

Highway Salt And Our Environment



Salt Institute

Published by the Salt Institute as an informational guide for public policy makers concerned with snow and ice control on public traffic ways and related public safety, health and environmental issues.

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1. Why We Use Highway Salt

Environmental protection, properly, is a high public priority. So are roadway safety and mobility. In our complex society, the public demands that governments keep traffic flowing smoothly and minimize the tragedy of car crashes. This is an economic necessity, not to mention good customer service for roadway maintenance organizations. Roads and highways must remain operational and safe even during adverse winter weather conditions. Medical emergencies like heart attacks and accidents including home fires and auto crashes occur all year long. In an emergency, a few minutes of response time is often a matter of life or death.

The fastest, least expensive and most effective method of coping with winter's ice and snow is highway salt. As early as 1970 the Highway Research Board concluded that there were no reliable or economical substitutes for salt in the foreseeable future.¹ Its study determined that environmental concerns are site specific and could be alleviated by proper storage, handling, application, drainage and landscaping. Since that time, highway departments have addressed these areas, and detrimental effects of deicing salt on the environment have been significantly reduced.

Today, thousands of municipal, state and provincial transportation agencies rely on deicing salt to assure wintertime mobility and safety. They must have a safe, reliable and economic means of clearing ice and snow, since, in the absence of specific protective legislation, they may be liable for their (perceived or real) failure to keep streets and roads in safe condition. One claim in Canada, alleging failure to provide safe and passable roadways cost the Province of Ontario \$4.5 million.²

An important role of the Salt Institute is to assist states, provinces, counties and municipalities throughout the United States and Canada, and the contractors they often employ, in developing state-of-the-art snow and ice control programs. The Salt Institute also encourages proper salt management by private contractors responsible for clearing private roads, such as on college campuses and parking lots at shopping malls, factories and businesses.

This brochure will explain why snowfighters use highway salt, how salt works, the effects of highway salt on the environment, infrastructure and motor vehicles, and application techniques to minimize adverse environmental impacts.

The Salt Institute will be pleased to provide copies or excerpts of studies, articles and research cited in this brochure and offers additional information on its website: <http://www.saltinstitute.org>.

¹ Highway Research Board 1970 - 49th Annual Meeting, Washington, D.C., January 12-16.

² *Roberts et al. v. Morana et al.* 1997. Ontario Court (General Division), Canada. July 24, 1997 p. 647.

1.1.

Sensible Salting Saves Lives

Snow and ice on streets and highways are a major threat to human life and limb. Traffic accidents and fatalities climb as snow and ice reduce traction on roadways. Lengthened emergency response times create additional risks for persons in urgent need of medical care, particularly in cases of heart attacks, burns, childbirth and poisoning.

In the early 1990s, a study by the Marquette University Center for Highway and Traffic Engineering in four snowbelt states examined the safety impacts of salt-based winter maintenance. The study documented an overall accident reduction of 85% and an even greater reduction in injury accidents, 88.3%.³

1.2.

Snowstorms Can Disrupt Economic Activity

As in the link of winter maintenance to traffic safety, studies have documented the vital economic role of clearing roads of ice and snow. Ice and snow also cause higher fuel cost as cars lose traction and spin their wheels to travel a given distance. A car that normally gets 25 miles per gallon may get only 15 mpg on a slippery road.⁴ Snow and ice storms have significant economic and social consequences that are tempered by winter programs designed to keep roads operable. Failure to get snowplows out and salt on the roads during a single day of a winter storm costs almost three times more in lost wages than the total annual costs for snowfighting.⁵

In just 12 states, this study found that \$526.4 million a day in federal, state and local tax revenues would be lost if impassable roadways paralyzed the region. This is more than the \$518.7 million spent by these twelve states for the entire winter season on snow and ice control to keep the roadways mobile and safe.⁶ Lost taxes are not the biggest economic hit to these states, according to the study. In addition, a crippling snowstorm costs \$1.4 billion per day in unearned wages and \$600 million per day in lost retail sales. To show how these losses could quickly multiply with each snowstorm, in the Chicago area, a normal winter averages 20-30 snowstorms requiring winter maintenance, and in New York State there are 40 average snowstorms statewide.

Even these dramatic figures are conservative. Not covered by the Standard & Poor's DRI study were factors such as vehicle crashes - fatalities, injuries and property

³ Kuemmel, David A. and Hanbali, Rashad M. 1992. *Accident Analysis of Ice Control Operations*. Third International Symposium on Snow Removal and Ice Control Technology, Sept. 14-18.

⁴ Hanbali, Rashad M. 1994. "Economic Impact of Winter Road Maintenance on Road Users," *Transportation Research Record* 1442.

⁵ The Economic Costs of Disruption from a Widespread Snowstorm. Standards & Poor's DRI, November 23, 1998.

⁶ Salt Institute Winter Maintenance Expenditures Survey of Twelve State Departments of Transportation and Provincial Ministers of Transportation, 1998.

damage, and increased health and insurance costs. These very real costs of inadequate winter maintenance were beyond the scope of this study.

The new analysis confirms other earlier studies of economic disruption. In 1996, Standard & Poor's DRI calculated that the Blizzard of '96 cost the Eastern states as much as \$10 billion in lost production and \$7 billion in lost sales for 4 days of being shut down, losses caused by the fact that people could not get to the store or to work. First Union Corp. estimated the same blizzard cost, measured in lost goods and services produced by factories, offices, shops, and other enterprises at about \$4.8 billion per day in the Northeast corridor of the U.S. from Virginia to Massachusetts.⁷

We can't prevent snow and ice, but we can prevent much of the economic calamity they can cause. Winter storms may be unpredictable and unique, but investments in professional snowfighting can keep snow- and ice-storms from paralyzing local economies, keeping children home from school and preventing emergency vehicles from making their lifesaving trips. Good winter maintenance keeps the roads open and saves lives. It is possibly the single most cost-effective investment of our highway tax dollars, returning at least \$60 in benefits for every dollar spent.

1.3.

Why Salt Works Best

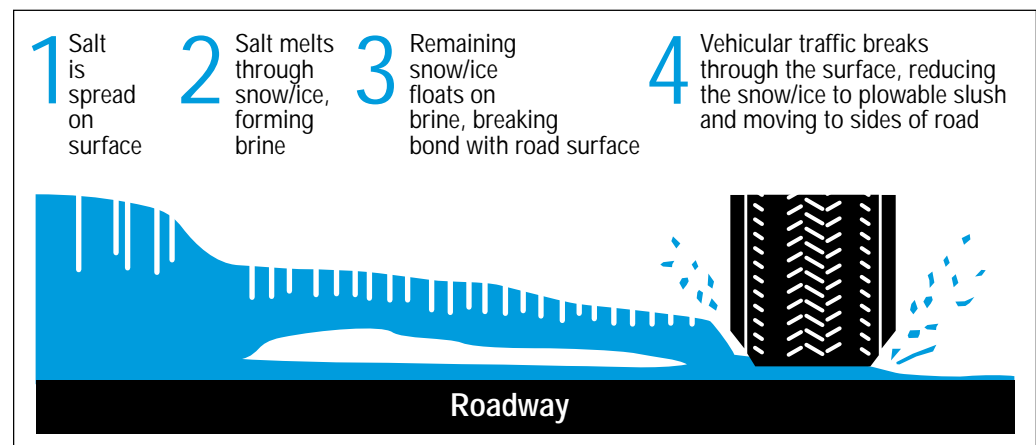
Most ice storms and snowstorms occur between 20° F and 32° F. Often after the storm breaks, high pressure systems move in and temperatures plummet, sometimes to well below freezing. So, it is important to apply salt early during the storm when salt will be most effective as a melting agent and will prevent ice and hard pack from bonding to the pavement.

