County of Nassau

DEPARTMENT OF PUBLIC WORKS

Nassau County Storm Water Management Program
Minimum Control Measure Six
Pollution Prevention/Good Housekeeping

Capital Project No. 82010

Task 4: Best Management Practices for Sand/Salt Use

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NASSAU COUNTY
STORM WATER MANAGEMENT PROGRAM
MINIMUM CONTROL MEASURE SIX
STORM WATER RUNOFF IMPACT ANALYSIS

TASK 4 - BEST MANAGEMENT PRACTICES FOR SAND / SALT USE

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1.0 INTRODUCTION

This task identifies potential adverse impacts to storm water runoff quality related to municipal snow and ice control activities, describes and evaluates existing management practices and recommends techniques to reduce the adverse storm water runoff quality impacts of winter maintenance operations in Nassau County.

Under the United States Environmental Protection Agency's (EPA's) Phase II Storm Water regulations, the approximately 5,000 communities around the country with populations under 100,000 are required to control their urban storm water discharges. The final EPA Phase II regulation requires that the owners and operators of municipal separate storm sewer systems (MS4s) develop and implement a storm water control program involving six minimum control measures (MCMs). These MS4s are required to develop and implement a Storm Water Pollution Prevention Program (SWPPP), including programs for:

- Public education and outreach on the impacts of storm water runoff;
- Public participation/involvement in developing and implementing storm water control programs;
- Detection and elimination of illicit and illegal connections to storm sewer systems;
- Control of runoff from construction sites disturbing more than 1 acre of land;
- Post-construction storm water controls or treatment from new developments and redeveloped sites; and
- Pollution prevention and good housekeeping practices as part of regular or routine operations and maintenance of storm sewer systems.

Each MS4 must identify Best Management Practices (BMPs) and measurable goals associated with each minimum control measure. An annual report on the implementation of the entire SWPPP must be submitted each year.

Minimum Control Measure (MCM) 6, Pollution Prevention/Good Housekeeping for Municipal Operations, addresses improvements to ongoing operations and maintenance (O&M)

activities and addresses adequate consideration of water quality concerns rather than flood/drainage (quantity/volume) considerations in managing urban storm water runoff. Thus, O&M programs need to be expanded to complement the other five MCMs by adding training and water quality items to maintenance activities, inspections, pesticide use, catch basin clean-outs, sewer/catch basin repairs and disposal of waste from cleaning storm water systems.

Additionally, the SWPPP activities implemented under MCM 6 should focus on the development of a program(s) that will reduce or eliminate the impacts of storm water pollution from open space maintenance, snow disposal, vehicle and building maintenance, land disturbances and storm sewer system maintenance during the permit term throughout the community.

This report addresses the County's winter maintenance activities (including sand/salt use) and suggests BMPs pursuant to the goals for MS4's under MCM 6 of the County's Storm Water Management Program. In conjunction with this report, the County has initiated the preparation of reports related to six other municipal operation and maintenance activities related to MCM 6 including:

- Evaluate daily operations at County Agencies (Department of Public Works, Parks/Recreation/Museums, Police and Sheriff's) and recommend generic storm water-related BMPs for each category;
- Prepare Storm Water Pollution Prevention Plans;
- Evaluate the current Integrated Pest Management Program (IPM) including its expansion County-wide and possible inclusion of rodent and mosquito control;
- Evaluate and prepare recommended changes to the County's standard specifications and drawings for Highways and General Engineering and Sanitation and Building Construction as well as front-end provisions for publicly bid construction contracts;
- Prepare a list of candidate sites for using storm water treatment devices for use at:
  - County-owned outfalls and facilities and
  - Other municipally owned outfalls and facilities to address impairments/water quality problems identified in the State's 303(d) list;

- Develop standard specifications and drawings for storm water BMPs related to catch basin inserts, inline devices and other similar measures.

This task of the report addresses key issues related to current County sand/salt use in winter maintenance operations and recommends a variety of actions/measures to be undertaken to reduce adverse quality impacts on urban storm water runoff while balancing safety and financing concerns.

County road networks are relied upon for transport to the workplace and other commercial activities, for recreation and leisure activities and for emergency and security services. The Nassau County Department of Public Works is responsible for maintaining 500 centerline-miles (2,000 lane-miles) of roadway in order to provide for safe and efficient transportation for road users. The safety, efficiency and beneficial uses of roads are sometimes compromised by snow and ice accumulation. Snow and ice accumulation can result in a number of highly visible consequences, including increased motor vehicle accident rates and corresponding damages to human health, property and wildlife.

The objective of winter road maintenance is to provide the traveling public with passable roads as much of the time as possible given the constraints of operational resources and the character of the storm. Safe winter roads depend upon maintaining sufficient traction between vehicles tires and the road to prevent skidding during vehicle operation and braking. Slippery conditions result from moisture freezing on the road during periods of precipitation when the road temperatures are below freezing. Highway deicing/anti-icing materials are used to minimize ice build-up on highways and roads to facilitate the safe flow of traffic during severe winter storms.

Administrators of winter maintenance programs are involved in a delicate balancing act, striving to achieve the highest possible level of service/safety on winter roadways while considering budgetary limitations and simultaneously trying to minimize adverse impacts to the environment. Additionally, the costs of winter maintenance operations are perceived differently from various stakeholder perspectives.

For instance, cost concerns of greatest importance to the residents of an MS4 may include:

- Emergency response
- Personal injury
- Property damage
- Lost wages
- Lost production

While from the perspective of the municipal government, cost factors of concern include:

- Labor
- Fuel
- Equipment
- Materials
- Facilities

From an environmental perspective, costs of greatest import include:

- Water quality
- Vegetation damage
- Stream siltation
- Fish and wildlife habitat degradation
- Corrosion

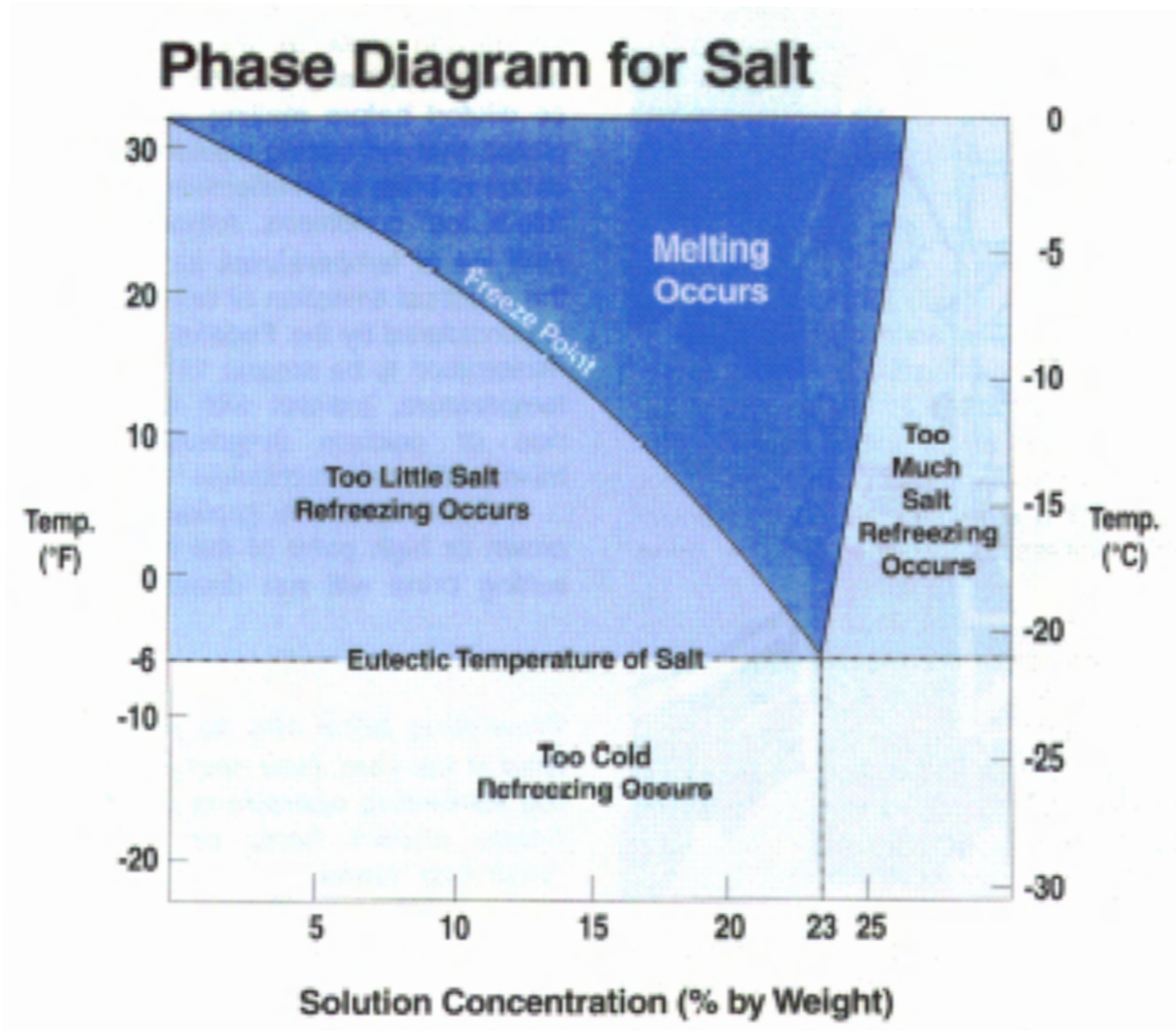
It is the job of the road maintenance manager to balance the concerns of various stakeholder groups by providing for the highest possible level of service on roadways to prevent personal injury and allow for safe travel while minimizing adverse impacts to the environment through a carefully regimented plan. These goals must be accomplished within a limited budget, which can make certain innovative technologies unfeasible to implement.

The various roadway snow and ice control strategies used in winter maintenance operations in the United States can be classified into four general categories:

- Deicing (either by traditional methods of using materials such as salt, abrasives and chemicals or prewetted/pretreated salt) – reactively applying materials after the onset of a storm.
- Anti-icing – proactively applying melting materials long before or just prior to the onset of a storm.
- Mechanical removal (i.e., plowing) coupled with friction enhancement (e.g., abrasives or a chemical freezing point depressant).
- Mechanical removal alone.

As snow accumulates on the road surface and is compacted by traffic, it forms a bond with the pavement, making it difficult to remove with plows. In these situations, salt is needed to break through the snow to prevent this bond from forming. The salt reacts with moisture to create a layer of salty water (brine) between the snow/ice layer and the road. This brine layer has a freeze point below 32 degrees Fahrenheit and breaks the bond, permitting the snow and ice to be plowed from the road. The ability of salt to melt ice or form brine is highly temperature dependant. When pavement temperatures are 30 degrees Fahrenheit, one pound of salt will melt 46.3 pounds of ice. At 15 degrees Fahrenheit, the same amount of salt will only melt 6.3 pounds of ice (NYSDOT). This characteristic of salt primarily dictates when it can be used as a deicing agent. Refer to Figure 1-1 entitled "Phase Diagram for Salt."

Deicing materials include salts (primarily sodium chloride), abrasives (sand and gravel) and alternative freeze-point depressant chemicals. Road salts are the preferred deicing/anti-icing chemicals for maintaining winter roadway safety because of their cost, effectiveness and ease of handling. Materials used by the County for snow and ice control operations are salt (under most



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PHASE DIAGRAM FOR SALT

FIGURE 1-1

conditions) and sand (under icy conditions below the effective temperature range for salt, i.e., below 20-degrees Fahrenheit).

Sodium chloride, the only road salt utilized by the County, is applied directly, in granular or rock form or combined in varying ratios with abrasives. Chloride salt applied to a roadway crates a layer of brine at the road's surface preventing ice from freezing and bonding to the roadway. Salt application is not intended to melt all of the snow falling on a road during a storm event, but instead to melt the layer of accumulated precipitation closest to the pavements' surface, increasing the ease with which all overlying snow can be plowed off.

Roadway anti-icing is a proactive snow and ice control strategy of preventing the formation or development of bonded snow and ice to pavement surface by timely applications of a chemical freezing-point depressant long in advance of or just prior to an onset of a storm to prevent the formation of a bond between the pavement and any packed snow or ice. Deicing is a snow and ice control strategy of destroying the bond between snow and ice and the pavement surface by chemical or mechanical means or a combination of the two.

Through the implementation of a proactive anti-icing strategy, it is possible for a municipality to return to bare pavement conditions more quickly during a winter storm, saving lives and reducing property damage due to fewer accidents, as well as the reduction of traffic delays and the resulting reduction of losses to local economies. Additionally, a reduction in the quantity of deicer used can be achieved, resulting in cost savings and reduced adverse environmental impacts. Finally, it may also be possible to reduce the manpower necessary to maintain safe road conditions, resulting in less overtime costs, less operator fatigue and safer working conditions.

Mechanical removal (i.e., plowing and scraping) coupled with friction enhancement requires applying abrasives or a mixture of abrasives and deicers to a layer of compacted snow or ice already bonded to the pavement surface. This strategy is used to increase the coefficient of friction for vehicular traffic. Abrasives, by themselves, are not ice control chemicals and will not support the fundamental objective of either anti-icing or deicing. However this strategy may prove effective at road surface temperatures below the effective range of conventional chemical deicers.

Mechanical removal alone is a strategy that involves the physical process of attempting to remove an accumulation of snow or ice by means such as plowing, brooming, blowing, etc., without the use of snow and ice control chemicals. This strategy is strictly a physical process that has some merit during and/or after frozen precipitation has occurred at very low pavement temperatures (below 15-degrees Fahrenheit) and on very low volume and unpaved roads.

Most problems related to municipal highway deicing programs result from improper salt storage and perverse/excessive highway application of salts. Highway deicing salts are highly soluble in storm water and therefore a significant adverse impact upon the environment occurs when salts from unprotected salt storage piles and salts applied to highways percolate through soils and subsurface materials to the water table. Some of this leachate is absorbed by soil particles or may be taken up by plants. However, once in the groundwater, both sodium and chloride ions can persist for centuries. They move with the groundwater flow and can be carried down to deeper aquifers that are use for public water supply.

Higher levels of service can only be provided if snow/ice is not bonded to the pavement. There are only two mechanisms that will achieve this: the use of ice control chemicals and favorable temperatures. Using the right amount of chemical for the operational, weather and pavement conditions is the most efficient and effective way to meet most higher level-of-service goals.

Excessive use of salt can have adverse environmental impacts. The amount of salt used is a function of local policies, practices, roadway system, funding constraints and weather conditions. The purpose of this task is, based on an analysis of current practices, to synthesize BMPs for Nassau County while taking into consideration the abovementioned factors. The salt management plan will implement BMPs while balancing the obligation to provide safe, efficient and cost-effective roadway systems.

According to the National Research Council (NRC), road salt usage in the United States ranges from 8 million to 12 million tons of NaCl per year. New York State is among the three states with the highest annual road-salt loadings (Storm Water Environmental Impacts of Road Salt and Alternatives in the New York City Watershed). New York's annual road-salt loading averages 500,000 tons per year or 16.6 tons per lane-mile per year. New York State Department of Transportation (NYSDOT) requires a road salt application rate of 225 pounds per lane-mile for light snow and 270 pounds per lane-mile for each application during rapidly accumulation snow (NYSDOT 1993).

Recently, after more than half a century of its widespread use in North America, the application of sodium chloride and its environmental consequences have come under scrutiny by the environmental and scientific communities as well as regulators and legislators. For example, in 1999 Environment Canada conducted a comprehensive assessment of road salt application to determine whether conventional deicers should be considered toxic substances under the Canadian Environmental Protection Act due to growing concern over roadside habitat degradation, wildlife kills and water-quality issues. Massachusetts turned to alternative road deicers to prevent sodium contamination of residential drinking wells. In New York State, legislators recently proposed a pilot study in the New York City watershed to examine road-salt alternatives that might be more protective of drinking water quality.

Prior to the mid-1980s, sand was the widely preferred method treating snow/ice impaired winter roadways. Aside from the inability of abrasives to melt snow or ice (inability to contribute to breaking of the road/ice bond), additional negative impacts include clogged drains and catch basins and siltation of receiving waters. Additionally, abrasives must be applied frequently and in large quantities to avoid the reduced benefits to traction caused by traffic polishing and rounding of the abrasive particles. In the midst of a storm, abrasives must often be applied frequently as they are covered by falling snow. Cleanup costs associated with street sweeping and disposal of collected sweepings can become astronomical.

As is discussed later in this report, four primary pathways exist to reduce or prevent the adverse impacts on storm water runoff quality caused by winter maintenance operations. These are:

- Implementation of proper storage practices;
- Selection of appropriate materials;
- Timing of application; and
- Controlled application.

2.0 EXISTING PRACTICES

This section presents an inventory of current County practices, which will be used to identify components of the winter maintenance program most in need of improvement, to determine which Best Management Practices (BMPs) are most feasible for implementation in the short and long-term and will establish a benchmark against which progress can be measured.

2.1 Procurement and Receipt of Snow and Ice Control Materials

Road salt (sodium chloride) is procured through a bid process occurring in the autumn of each year (October/November). Bids are placed per ton unit of salt. At this time, enough salt is purchased to supplement leftover salt from the previous season to completely fill the seven storage domes to their capacity of 20,000 tons (2,500 tons per dome). It is estimated that approximately $500,000 to $600,000 worth of salt are purchased at the beginning of each snow season. More salt is ordered after the first snowfall of the season to once again fill the salt domes to capacity. Additional salt may be purchased throughout the season as needed. In addition, the County issues a bid for standby-on-call outside/contractor assistance should it be required prior to the onset of winter weather.

Each of the 30 municipalities within the County has the option of participating in the County bid process to obtain materials at the same price as the County. Approximately 13 of these 30 municipalities participate regularly in the County bid. The ten-year purchase history for salt and sand is shown in Table 2-1.

2.2 Salt Storage Facilities and Technologies

Salt and sand are stored at seven primary and two satellite locations throughout the county. The seven primary locations include DPW yards in:

1. Hicksville

Table 2-1

10-YEAR COUNTY SAND/SALT PURCHASE HISTORY

SNOW SEASON	SAND (tons)	SALT (tons)	SNOWFALL (inches)	CALLOUTS	BUDGET YEAR	EXPENDED
1995/1996	17,017	19,775	78	20	1996	$1,090,163
1996/1997	1,015	3,484	12	10	1997	$242,492
1997/1998	34	1,891	6	3	1998	No purchase
1998/1999	2,065	11,395	15	9	1999	$71,954
1999/2000	2,813	7,591	16	7	2000	$257,507
2000/2001	1,234	21,596	42	14	2001	$656,748
2001/2002	30	1,255	3.5	2	2002	$185,782
2002/2003	6,255	15,647	66	13	2003	$792,451
2003/2004	5,990	19,750	62	10	2004	$700,922
2004/2005	9,102	19,822	48	13	2005	$1,031,427
Average	4,556	12,223	35	10.0	--	$558,760

Notes:

1. Sand and salt usage is per season while amount expended is per budget year
2. Sand and salt may not be used during the same year it was purchased
3. Snow season runs from November through March.

Source: NCPDPW 2006

2. Hempstead
3. Franklin Square
4. Inwood
5. Glen Cove
6. Port Washington
7. Manhasset

Two satellite locations with outdoor sand and salt piles, but without full-service facilities are located at Nickerson Beach and Bay Park Sewage Treatment Plant (STP). Refer to Figure 2-1 for the general locations of these facilities.

Salt is stored in domes of varying capacity (up to 6,500 tons) at each of the seven primary storage facilities. The cumulative total salt storage capacity of the seven full-service salt storage facilities is estimated to be approximately 20,000 tons. The snow and ice control materials stored at the satellite locations are uncovered. An aerial photograph of a typical County sand/salt storage facility is presented in Figure 2-2.

Sand is stored outside and uncovered in the same seven full-service locations at which the salt storage domes are located. Sand is purchased in one large order at the beginning of the season. In addition, a 2:1 sand to salt mix is stored outside at the two satellite locations as well as at County parks, the Jail, the College and police stations.

Runoff from the sand/salt storage locations (i.e., loading and unloading areas outside storage domes and runoff from outdoor sand and sand/salt mixture piles) is not treated at any of the County facilities. Payloader accomplishes loading and unloading of vehicles and all loading/unloading activities occur outside the salt storage zones either on asphalt or dirt surfaces.

The fleet deployed by the County during storm events consists of approximately 125 vehicles including 96 six-wheel dump trucks (6 to 8 yard material capacity), 22 ten-wheel dump

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COUNTY SAND AND SALT STORAGE FACILITIES

FIGURE 2-1

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AERIAL PHOTOGRAPH OF SALT STORAGE FACILITY

FIGURE 2-2

trucks (12 to 18 yard material capacity) and three trailers (20 yard material capacity). All of these vehicles, trailers excluded, can be equipped with plows.

Plow types used include steel bladed plows and rubber bladed plows. Blade replacements for broken/bent blades (caused by raised manhole covers and protruding concrete curbs) cost the County an estimated $100,000 annually. Curb markers are placed in necessary locations (areas where a driver might not be able to detect the presence of a curb when snow covered) prior to the start of the snow season in an effort to prevent plow blade brakeage. Snow fencing is installed at approximately five or six sections of roadway that are particularly prone to snowdrifts.

Vehicles are equipped with two different kinds of spreaders: conventional spreaders (which the County is phasing out) and flow and dump spreaders. The flow and dump spreader is favored by the County because it is a multi-use vehicle with off-season applications. The most important feature of these spreaders is their ability to regulate the amount of salt that is being deposited on the roadway.

The regulatory device, which is located in the cab of the truck, controls conveyor belt and spinner speed. The salt in the truck bed is carried along a metal or rubber belt system and is deposited in a hopper. Adjustable deflection plates control the width of the spread, depending on road width. The rate at which material is discharged from the spreader is related to the speed at which the vehicle is moving.

2.3 Mobilization and Deployment

The personnel at the Hicksville DPW facility dictate deployment of vehicles from other DPW locations based on the following factors:

- Radar devices/ radar service.
- Weather forecasting devices/service (Metro Weather D.J.N. Meteorologix).
- Accident reports/calls from police.

