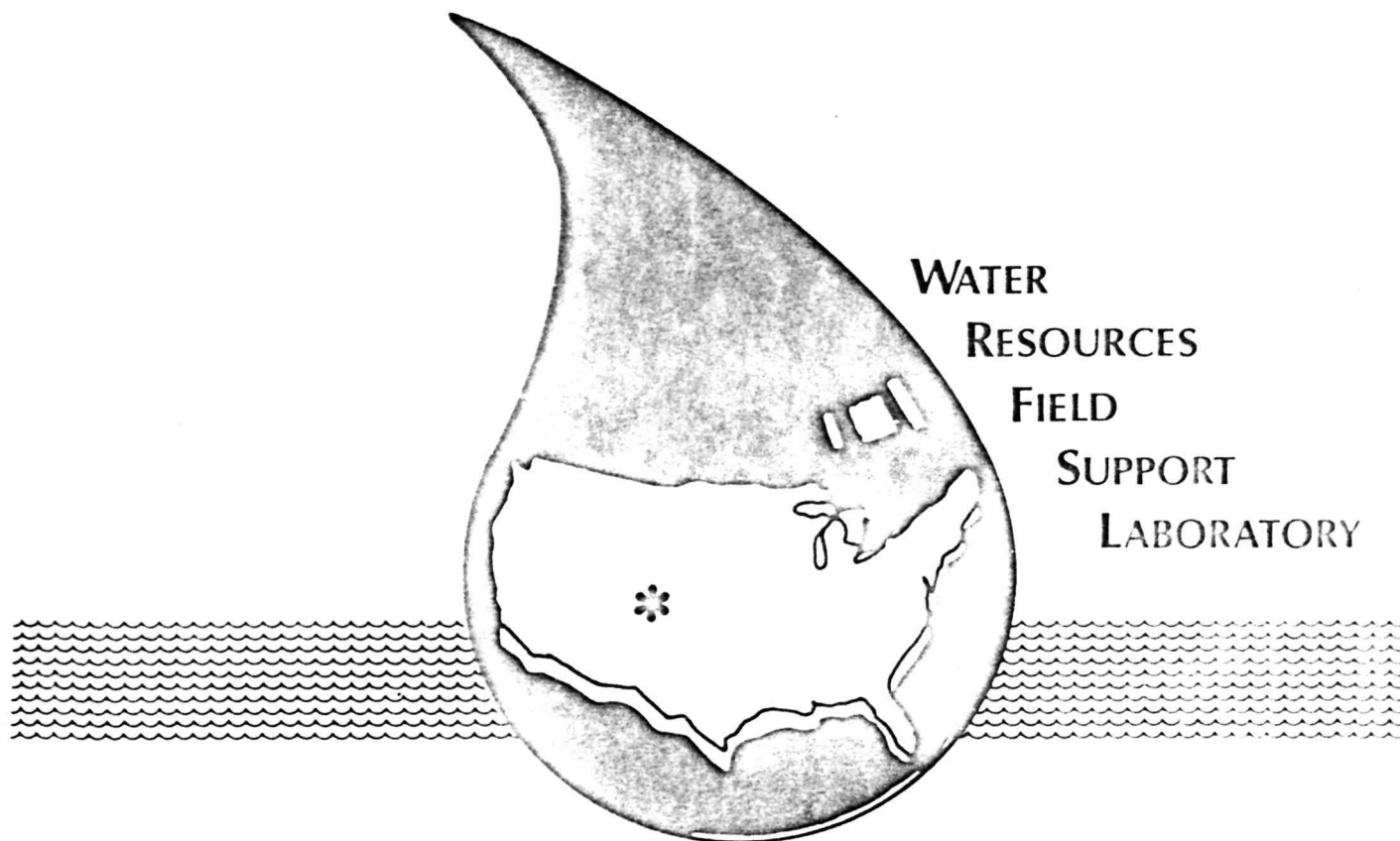


STATE OF THE ART IN ROAD SALT DEICING 1982



WRFSL REPORT No. 82-3



WATER RESOURCES FIELD SUPPORT LABORATORY
NATIONAL PARK SERVICE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

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SUMMARY

This paper was prepared by request as an informative update on road deicing agents other than sodium and calcium chlorides as the use of these standard salts are known to kill roadside plants, cause accelerated corrosion and deterioration of roads and road structures, and reduce the quality of surface and ground waters.

Present literature indicates, however, that at this time no practical alternatives to sodium chloride or sodium/calcium chloride combinations exist, except in special cases. But proper application and timing in the use of standard salts can help clear roads and minimize detrimental effects.

The paper reviews the effects of road salting and presents alternatives along with their costs, practicability, and potential for future National Park Service use.

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INTRODUCTION

Highway departments throughout the United States have been applying sodium and calcium chloride as deicing agents to the nation's roads for the past 30 years because they are both effective and relatively inexpensive. During the past several years, however, many concerns have surfaced because of the potential for chlorides to disrupt immediate roadside environments, affect the quality of both surface and ground waters, and damage roads and road structures.

This report discusses the uses and effects of chlorides and the alternatives to chloride deicing. An attempt has been made to consider both environmental and monetary costs to enable National Park Service managers to better select options and minimize environmental degradation.

Sodium chloride (NaCl) is an effective deicing agent at temperatures above -7°C (20°F); below that temperature calcium chloride (CaCl_2) is added. Although CaCl_2 is more expensive, it is more effective per unit volume than NaCl . Below -18°C (0°F) neither NaCl nor CaCl_2 are very effective and an abrasive, usually sand, is applied to increase skid resistance.