The melting action of salt forms brine at the ice pavement interface. Brine prevents water from freezing into ice and bonding to the pavement and destroys the bond between ice and pavement. Once bonded to the pavement, ice cannot be removed by plowing without damaging the road surface or plowing equipment. Salt is used because it lowers the freezing point of water. If not applied before the storm as an anti-icing treatment to prevent a bond between ice and pavement, salt is usually applied as a deicer in conjunction with plowing because it will penetrate snow and ice left on the pavement. Salt must sometimes be used alone when there is insufficient snow accumulation to permit plowing. Often, salt is applied with liquid salt brine or pre-wet with other melting agents both to prevent the salt from bouncing off the roadway surface and to speed its melting effectiveness. The action of vehicle tires, combined with salt, will break up hard snow and ice, and gradually move it toward the pavement's edge.

⁷ Faiola, Anthony and Behr, Peter. Jan. 1996. "All That White Is Putting Cities, Businesses in the Red," *Washington Post*.

Highway agencies report that deicing salt is most effective at temps above 12° F (-11° C) but it continues to melt ice and snow, although at a slower rate, to temperatures approaching the eutectic temperature of -6° F (-21° C). Calcium chloride and magnesium chloride, which melt ice better at much lower temperatures, can be added to deicing salt for more rapid and effective melting when the temperature really dips. Why not use calcium chloride or magnesium chloride all the time? Because they are far more expensive than sodium chloride^{8 9}.

Figure 1: Salt/Brine Action on Road Surface



1.4.

Other Materials (Should) Have Limited Application

Abrasives

Sand and other abrasives have been used in an attempt to avoid perceived environmental effects of salt. However, abrasives are inert substances that provide limited traction. Abrasives are not melting agents. They must be used in large quantities and applied frequently, making abrasives more expensive than salt in terms of material and manpower. Salt is frequently added to abrasives to prevent freezing. After years of experience, for example, the City of Milwaukee, WI concluded:

“... Although the use of abrasives like sand instead of salt can be effective in rural areas and smaller communities, heavy traffic volumes in urban areas quickly pound down and bond untreated snow into hardpack that is extremely difficult to remove. It takes four to seven truckloads of abrasives to treat the same number of lane miles as one truckload of salt, and abrasives must be reapplied frequently. Sand builds up in catch basins and sewers, necessitating expensive cleanup.”¹⁰

⁸ *The Use of Selected Deicing Materials on Michigan Roads: Environmental and Economic*. Public Sector Consultants, Inc., Michigan Department of Transportation, Dec. 1993.

⁹ “Characteristics of Common Chemicals,” Iowa Winter Training Expo, October 8-9, 1997.

¹⁰ Milwaukee’s Salting Policy, from website <http://www.mpw.net/Pages/salt.htm>, downloaded 7/23/03.

After natural melting has occurred, abrasives create after-the-storm hazards. On a dry surface, abrasive materials can become a spinning-skidding hazard until road crews remove it. Windshield damage from airborne particulates is 365% higher in areas using sand and abrasives instead of salt. In Denver, Colorado, annual claims were \$27.1 million, and claims reached \$59.6 million throughout the entire state.¹¹ A build up of abrasives can create problems such as unhealthy dust, smothered roadside vegetation, silted waterways, plugged storm drains, and costly Spring clean-up costs.¹²¹³¹⁴ This led an environmental advocacy group to conclude:

“The main disadvantage associated with abrasives is their lack of staying power. When applied to heavily traveled areas, sand tends to be kicked off the roads. Therefore, it must be reapplied more frequently than road salt. Sedimentation caused by sand run-off into lake and riverbeds and roadside drainage ditches can create environmental problems which require occasional dredging. ...”¹⁵

Another study by the Marquette University research group determined a safety benefit:cost ratio 15 times greater when using salt than using salt/abrasive mixtures for winter highway maintenance. Using salt to restore safe driving conditions pays for itself at least 10 times faster than using a salt/abrasive mixture. On 2-lane roads, salt paid for itself in the first 25 minutes after achieving bare pavement, while using salt/abrasive mixtures did not pay for itself in the 12 hours after the period studied; for freeways, the payback required only 35 minutes for salt compared to six hours for salt/abrasive mixtures.¹⁶

Other chloride deicers

The most popular “alternatives” to common salt (sodium chloride) are the other chloride salts. Calcium chloride and magnesium chloride are used to melt snow and ice more quickly at lower temperatures. They are often combined with salt to make a more effective deicing mixture. They cost more and also contribute chloride ions to

¹¹ Deicing Salt, Corrosion and Our Environment. *Salt & Highway Deicing Newsletter*, Vol. 34, No.2, Fall 1998.

¹² Environmental Protection Agency, “Clean Air Act Approval and Promulgation of State Implementation Plan for Colorado; Denver Nonattainment Area PM10 Contingency Measures,” 61 *Federal Register* 185:49682-49684 (Sept. 23, 1996).

¹³ The Contribution of Road Sanding and Salting Material on Ambient PM10 Concentrations. *Proceedings of an International Specialty Conference* Jointly Sponsored by Air & Waste Management Assn. and the U.S. Environmental Protection Agency, 1995, pp. 161-188.

¹⁴ Brant, Lynn. “Winter Sanding Operations and Air Pollution.” Montana Department of Health and Environmental Science, *Public Works* for Sept. 1972.

¹⁵ “Where Streets Are Paved with Salt”, *Lake Michigan Monitor*, Lake Michigan Federation, 59 E. Van Buren St., Suite 2215, Chicago, IL 60605, (312) 939-0838, Winter 1992-93 p.3.