- Communication with the Long Beach Bridge attendant (present until midnight, seven days a week; the bridge is equipped with pavement and air temperature sensors) or the Bayville Bridge attendant.

- Access to NYSDOT pavement and air temperature sensors (on major highways and other main arteries) and phone conversations with DOT personnel in Hauppauge to gain access to live video feed information.

- Four to five County-owned cars equipped with air/pavement temperature sensors.

Plows are attached to trucks early the day of an expected storm, prior to the arrival of drivers and other road crew to the facility. The crew deployment process takes approximately one hour from the time a call is initially placed to the crew personnel. Generally, a crew is not called until snow has fallen or a call has been received from the police. However, in cases of storms predicted to hit during periods of rush-hour traffic, the County begins assembling crews an hour prior to the predicted storm. Plows are generally not deployed to the roadway until there are 2" to 3" of accumulation on the pavement surface, but material application is initiated earlier in the storm.

Loading of trucks begins when crews arrive at the facilities. This loading process begins at approximately the same time at facilities throughout the County. However, the number of facilities called on to deploy crews varies with the predicted affected area for a given storm. As vehicles are loaded, the payloader operator records the amount of material loaded and the vehicle I.D. number. This information is subsequently recorded into a computer database and helps to account for the amount of salt used and where it is being applied.

A driver is designated to be responsible for the Long Beach and Bayville Bridges. This driver is mobilized earlier than other drivers to provide early treatment to these freeze prone areas. However, it is estimated that the majority of drivers do not start their routes until at least an hour into the storm. This has proven particularly problematic for the County in the case of winter storm events that hit during rush hour because the one hour response time from the storms' beginning allows critical time for an ice/pavement bond to form. During the mobilization of road crews and throughout the treatment process, personnel at the Hicksville

DPW facility maintain radio contact with each yard supervisor who contacts foremen and crewmembers from each of the seven other facilities.

2.4 On Road Application and Treatment

Each truck can cover 5 centerline miles per load. A driver marks the location at which a load is completed and returns once the vehicle has been reloaded. During the application/treatment process special attention and repetitive application is required at certain high risk locations, such as:

- 26 miles of L.I.E. service roads
- Numerous overpasses
- North shore hills

In the 2003-2004 winter maintenance season, the average material cost (including sand and salt) per lane mile for all the County facilities was approximately $325,000. Salt usage by the seven primary facilities ranged from approximately 775 tons of salt at the Hicksville Facility down to 140 tons at the Glen Cove facility. Sand usage ranged from 180 tons at the Glen Cove and Hicksville facilities, to no sand used at the Port Washington facility. Facilities responsible for a greater number of lane miles generally used more salt than those with smaller service areas. However, higher sand usage was not directly associated with service area.

Salt is used exclusively for road treatment at temperatures above 25-degrees Fahrenheit. For road temperatures below 25-degrees Fahrenheit, a 2:1 sand: salt blend is utilized. Prior to the mid-1990's, the County was more heavily reliant on sand for winter roadway maintenance. However, this practice became economically unfeasible when disposal of post-winter street sweepings became too costly.

2.5 Post-Winter Operations

The disposal of accumulated sand from streets and catch basins became difficult and expensive after the closing of the Port Washington Landfill. This resulted in a shift to heavier salt usage and less sand usage. Current post-winter maintenance includes sweeping and disposal of any sand that has accumulated in the roadway. It currently costs approximately $27.00 per ton to dispose of street sweepings.

Additional post-winter maintenance activities include:

- Debris removal (on road/ off-road)
- Mechanical sweeping
- Manual sweeping
- Catch basin cleaning (inlets and chambers)
- Storm water drain pipe cleaning
- Storm debris removal

The cost of these traditional post-winter maintenance activities were reduced when the County made the transition from a sand application dominated strategy of winter maintenance to a strategy dominated by the application of sodium chloride road salts. Currently, the County undertakes few efforts to specially treat chloride-laden storm water at sites. In addition, little is done to minimize or monitor the impacts of chloride influx to the environment during snowmelt.

2.6 Recordkeeping

The County has implemented numerous means of recording the practices and costs involved in their snow and ice control program. The first of these measures is their annual and 10 year-history of materials purchases that documents the total volume of material used annually. In addition, the loader at each facility logs the amount of material loaded into each truck and the truck identification number at the beginning of each route and for each subsequent reloading.

From this materials purchase and truck loading data, the County is able to calculate the annual sand and salt usage for each facility (in tons) and is able to calculate the annual cost per lane mile for each facility (using the amount of sand loaded that season and the amount of lane-miles in the service area). This information is stored in a computer database.

In addition to these record-keeping practices, County employees keep track of their working hours by activity code. This data is compiled annually to determine the total man-hours devoted to each category of snow and ice control activity.

3.0 EVALUATION OF ALTERNATIVE BMPs

This section presents an analysis of the County operations presented in Section 2 of this report, "Existing Practices." Based on this analysis, the feasibility of implementing alternative County-wide BMPs will be evaluated.

3.1 Procurement and Receipt of Snow and Ice Control Materials

Salt and sand should be loaded and unloaded either indoors or on impervious bituminous concrete pads or concrete that has been treated with a sealant. Neither of these practices is currently implemented at County storage facilities. Rather, materials are unloaded either on asphalt or on unpaved (dirt) surfaces and may remain there for hours waiting transfer to an indoor facility. This practice can allow for salt and sediments to infiltrate into the soil, threatening underground water supplies or enter the storm sewer system. Salt and sediments can be a stress to the receiving waters and cause damage, corrosion and restrictions to the storm sewer system. Because salt is left outside the facility during this loading/unloading process, it is important that loading and unloading be performed under dry weather conditions when possible to minimize salt runoff.

Preferably, the storage facility has been designed and constructed to allow the salt to be unloaded directly inside. However, the County salt domes are not designed to allow for indoor unloading of snow and ice control materials. This situation typically calls for the delivery transport trailer end to dump or offload salt outside of a storage dome on an asphalt or unpaved surface via a longitudinal conveyor. It is stored there while awaiting transfer to the storage dome. The salt must be then be reloaded into a pile under cover. A payloader transfers salt to the storage dome. Salt lost to the pavement during outdoor unloading operations should be collected before being allowed to enter into the municipal storm drainage system or infiltrating into the groundwater.

Ideally, the salt should not be "double-handled." To avoid this salt can be blown into storage facilities using a closed pipe system to eliminate double handling. Whether mechanically piled or blown, each handling can cause particle breakdown, segregation and loss. While handling can serve to break up any chunks that may be present, the gradation will usually vary and this effort is inefficient. It also allows for a greater wind-blown loss of salt and the loss of salt fines that are remaining on the outdoor surface.

3.2 Salt Storage Facilities and Technologies

In general, maintenance yards are constructed for multiple purposes including the delivery of winter road maintenance services. For winter operations, there is a strong need to focus on salt loss, whether in the form of salt dust, brine runoff or simple wastage of road salts through improper handling practices. Lost salt will dissolve and can infiltrate into the soils below and adjacent to the site. Components of road salt entering the groundwater can travel great distances and affect wells, vegetation and surface water where the groundwater emerges as springs or discharges into streams and other receiving waters. Road salt from the storage facility can also enter salt sensitive environments or surface waters when conveyed directly in storm water runoff.

In order to minimize salt loss, the yard layout should be designed to be efficient in all activities. Considering the cycle of handling road salts in the yard may reveal potential enhancements that can be made to improve yard efficiency and reduce salt loss. The typical salt handling cycle flows from delivery, to stockpiling, to loading on the spreader and then exiting the yard. Upon return, the spreader offloads unspent salt (preferably indoors) and the equipment is washed to remove remaining salt residue. Each of these activities provides an opportunity for improvement.

Sites for the storage of road salt should be chosen carefully and numerous factors should be considered including: location relative to the road network to be serviced, physiography and topography, ground conditions and drainage patterns. Ground conditions (soil or rock) and lay of the land complement the drainage management objectives. For example, unlike granular bases, clay bases will prevent rapid infiltration of salt laden water. Conversely, highly permeable soils almost always allow the surface water to reach the groundwater table. This may not be a concern if there is a quick outlet to a tolerant watercourse, but this can generate considerable liability if the groundwater impacted by salt becomes a well water source or enters a sensitive ecosystem.

Although permanent, covered storage is recommended, some agencies still store or load salt outside. Whether stored inside or outside, salt must be on an impermeable pad or base. The pad site should be located away from wells, reservoirs and groundwater sources and situated so that if any drainage inadvertently leaves the storage area it will not affect them. Concrete pads should be constructed of air-entrained or bituminous concrete. The pad should be treated with a high quality concrete sealant to prevent infiltration.

Ramps are prone to tipping and spillage accidents. Larger loaders and bucket sizes have increased the speed of this operation; however, spillage at the time of loading is made worse by overloading. This spillage can occur either at the yard exit or before the spreader reaches the designated location and to the operator yielding to the temptation of spreading the entire load rather than spinning off a potential surplus.

Where liquid melting agents are used, spillage of liquids can occur during production, delivery and transfer to spreaders. It is not always necessary to spread the full load of material. Operators should be instructed to spread only what is needed to achieve the prescribed level of service. Unused materials should be returned and offloaded to the storage facility. To minimize corrosion, spreaders are often washed following a winter storm event. The wash water is likely contaminated with dirt, oil, grease and salt (chlorides). If not properly handled, this wash water can harm groundwater quality, receiving streams ponds and lakes and adjacent vegetation or agricultural operations.

In their 2003 Synthesis of Best Practices for Road Salt Management, the Transportation Association of Canada developed criteria for the design and operation of road maintenance yards at the local level. Designs for such yards include:

- Safe, cost-effective location.

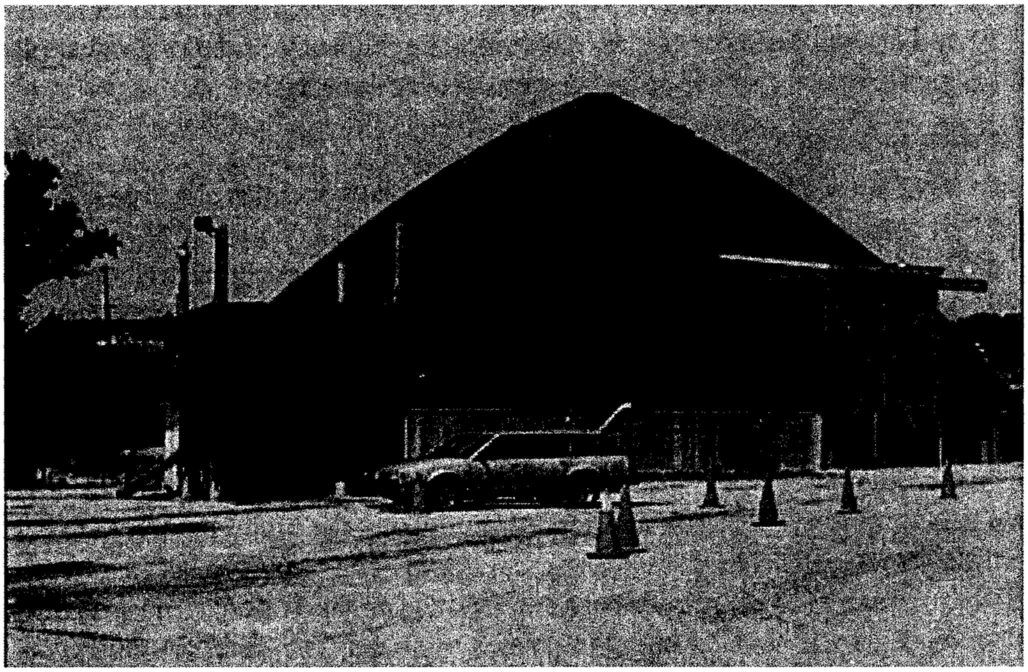
- Management of site drainage, especially when salt and chemicals will be stored.
- Protection of salt vulnerable areas (sensitive receiving waters/roadside vegetation).
- Use of indoor storage for greater salt and sand control and for spreader storage.
- Positioning buildings and their doors to minimize snow drifting and snow entry into the structures.
- Use of low-permeability pads under the structures to help control salt and chemical drainage.

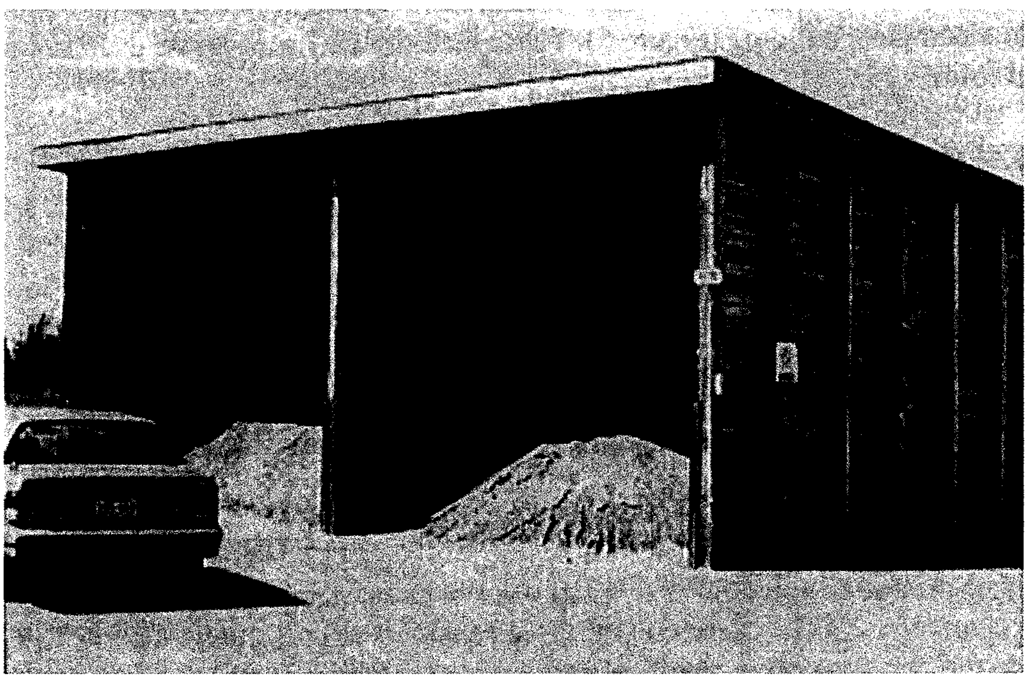
Two designs for sand/salt storage facilities are presented in Figure 3-1.

Brine Production and Storage

The production and storage of salt brine on DPW premises is a feasible alternative or complement to traditional solid material storage practices. Simple NaCl brine manufacturing plants that can operate relatively trouble-free became a necessity with the use of salt brine or prewetted salt for anti-icing treatments. Highway agencies working with private companies have designed a number of salt brine production plants. As a result, there are several companies that manufacture salt brine production systems. Two types of manufacturing plants are currently in use for preparation of saturated brine: batch and continuous flow. Simple batch units for temporary or small-scale production can be assembled using small tanks. Water passed through a bed of rock salt by gravity will produce a solution saturated at the water temperature. Continuous flow production involves loading a tank with salt and running water through it and collecting the brine in a holding tank. From there, the brine is passed through a filter or pumped into a storage tank or directly into a spreader truck.

Brine production facilities have the potential to cut down on the concentrations of chlorides lost to the environment compared to traditional solid chemicals. In addition, the production of brine is a fairly cost efficient operation. Table 3-1 shows the cost of brine production. Another attractive aspect of brine operations is a decrease in the amount of time required to load and unload vehicles with materials, whereby cutting down on time required for mobilization and deployment.





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DESIGN FOR SAND/SALT STORAGE FACILITIES

FIGURE 3-1

Table 3-1

BRINE PRODUCTION COST ANALYSIS

Material	Unit Cost	Quantity	Total Cost
Bulk Salt (ton)	$41.24	5.625	$231.97
Water (gallon)	$0.003	5,000	15.00
Labor (hour)	$45.44 per hour	1	45.44
Loader (hour)	$23.51 per hour	1	23.51
Electric (hour)	$0.14 per kw	1	0.14
		TOTAL	$316.06

$316.06 / 5,000 Gallons = $0.06 per Gallon

Source: Town of Orangetown, NY

3.3 Mobilization and Deployment

When selecting and deploying equipment, the best decisions can be made when proper information is available. In order to properly match equipment and service delivery in a way that optimizes winter maintenance performance, personnel need to understand snow and ice control strategies and methods available to them, existing and forecasted road and weather conditions, and the equipment and material availability, capability and limitations. Equipment, labor and materials are significant cost components in a winter road maintenance program. It is important for an organization to continuously identify and assess new and innovative technology that supports best practices. Also, there are seasonality and frequency of use considerations as well as multi-functionality aspects in evaluating the economics of renewing the fleet. Management must balance all of the competing agendas in choosing the preferred equipment configuration, and a phase-in/out strategy for the fleet, with an understanding of salt use considerations.

A critical component of the mobilization and deployment of road crews is the implementation of an early deployment program. These programs allow crews to treat roads prior to the formation of a bond between the road and any accumulating precipitation. Road managers are developing many innovative technologies designed to allow crews to deploy with maximum efficiency given the existing weather conditions and forecast predictions. Included amongst these new developments are the Road Weather Information Systems (RWIS) and the Federal Highway Administration's (FHWA) Maintenance Decision Support System (MDSS).

3.3.1 Road Weather Information Systems (RWIS):

Road Weather Information Systems (RWIS) use specialized equipment and computer programs to monitor air and pavement temperatures and predict if precipitation will freeze on the pavement (Public Works Magazine, April 2002). RWIS with pavement and atmospheric sensors provide up-to-the-minute information to the road maintainers about what is happening at the road surface. Parameters measured by RWIS units include:

- Temperature;

- Dew point;
- Optical weather identifiers;
- Pavement temperature;
- Surface status; and
- Chemical information (i.e., chloride concentration at road surface).

The RWIS can maximize the effectiveness of icing and plowing efforts by pinpointing and prioritizing the roadways that need attention. It can also eliminate unnecessary call-outs and improve scheduling of crews based on estimates of the extent and severity of the storm. The implementation of an early anti-icing program assisted by RWIS could assist the County in deploying crews to the road in a timely manner and cut down on delays in treating rush hour storms.

The Ohio Department of Transportation (ODOT), already active in RWIS with 72 sites in the Columbus, Cleveland and Toledo areas, has recently expanded the system statewide with 88 uniquely designed wireless Environmental Sensing Stations (ESS) and more than 160 additional pavement sensors on Ohio's roads. The system has a total number of 160 reporting stations and 400 pavement sensors statewide. This provides ODOT, city and county highway managers and the general public with a real time weather and pavement condition resource. The new ESS sites were designed to be completely wireless, combining wireless pavement sensors with solar power and a mixture of Radio Frequency (RF) to Ethernet and IP over cellular communications. ESS sites using radio frequencies report at one-minute intervals 24/7 with no recurring monthly fees. The same reporting cycle using conventional telephone lines would cost thousands per month.

An exciting feature of ODOT's ESS sites is the use of multi-vendor technology. They are equipped with NuMetrics Pavement Sensors, Vaisala Atmospheric Sensors and Surface Systems ScanCast capabilities. Summit County's Road Maintenance Manager, Gary Ellison, says RWIS has been an extremely helpful tool: "We use RWIS quite regularly to predict when storms will hit and either get out there to pre-salt or hold crews because pavement temperatures aren't cold enough for things to freeze."

The RWIS keeps a history of events so road managers can track different storms, salt use, manpower and then look back on what was done to plan for the future. According to the Strategic Highway Research Program (SHRP), using data from an RWIS station, the North Dakota DT reduced the use of sand significantly on an I-94 bridge near Fargo and saved $10,000 to $15,000 in just four storms. RWIS network data saves the 153-km West Virginia Parkway about $2,300 in labor costs and $6,500 in materials costs per storm.

3.3.2 Maintenance Decision Support System (MDSS):

The FHWA has developed a decision support tool, the Winter Maintenance Decision Support System (MDSS). The MDSS serves the purpose of providing storm specific forecast and weather information to road managers to inform their decisions. The MDSS provides weather predictions focused toward the road surface. These predictions are then merged with customized rules of practice that have been captured from maintenance managers and coded into a computer algorithm. The outcome is a set of treatment recommendations that will help an agency maintain the highest level of service possible given available staff and equipment resources, while minimizing the amount of material applied to the roads.

The ultimate goal of the project is to create a prototype system that private sector companies can take, integrate into their product lines and offer as a service back to states and local jurisdictions. The MDSS provides a subset of weather parameters important for maintenance operations. This includes forecast values of air and road temperatures, precipitation start and stop times, precipitation types and accumulation amounts. The MDSS can also be used as a training tool to play back conditions after the season has ended and to determine if different courses of action would have been more beneficial. In addition, by capturing the current rules of practice, the MDSS could serve as a training tool for new or less experienced maintenance managers. Appendix A provides an overview of the demonstration MDSS prepared by the FHWA Road Weather Management Program.

3.4 On Road Application and Treatment

Snow and ice control on United States roadways costs approximately $2 billion per year. Additional, indirect costs of approximately $5 billion result from corrosion, water quality degradation and other environmental consequences of snow and ice control operations. Increased efficiency and effectiveness of municipal snow and ice control operations could result in substantial economic savings through decreased material and man-hour needs. In addition, better snow and ice control means better safety and mobility and a reduction in adverse environmental impact.

Winter sand and other abrasives can be used when temperatures are too cold for deicing chemicals to be effective. Otherwise, a sand/salt mix is generally not recommended. Salt will not improve the effectiveness of abrasives at creating friction at the road surface (particularly at temperatures below the effective range for a specific chemical solution). Likewise, abrasives will not assist in melting snow and application should be highly limited during the implementation of an anti-icing operation. The cost of cleanup incurred by the use of abrasives makes them an imprudent complement to an anti-icing program.

