showed 14 cities reporting an average 82 percent of accidents occurred on untreated pavements (range 63 to 95 percent).

An experiment reported (*12*) to have taken place in Rochester, New York, in March 1959 was an attempt to keep the city streets open during a snow storm by plowing only. The experiment was unannounced, but 12 hr after the storm commenced, the city had to return to the use of salt to enable traffic to flow again.

Perhaps the most useful evidence bearing on the relation

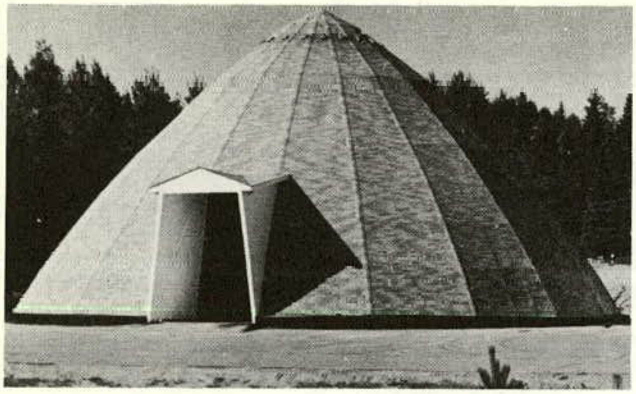


Figure 7. "Beehive" dome for storage of salt or sand.

TABLE 2

POST-STORM CARRYOVER

PRECIPITATION	STREET CLASS	DURING STORM ACCIDENTS	DURING STORM %	AFTER STORM ACCIDENTS	AFTER STORM %
Rain	Major	2539	73.4	917	26.6
	Local	639	62.7	381	37.3
Snow	Major	5131	40.2	7595	59.8
	Local	1999	26.6	5484	73.3

between ice control and accident rate, or at least accident potential, is the effect of treatments on skid resistance.

Skid resistance tests conducted in Japan with snow tires (*38*) have shown that, for a snow-covered pavement, the coefficient of friction of approximately 0.25 can be increased to 0.40 to 0.45 by application of calcium or sodium chlorides (application rate of 50 g/m^2 or 0.01 lb/ft^2). Application of sand at a rate of 0.4 to 0.6 kg/m^2 (0.08 to 0.12 lb/ft^2) resulted in a coefficient of friction of 0.25 to 0.29. Addition of 45 kg/m^3 (76 lb/yd^3) of calcium chloride to sand, the mix spread at 0.4 to 0.6 kg/m^2 (0.08 to 0.12 lb/ft^2), increased the coefficient of friction to 0.40 to 0.49. In all cases the temperatures at times of test were between 0 and −1.5°C (32 and 29°F).

The increase in skidding resistance of icy roads following salt treatment is shown in Figure 8. The data were obtained from simulated outdoor tests in England (*39*). Section B, treated at a rate of 60 g/m^2 (0.0123 lb/ft^2), improved over the untreated Section A but never did reach the values of wetted road surface during the observation period. The test sections were trafficked to distribute the brine, and then a test vehicle was used to measure the skid resistance.

If spread at a rate insufficient to continue melting when diluted or when temperatures fall, deicing chemicals can increase pavement slipperiness. Empirical observations have noted this (*40*). However, a more ubiquitous, and potentially more serious, effect has been reported—that of the decrease in skid resistance resulting from the residual water film induced by the presence of deicing chemicals (*41*). Deicing chemicals reduce the evaporation rate of water by lowering the bulk water vapor pressure of the solution, and thus prolong the transition of tire friction from the wet to the dry value. Skid resistance of road sections wetted with water, NaCl solution, and $CaCl_2$ solution were measured with a two-wheeled skid trailer. The average coefficient of tire friction (μ) in full skidding at 40 mph (65 km/hr) is shown as a function of time (t) in Figure 9. The decrease in μ below the plain water-wetted value is reported as 7 percent for the NaCl solution and about 18 percent for the $CaCl_2$ solution.

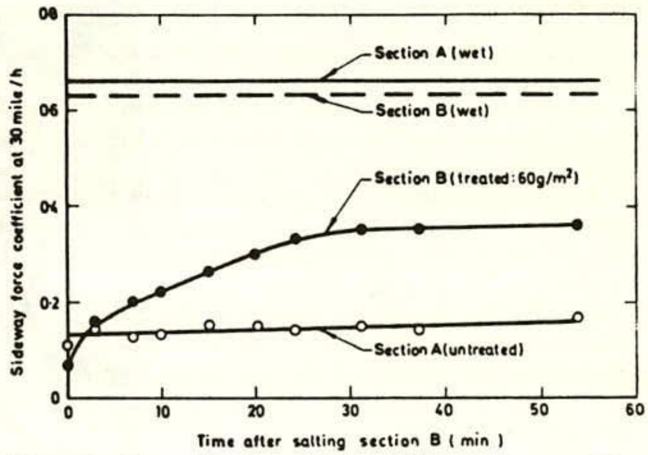


Figure 8. Rate of improvement of skidding resistance of icy roads after treatment with salt (39).

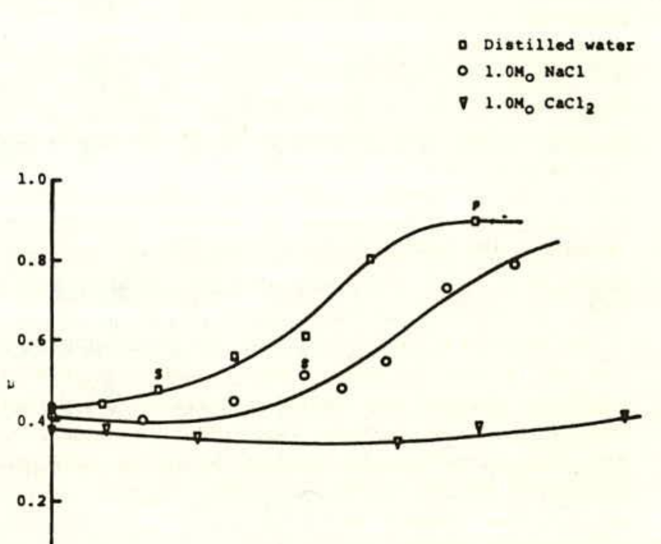


Figure 9. Portland cement concrete coefficient of friction (μ) *versus time* (t) (41).

CHAPTER TWO

APPROACHES TO MINIMIZING DEICING CHEMICAL USE

USE OF LIQUID CHEMICAL

Liquids for Prewetting Salt

A number of agencies are experimenting with the use of liquid calcium chloride to provide the needed moisture for initiating the melting action of sodium chloride. Field tests that Iowa conducted during the winter of 1970-71 with 35 liquid calcium chloride applicator kits (*42*) showed that prewetting salt prior to application on the road produced:

- Quicker snow melting because the 30- to 45-min period usually required for brine to form was nearly eliminated.
- Less salt waste because prewetted salt does not bounce on ice or snow but adheres and immediately begins to bore through the frozen layer.
- Greater latitude in use of rock salt; melting has been experienced with prewetted salt at temperatures as low as 3°F (−16°C) whereas normal salting is terminated when temperatures drop below 20°F (−7°C).
- Reduction in salt use because of the quicker, more effective use of the material. It is estimated that prewetting may reduce the quantity of salt required by 40 percent.
- Greater periods of bare pavement surfaces during winter snow and ice storms.

Liquid calcium chloride is purchased from suppliers in Iowa at prices ranging from $0.16 to $0.25 per gallon ($0.04 to $0.07/l). It is stored in 6,000-gal (23,000-l) tanks that hold liquid asphalt during the summer and the chloride during the winter.

Application of liquid calcium chloride to rock salt requires the addition of 50- to 60-gal (190- to 230-l) fiberglass storage tanks on snow removal trucks. These trucks are currently equipped with the ground speed control hopper spreader that holds about 5 tons (4,500 kg) of salt. A pump kit and spray bar holding two 50° fan nozzles near the discharge chute are used to prewet the salt. The pump is driven by the spreader driveshaft, providing positive control and proportioning between the salt and liquid chloride delivered. A liquid applicator kit includes fiberglass tank, pump, filter, valve, and piping—the total material cost is $150. Installation is shown in Figure 10.

The spreader truck is loaded with salt, the calcium chloride tank is filled, the pump is engaged, spreader gates set, equipment checked, and the unit checked for correct salt and liquid calcium discharge. Operators are cautioned that prewetted salt will have less tendency to bounce and scatter and will be less affected by crosswinds. One gallon of fuel oil is pumped through the suction intake of the three-way valve to flush and lubricate the pump.

The gradation of the salt used by Iowa required 8 gal of liquid per ton (32-1/1,000 kg) of salt to wet the surface of each particle based on an average application rate of 300 lb per mile (85 kg/km) distributed at 20 mph (32 km/hr). The liquid used is a 32-percent solution of calcium chloride, which has a eutectic temperature of about −17°F (−27°C). Properties of calcium chloride are tabulated in Appendix D.

During the winter of 1972-73, two maintenance sections of the Illinois Tollway experimented with prewetted salt. The 8-cu yd (6-m³) hopper trucks in these sections were equipped with 69-gal (260-l) holding tanks, hoses, valves, and spray nozzles. The nozzles were positioned at the discharge end of the hopper conveyor to coat the salt; approximately 10 gal of liquid was applied to a ton (42-1/1,000 kg) of salt. On those trucks equipped with tail-gate spreaders, liquid calcium chloride was sprayed on the load at the yard by means of a multi-nozzle spray bath. Spreader gates and conveyor chain speed were set to spread at the rate of 300 to 400 lb per lane-mile (85 to 110 kg/km), in contrast to many previous dry salt applications at 1,000 lb per lane-mile (280 kg/km). The spinner speed was reduced and the shields lowered to confine the spread to 8 ft (2.4 m). These experimental sections cut their salt use by 28 percent, and the experience gained in making spreader adjustments and in driving no faster than 30 mph (48 km/hr) cut salt use in all other sections also. A further saving was realized on the use of liquid calcium chloride: an 8-ton (7,300 kg) load of salt used $7.60 of liquid at $0.095 per gallon ($0.025/l) compared to $90 for 2 tons (1,800 kg) of pellet calcium chloride previously used in a 3:1 salt-calcium chloride mix.

The original installations were improved by adding a positive on-off switch for the liquid-$CaCl_2$ tank coupled with the spreader on-off lever to prevent operators from forgetting to turn on the liquid. Also, gravity flow, which was

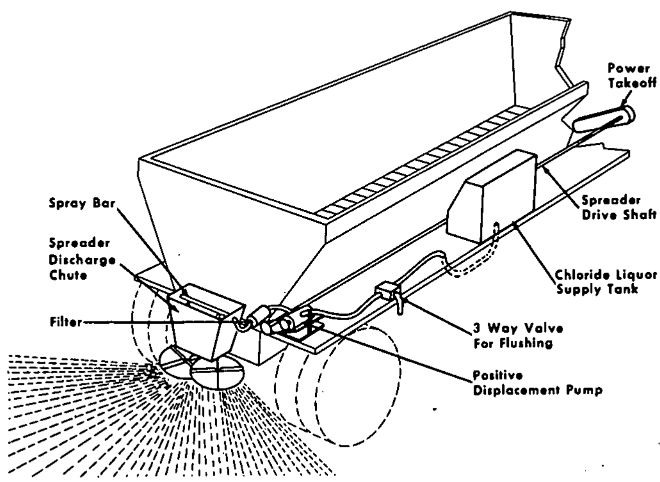


Figure 10. Liquid calcium chloride applicator kit mounted on salt spreader (42).

used originally, allowed the pressure to drop as the tank emptied, so a small liquid pump was added to maintain continuous and uniform spray pressure.

Connecticut is using propylene glycol for wetting salt on a road passing close to a reservoir (*43*). Other materials (salt brine, methanol) have been used by some agencies for prewetting salt.

Use of Liquid Chemicals Alone

Since 1967 North Dakota has been applying brine in several parts of the state (*44*). Natural brines occur in the western part of the state as a by-product of oil production and have long been wasted. Besides lower costs, use of liquid in preference to that of dry chemical has provided additional advantages: (1) it can be spread at temperatures down to −20°F (−29°C), (2) it does not blow off the road, and (3) its action is faster. Methods of application have been by discharge in a stream on the centerline, from a spray bar situated behind the rear wheels across the full width of the tank truck, and from a full-width spray bar situated underneath the tanker in front of the rear wheels. However, the last method has resulted in maintenance problems with the tanker brakes and bearings. The same quantity of solution is applied by all methods. For ice no greater than ¼ in. (6 mm) thick, about 400 lb of salt (130 gal of 27 percent by weight) are applied per mile [110 kg salt (310 l of 27-percent solution) per km] by traveling 20 to 25 mph (32 to 40 km/hr). A unit can cover 30 to 35 miles (48 to 56 km) on a tank load. Though slipperiness is initially increased, the more rapid action compared to dry chemical usually results in bare pavement in less time.

Aqueous solutions of $CaCl_2$ were used in a series of tests in Italy (*45*). A concentration of about 15 percent (ice crystallization temperature of −10.3°C, or 14.5°F) was applied for anti-icing at the rate of 45 cm^3/m^2 (0.01 gal/yd^2) and a 26-percent solution for deicing (ice crystallization temperature of −32.5°C, or −26.5°F) at a rate of 100 cm^3/m^2 (0.022 gal/yd^2).

Over several years of operational tests on short sections of public highway, the Italian investigators concluded that liquid $CaCl_2$ application was effective as a preventive measure and for removing thin layers of solid ice. Recrystallization of the chemical was observed when the humidity dropped below 45 percent at a temperature of 0°C (32°F), and when strong wind and sunshine assisted. The chemical residue frequently provided sufficient concentration to prevent ice bonding for up to 6 days after treatment. Concentration of $CaCl_2$ on the pavement was determined periodically using chemical tests. Reagents used were:

- 3 percent ammonium oxalate in water—positive reaction (white precipitate) indicates $CaCl_2$ concentration of 5 to 30 percent.
- 5 percent sodium sulfate in water—positive reaction (precipitate) indicates $CaCl_2$ concentration of 25 to 30 percent.
- 10 percent sodium sulfate in water—positive reaction indicates $CaCl_2$ concentration of 15 to 20 percent.
- 25 percent sodium sulfate in water—positive reaction indicates $CaCl_2$ concentration of 5 to 10 percent.

CONTROL OF SPREADING RATES

Calibration of Spreaders

Calibration is essential for controlling application rates. Maine has prepared the following instructions for calibration, which are typical of the procedures used:

> The following equipment is recommended to calibrate a hopper sander—portable scale capable of weighing 100 lb, stopwatch, two shovels, one pushbroom, one box to weigh salt, and clipboard and pad to keep notes.
>
> When calibrating hopper sanders we make arrangements to calibrate at the location the equipment is normally housed. This aids us by having a ready supply of salt and a smooth floor to work on. An entire calibration takes approximately 35 minutes.
>
> We calibrate each hopper at nine individual settings. The discharge gate is set at 1-, 2-, and 3-inch openings and the hydraulic control that regulates the speed of the feed belt is set at three separate settings with each gate change. [See Fig. 11.]
>
> The truck driver is instructed to race his engine to working rpm, 1200-1500 for diesel-powered equipment and 2000-2500 for gasoline-powered equipment, put his hopper belt in gear, and run salt for a timed minute. Two technicians then weigh and record the amount of salt that is discharged. This process is repeated for each individual setting. For convenience and ease of handling, we use a cubic foot box for weighing purposes. A full box

TRUCK NO. ______
SANDER NO. ______

GATE OPENING 1"

POUNDS PER MILE

BELT	SPEED — MPH									
SPEED	10	15	20	25	30	35	40	45	50	55
2										
3										
4										

GATE OPENING 2"

POUNDS PER MILE

BELT	SPEED — MPH									
SPEED	10	15	20	25	30	35	40	45	50	55
2										
3										
4										

GATE OPENING 3"

POUNDS PER MILE

BELT	SPEED — MPH									
SPEED	10	15	20	25	30	35	40	45	50	55
2										
3										
4										

Figure 11. Form for calibrating hoppers (Maine).

of salt is weighed and the net weight recorded, thereafter we only weigh the partial boxes. As is often the case, any one setting will contain two to five full boxes and one partial box of salt. Our calibrations will range from 50 to 500 pounds of salt per minute. The calibration results are then returned to our office and transferred to a calibration chart, which is then returned to the truck driver using the equipment. We have found no two pieces of equipment calibrate the same, making it necessary to calibrate each of our hoppers.

Other records and instructions furnished Maine operators are shown in Appendix E.

A similar method suggested by the Salt Institute involves measuring the amount of salt discharged by one turn of the auger. By relating this to the rotational speed of the auger, the amount of salt that will be spread over one mile can be calculated.

A rapid yard method is used by the Hennepin County, Minnesota, Maintenance Section (Figs. 12 and 13). A truck loaded with salt is backed up onto shop-built rollers near a low embankment, and salt is discharged into the bucket of a front-end loader while the truck is run in place at specified highway speeds. The salt collected in the bucket is then weighed. This method permits many runs at different speeds to be made in a short time.

An alternate method of calibration involves actual spreading of a measured load on the pavement at constant speed. Iowa uses both methods and provides a form (Fig. 14) to assist in the recording.

Though Maine is converting its spreader fleet to hopper bodies, and has three electronic spreader controls on these under test, the bulk of the equipment is still tail-gate sanders. When it was found that excessive quantities of salt were applied with the latter, a simple device was designed and installed to restrict material flow. This is a disk that can be adjusted to constrict the auger opening (Fig. 15). Weld beads on the inside of the restrictor plate aid in breaking salt chunks. Because auger speed varies among trucks, each unit is calibrated. Use of the restrictor is credited with reducing salt application from 31.5 tons per mile (18,000 kg/km) in 1967-68 to 20 tons per mile (11,000 kg/km) in 1969-70 when all tail-gate trucks were equipped with a restrictor. Salt is applied from hopper-body trucks by windrowing and the goal of dropping it along the center line is assisted by the use of a chute made of sheet metal (Fig. 16).

Performance requirements for chemical-spreading equipment have been established by the Michigan Department of State Highways and Transportation that state:

1. The rate of application and width of spread are to be controlled from the cab.

2. Controls are to regulate rate of application in 200-lb (90 kg) increments from 0 to 2,000 lb per mile (0 to 560 kg/km) at a uniform road speed; the increments are allowed a tolerance of ±50 lb/mi (±15 kg/km) at road speeds to 30 mph (50 km/hr).

3. At a maximum road speed of 20 mph (32 km/hr), 100 percent of material must be within the 24-ft (7.3-m) wide pavement, and 75 percent within the middle third [8 ft (2.4 m)] of the pavement when spread from the driving lane.

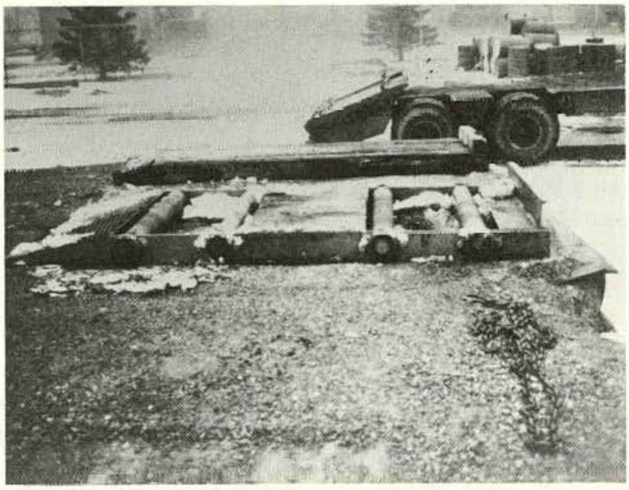


Figure 12. Shop-built rollers at edge of embankment, used by Hennepin County for calibration of spreaders (Minnesota).

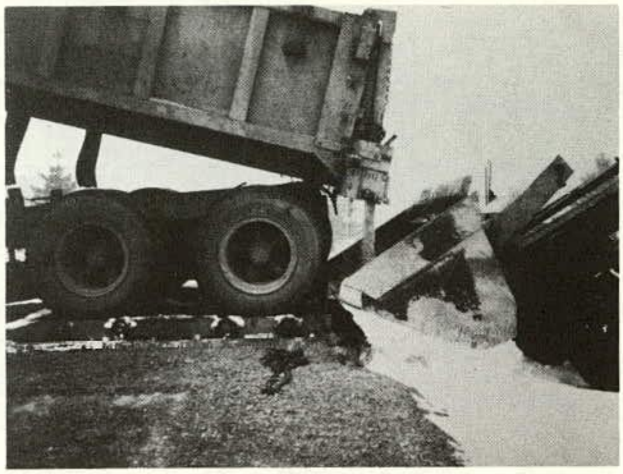


Figure 13. Truck-mounted spreader discharging salt into bucket of front-end loader for weighing.

Figure 17 shows the configuration adopted by Michigan. A baffle plate above the spinner diverts salt to an auger carrying the material to a discharge fan behind the left rear wheel. Liquid $CaCl_2$ is sprayed by a nozzle in the chute.

Tests by Michigan showed that at temperatures between 27 to 32°F (−4 to 0°C), there is very little difference in the melting action between dry salt and salt activated with liquid $CaCl_2$, but at temperatures below 20°F (−7°C) accelerated action was noticeable. Distribution pattern tests were run during the summer of 1972 on an unopened road and showed that wetted salt was confined to the pavement to a greater extent, as indicated in Table 3.