¹⁶ Kuemmel, David, “Accident Analysis of Ice Control Operations,” Transportation Research Board’s Fourth International Symposium on Snow Removal and Ice Control, August, 1996.

the environment, but they enjoy operating advantages in certain storm conditions as can be seen in the following table:

Table 1 – Ice Control Chemicals

Deicing Chemical	Eutectic Temp. (F)	Concentration At Eutectic (%) ¹⁷	Cost Comparison
Calcium Chloride	-67	29.8	7x
Calcium & Sodium Formate	+11	32.6	17x
Calcium and Magnesium Acetates	+5 / -22	44 / 31	35x
Ethylene Glycol	-60	60	28x
Magnesium Chloride	-28	21.6	7x
Methanol	-144	100	10x
Potassium Chloride	+13	19.5	4x Greater
Propylene Glycol	-71	60	28x
Sodium Chloride	-6	23.3	1
Urea	+11	32.5	7x

As Table 1 shows, some organic chemicals have also been used to melt snow and ice. Organics melt ice more slowly and at a higher working temperature range. They are chosen to avoid using the chloride ion although many “alternatives” are designed to be mixed with chlorides, enhancing their melting effectiveness. Organics also impose (different) environmental stresses and cost significantly more than salt.

Urea, a fertilizer, adds nutrients to surface water and hastens eutrophication that also reduces available oxygen. Calcium magnesium acetate (CMA) can also reduce available oxygen.^{18 19 20 21 22} Recent research involving liquid CMA and a few other

¹⁷ The point in the sodium chloride-water phase diagram indicating the composition and temperature of the lowest freezing point of the system. (See: Parker, Sybil P. ed. 1989 McGraw-Hill Dictionary of Scientific and Technical Terms, Fourth Edition; and Kaufmann, Dale W. ed. 1960. Sodium Chloride, The Production and Properties of Salt and Brine. Reinhold Publishing Corp.)

¹⁸ Ernst, Donald D., Demich, Gary and Wieman, Tom. Calcium Magnesium Acetate Research in Washington State, Transportation Research Record 1019 pp.8-12.

¹⁹ Comparing Salt and Calcium Magnesium Acetate. *Transportation Research Board Special Report 235*, 1991.

²⁰ Environmental Evaluation of Calcium-Magnesium Acetate (CMA), Federal Highway Administration Technical Report RD-84/094, June 1985, pg. 2.

²¹ Environmental Monitoring and Evaluation of Calcium Magnesium Acetate (CMA), “...Effects of CMA on Surface Water Quality,” National Cooperative Highway Research Program Report 305, Transportation Research Board, National Research Council 1988, 161 pages, pg. 2.

²² McCrum, Ron L. Dec. 1998. Calcium Magnesium Acetate and Sodium Chloride as Highway Deicing Salts, A comparative Study, Michigan Department of Transportation, Materials and Technology Division, P.O. Box 30049, Lansing, Michigan 48909, pp. 25-28.

liquid deicers indicated high biochemical oxygen depletion levels meaning these alternatives were more toxic to fish than salt brine.²³ As the search continues for an environmentally-friendly alternative to salt, careful studies are required to compare these proposed substitutes with the well-understood impacts of highway salt.

1.5.

Salt is the Sensible Deicer

Alternatives to salt have been tested, but none has proved completely satisfactory. The best way to satisfy the demand for wintertime mobility and safety is to determine salt use with regard to the site-specific environmental situation. The Salt Institute has been working since 1972 to achieve sensible salt use by encouraging training for highway personnel and disseminating the latest research and information.

²³ Guthrie, Thomas F. and Larson, Don. June 2001. "Liquid Deicers and the Environment: A summary of a 2 year laboratory & field study of all liquid Deicers in British Columbia," presented at the Pacific Northwest Snow Conference.

2. Road, Bridge and Vehicle Corrosion

Of all “environmental” impacts, the greatest costs are associated with chloride-accelerated corrosion of man-made structures and vehicles. By comparison, impacts on water, vegetation and wildlife are relatively small.

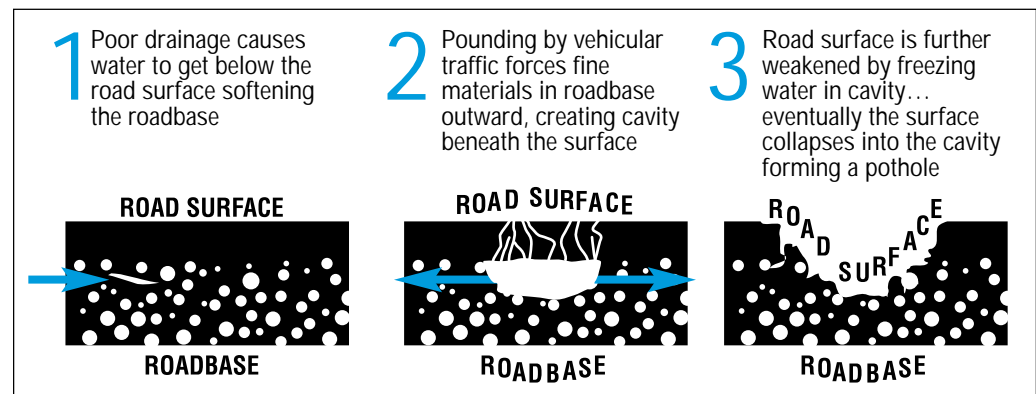
2.1.

Roads

Roads and highways can be constructed to withstand the use of deicing salt. High quality, air-entrained concrete with corrosion-resistant reinforcing steel allows extended design lifetimes for highway structures. Roadway surfaces may also be treated to inhibit the ingress of the chloride ion.

Contrary to popular belief, potholes that plague motorists in early spring are not caused by deicing salt. Potholes are the result of water entering the road base below the concrete or asphalt pavement surface. These weak spots can't support traffic during winter/spring freeze-thaw cycles, and result in structural failures.²⁴

Figure 2: Steps to Pothole Formation



Poor drainage allows water to penetrate into the base or sub-grade where it weakens the pavement’s support structure. Repeated pounding by heavy trucks and car tires causes localized liquefaction, dispersing the “fines” (finer graded materials) out with the water, thus leaving a void that eventually collapses. If water freezes in these voids, it expands and forces the pavement upward, causing cracking and increased water penetration. As the ice thaws, traffic passing over the weakened pavement causes it to flex and finally collapse. The pieces of broken pavement are forced out of the weak spot by the action leaving an open pothole.

²⁴ Berlin, Marcus and Elizabeth Hunt, Oregon DOT, Asphalt Concrete Patching Material Evaluation, Interim Report, SR 458, June 2001, http://www.odot.state.or.us/tddresearch/reports/concrete_%20patch.pdf.

2.2.

Bridges

Corrosion of bridge deck reinforcing steel has been of serious concern. New technologies and designs are minimizing this problem. Still, chlorides accelerate the corrosion of steel caused by moisture and oxygen coming into contact with bare steel. The exposed steel supports of most bridges are protected with coating systems and, if well maintained, protect the exposed steel from serious corrosion. The most serious concerns are for bridges near seacoasts, particularly in humid areas like the Gulf coast.²⁵

The greater problem lies below the surface, with corrosion of reinforcing steel in concrete bridge decks. Cracks and other openings in the deck pavement surface allow moisture, oxygen and chloride ions to attack the steel rebar. All new bridges today are constructed with corrosion-resistant rebar to keep moisture, oxygen and chloride ions away from steel. Bridge deck designs now require high quality air-entrained, high density concrete, with adequate cover (2 inches or more) over the reinforcing steel. Air-entrainment means that thousands of minute air bubbles are purposely trapped in the concrete and allow it to expand and contract during the freeze-thaw cycle without cracking.