3.4.1 Chemical Freezing Point Depressants:

Chloride Freezing Point Depressants

The most commonly used chemical freezing point depressant in the United States and the chemical used exclusively by the County, is the common table salt sodium chloride (NaCl). The effectiveness of salt is highly temperature dependent. Pavement temperature is the key temperature in this situation. It is important to note that pavement temperature is seldom the same as air temperature. For example, starting about mid-morning and with solar warming, pavement temperature will exceed air temperature by as much as 40 degrees Fahrenheit. Due to heat retention pavement temperatures will still be higher than air temperature for several hours after sunset. By early to mid-morning, pavement temperatures will have dropped lower than air temperature. In the absence of the daily cycles, winter pavement temperatures are generally warmer than air temperatures. However, pavement temperatures become colder than air temperatures by late winter. In addition, salt is more effective during periods of higher traffic volumes. Frictional effects at the tire-pavement interface tend to warm the pavement. In addition, the mechanical impact of traffic can break up ice once the salt has prevented or broken the ice/pavement bond.

The ice content of the precipitation also influences the effectiveness of salt. The ice content of snow can vary from 10% to 90%. Sleet, freezing rain and compressed snow pack have ice contents in the range of 90% to 100%. With increasing ice content per inch of snow or ice, more salt will be required to reach the desired LOS.

While road salt is the preferred method for snow and ice control, salt-laden runoff can have adverse impacts on the natural environment. Appendix B provides a detailed description of the effects of road salt on the environment. The nature and extent of these impacts is site specific and may be temporary or enduring. In some areas, the concentration of chloride in the groundwater and stream base flow may reach levels sufficient to impair the potability of drinking water or threaten aquatic habitats.

Much of the salt that is placed on a road during snow and ice control operations eventually runs off with the roadway drainage. Chloride is one of the main components of road salt and is extremely soluble in water. As a result, it is unfeasible to remove the chloride once it enters surface and groundwater. The highest chloride levels are recorded in melt-water near salt deposits, major highways, snow piles in parking lots, local streets and urban streams. Table 3-2 provides the range of chloride levels in these waters.

Salt-laden roadway runoff enters the environment through three primary pathways. The first is through overland drainage or storm sewer system ultimately discharging to nearby receiving waters. The second is infiltration into the ground potentially entering groundwater. The third is through spray caused by traffic and wind, potentially effecting adjacent vegetation and agricultural crops. Adverse impacts may occur if any of these pathways introduce high salt concentrations to salt vulnerable areas. Proper drainage planning and design, in conjunction

Table 3-2

CHLORIDE CONCENTRATIONS IN MELT-WATER RUNOFF

Runoff	Chloride Concentration (mg/l)
Salt storage areas	50,000 to 80,000
Highway melt-water runoff	5,000 to 20,000
Snow piles in parking lots	5,000 to 15,000
Street melt-water runoff	2,000 to 4,000
Urban streams in winter	1,500 to 2,500
Normal freshwater	20 to 50
Ocean water	25,000 to 30,000

Source: Center for Watershed Protection: "Snow, Road Salt and the Chesapeake Bay" with the implementation of BMPs for salt/abrasive storage and on-road application, can reduce the potential impacts on salt vulnerable areas.

Salt infiltrating into the ground will dissolve and increase the salt content of the groundwater. Generally the presence of chlorides in drinking water is not a major health concern. However, high concentrations salt will affect the taste of the water. Our tongues can detect saltiness in drinking water when chloride levels exceed 250 mg/l. Water utilities routinely report a peak in complaints about the taste of drinking water during winter melt events.

High levels of salt are frequently measured in roadside soils. Roadside vegetation (i.e., trees, shrubs and grass) can be damaged by high concentrations of salt in soil groundwater and salt spray from roadways. Environment Canada (EC) cites numerous studies attributing tree injury and decline to road salt application, concluding that NaCl can cause severe injury to the flowering, seed, germination, roots and stems of roadside plant species. Damage to vegetation can occur up to 200 meters from roadways that are treated with deicing salts. Greater than half of all woody plant species are sensitive to NaCl and many of these have disappeared from Canadian roadsides. Of the 15 principal tree genera occurring in Canadian forests, 11 have been rated as sensitive to road salt (Stormwater Magazine, 2005).

Some species of plants are more tolerant of high salt concentrations and therefore should be used near roadways. Vegetation should be planted in groups to maximize protection afforded by other vegetation. Tables 3-3 and 3-4 present the salt tolerances of common roadside vegetation. However, two notable examples of salt tolerant wetland plants, cattails and *Phragmites*, have become invasive in roadside swales and wetlands as they flourish in soils with high chloride levels.

Damage to roadside vegetation can amplify adverse impacts on drinking water quality. Degradation of soils and vegetation buffer areas between roads and watercourses compromises the retention and processing of pollutants transported in storm water runoff and diminishes the beneficial value of buffer zones to groundwater sources and reservoirs. Impacts to water quality

Table 3-3

SALT TOLERANCE IN ROADSIDE TREES

Salt Tolerant	Moderate Salt Tolerance	Salt Intolerant
Common Horsechestnut (*Aesculus hippcastanum*)	Amur Maple (*Acer ginnala*)	Balsam Fir (*Abies balsamea*)
Serviceberry (*Amelanchier canadensis*)	Manitoba Maple (*Acer negundo*)	Red Maple (*Acer rubrum*)
Maidenhair Tree (*Ginko biloba*)	Yellow Birch (*Betula alleghaniensis*)	Sugar Maple (*Acer saccharum*)
Honey Locust (*Gleditsia triacanthos*)	Paper Birch (*Betula papyrifera*)	Silver Maple (*Acer saccharinum*)
Tulip Tree (*Liriodendron tulipfera*)	White Ash (*Frazinus americana*)	Eastern Redbud (*Cercis Canadensis*)
Colorado Blue Spruce (*Picea pungens glauca*)	Large-toothed Aspen (*Populus grandidentata*)	Shagbark Hickory (*Carya ovata*)
Mugho Pine (*Pinus mugho*)	Trembling Aspen (*Populus tremuloides*)	Black Walnut (*Juglans nigra*)
Austrian Pine (*Pinus nigra*)	Cottonwood (*Populus deltoides*)	Ironwood (*Ostrya virginiana*)
Jack Pine (*Pinus banksiana*)	Black Cherry (*Prunus serotina*)	Norway Spruce (*Picea abies*)
Hop Tree (*Ptelea trifolata*)	Japanese Pagoda Tree (*Sophora japonica*)	Red Pine (*Pinus resinosa*)
White Oak (*Quercus alba*)	Eastern White Cedar (*Thuja occidentalis*)	White Pine (*Pinus strobus*)
Red Oak (*Quercus rubra*)		Scot's Pine (*Pinus sylvestris*)
English Oak (*Quercus robur*)		London Plane Tree (*Plantanus acerifolia*)
Black Locust (*Robinia psuedoacacia*)		Douglas Fir (*Pseudotsuga menziesii*)
		Basswood (*Tilia Americana*)
		Littleleaf Linden (*Tilia cordata*)
		Hemlock (*Tsuga Canadensis*)

Source: Transportation Association of Canada, 2003

Table 3-4

SALT TOLERANCE IN ROADSIDE SHRUBS

Salt Tolerant	Moderate Salt Tolerance	Salt Intolerant
Silverberry (*Elaeagnus commutate*)	Forsynthia (*Forsythia ovata*)	Grey Dogwood (*Cornus racemosa*)
Sea Buckthorn (*Hyppophae rhamnoides*)	Red Cedar (*Juniperus virginiana*)	Red-osier Dogwood (*Cornus stolonifera*)
Common Ninebark (*Physocarpus opulifolius*)	Mock Orange (*Philadephus coronarius*)	Winged Euonymous (*Euonymous alatus*)
Choke Cherry (*Prunus virginiana*)	Smooth Sumac (*Rhus glabra*)	High-bush Cranberry (*Viburnum trilobum*)
Staghorn Sumac (*Rhus typhina*)	Elderberry (*Sambucus candensis*)	
Buffaloberry (*Shepherdia canadensis*)		
Snowberry (*Symphoricarpus albus*)		
Japanese Tree Lilac (*Syringa reticulate*)		

Source: Transportation Association of Canada, 2003 can be particularly acute when high LOS roads are adjacent to drinking-water reservoirs insulated by narrow buffers.

Adverse effects on aquatic biota have also been linked to road salt loadings. Salt held in solution in snow or deposited on surface soil layers is readily dissolved by storm water and can be transported to receiving waters in runoff. Although snowmelt may proceed gradually overall, it increases dramatically following application of road salt. Shock loads of salt to aquatic ecosystems might last less than a day following application, with concentration decreasing thereafter. Heavy salt loading to streams during sensitive periods of the year can adversely affect fish populations and other aquatic fauna. Prolonged retention of salt in streambeds or lakebeds decreases dissolved oxygen and can increase nutrient loading, which promotes eutrophication.

Reports of chloride concentration in highway runoff are as high as 20,000 mg/l. Salt tolerance of freshwater and marine fishes range from 400 to 30,000 mg/l. Chloride can be harmful to many forms of aquatic life at concentrations over at 1000 mg/l. Chloride levels above this level are not uncommon in many small or urban streams and wetlands during a thaw period. Stream studies in northern New York revealed that benthic diversity decreased as salinity increases, partially due to the dominance of salt-tolerant invertebrates during periods of road-salt application.

Negative impacts of salt contamination on wildlife include destruction of sensitive habitat. Additionally, mammals and birds have seen increasing mortalities resulting from road salt application. Birds and mammals often lack salt in their diet. Wildlife craving salt are attracted to the salt laden roadside, increasing their exposure to traffic and increasing the frequency of traffic-related wildlife mortalities. Additionally, high concentrations of chlorides in water can kill sensitive birds and mammals.

Highway agencies have begun to take the salt problem seriously and are working hard to develop new technology to reduce its environmental impacts. A number of chloride alternatives to sodium chloride exist. These salts are often more effective at lower temperatures (below 20-degrees Fahrenheit) than common road salt, however they are much more expensive. Calcium chloride (CaCl) and magnesium chloride (MgCl) are used to melt snow and ice at faster rates and 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 the environment.

Non-chloride Freeze Point Depressants

Due to the environmental concerns associated with chloride freezing point depressants, the use of a number of alternatives chemicals has been implemented by many road agencies. 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, whereby enhancing their melting effectiveness. Organics also impose (different) environmental stresses and cost significantly more than salt. Tables 3-5 and 3-6 present cost comparisons and effective temperature ranges for numerous chloride and non-chloride freezing point depressants.

Urea, a fertilizer, adds nutrients to surface water and hastens eutrophication, whereby reducing dissolved oxygen levels. Calcium magnesium acetate (CMA) and potassium acetate (KA) can also reduce available oxygen in receiving waters of storm water runoff flows. Research presented at the Pacific Northwest Snow Conference indicated that liquid organic deicers could cause high biochemical oxygen depletion levels. The eutectic point describes the concentration that results in the lowest temperature at which a solution can exist while remaining completely liquid.

CMA is made from delometric limestone treated with acetic acid. While CMA does not overcome all the undesirable characteristics of salt, it is still an effective deicer. CMA is frequently used because it has less potential to affect the environment and is not as corrosive as salt. However, to achieve the same deicing effectiveness of salt, CMA materials need to be applied in larger quantities and cost 10-20 times as much as sodium chloride.

Table 3-5

COSTS AND TEMPERATURE RANGES FOR DEICING CHEMICALS

Deicing Chemical	Eutectic Temp. (°F)	Concentration at Eutectic (%)	Cost Comparison
Calcium Chloride	-67	29.8	7x greater
Calcium and Sodium Formate	+11	32.6	17x
Calcium and Magnesium Acetate	+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
Propylene Glycol	-71	60	28x
Sodium Chloride	-6	23.3	1
Urea	+11	32.5	7x

Source: Salt Institute: "Highway Salt and Our Environment"

Table 3-6

ESTIMATED COST FOR FOUR DEICER TYPES

Deicer Type	Material Cost per Ton	Cost per Lane Mile per Season
Sodium Chloride	$20 – $40	$6,370 – $6,910
Calcium Chloride	$200	$6,980 – $7,530
Calcium Magnesium Acetate (CMA)	$650 – $675	$12,960 – $16,320
CG-90 Surface Saver	$185	$5,930 – $6,150

Source: Center for Watershed Protection: "Stormwater BMP Design Supplement for Cold Climates"

3.4.2 Anti-Icing

A clear trend to achieving more efficient salt use and safer road conditions is to apply a chemical freezing point depressant at the beginning or onset of the storm to create a road condition that will prevent the initial freezing and the formation of the snow/pavement bond. This proactive and preventative approach requires less road salt than is required to deice the road once the snow/ice pack has formed. It also helps keep the road ice-free throughout the storm event. The early application of salt is often referred to as "anti-icing."

Anti-icing can be particularly effective in supporting strict requirements for safe road conditions during a winter storm, while deicing is more effective for after-storm cleanup. This factor is of particular concern to the County because they have experienced past difficulties in deploying winter maintenance crews in time to achieve high levels of service during rush-hour storm events, a time at which it is crucial for safe travel conditions to be provided.

Anti-icing can be performed with solid chemicals, however this is rare due to the ease with which these chemicals can be blown or pushed from the road. Solids are not a good choice for early anti-icing operations because most will have been removed from the road by the onset of the storm (even if applied only shortly prior to the onset).

Similarly, pretreated or pre-wet solid chemicals are not ideal for early anti-icing scenarios. Pretreated or pre-wet solids consist of a traditional solid deicing chemical (usually NaCl) sprayed with either liquid salt brine or an alternative deicing material. The solid is wet in order to increase the rate at which the solid will dissolve into a brine solution at the roads surface, whereby melting snow/ice more quickly.

Depending on the configuration of a prewetting program, solids can be sprayed at a variety of times including:

- Direct application of liquids to a solid storage pile (not recommended due to runoff issues)

- Application of a liquid to solids loaded in trucks via an overhead spray bar prior to leaving the storage facility; or
- Application of a liquid to a solid as it is dispensed from a truck by onboard spray nozzles.

The use of prewet solids is also not ideal for an early anti-icing scenario (application many hours to a day prior to expected storm) because, as the applied liquid dries, granular solid that is easily blown or pushed from the road is left behind. This strategy, however, may be useful for a just-in-time anti-icing strategy in which crews are deployed to minutes to a few hours before a predicted storm event.

Anti-icing practices provide maintenance managers with two major capabilities: the capability for maintaining roads in the best conditions possible during a winter storm and the capability to do so in an efficient manner. According to the Minnesota Department of Transportation, anti-icing requires about 1/4 of the material of deicing at 1/10 the overall cost, making it the least expensive option for increasing traffic safety (*Minnesota Snow and Ice Control Manual,* Minnesota DOT).

Most anti-icing programs incorporate the application of a liquid deicing chemical, usually in the form of salt brine (but sometimes brine in combination with other liquid deicers), because of the ability of liquids to remain on the road surface even when applied long before a storm event. Liquids dry on the pavement surface, leaving behind a thin layer of dry salt that is not easily pushed to the roadside.

According to a January 7, 2005, News Release form the State of New Hampshire Department of Transportation, the introduction of a new anti-icing treatment aimed to reduce salt use while allowing for a more effective pre-treatment of highways (not to be confused with pre-treatment of solid deicing chemicals with liquid additives) before bad weather arrives. The NHDOT anti-icing treatment experimented utilized a liquid salt brine solution of approximately 2.2 pounds of salt dissolved per gallon of water. It was estimated that up to 60 gallons of salt brine (containing approximately 132 pounds of dissolved rock salt) would be required per lane mile instead of the normal 250 pounds per lane mile of rock salt currently used. This would save over 100 pounds of salt per lane mile, a 40% reduction below current application rates (NHDOT, 2005). The estimated cost to produce a gallon of salt brine is just five cents per gallon, compared, for example, to approximately 88 cents per gallon for the anti-icing alternative calcium chloride.

Liquid chemical solutions, including sodium chloride (NaCl), magnesium chloride (MgCl), calcium chloride (CaCl), calcium magnesium acetate (CMA) and potassium acetate (KA) can be applied to highways using two principle types of equipment:

- A system using spinners consisting of either multiple rotating disks or a single disk or
- A system using nozzles on a distributor bar.

Either of these spreader types may be chassis-mounted (fixed on frame); be a "slip-in" unit that can be placed temporarily in the bed of a dump truck or on the frame and removed during the off-season; or it can be a trailer or tow-behind unit.

A nozzle type spreader sprays liquid from nozzles at a low height above the road to reduce the influence of air turbulence behind the vehicle that can cause the liquid to disperse before hitting the pavement (Manual for an Effective Anti-Icing Program, Federal Highway Administration). The unit is designed to be towed by a truck equipped with a liquid tank. The spreader is powered by its own traction-driven wheel and also has a ground-speed control. A spinner type spreader attaches to the rear of a truck equipped with liquid tanks. The unit can be powered either by the vehicle's hydraulic system or by a separate road wheel.

According to the Federal Highway Administrations "Manual of Practice for an Effective Anti-Icing Program," highway agencies that are interested in beginning or experimenting with an anti-icing program might consider modifying some existing spreader equipment before investing in new equipment. Asphalt distributor trucks, liquid fertilizer spreaders and spreaders used to spray for weed control have been modified and successfully used by some highway agencies (Nevada Department of Transportation and Colorado Department of Transportation) in their initial anti-icing programs.

Regardless of the type of spreader used for either solid or liquid application, it is extremely important to calibrate it to ensure that the desired quantity of material is actually being applied. All equipment should be calibrated before winter operations begin as well as periodically throughout the winter maintenance season in order to ensure that settings have not changed with use.

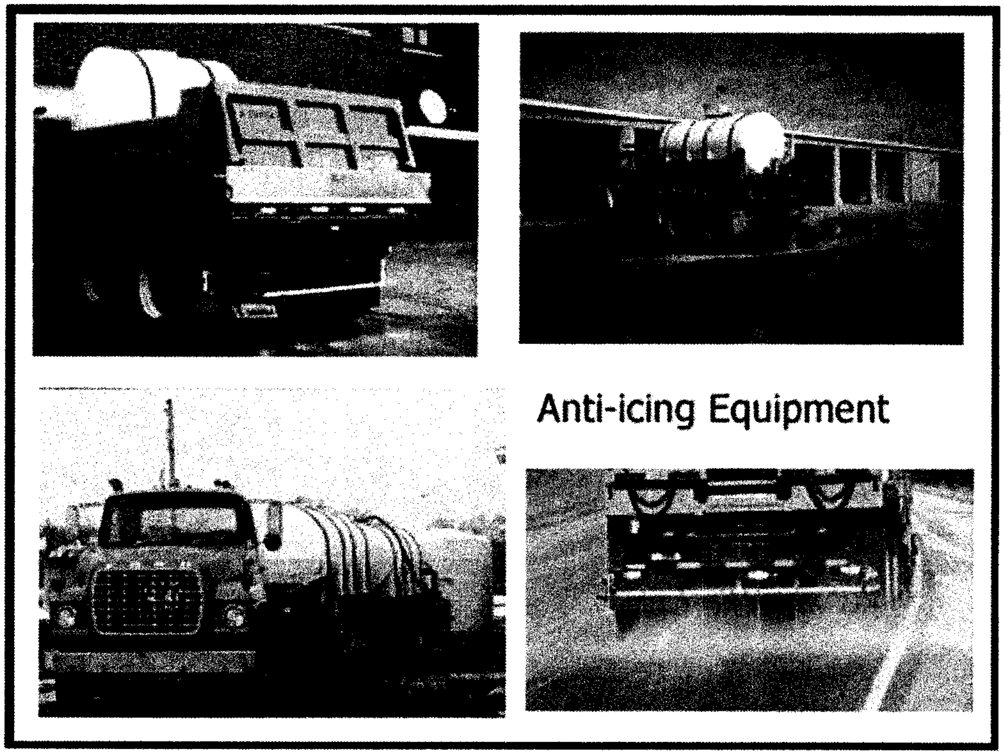
Liquid supply tanks use on spreader vehicles should be made of non-corrosive material such as polyethylene. Some states have used stainless steel tanks but this adds to the weight of the system. Refer to Figures 3-2 and 3-3 for examples of truck and spreader types utilized in anti-icing and prewetting programs.

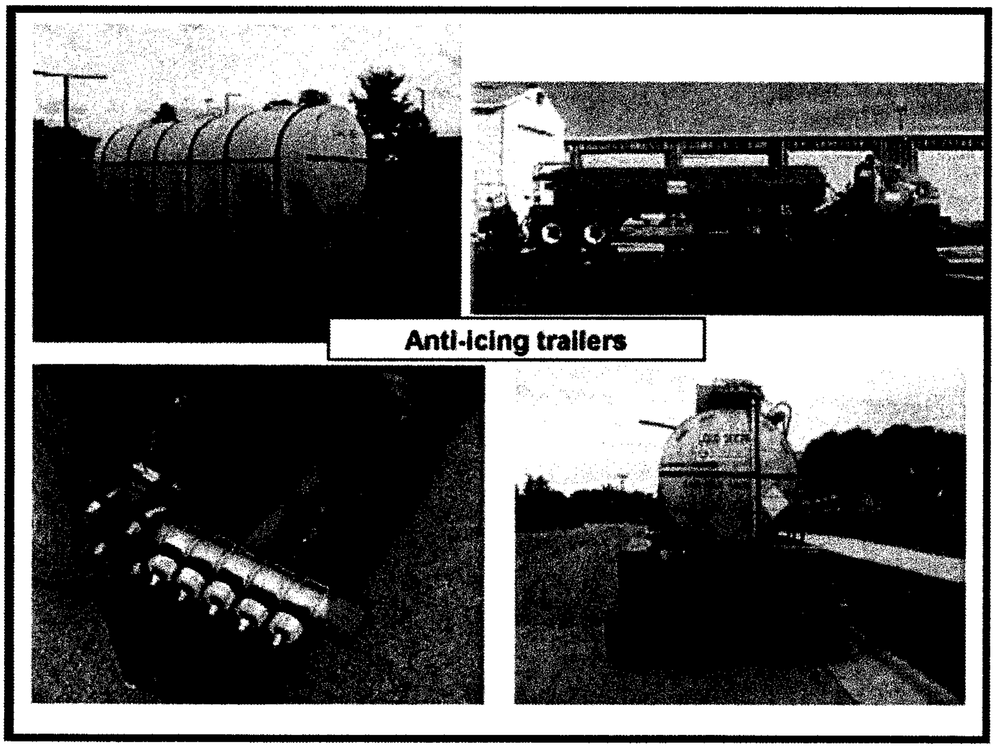
Fixed Anti-Icing

The New York City Department of Transportation (DOT) developed a fixed anti-icing system prototype for a portion of the Brooklyn Bridge (Appendix C). The system sprays an anti-icing chemical on the bridge deck when adverse weather conditions are observed. Anti-icing reduces the need to spread road salt, which has contributed to the corrosion of bridge structures.