EFFECTS OF DEICERS

Plants

The effects of excessive chloride salt intake on vegetation include reduced photosynthesis (Bedunah and Trlica 1979), reduced growth (Gallagher 1979), early leaf fall and winter dieback (Sucoff 1975), leaf burn and plant mortality

(Holmes 1961), and reduced germination success (Pitelka and Kellogg 1979). The exact mechanisms are not clear, but observed physiological responses to increased chloride ion concentrations include changes in water and osmotic potentials (Adams, et al 1979), CO_2 exchange (Bedunah and Trlica 1979), succulence (Waisel 1972), and possibly membrane stability (Santarius and Heber 1970). Damage potential is increased during periods of water stress and cold temperatures (Sucoff 1975). Increased ion concentrations further reduce the plants' cold resistance, allowing freeze damage to occur at warmer temperatures (Sucoff and Hang 1976). Evergreen species may be particularly susceptible to salt damage because they retain their leaves for several years, increasing the period in which salt accumulation can occur (Hall, et al 1972).

Exposure of twigs and leaves to salt spray caused by automobile traffic (Bedunah and Trlica 1979) can cause trees growing next to roads to show greater leaf damage on the side of the tree that faces the road compared to the side that faces away (Hall, et al 1972).

Several detailed reviews of salt damage to plants are available in the literature (Hayward and Bernstein 1958, Thomas, Jr. 1965, Westing 1969). The overall effects of increased levels of Na^+ and Cl^- ions in the roadside environment may include reduced production, loss of intolerant species, and invasion of tolerant species. Appendix C lists the relative salt tolerances of trees and shrubs and serves as a reference to determine potential salt damage.

Soils

Salt indirectly affects plant communities by altering the chemical and physical structures of soils. Specific effects are a function of soil type, precipitation, depth of water table, and other related factors. In general, as Na^+ and Cl^- ions become disassociated in soil water, the Cl^- ions are repelled by the negative charge of clay particles and leach out more readily, while the Na^+ ions are adsorbed by clay particles and, therefore, more persistent (Hutchinson and Olson 1967). Increases in soil ion concentrations raise osmotic pressure which reduces water availability to plants, causing physiological drought (Hayward and Spun 1943, Long 1943). Increased sodium concentrations make fewer binding sites available for other cations, such as potassium and calcium, and results in the dispersion of colloidal particles, increasing the leaching of silicon and organic matter (Plice 1949).

In drier soils, water movement is typically upward from the water table to the soil surface. This movement tends to concentrate salts at the soil surface. Salt loading from deicing agents enhances this process, raising the osmotic gradient, which causes increased upward movement and evaporation of soil water (Qayyum and Kemper 1962).

The discussion of the effects of salt on soil have thus far been restricted to NaCl . The alternative use of CaCl_2 eliminates the concern for sodium. Calcium has been shown to have a beneficial effect on soil and Ca compounds are recommended soil additives to reverse the effects of high Na concentrations and restore productive soil conditions (U.S.D.A. 1954). However, CaCl_2 presents other problems similar to those seen with NaCl .

In laboratory tests, CaCl_2 and rock salt (NaCl) were approximately equal in deicing effect at a temperature of -4.0°C (25°F) over a one hour time period, indicating twice as many Cl^- ions are released into the environment when CaCl_2 is used under those conditions. At colder temperatures ($-15^\circ\text{C}/5^\circ\text{F}$), more than three times as much rock salt is required to produce the same effect as a given amount of CaCl_2 in one hour. If the time period is reduced to thirty minutes, eight times as much rock salt is required (Sinke and Mossner 1976). These data indicate that Cl^- use can be minimized by as much as a factor of four by using the compound that is most efficient at a given temperature.

Water

As deicing salt dissolves into solution, it follows the normal water pathways into streams, lakes and groundwaters. The Cl^- ion is readily leached from soils and has a greater probability of contaminating groundwater than Na^+ . However, Na^+ also will leach out of the soil or be carried by surface runoff. As salt concentrations increase in lakes and ponds fed by surface runoff, the salt water becomes stratified in the lower depths of the water body. Chemical stratification reduces the ability of lakes and ponds to undergo the seasonal mixing required to replenish oxygen. Lowered oxygen content reduces survival of some organisms, and in extreme situations can act as a toxic agent or break the food chain, ultimately resulting in fish kills. A more gradual process, salinity-induced eutrophication, takes place when salt accumulates over extended periods (Hawkins and Judd 1972).

Public safety reports have shown increases in salt concentrations of groundwater resulting from road deicing that sometimes exceed the maximum chloride concentration of 250 mg/l recommended by the U.S. Public Health Service (1962).

In eastern Massachusetts, normal uncontaminated groundwater contains from 5 to 15 mg chloride per liter. Several wells dug near a salted highway showed Cl^- concentrations increasing from less than 100 mg/l to greater than 350 mg/l over a six-year period (Figure 1). The U.S. Public Health Service recommendation was based primarily on the taste threshold of NaCl (200 mg/l) (McKee and Wolf 1963). The American Heart Association's standardized low sodium diet for persons required to restrict Na^+ intake requires water for cooking or drinking to contain a maximum of 20 mg Na^+ /l.

In a study of the Irondequoit Bay drainage, New York, Cl^- concentrations in the bay and feeder stream increased steadily from 1910 through 1970 (Figure 2). Further study showed that the depth of complete mixing in the bay decreased from 18 meters in 1970 to 12 meters in 1972. The observed Cl^- increase paralleled increases in the use of deicing salts (Diment et al 1973).

Roads and Structures

Accelerated deterioration of roads and structures was reviewed by Belangie (1979). Reactions involving salt that result in damage vary from cracking and scaling of concrete due to differential freezing temperatures associated with salt buildup in concrete surface layers, to corrosion of metal structural components in bridges and overpasses. Corrosion caused the unexpected collapse of an elevated highway in New York (Murray and Ernst 1976). Estimated salt damage to the nation's bridges costs some \$200 million annually in maintenance and repair costs (Belangie 1979).