Corrosion damage in older bridges can be halted with cathodic protection systems. Corrosion is caused by a flow of electrons set in motion when an electrolyte like salt and water contacts steel. The cathodic protection system sends a low-level reverse electrical current through the bridge deck and counters the flow of electrons. Even if corrosion has been underway for some time, cathodic protection can stop it cold. Cathodic protection is used in new bridge construction to prevent chloride ingress. Treatments have also been devised to remove chlorides from chloride-impacted bridges.²⁶

Proper maintenance and operation of bridges is necessary to protect against corrosion. Bridge surfaces, exposed from both above and below to freezing temperatures freeze before adjacent pavement. Newer bridges sometimes incorporate automatic systems to spray deicing liquids on the bridge deck when sensors detect moisture at freezing temperatures. This makes it even more important that drain systems on bridges be checked to make sure they are open and running, assuring that once its ice-melting task is complete, the brine solution will not remain on the bridge deck.

²⁵ “Interim Conclusions, Recommendations, and Design Guidelines for Durability of Post-Tensioned Bridge Substructures” Research Report 1405-5, Center for Transportation Research, The University of Texas at Austin, 1999, p. 12. http://216.239.37.104/search?q=cache:PYrmohHmSwAJ:www.utexas.edu/research/ctr/pdf_reports/1405_5.pdf+%22rebar+corrosion%22+and+%22Gulf+coast%22&hl=en&ie=UTF-8

²⁶ “Chloride Removal Implementation Guide,” Strategic Highway Research Board, National Academy of Sciences, 1993; <http://gulliver.trb.org/publications/shrp/SHRP-S-347.pdf>

2.3.

Vehicles

Until the past decade, vehicle corrosion was the most costly impact of using highway salt. Vehicle manufacturers have engineered corrosion resistance into their cars and trucks using improved vehicle design and new non-corrosive materials like plastics, zinc-coated steel, improved paints and anti-rust coatings. These have all served to greatly increase the life span of the automobile. "...Some models nearly manage to avoid corrosion completely, by a combination of good construction and materials, together with a careful application of anti-rust agent and adhesives, penetrating and covering crevice surfaces."²⁷ Thirty years ago, spurred by oil embargoes, automakers discovered that plastics make cars lighter and more energy efficient and began incorporating plastics into automobile components such as bumpers, fenders, doors, safety and rear-quarter windows, headlight and sideview mirror housings, trunk lids, hoods, grilles and wheel covers. Plastics reduced the weight of the average passenger car built in 1988 by 145 pounds, saving millions of gallons of gas each year and the energy equivalent of 21 million barrels of oil over the average lifetime of those cars.²⁸ By the 1993 model year, over 250 pounds of plastics were used in the average vehicle. Futurists²⁹ predict the average car will be a modular 2-piece design of a chassis/drive train/power unit and a body/passenger compartment. Made of plastic, the average car will be built for a 20-year service life by the middle of the 21st century.³⁰ Anti-corrosion warranties are increasing in length every year, with present coverage up to 5 years or 100,000 miles and even unlimited-mileage and 12 years in some cases.³¹ See Table 2.

Older model cars without this assembly line protection can still increase their resistance to corrosion. Taking your car through a car wash once a week during the winter weather will also go a long way towards preventing rust problems.

Due to ongoing improvements by auto manufacturers, auto corrosion is at an all-time low. Less than 1% of 6-year old (1990) vehicles show signs of rust perforation.³² The average cost of corrosion protection has decreased from \$500 to \$150 (2000). The percentage of the GDP (Gross Domestic Product) due to motor vehicle corrosion has decreased from 0.37 percent in 1975 to 0.27 percent in 1998.³³ See Figure 3.

²⁷ CORROSION98 – Evaluation of Corrosion Protection on Recent Model Vehicles. NACE International, Paper 741, 1998.

²⁸ Society of the Plastics Industry website, <http://www.plasticsindustry.org/industry/2118.htm>, downloaded March 23, 2003.

²⁹ Snyder, David, www.the-futurist.com.

³⁰ Burns, Lawrence D., McCormick, J. Byron, and Borroni-Bird, Christopher E., *Vehicle of Change*, Scientific American, October, 2002.

³¹ Report FHWA-RD-01-156, Motor Vehicles, Appendix N., Johnson, Joshua T., 2000. <http://www.corrosioncost.com/transportation/motorvehicles/index.htm>

³² This compares to 96% of six-year old cars with rust perforation measured in a 1976 NACE study. Ostermiller, Michael R., Piepho, Lee L., and Singer, Larry, 1996, "Advances in Automotive Resistance" presented at the Fall meeting of the Salt Institute, p. 10.

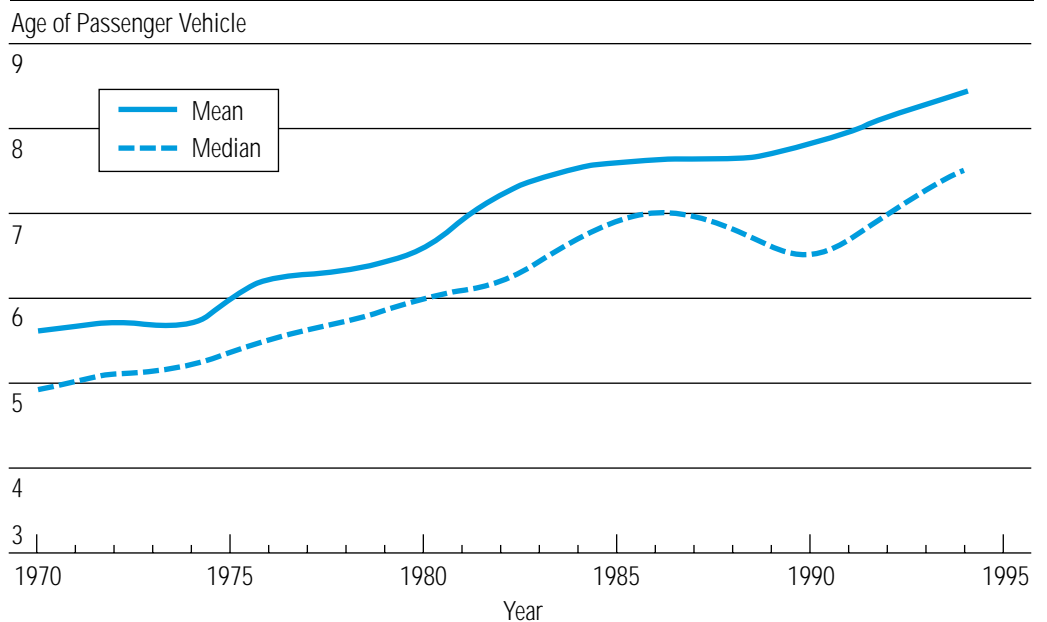
³³ Op cit. Johnson, Joshua T.