The anti-icing system is comprised of a control system, a chemical storage tank containing liquid potassium acetate, a pump, a network of PVC pipes installed in roadside barriers, check valves with an in-line filtration system, 50 barrier-mounted spray nozzles and a Dynamic Messaging Sign (DMS). The DMS displays warning to alert motorists during spray operations. A closed circuit Television (CCTV) camera allows operators to visually monitor the anti-icing system.

In the New York City case, evaluation results indicated that the anti-icing system improves roadway mobility and safety in inclement weather. Bridge sections treated with the anti-icing system had a higher LOS than segments treated by snowplows and truck-mounted chemical sprayers. Road segments treated by the anti-icing system have less snow accumulation than sections treated conventionally (Figure 3-4). The system was most effective when chemical





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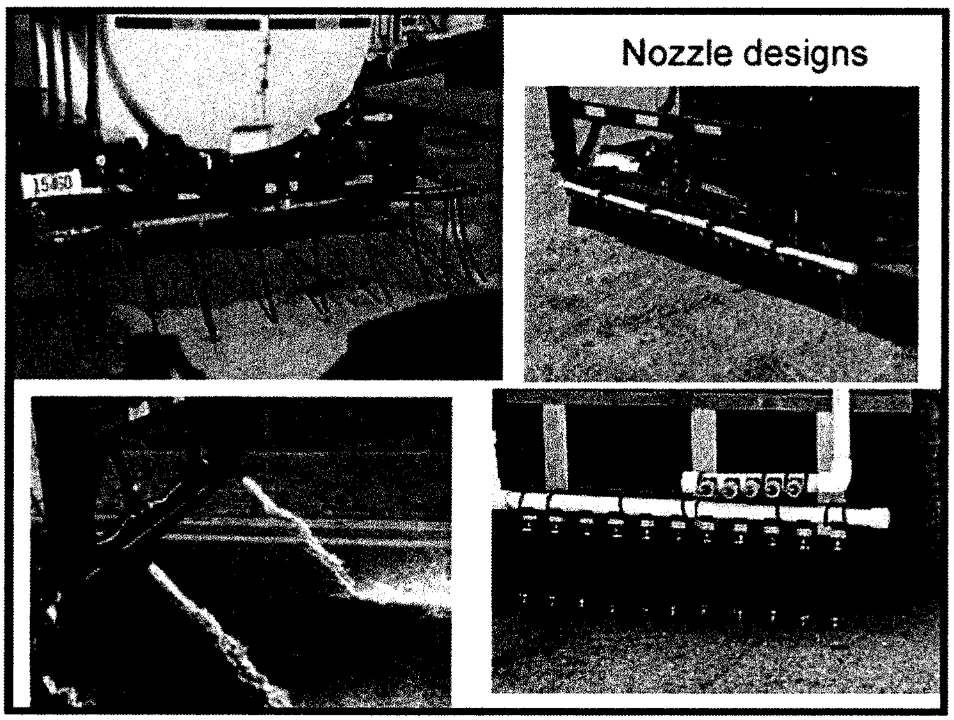
EXAMPLE SPREADER TYPES

FIGURE 3-2

LIQUID APPLICATIONS

PRE-WETTING

ANTI-ICING



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NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

EXAMPLE SPREADER TYPES

FIGURE 3-3

applications were initiated at the beginning of weather events. The system also improves productivity by extending the life of bridges and minimizing treatment costs associated with mobilizing maintenance crews, preparing equipment and traveling to treatment sites on congested roads.

Such a system might be feasible for the County to implement on bridges prone to icing, such as the Long Beach Bridge. Fixed anti-icing systems can be designed and installed as a component of a new bridge or road section or retrofitted during a bridge rehabilitation or roadway upgrade. Incorporating fixed anti-icing systems during the initial design and construction is considered more economical than retrofitting a system after construction.

3.4.3 Abrasives

Use of abrasives is sometimes advocated as an alternative to the application of freezing point depressant chemicals in an attempt to avoid perceived adverse environmental impacts of salting procedures. It must be understood, however, that abrasives are inert substances that provide limited traction. They must be used in large quantities and applied frequently, making abrasives more expensive than salt in terms of material and manpower. The City of Milwaukee, WI, in their Salting Policy, concluded:

> *"...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 be reapplied frequently. Sand builds up in catch basins and sewers, necessitating expensive cleanup"*

The use of sand is sometimes considered a cost effective alternative to utilizing more expensive alternative deicing chemicals such as CaCl, MgCl, CMA, other acetates or organics. However in these analyses, little consideration is given to the cleanup cost associated with sand that can clog sewers, catch basins, ditches and streams. After melting has occurred, abrasives

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NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

Dvirka and Bartilucci
CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

BROOKLYN BRIDGE FIXED ANTI-ICING SYSTEM

FIGURE 3-4

create after-the-storm hazards. On a dry surface, abrasive materials can become a spinning/skidding hazard until road crews remove it. A build up of abrasives can create problems such as unhealthy dust, smothered roadside vegetation, silted waterways, choked wetlands, plugged storm drains and costly spring season clean-ups. Table 3-7 presents a cost per lane mile comparison of abrasives and salt.

Abrasives may be an effective choice for servicing roads when pavement temperatures are below 20°F and sodium chloride is no longer an effective treatment option. A way to reduce the water quality impacts of sand application is to use "clean" sand (i.e., free of fine materials). The fine particles mixed in with sand can further increase stream turbidity and carry the majority of pollutants such as phosphorous and metals. In addition, street sweeping during the spring snowmelt and training sand application operators can reduce pollutant loads from road sanding.

A more judicious and cost effective means of treating roads at temperatures below the effective range for conventional deicing chemicals (i.e., sodium chloride) is the use of a mixture of a number of different chemicals. For example, the McHenry County DOT utilizes a mixture they call "Super Mix" to their local roads. They require approximately 80,000 gallons of Super Mix per season to cover their 550 lane miles of roadway. The anti-icing program currently covers bridges, overpasses and low average daily traffic (ADT) roadways. They have developed a manifold blending system with product controls consisting of a regulation station and flow meters. Super Mix is 85% salt brine, 10% Deice 55 (a commercial deicing product) and 5% calcium chloride. Super Mix has been found to be effective even at very low temperatures (between 3-6 degrees Fahrenheit) and has proven cost effective as well. By producing their own salt brine, the McHenry County DOT saves 17 cents per gallon. Their calcium chloride use and purchase has decreased as well. To date, a 10% reduction in salt used has been achieved.

3.4.4 Global Positioning Systems (GPS)

Several cities received FHWA Best Practices for their winter maintenance in 2005. Aurora, Colorado was listed for its maintenance vehicle management system. Used in snowplows and other winter maintenance vehicles, an integrated display, messaging and

Table 3-7

COST PER LANE–MILE COMPARISON OF SALT AND ABRASIVES

	Salt	**Abrasives**
Cost/ton	$41.24	$19.75
Added salt/ton	---	3.71
Mixing cost	---	0.75
Total	$41.24	$24.21
Application rate (ton/lane-mile)	0.112	0.375
Cost/lane-mile	$4.61	$9.08

Source: Town of Orangetown, NY

communications device lets operators text message each other and operation data is sent to a central computer every 20 seconds.

Using GPS, managers can tell which routes have been plowed, whether the plows blade is up or down, determine whether a spreader is being used and, if so, which materials are being dispersed. Use of this system reduced the winter maintenance costs and increased productivity 12%.

The city of Detroit and Oakland County, Macomb County and Wayne County, Michigan joined forces with the Suburban Mobility Authority to create a winter maintenance plan for the more than 15,000 lane miles for which they are responsible. Snowplow, communication and control systems are combined for joint use among the participant Counties. Sensors mounted on snowplows record air and pavement temperatures as well as material application rates. Computerized salt spreaders adjust salt application rates based on plow speed. A GPS receiver helps road managers locate equipment and assists in determining which routes require attention. Another component of the plan involves central computer maps, which combine winter storm conditions, snowplow locations and treatment types.

In addition to use of GPS for the collection and display of spatial data related to truck positions and progress on winter maintenance routes, there are further innovative uses for Geographical Information Systems (GIS) and GPS in winter maintenance practices. The University of Birmingham, UK, is developing a new generation of ice prediction techniques called Ice-Miser. The inspiration for a new system is a result of the proliferation of commercial "off the shelf" geomatics technologies; in particular GIS and GPS. The collection and display of spatial data and the synergy of geomatic techniques has enabled massive innovation in road ice prediction.

Ice-Miser takes a novel approach to road ice prediction by modeling the surface conditions at thousands of sites around the road network (typically every 20m of road) instead of modeling road conditions at a single site and interpolating temperatures by thermal maps. This is achieved by considering the influence of site-specific geographical parameters on the climatology of the road. Data is collected by a single survey of the sky-view factor (measure of the degree of sky obstruction by buildings and trees) along the road network. This is then combined with land use and elevation data in a GIS to produce a high-resolution geographical parameter database.

The geographical data is combined with meteorological data in a forecast model to predict road condition at typical spatial and temporal resolutions of 20 meters and 20 minutes respectively. The output is displayed as a color-coded map of the road temperature and disseminated over the Internet to the end-user. This sort of system is easily integrated with winter maintenance fleet-fitted GPS units for monitoring and exception reports.

3.4.5 Mobile Snow Melting Equipment:

Many winter maintenance managers are also experimenting with the use of mobile snow melting equipment and some have implemented this technology as a key component of their winter maintenance program.

For example, in the winter of 2005 the City of Evanston Illinois ordered a mobile snow melting unit capable of melting 60 tons of snow per hour in order to minimize the cost of hauling and disposing of snow. The City estimated the cost of having a contractor haul snow for them during a major snow event ranging from $12,000 to $28,000 per night depending on the intensity of the storm.

The mobile snow-melting unit cuts down on hauling costs by allowing City front-end loaders to dump snow directly into the unit's hopper, which melts snow directly into the City's storm sewer system. The City had previously experimented with a unit capable of processing only 40 tons per hour and found that crews were able to load the melter faster than the machine was capable of running.

In New York City, in order to hasten the cleanup after snowstorms, the Department of Sanitation employs a fleet of snow melting devices. After the DSNY tows a snow melter into place, trucks can cart piles of snow to it from the surrounding neighborhood. The device filters snow in order to catch debris, melts it and releases the 50-degree water that results directly into the sewer. The mobile snow melting units utilized by the city process 60 tons of snow per hour discharging about 240 gallons of water per minute. The City currently has a fleet of approximately 10 diesel powered snow melters, which it obtained at a cost of $183,000 a piece. Table 3-8 presents the melting capacity of a commercial snow melting unit and compares operating costs with the costs of hauling snow.

Mobile snow melting units may prove useful in any congested area where disposal sites for plowed snow are scarce. These could include downtown areas where snow piles might prohibit access to on-street parking or any area where snow piles could obscure drivers' line of vision whereby creating hazardous driving conditions. Hauling often proves to be a less cost effective alternative when the costs of truck operation and required man-hours are taken into account. In instances where snow-dumping sites are distant to the location from which snow was removed, snow melting units may prove a particularly cost effective alternative.

3.5 Post-Winter Operations

Improvements in operations and equipment can be identified through a post-storm assessment of the practices and treatments used. It is important that all levels of maintenance personnel, from district level supervisors to equipment operators, be involved in these evaluations. As part of the post-storm assessment, it is suggested that the highway agency track the cost and effectiveness of their program and if possible evaluate the effectiveness of alternative programs utilized in comparable locations. This process should include evaluations of treatment effectiveness and examinations of cost.

Evaluations of treatment effectiveness need to be based on a number of information sources. This is a crucial part of a dynamic snow and ice control program, rather than a static program that responds to different varieties of winter weather events with the same prescribed methods.

Table 3-8

COST COMPARISON OF SNOW MELTING VERSUS SNOW HAULING OPERATING COSTS

Melting/Hauling Capacity (ton/hr)	Melting Operating Costs/hr	Hauling Operating Costs/hr	Savings with Snow Melting/hr	Savings (%)
20	$69.00	$186.67	$117.67	63%
60	$177.00	$560.00	$383.00	68%
135	$347.00	$1,260.00	$913.00	72%
350	$805.00	$3,266.67	$2,461.67	75%

Notes:

1) The cost of loading hauling trucks and snowmelters is identical.
2) The melting operating costs are directly related to the amount of fuel used.
3) Snow hauling trucks carry 6-ton loads with a 30-minute turnaround time.
4) Snow hauling truck operating costs are assumed to be $112/hr.

Source: http://www.snowmelter.com/cost.html

Treatment effectiveness can be monitored through the visual observation or precipitation/weather and pavement conditions from patrols and operators. Additional means of determining effectiveness include a measurement of the chemical concentration on the pavement (in order to time reapplication of chemicals) and measuring the frictional resistance sliding of the pavement.

The cost data of a storm or weather event can be organized according to the total costs for materials, labor and equipment employed in operations. For chemicals, this includes:

- Purchase price
- Transportation to storage site
- Storage
- Truck loading
- Handling and mixing of solid chemicals
- Solution preparation

For abrasives, cost considerations include both materials costs and any associated cleanup costs. The costs and effectiveness evaluations of the anti-icing and conventional operations should be recorded separately for each highway segment or route considered. The cost per lane mile can then be calculated for each type of operation and the relative success of the two operations can be compared.

3.6 Recordkeeping

Determining whether or not procedures are effective or there are benefits to performing certain procedures can be a difficult or involved process for an agency to undertake. Agencies have little guidance on how to document benefits. Opportunities to document benefits range from comparing costs when using different strategies and tactics to evaluating the results of procedures using measures of performance such as level of service goals.

A May 2001 report prepared for the National Cooperative Highway Research Program entitled "Benefit/Cost Study of RWIS and Anti-icing Technologies," examined several studies conducted by the Strategic Highway Research Program and the American Association of State Highway and Transportation Officials to determine the effectiveness of anti-icing. The May 2001 report found that these studies, conducted in the mid-1990's, failed to produce quantitative measures of the benefits of anti-icing because none of the participating transportation agencies (including New York State DOT, Ohio DOT, Colorado DOT, New Hampshire DOT, Iowa DOT, California DOT and Washington State DOT) had developed a formal performance measurement program that could be used to assess the benefits of anti-icing.

Nassau County currently records the following data relevant to their snow and ice control operation:

- Sand usage (tons per season)
- Salt usage (tons per season)
- Snowfall (inches per season)
- Number of callouts per season
- Amount expended per budget year
- Year to date material cost per mile per storage/deployment facility
- Year to date sand and salt usage (tons per storage/deployment facility)
- Man-hours expended on winter maintenance operations

Although these are all important pieces of information about a winter maintenance program, there are additional items that, if monitored, could assist the County in honing the material use efficiency of their winter maintenance program. For example in their snow and ice control program, which involves the usage of some liquid chemicals, the Minnesota Department of Transportation keeps records of:

- Daily sand/salt use (per route per truck)

- Amount of sand/salt returned to yard (per route per truck)
- Amount sand/salt loaded by loader to each truck

A special documentation form for anti-icing tracks:

- Air temp, pavement temp, relative humidity, dew point and sky conditions
- Reason for choosing an anti-icing strategy
- Route number
- Chemical used
- Application time
- Application amount
- Driver observations (first day following application, after the snow event has ended and prior to the next application)

A bare lanes data collection sheet tracks the following:

- Date/time of event start
- Date/time of event end
- Event type
- Road condition description
- Route number
- Bare lanes lost (date/time)
- Bare lanes regained (date/time)

Implementation of alternative and more extensive record-keeping strategies improves the ability of road managers to gage the effectiveness of their winter maintenance program. The effectiveness of specific treatments at various temperature ranges and in various storm conditions can help refine treatment strategies. Detailed records of weather conditions, road conditions and material used and application rates are crucial to decisions about timing of application and material choices. Managers can hone their treatments and application rates for various types of storms to maximize the efficiency of resource allocation (e.g., man-hours, materials, equipment, etc.).

4.0 RECOMMENDED BMPs FOR SAND/SALT

Based on the analysis of existing sand/salt storage and application practices implemented by the County and on an evaluation of potential alternative BMPs, this section presents recommendations for sand/salt BMPs that could feasibly be implemented as part of the County's winter maintenance program. A collection of sand/salt BMPs from federal, state and private agencies can be found in Appendices D to G.

4.1 Background

Prior to laying out a strategy for the most efficient snow and ice control strategies for a particular road management agency, it is important to establish a set of goals or set of operational guidelines that establish the timing, type and frequency of treatments. These goals are deemed Level of Service (LOS) guidelines.

For example, a road management agency may have certain priority areas where a bare pavement LOS is always in effect during winter storm events due to the volume of traffic at these sites or the frequency of accidents that occur there. Other, secondary roads may be given a lower LOS priority. It is important that all maintenance managers and crew have a firm concept of the LOS determination for all road networks on their routes.

When a road agency is attempting to establish LOS goals, these goals (i.e., a bare pavement policy) are driven by climate conditions in terms of what is and is not possible. Certain recurring site conditions (microclimates) are climate driven and require specific recurring operational responses. These include cold spots, high humidity locations, persistent windy areas, etc.

In addition, the average long-term weather conditions influence the strategies and tactics chosen by road managers to support LOS goals. In any climate, the achievable LOS is limited by the rate of precipitation, cycle time capability, sustainability of the maintenance effort, site conditions that may cause road closure and materials options.

This LOS determination helps clarify the priority routes to both managers and operators and can assist a road manager in making staff effort allocation decisions. For example, heavily trafficked roadways prone to high accident frequencies may be designated to have a bare pavement LOS within an hour following a storm and may require more attention than lower priority roadways.

According to the National Cooperative Highway Research Program (NCHRP) 2004 Report 526 entitled "Snow and Ice Control: Guidelines for Materials and Methods," a "design" winter event should be utilized as the basis for determining what LOS can be provided with existing resources or determining the necessary resources to provide a desired LOS. A snowfall rate of "X" inches per hour should be chosen. "X" should be a rate that is only exceeded in "Y" percent of snowfall records in an average year (from climatological records). The "Y" value of approximately 20% should be selected.

Two components of a winter weather event are important in determining LOS. These include the amount of loose snow/ice/slush that is allowed to accumulate between plowing cycles and the condition of the ice/pavement in terms of bond and packed snow/ice.

The amount of loose snow that should be allowed to accumulate on the roadway between plowing cycles is the driving force for plowing resource requirements. Plowing operations are limited to one lane at a time while material spreading operations can treat more than one lane at a time. Once the allowable amount of loose snow/ice has been established, the necessary equipment resource can be determined.

First, the local plowing production rate in terms of lane miles per hour (including reloading and deadheading) has to be determined. This, in conjunction with design snowfall rate, yields the cycle time required to meet the accumulation goal. Sufficient equipment has to be provided to achieve the desired cycle times.

Major snow and ice control operational considerations, exclusive of transportation agency resources, are:

- Climate;
- Weather;
- Site conditions; and
- Traffic.

Each has a profound effect on some aspect of operations.

Aside from these broad concerns, it is important to anticipate and think strategically about how a storm will be handled. Important considerations include:

- Expected start time of storm
- Expected type of precipitation
- Expected amount of precipitation
- Expected duration of storm
- Expected road surface temperature

Winter maintenance personnel are mostly concerned with anticipated winter weather conditions and not with climate considerations. Weather usually refers to the measurable or identifiable meteorological events that occur at a given site or in a given area at a particular point in time. Important meteorological variables are:

- Precipitation
- Sky or cloud conditions (solar radiation effects)
- Air temperature (to the extent it establishes the trend in pavement temperature)
- Dew point temperature

- Condensation
- Pavement temperature
- Relative humidity
- Wind speed and direction
- Evaporation

Condensation occurs when the pavement or bridge deck temperature is above 32° Fahrenheit and below the dew point temperature. Frost, on the other hand, occurs when the pavement temperature is at or below 32° Fahrenheit and below the dew point temperature. It is common for bridge deck surfaces to develop frost even when the adjacent highway surfaces do not. The prediction of these icing conditions is particularly difficult, especially for areas with elevation changes and varied roadside vegetation coverage.

Traditional weather forecasts, private forecaster services, radar and temperature sensors are helpful in predicting the timing, duration and type (i.e., snow, sleet, rain) of a predicted storm, but because snow and ice control is highly dependent on pavement temperature, Road Weather Information Systems (RWIS) and vehicle mounted pavement sensors are more valuable to road maintenance workers for an effective storm response strategy. Location of RWIS pavement and air temperature sensors, discussed Section 3.0, in these sensitive areas can be helpful in detecting the onset of frost conditions.

Site conditions are those local situations that affect how snow and ice control operations are conducted. They influence type of equipment, material choices, material application rate, priority and sequence of treatment and type of treatment. Important/influential site conditions include:

- Area type (i.e., urban, suburban, rural)
- Special highway/roadway segment areas (i.e., hills, curves, grades, intersections, bridges, etc.)

- Shading from solar influence (i.e., forest/vegetation, buildings/structures)
- Pavement conditions (i.e., temperature, ice/pavement bond, frost or thin ice, slush, loose snow, packed snow, thick ice)

Traffic considerations include those relating to operational difficulty (i.e., slow and fast moving traffic, stranded/obstructing vehicles); timing (i.e., rush hour, congestion); and influences on treatment effectiveness and longevity. The variation of traffic rate throughout the day is an important consideration in the operational decision making process.