FIGURE 1

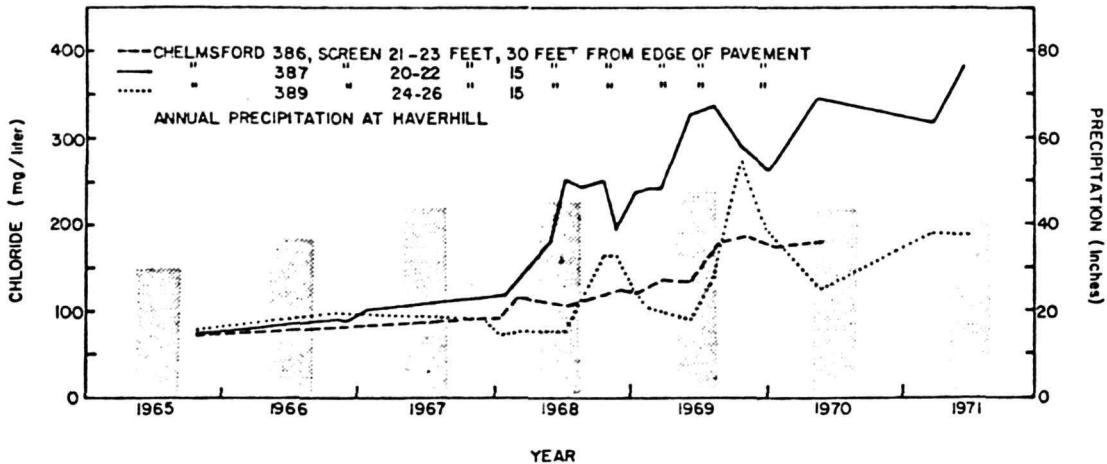


Figure 1. Chloride concentration in samples from Chelmsford wells. From Pollock and Toler 1973.

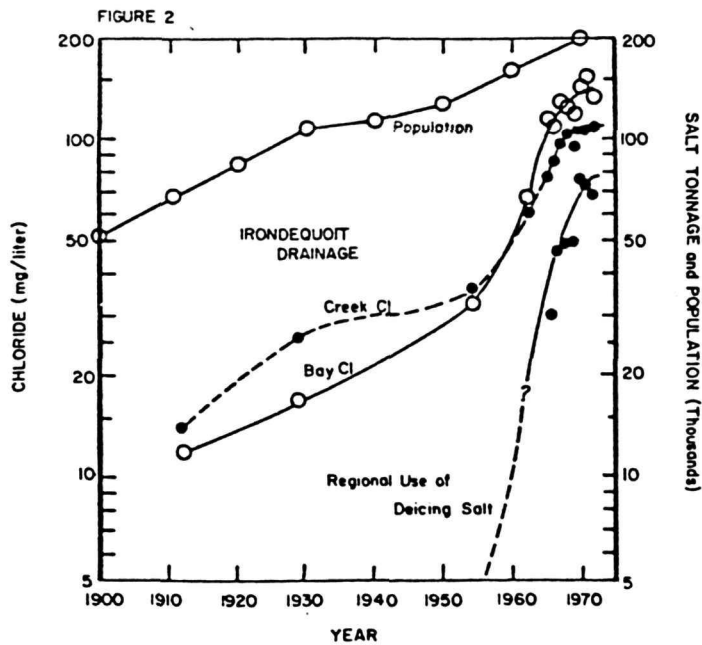


Figure 2. Chloride concentration in surface waters of Irondequoit Bay and Creek. Adapted from Diment et al. 1973.

ALTERNATIVES TO CHLORIDE DEICERS

Alternatives to chlorides include abrasives, other deicer chemicals, and structural modifications that are incorporated directly into roads during construction.

Abrasives

Abrasives are used mainly for increasing traction on slippery surfaces, but do stimulate melting through absorption of solar energy. Examples of abrasives are sand, lampblack, and waste products such as the sugar beet ash used in Rocky Mountain National Park. To be effective, abrasives must be clean, hard, and free from clay, preferably between 0.5 and 0.01 inch in diameter, resistant to crushing, uniform in grain size, and applied at a rate of 2-4 tons per lane mile (Keyser, 1973).

Disadvantages are that they are quickly blown off the ice by wind and the mechanical action of passing traffic. They retain moisture in stockpiles and during cold periods may freeze into solid clumps. Proper storage and handling can minimize this problem, but stocks of abrasives are sometimes treated with salts to prevent freezing and improve adherence to road ice. This, however, presents all the problems of introduced chlorides discussed earlier. Further disadvantages are that abrasives accumulate along the road shoulder and may change runoff characteristics that lead to localized flooding of the road, necessitating clean-up operations at the end of the season.

Chemicals

Comprehensive discussions on the benefits and hazards of many chemical alternatives to chloride salts are found in Dunn and Schenk (1979a) and in Zenewitz (1977). Dunn and Schenk (1979a) initially ruled out numerous chemical groups and elements due to insolubility, scarcity, cost, and/or hazard. Appendix B lists alternative chemical deicers, their unit cost, and their cost relative to NaCl based upon 1981 prices. In evaluating the remaining possibilities, one or more of the following reasons were given for rejecting some of the alternatives: insufficient solubility, relatively high freezing temperature, too corrosive, excessive variations in pH when in solution, potential for causing overgrowth in aquatic systems, production of nitrate (NH_3) in amounts sufficient to endanger aquatic biota, and high cost. The inorganic salts judged not acceptable for the above reasons are listed in Table 1. Use of ammonium carbonate and ammonium bicarbonate was ruled out for wetter regions due to the extreme toxicity of ammonium ions to fish (McKee and Wolf 1963). Dunn and Schenk (1979a) suggested that ammonium compounds may be used in arid climates where few aquatic environments persist. It is not known, however, what problems may occur during "pulsed" release of these compounds into drainages during seasonal rains. We therefore recommend that ammonium compounds not be used until it can be determined whether or not "pulse" concentrations would be within acceptable limits. Tetrapotassium pyrophosphate (TKPP) was considered inappropriate by Dunn and Schenk (1979a), but it was considered as a reasonable alternative (with qualifications) by Zenewitz (1977).

Table 1. Unacceptable inorganic deicing alternatives to sodium chloride.