Table 2 – Length of Corrosion Perforation Warranties on Model Year 2000 Automobiles Sold in the United States

Make	Length of Warranty		Make	Length of Warranty	
	Years	Miles		Years	Miles
Acura	5	Unlimited	Lincoln	5	Unlimited
Audi	12	Unlimited	Mazda	5	Unlimited
BMW	6	Unlimited	Mercedes-Benz	4	50,000
Buick	6	100,000	Mercury	6	Unlimited
Cadillac	6	100,000	Mitsubishi	7	100,000
Chevrolet	6	100,000	Nissan	5	Unlimited
Daewoo	5	Unlimited	Oldsmobile	6	100,000
Dodge	5	100,000	Plymouth	5	100,000
Ford	5	Unlimited	Pontiac	6	100,000
GMC	6	100,000	Porsche	10	Unlimited
Honda	5	Unlimited	Saab	6	Unlimited
Hyundai	5	Unlimited	Saturn	6	100,000
Infiniti	7	Unlimited	Subaru	5	Unlimited
Isuzu	6	100,000	Suzuki	3	100,000
Jaguar	6	100,000	Toyota	5	Unlimited
Kia	5	100,000	Volkswagen	6	Unlimited
Land Rover	6	100,000	Volvo	8	Unlimited
Lexus	6	Unlimited			

1 mi = 1.61 km

Figure 3 – Average Mean and Median Ages of Passenger Vehicles from 1970 to 1994³⁴



³⁴ IBID.

3. Roadside Vegetation

All materials used in winter maintenance have the potential to harm the natural environment. The most visible impacts are seen on roadside trees and shrubs.

3.1.

The Problem

Roadsides are a stressful environment for vegetation. They are always man-made environments, created when the roadway was constructed. Often, soils are compacted. The exposure to wind and traffic – and toxic contaminants deposited by that traffic – make roadsides a dry and harsh environment for plants. Salt can add to that stress. High concentrations of chloride can interfere with a plant’s absorption of moisture from soil and cause browning or burning of leaves. High sodium concentrations may affect plant growth by altering soil structure, permeability and aeration. The additional harm to vegetation which salt may inflict depends on six characteristics: the amount of salt, type of soil, total precipitation, distance from the roadway, wind direction, and plant species. In short, the impacts are highly site-specific.

Assessing the environmental impact of salt requires an understanding of the concentrations and durations of the exposures and the types of plants that are exposed. Different soils tolerate sodium differently. Different plant species tolerate chlorides differently. Different climates affect the frequency and duration of wintertime exposures. Exposures vary by season from the high chloride loadings of winter and spring to the low exposures during summer and fall. Elevated soil levels of sodium and chloride decrease over the growing season due to leaching of the ions by rainfall and run-off. Soil measurements in summer and fall indicate a decrease to background soil levels following elevated spring levels.³⁵ Recent studies have indicated that some plants under stress are able to fight off diseases better when salt application is added than the same species of plants not exposed to salt.³⁶ Again, these variables differ from one locale to another.

Different rates of precipitation affect the saline concentration of the runoff. The Federal Highway Administration has studied highway runoff and concluded: “highway runoff is generally cleaner than runoff from buildings, farms, harbors, or other non-point sources...it is important to recognize that highway runoff need not be and most often is not a serious problem.”³⁷

After more than 50 years of salting, it is *theoretically* possible that sodium buildup in roadside soils may indirectly affect plant growth. A solution would be to chemically amend excess salinity from the soil by adding gypsum or anhydrous ammonia.

³⁵ Hofstra, G. and Smith, DW. 1984. The effects of road deicing salt on the levels of ions in roadside soils in southern Ontario. *J. Environ. Manage.* 19:261-271.

³⁶ Elmer, W. H., Sodium Chloride Can be used to Control Plant Disease, <http://www.saltinstitute.org/elmer.html>

³⁷ Federal Highway Administration Technology Brief, “Is Highway Runoff A Serious Problem?”, accessed 3/23/03 at: www.tfhr.gov/hnr20/runoff/runoff.htm , 8 pages.

Currently, gypsum treatments appear to be the most efficient and least expensive reclamation method.³⁸

Some general observations about the ten-year impact of deicing salt on roadside vegetation and soil were made in the study report:

Although there was a general cumulative trend of sodium ions, it was far below sodium levels that are considered damaging.

Chloride ions leached out of the soil fairly rapidly and thus had no cumulative effect.

The overall effect diminished as distance from the roadway increased and became insignificant beyond 80 feet.

Potassium chloride and urea are common fertilizers that are sometimes used for roadway or sidewalk deicing. They are commonly thought of as safe products to use around vegetation, but application rate determines vegetative damage and melting ice usually requires dosages far greater than recommended fertilizer application rates.

Another U.S. Geological Survey and Ohio Department of Transportation study underway, halfway through a 10 year study with an accumulation of 5,000 water samples, is reported by the *Dayton Ohio News* to find that “Road salt and other deicing chemicals appear to have little, if any, long-term impact on the environment.” “Several of the sites have shown evidence of salt entering the groundwater but not at high concentrations,” notes a USGS official, conducting the study for ODOT.³⁹

3.2.

Salt-Proofing the Roadside Environment

Sensible Salting can reduce the salt loadings to the roadside environment, but key contributions can be made by good engineering so that roadside environment to be salt-tolerant. Just as car manufacturers have “salt-proofed” their vehicles, highway agencies can “salt-proof” the roadside environment. The roadway right-of-way is not a natural environment; it is engineered to create a roadway. Good highway engineering practice channels runoff to facilitate drainage and prevents adverse environmental impacts. Trees adjacent to arterial roadways or major highways are generally removed as safety hazards. Replacing grass, shrubs and trees (where they can be located safely) involves a choice. Environmentally-conscious highway planners choose species which can tolerate the severe operating conditions of the roadway environment they are

³⁸ Suarez, Donald, “Sodic Soil Reclamation: Model and Field Study”. USDA, July 18, 2000. <http://www.nal.usda.gov/ttic/tektran/data/000011/71/0000117105.html>

³⁹ Jones, Allison L. and Sroka, Bernard N. “Effects of Highway Deicing Chemicals on Shallow Unconsolidated Aquifers in Ohio, Interim Report, 1988-93, U.S. Geological Survey, Aug. 6, 1997.

creating. Of course, all the adverse impacts of roadways diminish with distance from the travelway, with lesser impacts recorded up-hill and up-wind as well.