Vehicular traffic can affect the pavement surface in several ways. Tires compact snow, abrade it, displace it or disperse it. Heat from tire friction, engine and the exhaust system can add measurable heat to the pavement surface. Traffic can also result in applied chemicals and abrasives being blown from the pavement surface when applied before precipitation or the migration/spray of chemical laden brine to the side of the road and roadside vegetation.

Climate and weather forecasting are the key factors in the planning phase of snow and ice control operations. The difference among climate zones is in the distribution of expected precipitation class events. This generalized expected precipitation classification, determined from historical trends, allows road managers to gauge which snow and ice control techniques are most practical and establishes a baseline for quantities of materials required, sizes of fleets and other important winter maintenance factors.

The ability to forecast and recognize the various types of precipitation is of crucial importance. This influences to a large degree the type of treatment, material choice and material application rates. Site conditions, especially pavement temperature, the status of precipitation accumulation and the presence of an ice/pavement bond are major factors when deciding on material type and application rate.

Many snow and ice control practices are evolving and strive to balance the need to provide safe and efficient transportation opportunities and carefully manage and minimize adverse environmental impacts of snow and ice control practices while remaining economically sensible for municipalities.

The use of forecasting systems in conjunction with pro-active anti-icing and pre-wetting/pre-treating strategies can help maximize the efficiency of salt and abrasive application by customizing application rates to pavement and precipitation conditions. These activities can help save time and man-hours that would normally be spent in conventional deicing activities because the snow-pavement bond is prevented from forming. The effort normally required to break this bond can be used to more effectively treat a greater number of lane miles.

4.2 Procurement and Receipt of Snow and Ice Control Materials

The unloading of sand and salt at County storage facilities usually takes place outside either on asphalt or unpaved (dirt) surfaces and may remain there for hours awaiting transfer to the indoor facility. Materials spilled, leaked or lost during unloading may collect in the soil and have the potential to be carried away by storm water runoff or infiltrate into the soil. Additionally, rainfall may wash pollutants from machinery used to unload or move materials.

Utilize the following BMPs for procurement and receipt of snow and ice control materials:

- **Unload and load materials either indoors or on impervious surfaces:** Salt and sand should be loaded and unloaded either indoors or on impervious bituminous concrete pads or concrete that has been treated with a sealant.
- **Control storm water runoff:** Collect salt lost during outdoor unloading operations before being allowed to enter into the municipal storm drainage system or infiltrating into the groundwater. Grade and/or berm the unloading area if possible to a drain that is connected to a dead-end sump to collect storm water.
- **Plan for deliveries:** Develop an operations plan that describes procedures for unloading. Schedule unloading of sand and salt materials under dry and calm weather conditions. When practical, deliver salt as late as possible in the fall to minimize the exposure of the salt pile to fall and early winter rains. Wind and rain can spread the salt to unprotected areas or create brine runoff. Park tank trucks or delivery vehicles in designated areas so that spills can be contained. Limit the exposure of materials

with the potential to contaminate storm water. Cover designated areas to reduce exposure of materials to rain. Avoid placing storm drains in the area.

- **Prevent "double-handling" of materials:** Minimize the number of times chemicals are handled. Blow salt into storage facilities using a closed pipe system to eliminate double-handling. Whether mechanically piled or blown, each handling can cause particle breakdown, segregation and loss.

- **Keep accurate records of deliveries:** Maintenance should include keeping a log of the amount of sand or salt received and data on the delivery.

- **Conduct regular inspections:** Check loading and unloading equipment regularly. Make repairs as necessary. The frequency of repairs will depend on the age of the facility.

4.3 Salt Storage Facilities and Technologies

This section presents recommendations for best management practices related to salt storage facility design and operation. These BMPs will strive to minimize the concentrations of salt and sand conveyed from storage sites in storm water runoff. Good storage facility and municipal yard design and salt handling practices are essential to preventing unnecessary salt loss and the resultant environmental impacts.

4.3.1 Salt Storage Facilities:

Utilize the following BMPs for salt storage facilities:

- **Choose salt storage sites according to environmental conditions:** Locate and operate salt storage sites to minimize impacts to the natural environment and control nuisance effects including noise, dust, litter and visual intrusion on adjacent landowners. Sites should be as centrally located as possible to minimize the number of sites required. A proper selection of the storage site reduces the potential for groundwater contamination.

  Winter route times and service levels are the determining factor in establishing the numbers of staff and equipment that must be allocated and housed. However, when evaluating the existing system of maintenance yards, there is more to consider than simply efficiency improvements. This provides an opportunity to achieve the most functional design with positive environmental returns. The benefits of environmental protection should outweigh the inconvenience of constructing a facility at an alternate location.

Consider all functions conducted at a maintenance yard when designing the most suitable layout and features for the yard. Considering the cycle of handling road salts in the yard may reveal potential enhancements that can be made to improve yard efficiency and reduce salt loss. The typical salt handling cycle flows from delivery, to stockpiling, to loading on the spreader and then to exiting the yard. Upon return, the spreader offloads unspent salt, and then the equipment is washed to remove remaining salt residue. Each area affected by these activities can provide an opportunity for improvement.

- **Conduct an environmental impact statement:** Understand the underlying soil and rock characteristics and use and proximity to and sensitivity of surface water, groundwater and salt sensitive sites in order to evaluate the potential impacts from the presence of salt. A properly conducted environmental impact assessment, emphasizing the risks associated with maintenance activities, will present site-specific constraints and engineering solutions.

  When selecting the site for a new maintenance yard, important considerations include:

  – Proximity to the road network to be serviced.

  – Site physiography and topography.

  – Ground conditions.

  – Floodways and floodplains.

  Each of these factors influences the strategies for achieving the drainage management objectives.

- **Minimize infiltration:** For example, unlike granular bases, clay bases will prevent rapid infiltration of salt laden water.

  Keeping a minimum distance from receiving water bodies reduces the possibility of surface and groundwater contamination. When planning and designing road maintenance yards, salt vulnerable areas must be taken into account. Salt sensitive sites include:

  – Areas draining into bodies of water with low dilution, low volume or salt sensitive species.

  – Areas adjacent to salt sensitive vegetation, agricultural areas, protected wetlands and water supply reservoirs.

- Areas draining into a source of drinking water (surface water and groundwater); and areas associated with groundwater recharge zones or shallow water table, with medium to high permeability soils.

- Protected wellhead areas of community water supplies or private wells.

- **Store salt piles indoors if possible:** Promote indoor operations where possible and place stockpiles inside storage structures to protect the salt from direct precipitation year-round. Sheltering is the most important component of the salt storage facility design and can often compensate for the lack of other practices. Properly constructed salt storage sheds can be highly effective in protecting surface and groundwater.

  Take into account various elements in the design of a storage structure to prevent the loss of salt from the facility. Design the storage facilities so that they are large enough to hold the maximum load of chemicals required seasonally without overflowing. Some structures provide a more efficient capacity than others depending on the intended methods of putting up the piles as well as in using the materials. Structure designs range from domes, to rectangular sheds or barns to high arch structures and elevated silos. Storage structures can be made of a variety materials including: wood, steel, aluminum, fiberglass or fabric. Construct and position the roof and exterior of the storage structures out of waterproof material so that precipitation, moisture and snowdrifts are prevented from entering the building. Provision of a roof overhang, particularly where the door or opening is located, is a proper precaution.

- **Enclose the base of the pile with a concrete wall:** Walls need to be designed to withstand the strain of materials and loaders pushing against them. They must be free of gaps that would allow salt or salt impacted drainage to escape. It is recommended that the wall and foundation be an integral structure at least to the highest point of salt stockpiling. The two general approaches to the wall design are continuous and buttress.

- **Pave contact areas with impermeable surfaces:** It is particularly critical that the County initiates loading and unloading of salt on impermeable surfaces at those DPW locations where these activities are currently conducted on unpaved areas. Pave any site that comes in contact with salt or salt-contaminated storm water, including storage, mixing and loading areas, with a concrete mix that has the lowest permeability and can withstand alternate cycles of freezing and thawing. Do not install drains in the floor slab inside the storage building. Minimize the size of the loading and unloading area to reduce costs and the amount of storm water that needs to be contained.

- **Grade the area around the salt pile and loading area:** Raise the foundation to an elevation higher than the surrounding terrain to prevent run-on and to keep the interior slab dry. Develop and implement a detailed grading plan to prevent salt contaminated storm water runoff from coming into contact with unpaved areas where it can infiltrate into the groundwater. Paved areas should not contain slopes greater than 2.5 to 3%. Design the final grading to slope away for drainage purposes.

- **Design for storm water runoff control:** The first priority in storm water runoff control is to prevent the formation of brine and polluted storm water. However, chemicals do come into contact with storm water. Implement a system of controlling salt-laden runoff (from exposed piles or from spillage during loading/unloading operations) retained in the storm water management system. It may be advantageous to install ditches, pipes and tiles where necessary for effective drainage with a minimal environmental impact to receiving waters. Divert runoff from roofs and surrounding areas away from contaminated mixing and storage sites. Design and size drainage channels for the maximum volume of storm water. Use impervious and non-corrosive materials for all drainage facilities. Inspect drainage structures for damage, corrosion, obstructions and crystallized salt regularly.

- **Channel salt-laden runoff into collection areas:** It is an environmentally sound and cost-effective solution to channel salt-laden storm water runoff to a specially designed sump area or collection point for reuse as brine or a pre-wetting agent. Provide a brine storage/holding tank of sufficient capacity to prevent overflow from several minor storm events and avoid frequent pumping. Manage for the maximum volume of storm water runoff that can be expected during a 60-hour period. Design the storm water system to contain all salt contaminated storm water generated on the site so that no salt contaminated storm water will reach the unsaturated zone. If the holding tank is not large enough to contain several winter storms, then provide an overflow containment pond or adequately sized, impermeable storage area. Continue to capture salt-laden runoff for a short while after the end of the snow season after salt handling activities at the facility are over.

  Control salt-laden storm water runoff at all facilities by one of the following methods:

  - Storage in a holding area, such as a storage tank, until the tank becomes relatively full and then removing the brine for use as a liquid snow and ice control material.

  - Onsite storage of salt-laden runoff to be pumped back onto the storage pile as a pre-treating agent.

  - Onsite storage for eventual disposal at a special facility.

- **Dispose of salt-laden runoff properly:** Never dispose of salt-laden runoff in the soil or in fresh surface waters. Remove the brine solution form the holding tank at regular intervals throughout the year. Dispose of the brine by discharging to one of the following:

  - A secondary or tertiary sewage treatment plant outfall pipe (not directly into the treatment plant that discharges to marine waters).

  - Primary treatment plants where it may be discharged into marine waters.

– Directly into marine waters.

All such discharges must be NYSDEC approved.

- **Cover outdoor salt piles:** Not all road jurisdictions can afford to house all their stockpiles inside buildings. These maintenance facilities have a high potential for salt loss generally from unprotected salt or sand/salt piles and spillage during the handling of salt. Salt and sand/salt mixes must be covered to protect them from the elements and prevent runoff of salt-laden water to drainage systems year-round. Salt stored in bins or on pads must be covered with a suitable waterproof material and collection/treatment of runoff from uncovered materials is recommended. Coverings must be appropriate for the size and shape of the stockpile, and for the methods of receiving salt shipments and loading out during storms.

  The storage of salt piles outdoors on low permeability asphalt or concrete pads covered with tarps is not recommended. It is difficult to maintain tarps and keep the piles covered, which can result in salt loss. In some cases, a plastic liner under sand piles is used to contain and collect drainage. This practice, although preferable to unlined sand/salt piles, poses problems with covering the piles.

- **Uncovered piles should be windrow shaped:** This will minimize the impact of northwesterly winds upon the pile. The working face should be maintained perpendicular to the long axis of the pile by loading alternately left/right and right/left. Avoid creating a horseshoe shaped working face that results from removing the center of the pile and leaving extended edges or aprons. Plant vegetation around exposed piles to reduce the effect of winds.

- **Store salt piles on impermeable surfaces:** Facilities where outside storage is necessary, place stockpiles on impermeable asphalt or concrete pads and covered with tarps or other temporary coverage methods year-round.

- **Minimize salt losses:** Spillage during stockpiling and spreader loading is a major source of salt loss. Carry out these activities under cover (either indoors or under an outdoor canopy) to minimize salt loss. If loading and stockpiling activities are conducted outside, make an effort to collect any lost salt immediately following these activities. The presence of an outdoor canopy is essential to outdoor loading and stockpiling activities to prevent lost salt from entering storm water runoff.

  Collect and reuse or properly manage salt impacted site drainage and vehicle wash water to comply with local water quality regulations and protect surface and groundwater resources. Handle materials and clean up spilled salt to minimize salt loss to the environment. Maintenance personnel should sweep the site after all loading, mixing or transportation operations to collect any lost salt or abrasives. Clean trucks, spreaders and other equipment of loose salt and residue before leaving the loading area.

- **Minimize other pollutants associated with salt storage:** Collect and dispose of onsite contaminants and wastes in accordance with local waste management legislation. Control emissions (drainage, noise, dust, litter, fumes) to prevent off-site impacts.

4.3.2 Salt Brine Production:

The production and storage of salt brine on DPW premises is a feasible and cost effective alternative or complement to traditional solid material storage practices. Mixing rock salt or solar salt with water makes salt brine. Brine concentration should be approximately 23% NaCl (Public Works Magazine, April 2000). The proportion of salt to water is critical to the effectiveness of the brine.

Utilize the following BMPs for salt brine production:

- **Handle materials in covered areas:** Perform all mixing, handling and loading of chemicals in covered areas or where storm water and brine controls are in effect.

- **Use a 23.3% salt content by weight brine solution for anti-icing treatments:** Too much or too little salt affects the freezing point depressing qualities of the brine. A solution with 23.3% salt content by weight achieves the concentration at which salt brine has the lowest freezing point temperature of -6°F. This is known as the eutectic point.

- **Measure the salt concentration of brine solutions:** Salt concentration in a brine solution is measured with a salometer, a specialized hydrometer. Salt is added to the water until an 88.3% salometer reading is obtained. Salt concentration can also be measured with a hydrometer, which measures the specific gravity of the solution, which will increase as the concentration increases. A table of hydrometer readings and corresponding salt concentration for a solution temperature of 15°C (59°F) is presented in Table 4-1.

  Commercial brine makers are available at a cost of about $5,000. Many agencies have less costly do-it-yourself brine makers, assembled using water tanks and PVC pipe. Brine is usually made at the local maintenance facility sites and stored in large tanks in locations convenient for loading into saddle tanks on the sides of the V-box or anti-icing equipment.

- **Utilize salt brine production plants:** Simple NaCl brine manufacturing plants that can operate relatively trouble-free became a necessity with the use of salt brine or prewetted salt for anti-icing treatments. Highway agencies working with private companies have designed a number of salt brine production plants. As a result, there are several companies that manufacture salt brine production systems.

The following should be considered in specifying of designing a brine manufacturing plant:

- Future need for additional capacity.
- Adequate water inlet capacity.
- Suitability of the proposed site from an operational and environmental standpoint.
- Pump capacity requirement.
- Possibility of using earth heat for storage tanks.
- Overflow control requirement.
- Containment of spills.
- Use of non-corrosive material in plant production.

4.4 Mobilization and Deployment

Treating roads prior to the formation of a bond between the road and any accumulating precipitation is an efficient and economical strategy for winter road maintenance. Many innovative technologies designed to allow crews to deploy with maximum efficiency given the existing weather conditions and forecast predictions are being developed. The Road Weather Information Systems (RWIS) and Maintenance Decision Support System (MDSS) are two technologies available to assist road managers in making decisions on the implementation of early anti-icing programs. RWIS and MDSS are discussed fully in Sections 3.3.1 and 3.3.2 respectively. The County should consider the implementation of these tools once they are fully developed and available on the market.

Accurate weather information is essential to effective winter road maintenance. Possible sources of this information, according to NYSDOT, include:

Table 4-1

SALT CONCENTRATION VS
WEIGHT OF SALT IN BRINE SOLUTIONS

Percent Salt	Specific Gravity at 15°C (59°F)	Percent of Saturation	Weight of salt kg/m^3 (lb/gal)
0	1.000	0	0 (0)
5	1.035	20	51.8 (0.432)
6	1.043	24	62.7 (0.523)
7	1.050	28	73.5 (0.613)
8	1.057	32	84.6 (0.706)
9	1.065	36	95.9 (0.800)
10	1.072	40	107.2 (0.895)
11	1.080	44	118.9 (0.992)
12	1.087	48	119.8 (1.000)
13	1.095	52	131.8 (1.100)
14	1.103	56	154.7 (1.291)
15	1.111	60	166.8 (1.392)
16	1.118	63	178.9 (1.493)
17	1.126	67	191.5 (1.598)
18	1.134	71	204.3 (1.705)
19	1.142	75	217.2 (1.813)
20	1.150	79	230.1 (1.920)
21	1.158	83	243.4 (2.031)
22	1.166	87	256.8 (2.149)
23	1.175	91	270.3 (2.256)
24	1.183	95	284.1 (2.448)
25	1.191	99	293.3 (2.448)
25.2	1.200	100	

Source: Federal Highway Association – Innovative Environmental Management of Winter Salt Runoff Problems in INDOT Yards

- **NOAA Weather Radio Network:** The National Oceanic and Atmosphere Administration (NOAA) of the U.S. Department of Commerce provides continuous broadcasts of the latest weather information directly from National Weather Service offices. Residency radio scanners equipped to pick up the 162.550 M Hz frequency from New York City can monitor NOAA Weather Radio broadcasts.

- **Private weather forecasting services:** There are a number of private weather forecasting companies that offer a variety of services.

- **In-house weather radar and live video:** This provides excellent data on storm location and timing.

- **Knowledge, experience and communication with locations in the storm path:** Over time, professionals develop a sense of local weather patterns. It is recommended that supervisors in light vehicles having communications capability patrol areas likely to be affected by a predicted storm even for the purpose of directing the appropriate response. In addition, certain bridges and sections of highways tend to be problem spots. This information should be communicated to all employees that are likely to have winter road maintenance responsibilities for those areas. When general storms are approaching, communication with locations closer to the storm will yield valuable information on the timing and character of the storm as well as information on the cessation of the storm.

- **Other sources of weather data:** Local radio and television stations provide some weather information. The amount and priority are a matter of local station policy. Also, cable television provides access to 24-hour weather channels. Various kinds of internet weather information can be provided by computer access through a selection of subscription vendors. Local and national newspapers contain varying amounts of weather information.

- **Reverse 911:** Services such as Reverse 911 can quickly notify road crews or alert citizens of potentially dangerous weather and roadway conditions.

4.5 On Road Application and Treatment

This section presents recommendations of best management practices to be implemented by the County during the treatment phase of winter maintenance operations. These recommended BMPs would strive to increase the efficiency of operations by reducing the quantity of materials used, maximizing response time, minimizing environmental impacts and maximizing driver safety.

4.5.1 Anti-icing:

Anti-icing is a proactive and preventative approach. It helps keep the road ice-free throughout the storm event and can be particularly effective in supporting strict requirements for safe road conditions during a winter storm. Anti-icing practices provide maintenance managers with two major capabilities: the capability for maintaining roads in the best conditions possible during a winter storm and the capability to do so in an efficient manner. A comprehensive discussion of anti-icing is provided in Section 3.4.2.

Utilize the following BMPs for an effective anti-icing maintenance strategy:

- **Apply before the start of the storm:** Anti-icing is particularly effective a treatment prior to the onset of the storm, using liquid chemicals for anticipated frost and preferential icing situations. The timing of the operation is crucial. Time applications such that the formation of bonded snow and ice to the road way is prevented. By continuing the strategy throughout the event there should be a very rapid recovery or achievement of a satisfactory pavement condition after the end ofthe event. Anti-icing produces very high within-winter weather event and after-winter weather event LOS.

  Much more judgment on the behalf of the road maintenance manager is required in the anti-icing decision making process than is necessary to implement a deicing strategy. Available information sources must be utilized methodically and the operations must be anticipatory or prompt in nature. Figure 4-1 presents an outline of an anti-icing program in the context of a winter maintenance program.

- **Apply anti-icing liquid chemicals when pavement temperatures are above 23° Fahrenheit:** Anti-icing with a liquid chemical is a good strategy when the pavement temperatures are above 23° Fahrenheit at the onset of a snowfall event. It is not a good strategy when the pavement temperatures are below 23° Fahrenheit at the onset of a snowfall event or at any freezing pavement temperatures when the snowfall event is preceded by rain. The use of chemical freezing-point depressants below these minimum pavement temperatures will require excessive amounts of chemicals to be used.

- **Plow after salt application:** Following the initial salt application, plowing can proceed to remove continuing snow accumulations. Additional salting is only required to ensure sufficient traction. Therefore, a chemical such as road salt, due to its freeze point depressing characteristics, effectiveness, cost efficiency and ease of handling, is critical to restoring safe road conditions where snow and ice conditions occur.

- **Apply dry solid anti-icing chemicals only in moist conditions:** The use of dry solid chemicals as an anti-icing treatment can be effective in many circumstances, but only those where there is sufficient moisture or accumulation on the pavement. Moisture must be available for two reasons:

  – To prevent the loss of material off of dry pavement (bouncing to the ditch)

  – To trigger the solution of the salt in water

  An advantage of utilizing dry solid chemicals for an anti-icing program is that the material and equipment requirements are similar or identical to those used conventionally. For initial operations, solid chemicals will be effective when a maintenance team has the operation resources to apply the chemical as soon as possible after sufficient precipitation has fallen, but before snow pack or ice bonds to the pavement.

  This is a strategy sometimes referred to as "just-in-time" anti-icing. This is in contrast to early anti-icing programs that rely on the application of liquid or pre-wetted solid chemicals early in the day of an expected storm. For this early anti-icing strategy, less reliance on RWIS and pavement monitors is required for the initial application because timing is not as crucial as it is in "just-in-time" anti-icing operations. These tools are still crucial in determining the timing and the rate of application for subsequent treatments following the onset of the storm.