<u>Generic name</u>	<u>Formula</u>	<u>Reasons for unacceptability</u>
Sodium carbonate	NaCO_3	insufficient solubility
Sodium bicarbonate	NaHCO_3	insufficient solubility
Sodium monohydrogen phosphate	Na_2HPO_4	insufficient solubility
Sodium dihydrogen phosphate	NaH_2PO_4	acidic aqueous solution, pH=3-4
Potassium carbonate	K_2CO_3	too caustic
Potassium bicarbonate	KHCO_3	insufficient solubility
Potassium monohydrogen phosphate	K_2HPO_4	high pH of aqueous solution, high cost
Potassium dihydrogen phosphate	KH_2PO_4	high cost
Ammonium carbonate	$(\text{NH}_4)_2\text{CO}_3$	highly toxic to aquatic biota
Ammonium bicarbonate	NH_4HCO_3	highly toxic to aquatic biota
Ammonium monohydrogen phosphate	$(\text{NH}_4)_2\text{HPO}_4$	highly toxic after degradation
Ammonium dihydrogen phosphate	$\text{NH}_4\text{H}_2\text{PO}_4$	highly toxic after degradation
Tetrapotassium pyrophosphate	$\text{K}_4\text{P}_2\text{O}_7$	high pH of aqueous solution, high cost

Of the organics investigated by Dunn and Schenk (1979a), a few were determined acceptable. Ethanol and isopropanol, urea, urea ammonium carbonate, formamide, and dimethyl sulfoxide (DMSO) were all found less than desirable due to cost, insolubility, toxicity, flammability, high nitrogen content, unpleasant odor, and/or problems associated with storage.

Two organics did show potential to substitute for NaCl as a deicer: acetone and methanol. Acetone and methanol were similar, but the high cost of acetone made it acceptable only when used as a component of another deicing mixture.

An aqueous solution of methanol has a neutral pH, contains no nitrogen or phosphorous, and is less flammable than ethanol or isopropanol. In controlled tests to evaluate its corrosive ability, 25-50 percent solutions (by volume) of methanol did not corrode steel, and in only one instance did it show greater corrosion of metal (sheet aluminum) than deionized water. In the same study, it had no adverse effects on portland cement over a nine-month period (Dunn and Schenk 1979b). Methanol is volatile, with a density of 0.7914g/cc (20°C) which allows it to evaporate from water surfaces and run off in reduced concentrations.

Problems associated with methanol include flammability, but it can be mixed with water to prevent this. Its flammability may produce storage problems but much less than those associated with gasoline. It is as efficient a deicer as NaCl above -15°C (Dunn and Schenk 1979b), but due to its volatility is less persistent than NaCl. It therefore requires more frequent application during periods of continuous ice formation. The cost is about five times that of NaCl (Appendix B) but its use in critical areas would

reduce chloride-type environmental damage over the short term. There are no data on the long-term effects. Also to be considered is the concentration at which methanol would be handled and applied. Inhalation of fumes must be avoided, and ingestion of small amounts by humans can cause blindness or death. Fingerling trout subjected to 8100 mg/l concentrations of methanol in natural waters showed no harmful effects after 24 hours (McKee and Wolf 1963), but the effects of slug dosing to waters from methanol-treated roads are unknown.

Calcium-magnesium acetate (CMA), a metal organic salt, was also determined to be a potential replacement for NaCl. CMA can be spread with the same equipment used for NaCl and is similar to NaCl in deicing ability. In the same tests described above for methanol, CMA showed no corrosion of steel, zinc or aluminum. Behavior of the calcium and magnesium ions after application of CMA to roads would depend upon the existing chemistry of the soils and waters in the area. Local, qualified advice should be sought if CMA use is considered.

In terms of human consumption, the CMA ions are no more hazardous than Na^+ ions and reduce hazards to people on low Na^+ diets. CMA is not flammable, but because it is slightly caustic, protection may be required for employees handling it to prevent prolonged exposure to dusts (Dunn and Schenk 1979a,b).

Toxic and recommended concentrations of deicing chemicals, or their breakdown products, in water are given in Tables 2 and 3, respectively. Data in these tables are from McKee and Wolf (1963). It should be noted that these data are based on literature and laboratory toxicities, and do not necessarily represent field toxicities.

Table 2. Reported acute toxic or lethal concentrations of selected deicing chemicals or their breakdown products in water 1/

<u>Deicer/product</u>	<u>Toxic-lethal concentration mg/l</u>	<u>Organism tested</u>
Ammonia	0.3	trout fry
Calcium	800	stickleback
Calcium chloride	555	rock bass
Chloride	400	trout
Ethanol	7800	daphnia
Magnesium	300	stickleback
Methanol	250	goldfish
Potassium	50	stickleback
Potassium bicarbonate	2000	minnows, goldfish
Potassium phosphate (tribasic)	750	mosquito-fish
Sodium	500	stickleback
Sodium bicarbonate	2350	daphnia
Sodium carbonate	68	king salmon
Sodium chloride	1270	fish (unknown species)
Sodium phosphate	720	mosquito-fish
Urea	16,000-30,000	creek chub

1/ From McKee and Wolf 1963.

Table 3. Recommended maximum concentrations of selected deicing chemicals or their breakdown products in various waters. ^{1/}

<u>Deicer</u>	<u>Concentration (mg/l)</u>		
	<u>Domestic Water Supply</u>	<u>Industrial Water Supply</u>	<u>Stock and Wildlife</u>
Ammonia	0.05- 0.10	-	-
Calcium	75	10-200	1000
Calcium chloride	40 - 50 ^{2/}	35-200	-
Chlorides	250	50	1500
Magnesium	30 -125	5- 30	500
Potassium	1000	50	-
Sodium	10	50	2000
Sodium bicarbonate	1060 ^{2/}	35	< 6000
Sodium carbonate	15 - 75 ^{2/}	100	-

^{1/} From McKee and Wolf 1963.

^{2/} Based on taste and hardness.