There are species of plants, trees and shrubs that have a high salt tolerance (see Table 2) and other species which have a very low salt tolerance. Oaks, locusts, Scotch elm, Russian olive, hawthorne, and silver and gray poplars all have high resistance to salt. On the other hand, sugar and red maples, Lombardy poplar, black walnut, and rose and spirea bushes would be poor choices for locations exposed to salt runoff and spray from deicing operations. The United States Department of Agriculture Research Service has done extensive testing on the salt sensitivity of 13 different pine species.⁴⁰ Seedlings sprayed with salt solutions were compared with control groups sprayed with distilled water. Three of the 13 species did very well even under extremely salty conditions, which were saltier than the worst roadside conditions—*Pinus thunbergii* and *P. nigra* showed an 89 percent survival rate and *P. ponderosa* had a 95 percent survival rate. The noted survival rate is % of control - so 100% would be “normal” under lab conditions.

Table 3 – Relative Salt Tolerance of Trees and Ornamentals

Low Salt Tolerance	Moderate Salt Tolerance	Good Salt Tolerance
Filbert	Birch	Mulberry
Compact boxwood	Aspen	Apricot
Sugar maple	Cottonwood	White oak
Red maple	Hard maple	Red oak
Lombardy poplar	Beech	Hawthorne
Speckled alder	White spruce	Tamarix
Sycamore maple	Balsam fir	Squaw bush
Larch	Douglas fir	Russian olive
Black alder	Blue spruce	Scotch elm
Italian poplar	Texas Privet	White poplar
European beech	Xylosma	Osier willow
Rose	Pyracantha	Black locust
Pineapple	European black current	Gray poplar
Viburnum	Siberian crab	Silver poplar
Arctic blue willow	Boxelder maple	English oak
Spirea	Japanese honeysuckle	White acacia
Multiflora rose	Eastern red cedar	Bottlebush
Winged euonymus	Green ash	Oleandar
Barberry	Ponderosa Pine	Common matrimony pine
Little leaf linden	Golden Willow	
Black Walnut	Lantana	
	Spreading juniper	
	Arbor vitae	
	Silver buffalo berry	

⁴⁰ Townsend, A.M. and W.F. Kwolek. 1987. Relative susceptibility of thirteen pine species to sodium chloride spray. *J. Arbor.* 13:225-228.

Table 4 – Salt Tolerance of Grasses and Legumes

Sensitive	Moderately Tolerant	Tolerant
White Dutch clover	White sweetclover	Alkali sacaton
Meadow foxtail	Yellow sweetclover	Salt grass
Alsike clover	Perennial ryegrass	Nuttall alkali grass
Red clover	Mountain brome	Bermuda grass
Ladino clover	Harding grass	Tall wheatgrass
Burnet	Beardless wild rye	Rhodas grass
	Strawberry clover	Rescue grass
	Dallis grass	Canada wildrye
	Sudan grass	Western wheatgrass
	Hubram cover	Tall fescue
	Alfalfa	Birdsfoot trefoil
	Orchard grass	
	Blue grama	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oatgrass	
	Milkvetch	
	Sourclover	

4. Wildlife and Fish

Salt impacts not only plants, but animals as well. Salt is an “essential nutrient” – life depends on it. Many species of fish have the ability to exist in salt water, i.e., the oceans and seas, where the concentrations of salt exceed 3 percent. Given access to water, animals will not overindulge their inherent “hunger for salt.” Salt licks are widely used to give domesticated and wild animals free access to sodium chloride.

4.1.

Salted Roads and Animal-Car Collisions

There is little scientific information about vehicle-wildlife collisions related to the presence of highway salt along the roadside.⁴¹ Some have argued that animals’ need for salt attracts wildlife to salted roads in the wintertime, increasing vehicle crashes. It is difficult to gauge the motivation of wild animals; we must observe their behaviors. According to the Wisconsin Department of Transportation, the highest incidence of motor vehicle-deer crashes (38 percent) occur in October-November and the second highest period (16 percent) occur in May or June.⁴² Obviously, these are not months when highway salt is used on the roads. A survey of wildlife mortalities due to vehicle accidents in Canadian national parks confirmed that the majority of kills occurred in spring or fall, not when salt is applied to the road.⁴³

A study by the Michigan Department of Natural Resources (Langenau, et al. 1997)⁴⁴ found that most wildlife-vehicle collisions occurred on paved local roads rather than Interstate Highways. A higher frequency of deer-related accidents are reported where roadsides are planted with foods deer prefer, “such as rye, alfalfa and clover.” Mowing keeps much of this roadside vegetation green and lush, which attracts deer. The authors said half of all deer-vehicle collisions in Michigan occurred in autumn during the breeding season for deer. A second peak occurs in the spring when deer move to summer range from winter concentration areas. A 1998 Wisconsin Safety Council publication⁴⁵ refers to a recent study by the Wisconsin Department of Transportation⁴⁶ stating deer-vehicle collisions peak during the October-November “deer breeding or rut” season, which is also the state’s deer hunting season.

⁴¹ The best single source is <http://www.deercrash.com>, particularly its evaluation of the potential for “deicing salt alternatives” to reduce the incidence of vehicle-wildlife collisions. See: <http://www.deercrash.com/Toolbox/CMToolboxDeicingSaltAlternatives.pdf>.

⁴² Thompson, Charles H., Secretary, Wisconsin Department of Transportation, Nov. 1998.

⁴³ Damas and Smith, consultants, 1982. Wildlife mortality in transportation corridors in Canada’s National Parks, Volume I & II. DSL Consultants Ltd. Ottawa.

⁴⁴ Langenau, E. et al. eds. 1997. Deer-Vehicle Accidents in Michigan: a Task Force Report. Michigan DNR Wildlife Division Report No. 3072. October 15.

⁴⁵ 1998. Deer Crashes to Peak in Oct/Nov. Wisconsin Council of Safety.

⁴⁶ McClain, T. and Kunkel, M. Motor Vehicle-Deer Crashes in 2001. Wisconsin Department of Transportation. Bureau of Transportation Safety

4.2.