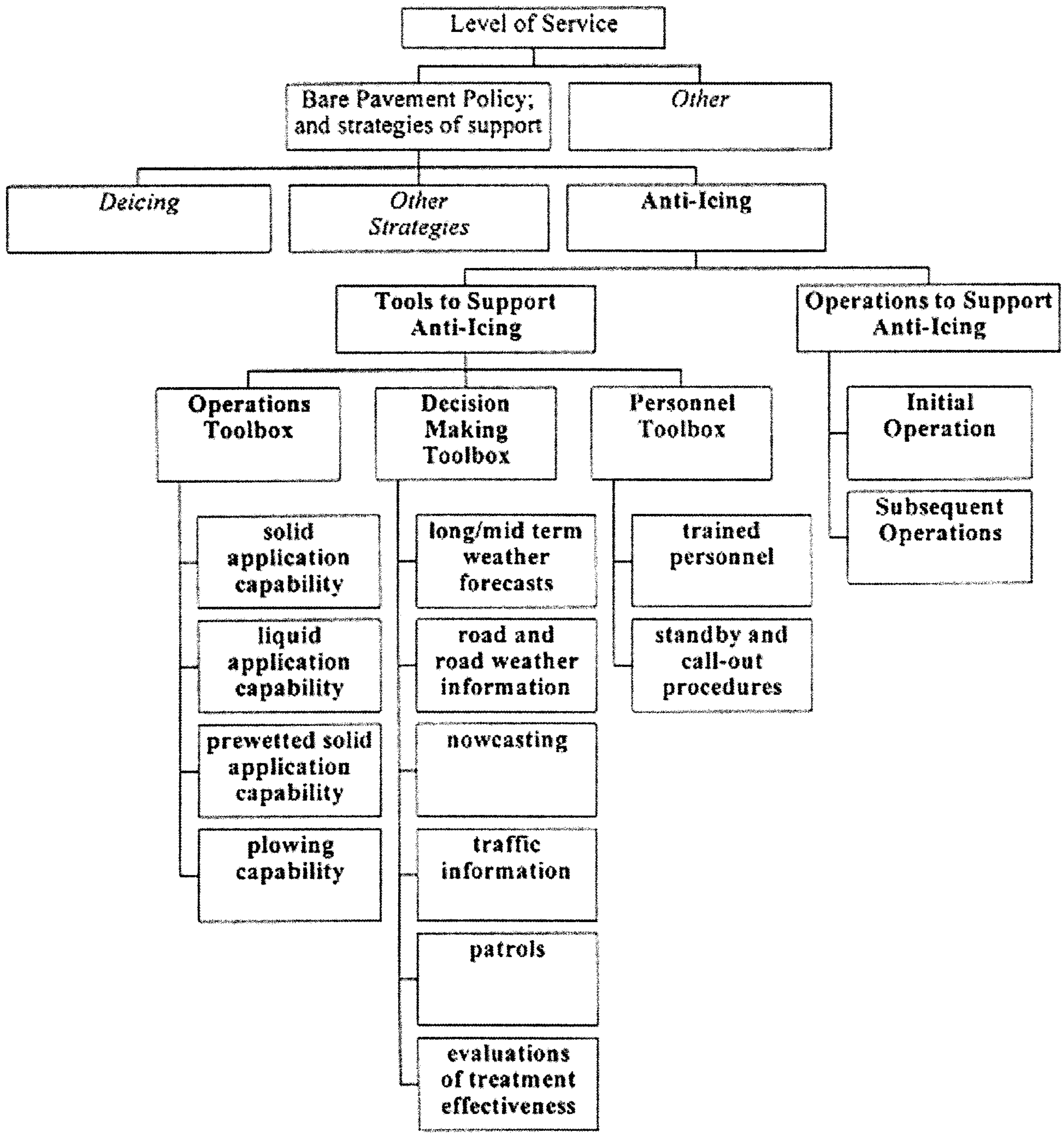
- **Consider available solid chemical dispersal technologies:** In the Town of North Hempstead, the Department of Public Works has adopted a new technology for the application of solid chemicals to their roadways. Eight Epokes are a supplement to their normal fleet of plows, sand spreaders and salt trucks. An Epoke is a type of spreader that grinds salt into a fine powder, which melts ice twice as fast as normal salt.

- **Use weather and road condition prediction technologies where available:** According to a March 2001 Report entitled "Benefit/Cost Study of RWIS and Anti-icing Technologies," prepared for the National Cooperative Highway Research Program, a fully-implemented strategy of roadway anti-icing used in conjunction with RWIS can be an effective strategy to improve the snow and ice control LOS. The report also concluded that this strategy could reduce the costs of providing a specified LOS.

- **Keep detailed records of anti-icing activities:** The National Cooperative Highway Research Program report emphasized the need for agency's to employ detailed record-keeping systems. A good documentation program should, at a minimum, address:

  – Material purchases

  – Rate of material use



RLA/FIGURES/NASSAUCO2423(01/03/07)

NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

OUTLINE OF ANTI-ICING PROGRAM IN THE CONTEXT OF A WINTER MAINTENANCE PROGRAM

Dvirka and Bartilucci CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

FIGURE 4-1

- Target LOS for each route

4.5.2 Brine Application:

Brine applicators are commercially available for about $1000. Some agencies have manufactured their own application equipment using large tanks and PVC piping. Some equipment is designed to be loaded onto the bed of spreading trucks, towed behind maintenance equipment or permanently mounted on truck beds. Systems can be as simple as gravity spread sprayers with operator controlled cutoff valve or can be more complex like a pump driven sprayer system.

Utilize the following BMPs for brine application:

- **Control the application of brine:** Use control measures to vary spraying rates from 25 to 60 gallons per lane mile. If large, horizontal tanks are used in the design, consider installing baffles inside the tanks to help prevent the liquid from suddenly shifting in the tank, creating a hazardous control situation for the operator.
- **Store brine according to temperatures:** The decision whether to use inside or outside storage facilities for a liquid freezing point depressant chemical solution depends on the freezing temperature of the solution and the lowest air temperature expected in the area.

4.5.3 Pre-wetting and Pre-treating with Liquid Ice Control Chemicals

As dry materials are deposited on the roadway, particles of salt can bounce or scatter to the sides of the road. Several techniques have been developed to reduce the loss of salt to the side of the roadway. Better distribution techniques, such as windrowing on the crown of the road and more accurate spinners are being used. Additionally, techniques involving the pretreatment or Pre-wetting of solid salt are being implemented to prevent bouncing and migration. Liquids also increase salt's effectiveness by jump-starting the melting process. Because Pre-treating and Pre-wetting cause material adhere to the road, 20 to 30% less material is used, saving money and reducing environmental impacts.

The wetting of solid chemical prior to spreading can improve the effectiveness of the solid chemical in many situations. The primary function of the liquid in Pre-wetting is to provide the water necessary to start the brine generation process for the solid chemicals. A solid chemical requires energy to go into solution and a dry solid chemical particle will remain inert until a liquid film forms. The process of going into solution will be accelerated if a liquid is added to the solid's surface. Prewetted and pretreated salt is already wet and therefore starts to form the brine that is needed to break the ice-road bond more quickly. When used on abrasives, the liquid helps the solids adhere to the ice surface and provides some ice control chemicals to the roadway that may at some point improve LOS.

- **Pre-wetting**: A widely used technique for keeping the salt on the road and increasing the speed of the melt action is "Pre-wetting." Pre-wetting involves spraying liquid salt brine onto the solid salt as it is being spread. This makes the salt sticky and allows it to adhere to the road better. Studies show that Pre-wetting can increase the retention of salt on the road to 96% as compared to about 70% with dry salt application.

  Most commercially available liquid ice control chemicals can be used for Pre-wetting so lid ice control chemicals, abrasives and abrasive/solid chemical mixes. Pre-wetting solutions can be made from sodium chloride (NaCl, salt brine), calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$).

- **Pre-treating:** Pre-treating is mixing a liquid into the stockpile of salt or sand before it is applied. Unlike Pre-wetting, it does not require equipment changes and requires no new capital investment for equipment (Minnesota DOT). When Pre-treating a salt stockpile with a liquid deicing chemical, such as MgCl or CaCl or acetates (CMA), approximately 6 to 10 gallons of liquid should be applied per ton of salt.

4.5.4 Abrasives

If the conditions are favorable, salt should be the first choice for deicing. The use of abrasives when salt will work encourages the formation of a compacted snow layer. The overall resource requirements for dealing with a compacted snow layer are far greater than preventing a compacted snow layer by the timely use of salt. Winter sand and other abrasives can be used when temperatures are too cold for deicing chemicals to be effective. Abrasives will not assist in melting snow and application should be highly limited during the implementation of an anti-icing operation. The cost of cleanup incurred by the use of abrasives makes them an imprudent complement to an anti-icing program.

Utilize the following BMPs for abrasives:

- **Do not use abrasive applications if salt will be effective:** Abrasive applications should not be a routine operation of a winter road maintenance program because of the cost associated with both application and clean up of roads and drainage facilities (clogged catch basins, etc.) and because of the potential airborne dust problem accompanying their use. In addition, the use of abrasives creates little improvement to winter roadway conditions. When anti-icing operations have successfully mitigated the hazards associated with packed snow or ice, straight abrasives will provide no significant increase in friction or improvement in pavement condition.

- **Use abrasives in the proper locations:** Abrasives should generally be used where low traffic volume and/or low pavement temperatures will preclude salt from working properly. Abrasives may be used initially in some circumstances where salt will work. These include steep slopes and other situations where the normal working time associated with salt could result in road blockage by vehicles stranded due to lack of traction.

  Abrasives should be spread as near to full pavement or lane width as possible. Traffic quickly diminishes the effect of abrasives and frequent re-application is necessary. Depending on the road and traffic conditions, speeds of spreader trucks should be in the range of 15 mph to 35 mph.

- **Mix in a small amount of salt:** A small amount (approximately 5%) of salt must be added to abrasives in order to keep the sand in a workable or spreadable condition and have them adhere to the snow or ice. Mix sand and salt on sunny, calm days.

  However, a mix of abrasives with high salt ratios will usually be no more effective as an anti-icing treatment during snowstorms than the same amount of chemical placed alone. If spread at the normal application rate for abrasives, a 50-50 mixture of sand and salt will place 40% more salt on the road than a normal application of pure salt. In addition, the effectiveness of that salt is reduced by the presence of the abrasives.

- **If abrasives are used, clean up after the thaw:** Such actions include: street sweeping and pick up of sand from roads and shoulders in a timely manner, removal of excess sand from intersections, ramps, gutters and paved ditches and clean up of catch basins near the end of the snow season. Clean up processes should be done manually or by sweepers, never by washing equipment that flushes the material to the storm water conveyance systems. BMPs for these operations are documented in the County publication entitled "Generic Operational Storm Water Pollution Prevention Plan for Department of Public Works Facilities."

4.5.5 Deicing

In contrast to anti-icing operations, a common procedure of traditional snow and ice control practice is to wait until an inch or more of snow accumulates on the pavement before beginning to plow and treat the highway with chemicals or abrasives.

Utilize the following BMPs for deicing:

- **Use anti-icing techniques when possible:** While deicing is straight forward, it frequently leads to a compacted snow layer (pack) that is tightly bonded to the pavement surface. A subsequent deicing of the pavement is then necessary, usually requiring a large quantity of chemical to work its way through the pack to reach the snow/pavement interface and destroy or weaken the bond. Because this operation is reactionary (vs. anticipatory), it requires less judgment on the part of managers than anti-icing. Yet as a result of its inherent delay, it often provides less safety, at a higher economic burden, than anti-icing.

  Nonetheless, the reactive technique of deicing will remain important for snow and ice control, as there will always be lower priority service levels that preclude preventative measures. Deicing usually produces lower within-winter weather event and after-winter weather events levels of service than those produced by more proactive, anticipatory methods. Deicing will require more chemicals than anti-icing to produce the same LOS.

- **Deice in temperatures above 20-degress Fahrenheit:** Deicing is a suitable strategy for most weather, site and traffic conditions except when the pavement temperatures are below 20° Fahrenheit. Deicing operations can be accomplished at temperature lower than 20° Fahrenheit, but the number of chemical applications and/or chemical application rates will be excessive and the time to accomplish deicing will be long. Chemical treatments are usually initiated later in a winter weather event and continued well after the end until a satisfactory pavement condition is reached.

  Do not use salt when temperatures are very low. Usually snow will not bond to the pavement and can be effectively substantially removed by plowing. Traffic will then whip the rest of the snow away. In this situation salt may make the snow stick to the pavement causing icy spots.

- **Use deicing materials during the correct time of day:** The time of day when chemical treatments are applied can greatly influence their effectiveness. For example, applications during mid-morning sunny skies and 18-20-degree Fahrenheit air temperatures will allow the salt to work as the day warms up and traffic conditions dry the pavement. However, if it is a 25-degree Fahrenheit afternoon, salt should be used with caution because temperatures will usually fall after sundown and the roads may re-freeze. If necessary, abrasives should be applied in this situation. This concept of not salting should not be implemented without careful consideration. A written plan should be in place that specifies when salting should and should not occur.

- **Use the appropriate amount of deicing materials:** It is important to note that in any deicing activity, an appropriate amount of salt must be used. The majority of over-salting can be prevented by using calibrated, speed-synchronized spreaders and good judgment in selecting application rates and truck speeds (Minnesota DOT). It is not necessary to melt all of the snow or ice on the road with salt. This is an unnecessary overuse of materials. Instead, apply just enough to loosen the bond between the road and the ice so it can be plowed off.

  Salt is placed through the use of spreaders. Do not load spreaders beyond their capacity. Overloaded spreaders are prone to spilling salt during operations. New spreader technology allows road maintainers to place exactly the right amount of salt in the correct location regardless of the operating speed of the spreader. Furthermore, electronic spreader controls permit a better understanding of the amount of salt being used so that proper applications are documented and wasteful practices can be identified and corrected.

  The preferred spreading pattern of the salt will be dictated by the type of road, number of lanes being spread and the character of the storm. Depending on the road and traffic conditions, speeds of spreader trucks should be in the range of 15 mph to 35 mph.

- **Inspect and calibrate equipment:** It is important that the right amount of salt is placed to achieve the objective. Accurate calibration of equipment can assure that the rate of deicing agents spread provides the rate intended. Check equipment periodically for adjustment and proper functioning such as spinner speed or drop location. Timing of application is crucial and is highly effective in reducing the salt applied on the road.

4.5.6 Plowing Capability

Types of snowplows include one-way front plows, reversible plows, deformable moldboard plows, underbody plows, side wings and plows specifically designed for slush removal. All plows are hydraulically controlled. In most cases, it takes only a short while to mount and dismount the plows using a quick-change buffer system.

Hydraulically extendible plows have recently been developed. The width of the plow can be extended to the left or right hand side, depending on the manufacturer. These plows are best suited to roads that vary in width. The extendible plows typically allow width adjustment between 3 and 4m (9-12 ft). Missouri's Department of Transportation uses 14-foot plows to clear 12-foot lanes in just one pass.

Utilize the following BMPs for plowing:

- **Prepare vehicles:** Mount a few plows well in advance of the anticipated date of the first snowstorm. As more consistent winter weather approaches, additional units should be readied. All plows should be mounted by a date determined by the previous experience of the location. During the winter season, equipment should be serviced at the end of each storm and at opportune times during a storm.

- **Plow prior to the application of chemicals:** The primary role of snowplowing in an anti-icing operation is to remove as much snow or loose ice as appropriate before applying chemicals in order that excessive dilution is avoided and the applied chemical can be effective. Because, in anti-icing operations, the initial chemical treatment should be placed before a significant accumulation, plowing is generally more important for subsequent operations. However, prior to liquid applications, it is essential that the pavement be cleared of as much snow or loose ice as possible, which may be important even for the initial operation.

- **Keep cutting edges as close to the pavement as possible:** Keep the cutting edge as close to the pavement as possible in an attempt to remove all the snow and slush. Thus, the use of casters or shoes on the plow is not recommended. Inspect cutting edges on each shift and change as necessary in order to prevent moldboard damage and wear.

- **Use the appropriate blade for road type and ice conditions:** Cutting edges are available that are made of synthetic polymers, rubber, steel and carbide inserts. Their performance is dependent on highway snow and ice conditions.

  So-called slush plows have been developed in Sweden and Finland that use two blades, the leading blade having a cutting edge of steel and the trailing blade having an edge of rubber. This design is more effective over a wider range of conditions than is possible with either blade alone. The double blade plows are very good when the consistency of slush varies.

  Rubber blades are effective only in the removal of wet slush. The wetter the slush, the thicker the rubber blade can be. The slush blades are either spring loaded or hydraulically controlled to maintain pressure on the road surface. These blades cannot remove wet or compacted snow because of their flexibility; they will fold back and become ineffective.

- **Install snow stakes:** Install snow stakes at locations of possible obstructions within the plowing and winging area that may interfere with the snow removal process. Install stakes before the ground freezes and well in advance of the first anticipated snowfall. Stakes should be tall enough to extend above the anticipated depth of snow in the area. Paint, flag or tape the top six inches of the stake to provide better visibility.

4.5.7 Preventing Snow Drifts

Snow drifts will occur when the local wind speed exceeds the threshold speed of 9.3 mph. Threshold speed is the limiting speed below which the wind will not lift and transport snow particles. Once these conditions exist, the wind will transport the snow towards the roadway in a thin layer close to the ground. As long as there are no obstructions to slow the wind, the snow will blow across the roadway and will not accumulate. This slowing of the winds can be caused by an obstruction such as tress, shrubs, posts, guide rails, fences or a change in the terrain such as a ditch. Even parts of the road itself can create a snow drifting problem. For example, if a road is divided by a median and the upwind lanes are higher than the downwind lands, drifting can occur on the downwind lanes. Also, bridges and interchanges can create drifting problems around piers and abutments. The objective of snow fences (non-living or living) is to leave little snow left to drift onto the roadway by encouraging a snow drift immediately downwind of the fence or vegetation.

Utilize the following BMP for preventing snowdrifts:

- **Use snowfences:** Strategic use of snowfences can prevent the drifting of snow onto heavily trafficked roadways. This can help reduce the cost and effort of snow removal on heavily trafficked roads prone to the accumulation of drifting snow. Snow fences are already a component of the Nassau County Department of Public Work's snow and ice control strategy. However, the possibility for more widespread implementation of this tactic should be evaluated.

  Snowdrifts will vary according to the location. Snowfences should have 40% to 50% porosity and be of adequate height to store the expected amount of snow that will be blown through the location. Snowfences should be place at a distance of 35 times the height of the fence from the road to ensure that the drift generated by the fence will not encroach onto the roadway. If the fence becomes full during most winters, the height should be increased and the distance from the roadway adjusted accordingly.

It is more cost effective to adjust the height of a single fence than to add additional rows of fences. A taller fence not only traps more snow, but also much more effectively improves driver visibility and requires less land.

All fences should have a gap at the bottom to prevent the fence from being buried. The gap should be 10% of the total fence height. Orient the fence parallel to the road except when the prevailing wind direction is more than 30 degrees from perpendicular to the road. Extend the fence 50 feet beyond the area to be protected to prevent snow from being blown around the ends of the fence.

- **Use shelterbelts:** Shelterbelts are single or multiple rows of plantings. They have a lower cost than snowfences, wildlife and aesthetic benefits, little or no maintenance after establishment and long service life. Shelterbelts will perform similar to snowfences during the first several years of growth. After crown enclosure is attained, the plantings will perform more like a solid barrier.

  Trees and woody plants are better as they do not tend to bend as much under the weight of the snow. Always plant salt tolerant species in areas subject to salt spray. The plants should be placed no closer than 3 times their mature height from the road. Plant two or more staggered rows of trees to provide full coverage and to prevent gaps caused by plant loss or damage. Space the trees so that crown closure will be achieved within five to ten years. Protect the plantings in the first few years with temporary snowfences. Ensure that the fence drift does not bury the new plantings.

- **Modify roadway features:** Provide aerodynamic cross sections so that the roadway is swept clear by the wind. Flatten backslopes and foreslopes to a 1:6 slope or flatter. Widen ditches as much as possible. Ditches should be adequate enough to store the snow plowed off of the road. Widen cuts to allow for increased snow storage. Eliminate the need for guiderails. Replace W-beam guiderails with cable guiderails where possible. W-beam will perform like a miniature snowfence and should be removed or replaced with cable whenever possible.

4.5.8 Maintaining Storm Water Control Structures

Snow and ice accumulations on the side of the road can block storm water control structures. This can crate hazardous flooding and ponding situations during periods of thaw. Through knowledge and experience, the critical storm water control structures should be identified. It is important to maintain their functionality throughout the snow and ice season.

Utilize the following BMPs for maintaining storm water control structures:

- **Clear snow and ice from critical areas:** In order to maintain safe roadways and protect against flooding and freezeovers, the tops of catch basins, drop inlets and bridge drainage systems should be cleared of snow and provided with reasonable means to prevent possible development of ice. Prior to thaws and subsequent runoff, remove packed snow and ice from the ends of culverts and their inlet and outlet ditches. At the beginning or middle of winter, the snow should not be removed if the water is flowing adequately underneath the snow because this might cause the water to freeze.

- **Apply salt to critical structures:** If a system is likely to freeze up, deicing chemicals may be periodically applied. However, salt vulnerable areas need to be identified and the potential for salt impacted drainage to affect these vulnerable areas must be assessed. Special design modifications to traditional storm water management measures may be warranted to protect these salt vulnerable areas. Measures may include clay or geosynthetic liners in conveyance ditches and ponds, infiltration ponds where appropriate or use of storm sewers to transport drainage past vulnerable areas.

4.6 Post-Winter Operations

Improvements in operations, equipment and materials can be identified through a post-storm assessment of the practices and treatments used during the storm.

Utilize the following BMPs for post-winter operations:

- **Maintain equipment:** Perform major repairs and overhauls of winter road maintenance equipment well in advance of the anticipated time of need. Lubricate, protect and paint stored equipment (plows, spreaders, snowblowers, etc.) prior to storage. Thoroughly check and run this stored equipment prior to the time of anticipated need. Proper preventive maintenance and daily maintenance on multi-seasonal equipment is a good way to ensure readiness and proper performance.