Physical Alternatives

A variety of possibilities exist for the physical removal or prevention of ice and snow accumulation on roadways. Some are recently invented devices that attach to vehicles; others are electrical/mechanical devices that are built into or attached to structures. Also available is a compound that is mixed directly into asphalt, making it more resistant to ice formation.

Brink et al (1967) experimentally tested various coating materials to determine their ability to prevent scaling of concrete slabs after NaCl deicing treatment. Such coatings increase the life span of a bridge or road by reducing Cl^- infiltration and the resulting corrosion of reinforcement bars.

A prototype vehicle-mounted deicer that utilized a gas plasma arc lamp has been tried in British Columbia. Preliminary results were encouraging, but a snow covering over ice greatly reduces its effectiveness. Plowing the snow layer off first would alleviate this problem, and with modifications the arc lamp may be an effective deicer of the future. Capital costs were not given, but energy costs were estimated to be 120 kw per 30 cm (1 ft.) of lane width to detach clear ice from pavement at 24 km/hr (15 mph). Other physical ice removal methods include microwave power, electrical discharge, vibration/ultrasonics, and infrared heating. These have been tested, but none so far have been effective and their energy requirements are excessive (Mouat and Saunders 1979).

Havens et al (1979) described a successful electric heating system built into a highway interchange that prevented snow and ice accumulation. Long-term operation costs are unknown, as the system is only three years old. Final capital cost was \$1,878,170 for 174,095 square feet of heated pavement (\$10.78 per square foot) and included a television monitoring system. Operational cost was \$10.79 per square foot for the winter of 1976-77, with maintenance costs being approximately \$50,000 annually. The effectiveness of this system indicated that fewer heating elements may have produced the same results at a reduced cost. Indeed, this was partially proven when power interruption on some cables did not change the capability of the mechanism to keep the road clear.

Similar techniques with infrared heaters under bridges were tested unsuccessfully in Colorado and successfully in Wyoming by Cundy et al (1979). Cundy et al also performed preliminary experiments with gravity-operated heat pipes that transfer geothermal energy to bridge decks. The latter system was considered a success, but unanswered environmental questions concerning the potentially permanent depression of the earth temperature in the heat pipe field require further study before large scale operations can be attempted.

The Swiss have tested an additive called "Verglimit" (formula unknown) which, when mixed directly with asphalt, prevents ice formation on the road surface. It reduced the service life of the test course by 50% while adding 40% to the pavement costs, however, and does not seem economically feasible. The additive is not effective unless temperatures are very close to freezing (Zenewitz 1977).

DISCUSSION

Many alternatives to chlorides as deicing agents are currently available. The majority of these pose risks that are equal to or greater than those posed by NaCl. Of the many chemical compounds investigated, only CMA and methanol appear to offer efficient deicing properties with minimal short-term adverse environmental effects. While CMA and methanol are similar to NaCl as deicers, they are both about five times as expensive as equivalent amounts of NaCl.

CMA can be applied with the same equipment used for NaCl. This is an advantage over methanol, which needs liquid dispensing equipment. Alternatively, liquids can be dispensed with greater control than solids. The exact rates of application for CMA and methanol under given ice conditions have not been determined.

Non-chemical deicing alternatives are diverse but not yet sufficiently tested for general application and their long-term cost and effectiveness has not been determined. The use of electrical energy has been shown to be effective at keeping elevated roads free of ice and snow, but local energy costs and availability may affect its practicability. Geothermal heating of road structures has also been tested and is effective in areas that contain this resource. However, further testing of these techniques is required before use is encouraged. If electrical or geothermal methods prove successful over long time periods, combining them with CMA or methanol may provide superior ice control at a cost that is both financially and environmentally acceptable.

While the harmful short-term environmental effects of deicing salt can be avoided by using alternative methods, the availability, operational costs, and/or new equipment costs, not to mention detrimental long-term impacts, of the alternatives may be serious deterrents to their use. Investment in new deicing techniques that have not been tested over several years may be risky for the National Park Service. However, the continued use of NaCl or CaCl_2 will damage the environment.

CONCLUSIONS

The critical decision at the park level relates to the need to apply deicing chemicals. Is it really necessary? In the few instances where the need truly exists, environmental consequences are inevitable and every effort must be made to minimize long-term effects. But the use of chemically untreated abrasives and the seasonal termination of road service in parks appeal to both environmental and economic logic.

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APPENDIX A

APPLICATION RATE FOR DEICING MATERIAL

Experimentation may allow further reduction in salt application rates, as will convincing the public that "bare pavement" policy may result in unnecessary environmental damage. To encourage conservative use of salts until alternative methods can be implemented the following was reproduced from the "Manual of Deicing Chemicals: Application Practices" (EPA-670/2-74-045):

"The amount of deicing material that must be applied to improve the driving conditions on a particular section of highway at any specific time during a given storm is dependent primarily on the weather, the traffic conditions, and the level of service to be maintained. From an environmental point of view, the minimum amount to be applied would be no chemicals--clearly not an acceptable alternative except perhaps on little-used rural roads. From the point of view of improved driving conditions, an amount equal to or slightly in excess of a not-yet determined minimum should be used. Unfortunately, no generally accepted guidelines have been established for minimum amounts of chemical to be applied for different weather and traffic conditions. Furthermore, no experimental programs have been conducted to determine the minimum amount of chemicals required--a condition that has been long recognized by many maintenance managers.

Those guidelines that are presently being used have evolved from the point of view of improving the driving conditions. Until there is widespread concern for the environment on the part of the driving public (see Part Five of this manual), or until the demand for bare roads at all times is diminished, these guidelines will not change significantly. In addition, since existing guidelines have not been verified experimentally, they have simply been found to be adequate. The critical environmental issue is not the exact amount of chemical material that is prescribed for a given set of weather, traffic, and road capacity conditions, but rather that no more than the recommended prescribed amount be used (a matter of equipment calibration) and that a minimal number of applications be made during each storm (a matter of weather prediction and supervision of the operation.