Salt Tolerance in Fish

Healthy fish need salt too. Aquaculturists use salt as a medication to combat certain fish diseases and add salt to the water when they transport freshwater fish.^{47 48} But even a good thing can be overdone. Freshwater fish usually tolerate high salinity well. Again, exposure is a combination of concentration and duration. When chloride enters a stream as runoff, it creates a chloride “pulse” which will travel down and out of the stream in a relatively short time (i.e., days to weeks, depending on the width, gradient and length of the stream) because the water is constantly flowing through the stream.⁴⁹ Different fish species exhibit a range of tolerance to different salts according to the time of exposure, salt concentration, temperature and character of the test water.⁵⁰ The short-term effects of salt on channel catfish (*Ictalurus punctatus*), bluegill sunfish (*Lepomis macrochirus*), smallmouth bass (*Micropterus dolomieu*), rainbow trout (*Oncorhynchus mykiss*), yellow perch (*Perca flavescens*), fathead minnows (*Pimephales promelas*), brown trout (*Salmo trutta*), lake trout (*Salvelinus namaycush*) and walleye (*Stizostedion vitreum*) survive well at test conditions involving a concentration of 10,000 mg/L NaCl for 24 hours (with water temperatures of 12° C and water hardness at 140 mg/L CaCO₃). All species showed 0% mortality, with the exception of smallmouth bass, which had 3% mortality.⁵¹

⁴⁷ Swann, L. and Fitzgerald, S. 1993. Use and Application of Salt in Aquaculture. University Extension. University of Missouri-Columbia. <http://muextension.missouri.edu/explore/miscpubs/mx0393.htm>

⁴⁸ Kapuscinski, Anne R., Gross, Mark L. and Woiwode, John. 2002. Information about the Diagnosis of Fish Diseases in the Upper Midwest. Minnesota Sea Grant. University of Minnesota. <http://www.seagrant.umn.edu/aqua/disease.html>

⁴⁹ Mayer, T., Snodgrass, WJ and Morin, D. 1999. Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments. Water Quality Res. J. Can. 34(4):545-574.

⁵⁰ Waller et al, 1996.

⁵¹ Ibid.

5. Human Health

Humans need salt to survive. Both sodium and chloride are essential nutrients. Most people easily obtain their minimum requirements. The physiological impacts of salt intake are among the most studied in medical science.

5.1.

The “Salt Hypothesis”

Undeniably, salt is involved in blood pressure. Sodium helps signal blood vessels when to tighten up or relax to keep blood pressure at the correct level. Back in the 1960’s and 1970’s, research into primitive peoples alleged a direct relationship between salt intake and population blood pressure, the so-called “salt hypothesis.”⁵² Because high blood pressure, “hypertension,” is a known risk factor for such cardiovascular events as heart attacks, public health authorities responded quickly urging moderation in salt intakes.⁵³ More recent research has documented no increase in risk of heart attacks based on salt intake levels and, in fact, further research has discovered other primitive peoples with high salt intakes and no hypertension.⁵⁴ Researchers now understand that not only is blood pressure important, but how drug or diet interventions lower blood pressure are also important – and that the important consideration is the ultimate health impact on individuals taking medication or changing their diets. Of the accumulating number of “health outcomes” studies of dietary sodium, none has identified a health benefit in the general population associated with sodium reduction.⁵⁵

5.2.

Drinking Water and Sodium

The amounts of sodium and chloride being consumed by humans in drinking water are rarely a significant source of either element so neither has a health standard.⁵⁶ Sodium concentrations above 20 mg/L are monitored to provide consumers information useful if they are placed by their doctors on medically-supervised low-salt dietary therapy. At 20 mg/L, regulations of the Food and Drug Administration would consider beverages “sodium free,”⁵⁷ US EPA has conducted several rulemakings designed to de-emphasize

⁵² Dahl, LK, 1960. Possible role of salt intake in the development of essential hypertension, in Bock, KD, Kottier, PT (eds): *Essential Hypertension*. Berlin, Springer-Verlag, pp 53-60.

⁵³ *Healthy People: The Surgeon General’s Report on Health Promotion and Disease Prevention*. 1979. U.S. Department of Health, Education and Welfare. Government Printing Office (Stock Number 017-001-00146-2).

⁵⁴ Hollenberg, Norman K. 1997. Aging, Acculturation, Salt Intake, and Hypertension in the Kuna of Panama. *Hypertension*; 29:171.

⁵⁵ These studies are cited at <http://www.saltinstitute.org/healthrisk.html>.

⁵⁶ “EPA believes that the contribution of drinking water to daily sodium intake is very small when compared to the total dietary intake and that short-term excursions beyond the benchmark values pose no adverse health risk for most individuals, including the majority of persons with hypertension.” 67 *Federal Register* 106: 28238 (June 3, 2002).

⁵⁷ 21 *Code of Federal Regulations* 101.61.

concern with sodium in drinking water,⁵⁸ and state citizen notifications have been abolished.⁵⁹

5.3.

Drinking Water and Chlorides

Some people can detect an unacceptable taste in water with chloride concentrations exceeding 250 mg/L. Though drinking water chloride levels rarely ever reached the 250 mg/L concentrations triggering concern for human palatability, long term trends show steady improvements in the environmental releases of chlorides. Water quality trends in the Great Lakes show a declining trend in chloride. A recent search of the literature shows that progress in reducing chloride discharges has so diminished their environmental impact in the Great Lakes that they are no longer mentioned in “the State of the Great Lakes” reports.⁶⁰

5.4.

Hexacyanoferrates

Humid conditions and precipitation cause salt crystals to “cake” or stick together. Salt producers add several anti-caking agents to highway salt and to table salt to keep them free-flowing. Among the most popular is sodium hexacyanoferrate(II). It is an FDA-approved food additive. Common names for the two most popular hexacyanoferrates, sodium hexacyanoferrate(II) and iron(III) hexacyanoferrate are yellow prussiate of soda or YPS and Prussian blue; other common names are sodium ferrocyanide and ferric ferrocyanide. This has led to confusion with some people anxious about the safety of these additives because free cyanide and hydrogen cyanide are highly toxic. Hexacyanoferrates (or ferrocyanides) are not toxic; they are chemically-stable metal complexes and completely non-toxic.^{61, 62} To make the point, one study gave rats a solution of 20,000 mg/L ferric ferrocyanide in drinking water for up to a total intake of 3,200 mg/kg (bw)/day for 12 weeks and the rats showed no signs of toxicity.⁶³ In highway salt, concentrations range between 20 and 150 mg/L. Despite their threatening names, these stable, complex metal cyanides (YPS, $\text{Na}_4\text{Fe}(\text{CN})_6 \cdot 10\text{H}_2\text{O}$ and Prussian blue, $\text{Fe}_4[\text{Fe}(\text{CN})_6]_3$) should not be confused with highly toxic free cyanide (CN^- , hydrogen cyanide, HCN or simple metal cyanides, such as sodium cyanide, NaCN or calcium cyanide, $\text{Ca}(\text{CN})_2$).

⁵⁸ 60 Code of Federal Regulations 138, July 18, 2003.

⁵⁹ The Connecticut rules were not abolished, but changed. Previously, water customers with 20 mg/L sodium in their drinking water were advised that “Your water exceeds the maximum permissible level of sodium.” Now they are advised when sodium concentrations reach 28 mg/L that “If you have been placed on a low-sodium diet, please inform your doctor that your water has X mg/L sodium.” Other states (e.g. Massachusetts) did away with public notice requirements altogether.

⁶⁰ International Joint Commission. Seventh Biennial Report Under the Great Lakes Water Quality Agreement of 1978 to the Governments of the United States and Canada and the State and Provincial Governments of the Great Lakes Basin. Washington, DC and Ottawa, Ontario, March, 1994, 64 pp.