- **Maintain the physical integrity of facilities:** Regularly inspect pad, drainage, collection and other systems affecting potential discharge of storm water runoff from the site. Perform preventive maintenance such as periodic resealing of the pad to ensure non-degradation of the low permeability of the pad and base. Expansion joints must be resealed when necessary. Take other corrective action as needed to maintain storm water discharges at levels consistent with best management practices and/or discharge permits.

- **Use a number of sources of information in winter road maintenance evaluations:** Involve all levels of personnel in the evaluation process, from the district level supervisors to equipment operators. Use visual observations, meteorological data and pavement condition information in the evaluation of your program.

- **Track costs and effectiveness of winter road programs:** Review the results of the winter road maintenance to confirm that the program is achieving the desired results and to adjust the next year's maintenance options to respond to shortcomings and new opportunities. Quantify the total costs and per route costs of a storm even using materials, labor and equipment cost information. Include the costs of cleanup if abrasives were used during the storm. If possible, evaluate and compare alternative programs utilized in comparable municipalities. Update policies and procedures prior to next season. Integrate this review into the budgetary process to permit timely acquisitions of new equipment and to identify other funding needs. Communicate progress on implementation to senior management, local politicians, staff and the public.

4.7 Recordkeeping, Documentation and Training

4.7.1 Record Keeping and Documentation

Document progress in winter road maintenance programs. Record typical items such as meteorological and road conditions, materials used, the results of routine inspections, reported spills or other discharges, etc. Record keeping is usually coordinated with internal reporting and other BMPs. Record keeping is a basic business practice. Keeping records will aid in a more efficiently and clean winter road maintenance program. Records contain useful information for improving winter road maintenance and Best Management Practices (BMPs). Where there are new issues or activities being implemented as part of the winter road maintenance programs, new monitoring initiatives may be required. If a separate record keeping system for tracking BMPs, monitoring results, etc., is not currently in place at a facility, existing record keeping structures can be easily adapted to incorporate this data. NYSDEC recommends that recordkeeping reflect the organization of the municipal government and its operations. This should facilitate and simplify both collecting information and communicating BMP information to field staff.

Records should include:

- The date, exact place and time of material inventories, site and equipment inspections, observations, equipment maintenance and calibrations, etc.
- Weather information for each storm event.
- Names of inspector(s) and observers(s).
- Analytical information including the date(s) and time(s) analyses were performed or initiated, the analysts' names, analytical techniques or methods used, analytical results and quality assurance/quality control results of such analyses.
- The date, time, exact location and a complete characterization of significant observations.
- Notes indicating the reasons for any exceptions to standard record keeping procedures.
- All calibration and maintenance records of instruments used.
- All original strip chart recordings for continuous monitoring equipment.

4.7.2 Training

The training of winter road maintenance personnel to safely and efficiently perform their duties should be a continuing effort. Basic training for new employees and focused training for specific programs is essential for effective implementation. For example, anti-icing techniques and operations may be so foreign to many operators and managers that old ideas must be banished before a workable program can be started. Everybody resists change, but change in most cases is what is required for an anti-icing program to be successful. The result of training is a change in attitude and habits.

An anti-icing program will necessitate more information for making an informed decision and may involve different methods and materials than do conventional programs. This will require and emphasis on training. A consultant or highway agency staff can accomplish this training using a number of government manuals.

At this year's North American Snow Conference, the Anti-Icing/RWIS Computer-Based Training (CBT) program was released for sale through the APWA bookstore. The objective of the training was to develop and deliver a comprehensive training program on anti-icing strategies, RWIS and snow and ice control materials and equipment. Another objective was to provide training on procedures for the personnel responsible for decisions regarding the LOS to be provided on highways and streets under winter conditions.

Successfully implementing RWIS and anti-icing strategies requires a shift in the way winter maintenance is carried out. Merely presenting the material in a classroom setting would have limited success in changing the culture of winter maintenance. Maintenance engineers and workers need more than the principles of RWIS and anti-icing. Applying the knowledge through decision-making during winter storms and understanding the outcome of those decisions are important to success.

The performance-based training model requires students to demonstrate proficiency by successfully performing a series of tasks. To remove the risk associated with poor decisions during actual winter storms, the training program utilizes a series of storm scenarios or simulations for students to practice what they have learned. To purchase a copy of the Anti-icing/RWIS Computer Based Training for the Nassau County DPW, contact the APWA Bookstore at www.apwa.net/bookstore or call the Member Services Hotline at (800) 848-APWA, ext. 3560.

BMPs for training include the following:

- **Provide general and targeted training:** Include a comprehensive training program that demonstrates the purpose and value of new procedures and ensures that personnel are competent to carry out their duties. Address worker training at an early stage. Municipal employees who are directly involved in winter road maintenance should receive both general storm water and targeted BMP training tailored to their activities. This will increase the likelihood that receiving waters and the storm drain system will be protected.

  It is important to train all municipal staff, however, regardless of field responsibilities, about general storm water awareness. Very often, municipal staffs are residents as well and improving the awareness of municipal employees may reduce residential impacts and increase reporting of illicit discharges, dumping and spills. Also, because municipalities expect residents and business owners to practice pollution prevention and good housekeeping, municipal employees should set an example for the rest of the community to follow.

- **Include basic concepts of winter road maintenance in training programs:** Incorporate salt application policies, the chemistry and application of salt, principles of ice formation, material use, weather forecasting, the environmental issues, good housekeeping practices, record keeping, equipment operation and relevant decision-support information.

- **Use multiple training techniques when available:** Managing the learning environment is critical to the success of the knowledge transfer. Perceptions vary so material should be presented in different ways. Instruction methods should include a combination of verbal and visual aids, group discussion and practical application. Employees can be taught through:

  - Posters, employee meetings, courses, workshops, conferences, videos, bulletin boards, paycheck inserts and email notices and

  - Field training programs followed by a discussion of site-specific BMPs by trained personnel.

  Pollution prevention and storm water management BMP training materials are offered by numerous federal and state agencies and professional and nonprofit organizations. Establish and continue employee rewards or recognition programs for those who participate. In addition, seek employee ideas on pollution prevention methods and priorities for winter road maintenance.

- **Include key program components:** These programs can be standardized and repeated as necessary, both to train new employees and to keep objectives fresh in the minds of more senior employees. A training program is also flexible and can be adapted as a facility's needs change over time. Key program components and specific criteria for implementing an employee training program include:

  - Ensuring strong commitment and periodic input from senior management.

  - Communicating frequently to ensure adequate understanding of pollution prevention goals and objectives.

  - Utilizing experience from past pollution incidents to prevent future pollution.

  - Making employees aware of BMP monitoring and reporting procedures.

  - Developing operating manuals and standard procedures.

- **Make training an on-going process:** An employee-training program should be a continuing, yearly process to ensure that the appropriate learning goals are taught, reinforced and tested. Schedule yearly training for each fall, close to the onset of the snow and ice control season and include seasonal and contracted personnel. Hold periodic refresher sessions to correct unacceptable behavior and reinforce expectations.

- **Track employee's work practices and training:** After training, it is helpful for managers to periodically check employees' work practices to ensure BMPs are implemented properly. Periodic unscheduled inspections of facilities and maintenance activities will allow managers to gauge what has been learned. Posting reminders at facilities of proper procedures. Stenciling or marking all storm drains at municipal facilities will prompt employees to be conscious of discharges. Make facility BMP guidance documents available to all employees as a reference to use after training.

APPENDIX A

FEDERAL HIGHWAY ADMINISTRATION –

THE WINTER MAINTENANCE DECISION SUPPORT SYSTEM (MDSS):

DEMONSTRATION RESULTS AND FUTURE PLANS

18.4

THE WINTER MAINTENANCE DECISION SUPPORT SYSTEM (MDSS): DEMONSTRATION RESULTS AND FUTURE PLANS

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1. INTRODUCTION

Managing a winter maintenance program today is an increasingly complex endeavor. Just making sure that a plow blade is at the ready when the first flake falls is only a small part of the task. With tight budgets and the high expectation of the public for keeping roads clear of snow and ice, today's maintenance manager has to be able to handle multiple tasks or risk getting behind the onslaught of winter weather. All of the regulations about chemical applications, environmental impacts and multiple, often contradictory weather forecasts can lead to information overload.

The Federal Highway Administration (FHWA) recognized this potential problem in the late 1990's. Generally speaking, there were plenty of weather forecasts, along with a few companies that issued road-specific forecasts, but there was a lack of linkage between the information available and the decisions made by winter maintenance managers. It was this weak link that became the genesis for the winter Maintenance Decision Support System (MDSS).

The MDSS has since matured into a functional prototype. During the winter of 2002-2003, the prototype was deployed at several maintenance garages in central Iowa for a field demonstration. This paper will document the implementation of the demonstration, a summary of lessons learned, verification statistics, and technology transfer activities. It will also describe plans for a longer, more comprehensive demonstration during the winter of 2003-2004.

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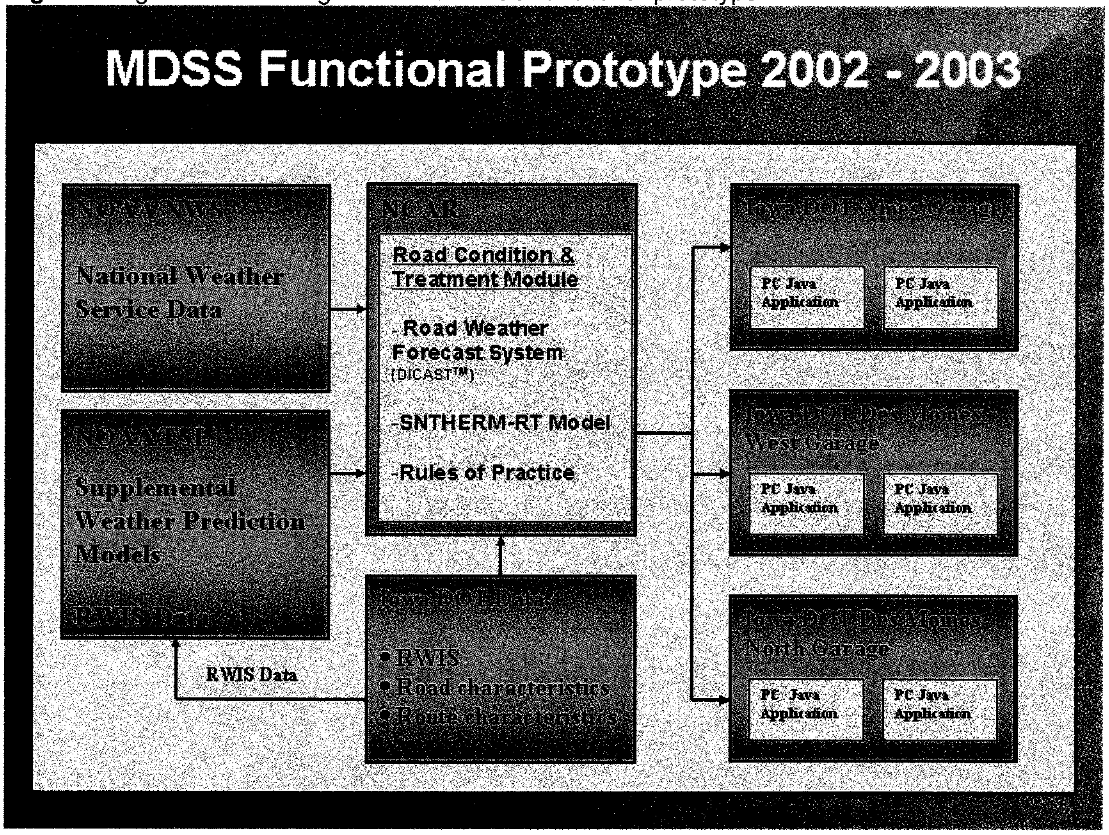
2. System Overview

The MDSS is a research project that is funded and administered by the FHWA Road Weather Management Program. Five national laboratories have been participating in the development and implementation of the project. Participating laboratories include:

- Army Cold Regions Research and Engineering Laboratory (CRREL)
- National Center for Atmospheric Research (NCAR)
- Massachusetts Institute of Technology – Lincoln Laboratory (MIT/LL)
- NOAA Forecast Systems Laboratory (FSL)
- NOAA National Severe Storms Laboratory (NSSL)

The MDSS project attempts to take state-of-the-art weather forecasting and data fusion techniques and merge them with computerized winter road maintenance rules of practice. The result is a set of guidance aimed at maintenance managers that provides a precise forecast of surface conditions and treatment recommendations customized for specific routes.

Figure 1 High-level flow diagram of the MDSS functional prototype



Each laboratory brings unique capabilities and expertise to the project. Much of the software used in the core MDSS modules has been reused from other projects and tied together via inter-process communications.

Figure 1 shows a high-level flow diagram for the MDSS functional prototype that was used in the winter 2002-2003 demonstration. The top box in the left column represents data received from the National Weather Service (NWS). These data include both surface observations and numerical model output from both the ETA and GFS (Global Forecast System – formerly known as AVN) models.

The lower box in the left column represents supplemental mesoscale numerical weather prediction models that were provided and run by FSL. These models were the MM5 (Mesoscale Model 5), the RAMS (Regional Atmospheric Modeling System) and the WRF (Weather and Research Forecasting model).

In order to provide diversity into the data fusion module, FSL used the NWS models to provide lateral boundary conditions to initialize each mesoscale model. Hence, four times per day, FSL would generate six model solutions for the forecast domain (Figure 2).

Figure 2 Model domain for the MDSS demonstration. Area under the red star represents the approximate demo area.

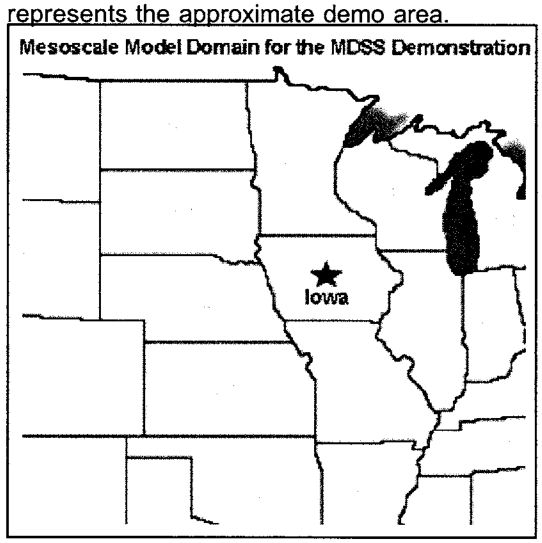
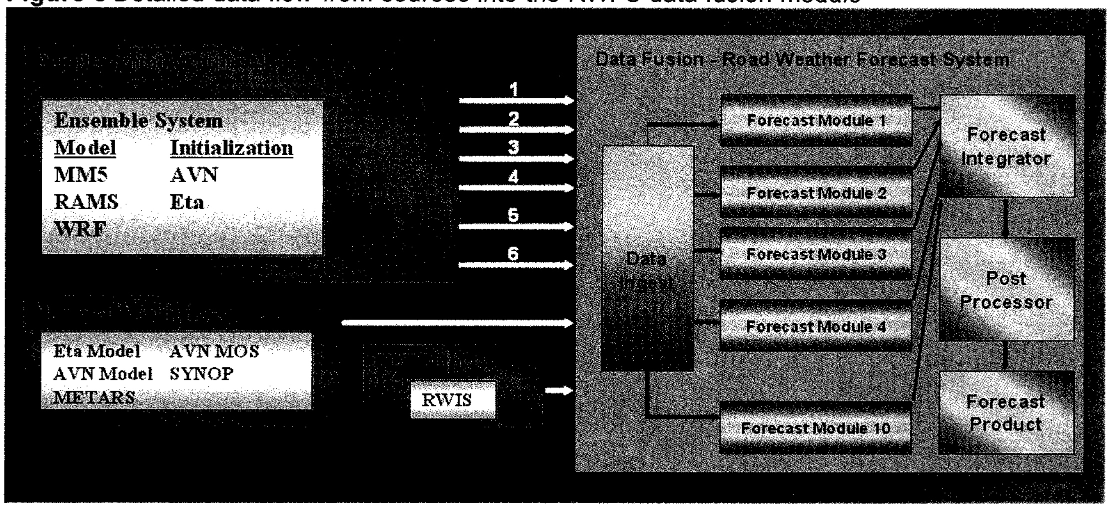


Figure 3 Detailed data flow from sources into the RWFS data fusion module



FSL model ensemble members included:

- ETA & MM5
- ETA & RAMS
- ETA & WRF
- GFS & MM5
- GFS & RAMS
- GFS & WRF

Different from the NWS models, the mesoscale models used a new initialization routine to add realistic distributions of moisture and clouds to the model atmosphere. This method, called "hot-start" (McGinley, 2000), allows the mesoscale models to have a more realistic and accurate set of forecast output sooner rather than having to wait the customary 6 (model) hours before the models begin to generate realistic moisture fields.

Forecast output from these six models, plus surface observations from state departments of transportation (DOT) road weather information systems (RWIS) were forwarded to NCAR's data fusion engine (Figure 1 – top center box, or Figure 3) called the road weather forecast system (RWFS).

The RWFS module used a fuzzy logic ensembling scheme that has the ability to generate more accurate forecasts than any individual model input. Section 3.1.2 later in this document provides verification information on this capability.

Once forecasts have been generated by the RWFS, a number of algorithms are queued for execution. These include the road temperature forecast module and the road condition and treatment (RCTM) module. The former generates temperature forecasts for the state and condition of the road surface. This is used as input into the RCTM which contains algorithms such as for chemical concentration and dilution.

The final module in the system contains the rules of practice algorithms. The rules of practice are customized rules and techniques that are used at DOT maintenance garages for maintaining mobility during winter conditions. These rules tend to be different for each state and in many cases are different for each garage. Hence, this module has the ability to customize many of its inputs so that it can be portable between garages.

Output from the rules of practice module includes treatment recommendations for the DOT garage supervisor. Some of the guidance information can contain:

- Timing information for the start and duration of precipitation
- Precipitation type and accumulation
- Optimized treatment times
- Recommended chemical types and dispersion rate

Figure 4 MDSS functional prototype main user screen (from the 2002-2003 demonstration)

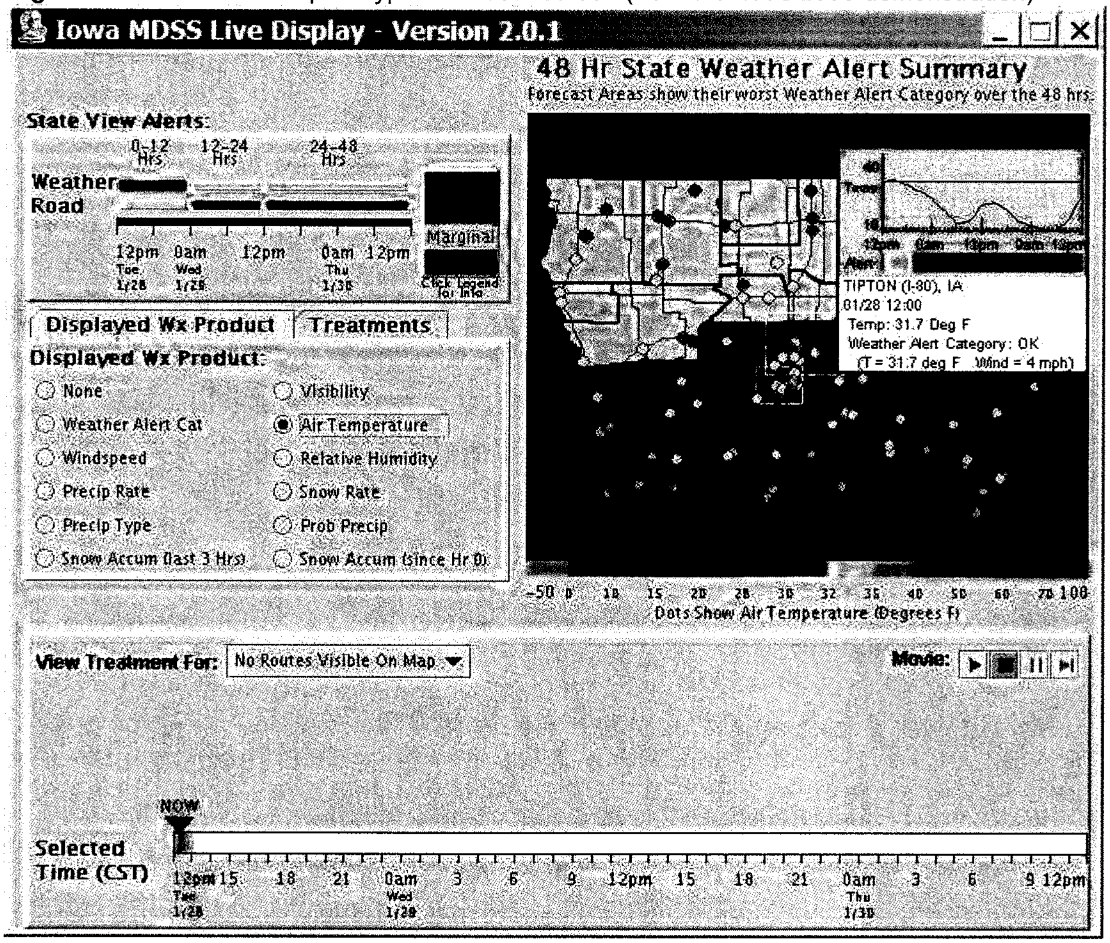


Figure 4 is an example from the MDSS prototype main display. The top left panel shows a summary table with color coded bars showing forecast weather and road conditions for the next 48 hours. The panel at the left center provides access for displaying weather parameters or treatment routes. The bottom section controls the forecast time selection and animation. The main map (top right) can show either an entire state view or a zoomed-in route view (Figure 5).

Each dot on the main map represents a forecast point. Moving a cursor over any point brings up a trace of the selected forecast parameter plus additional site specific details.