A major finding of the study leading up to the writing of this manual was that many agencies did not know how much salt or deicing chemical was being spread with each application and, in most instances, the amount was not only greater than expected but also greater than the amount prescribed. This startling fact was revealed in many agencies when, for either financial or ecological reasons, a concerted effort reduced the use of chemicals yet did not reduce the level of service or the driving conditions.

General Guidelines

In view of all of these limitations, suggested guidelines for chemical application rates are given in Table 3. These guidelines reflect the lower limits of chemical usage in current practice among a wide range of city, town, county, state, and toll-road authorities. Five classifications of roads comprise the basic parameters. The guidelines are presented in terms of the amount of material that is to be spread upon a mile of two-lane road or per mile of two lanes of a divided highway. How this material is to be spread on the highway must be determined by each agency.

Generally, chemicals such as salt (sodium chloride) and/or premixes of salt and calcium chloride are spread in a narrow pattern in the center of two-lane roads or on the crown of multi-lane divided highways. On super elevated curves, the material should be placed as high as possible on the curve so that the brine produced will flow across the road surface. Under some conditions a full width pattern is required particularly on heavily traveled roads where all lanes carry equal traffic.

In some agencies, particularly on secondary roads, the material is not spread but simply placed in a windrow right on the centerline of the highway where the melting action produces brine which will flow in both directions across the road. In the case of abrasives, a larger spread pattern is generally used in order to obtain good coverage of both driving lanes either on a two-lane road or on a multi-lane highway. Care must be exercised during spreading to ensure that material is not spread into the breakdown lanes or onto the shoulders where it is not effective.

The New York State Department of Transportation has developed guidelines for spreading of deicing chemicals that call for an initial application of material at the beginning of storms followed by applications at a lower rate on an as-needed basis. The initial application forms a brine on the road surface which prevents bonding of snow and ice and the subsequent buildup into snow pack. The smaller applications, particularly when made immediately after plowing (often by the plow truck itself), maintain this film of brine at the road surface. The last small application is made when the storm is almost finished and is beneficial in drying the road particularly if a temperature drop occurs at storm's end.

The quantities prescribed in Table 3 are for two-lane roads; when single lanes are being treated, such as exit ramps and acceleration lanes, the rates should be half of those stated in Table 3. Reducing this rate should be the duty of the spreader operator or his assistant and is an important environmental consideration, particularly for large cloverleaves at the junction of multi-lane highways where there is a large, concentrated usage of deicing chemicals.

Included in Table 3 are the timing of applications and suggested waiting periods between chemical application and the initiation of plowing. This waiting period is critical from the points of view of operations, improved driving conditions, and the environment because it allows the deicing chemical to form a brine, spread out on the highway, prevent bonding of precipitation (snow, sleet, or freezing rain) and to be dissolved completely in this process before plowing occurs. Premature plowing will pick up the material in undissolved form and deposit it on the shoulder where it is of no use in improving the driving conditions. In short, when deicing chemicals are used, the philosophy should be to use them fully and not throw them away.

Oftentime highway men are confronted with a problem of changing weather conditions. This emphasizes the need for close monitoring of the weather and judging what the weather will do on the basis of past experience with similar storms. This is where the skill of maintenance managers is crucially important. When changes in weather conditions are predicted, the supervisor should take these changes into account when prescribing the material and quantities. For instance, if there is a high probability of rising temperature, the amount of material prescribed should be reduced in anticipation of the temperature rise. Likewise, if the temperature is predicted to drop rapidly at the end of a storm, it is important to get a final application of salt down so that the road will dry up as the storm ends and so that icy patches cannot form.

Environmentally Critical Areas

Some agencies are consciously reducing the amount of material that is used in environmentally critical areas, such as watersheds used for water supply. Several courses of action are open in these areas.

First of all, the level of service of roads in these areas can be lowered, particularly on primary and secondary roads. Care should be taken to notify motorists that there will be a reduction of the level of service in these areas.

Next, the amount of salt used can be reduced by application of smaller amounts and less frequently. Some jurisdictions are reducing the amount of sodium that enters such environmentally critical areas by using mixtures of salt and calcium chloride in ratios of 3:1 or 5:1 salt to calcium chloride.

Prewetting of the salt has been used in order to accelerate the action of salt, and at the same time to utilize less total material. These salt prewetting schemes usually use materials that do not freeze at extremely low temperatures, such as solutions of salt, calcium chloride, methyl alcohol, or propylene glycol.

The North Dakota Highway Department has successfully prewetted salt with water alone sprayed on top of the loaded truck at a rate of 18-20 gallons per cubic yard of salt. Salt brine pumped from an area drainage catchment basin can also be used for prewetting salt. Care must be exercised when using water or dilute solutions in sub-freezing weather to keep water hoses and pumps from freezing. A prewetted load of salt must not remain in the truck for a prolonged period during sub-freezing weather because it will freeze.

The prewetting material of choice by some agencies is a 32% (by weight) solution of calcium chloride (4.12 lbs. of 94-97% CaCl_2 in 1.0 gal of water, or 5.79 lbs of 77-80% CaCl_2 in 1.0 gal of water). Several techniques are used for applying it to the salt. In some jurisdictions, calcium chloride solution is pumped onto the dry load of salt before the truck driver proceeds along his route. In Iowa, Michigan, New York, and others, a tank of calcium chloride solution is carried on the truck, and the calcium chloride solution is dispensed into the discharge chute of the spreader either by means of a pump or under gravity. The object is to coat thoroughly each particle of salt with calcium chloride solution before it is applied to the snow or ice on the road; this can initiate immediate melting of the snow or ice to form additional brine that dissolves the crystals of salt. Prewetting keeps the salt from bouncing off the roadway during spreading and from blowing away once it is on the road. A typical application rate for prewetting of salt as it is dispensed at the back end of a spreader is at 8 gal per ton. For calcium chloride solutions applied beforehand to a full load of salt in the truck, a typical application rate is 10 gal per ton, and the material is pumped into the top of the load just before the truck leaves the yard.