Spreading equipment has been designed for sand and is generally incapable of metering the lower, more precise

FORM 515
12-71

IOWA STATE HIGHWAY COMMISSION

HOPPER SPREADER SALT CALIBRATION CHART

MAINTENANCE DEPARTMENT

CALIBRATE ALL SPREADERS AT 20 MILES PER HOUR
(Reference Maintenance Policy and Procedure Section XIII, No. 2A)

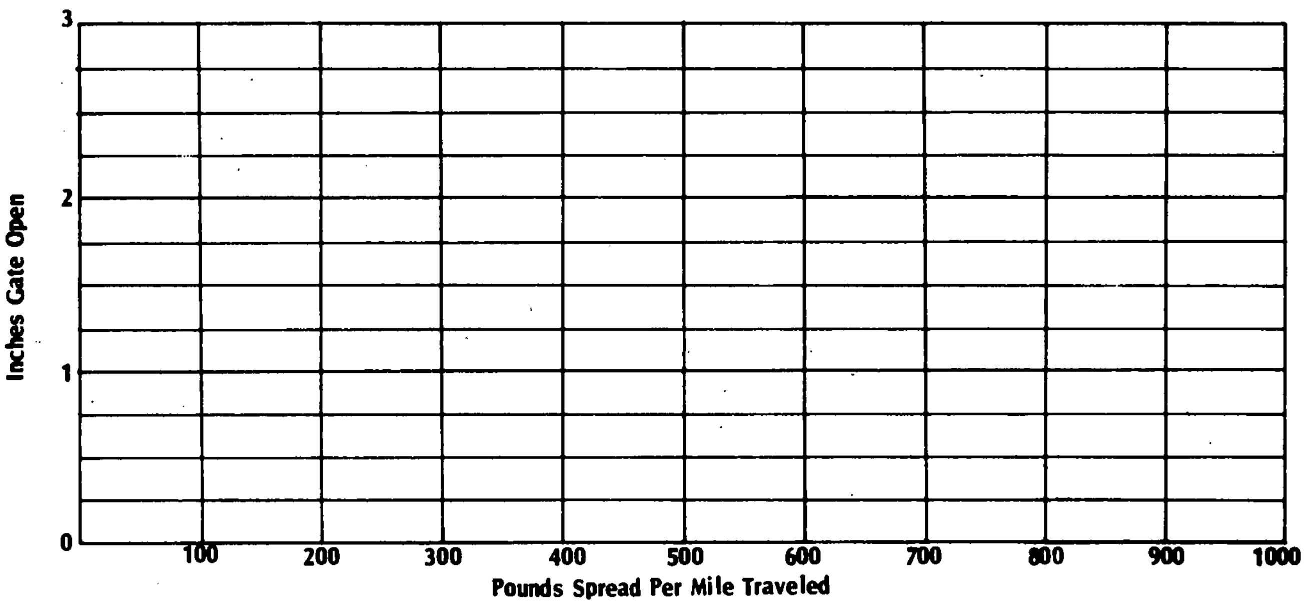
Residency ______________________ Location ______________________

Truck A# __________ Spreader Make ______________________ B# __________

Is salt gauge installed __________

Spreader drive is: Mechanical ______________________ Hydraulic __________

Transmission gear Used ______________ Auxillary Trans. or rear end ratio ______________



	Gate Opening	Lbs. Used	Dist. Traveled	Lbs./Mile
1.				
2.				
3.				

Calibrated by ______________________ __________

Date ______________________

Prepare two copies for each truck. Forward original to Central Office Maintenance, retain copy for file.

Figure 14. Hopper spreader salt calibration chart (Iowa).

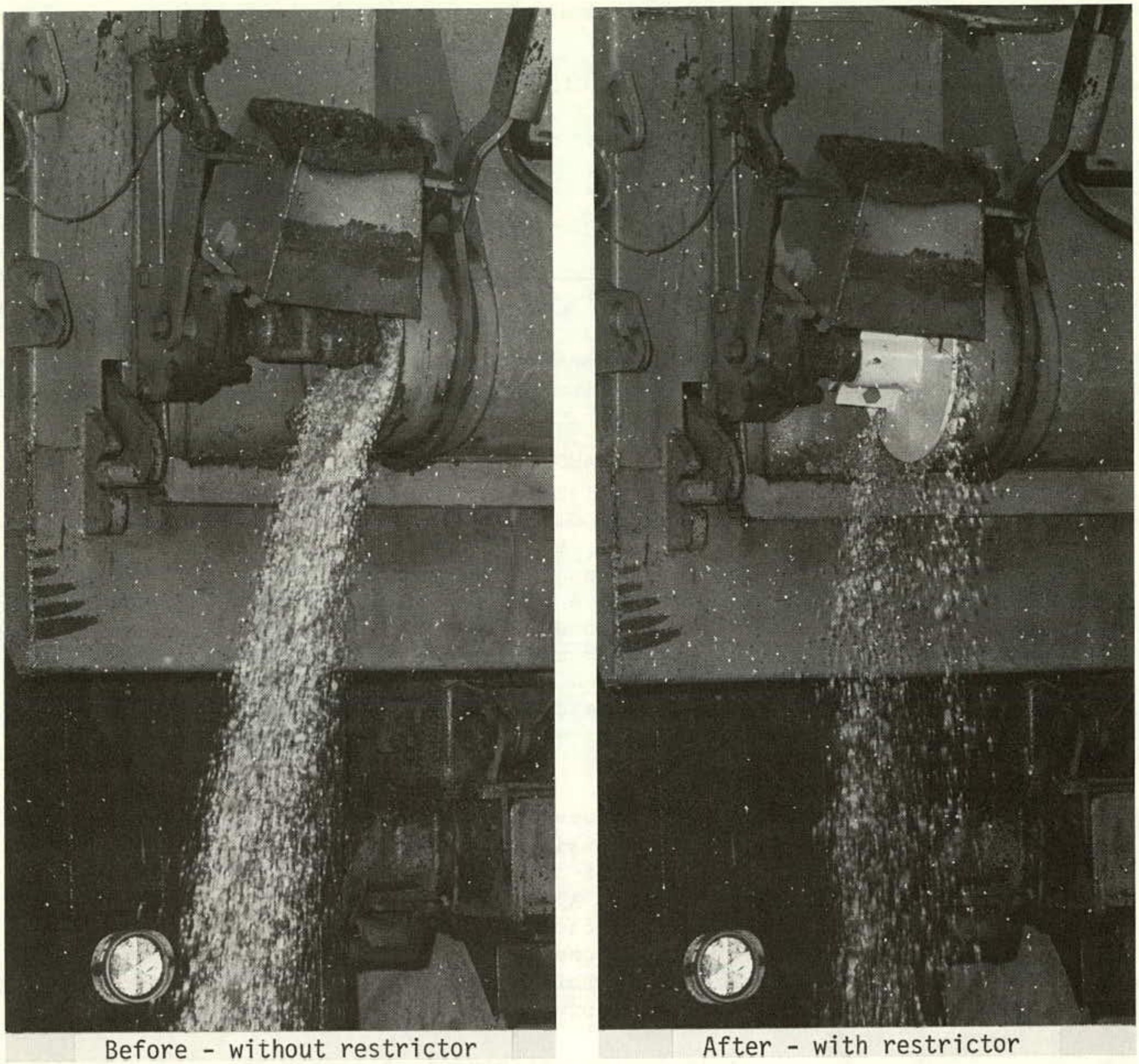


Figure 15. Restrictor plate to reduce material flow of tail-gate spreaders (Maine).

amounts of salt desired. Massachusetts has been installing gear reduction drives to reduce the speed of the hydraulic motor driving the conveyor or auger on its hopper-body spreaders. The conveyor drives are not as dependable as augers. Electronic ground-oriented spreader controls have been installed on 19 trucks and have been instrumental in reducing the amount of deicing chemical applied when teamed with the gear reduction units. Eighty trucks will be equipped with the gear reduction units. Electronic spreader controls available commercially are shown in Figure 18. These units modulate the spreading mechanism to deliver a preset amount per unit area regardless of truck speed. The controls are in the cab and can be reset or overridden by the driver as requirements dictate.

New Hampshire has used tubes for application of salt by windrowing. Moisture content of salt greatly affects flow rate through the tubes. Until the early 1960's dry salt deliveries were made in covered rail cars. About 1962, specifications allowed solar salt with a 3-percent moisture content. At the same time, rock salt suppliers built stockpiles within the state and made truck deliveries from these to state facilities. Moisture became a significant problem and was probably the major factor in nearly doubling the use of salt in a decade—from about 83,000 tons (75×10^6 kg) in 1960-61 to 143,000 tons (130×10^6 kg) in 1971-72. Consumption has begun to drop because of two factors: the switch to slide-in hopper bodies with hydraulic spreaders, and the tightening of specifications on salt moisture

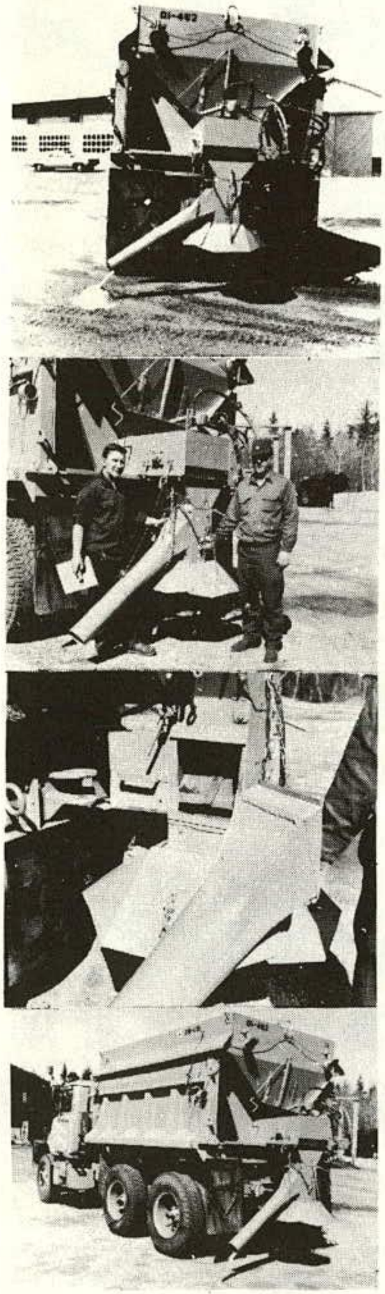
content. In 1970-71, 26 percent of the application equipment was hydraulic or mechanical; this increased to 48 percent in 1972-73. In 1972, bids for salt were requested early so that most deliveries could be made in the dry summer months. The allowable moisture content in rock salt was decreased to 1.5 percent in 1973, and may be dropped to 1 percent in 1974. Three of the five salt suppliers to the state now have storage buildings or use covered cars for storage. Use of salt in New Hampshire is expected to level off at 100,000 tons (91×10^6 kg) per year.

A towed unit whose mechanism is geared to road speed to give a constant spread rate has been used in Europe and is now being introduced into the United States (Fig. 19).

Among comments made by states regarding equipment are that hydraulic mechanisms need improving—after running for a while they become hot and flow rate varies, and hydraulic motor speeds vary with load. In the opinion of one engineer, ground-oriented electronic spreader controls should be provided or subsidized by salt suppliers.

Management Factors

The awareness of the importance of better management of snow and ice control is increasing. Massachusetts has a full-time snow and ice control engineer reporting directly to the maintenance engineer. Each of the eight districts also has a snow and ice control engineer. Pennsylvania has



HOPPER SANDERS

Since 1968, the quantity of hopper sanders (slip-in type) has increased from 3 to 104. These, of course, have many advantages over the tailgate type, but one major disadvantage, that of having to straddle the centerline when distributing salt. This problem could be overcome by proper adjustment of the deflector flaps but only to a certain degree, the worst problem occurring on a two lane highway.

Two employees of the Department working out of the Kennebunk Maintenance Camp, Ellsworth Bridges, Jr., Operator of a wheeler equipped with a 10 yd. hopper sander and Allen Bickford, P.M. Mechanic developed a quick detachable chute which could be attached to the discharge chute of the hopper operated by Bridges. This device diverts the salt to the left hand side of the truck.

This device was constructed from stove pipe attached by two flanges on the hopper discharge chute. A damper was installed in the hopper chute just below the point of attachment which permits the use of either side discharge or normal operation. The end of the pipe is supported by a guy chain and the weight of the chute holds it in place.

The truck experimented with is used on a two lane highway. The driver can stay in his normal travel lane and place salt along the centerline of the highway. The salt actually hits the highway approximately 2 feet to the left of the left rear duals.

Figure 16. Chute added to spreader for center-line windrowing (Maine).

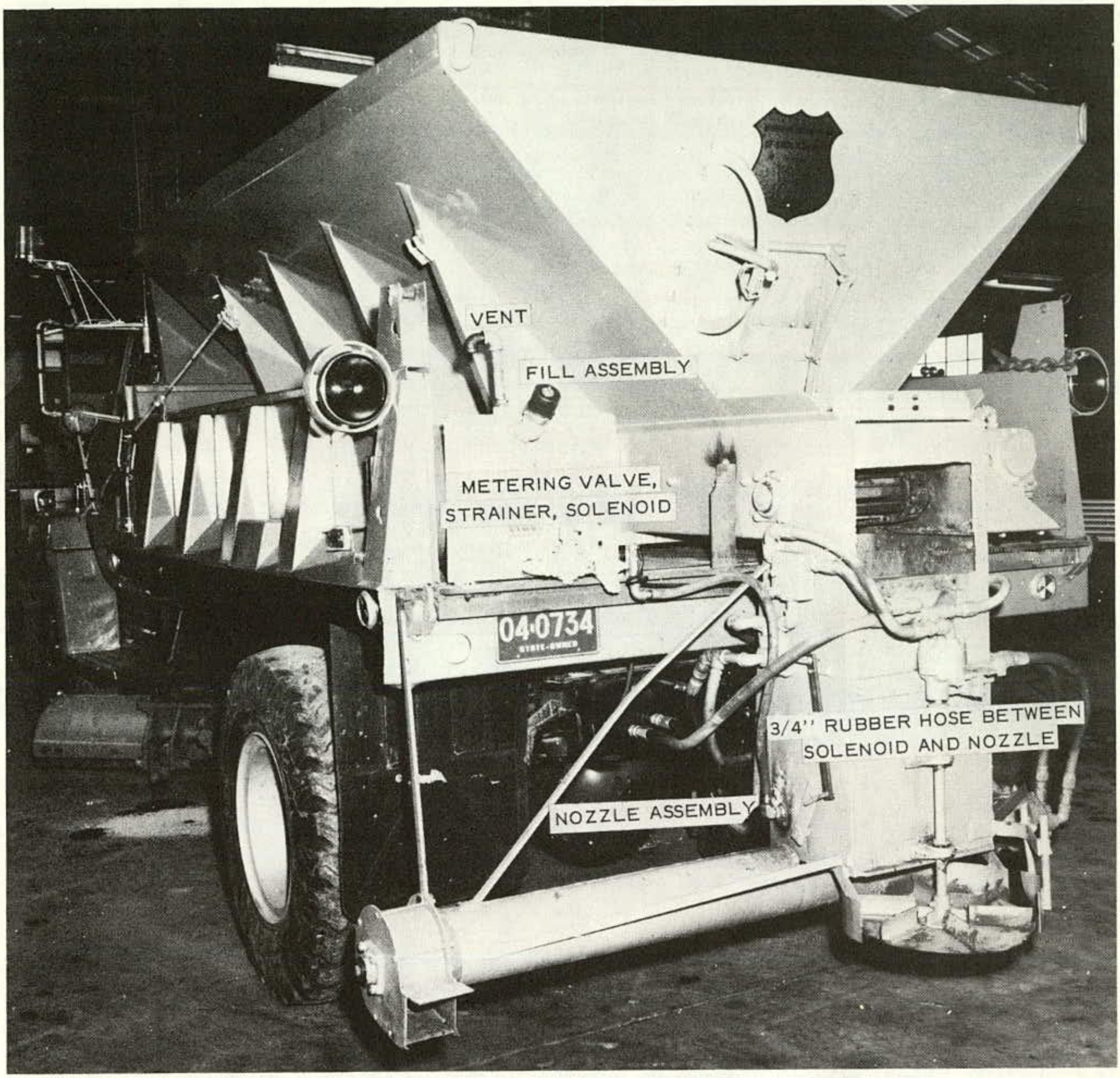
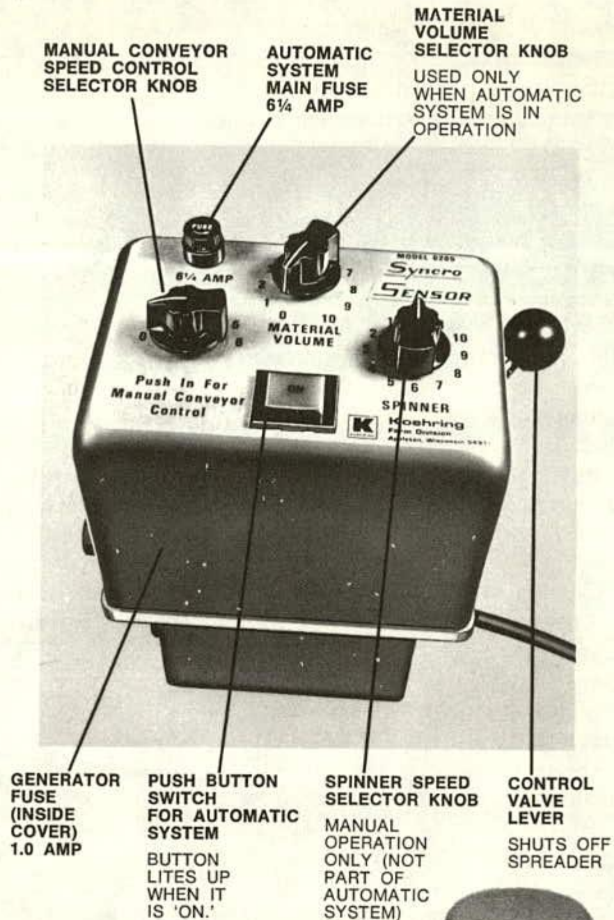


Figure 17. Salt spreader truck for dry or prewetted spreading, incorporating an auger for center-line windrowing (Michigan).

created the position of snow and ice control engineer to develop and monitor programs for controlling the use of deicing chemicals. In addition, a computerized materials inventory system has been developed and will be used for monitoring the use of chemicals and abrasives by county, by stockpile, and by individual truck. A record is made of tons, miles, and time for each load spread (Fig. 20). From this the amount of material spread per mile can be determined and controlled. The system is under test and will be extended statewide.

Better management generally requires more complete and accurate reporting systems. In Vermont, the adoption of standards of ice control (Fig. 21) and the introduction of a reporting system have been the most effective approaches. This accountability has tended to create an acute awareness and sense of responsibility among the drivers. Reports required from drivers include salt tonnage, sand yardage, control section covered, miles spread, snow depth, time of application, temperature, and shed number where the material was obtained (Fig. 22). ADT on all routes is known.

New Hampshire requires weekly reports listing salt use each day by patrol section, but individual truck operators are not yet required to submit detailed reports from which their rate of application may be determined precisely. Patrolmen check returning trucks and estimate the quantity



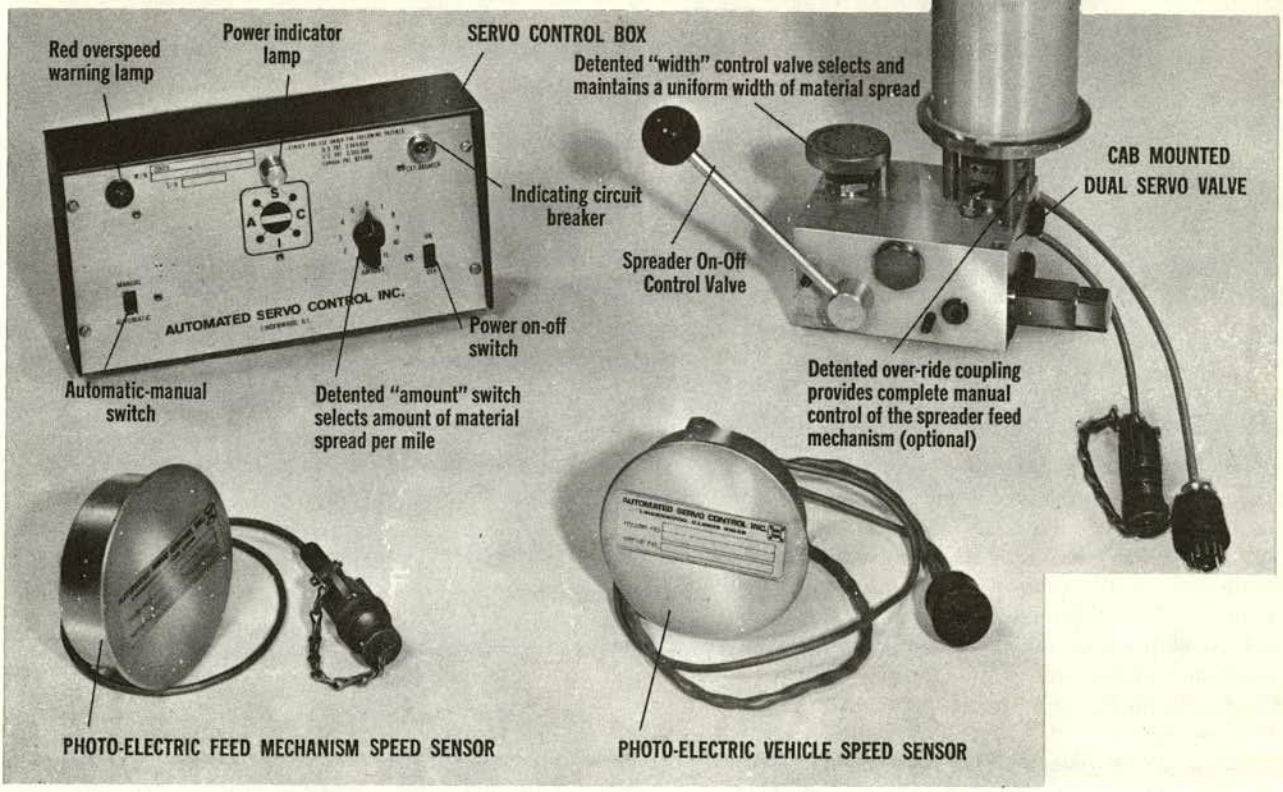


Figure 18. Ground-oriented electronic spreader controls.

used on the basis of one ton of salt being equivalent to one cubic yard.