⁶¹ Meeussen, JCL, Keizer, MG and De Haan, FAM. 1992. Chemical stability and decomposition rate of iron cyanide (prussian blue) complexes in soil solutions. *Environ. Sci. Technol.* 26(3): 511-516.

⁶² Letts, Arthur. Effects of Sodium Ferrocyanide Derived from Road Salting on the Ecosystem. Presented to the Environmental Resource Group on Road Salts, Ottawa, Ontario, May 30, 2000.

⁶³ Dvorak, PM, Gunther, U, Zorn, and Catsch, A. 1971. Metabolisches Verhalten von kolloidalem Ferrhexacyanoferrat (II). *Naunyn-Schmiedeberg Arch. Pharmak.* 269: 48-56.

6. Sensible Salting - Safeguarding the Environment

Since environmental impact is related directly to exposure, one obvious means of reducing the risk of an environmental problem is to reduce the amount of salt applied to the roadway. Sufficient salt is required to produce the desired safety and mobility, the goal level-of-service. “Excess” applications add costs, but no further benefit. Since 1972, the Salt Institute has trained more than 100,000 American and Canadian snowfighters in Sensible Salting Seminars. The Salt Institute has a formal partnership with the nation’s Local Technology Assistance Programs (NLTAPA) to provide training materials for professional snowfighters. “Sensible Salting” is another way of saying: enough and no more. Professional snowfighters understand this principle and minimize salt applications while maximizing customer service.

6.1.

Just Enough and No More

The Institute’s Sensible Salting Program has been recognized for excellence in community relations, receiving the Silver Anvil Award of the Public Relations Society of America. The program’s two basic manuals, the *Salt Storage Handbook* and *The Snowfighter’s Handbook*, are available from the Institute; they have also been posted on the Institute’s website for free downloading: <http://www.saltinstitute.org/snowfighting>. This website also has other free materials (both publications and slide shows) designed for use by trainers in preparing equipment operators for winter and instilling the Sensible Salting philosophy.

6.2.

Proper Storage

Most environmental problems associated with highway salt result from improper bulk storage of salt by end users. Bulk storage is necessary because agencies need to have ready access to enough highway salt to meet their anticipated needs. Securing adequate re-supply during winter storms could be difficult, so the need for storage stockpiles is reasonable.

A half century ago, it was common practice to store highway salt outdoors, without protection from precipitation.⁶⁴ These practices led to problematic salt runoff leaching into surrounding soils, surface water and groundwater. Unprotected stockpiles also could lose 4 to 5% per year⁶⁵ of their salt by dissolution and leaching due to snow and rainfall.⁶⁶

⁶⁴ The use of selected deicing materials on Michigan Roads: Environmental and Economic Impacts. Michigan Dept. of Transportation, 1993, 105 pp.

⁶⁵ Hogbin, LE. 1966. Salt Loss due to Rainfall on Stockpiles used for Winter Road Maintenance. Road Research Laboratory. Ministry of Transport. RRL Report No. 30 (UK)

⁶⁶ Hart, JN. May 26-27, 1981. “An investigation of the quantity and quality of leachate from highway salt treated sand pile” in 5th Canadian Hydrotechnical Conference, Fredericton, New Brunswick, Vol. 1: 135-155.

This is unacceptable and easily corrected. The *Salt Storage Handbook* is the best resource for planning a salt storage facility. The principles of proper storage are that all salt should be covered, to prevent rain and snow from reaching it, either in a building or, if this is not feasible, by covering the stockpile with a waterproof covering, weighted and tied down. Salt should be stored on an impermeable pad, not directly on the ground. Asphalt is the most widely used material for pads, since salt has no effect on it. But concrete is sometimes used. It must be high quality, air-entrained and treated with proprietary sealers, linseed oil or asphalt type coatings to reduce chloride penetration, keep salt out and prevent scaling or spalling. There are hundreds of concrete storage facilities in use with no adverse effect. Finally, storage pads should slope to let water drain away and prevent run-on from adjacent terrain.

The Salt Institute annually selects the best storage facilities in North America and recognizes their achievement with its Excellence in Salt Storage Award.⁶⁷ For further details, visit <http://www.saltinstitute.org/39.html>.

6.3.

Application Guidelines

The Snowfighters Handbook and the Institute's online snowfighting materials help professional snowfighters know how much is "just enough and no more." This requires that snowfighters receive clear level-of-service expectations from their political policy-makers. They often use specialized weather forecasts or invest in local road-weather information systems to give them real-time readings of pavement temperature and precipitation. Then, they plan ahead what their salt application strategy will be for each of the five basic kinds of storms (which reportedly can have over 66,000 varying conditions affecting salt application rates). Before the snow flies, professional snowfighters calibrate each spreader unit so they know exactly how much salt is being discharged to the road. They also determine whether to apply the salt as a liquid brine to prevent an ice-pavement bond, to pre-wet the salt to speed its melting rate or to apply the salt dry in conditions like freezing rain. Sometimes, low temperatures will suggest addition of calcium chloride or magnesium chloride to the brine mixture or even, in extreme cases, as a substitute.

Timing is of crucial importance. Snowfighters either apply salt before or early in the storm to prevent ice from bonding to the pavement (called anti-icing), or later in the storm to destroy a bond that has already formed (deicing). Anti-icing preserves safe driving conditions with the lowest use of salt. Depending on traffic density and highway design, they determine the spreading pattern, using windrow applications on two-lane roads with few cars, a four-to-eight foot centerline application for major roads and full width spreading on multiple-lane pavements with medium to high traffic volumes.

⁶⁷ Excellence In Storage Award Application. Salt Institute, 2004.

Sophisticated snowfighters even factor in the wind, spreading salt on the upwind side of the road. Since salt brine will flow down and across a banked curve, they spread salt on the high side and let gravity do its work. Part of timing is prioritizing routes and assuring that salt is applied early with on and off ramps —safe roads are of little use if access ramps are hazardous.

With proper application, less salt is needed, an additional safety buffer for the environment.

7. Summary and Conclusion

Using highway salt involves trade-offs: reducing the risk of accident and injury to drivers and the economic consequences of a weather-related economic shut-down versus the risk of injury to roadside vegetation, wildlife and water quality. Fortunately, through Sensible Salting, the environmental downside can be mitigated while preserving the social and economic benefits of proper winter maintenance. “Use of road salt (sodium chloride) is both cost-effective and environmentally acceptable at current levels,” according to a study commissioned by the Michigan Department of Transportation.⁶⁸ The Transportation Research Board of the National Academy of Sciences agrees – salt will remain the deicer of choice when all the alternatives are examined. Used sensibly, salt is the best means of providing safe roads in winter.

⁶⁸ “Study Finds Road Salt Still Best De-Icer for Michigan Roads,” Michigan Dept. of Transportation, New Release, March 15, 1994.