Connecticut's Bureau of Highways has been experimenting in 21 critical watershed areas with several mixtures of sand, salt, calcium chloride, and 50/50 mixture of propylene glycol to accelerate the action of the salt and calcium chloride. The three mixtures being used are summarized in Table 4. Mixture One containing no sand, is used on the interstate highways where they pass through these watersheds. The standard Connecticut premix (3:1 salt/calcium chloride) is spread at a rate of about 430 lb. per two-lane mile and is prewetted with a 50-50 mixture of propylene glycol and water at a rate of 10 gal per two-lane mile. Mixture Two uses 11 parts sand and two parts of standard premix. This mixture is prewetted with 10 gal per mile of 50-50 propylene glycol water mixture. Of the three mixtures being used Mixture Two, as noted in Table 4, contains the smallest amount of salt and calcium chloride. Mixture Three is made from seven parts sand and two parts of standard premix. No propylene glycol is used for prewetting of this mixture.

Additional Techniques for Minimizing Chemical Applications

In one way or another, all of the techniques outlined in this manual are directed toward minimizing the amount of deicing chemicals and/or maximizing the effect of those chemicals that are used. As many of these techniques should be incorporated as possible, appropriate, and economically feasible.

Table 3 GUIDELINES FOR CHEMICAL APPLICATION RATES

WEATHER CONDITIONS			APPLICATION RATE (Pounds of material per mile of 2-lane road or 2-lanes of divided)			
Temperature	Pavement Conditions	Precipitation	Low-and High-Speed Multilane Divided	Two and Three-Lane Primary	Two-Lane Secondary	INSTRUCTIONS
30°F and above	Wet	Snow	300 salt	300 salt	300 salt	- wait at least 0.5 hour before plowing
		Sleet or Freezing Rain	200 salt	200 salt	200 salt	- reapply as necessary
25-30°F	Wet	Snow or Sleet	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	initial at 400 salt repeat at 200 salt	- wait at least 0.5 hour before plowing; repeat
		Freezing Rain	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	initial at 300 salt repeat at 200 salt	- repeat as necessary
20-25°F	Wet	Snow or Sleet	initial at 500 salt repeat at 250 salt	initial at 500 salt repeat at 250 salt	1200 of 5:1 Sand/Salt; repeat same	- wait about 0.75 hour before plowing; repeat
		Freezing Rain	initial at 400 salt repeat at 300 salt	initial at 400 salt repeat at 300 salt		- repeat as necessary
15-20°F	Dry	Dry Snow	plow	plow	plow	- treat hazardous areas with 1200 of 20:1 Sand/Salt
	Wet	Wet Snow or Sleet	500 of 3:1 Salt/ Calcium Chloride	500 of 3:1 Salt/ Calcium Chloride	1200 of 5:1 Sand	- wait about one hour before plowing; continue plowing until storm ends; then repeat application
below 15°F	Dry	Dry Snow	plow	plow	plow	- treat hazardous area with 1200 of 20:1 Sand/Salt

Table 4 MIXTURES FOR ENVIRONMENTALLY CRITICAL AREAS
 Courtesy of State of Connecticut Department
 of Transportation

	<u>Mixture 1</u>	<u>Mixture 2</u>	<u>Mixture 3</u>
Spread Rate (lbs/mile of 2-lane road)	430	1500	1500
Description of Mixture Dry Ingredients	all 3:1 Premix	11 parts sand 2 parts 3:1 Premix	7 parts sand 2 parts 3:1
Amount of 50/50 propylene glycol	10	12	none
Calculated Quantities (lbs/mile of 2-lane road)			
o salt	320	180	260
o calcium chloride	110	45	86
o sand	---	1275	1154

3:1 Premix = 3 parts Rock Salt and 1 part Hydrated Calcium
 Chloride by weight

During each winter storm, the optimum chemical application rate is a combination of many factors including the level of service, weather conditions changing with time, the state and characteristics of the chemicals used, the time of application relative to both changing traffic and weather conditions and the topography and type of road surface. The actual determination of an application rate by a maintenance manager is a matter of his best judgment. Usually the rate is chosen that will reasonably cover as many of the uncontrollable variables as possible.

Many noteworthy techniques have been developed by maintenance managers who are attempting to minimize the application rates for deicing chemicals and abrasives, and/or to maximize the deicing effect of those materials applied. In the following listing, are some additional techniques that were noted during the course of the study preceding the writing of this manual.

- Application of chemicals should occur in smaller increments in response to changing traffic and weather conditions. Although this requires more attention by operators, foremen, and other maintenance managers and much more intensive use of equipment, the techniques guards against the possibility of unnecessary over-application of environmentally harmful chemicals.
- Abrasives should be used with little or no use of chemicals in locations where traffic is not heavy enough to remove them rapidly from the road. A mixture of 20 parts of sand and one part salt (the minimum amount required to keep a sand pile from freezing) often results in sufficient melting action to provide an adequate level of service on secondary roads and roads in residential areas.
- For storms that are expected to produce heavy snowfalls, application of salt at the onset of the storm followed by early and continued plowing throughout the storm will provide an adequate level of service, particularly if it is followed by a light application of salt at the end of a storm in order to clear up the road and prevent freezing when the temperature drops.
- Less chemicals are required to prevent snow pack from forming if underbody scrapers are used extensively in the plowing program. These scrapers can clear the road surface of hard-packed snow more readily than a conventional front-mounted plow.
- Through coordination of the timing of plowing and chemical applications, the salt is allowed to melt, form brine, and break the snow-ice bond at the road surface before snow is plowed off. Success of this technique requires keen observation of conditions and good communication among crew foremen and district supervisors.

- When roads are subject to regular one-way commuter traffic, both plowing and chemical applications should be concentrated on in-bound or out-bound lanes as appropriate to the peak traffic load and time of day.
- A towed spreader (see Figure 25 in Chapter V) is useful for applying concentrated and controlled amounts of chemicals to areas on the roadway (such as the passing lane) that may need additional applications in such a well-defined area that a large spreader truck would put too much material out over a too large area.