Minnesota has instituted a comprehensive reporting system (*46*) to aid in restricting chemical use as mandated by the legislature (see Fig. 32). Level of service is specified by maintenance standards (Fig. 23). Forms provided for reporting use are shown in Figures 24 and 25.

In Toronto, spreader runs are organized so that an operator can cover his section with one load, if he uses the specified rate (700 lb per lane-mile; 200 kg/km). Salt use has been reduced in the last three years by lowering the level of service at night and on weekends. No attempt is made now to achieve bare pavement at all times; rather, snow is allowed to accumulate after an initial salt application until plowing runs can be made. Though salt use has declined in Toronto, costs have increased because of the increased plowing and snow disposal requirements. However, roads are maintained at the previous high standard prior to and during rush hours. This can be achieved only by use of salt because use of plows in heavy traffic adds to congestion. When a storm is predicted to start just before or during a rush hour, spreaders are loaded and positioned at predetermined locations on their runs so that when snowfall begins they can travel against the rush-hour traffic flow and avoid being impeded by heavy traffic. Thus, when additional applications are needed, the trucks can return to the yard for reloading with minimum delay.

TABLE 3

PERCENT SALT RETRIEVED FROM PAVEMENT

PAVEMENT LOCATION	WETTED	DRY
Center 1/3	78	46
Outside 2/3	18	24
Off pavement	4	30

Training

Many engineers believe that education of drivers is second only to adequate equipment as the most important factor in controlling chemical use.

Massachusetts holds two training sessions in each district for all personnel involved with snow and ice control. These cover theory, policy, equipment, and required practices of storing and applying deicing chemicals. Nova Scotia has prepared a 30-min audio-visual presentation on salting directed primarily to operating personnel. This covers policies, planning, levels of service, calibration of equipment, procedures for spreading, and application rates. A program has also been initiated to test all operators/drivers of plows and salt trucks for required operating skills. It has identified potentially poor operators who should be trained or replaced.

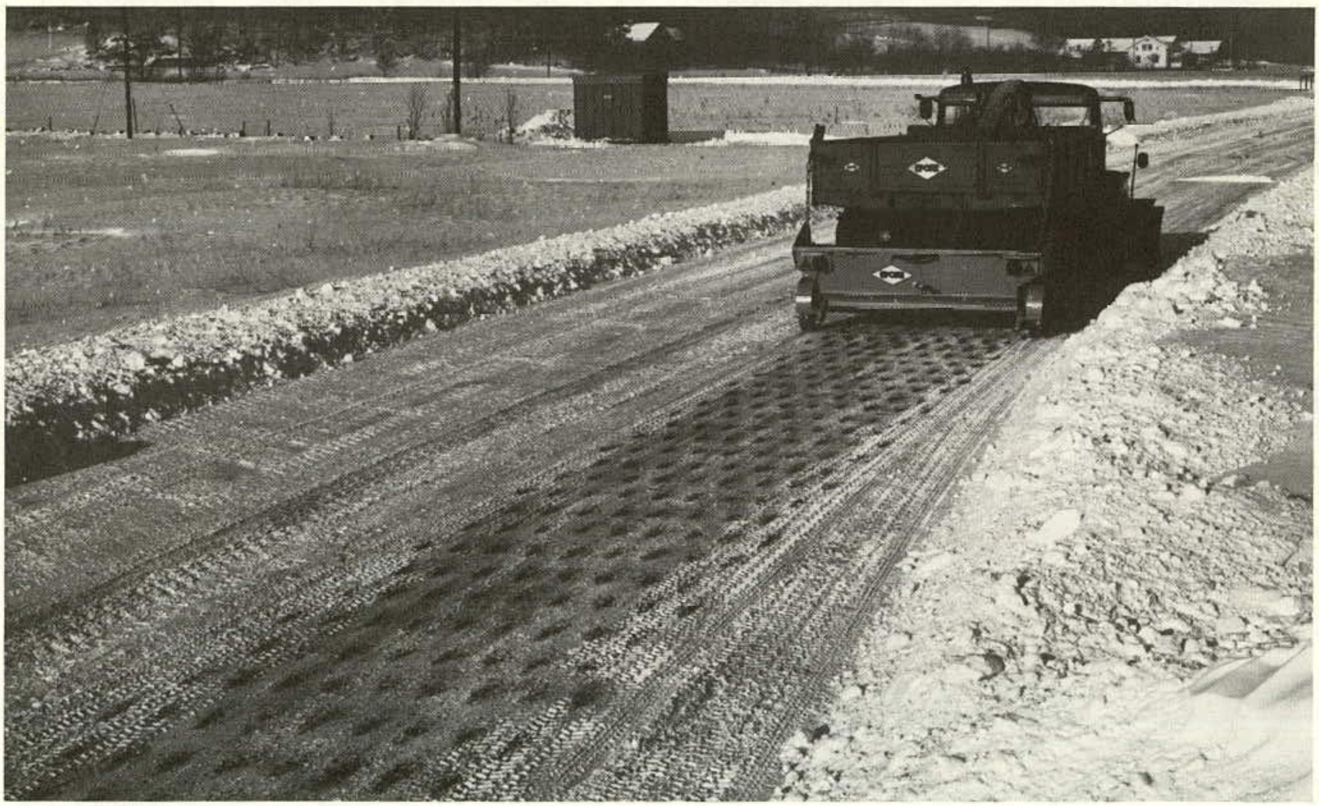


Figure 19. Towed spreader unit used in Europe. This unit distributes a constant amount of material per unit distance regardless of speed.

OS-5208 (9-73)
CC-0830-2500-0220

WINTER MATERIAL ISSUE FORM

COUNTY Monroe
ORG. NO.

DATE 2/21/74
START MILEAGE 15396 END MILEAGE 15480
DRIVER A. L. Smith
EQUIPMENT NO. 595-7036
TRUCK CAPACITY 7 yds Cubic Yards

STOCKPILE NO.	ANTI-SKID A 100% Amt.	Type	ANTI-SKID AND SODIUM MIX B 90 - 10% Amt.	Type	C 75 - 25% Amt.	Type	D 50 - 50% Amt.	Type	SPECIAL MIXES Amt.	Type	%	SODIUM E 100% Amt.	Type	DISTANCE SPREAD	RATE OF APP'L.	TIME LOADED
05402												7yd		19 mi		8 PM
05402												7yd		27mi		10:30 PM
2/22/74																
05402												5yd		11 mi		1 AM

ANTI-SKID
TYPE I 5610-1500-0100 Cinder
II 5610-1500-0200 Stone
III 5610-1500-0300 Sand
IV 5610-1500-0400 Mine Waste

SODIUM
6810-8120-0400 Salt

BAG CALCIUM
TYPE I (Flake) 6810-2390-0120 (R.R.)
6810-2390-0140 (STPL)
TYPE II (pellet) 6810-2390-0310 (R. R.)
6810-2390-0340 (STPL)

BULK CALCIUM
TYPE I (Flake) 6810-2390-0210 (R.R.)
6810-2390-0230 (STPL)
TYPE II (Pellet) 6810-2390-0410 (R.R.)
6810-2390-0430 (STPL)

STOCKPILE NO.	CALCIUM AND SODIUM MIX F 10 - 90% Amt.	Type	G 25 - 75% Amt.	Type	H Premix Amt.	Type	SPECIAL MIXES Amt.	Type	%	K CALCIUM BULK Amt.	Type	CALCIUM BAG Amt.	Type	DISTANCE SPREAD	RATE OF APP'L.	TIME LOADED

INSTRUCTIONS:

1. Form to be filled out by truck driver and deposited in stockpile mailbox with each change of operator. (No form to be held more than 12 hours.)
2. This form can be used for more than one stockpile within a county.
3. When receiving a load of material from another county's stockpile, fill out a separate Winter Materials Issue Form and deposit in that Stockpiles mailbox.
4. For less than a full load, indicate estimated cubic yards loaded.
5. Rate of Application - Amount of materials applied per two (2) lane mile as determined by the Assistant Superintendent.

Figure 20. Materials inventory form (Pennsylvania).

VERMONT DEPARTMENT OF HIGHWAYS
STANDARDS
FOR THE APPLICATION OF SALT ON WINTER HIGHWAYS

The following standards are hereby adopted and will be followed in the application of salt and sand on two lane highways and on two lanes of four lane highways.

Condition I

STORMS WHICH ARE PREDICTED TO BE OF SHORT DURATION OR SQUALLS AND FLURRIES NONE OF WHICH ARE EXPECTED TO REQUIRE PLOWING.

Apply not more than 600 pounds of salt per mile in a narrow strip in the center or as high as possible on banked curves. On the return trip, touch up danger spots with a second strip. If this does not provide safe conditions, apply 1 yard per mile of sand in danger spots.

Condition II

SNOW STORMS OF EXPECTED PLOWABLE DEPTH.

Apply 500 pounds of salt per mile in a narrow strip along the center and as high as possible on banked curves. Touch up with extra salt or sand only the danger spots where traffic gets tied up. Commence plowing and continue as long as necessary.

To clean up, it is usually necessary to apply a second application under foreman's direction of 400 to 600 pounds per mile before the edges are plowed off. Minutes count in giving the salt a chance to clear the pavement before it gets too cold to work.

Condition III

RAIN ON COLD PAVEMENT OR SLEET CONTINUING AND FORMING ICE.

Apply 300 to 500 pounds of salt per mile. The first application should be determined by the weather reportes, the speed of ice build up, the temperature and the time of year. Much can be gained by using an adequate amount to prevent an ice build up if it turns cold. If the rain, sleet or snow continues, 500 to 800 pounds per mile may be necessary to clear the pavement before it turns too cold for the salt to work. Timing of the application is extremely important.

(Excerpt from Commissioner of Water Resources' letter dated October 31, 1972, Page 2, Number 2)

"A report shall be forwarded within 14 days to the Department of Water Resources on each single application of de-icing salt in excess of 800 pounds per mile."

APPROVED BY: Date: Oct 1/1973	APPROVED BY: Date: Oct 1 1973
E. H. Stickney, Chief Engineer	John T. Gray, Commissioner of Highways

Figure 21. Maintenance standard adopted by Vermont.

WINTER WORK REPORT
SALT, SAND & PLOWS

DISTRICT..........
WEEK ENDING..........

INSTRUCTIONS:
List Each Application By Date & Time
Submit Weekly with Payroll for Each Truck

Weather—Radio Designations

TRUCK NO..........

CONTROL SECTION	DATE	STARTING TIME	W?	TEMP	SNOW DEPTH	FROM SHED NO.	MILES COVERED INCL. TOUCH-UP	QUANTITY USED		RESULTS G-GOOD F-FAIR P-POOR	REMARKS
								TONS SALT	YDS. SAND		

CHANGED PLOW BLADES AND SHOES

Carbide Date

Plain Date

Shoes—Date

Signed by..........

Figure 22. Control form used by Vermont.

Though primarily devoted to techniques of snow plowing, a training film has been prepared by the New England Chapter of the American Public Works Association (*47*).

A very comprehensive training program has been organized by Ontario, and includes the use of flip charts, a programmed text, and a test for operators; excerpts are given in Appendix F. Virginia has also developed an effective set of visual aids for its training program, and portions of the program "Use of Chemicals" are also included in Appendix F. A similar program has been prepared on "Planning Chemical and Plowing Routes."

Weather Factors

The most significant factor in starting snow and ice control operations is adequate warning of an approaching storm.

A number of states and cities contract for weather advisories with a private weather service. Massachusetts expects storm warnings to be given at least two hours in advance. Each maintenance district records storm information (Fig. 26). Connecticut uses a "weather round-up" during storms: each maintenance garage reports weather conditions to maintenance headquarters on an hourly schedule on the same radio channel, and thus all areas are aware of the conditions across the state.

The prediction of snow or of icing conditions or the early detection of the presence of ice on pavements can reduce the time required to commence operations, and therefore can serve to reduce the amount of chemical needed to prevent bonding or to effect removal of ice. Considerable work has been done on detection of ice or frost on localized areas such as bridge decks (*48, 49*). Detection most commonly involves measurement of pavement temperature, air temperature, surface moisture, and relative humidity, though other techniques include direct measurement of surface friction, detection of the change in heat transfer rate associated with water phase changes, the change in resonant frequency of a vibrating element when its mass is increased by ice accumulation, the change in capacitance and dissipation factor when the dielectric of a capacitor changes from air to air containing snow or water droplets, temperature-dependent light scattering of a crystal, light scattering from a road surface, and the scattering of gamma radiation by water, ice, or snow (*49*).

An extensive ice prediction, detection, and warning system has been incorporated in two Japanese express highways (*50*). Road surface moisture is detected by electrical conductivity and the scattering of a light beam; air and road surface temperatures are measured, as well as subsurface temperatures at 5, 10, 20 and 50 cm (2, 4, 8 and 20 in.). Dew point temperature, net radiation, wind direction, and wind velocity are also measured. The sensor signals are processed by a central computer. Information affecting traffic is displayed on changeable message boards. In addition to motorists' warnings, the system is used to predict icing conditions. A forecast of pavement temperatures for the period from 5 PM to 8 AM the following day is one factor utilized in dispatching maintenance trucks for chemical deicing.

Massachusetts has also installed a temperature sensor in

5-792.44-100 RECOMMENDED LEVEL OF SERVICE FOR SNOW AND ICE CONTROL

A. Route Classifications

Classification	ADT
Urban Commuter	Over 10,000
Rural Commuter	2,000-10,000
Primary	800-2,000
Secondary	0-800

B. Quality Standard for Snow and Ice Removal

Classification	ADT	Level of Service*
Urban Commuter	Over 10,000	Bare pavement within 6 hours after termination of storm (12 hours for severe storms).
Rural Commuter	2,000-10,000	Bare pavement within 24 hours after termination of storm. (On divided highways, left lanes should be half bare with sanded curves and hills before termination of snow removal effort.
Primary	800-2,000	Intermittent bare pavement, clear Wheel Tracks (compacted snow with appropriate sanding allowed in towns and sheltered areas).
Secondary	400-800	Two bare wheel tracks and sanded hills and curves.
Secondary	250-400	Bare left wheel track and sanded hills and curves.
Secondary	Under 250 & Gravel Roads	Compacted snow is acceptable.

*Based on an average snowstorm of four inches falling in a six to eight hour period. Standards apply only to the mainline and interchange roadways; frontage road, crossover and other clean-up operations are not included.

C. Snow Removal Coverage and Cycle Times

Classification	ADT	Coverage Time	Cycle Time
Urban Commuter	Over 10,000	24	2
Rural Commuter	2,000-10,000	18	3
Primary	800-2,000	18	4
Secondary	Under 800	12	8

1. Coverage time is defined as number of hours per day that service will be provided during the storm.

2. Cycle time is defined as the amount of time allowed to remove snow on through lanes of a given route section while providing the specific level of service under average conditions.

As with level of service, these times do not apply to frontage roads and clean-up operations.

D. Equipment Requirement Criteria

1. The required number of single and tandem axle dump trucks (class 33 and 35) is directly related to lane mileage, number of interchanges and cycle time. The criteria used in this process are as follows:

a. Average net plowing speed of 15 miles per hour (based on total operating time). The net plowing speed is based on the standard time for one man plowing operations.

b. Cycle time for interchanges increases to 1-1/2 times the cycle time for the adjacent mainline. This criteria can be satisfied by providing one truck for each:

i) 1-1/2 urban complex interchanges
ii) 2 urban simple interchanges
iii) 4 rural simple interchanges

2. The procedure for determining the number of trucks required employs the equation

$$N_t = \frac{D}{15C} + \frac{N_{A_u}}{1\text{-}1/2} + \frac{N_{B_u}}{2} + \frac{N_{A_r}}{2\text{-}1/2} + \frac{N_{B_r}}{4}$$

where

N_t = number of trucks required
D = distance to be plowed in lane miles
15 = average plowing speed in miles per hour
C = cycle time in hours
N_{A_u}, N_{B_u}, N_{A_r}, and N_{B_r} = the number of complex (A) and simple (B), urban (u) and rural (r) interchanges.

Example: Consider an urban commuter route which has 90 lane miles and four urban simple interchanges. The number of trucks required would be

$$N_t = \frac{90}{15 \times 2} + \frac{4}{2} = 3 + 2 = 5 \text{ trucks}$$

E. Personnel Requirements

1. Regular complement is based on manpower needed to operate required number of trucks. Assume that one man is to be used per truck per:

8 hr. shift	Urban Commuter
9 hr. shift	Rural Commuter
9 hr. shift	Primary

One man for twelve hours or one man for six hour shifts may be used on secondary routes. Only highway, freeway and landscape maintenance men are to be included in this complement.

2. Auxiliary complement required for snow removal support operations includes heavy equipment operators, bridge workers, signmen I and freeway maintenance men - sign option. No recommendation has been made as to the criteria for determining this complement of specialists.

3. Highway technicians should be used as replacement personnel and as second men when needed.

Figure 23. Maintenance standards adopted by Minnesota.

Form 17256 (9 71)

Minnesota Highway Department

CHEMICAL USAGE LOG

Complete in duplicate at end of each shift: Original to foreman, copy remains in book.

Date	Route No.	SHIFT HOURS
Unit No.	Source	[ ] 8 AM - 4 PM [ ] 4 PM - 12 M [ ] 12 M - 8 AM [ ] ____ M- ____ M
Single [ ] Tandem [ ]		

LOAD	COVERAGE Spot (%)	COVERAGE Continuous	Cu. Yds. of Winter Sand	Cu. Yds. of Chem. Added	Total Cu. Yds.
1	[ ]	[ ]			
2	[ ]	[ ]			
3	[ ]	[ ]			
4	[ ]	[ ]			
5	[ ]	[ ]			
6	[ ]	[ ]			
7	[ ]	[ ]			
8	[ ]	[ ]			
9	[ ]	[ ]			
10	[ ]	[ ]			
No. of Times Covered		Totals			

Signature of Operator

Remarks:

Figure 24. Log of chemical use (Minnesota).

the pavement on Route 128, the heavily trafficked Boston circumferential route. Pavement temperature is recorded continuously on a strip-chart recorder in the maintenance building near the site. Wind speed and direction, air temperature, and solar radiation will be obtained from an Air Force micrometeorological station adjoining the maintenance station. This experimental program was to get underway in the winter of 1973-74 and will attempt to correlate pavement temperature with development of icing conditions, and to use this information as a predictive tool. The contract weather service has been forecasting radiation cooling potential for flash frost formation with 60 percent success.

The effect of topography and elevation will significantly affect road surface conditions. Exposure to sunlight will greatly aid clearance of ice or snow with or without chemicals, and "daylighting" by cutting down brush or trees that shade the road is done (*48*). The drop in temperature with increase in elevation, about 4°F per 1,000 ft (0.7°C/100 m),* can result in rain changing to snow with only a slight elevation change.

The Ohio Turnpike requires detailed reporting of each storm, including a description of the precipitation type, procedures taken to maintain bare pavements, and an evaluation of the results (Fig. 27).

* Dry-adiabatic lapse rate (the change in temperature with elevation considering dry air) is 5.4°F per 1,000 ft (1°C/100 m). Saturated adiabatic lapse rate (air at 100 percent relative humidity) is about 3°F per 1,000 ft (0.55°C/100 m) (*51*).

Form T 9-71

Minnesota Highway Department

WINTER CHEMICAL USAGE SUMMARY

Maintenance Area ____________ 4 Week Period from ________ to ________ Submitted by ____________

Route Class	Lane Miles*	Sand Usage (Tons)	Chemical Usage (Tons)	Tons/L.M. Sand	Tons/L.M. Chemicals	Average No. of Coverages	Remarks
Urban Commuter							
Rural Commuter							
Primary							
Secondary							

*Indicate: Mainline only ☐ Mainline plus turn lanes, acceleration lanes and ramps ☐

Summary period should be four-week intervals ending on Tuesday one week after the end of a payroll month.

See "Recommended Level of Service for Snow and Ice Control" June 14, 1971, for route class definitions.

Sand and chemical usage should be tabulated from Form 17256, Chemical Usage Log

Average number of coverages is equivalent to the total number of reported times covered divided by the number of winter routes in the maintenance area.

Remarks should include a summary of the number and type of snowfalls and total snow accumulation.

Summary should be submitted to the Maintenance Office, Room G-29D within one week after the end of the reporting period.

Figure 25. Summary of chemical use (Minnesota).

The Federal Government provides two recorded radio weather services. One, operated by the National Weather Service of the National Oceanic and Atmospheric Administration of the Department of Commerce (*52*), provides continuous transmissions repeated every 4 to 6 min and revised every 2 to 3 hr, on VHF-FM from the cities indicated on the map (Fig. 28). Effective range is 40 to 60 miles (60 to 100 km). The other service is provided by the Federal Aviation Administration on low-frequency bands (Fig. 29) and is primarily aviation-oriented, though surface weather reports are included (*53*).

USE OF ABRASIVES/SALT

The claim that highway maintenance officials are attempting to maintain "June in January" road conditions is an oversimplification, though there is considerable public demand for maintaining high speeds during wintertime storm conditions. The principal justification for applying deicing chemicals is to prevent the buildup of snowpack. Salt distributed on the pavement during falling-snow conditions keeps the snow mealy and prevents the buildup of the compacted snow mass that would adhere tightly to the pavement. In those cases where maintenance people have not applied sufficient salt in time, a compacted snow mass has built up which has been known to take three to five days to remove by laborious, costly, time-consuming, and marginally effective methods. It is the possibility of this "highway horror" that motivates the maintenance man to spread an adequate quantity of salt early in the storm period. Viewed in this context, the reluctance to spread abrasives is understandable, for abrasives do nothing to prevent the buildup of "pack" but merely reduce skid qualities on the surface. Too, abrasives are soon covered by additional snowfall or scattered by traffic action. However, abrasives do have their place at such locations as low-speed highways and on hills, curves, and points of deceleration—locations where fast traffic and aerodynamics forces will not blow the abrasive off the surface promptly.

The performance of four types of antiskid materials (i.e., boiler-house cinders, coke cinders, sand, and stone) was evaluated on a laboratory circular track, and little difference was found in their effect on coefficient of friction (*54*). It was found that material passing the No. 50 sieve made no contribution to increasing the coefficient of friction. However, these materials exhibited considerable differences in retention of calcium chloride. Characteristics of the materials are given in Table 4.

Vermont considers sanding an emergency measure to be used only when salt cannot be applied. Freezeproofing of sand requires the addition of 50 to 100 lb of salt per cubic yard (30 to 60 kg/m^3) added at the earliest possible stage in the stockpiling operation and mixed as thoroughly as possible as it is placed in the pile. Stockpiling is done early enough in the season to allow the salt to dissolve in the sand. A thin layer of salt is spread on the top of the pile. Vermont also uses salt-sand mixtures. Average mixture ratios have varied from 4.5:1 to 3.5:1 sand-to-salt ratio.

MASSACHUSETTS DEPARTMENT OF PUBLIC WORKS

MAINTENANCE DIVISION — STORM REPORT — ADVISORY# TIME: ______

DATE: ______

DIST	STORM B/S TIME DATE	WEATHER & WINDS	AVE. TEMP. R/F*	AVE. ACCUM. INCHES &	PAVEMENT CONDITION	OPERATIONS	EQUIPMENT HIRED FIRST ON	HIRED LAST OFF	HIRED PLOWS	HIRED SAND CLS	HIRED LOAD MAT	HIRED LOAD SNOW	STATE PLOWS	STATE SAND CLS	STATE LOAD MAT	STATE LOAD SNOW	MEN	** TIE UPS	** ACCID STATE	DIST ON/OFF AIR	ENGRS. IN DISTRICT REPORTING
1		WE / WD		N / S																/	
2		WE / WD		N / S																/	
3		WE / WD		N / S																/	
4		WE / WD		N / S																/	
5		WE / WD		N / S																/	
6		WE / WD		N / S																/	
7		WE / WD		N / S																/	
8		WE / WD		N / S																/	

LEGEND:

WEATHER
1. CLEAR
2. PARTLY CLOUDY
3. CLOUDY
4. RAINING
5. FREEZING RAIN
6. SLEETING
7. LIGHT SNOW
8. MODERATE SNOW
9. HEAVY SNOW
10. STORM OVER

B-TIME STORM BEGAN, S-TIME STORM STOPPED

WIND/MILES PER HOUR
1. LIGHT 0-12MPH
2. MODERATE 13-22MPH
3. STRONG 23-30MPH
4. GALE 31-70MPH
5. HURRICANE 71

PAVEMENT CONDITIONS
1. BARE & DRY
2. BARE & WET
3. SNOW ON PAVEMENT
4. ICE ON PAVEMENT
5. SLUSH ON PAVEMENT
6. PAVEMENT PARTLY BARE
7. PACK ON PAVEMENT
8. SLIPPERY IN SPOTS

OPERATIONS
1. PATROLLING
2. PLOWING
3. SAND & CHLORIDES
4. PUSHING BACK
5. LOADING & HAULING SNOW
6. CLEARING WATERWAYS

WE= WEATHER
WD= WINDS
N = NORTH
S = SOUTH

* NOTE: R/F After temperature Indicates rising or falling Temperature since last Advisory.

** Information on Tie-Ups or Accidents on reverse side of report.

______

______

ENGINEERS

HMD-735

Figure 26. Storm report form (Massachusetts).

OTC 6-8-60

STORM REPORT
OHIO TURNPIKE

Report No.________
Section________
Division________
Date________

Prepare a complete and independent report of each storm in your section. Forms should be numbered consecutively for each storm in the season. Form shall be completed and distributed as follows: Original-Maintenance Engineer; second copy-Division Superintendent; third copy-File, section office.

A storm is defined as starting with the beginning of precipitation which necessitates corrective action by maintenance forces to provide a clear pavement. The storm has ended when the precipitation ceases and that condition continues for a period sufficient for a clear, normal pavement surface to be restored.

1. Time

	(a.m.	p.m.)	Day of Week	Mo.	Day	Year
Storm started:						
Storm ended:						
Pavement completely cleared:						

2. Location General ☐ Local ☐ Structures only ☐
From________ M.P. to ________ M.P.
Adjacent sections having same condition: East ☐ West ☐

3. Description
Dry snow ☐ Sleet ☐ Freezing rain ☐
Wet snow ☐ Other (describe)________
Temp. (°F.) . . . . Max.________ Min.________
Depth of snow . . . . Aver. (in.)________ Drifts (ft.)________
Wind . . . . Direction________ Velocity (Mph)________
Visibility: Good ☐ Fair ☐ Poor ☐ Feet:________

4. Forecast
Source________ Time________
Dry snow ☐ Sleet ☐ Freezing rain ☐
Wet snow ☐ Other (describe)________
Temp. (°F.) . . . . Max.________ Min.________
Depth of snow . . . . Aver. (in.)________ Drifts (ft.)________
Wind . . . . Direction________ Velocity (mph)________

5. Procedure

		Time		Time
Chemical	☐	From		To
Plowing	☐	From		To
Abrasive	☐	From		To

6. Results

	Excellent	Good	Poor	Ineffective	Remarks
Chemical	☐	☐	☐	☐	
Plowing	☐	☐	☐	☐	
Abrasive	☐	☐	☐	☐	

7. Manpower and Materials

Men on duty:	Number	Reg. Hours	Over. Hours	Total Hrs.
"A" Crew				
"B" Crew				
Other				
Total Men				

Equipment:	Number	Patrol Hrs.	Spread Plow Hrs.	Total Hrs.
Light Trucks				
Heavy Trucks				
Graders				
Loaders				
Total Equip.				

Materials Used:
Salt________tons; Calcium Chloride________tons; Abrasives________tons/yds.

8. Remarks: (Comment on use of procedure and materials. Did you follow charted assignments of men and equipment? Did you use call-out men? What suggestions do you have for improving procedure, equipment or materials? Use blank side of form for comments.)

Figure 27. Storm report (Ohio Turnpike).

Submitted by________
Section Foreman

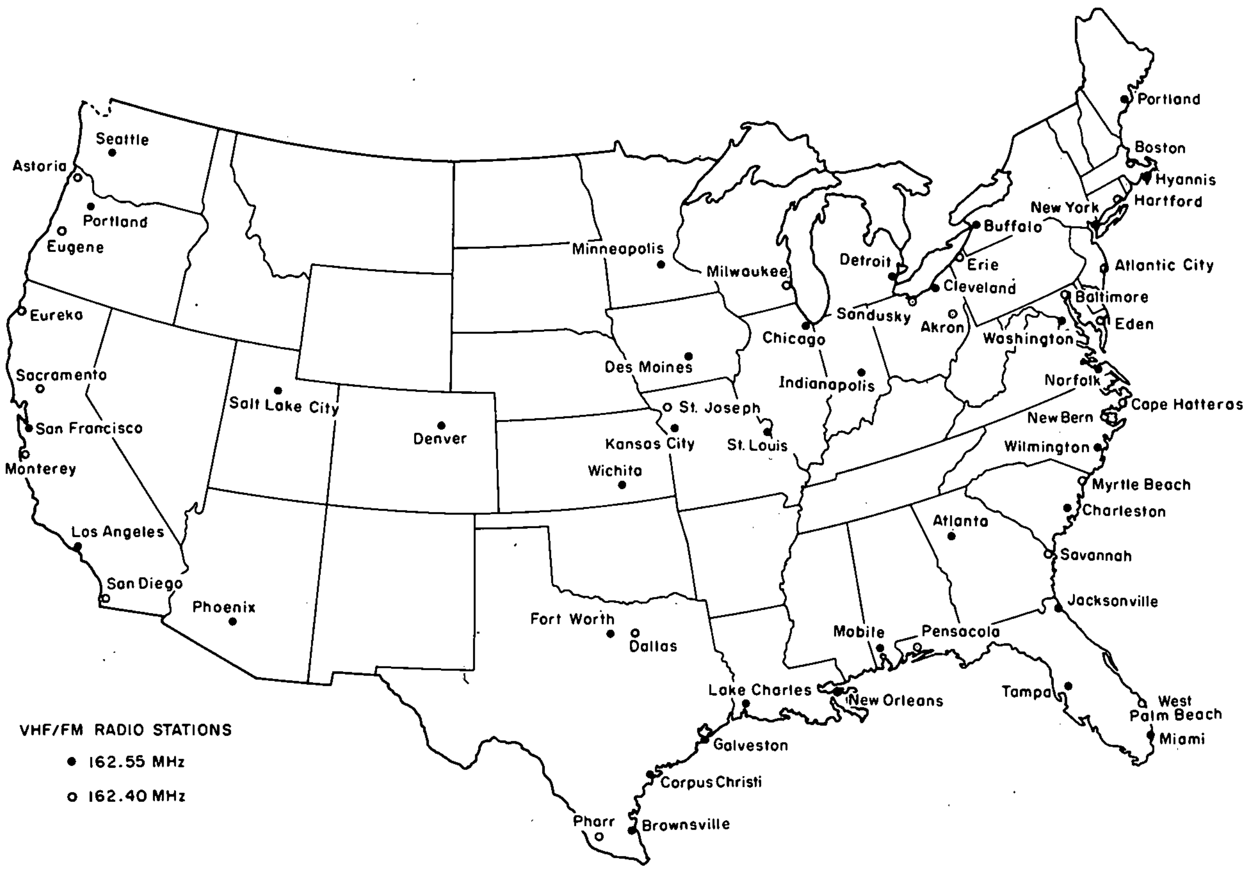


Figure 28. Locations of VHF-FM automatic weather broadcast stations.

However, use of the mixtures is a practice that is discouraged: "If it's cold enough for sand, you don't need salt; if it's warm enough for salt, you don't need sand."

The use of sand has been decreasing in Massachusetts. Instead, premix 5:1 sodium chloride-calcium chloride is used in many situations where sand was formerly used. A 50-50 sand-salt mixture is used for sharp curves, steep hills, intersections, and low-traffic roads. There is no extensive stockpiling of mixtures unless stockpiles can be covered. Several years ago the cost of sand, spreading, and cleanup was $20 per cubic yard ($26/m^3); it is now estimated at $30 per cubic yard ($34/m^3).

All two-lane highways in Connecticut are treated with 7:2 sand-salt mix at the rate of 5 cu yd per 8-mile (3.7 m^3/13 km) run and/or at the rate of 1,182 lb sand and 300 lb salt per two-lane mile (330 kg sand and 90 kg salt/km), spread over a 6- to 8-ft (1.8 to 2.4 m) width. The same mix is used on ramps because of the slower traffic action. Abrasives with only freezeproofing salt added (16:1 mix) are used on multi-lane highways, spread 4 to 5 ft (1.2 to 1.5 m) on either side of the center line, when conditions require. The amount of material loaded into each truck is only that required to cover the assigned run at the specified application rate. In watershed areas where it is desired to reduce the sodium-ion level, a sand-chloride mix consisting of 11 parts sand to 2 parts of a 3:1 sodium chloride-calcium chloride premix is applied at the rate of 5 cu yd per 8 miles. Where equipment is available to spray a 50-percent solution of propylene glycol on the solid material, the sand-premix ratio is reduced to 7:2, applied at the same 5-cu-yd-per-8-mile rate.

Sand is being recovered from shoulders after application for ice control purposes, trucked to a stockpile area, and later screened for reuse on Connecticut roads. It was found that 1 part reclaimed sand mixed with 2 parts new sand met dry specifications for an ice control abrasive, but was slippery when wet. A blend of 1 part reclaimed to 10 parts new sand is satisfactory.

Sodium chloride is used in Idaho as a sand additive at the

TABLE 4

RETENTION OF CALCIUM CHLORIDE ($CaCl_2$) BY ANTISKID MATERIALS

MATERIAL	WEIGHT (PCF)	$CaCl_2$ RETENTION * (% BY WEIGHT)
Boiler-house cinders	48.6	13.5
Coke cinders	60.5	9.9
Sand	117.5	6.9
Stone	103.0	0.9

* Retention determined from the weight increase of oven-dried material soaked for 75 min in saturated $CaCl_2$ solution, drained, and dried.

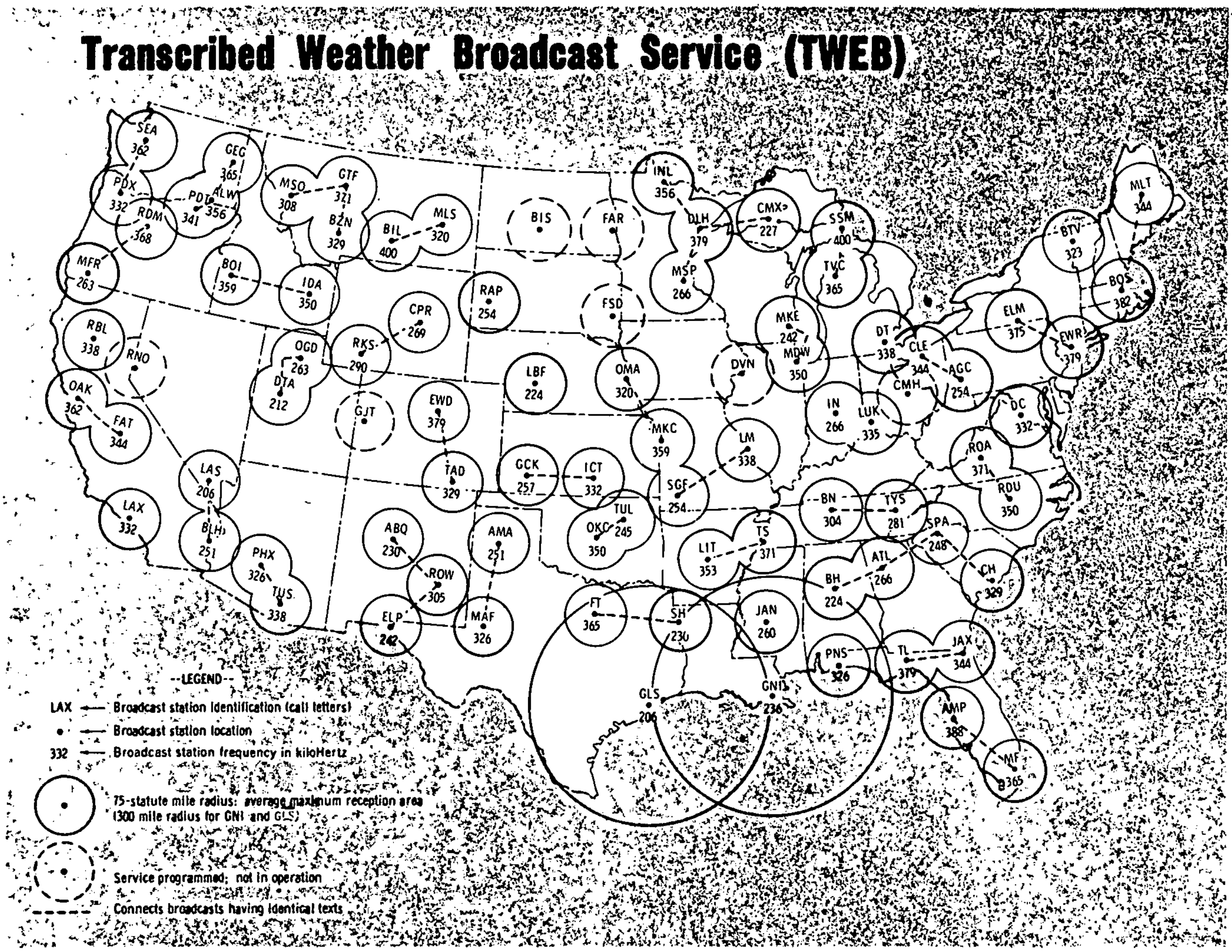


Figure 29. Locations of transcribed aviation weather broadcasts; frequencies are in kilohertz.

rate of 100 lb per cubic yard (60 kg/m³). Straight salt is applied only on icy spots, generally only on curbed sections where storm sewers are involved. The maximum rate of 500 lb per lane-mile (140 kg/km) is stipulated by the Public Health Department. The use of sand has increased tremendously in order to keep the use of salt to a minimum: it has tripled in the last eight years.

OTHER PRACTICES

More complete removal of snow from the pavement is one approach to reducing the need for chemical treatment. Truck-mounted underbody blades (Fig. 30) accomplish this by providing constant down-pressure, thus avoiding the bouncing of a front-mounted blade. A further advantage is improved visibility because the snow cloud whipped up by a front-mounted plow at moderate to high speeds is eliminated. Other states (such as Maine, Michigan, and North Dakota) have used underbody blades successfully to remove compacted snow.

High speed of operation is a truck's principal advantage over a motor grader; New Hampshire has assigned trucks on an Interstate route to plow at speeds up to 60 mph (100 km/hr).

Washington has initiated a program of checking the effect of its salting program on the surrounding roadside vegetation. Most of the state's use of salt is in Snoqualmie Pass (Interstate 90). In this area samples of vegetation have been taken at roadside ditch line within the limits of snow casting and outside the limits both uphill and downhill of the roadway. These vegetation samples were sent to an independent laboratory for analysis of sodium and chloride contents. Plant density and annual growth were recorded for a 3-ft (0.9 m) radius around each sample. This information will be used for future comparison.

Seattle reduces chemical use by early plowing under conditions of moderate to heavy snowfall, rather than relying on salt. Also, they apply salt to inbound routes in the morning only and to outbound routes in the afternoon only. When temperatures drop, salt-sand mixtures varying from 1:1 to 3:1 sand/salt are applied at the rate of 600 lb per two-lane mile (170 kg/km). The salt and sand are not premixed; the two materials are loaded into the truck in the

required proportions and are mixed adequately by the hydraulic tail-gate spreader.

In Vermont, random samplings of salt from vendor's sheds, vendor's trucks, and the state's stockpile sheds are frequently checked for gradation and moisture content. Considerable variation in gradation is often noted. Though no formal study of the effect of this variation in gradation has been made, additional applications have been made at times when there were too many fines. The use of salt in Vermont has been declining. Using the winter of 1969-70 as the base year, 22 percent less was used in 1970-71 and 12 percent less in 1971-72. The average rate of application has declined from 630 lb per mile (180 kg/km) in 1970-71 to the present 546 lb per mile (150 kg/km) of two-lane highway.

In New Hampshire, salt use has been reduced by calibrating all spreaders individually; experimentally using lower rates of applications; and substituting sand for intermediate runs during storms on hills, curves, intersections, and trouble spots, thus eliminating intermediate straight salt applications unless actual compaction takes place. Salt has been eliminated experimentally on certain low-traveled roads, which are mostly in the northern parts of the state where temperatures are generally low and traffic light and which, therefore, are not subject to packing snow conditions. The contamination of water supplies in certain areas has forced the state to use more sand and to restrict the use of straight salt only to those conditions when packing of snow will occur or freezing rain occurs.

Wind can have a significant effect on the distribution of salt, which can drift just like snow. Therefore, the operator should "play the wind." Some indication of the necessity for another chemical application is the slush kicked out from behind vehicle tires. If the slush is soft and "fans" out, the salt is still working. Once the slush begins to stiffen and is thrown directly to the rear of the vehicle tires, it is time to plow and spread more chemicals. It is important that slush be bladed off the highway before rutting and freezing occur. This advice holds special importance when the application of chemicals has made the pavement wet and drifting snow has stuck to the wet pavement.