PRECAUTIONS IN HANDLING OF DEICING CHEMICALS

Once the application rate has been prescribed, the action shifts from the supervisors or managers to the men who must carefully use these deicing chemicals. A complete description of precautions concerning handling of deicing chemicals before application is given in Part III of Manual for Deicing Chemicals: Storage and Handling (EPA-670/2-74-033).¹ When the spreader trucks are being loaded before and during a storm good practices should be followed. In general, five precautions should be observed.

- If possible, load trucks or spreaders inside the salt storage shed. This reduces spillage and cleanup problems.
- Before the spreader truck leaves the shed or the loading area, clean it off--catwalks, top edges and ledges of the body, tanks, roof and fenders. This will keep the salt from spilling off where it is not wanted.
- Keep the loading area clean by immediately cleaning up any salt lying on the loading pad, and get it back under cover.
- Keep the salt dry by keeping it under cover as long as possible before loading it onto the trucks.
- Handle the salt as little as possible. Excessive handling causes large particles to break down into finer particles which reduces their effectiveness for clearing snow.

ROLE OF THE SPREADER OPERATOR

The spreader truck operator has the ultimate control over the amount of chemical that is spread on highways. The success of any program to minimize the amount of chemicals spread on highways is totally dependent on his enthusiastic acceptance of this goal. Thus, it becomes increasingly important that spreader operators be thoroughly familiar with the equipment and the desires of the foremen, supervisors, and other high officials responsible for the snow and ice control program.

Further, because he is out in the storm, the spreader operator is in the best position to judge the condition of his section of the road and the efficacy of his snow and ice control efforts, and can feed this information back to his foreman and supervisors. Maintenance of two-way radio communication with each spreader operator is as important as use of a well-calibrated, easily controlled salt spreader.

Control of the actual amount of salt spread should be in the hands of the spreader operator. He should be told by his supervisor the standard amount of salt that is to be spread on his particular run. The actual spreading rate may vary from place to place throughout the run depending upon the number of intersections, grades, and bridge decks that are subject to icing before the main road. However, as weather conditions change for better or for worse, the operator should have the option of increasing or decreasing his amounts within some limit, for instance +20 or -100 lb depending upon the weather and traffic he encounters. Before increasing the spreading amounts above this upper discretionary limit, the operator should seek guidance from his supervisor via the two-way radio. Clearly, to vary the spreading rate this way during a run requires equipment with in-cab controls which are in good operating condition.

All spreader operators should be trained to spread chemicals on the crown of the road or on the high side of the road and should know how to change spreading techniques or pattern in response to crosswinds that blow the material before it settles on the highway pavement. Further, he should know when to cease spreading chemicals and initiate a plowing operation."

EPA-670/2-74-032
July 1974

Environmental Protection Technology
Series:

Manual for Deicing Chemicals:
Storage and Handling

Order No: PB# 236152/AS \$ 9.50

EPA-670/2-74-045
December 1974

Environmental Protection Technology
Series:

Manual for Deicing Chemicals:
Application Practices

Order No: PB# 239694/3BA \$14.00

The above manuals are available from: National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161, Telephone: (703) 487-4650, at the cost of \$23.50.

APPENDIX B
Chemical Prices ^{1/}

Deicer needed to
liquify ice at -10°C

	Chemical	Price ^{2/}	Unit cost relative to NaCl	lb/100 lb ^{3/} of ice	Cost relative to that of NaCl
Inorganic	NaCl	50.00	1.0	16.0	1.0
	CaCl ₂	99.00	2.0	<u>5/</u>	<u>5/</u>
	CaCl ₂ (liquid 40-45%)	38.75	0.8	<u>5/</u>	<u>5/</u>
	CaCl ₂ (anhydrous)	140.00	2.8	<u>5/</u>	<u>5/</u>
	NaHCO ₃	222.00	4.4	<u>b/</u>	-
	NaCO ₃	56.00	1.1	<u>b/</u>	-
	Na ₂ HPO ₄	705.00	14.1	<u>b/</u>	-
	NaH ₂ PO ₄	680.00	13.6	~55.	46.8
	K ₂ CO ₃	278.00	5.6	19.	6.6
	KHCO ₃	278.00	5.6	<u>b/</u>	-
	K ₂ HPO ₄	290.00 ^{3/}	10.4 ^{3/}	47.0	30.4 ^{3/}
	KH ₂ PO ₄	268.00 ^{3/}	9.6	<u>b/</u>	-
	K ₄ P ₂ O ₇ (TKPP)	920.00	18.4	37.4	43.0
	(NH ₄) ₂ HPO ₄	200.00	4.0	32.5	8.1
	NH ₄ H ₂ PO ₄	174.00	3.5	<u>b/</u>	-
	(NH ₄) ₂ CO ₃	80.00 ^{3/}	2.8 ^{3/}	31.6	5.6 ^{3/}
	NH ₄ HCO ₃	292.00	5.8	11.9	4.3
Organic	Ethanol	1.83/gal (0.28/lb)	11.0	23.5	16.4
	Isopropanol	1.90/gal (0.29/lb)	11.6	29.9	21.7
	Urea	160.00	3.2	34.	6.8
	Formamide	880.00	17.6	34.	37.4
	Dimethyl Sulfoxide	740.00	14.8	35.1	32.5
	Methanol	0.75/gal (0.11/lb)	4.4	19.	5.2
	Acetone	620.00	12.4	50.	38.8
	CMA			25. ^{4/}	~5. ^{3/}

^{1/} From Chemical Marketing Reporter. Mar. 16, 1981

^{2/} Prices are per ton unless indicated otherwise

^{3/} From Dunn and Schenk (1979a)

^{4/} From Dunn and Schenk (1979b)

b/ No liquid phase at -10°C
5/ See text for comparison of
CaCl₂ and NaCl, price of
CaCl₂ not available.



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