North Dakota's maintenance manual states that the speed of a salt spreader should never exceed 20 mph (30 km/hr) because any higher speed tends to destroy the desired spread pattern. The trend in Massachusetts has been to shift from broadcast distribution with a spinner to wind-

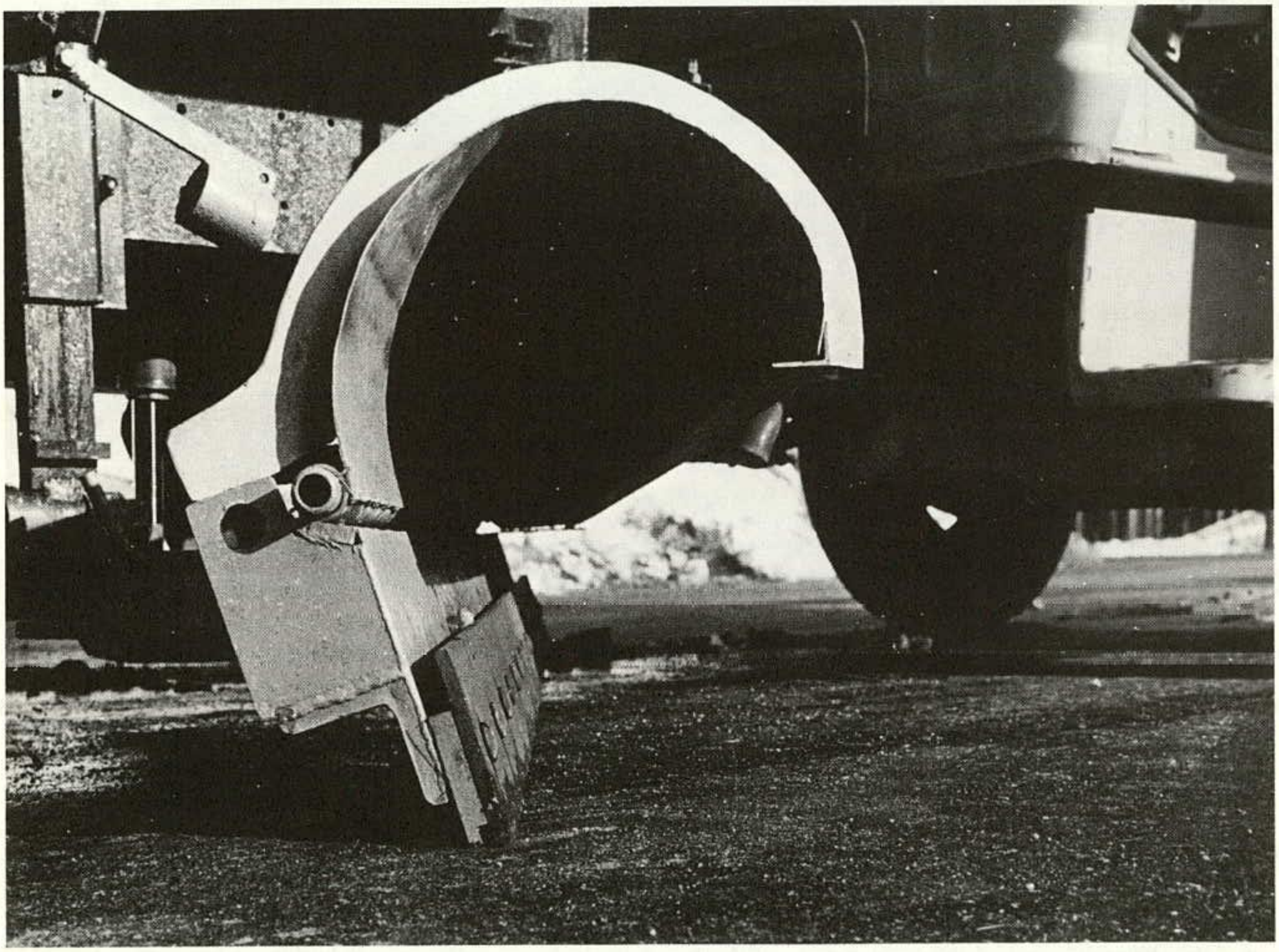


Figure 30. Truck-mounted underbody blade. This unit is designed to be operated at high speeds (up to 60 mph) and is shown here in working position with the right-hand discharge in foreground (New Hampshire).

rowing. Other practices that have been instituted to reduce salt use include preventing heaping of spreader loads to avoid unnecessary spillage and prohibiting the practice of "burning off" light deposits [2 to 3 in. (50 to 75 mm)] of snow instead of plowing.

When Connecticut uses salt on multi-lane highways, it is applied in a windrow at the rate of 430 lb per two-lane mile (120 kg/km) of multi-lane highways. In watershed areas the sodium-ion content is reduced by applying a 3:1 sodium chloride-calcium chloride premix at the rate of 4 cu yd per 20 (two-lane) miles (3 m^3/32 km). As a trigger to increase the action of the chemical mixture, a 50 percent solution of propylene glycol is sprayed on the chlorides at the rate of 10 gal per mile (24 l/km) as they are discharged from the spreader.

Flow of melt water from the high side of superelevated curves across the pavement, with the potential danger of refreezing, is minimized in a design used by Quebec Autoroutes Authority. The outside shoulder slope is reversed in this design (Fig. 31) (*55*).

High salt content in soils affects plant growth by reducing water absorption because of high, external osmotic pressure and by the effects of specific ions on the metabolic process (*56*). Experiments (*57*) conducted in Maine have shown that the concentration of sodium ions can be reduced by heavy treatments of gypsum ($CaSO_4 \cdot 2\ H_2O$). Sodium is replaced by calcium in the presence of sulfate ions and forms soluble sodium sulfate, which readily leaches from the soil. Limestone ($CaCO_3$) was also used in the trials, but it forms an insoluble sodium carbonate that remains in the soil. During the two-year study, an application of gypsum at 14 tons per acre (3.14 kg/m^2) consistently reduced the sodium level in the surfaces of two sites that initially had high levels. At one site, the sodium level was reduced from 734 ppm to 231 ppm.

ALTERNATIVES TO CHLORIDES

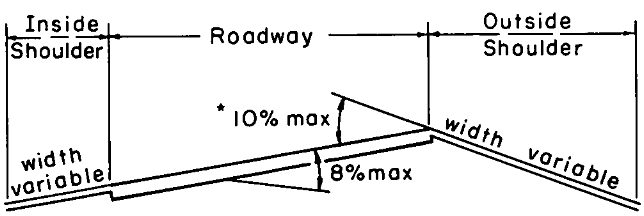
Other Chemicals

Efforts have been made to find an alternate to sodium and calcium chlorides for application on bridge decks, where the more frequent freeze-thaw cycling often results in scaling or spalling. Tests in California (*58*) have pointed to tetrapotassium pyrophosphate (TKPP) as an effective chemical for anti-icing applications at temperatures of 25°F (−4°C) and higher when applied at a rate of 0.01 lb per square foot (0.05 kg/m^2) of 30 percent aqueous solution. There was a residual antifrost effect for up to two weeks because rain did not dilute the TKPP. The chemical does not readily penetrate concrete and therefore has not caused spalling or scaling. Its slight corrosivity to steel is controlled by addition of 2 percent calcium hydroxide (lime).

The highly ionizing chloride deicing chemicals cannot be used on airfields because of corrosion to aircraft materials. A number of nonchloride chemicals have been investigated and are listed in Table 5.

Alcohols have been used at U.S. Air Force bases in Alaska and in other states, but their flammability and high rate of evaporation limit their usefulness. Sodium sulfate causes concrete deterioration and should not be used. Only urea, formamide, and TKPP have been used in practical applications.

Proprietary liquid deicing chemicals have been tested by the Port Authority of New York and New Jersey at LaGuardia and Clinton County (Plattsburgh, N.Y.) airports (*61*). These chemicals, listed in Table 6, were found to be generally equal in effectiveness, and to reduce the coefficient of friction of dry pavement by 15 to 20 percent but only temporarily after application. The chemicals did not melt ice rapidly without trafficking or mechanical assistance, and during the melting process the coefficient of friction remained very low (for about 4 hr at an unspecified temperature the coefficient of friction as measured with a Soiltest MuMeter remained below 0.20 in tests with all four chemicals).



* AASHTO: 7% max.

Figure 31. Design of shoulder to reduce melt water flowing from shoulder onto superelevated curve and refreezing (Quebec).

TABLE 5

NONCHLORIDE DEICING CHEMICALS

MATERIAL	REFERENCE
Tripotassium phosphate	59
Tetrapotassium pyrophosphate (TKPP)	59
Acetamide	28, 59
Ammonium acetate	28, 59
Urea	28, 59, 60
Sodium sulfate	59
Formamide	28, 59, 60
Ammonium carbamate	28
Methyl alcohol	28
Ethyl alcohol	28
Isopropyl alcohol	28
Calcium formate	60

TABLE 6

PROPRIETARY LIQUID CHEMICALS

NAME	MANUFACTURER	PRINCIPAL CONSTITUENTS
LRD	Lyndhurst Chemical Co.	Ethylene glycol-urea
ARD-45	Allied Chemical Corp.	Ethylene glycol-urea
UCAR	Union Carbide Corp.	Ethylene glycol-urea
ISOLV	Kaiser Agricultural Chemicals	Urea-formamide

The use of ethylene glycol-based deicing fluid applied at a rate of 1 gal/1,000 sq ft (4 l/100 m^2) for both deicing and anti-icing has been reported (*62*). This quantity is sufficient to completely wet a surface if applied in a fine spray. Its reported cost is $0.72 per gallon ($0.19/l), and materials to treat a 10-ft-wide lane-mile would cost about $38 ($24/km, 3 m wide).

Heated Pavements

Applying thermal energy to the pavement surface from within the pavement is one of the most effective methods of melting ice and preventing the formation of compacted snow. However, the high cost of both capital construction and operating has restricted application to limited areas such as bridge decks (*63*), toll plazas, interchange ramps (*64*), and parking ramps (*65*). Installation costs of $3.50 to $4.50 per square foot ($38 to $48/$m^2$) have been reported for circulating liquid systems, and $4.00 to $5.50 per square foot ($43 to $59/$m^2$) for electrical systems (*66*). Operating costs in Toronto (1965) were $0.32 per square foot ($3.40/m^2) (*64*).

A heat input of 10 to 20 w per square foot (108 to 215 w/m^2) is necessary to maintain the road surface temperature above freezing. Calculated snow-melting rates for

1971 REGULAR SESSION — Ch. 623

HIGHWAYS--SNOW REMOVAL--USE OF SALT OR CHEMICALS

CHAPTER 622

S.F. No. 225

[Coded]

An Act relating to highways; restricting the use of salt or harmful or corrosive chemicals upon highways or streets; amending Minnesota Statutes 1969, Chapter 160, by adding a section.

Be it enacted by the Legislature of the State of Minnesota:

Section 1. Minnesota Statutes 1969, Chapter 160, is amended by adding a section to read:

160.215 Snow removal; use of salt or chemicals restricted

In order to:

(1) Minimize the harmful or corrosive effects of salt or other chemicals upon vehicles, roadways, and vegetation;

(2) Reduce the pollution of waters; and

(3) Reduce the driving hazards resulting from chemicals on windshields; road authorities, including road authorities of cities, villages, and boroughs, responsible for the maintenance of highways or streets during periods when snow and ice are prevalent, shall utilize such salt or other chemicals only at such places as upon hills, at intersections, or upon high speed or arterial roadways where vehicle traction is particularly critical, and only if, in the opinion of the road authorities, removal of snow and ice or reduction of hazardous conditions by blading, plowing, sanding, including chemicals needed for free flow of sand, or natural elements cannot be accomplished within a reasonable time.

Approved June 1, 1971.

Figure 32. Minnesota legislation concerning use of deicing chemicals.

snow of 6 lb per cubic foot (100 kg/m³) density on a 10-w-per-square-foot heated surface are about 0.4 in. per hour (10 mm/hr) [heater depth of 1 in. (25 mm)], 0.3 in. per hour (8 mm/hr) [depth of 2 in. (50 mm)], and 0.2 in. per hour (5 mm/hr) [depth of 4 in. (100 mm)] (*67*).

A comprehensive review of methods of heating pavements is available in *NCHRP Report 4* (*68*).

CURRENT LEGISLATION ON DEICING CHEMICAL USE

Minnesota and Vermont have enacted legislation to restrict the use of deicing chemicals. The Minnesota act and the Vermont resolution are given in their entireties in Figures 32 and 33. Hearings were held in Wisconsin during the summer of 1973 to prepare legislation for control of deicing chemical use.

NO. R-38. JOINT RESOLUTION RELATING TO THE BARE OR SAFE ROAD POLICY OF THE VERMONT DEPARTMENT OF HIGHWAYS

(J.R.H. 7)

Whereas, the state of Vermont has attained and enjoyed over the years the enviable reputation for outstanding maintenance of its state highway system; *and*

Whereas, this high quality of highway maintenance enhances and promotes the safety of the traveling public as well as the swift and efficient movement of goods into, within and from the state of Vermont; *and*

Whereas, the state's economy and the continuing well-being of its citizens are dependent, in part, upon the immediate availability and use of the highway network; *and*

Whereas, the immediate availability and use of the state highway system dictates a bare or safe road surface as soon as is possible after inclement weather; *and*

Whereas, the controlled use of chemicals has been proven from 30 years experience to be an effective method available to attain a bare or safe road surface; *and*

Whereas, there has been evidence presented indicating that the excessive use of chemicals may be harmful to the environment; *now therefore be it*

Resolved by the Senate and House of Representatives:

That the department of highways is commended for their program of research for less potentially harmful methods of obtaining bare or safe roads, *and be it further*

Resolved: That the department of highways be exhorted and encouraged to work with the Agency of Environmental Conservation in a continuing effort to discover methods of obtaining bare or safe roads which will be economically feasible and least harmful to the environment, *and be it further*

Resolved: That the Agency of Environmental Conservation shall work closely with the highway department in accomplishing the foregoing purposes, *and be it further*

Resolved: That the proper agencies encourage the testing and charting the effects of highway usage on both private and municipal water supplies, *and be it further*

Resolved: That the department of highways should continue to maintain a bare or safe road policy with appropriate adjustments determined advisable as a result of conducted research.

Approved: March 29, 1971.

Figure 33. Vermont legislative resolution on winter road maintenance policy.

CHAPTER THREE

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Deicing chemicals are applied to pavements to accomplish one of two things: to prevent the formation of ice or compacted snow, or to break the bond between ice or compacted snow and the pavement. The first objective can best be achieved by covering the pavement completely with a thin film of a "parting compound"; a spray application of liquid deicing chemical is one of the most effective techniques. Once formed, the ice-pavement bond is difficult to break. It is for just such a situation that the technique of windrow application of solid deicing chemical has evolved. Placement of the chemical near the centerline minimizes loss by traffic action before the chemical can go into solution and allows the concentrated brine to flow from the crown under the snow or ice to break the bond. Because chemical treatment is generally not commenced until precipitation is falling, deicing material is generally windrowed to attain both objectives.

A major problem in the use of salt is to know how much to apply for a given climatic condition and to be able to apply a known, controlled amount of chemical. Calibration of salt spreading equipment—variations between pieces of equipment are so great that each piece should be calibrated —is essential to control application rates. Calibration involves collecting and weighing the material discharged at known equipment settings. An alternate to this in-place method is over-the-road distribution of a known amount and measurement of the distance traveled. The capability of spreading a uniform rate regardless of speed reduces waste.

Abrasives can be used instead of chemicals in locations where traffic is not heavy enough to remove them rapidly from the road, or where aerodynamic forces will not remove them. However, abrasives can insulate the snow or ice and will not in themselves remove the buildup.

Close management controls are necessary to ensure the use of the minimum amount of chemical required for a given condition. Priorities, levels of service, and standards for application should be established. Inventory control and use records are important aids in determining conformance to standards.

Training of all personnel is important and should preferably be repeated every fall.

Precautions should be taken to minimize loss of salt from salt and treated sand storage piles. Stockpiles should preferably be kept inside covered buildings, or at least covered with an impervious material. Areas under large bridges or viaducts can be used for temporary storage. Water should be kept from entering the base of a stockpile. Treated sand should be mixed as late in the season as possible. Stockpiles should be placed on impermeable pads such as asphalt, and any salt-laden runoff should be collected for approved disposal, or diverted to a location where it is environmentally acceptable.

RESEARCH RECOMMENDATIONS

A few agencies currently are engaged in research that could result in minimizing deicing chemical use. These are identified in Table 7. It is readily acknowledged that this is not a comprehensive list and that productive research may be

TABLE 7

SUMMARY OF RESEARCH ACTIVITIES RELATED TO MINIMIZING DEICING CHEMICAL USE

RESEARCH PROJECT TITLE	RESEARCH AGENCY	HRIP NO.
Evaluation of Non-Corrosive Deicing Chemicals	California Division of Highways, Matls. & Res.	34 205479
Determination of Salt Requirements to Obtain Partially or Completely Bare Pavements	Montreal, Quebec (Canada)	40 050805
Facilitating Winter Road Servicing	Zulauf (Switzerland)	40 062184
Snow and Ice Control on Military Facilities	U.S. Army Cold Regions Research & Engineering Laboratory	40 213380
Nuclear Wastes in Comparison with Other Heat Sources for Deicing of Bridges, Ramps, and Pavements	Federal Highway Administration	40 214052
Frost and Ice-Detection on the Rouge River Bridge	Michigan Department of State Highways and Transportation	53 207574

in initial or continuing stages in highway agencies, universities, and research-oriented agencies.

The specter of formation of "pack," compacted snow building up on the pavement and sticking tightly to it, leads most frequently to the excessive use of salt. It is not the removal of ice that represents the major use of salt, but the attempt to prevent compacted snow formation. Therefore, a prime goal of research should be to develop a method of removing compacted snow. Underbody blades have been used with varying degrees of success in removing compacted snow, but a strictly mechanical method, requiring contact between the device and pavement, never can clean completely because of pavement irregularities and the likelihood of damage to the device and pavement if too intimate contact is made. The goal should be a noncontact device, using physical means based on the different properties of the ice-pavement system localized at the interface.

Though equipment for spreading controlled, known amounts of solid deicing chemical is becoming more sophisticated and more reliable, further development of rugged equipment is needed. A common complaint is that hydraulic equipment changes characteristics as it becomes heated with use, and therefore chemical spread rates will vary to an unknown extent.

Research is needed into methods to improve the coefficient of friction of treated and untreated ice and compacted snow surfaces.

Selection of salt application rates is based to a large extent on empirical tests, and in some cases may bear little relationship to actual need. Controlled tests over a range of climatic and traffic conditions can narrow the choice of an optimum application rate, but here a cautionary note is necessary: actual field conditions vary over such a wide range during the period of a storm and the cleanup that follows, and over a limited geographical area, that any recommendations must allow wide discretion for man-on-the-scene decisions. Furthermore, a more detailed knowledge of the microclimate of an area is necessary before "fine-tuning" of chemical application rates can be made over the course of a storm.

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APPENDIX A

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APPENDIX B

RESPONSE TO SURVEY ON DEICING CHEMICAL PRACTICES

To obtain data on current practices in the use of deicing chemicals, a questionnaire was sent to highway maintenance officials of 30 states, 6 Canadian provinces, 5 toll roads, 15 snow-belt cities, and 1 county. The questions asked were:

1. What types and amounts of chemicals have you used for each of the past three years? What is the application rate per lane-mile? Is chemical and abrasive premixed and stockpiled? In what proportions?
2. What is the basis for establishment of a road for salting (e.g., volume of traffic, rural versus urban routes, school bus route, editorial demand, accident rates)?
3. Who is responsible for selecting the application rate for a particular condition? What is the basis for selecting a specific chemical application rate? Manufacturer's recommendation? Tests conducted by your forces? Literature?
4. Have directives been published and distributed that advise supervisors, foremen, and equipment operators of agency policy on the use of deicing chemicals?
5. Do you have a training program that includes mixing, storage, and application of chemicals or chemicals mixed with abrasives?
6. Do you require detailed reports by operators on chemical quantities used? If so, is the information correlated with temperature, traffic, snowfall, humidity and/or other factors that may affect the quantities used?
7. Is chemical use checked after storm to determine effectiveness of treatment and/or adherence to specified application rate?
8. What specific practices have you used to minimize chemical use (i.e., lower rate, frequency of treatment, elimination of previously salted routes)?
9. Have you identified any particular type of equipment or application procedures that are more effective? How are the application rates set? Spreading pattern?
10. Do you have a policy to add ground-based spreader controls on all or most hopper bodies? If so, how many years will be required to complete the conversion?
11. Do you believe that your annual use of chemicals is staying about the same, considering variations in number of storms, or declining or increasing? If declining or increasing, at what percent per year?
12. Have you made any studies to determine whether or not salt gradation variations from point to point in the stockpile affect quantities applied to the road?

The replies are tabulated herein. None of the agencies had made any studies of salt gradation (Question 12) although a few replies indicated that they believe variations in gradation do affect application rates.

The following footnotes should be used in conjunction with the table:

(a) No formal check.
(b) 20% now equipped; 50% in 3 or 4 years. Only on new equipment in some areas.
(c) Use report; no correlation.
(d) No policy; new units have controls.
(e) Ten years for full conversion.
(f) Being tested.
(g) Industrial premix—5:1 NaCl-$CaCl_2$ by weight.
(h) Chemicals.
(i) Sand.
(j) Fifteen units being evaluated.
(k) Planned.
(m) Gallons of brine.
(n) Only for cost accounting.
(p) Material costs reviewed monthly; weekly inventory of salt storage bins.
(q) Detailed reports in one district; to be extended.
(r) Only spot checks at present; to be extended to all counties after every storm.
(s) Not formal.
(t) Up to supervisor.
(u) Three-year average.
(v) Gallons of liquid $CaCl_2$.
(w) Complete conversion in 3 to 4 years.

Metric equivalents:

1 ton = 907 kg
1 ton/mile = 560 kg/km
100 lb/mile = 28 kg/km
1 yd^3/mile = 0.475 m^3/km
1 gallon = 3.785 liters
1 oz/yd^2 = 34 g/m^2

AGENCY	1. CHEMICAL AND SAND USE — Annual Totals: Year	NaCl (tons)	$CaCl_2$ (tons)	Sand (tons)	Other	Tons/ lane mi	Application Rates	2. BASIS FOR SALTING	3. RESPONSIBILITY FOR RATE SELECTION
States									
California	69/70 72/73	22,000 31,000					400-600 #/mi on ice & compacted snow	Operator judgment	Foreman and guidelines
Colorado								Entire highway system	Area maintenance superintendent
Conn.	72/73	87,600						All routes	Department
Idaho		8,000					400 #/2-lane mi	Where hazards develop	Maintenance Engineer
Illinois	69/70 70/71 71/72	309,900 256,411 280,930	5,480 3,380 3,390				500 #/2-lane mi	All routes	Central office guidelines
Iowa								Traffic volume	Local foreman or crew supervisor
Kansas							500-1000 #/2-lane mi of 3:1 NaCl-$CaCl_2$; Abrasives with 10-15% salt at 1500 #/mi	All routes	Dist. super. & foreman; 3 yr selected perf. observation and tests
Maine	69/70 70/71 71/72	74,846 88,817 85,692				19.4 23.0 22.2		All routes	Highway foreman
Mass.	70/71 71/72 72/73	172,000 196,000 127,000		208,000 195,000 116,000	36,000[g] 36,000[g] 26,000[g]			All routes	Department
Minnesota	69/70 70/71 71/72	172,720 148,712 116,664	2,906 2,367 1,381	 283,552		 4.27[h] 10.38[i]	600-800 #/lane mi sand-salt; 400-500 #/lane mi salt	ADT	Area maintenance engineers; state law
Missouri	69/70 70/71 71/72	76,765 60,709 68,837	5,942 5,069 4,456				400 #/2 lane mi (maximum)	Volume and continuity; state routes in metropolitan areas	Area supervisor
Montana		2,850	45				100-300 #/lane mi	Streets or ramps where sand clogs drains; also mountains	Division supervisor
Nebraska	72/73	18,000	800				200-500 #/2-lane mi	Traffic volume; school bus routes; accident rates; etc.	Dist. maint. super. & area superintendents
Nevada							0.5 yd^3/2-lane mi	Traffic volume; school bus routes; topography	District Engineer
New Hamp.	69/70 70/71 71/72 72/73	153,742 144,982 157,238 96,983				19.5 18.3 19.8 12.2		Traffic volume and speed; gradient	Highway patrolman

4. DIRECTIVES	5. TRAINING	6. REPORTS	7. USE CHECK	8. PRACTICES TO MINIMIZE USE OF CHEMICALS	9. EFFECTIVE EQUIPMENT OR PROCEDURES	10. SPREADER CONTROLS	11. CHANGE IN ANNUAL USE OF CHEMICALS	AGENCY
Yes	Yes OJT	No	(a)	Alternate chemicals on bridges		(b)	Use is increasing	Cal.
No	No	No	No	Only abrasives used (no additive) in low volume areas	30% salt in sand in high traffic areas	No		Colo.
Yes	Yes			Reduce application rate; use abrasive	Windrow; sand-salt spread in 6-8 ft. band	No		Conn.
Yes	No	No	No	Increase use of abrasives		No		Ida.
Yes	Yes	Yes (c)	No	Abrasive-chemical mixture; spreader calibration; close supervision	Center half of pav't.; 3:1 $NaCl-CaCl_2$ at low temp. and 1:1 sand-salt in rural areas	(d)	Total use has leveled off even though mileage maintained increases every year	Ill.
Yes	Yes OJT	No	No	Use of liq. $CaCl_2$ as salt activator	Use diverter to deposit salt on center-line	Yes (e)	Use has been constant but now appears declining with increased use of liquid $CaCl_2$	Iowa
Yes	Yes	No	Yes	Application only at selected locations before blading			Use is declining as a result of training, experience and management control	Kan.
Yes	Yes	Yes	(a)	Restrictor on tailgate spreader; hydraulic hopper bodies	Windrow	(f)	Leveled off at 75,000-85,000 tons/year	Me.
Yes	Yes	Yes	(a)	Spreader controls	Windrow	Yes		Mass.
Yes	No	Yes	Yes	Reduced rate and freq. of application; closer supervisory control; not requiring bare pav't. on low volume roads	High capacity trucks for sand and sand-salt mixes in urban areas	(j)	Use has declined since new stds. went into effect in 1971/72 and is expected to continue at the reduced level	Minn.
Yes	Yes	No	No	Training		No		Mo.
Yes	Yes	No	(a)		Rural areas - sand w/ 100 # salt/yd^3. Salt never exceeds 1000 #/ lane mi per yr at any location	No	Chemical use is stable	Mont.
Yes	Yes	Yes	Yes	Training	$CaCl_2$ trigger	No		Neb.
No	No	No	No	Only use sand-salt 5:1 mix		No		Nev.
Yes	No (k)	Yes	(a)	Individual calibration and hydraulic spreaders	Windrow	No	Level off at 100,000 tons/yr	N.H.

AGENCY	1. CHEMICAL AND SAND USE							2. BASIS FOR SALTING	3. RESPONSIBILITY FOR RATE SELECTION
	Annual Totals						Application Rates		
	Year	NaCl (tons)	$CaCl_2$ (tons)	Sand (tons)	Other	Tons/ lane mi			
States									
New Jersey		35,000	8,000				150-500 #/lane mi	All routes	Local decision within guidelines
New York	69/70 70/71 71/72	192,384 205,744 315,000	2,285 2,535 4,920			 9.0	200-600 #/2-lane mi	All routes	General maintenance foreman
N. Dakota	70 71 72	4,800 4,100 4,000	1,000 1,375 650		32,000[m] 17,000[m] 174,000[m]			All routes	Supervisors and maintenance manual
Ohio	69/70 70/71 71/72	510,000 470,000 424,000	2,600 2,300 3,000			12.7 11.7 10.6		Priority system	Operators, checked by supervisors
Oregon	69/70 70/71 71/72	810 710 720	180 260 None						
Pa.	69/70 70/71 71/72	565,750 738,800 652,500	26,500 31,100 29,550				400 #/lane mi max. 60-80 #/Type 1 $CaCl_2$/ton sand	Priorities set at county and district levels	Ass't. county super. & dept. guidelines
S. Dakota	71 72 73	1,536 1,890 2,804	323 368 380	40,507 43,400 46,000			300-500 #/2-lane mi	Traffic volume & geometric design	Operators within departmental std. rates
Vermont	69/70 70/71 71/72 72/73	110,000 88,000 97,000 88,260				21.1 16.3 17.6 16.0	300-800 #/2-lane mi; 546 #/2-lane mi (average)	All highways	General and area foremen
Virginia	69/70 70/71 71/72	56,097 66,243 44,518	22,211 18,987 9,151	252,568 223,028 112,573				Traffic volume & type; no clear-cut policy	Maintenance area superintendent
Washington	70/71 71/72 72/73	7,051 15,251 16,665					25-32°F: 200-250 #/lane mi NaCl; 10-25°F: 250-300 #/lane mi 3:1 NaCl-$CaCl_2$; <10°F: 350-450 #/lane mi $CaCl_2$ flake or 300-375 #/lane mi $CaCl_2$ pellet	Priority classification	Division maintenance superintendents
W. Va.	69/70 70/71 71/72	152,453 148,570 112,244	10,045 7,325 2,380				500-600 #/mi	Type of surface and traffic volume	Director of Maintenance
Wyoming							2000 # sand-salt per 2-lane mi	Traction	Foreman
Provinces									
Alberta	69/70 70/71 71/72	16,494 26,910 23,461	324 240 50				500 #/2-lane mi NaCl max.	All routes	Local foreman; experience under different conditions
B. C.		45,000 (u)					100-300 #/lane mi	Volume of traffic; school bus routes	District Engineer

4. DIRECTIVES	5. TRAINING	6. REPORTS	7. USE CHECK	8. PRACTICES TO MINIMIZE USE OF CHEMICALS	9. EFFECTIVE EQUIPMENT OR PROCEDURES	10. SPREADER CONTROLS	11. CHANGE IN ANNUAL USE OF CHEMICALS	AGENCY
Yes	No	Yes	No	Equip. calibration; use of ground speed spreader control; use of chemical mixes	Restricting spread width 2-ft inside edge of traffic lanes; 4:1 salt $CaCl_2$	Yes	Increasing. If public continues to demand bare pav't. sooner, use will increase.	N.J.
Yes	No	No		Calibration				N.Y.
Yes		Yes	(n)	Use of brine		No	Use is static	N.D.
Yes	Yes	(n)	(a) (p)	Training	Use spinner to cover middle 1/3 of pavement	Yes		Ohio
No	No	No	No			No		Ore.
Yes	No	(q)	(r)	Random checking	Both hopper and tailgate spreaders are effective; 4-6 ft along road center	No	Present use can be reduced 20-30% and remain within maintenance manual guidelines	Pa.
Yes	Yes	Yes	Yes		Abrasives 6-10 ft in ctr. of 2-lane; straight NaCl 1-3 ft.	No	More chemicals used because of more Interstate mileage & public demand for higher service	S.D.
Yes	No	Yes	Yes	Reporting system standards	Windrow	No	Use has declined and is now stabilizing	Vt.
Yes	Yes	No	Yes	Spreader calibration	Hydraulic controls on spreaders; windrow	No	Use seems to be increasing because of increased road mileage	Va.
Yes	No	No	No	Calibration	Middle 1/3 of 2-lanes; abrasives	No		Wash.
Yes	Yes	Yes	(a)		Windrow	No		W.Va.
Yes	No	No	No	None	3-5% NaCl in sand	No		Wyo.
Yes (s)	(s)	No	No	Reduction in pre-storm salting; better judgment	Center of road; straight sand below 0°F	No	Annual use remains about the same, dependent on the weather	Alta.
No	No	No	(a)	Frequency of treatment		No		B.C.

AGENCY	1. CHEMICAL AND SAND USE							2. BASIS FOR SALTING	3. RESPONSIBILITY FOR RATE SELECTION
	Annual Totals						Application Rates		
	Year	NaCl (tons)	$CaCl_2$ (tons)	Sand (tons)	Other	Tons/ lane mi			
Provinces									
N. S.	69/70 70/71 71/72	59,448 121,328 145,755				7.1 13.9 15.4	300-600 #/2-lane mi 70/71 ave.: 490 71/72 ave: 450	Level of service	Field supervisors and department
Ontario	70/71 71/72 72/73	363,264 419,137 336,959					Sand: 2000 #/2-lane mi; salt: 450 #/2-lane mi	Maintenance level standards	Department and field variation
Toll Roads									
Ill. State Toll Hwy. Auth.		44,000 (u)	691 (u)	7,740 (u)			500-600 #/lane mi	All routes	Section foreman and guidelines
N. Y. Thruway	69/70 70/71 71/72	107,958 120,486 121,904				37.2 41.6 42.3		All routes	Area supervisor
Ohio Tpk.	69/70 70/71 71/72	26,645 27,162 24,638	1,335 1,363 837		29,498[v]		400 #/mi for snow 200 #/mi of 2:1 NaCl-$CaCl_2$ for freezing rain	All routes	Foreman in charge and directives
County									
Hennepin (Minn.)	70/71 71/72 72/73	11,252 7,541 5,260					250 #/lane mi max.	> 7500 ADT receive straight chem.; < 7500 ADT receive sand on hills, curves, intersections, rr crossings, school crossings	Foreman and operators
Cities									
Milwaukee	69/70 70/71 71/72	39,951 43,257 38,940					100-450 #/lane mi	Vol. of auto and pedestrian traffic; hazards at intersections, hills, viaducts & overpasses	Bureau of Sanitation superintendent
N. Y. C.	70/71 71/72 72/73	128,928 129,946 30,300					2 oz./yd^2 (salt only)	Bus routes; numbered roads; traffic volume; sharp curves; steep grades; hazardous intersections	Department
Seattle	69/70 70/71 71/72	27 2,320 4,120	19 3 44				600 #/2-lane mi	Arterials and bus routes	Committee
Toronto	70/71 71/72 72/73	65,570 66,141 38,000					700 #/lane mi	400 miles of arterial roads and freeways (1624 lane miles)	Department

4. DIRECTIVES	5. TRAINING	6. REPORTS	7. USE CHECK	8. PRACTICES TO MINIMIZE USE OF CHEMICALS	9. EFFECTIVE EQUIPMENT OR PROCEDURES	10. SPREADER CONTROLS	11. CHANGE IN ANNUAL USE OF CHEMICALS	AGENCY
Yes	Yes	Yes	(t)	Calibration; setting levels of service; training	Windrow	No		N.S.
Yes	Yes	Yes	Yes	Switch to ground-oriented spreaders	Windrow	Yes		Ont.
Yes	Yes	No	Yes	Variable speed spreader controls; liquid $CaCl_2$ additive	Variable speed controls on conveyor and spinner	No		Ill. Toll Auth.
Yes	(s) OJT	Yes (n)	No	Close supervision	Ground-oriented spreader controls	(f)	Weather patterns and rutting from studded tires have helped increase salt use. Some reversal of this trend now indicated.	N.Y. Thru.
Yes	Yes	Yes	Yes		Center 1/3 of 2-lanes; calibrate equipment; no abrasives used			Ohio Tpk.
Yes	Yes	Yes (c)	(a)	Modifying std. equip. to give lower discharge rate; setting max. applic. rates; eliminating routes for salting	Ground-oriented spreader controls	Yes	Since new policy went into effect in 71/72, no substantial variation in current rate is expected	Henn. Co.
Yes	Yes	Yes	Yes	Use of ground-oriented spreader controls		Yes (w)	Increase in number of vehicles and public demand for better road conditions during winter has resulted in increased chemical use	Milw.
Yes	Yes	Yes	Yes			No		NYC
Yes	Yes	Yes		Early plowing in heavy snowfall; salting inbound routes in morning only, outbound routes in afternoon only		No		Sea.
			No	Lowering level of service nights and weekends		Yes		Tor.

APPENDIX C

APPLICATION RATE SPECIFICATIONS

CONNECTICUT

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

October 1971

GUIDELINES FOR SNOW AND ICE CONTROL TREATMENT
UNDER VARYING FIELD CONDITIONS

Multi-Lane - Temperature 19° and Above

A. Heavy Snow - Initial application of salt @ 450 pounds per 2-lane mile and commence plowing in echelon. Second and repeated applications will be applied depending on length of storm and the formation of a snow pack. Abrasives will be applied as needed in accordance with the policy.

B. Light Snow and Sleet - Initial application of salt @ 450 pounds per 2-lane mile and commence plowing in echelon. Due to the indicated type of precipitation, second and repeat applications may not have to be at the rate of 450 pounds. Abrasives will be applied as needed in accordance with the policy.

C. Freezing Rain and Drizzle - Due to the nature of the precipitation and resulting pavement conditions, abrasives will be applied immediately. The mix used should depend on the severity of the precipitation, i. e., a heavy, rapidly freezing rain would be treated with the 16-1 and a light freezing drizzle would be treated with the 11-2 mix. The 7-2 mix should be applied in a freezing rain or drizzle that would fall somewhere in the middle of this range. The heavier the precipitation the more the salt is diluted.

Multi-Lane - Temperature 19° and Below

A. Snow - Due to the rapidly decreasing effectiveness of salt at temperatures below 20°F, continuous plowing and the application of one of the abrasive mixes as needed should continue until an indication that the temperature will rise sufficiently to allow an application of salt to work effectively.

B. Freezing Rain and Drizzle - Due to the rate that rain and drizzle will freeze and build up on the pavement at these temperatures, applications of 16-1 or 11-2 will be applied to provide traction until there is an indication that the temperature will rise sufficiently for an application of 7-2 to become effective.

"REMEMBER, IF A LITTLE BIT OF SALT IS GOOD -
MORE SALT IS NOT NECESSARILY BETTER!"

Ramps and 2-Lane Over 10,000 ADT and 2-Lane Under 10,000 ADT - Temperature 19° and Above - Procedures for these two classes will be the same as the multi-lanes for the varying types of precipitation, the difference being mixes will be used in lieu of straight applications of salt.

Ramps and 2-lane over 10,000 ADT will receive an initial application of 7-2, and 2-lane under 10,000 ADT will receive an initial application of 11-2. Second and repeated applications will be applied the same as the multi-lanes, keeping in mind the type of precipitation being dealt with and the results being obtained. If some melting is not resulting from the initial application, a rapidly repeated second application will not necessarily produce better results.

Because salt becomes less effective at temperatures below 20°F, the mixes will also become less effective and continuous plowing is necessary to maintain the accumulation as thin as possible until the temperature rises sufficiently to enable the salt to help us clean the pavement.

If these guidelines are used in conjunction with the preceding material obtained from tests conducted in the field and at our laboratory, field personnel engaged in snow and ice operation should have a better understanding of what can or can not be done with chlorides and their mixes.

"REMEMBER, IF A LITTLE BIT OF SALT IS GOOD -
MORE SALT IS NOT NECESSARILY BETTER!"

MAINE

8.130 Ice Control

When a storm is imminent get your crews and equipment ready and have them at their proper locations. Do not wait for the storm to strike. It is much better to have your crew waiting around for an hour or so than to have someone killed during the first hour of a storm. Occasionally it might be well to spread abrasives on a dry pavement to prevent that first slippery stage. Loaded abrasive trucks patrolling their section to be ready when needed may also prevent an accident. Even if the storm never hits your area it is money well invested.

8.131 General

Promptness in removing snow from the road will lessen the formation of packed snow and the necessity for expensive treatment later.

During the past few years numerous states, municipalities and toll road authorities have conducted extensive research for the most efficient use of chlorides and sand in snow and ice control operations while at the same time keeping the overall cost at a minimum. Certain basic methods are reported to have produced satisfactory results under weather conditions similar to those in Maine.

The effectiveness of any plan for snow and ice control depends mainly on two factors: (1) the choice of the correct procedure to be followed, and (2) the close observance of the procedures as outlined.

The results of the methods recommended should be closely observed to determine their efficiency. The objectives are to expedite the work of furnishing clear and safe passages for traffic and to reduce the amount of sand required for the job by the controlled use of chlorides. At some point there will be found an economical balance at which the cost of the chlorides is justified by the better results attained in the task of snow and ice control and the savings realized by the reduced expenditure for sand and the spring clean-up. The cooperation of all personnel is essential and suggestions for the improvement of the following methods will be welcomed.

8.132 Conditions

The procedure to be followed in combatting any storm will depend upon the temperature, the condition of the pavement, the nature of the precipitation and the forecast at the start of the storm. It is not the intent to completely detail the methods to be employed in combatting every possible condition. There are, however, 3 basic conditions, one of which will exist at the start or in the early stages of almost every storm, and the procedures to be followed under these 3 conditions are as follows:

Condition 1: Air temperature 25°F to 34°F and rising. Pavement wet. Precipitation snow, sleet or freezing rain.

Condition 2: Air temperature 20°F to 32°F. Pavement wet or icing. Precipitation rain, snow, sleet or freezing rain.

Condition 3: Air temperature below 25°F. Pavement dry. Precipitation snow.

8.133 Materials

Straight chlorides or sand and chloride combined and applied as follows:

1. Stockpile Sand. Sand to which 100 pounds of chloride has been added to each yard to prevent freezing in stockpile.

2. Treated Sand. Stockpile sand to which an additional 100 pounds of chloride is added to each yard at time of loading into trucks for spreading or at time of spreading. The rate of application will depend upon conditions.

3. Straight Chloride. Sodium chloride. Application will be at the rate of 500 pounds per mile of 2-lane highway.

MAINE (cont'd)

8.134 Condition 1. Condition 1 may prevail until the temperature rises through and above the critical zone (28°F to 34°F) in which case the precipitation will gradually change to rain, and the chance of packing or icing will diminish as the storm progresses. The temperature may, however, level off at a temperature within the critical range in which case packing or icing will take place. Actual temperatures and precipitation should be checked periodically with the forecast. The initial treatment should be the application of straight chloride at the rate of 500 pounds per mile of 2-lane highway in the form of a strip applied at the crown. If the temperature moves at a rapid rate through the critical zone, one application may be sufficient for the duration of the storm; but if the temperature rises slowly, or levels off in the critical zone, a second application may be necessary in storms of long duration. If the temperature levels off below the critical zone and storm continues in the form of snow and packing occurs, it may be necessary to plow and to treat the packed areas with treated sand.

8.135 Condition 2. Under this condition ice is likely to form on the pavement. There is a distinct possibility that the precipitation will turn to snow, even though it may start as rain. The initial treatment is the application of straight chloride at the rate of 500 pounds per mile of 2-lane highway as soon as possible. If this treatment is effective, the pavement will remain wet or will be covered with a slush according to the degree to which the temperature falls. If a slush occurs, it should be removed before it is hardened by freezing or by traffic. Subsequent treatment, when required, should consist of another application of straight chloride or plowing, whichever is indicated. Spot sanding with treated sand may be necessary.

8.136 Condition 3. Obviously this condition calls for plowing when sufficient accumulation occurs, and considerable sanding with treated sand will probably be required. Straight chloride application at this temperature should not be used as it tends to cause slime which becomes very slippery when brakes are applied. Plowing should continue for the duration of the storm and until pavement and shoulders are clear. If the temperature rises through the critical zone (28°F to 34°F) the application of straight chloride at the rate of 500 pounds per mile of 2-lane highway may be necessary to prevent icing. It is to be applied by windrow method, not spread.

8.137 Mixed Chlorides

Occasionally some icy spots have to be removed regardless of temperature, then a mixture of sodium chloride and calcium chloride are used.

MINNESOTA

The table gives a recommended range of application rate for eight ice removal material combinations. These rates are based on an ice thickness of about 1/16 inch and on clearing a wheel path 1½ - 3 feet in width. It should be pointed out however, that additional material may be required for complete removal of ice from the roadway.

TABLE

Recommended Application Rates of Chemicals and Chemical-Abrasives for Ice Removal

Ice Removal Material	Suggested Width of Spread (ft)	Application Rates (lb per lane mile[a]) for 1/16 in. Ice		
		Below 10°F.	10-20°F	20-32°F
$CaCl_2$ (pellets)	2-4	300-375	250-300	(175-250)[c]
$CaCl_2$ (flakes)	2-4	350-450	275-350	(200-275)[c]
NaCl (rock salt)	3-4	(400-550)[b]	250-400	200-250
NaCl (evaporated)	3	(325-500)[b]	200-325	150-200
1/3 $CaCl_2$ (pellets) - 2/3 NaCl (rock salt)	2-4	300-475	250-300	175-250
1/3 $CaCl_2$ (flakes) - 2/3 NaCl (rock salt)	2-4	350-500	275-350	200-275
50% $CaCl_2$ (pellets) - 50% Sand	4	(excess of 500)[b]	(300-500)[b]	200-300
50% NaCl (rock salt) - 50% Sand	4	(excess of 600)[b]	(325-600)[b]	225-325

[a] Quantities given shall be doubled for 2-lane roadways
[b] Not recommended because of the low rate of ice removal. Quantities given are suggested if no other material is available.
[c] Not recommended because a greasy condition often results. Quantities given are suggested if no other material is available.

Since the application rates recommended above are based on a limited number of tests, they may require modification after being used by the maintenance crews for a suitable period of time. Suggested modifications are therefore invited.

PENNSYLVANIA

4.5.3.2 - TREATMENT PROCEDURES

The rates of application of chemicals and anti-skid materials and procedures set forth herein, are intended as guide lines only and are to be adjusted in accordance with existing conditions. There are roughly five major kinds of storms. Each requires a somewhat different approach. All maintenance personnel should know the basic kinds of storms and how to combat them.

STORM CONDITION	PROCEDURES
CONDITION 1	
Temperature—Near 30° Precipitation—Snow, sleet or freezing rain. Pavement Condition—Wet	If freezing rain, apply salt at 200 lbs. per mile. If sleet, apply salt at 500 lbs. per mile. If snow continues and accumulates, plow and salt simultaneously. If rain continues to freeze, reapply salt at 200 lbs. per mile.
CONDITION 2	
Temperature—Below 30° and falling. Precipitation—Snow, sleet or freezing rain. Pavement Condition—Wet or Sticky	Immediately apply chemical at 500-600 lbs. per mile. If freezing rain, at 200-400 lbs. per mile. If snowfall continues and accumulates, plow and repeat chemical application simultaneously.
CONDITION 3	
Temperature—Below 20° and falling. Precipitation—Dry Snow Pavement Condition—Dry	Plow as soon as necessary. Do not apply chemicals. Continue to plow and patrol to check for wet, packet or icy spots; treat them with heavy chemically treated anti-skid material.
CONDITION 4	
Temperature—Below 20° and at night. Precipitation—Snow, sleet or freezing rain. Pavement Condition—Wet	Apply chemicals or anti-skid material as often as required by traffic conditions. If temperature starts to rise, apply chemicals at 600-800 lbs. per mile, then start plowing as soon as feasible. Continue until bare pavement is obtained.
CONDITION 5	
Temperature—Below 10° Precipitation—Snow or freezing rain. Pavement Condition—Accumulation of packed snow or thick ice.	Apply anti-skid. Apply chemicals at the rate of 500 lbs. per mile. When snow or ice becomes slushy remove by plowing. Repeat application and continue blading until pavement is clear.

Note: The above mileages are based on 2-lane pavement.

VIRGINIA

Application rates - lbs per lane mile These rates should be doubled for two lanes, etc.

Temperature	Below 10°	10°- 25°	25°- 32°
Calcium pellets	300 - 375	250 - 300	175 - 250
Calcium flake	350 - 450	275 - 350	200 - 275
Salt	400 - 550	250 - 400	200 - 250
¼ Calcium (pellets) 3/4 Salt	350 - 475	250 - 300	175 - 250
¼ Calcium (flakes) 3/4 Salt	250 - 500	250 - 350	200 - 250

The recommended materials & rates are underlined.

NOVA SCOTIA

NOVA SCOTIA
DEPARTMENT OF HIGHWAYS

SALTING GUIDE FOR ICE CONTROL - 1972-73

1 DESIRED STANDARD WITHIN REASONABLE TIME AFTER STORM	2 CLASS OF ROADS GENERALLY IN GROUP	3 TEMPERATURE RANGES	4 *NORMAL RANGE FOR TWO LANE APPLICATION	5 BEGINNING OF STORM	6 DURING STORM	7 AFTER STORM AND FINAL PLOWING	8 SANDING APPLICATION RECOMMENDED	9 REMARKS
Bare Pavement (not including paved shoulders)	All Arts. Most Coll. "D", e.g. 100 Series Some trunks	Below 10°F 10° - 20°F Above 20°F	300 - 600# if temp. rising. (Do not salt if temp. is dropping) 300 - 500# 300 - 400#	Apply salt only if accum. is less than 2"	Generally no, unless necessary to avoid packing.	As req'd to achieve bare pavement standard within a reasonable length of time.	Only in exceptional circumstances, e.g. below 0°F if icy conditions exist.	* Climbing lanes will receive additional run at normal two lane rates. ** As instructed by D.E. Salting of entire road is only to be done occasionally through the winter under ideal conditions to clear a heavy snow/ice pack. (Temp. above 25°F). *** Applic. rate approx. 1 cu.yd./mile. Level areas not normally sanded.
Bare Center strip 5'-10'	Balance of Coll. "D" Coll. E, F Locals G & J, e.g. 200-300 Series Some Local Paved Rds.	Below 10°F 10° - 20°F Above 20°F	300 - 500# if temp. rising. (Do not salt if temp. is dropping) 300 - 400# 300 - 400#	Apply salt only if accum. is less than 2"	Generally no, unless necessary to avoid packing.	Only to achieve bare center strip, but not more than is required.	Only in exceptional circumstances, e.g. below 0°F if icy conditions exist.	
Snow Packed**	Approved Paved Roads not in 1 or 2	Above 10°F	Buildup of snow/ice pack should be bladed off prior to salting. 450#/application maximum	No	No	On steep hills, turns, intersections and R.R. crossings only.	Only in exceptional circumstances	
Snow Packed***	Balance of paved and unpaved rds.	N/A	Nil	N/A	N/A	N/A	Hills, turns, intersections, R.R. crossings and continuous sanding on Local J's.	

ONTARIO

SUMMARY TABLE
BARE PAVEMENT LEVEL OF SERVICE

Page 16 of 25.

	Temperature Range	Type of Precipitation	Road Condition	Temp.	Activity	RECOMMENDED TREATMENT 1/ Beginning of Storm	During Storm 2/	After Storm 2/
1.	Below Zero	Dry Snow	No packing Dry Pavement	Rising	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement As necessary after plowing No	Wing back shoulders/clean-up Icy spots only Icy spots only
				Falling	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement As necessary after plowing No	Wing back shoulders/clean-up Icy spots only No
2.	0° - 10°	Dry Snow	No packing Dry pavement	Rising	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement No No	Wing back shoulders/clean-up Icy spots only Icy spots only
				Falling	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement No No	Wing back shoulders/clean-up Icy spots only No
3.	0° - 10°	Dry Snow	Packing	Rising	Plowing Sanding Salting	½ hour after salting No Before ½" snow accum.	Continuously to bare pavement Follow after plowing As necessary after plowing	Wing back shoulders/clean-up Icy spots only Icy spots only
				Falling	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement Follow after plowing No	Wing back shoulders/clean-up Icy spots only No
4.	10° - 20°	Dry Snow	No packing Dry Pavement	Rising	Plowing Sanding Salting	After ½" snow accumulates No No	Continuously to bare pavement No No	Wing back shoulders/clean-up Icy spots only Icy spots only
				Falling	Plowing Sanding Salting	After ½" snow accumulates Follow after plowing No	Continuously to bare pavement Icy spots only No	Wing back shoulders/clean-up Icy spots only No
5.	10° - 20°	Dry Snow	Packing	Rising	Plowing Sanding Salting	½ hour after salting No Before ½" snow accum.	Continuously to bare pavement As necessary after plowing As necessary after plowing	Wing back shoulders/clean-up No Icy spots only
				Falling	Plowing Sanding Salting	After ½" snow accumulates No No	Continuously to bare pavement As necessary after plowing No	Wing back shoulders/clean-up Icy spots only No
6.	Above 20°	Wet Snow	Packing, Wet Pavement	Rising	Plowing Sanding Salting	½ hour after salting No Before ½" snow accum.	Continuously to bare pavement Icy spots only As necessary after plowing	Wing back shoulders/clean-up No Icy spots only
				Falling	Plowing Sanding Salting	½ hour after salting No Before ½" snow accum.	Continuously to bare pavement As necessary after plowing As necessary after plowing	Wing back shoulders/clean-up Icy spots only No
7.	Above 20°	Sleet or Freezing Rain	Possible Icing, Wet Pavement	Rising	Plowing Sanding Salting	No No When icing starts	No Yes Yes	Remove slush Icy spots only Icy spots only
				Falling	Plowing Sanding Salting	No No When icing starts	No Yes Yes	Remove slush Icy spots only No
8.	After storm Any temperature	No Precipitation	Road snow-packed or icy	Rising	Plowing Sanding Salting			Continuously to bare pavement As necessary When above 0°
				Falling	Plowing Sanding Salting			Continuously to bare pavement As necessary No
9.	After storm Any temperature	No Precipitation	Drifting	Rising	Plowing Sanding Salting			Continuously to bare pavement No Icy spots only
				Falling	Plowing Sanding Salting			Continuously to bare pavement Icy spots only No

1/ NOTE: Recommended treatment for various conditions shown on this chart should be used in MOST cases. However, unusual circumstances may necessitate departure from the recommended treatment.

2/ NOTE: Salt should not be applied in "during storm" or "after storm" situation during night hours (to 5 a.m.)

ONTARIO (Cont'd)

SUMMARY TABLE

CENTRE BARE LEVEL OF SERVICE

Page 21 of 28

	Temperature Range	Type of Precipitation	Road Condition	Temp.	Activity	RECOMMENDED TREATMENT 1/ Beginning of Storm	During Storm 2/	After Storm 2/
1.	Below Zero	Dry Snow	No Packing, Dry Pavement	Rising	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	As necessary after plowing	Icy spots only
					Salting	No	No	Icy spots/outside edge
				Falling	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	As necessary after plowing	Icy spots only
					Salting	No	No	No
2.	0° - 10°	Dry Snow	No Packing, Dry Pavement	Rising	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	No	Icy spots only
					Salting	No	No	Icy spots/outside edge
				Falling	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	No	Icy spots only
					Salting	No	No	No
3.	0° - 10°	Dry Snow	Packing	Rising	Plowing	½ hour after salting	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	Follow after plowing	Icy spots only
					Salting	Before ¼" snow accum.	As necessary after plowing	Icy spots/outside edge
				Falling	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	Follow after plowing	Icy spots only
					Salting	No	No	No
4.	10° - 20°	Dry Snow	No Packing, Dry Pavement	Rising	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	Icy spots only	Icy spots only
					Salting	No	No	Icy spots/outside edge
				Falling	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	Follow after plowing	Icy spots only	Icy spots only
					Salting	No	No	No
5.	10° - 20°	Dry Snow	Packing	Rising	Plowing	½ Hour after salting	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	As necessary after plowing	No
					Salting	Before ½" snow accum.	As necessary after plowing	Icy spots/outside edge
				Falling	Plowing	After ½" snow accumulates	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	As necessary after plowing	Icy spots only
					Salting	No	No	No
6.	Above 20°	Wet Snow	Packing, Wet Pavement	Rising	Plowing	½ hour after salting	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	Icy spots only	No
					Salting	Before ½" snow accum.	As necessary after plowing	Icy spots/outside edge
				Falling	Plowing	½ hour after salting	Continuously (bare cent.6-8')	Wing shlds/bare pavt/clean-up
					Sanding	No	As necessary after plowing	Icy spots only
					Salting	Before ½" snow accum.	As necessary after plowing	No
7.	Above 20°	Sleet or Freezing Rain	Possible Icing, Wet Pavement	Rising	Plowing	No	No	Remove any slush
					Sanding	No	Yes	Icy spots only
					Salting	When icing starts	Yes	Icy spots only
				Falling	Plowing	No	No	Remove any slush
					Sanding	No	Yes	Icy spots only
					Salting	When icing starts	Yes	No
8.	After Storm Any temperature	No Precipitation	Road snow-packed or icy	Rising	Plowing			Bare cent/wing shlds/bare pavt
					Sanding			As necessary
					Salting			When above 0°
				Falling	Plowing			Bare cent/wing shlds/bare pavt
					Sanding			As necessary
					Salting			No
9.	After storm Any temperature	No Precipitation	Drifting	Rising	Plowing			Continuously
					Sanding			Icy spots after plowing
					Salting			No
				Falling	Plowing			Continuously
					Sanding			Icy spots after plowing
					Salting			No

1/ NOTE: Recommended treatment for various conditions shown on this chart should be used in MOST cases. However, unusual circumstances may necessitate departure from the recommended treatment.

2/ NOTE: Salt should not be applied in "during storm", or "after storm" situation during Night Hours (to 5 a.m.)

SUMMARY TABLE

SNOW PACKED LEVEL OF SERVICE

Page 25 of 25

	Temperature Range	Type of Precipitation	Road Condition	Temp.	Activity	RECOMMENDED TREATMENT 1/ Beginning of Storm	During Storm	After Storm
1.	Any Temperature	Dry Snow or Wet Snow	Road Snow Packed	N/A	Plowing	Continuously (maintain snow pack)	Continuously (maintain snow pack)	Wing back shoulders/scarify slippery sections/clean-up
				N/A	Sanding	No	On hills, curves, and other hazardous locations	On hills, curves and other hazardous locations
				N/A	Salting	No	No	No (on gravel surface) Yes (on paved surface if 15° and rising
2.	Any Temperature	Sleet or Freezing Rain	Possible Icing	N/A	Plowing	No	No	Scarify slippery sections
				N/A	Sanding	No	Icy Spots	Icy Spots
				N/A	Salting	No	No	No (on gravel surface) Yes (on paved surfaces if 15° and rising
3.	Any Temperature After Storm	No Precipitation	Drifting	N/A	Plowing			Continuously (maintain snow pack)
				N/A	Sanding			Icy Spots
				N/A	Salting			No

1/ NOTE: Recommended treatment for various conditions shown on this chart should be used in MOST cases. However, unusual circumstances may necessitate departure from the recommended treatment.

APPENDIX D

DENSITIES, CONCENTRATIONS, AND CRYSTALLIZING TEMPERATURES OF CALCIUM CHLORIDE SOLUTIONS *

Densities, Concentrations and Crystallizing Temperatures of Calcium Chloride Solutions

†Specific Gravity 60/60°F.	% $CaCl_2$ Actual	‡Crystallization Starts °F	*Weight of a Gallon at 60°F. Lb.	Pounds Calcium Chloride 77-80% $CaCl_2$			Pounds Calcium Chloride 94-97% $CaCl_2$		
				Per Gal. Solution	Per Gal. Water	‡Final Volume Gal. at 60°F.	Per Gal. Solution	Per Gal. Water	Final Volume Gal. at 60°F.
1.000	0	+32.0	8.34	—	—	1.000	—	—	1.000
1.009	1.0	+31.1	8.41	0.10	0.10	1.004	0.10	0.10	1.003
1.010	1.2	+31.0	8.42	0.13	0.13	1.006	0.11	0.11	1.004
1.018	2.0	+30.4	8.49	0.22	0.22	1.008	0.19	0.19	1.005
1.020	2.3	+30.2	8.50	0.25	0.25	1.011	0.21	0.21	1.006
1.026	3.0	+29.5	8.55	0.33	0.33	1.014	0.28	0.28	1.007
1.030	3.5	+29.1	8.59	0.39	0.40	1.017	0.32	0.32	1.008
1.034	4.0	+28.6	8.62	0.44	0.45	1.020	0.36	0.36	1.009
1.040	4.6	+28.0	8.67	0.51	0.52	1.022	0.42	0.42	1.011
1.043	5.0	+27.7	8.70	0.56	0.57	1.024	0.46	0.46	1.013
1.050	5.9	+27.0	8.75	0.66	0.68	1.031	0.54	0.55	1.016
1.052	6.0	+26.8	8.77	0.68	0.70	1.031	0.56	0.57	1.017
1.060	7.0	+25.9	8.84	0.79	0.82	1.036	0.65	0.66	1.019
1.069	8.0	+24.6	8.91	0.91	0.95	1.043	0.75	0.76	1.022
1.070	8.1	+24.6	8.92	0.92	0.96	1.043	0.76	0.77	1.022
1.078	9.0	+23.5	8.99	1.04	1.09	1.049	0.85	0.87	1.025
1.080	9.2	+23.2	9.00	1.06	1.11	1.050	0.87	0.89	1.026
1.087	10.0	+22.3	9.06	1.16	1.22	1.055	0.95	0.97	1.028
1.090	10.3	+21.9	9.09	1.20	1.28	1.058	0.99	1.01	1.029
1.096	11.0	+20.8	9.14	1.29	1.37	1.062	1.06	1.08	1.032
1.100	11.4	+20.3	9.17	1.34	1.43	1.065	1.10	1.13	1.033
1.105	12.0	+19.3	9.21	1.41	1.51	1.069	1.16	1.19	1.034
1.110	12.4	+18.7	9.25	1.47	1.57	1.071	1.21	1.24	1.036
1.115	13.0	+17.6	9.30	1.55	1.67	1.076	1.27	1.30	1.038
1.120	13.5	+16.5	9.34	1.62	1.75	1.080	1.33	1.37	1.040
1.125	14.0	+15.5	9.38	1.69	1.83	1.084	1.38	1.43	1.042
1.130	14.5	+14.5	9.42	1.75	1.90	1.087	1.44	1.49	1.044
1.135	15.0	+13.5	9.46	1.82	1.99	1.092	1.50	1.55	1.047
1.140	15.6	+12.2	9.50	1.90	2.08	1.096	1.56	1.62	1.049
1.145	16.0	+11.2	9.55	1.96	2.16	1.099	1.62	1.69	1.050
1.150	16.6	+9.7	9.59	2.04	2.25	1.104	1.68	1.75	1.052
1.155	17.0	+8.6	9.63	2.10	2.33	1.107	1.74	1.82	1.055
1.160	17.6	+7.0	9.67	2.19	2.44	1.113	1.79	1.88	1.057
1.165	18.0	+5.9	9.71	2.24	2.50	1.116	1.85	1.95	1.059
1.170	18.6	+4.1	9.75	2.33	2.62	1.122	1.91	2.01	1.062
1.175	19.0	+2.8	9.80	2.38	2.68	1.124	1.97	2.07	1.063
1.180	19.5	+1.2	9.84	2.46	2.78	1.131	2.02	2.13	1.064
1.186	20.0	−0.4	9.89	2.53	2.87	1.133	2.10	2.22	1.068
1.190	20.6	−2.0	9.92	2.62	2.99	1.142	2.15	2.28	1.071
1.195	21.0	−3.9	9.96	2.69	3.08	1.147	2.21	2.34	1.073
1.200	21.5	−5.8	10.00	2.76	3.18	1.152	2.26	2.40	1.075
1.206	22.0	−7.8	10.05	2.84	3.28	1.156	2.33	2.47	1.077
1.210	22.4	−9.4	10.09	2.90	3.36	1.160	2.38	2.53	1.078
1.218	23.0	−11.9	10.15	3.00	3.50	1.167	2.46	2.64	1.082
1.220	23.3	−13.2	10.17	3.03	3.54	1.170	2.49	2.67	1.083

Densities, Concentrations and Crystallizing Temperatures of Calcium Chloride Solutions

†Specific Gravity 60/60°F.	% $CaCl_2$ Actual	‡Crystallization Starts °F	*Weight of a Gallon at 60°F. Lb.	Pounds Calcium Chloride 77-80% $CaCl_2$			Pounds Calcium Chloride 94-97% $CaCl_2$		
				Per Gal. Solution	Per Gal. Water	‡Final Volume Gal. at 60°F.	Per Gal. Solution	Per Gal. Water	Final Volume Gal. at 60°F.
1.228	24.0	−16.2	10.24	3.15	3.71	1.176	2.59	2.77	1.087
1.230	24.2	−17.1	10.25	3.18	3.75	1.180	2.61	2.80	1.088
1.239	25.0	−21.0	10.33	3.31	3.93	1.188	2.72	2.92	1.092
1.240	25.1	−21.5	10.34	3.33	3.96	1.190	2.73	2.94	1.092
1.250	26.0	−25.8	10.42	3.48	4.18	1.202	2.85	3.08	1.097
1.260	27.0	−31.2	10.50	3.64	4.42	1.215	2.98	3.25	1.104
1.270	27.8	−37.1	10.59	3.79	4.65	1.227	3.10	3.38	1.107
1.272	28.0	−37.8	10.60	3.81	4.68	1.228	3.12	3.41	1.108
1.280	28.7	−44.3	10.67	3.93	4.86	1.237	3.22	3.53	1.113
1.283	29.0	−49.4	10.70	3.98	4.94	1.241	3.26	3.57	1.116
1.290	29.6	−59.8	10.75	4.08	5.10	1.250	3.35	3.69	1.120
1.295	30.0	−50.8	10.80	4.16	5.23	1.256	3.42	3.77	1.122
1.300	30.5	−41.8	10.84	4.24	5.36	1.264	3.48	3.85	1.125
1.306	31.0	−33.2	10.89	4.33	5.51	1.271	3.55	3.94	1.128
1.310	31.3	−29.2	10.92	4.38	5.58	1.275	3.60	4.00	1.130
1.317	32.0	−19.5	10.98	4.50	5.79	1.287	3.69	4.12	1.135
1.320	32.2	−17.0	11.01	4.54	5.86	1.293	3.73	4.17	1.137
1.328	33.0	−6.9	11.07	4.68	6.11	1.305	3.85	4.32	1.143
1.330	33.2	−4.7	11.09	4.72	6.18	1.309	3.88	4.36	1.146
1.340	34.0	+4.3	11.17	4.87	6.45	1.324	4.00	4.52	1.152
1.350	34.9	+14.3	11.25	5.04	6.76	1.341	4.14	4.71	1.159
1.351	35.0	+14.4	11.26	5.05	6.78	1.343	4.15	4.73	1.160
1.360	35.8	+21.7	11.34	5.20	7.07	1.359	4.27	4.90	1.166
1.363	36.0	+24.1	11.36	5.24	7.14	1.363	4.30	4.98	1.168
1.370	36.4	+30.0	11.42	5.33	7.30	1.375	4.38	5.07	1.174
1.374	37.0	+33.4	11.46	5.44	7.54	1.386	4.43	5.14	1.177
1.380	37.4	+37.0	11.51	5.52	7.69	1.393	4.53	5.24	1.181
1.386	38.0	+42.1	11.56	5.63	7.93	1.407	4.61	5.37	1.187
1.390	38.3	+44.4	11.59	5.69	8.05	1.414	4.67	5.45	1.190
1.398	39.0	+49.6	11.66	5.83	8.35	1.431	4.79	5.62	1.198
1.400	39.2	+50.9	11.67	5.86	8.41	1.435	4.82	5.66	1.200
1.410	40.0	+55.9	11.76	6.03	8.79	1.457	4.95	5.85	1.207
	40.9	+61.0							
	41.0	+61.5							
	41.7	+64.8							
	42.0	+65.8							
	42.5	+68.0							
	43.0	+69.8							
	43.3	+70.9							
	44.0	+73.0							
	44.2	+73.6							
	45.0	+75.6							

Note

At concentrations above 40.8% calcium chloride solutions contain suspended crystals at 60°F., and therefore hydrometer readings at 60°F. are of little value. For data at higher concentrations and temperatures see tables on pages 11, 12, 13 and 14.

* Allied Chemical Corp. data.

APPENDIX E

SPREADER CALIBRATION (MAINE)

Forms and tables used by Maine Department of Transportation to assist in calibrating spreaders; the graph (Table 2) is based on measured values, and the scales must be determined for individual spreader types. Table 3 is a time-weight relationship and is universally applicable.

—— INSTRUCTIONS ——

STEP NO. 1 — PLACE CHALK MARK ON WORM SO THAT IT IS VISIBLE WHEN WORM IS ENGAGED.

STEP NO. 2 — COUNT REVOLUTIONS OF WORM PER MINUTE AND ENTER IN REV. / MIN. COLUMN OF TABLE NO. 1 OPPOSITE CORRESPONDING AUGER SETTING.

STEP NO. 3 — FROM TABLE NO. 2 DETERMINE FLOW IN POUNDS PER MINUTE AND ENTER IN COLUMN NO. 3 OF TABLE NO. 1 .

STEP NO. 4 — AFTER FLOW IN POUNDS PER MINUTE HAS BEEN DETERMINED REFER TO TABLE NO. 3 TO DETERMINE POUNDS PER MILE FOR DIFFERENT SPEEDS AND ENTER IN TABLE NO. 4 FOR EACH AUGER SETTING.

STEP NO. 5 — TABLE NO. 4 IS TO BE RETAINED IN THE CAB OF THE CORRESPONDING TRUCK FOR THE DRIVERS USE.

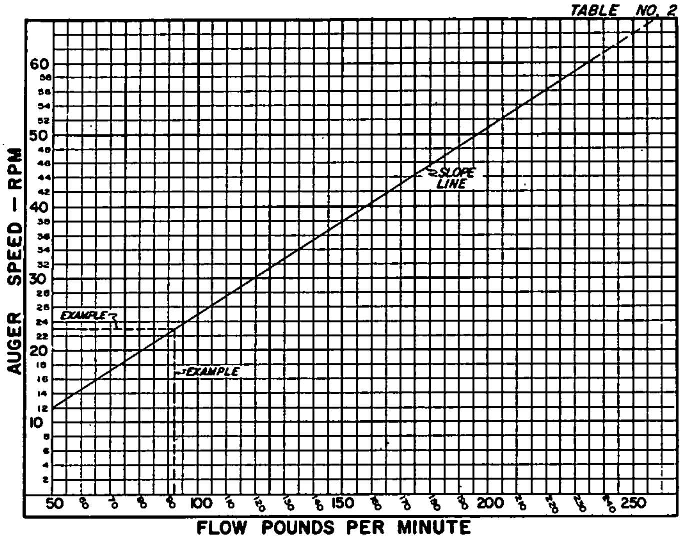
TRUCK NO. ________

SANDER NO. ________

TABLE NO. 1

COLUMN 1 AUGER SETTING	COLUMN 2 REV. / MIN.	COLUMN 3 FLOW IN LBS. / MIN.
1		
2		
3		
4		
5		

TABLE NO. 2



WHEN AUGER SPEED HAS BEEN DETERMINED FOLLOW THE HORIZONTAL GRID TO THE SLOPE LINE, HENCE FOLLOW THE VERTICAL GRID TO THE NUMBER OF POUNDS PER MINUTE.

EXAMPLE : FOR AN AUGER SPEED OF 23 RPM'S THE FLOW IS 92 POUNDS PER MINUTE.

TRUCK NO. ________

SANDER NO. ________

TABLE NO. 4

POUNDS PER MILE

AUGER SETTING	SPEED — MPH 10	15	20	25	30	35	40	45	50
1									
2									
3									
4									
5									

TABLE NO. 3

CALIBRATION OF TAILGATE SANDERS FOR APPLYING SALT —— POUNDS PER MILE ——

POUNDS PER MINUTE	SPEED — MPH 10	15	20	25	30	35	40	45	50
40	240	160	120	96	80	69	60	53	48
45	270	180	135	108	90	77	68	60	54
50	300	200	150	120	100	86	75	67	60
55	330	220	165	132	110	94	83	73	66
60	360	240	180	144	120	103	90	80	72
65	390	260	195	156	130	111	98	87	78
70	420	280	210	168	140	120	105	93	84
75	450	300	225	180	150	129	113	100	90
80	480	320	240	192	160	137	120	107	96
85	510	340	255	204	170	146	128	113	102
90	540	360	270	216	180	154	135	120	108
95	570	380	285	228	190	163	143	127	114
100	600	400	300	240	200	171	150	133	120
105	630	420	315	252	210	180	158	140	126
110	660	440	330	264	220	189	165	147	132
115	690	460	345	276	230	197	173	153	138
120	720	480	360	288	240	206	180	160	144
125	750	500	375	300	250	214	188	167	150
130	780	520	390	312	260	223	195	173	156
135	810	540	405	324	270	231	202	180	162
140	840	560	420	336	280	240	210	187	168
145	870	580	435	348	290	248	218	193	174
150	900	600	450	360	300	257	225	200	180
155	930	620	465	372	310	266	232	207	186
160	960	640	480	384	320	274	240	213	192
165	990	660	495	396	330	283	248	220	198
170	1020	680	510	408	340	292	255	227	204
175	1050	700	525	420	350	300	263	234	210
180	1080	720	540	432	360	309	270	240	216
185	1110	740	555	444	370	318	278	247	222
190	1140	760	570	456	380	326	285	253	228
195	1170	780	585	468	390	335	293	260	234
200	1200	800	600	480	400	343	300	267	240
205	1230	820	615	492	410	351	308	273	246
210	1260	840	630	504	420	360	315	280	252
215	1290	860	645	516	430	369	323	287	258
220	1320	880	660	528	440	377	330	293	264
225	1350	900	675	540	450	386	338	300	270
230	1380	920	690	552	460	394	345	307	276
235	1410	940	705	564	470	403	353	313	282
240	1440	960	720	576	480	411	360	320	288
245	1470	980	735	588	490	420	368	327	294
250	1500	1000	750	600	500	429	375	333	300

APPENDIX F

TRAINING AIDS

Selections of visual aids are given, but others have been prepared by the Salt Institute and are available from that source (*69-71*).

ONTARIO

DEPARTMENT OF HIGHWAYS ONTARIO

MEMORANDUM

To: All District Engineers

From: J. B. Wilkes

Date: November 22nd, 1966

Our File Ref.

In reply to

Subject: Training of Personnel re De-icing Chemical Application - Winter Maintenance

We are forwarding, under separate cover, one flip-chart training aid concerning the use of chemical applied by spreader in the winter maintenance operation.

The flip-chart is in two sections; the first section is directed primarily at patrolmen, night patrolmen, etc., and deals with two principles:

(1) Why salt is used.

(2) When salt should be used.

The second part is directed at all personnel and, particularly, the equipment operator who may be a Department employee, a hired trucker or a contractor's employee. The three additional principles covered in this section are:

(3) How much salt to use.

(4) Where to place it on the road surface.

(5) How to place it there.

In view of the expenditure involved in the application of salt, each District Engineer will be expected to take a personal interest in ensuring that all personnel connected with this phase of winter maintenance are instructed on the above points, using the flip-chart presentation.

A feed-back system presently being devised will ensure that this training has been understood and is being put into practice.

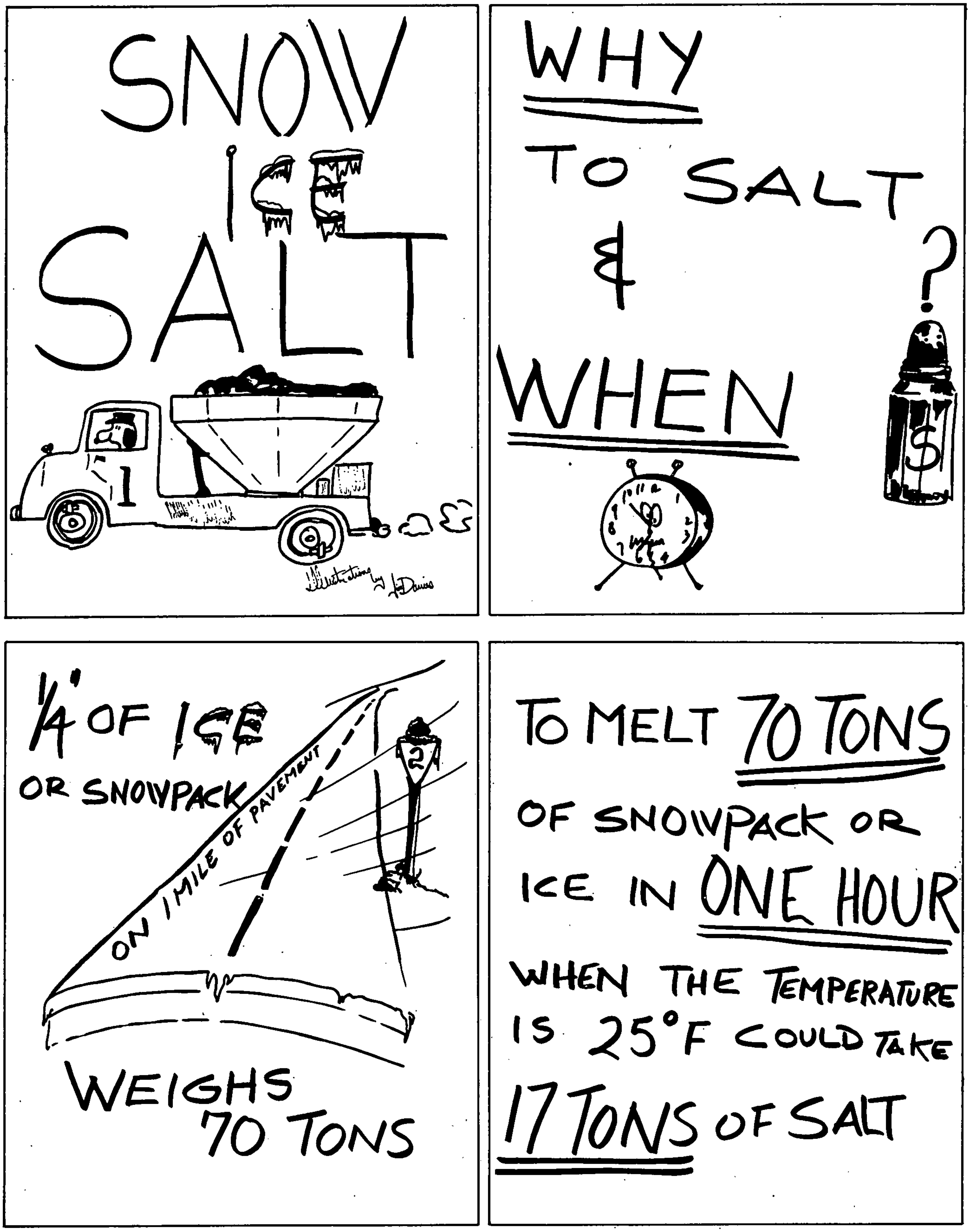
Difficulties arising out of poor co-operation by hired truckers are to be well documented for future action. In the event poor co-operation is encountered with the contractor's representative or his operators, I would remind you that the contracts are prequalified and that infraction reports for unsatisfactory performance may result in a penalty being imposed.

Would you please impress upon your staff the importance of understanding and carrying out the five principles outlined above and in the chart.

An 8½" x 11" copy of the training aid will be provided for each patrol in order that they may refresh their memory and instruct operators who may not have been previously trained.

J. B. Wilkes,
Director of Operations.

JMC/gm


SNOW
ICE
SALT
1
WHY
TO SALT
&
WHEN
?
$
1/4" OF ICE
OR SNOWPACK
ON 1 MILE OF PAVEMENT
2
WEIGHS
70 TONS
TO MELT 70 TONS
OF SNOWPACK OR
ICE IN ONE HOUR
WHEN THE TEMPERATURE
IS 25°F COULD TAKE
17 TONS OF SALT

SNOW AND ICE CONTROL

A Programmed Text Concerning the Principles and Procedures Involved in Keeping Ontario's Highways Open Throughout the Winter

This booklet contains a branching or scrambled program on snow and ice control.

Since no written answers are required, please avoid marking this booklet so it may be used again.

The information used in developing this program was obtained from District Maintenance Engineers, Maintenance Supervisors, Patrol Supervisors, Patrolmen and Equipment Operators. We were even able to get the odd answer from Head Office and we all know how difficult that can be.

We are sure you will disagree with some of our answers and would be grateful if you will contact us accordingly, at:

Department of Highways, Ontario,
Maintenance Training Section,
4, Allenby Avenue,
Rexdale, Ontario.

Each section in this program is referred to as a frame and numbered.

READ EACH FRAME CAREFULLY

If you can find your way through the program without making a mistake you may read as few as 25 frames out of a total of 65

Anything under 30 is very good

Anything over 45 and you might consider moving to a warmer climate

TURN THE PAGE AND READ FRAME NO. 1

Follow directions from there

GOOD LUCK

1

You are a Patrolman with the following winter equipment attached to your patrol -

1 - Hydraulic Spreader (for sand or salt)
1 - 6 ton Plow
1 - 3 ton Plow

A hydraulic spreader is used for both sand and salt application.
Although a properly adjusted modern plow can scrape right down to the pavement, it is generally accepted that ½ inch of snow should accumulate on the road before plowing is worthwhile.
Salt works best at warmer temperatures.
As a general rule, salt is not effective below zero.
Sand is used to improve traction on slippery sections of road.
Your patrol is a section of 2-lane paved road, 35 miles long.

On January 12 at 4 p.m. the roads are dry, the temperature is zero and the forecast is for temperatures to remain about the same overnight.

At 4:05 p.m. snow starts falling:
What would you do?

Send out the plows.
If this is your choice turn to Frame No. 10

Send out the spreader with sand.
If this is your choice turn to Frame No. 5

Send out the spreader with salt.
If this is your choice turn to Frame No. 17

Wait.
If this is your choice turn to Frame No. 6

YOU SHOULD NOT BE READING THIS IF YOU HAVE JUST FINISHED READING FRAME NO. 1. LOOK AT THE BOTTOM OF FRAME NO. 1 AGAIN.

2

Continue plowing. Wrong.
The snow has stopped, the plows have cleaned off all the snow they can.
All you are doing is wearing out plow blades.
Turn to Frame No. 13 and choose again.

3

Sand. Right.
Sand is used to provide traction on slippery sections of road and that is exactly what you have.
You sand all the slippery sections on the patrol at this time, with an extra application on the hills and curves.

By 7:00 a.m. the temperature is zero. The air is clear and still and the weather forecast is for a sunny day with a high temperature of 10 degrees. Would you -

Salt	turn to Frame No. 9
Put on another application of sand	turn to Frame No. 15
Wait	turn to Frame No. 20
Sand and salt at the same time	turn to Frame No. 14

4

Send out the small plow only. Wrong.
Remember, it is snowing hard and has been snowing hard for an hour.
Turn to Frame No. 6 and choose again.

5

Send out the spreader with sand. Wrong.
The sand will only be immediately covered with fresh snow.
Some say the sand will make the snow mealy and easier to plow.
Maybe, but it is not the answer we are after.
Turn to Frame No. 1 and choose again.

6

Wait. Right, in cases where the snow is blowing and drifting you might decide to do some spot plowing and sanding. In this case the air is still. There is not enough snow to plow, it is too cold for salt to do anything and sand would only be covered up with fresh snow. So good for you - wait, but...... the snow keeps falling at a very fast rate and by this time the road is snow covered.
It is now 5:00 p.m., the temperature is still zero. Would you -

Send out the small plow only	turn to Frame No. 4
Send out the large plow only	turn to Frame No. 11
Send out the spreader with salt	turn to Frame No. 16
Send out both plows	turn to Frame No. 13

7

Salt. Wrong.
Not at 5 degrees below zero.
Turn to Frame No. 13 and choose again.

8

You are a Night Patrolman, Patrol 8, District 12. Your winter equipment consists of:

1 - 6 ton Plow
1 - 3 ton Plow
1 - Hydraulic Spreader (for sand or salt)

Your 3 ton plow is equipped with a tail gate spreader which will do a good job of spreading sand at a fairly heavy rate of application.
The 3 ton plow is also used for applying salt by hand shovelling salt into a chute in the bottom of the dump box.
Used at the right temperature (generally above zero, the higher the better) salt is a very effective way to keep snow and ice from sticking to the pavement.
Your Patrol is a 30 mile section of very busy 2-lane highway with several bad hills and curves. There is one intersection with traffic lights.

At 7:00 p. m. on March 3 you are notified by the District that a storm with freezing rain is heading into your area and can be expected within an hour. The temperature is 29 degrees. Would you -

Load the spreader and the 3 ton with salt	turn to Frame No. 23
Load the spreader and the 3 ton with sand	turn to Frame No. 25
Load the spreader with salt and the 3 ton with sand	turn to Frame No. 35

9

Salt. Wrong.
Everyone says you should salt early in the day. If the forecast is correct the salt should work just fine once the sun gets up. The only trouble is the morning traffic. Traffic is wonderful for helping salt to work, it mixes the snow and salt to form a brine in much the same way as a spoon mixes sugar and coffee, but the temperature must be right. The date is January 12, it seems doubtful the sun will have much effect on the temperature until possibly 9:00 a. m. If the salt sits on the road without forming a brine for that long, the morning traffic will shove most of it into the ditch before it has a chance to work. Turn to Frame No. 3 and choose again.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF HIGHWAYS
RICHMOND, VIRGINIA

USE OF
CHEMICALS

THIS MATERIAL IS APPROVED BY:

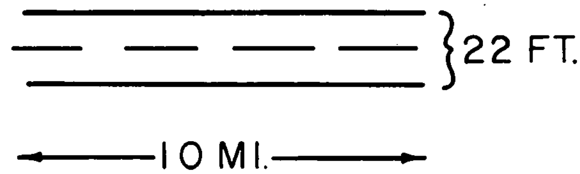
J. V. CLARKE, DIRECTOR OF OPERATIONS

J. M. WRAY, JR., STATE HIGHWAY MAINTENANCE ENGINEER

MAINTENANCE DIVISION
TRAINING PROGRAM

October 1967

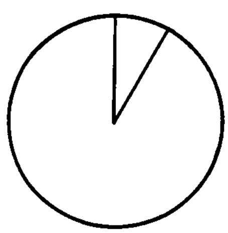
2 INCHES OF SNOW
1/4 INCH OF ICE
ON



WEIGHS

730-TONS

TO MELT
THAT MUCH
IN
ONE



HOUR

AT 26°

TAKES
170 TONS

OF SALT

THAT'S

40 FULL TRUCK LOADS
FOR EACH
10 MILE STRETCH
OF
ROAD

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Highway Research Board
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Rep. No.	*Title*
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
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12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
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49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20

* Highway Research Board Special Report 80.

Rep. No.	Title
50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00
52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
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74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60
76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $2.00
77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., $3.20
79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
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99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
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