Figure 5 Des Moines area MDSS routes and forecast points

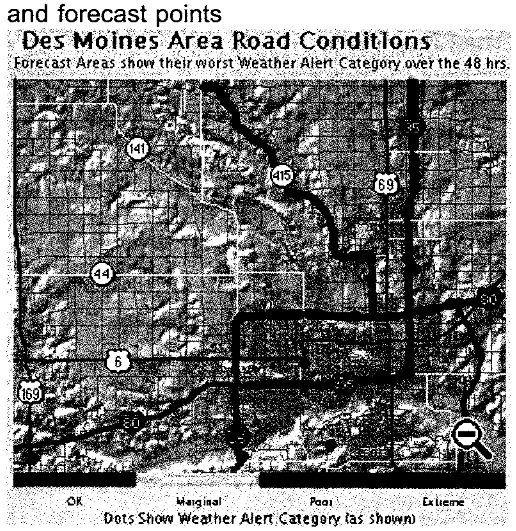
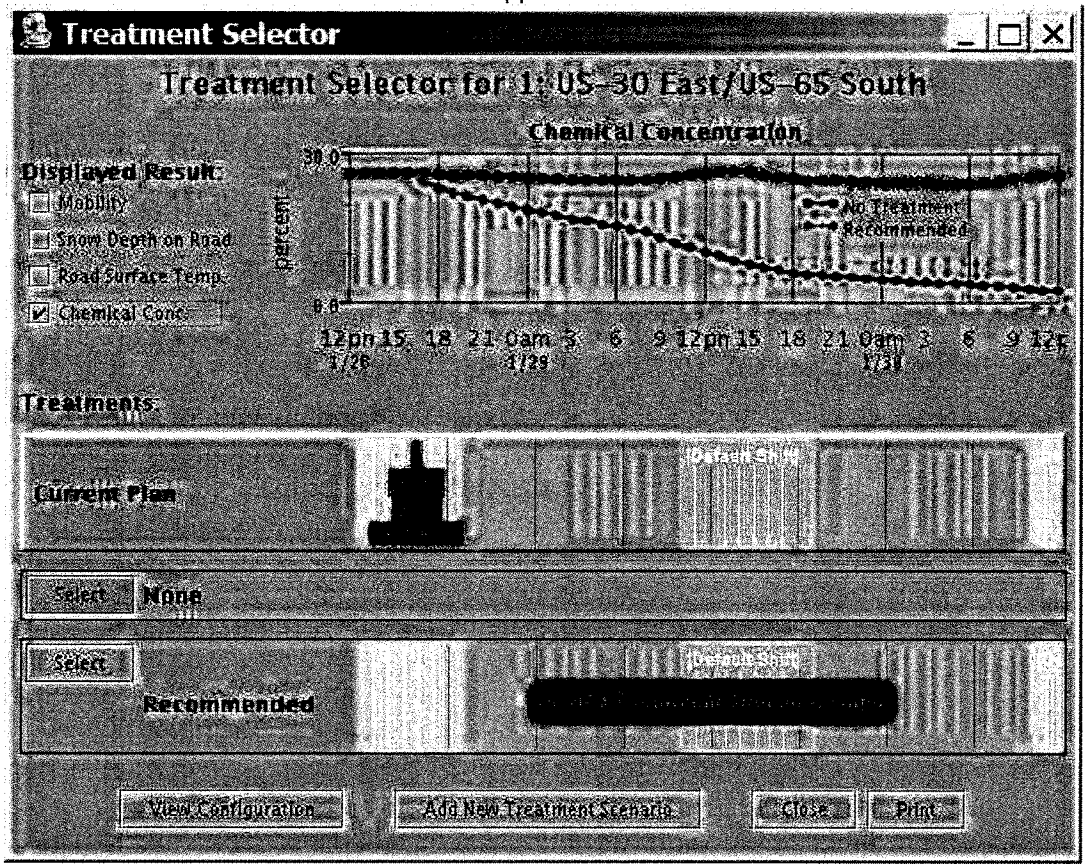


Figure 6 MDSS treatment selector screen. The red trace (top window) shows the predicted chemical concentration if the treatment application is followed. The green trace shows the chemical dilution rate if no chemicals were applied.



The MDSS contains a "what-if" scenario treatment selector. This means that the operator is able to modify the recommended treatment times, chemical types or application rates and submit other values to see how the road condition predictions might change.

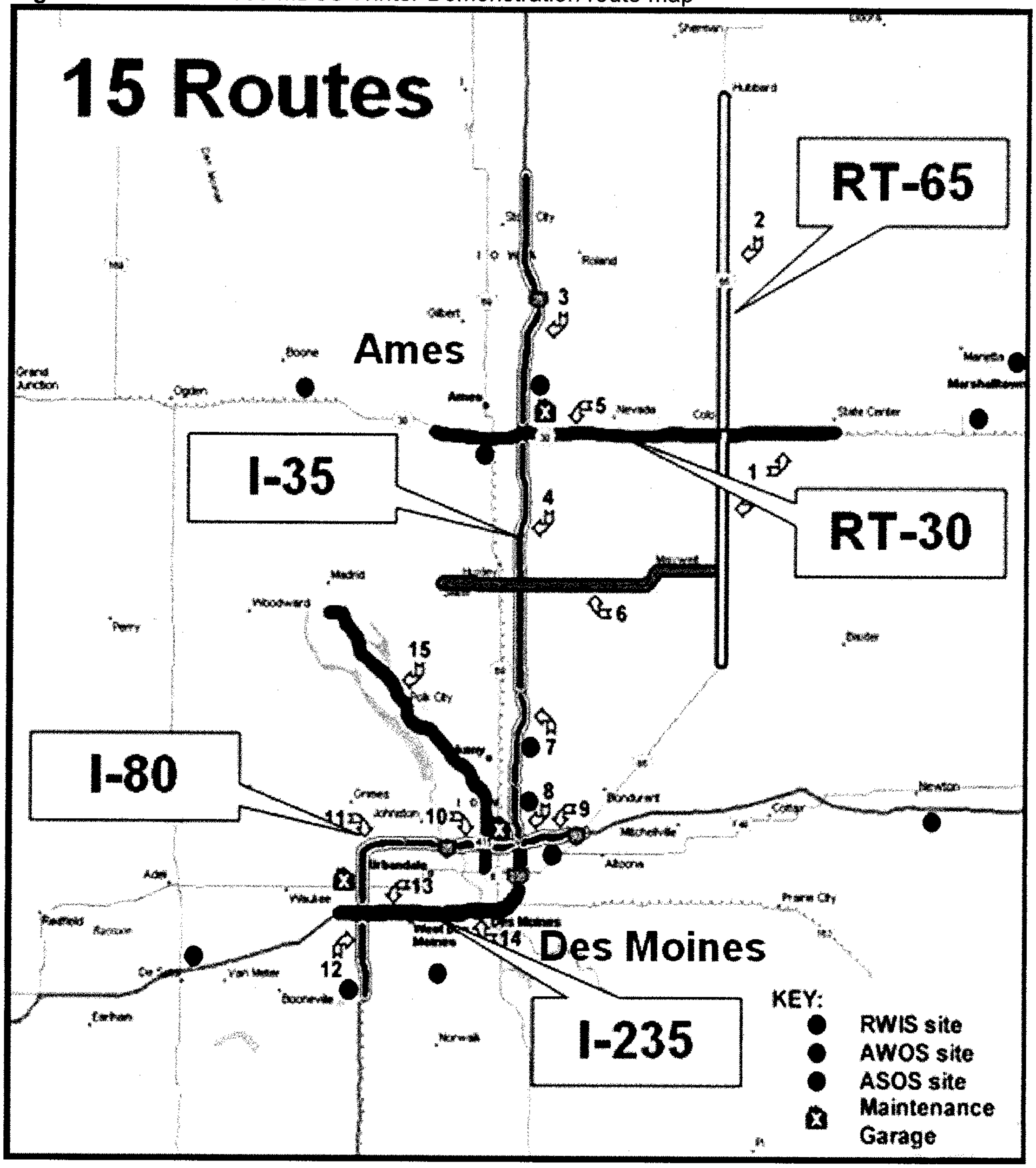
In Figure 6, a chemical concentration display shows the results of two scenarios. The green trace shows the dilution rate of sodium chloride on the road surface if no additional treatments of chemicals are applied. In this case, given the forecast weather conditions, the chemical concentration on the road surface would fall to 10 percent or less within 24 hours. With one application of sodium chloride (at a rate of 300 pounds per lane mile), the red trace indicates that the chemical concentration would stay about constant through the 48 hour forecast period.

3. Field Demonstration 2003

During the summer of 2002, a half dozen states competed to win the opportunity to host the MDSS project. While there were several very good candidates, the Iowa Department of Transportation (IADOT) was selected. Determining factors included their progressive maintenance programs, the availability of high speed communications and computers at maintenance garages and a willingness of the DOT personnel to participate in training and verification activities. Iowa also was surrounded by a dense network of surface observations and did not have complex terrain issues.

In all, 15 routes and three maintenance garages around Des Moines and Ames Iowa were selected to participate in the demonstration (Figure 7).

Figure 7 The 2002-2003 MDSS Winter Demonstration route map



The Des Moines West garage was located just to the west of I-80 and was responsible for portions of I-80 and I-235. The Des Moines North garage was located near the intersection of I-80, I-35 and I-235. This garage was responsible for the expressways through and north of downtown including secondary roads to the north of the city. The Ames garage was located about 40 miles north of Des Moines near the intersection of I-35 and U.S. 30. The Ames garage was responsible for longer, but less traveled routes through the corn fields of central Iowa.

The colored dots along the roadways represent automated surface observing stations that were either operated by the NWS, the state or the DOT. These stations served as ground truth for forecast initialization and verification.

The demonstration period began on Monday, 3 February 2003 and concluded on Monday, 7 April 2003. During that time, five light snow events (3 inches or less accumulation), three heavy snow events (accumulations of greater than 3 inches) and one mixed rain/snow/ice event occurred.

3.1 Verification

3.1.1 Establishing Data Quality

A study was performed to determine the quality of the NWS Automated Surface Observation System (ASOS), the state DOT operated Automated Weather Observing System (AWOS) and RWIS within the demonstration domain. Both ASOS and AWOS instrumentation are located at airports which typically have no obstructions. RWIS, on the other hand, are generally located along roads or near bridges and often have terrain or obstruction issues. All three systems are maintained and calibrated, however each is of a different quality and capability.

Table 1 shows overall results of comparisons between the automated airport observations and the roadside observations. For air temperature, most observations were within 2.5C (4.5F). However, compared with ASOS the Ames RWIS tended to be 1-2C (2-4F) too warm and the Ankeny AWOS (I-35 north of Des Moines) tended to be about 1C (2F) too cool.

Table 1 Comparisons between automated airport and roadside observations

Parameter	Comparison
Air Temperature	Most within 2.5C (4.5F)
Relative Humidity	Most within 10%
Wind Speed	Most within 4 knots
Cloud Cover	Not Available
Precipitation	Not Available
Road Temperature	Cloudy <2C (<4F) Sunny 4-5C (7-9F)

Most relative humidity readings were within 10 percent. However, some differences were noted because ASOS reports dew points in whole degrees C while RWIS uses tenths of a degree C. A possible calibration problem was also noted at the Ankeny AWOS as it consistently reported relative humidity 10-15 percent too high when the RWIS reported humidity of less than 50 percent.

In general, wind speeds were within 4 knots of each other. Probably due to better exposures in airports, ASOS reported higher winds than RWIS especially at speeds less than 12 knots. The only exception was found at the Ankeny AWOS where the RWIS reported higher winds.

No comparison was possible for cloud cover since RWIS has no cloud sensing capability and ASOS only approximates coverage. RWIS also does not have a heated precipitation gauge which means that winter precipitation cannot be measured by the IADOT RWIS network.

Interestingly, the NWS ASOS system also had major problems reporting winter precipitation (especially liquid equivalent), even though it employs a heated tipping bucket type gauge. During the evaluation period, most of the snow accumulations from ASOS were underreported when compared to human observed ground truth. In seven of the 11 significant periods of ice or snow, a value of zero liquid equivalent was reported for the entire event. The biggest snowstorm of the demonstration period produced 13 inches of snow at Des Moines airport. ASOS reported zero liquid equivalent for the entire storm.

This very poor ability to measure and disseminate winter precipitation can have a deleterious effect on systems such as the MDSS. One of the advantages of the MDSS logic is that it has the ability to forward correct its forecasts based on observations that are supposed to be ground truth. These grossly underreported precipitation observations produced a marked dry bias in the forecast. Hence, some of the precipitation observations (both ASOS and RWIS) were removed from the forward correcting scheme to overcome this deficiency.

Table 2 Verification statistics for the MDSS mesoscale models (2002-2003 Demonstration)

	Temperature (Deg C)		Wind Speed (m/s)		Dew point (Deg C)	
	RMS	**Bias**	**RMS**	**Bias**	**RMS**	**Bias**
MM5-GFS	3.1	-0.7	2.5	+0.8	5.6	+1.5
MM5-ETA	3.0	-0.5	2.5	+0.8	5.5	+1.6
RAMS-GFS	5.8	-1.1	2.6	+1.6	6.5	-0.9
RAMS-ETA	5.9	-1.1	2.6	+1.7	6.9	-1.0
WRF-GFS	3.1	-0.4	2.4	+1.1	5.7	+1.4
WRF-ETA	3.1	-0.4	2.4	+1.0	5.7	+1.3

3.1.2 Model Verification

The mesoscale models were run four times per day, providing output in three-hourly increments. The initial requirements when the ensemble scheme was constructed was to focus on the "planning" or 12-24 hour time span as being the most critical for maintenance managers. However, as the demonstration progressed, it became evident that more "tactical" (2 – 12 hour) forecasts were also very important.

Table 2 provides some statistics on the performance of each mesoscale model. Both the root mean square (RMS) error and the statistical bias are provided.

Temperature forecasts had an error of about 2.5C (4.5F) during the first 24 hours with RMS errors increasing to around 3C (5F) for both the WRF and MM5 models for the entire 48 hour forecast period. As shown in section 3.1.1, this error was close to the quality of the ground truth observations. Errors for the RAMS model were much higher. Also, all of the models showed a cool bias, forecasting temperatures colder than what was observed.

Wind speed forecasts had an error of around 2.5 m/s (5 knots) and all models displayed a high bias. This means that wind speeds were forecast to be somewhat stronger than what was observed. Forecasts of dew point had larger errors. For the 48 hour period the average RMS error was 6C (almost 11F). This resulted in relative humidity forecasts being off by +/- 20 percent. This type of error could pose problems for fog or frost deposition forecasting.

Cloud cover forecasts (not shown in Table 2) were generally one category off observed conditions. The forecast showed an overall bias toward more cloudy conditions. This type of error can produce problems with road temperature forecasts since the forecast energy fluxes would contain errors.

The models generated conditional probabilities of snow (CPOS), rain (CPOR) and ice (CPOI). Table 3 highlights some of the results.

The CPOS was most successful when values reached 70 percent. The same level of success was reached by CPOR when it reached 80 percent. However middle range

Table 3 Conditional probability of snow (CPOS), rain (CPOR) and ice (CPOI)

CPOS	CPOS>0.7 snow occurred 95%	0.2<CPOS<0.7 snow occurred 15-60% of the time. Remainder was a variety of precipitation	CPOS<0.1 rain occurred 95% of the time
CPOR	CPOR>0.8 rain occurred 95% of the time	0.3<CPOR<0.8 rain occurred 20-30% of the time. The remainder was snow.	CPOR<0.3 rain rarely occurred. Snow dominated
CPOI	CPOI>0.3 rain fell 85% of the time	0.2<CPOI<0.3 rain, snow and unknown precipitation occurred with equal frequency	CPOI<0.2 snow dominated

forecasts (20-80%) showed much more of a variety of forecast precipitation types.

Very few cases of ice were reported during the demonstration period and the probability value never exceeded 0.4. Table 3 shows that the ice forecasting skill was relatively low.

Average RMS errors for road temperature forecasts were about 2.5C (4.5F) with a slight cool bias regardless of temperature range. Errors were maximized during the daytime under clear skies. Under these conditions forecasts were too low by 5-10C (9-18F). Hand held radiometer tests showed the biggest discrepancies with the pavement sensors under these conditions (~5C or 9F). Hence, there may also be some pavement sensor error involved.

Forecasts under cloudy and precipitating conditions were much more accurate. The majority of road temperature forecasts were within 2C (3.6F) when precipitation was falling, especially snow.

3.1.3 Rules of Practice

The treatment recommendations that are provided by the MDSS are generated by the rules of practice module. During the demonstration period, both garage supervisors and plow operators were asked to fill out storm evaluation forms so that verification of the recommendations and a comparison to what treatments were actually performed could be tabulated.

Overall, it was found that given the forecasts from the RWFS, the recommendations were reasonable. The following section provides some insight to the rules of practice verification.

Case 3-4 February 2003 – Ames

This event was a short lived 5-7 hour event that deposited about one inch of snow (0.1 liquid equivalent) over both the Ames and Des Moines routes. The MDSS recommended a pretreatment of liquid brine followed by two successive treatments of sodium chloride with an application rate of 150 pounds/lane-mile.

The actual IADOT treatments consisted of one treatment of 300 pounds/lane-mile. However due to a rapid drop in air and road temperatures before the melted snow could dry, IADOT had to provide several more applications to keep the roads from refreezing.

It was determined that the MDSS recommendations were reasonable. However, the strong winds (> 18 knots) prior to the storm caused IADOT to not pretreat the roads. The initial treatments of the roads were similar. However, the lateness of the day and the blowing snow kept the road surface wet as temperatures dropped. The MDSS did not recommend additional treatments because the snow had stopped and it was believed that the applied chemicals were enough to last until the roads were dry.

Case 14-15 February 2003 – Des Moines

This event provided the heaviest snowstorm of the demonstration with nearly a foot of snow deposited over the region. In Des Moines, the event started as rain then changed to snow which lasted almost 20 hours.

The MDSS recommended a pretreatment of liquid brine several hours before the onset of precipitation. The Des Moines West garage did not perform a pretreatment since they recognized that the initial period of rain would have reduced the effectiveness of the brine.

The MDSS then recommended 12 chemical treatments ranging from 100 to 350 pounds/lane-mile. The overall treatment recommendation was about twice the tonnage that was actually applied by the Des Moines West garage. However, they did supplement their treatments with 'plow only' operations (something not currently supported by the MDSS).

As a result of the case studies, many algorithms within the rules of practice module will be updated with information collected during the winter 2003 demonstration. A more complete set of rules of practice verification examples can be found in NCAR, 2003 and Wolff, 2004.

3.2 Summary of Lessons Learned

The following list contains lessons learned or confirmed from the 2002-2003 MDSS field demonstration:

- The MDSS requires highly specific forecasts of precipitation, which is pushing the limits of predictability.
- The rules of practice module needs additional development to handle a wider variety of weather and road condition scenarios and treatment responses.
- The availability and quantity of real-time precipitation rate data are very poor.
- During a winter storm, the DOT operators often do not have the time to enter actual treatments for each route. Therefore, the MDSS can lose track of actual road conditions.
- Light snow events and intermittent events are critical to DOT operations and are particularly hard to predict.
- The road temperature prediction model did a good job given adequate weather inputs and road characteristic data. However, more work is needed to account for the impact of travel, chemicals, compact snow and blowing snow.
- The users have a strong desire for tactical (0-2 hour) decision support.
- Because weather will not soon be predicted perfectly at road scales, probabilistic products should be developed.
- Just varying the lateral bounds models (Eta, GFS) has little effect on adding dispersion to the ensemble.

In addition to lessons learned, several shortcomings in the system were noted:

- The MDSS prototype is not designed to provide treatment recommendations for blowing snow conditions.
- The MDSS does not contain explicit algorithms that identify road segments that may need treatments due to frost.
- Users indicate that a measure of forecast confidence would be beneficial.

3.3 Testimonials

Since the beginning of the MDSS concept, a large group of interested individuals has participated in the shaping and refinement of the project. Members of the road maintenance community, private sector vendors and academia have comprised a stakeholder group. Each year, the stakeholders gather to review past progress and to discuss and shape the future plans of the project.

Results from the 2002-2003 winter demonstration were presented at the 2003 annual stakeholder meeting. After the summary of lessons learned was discussed, a panel of participants was asked if the overall concept of the MDSS makes sense for the future. The following are some responses:

- "Absolutely. At first, some of the operators were really apprehensive that this tool was going to take away jobs. Then, it became like a video game and a discovery tool. Just don't take the ultimate decision away from the end user."
- "Very valuable – even if it wasn't totally accurate – getting people down to the surface and away from aviation weather was very important."
- "There will be a drastic reduction in guard rail repairs and this will save lives. This is very good for the Iowa DOT. It provides an opportunity to try new things. We constantly have to do more with less."

The members of the stakeholder group were pleased with progress made by the MDSS project and were looking forward to further refinements in 2004.

4.0 Plans for Demo II – Winter 2004

After evaluating the performance of the MDSS during the first demonstration, it was determined that the system was not yet mature enough to survive on its own in the private sector. Hence, the FHWA decided to fund one more complete field demonstration. It will again take place in central Iowa and extend from 29 December 2003 until 19 March 2004.

Numerous enhancements will be engineered and implemented prior to the start of the demonstration. These include:

- Continuing to develop, refine and tune the road temperature forecasting module
- Adding a 'plow only' treatment option. Investigating adding a 'pre-treat with brine' option
- Adding the ability of the users to reset the road conditions to zero for both road snow depth and chemical concentration on a route or network basis
- Creating a treatment recommendation to alert when blowing snow conditions are likely (in the absence of an actual blowing snow model)
- Continuing to expand, refine and test the coded rules of practice to better reflect actual treatment plans
- Modifying treatment recommendations to utilize estimates of road drying time
- Continuing to work with Iowa State University on adding frost deposition forecast support
- Deploying real-time snow gauges to obtain better liquid equivalent information for demonstration verification
- Revising the RWFS to accept, process and output hourly forecast data (rather than 3 hourly data) to at least 24 hours in the forecast period
- Generating probabilistic information for selected data fields (such as precipitation occurrence, precipitation type and air temperature)
- Reconfiguring the ensemble modeling system to remove the under-performing RAMS model. Since the parallel ensemble scheme did not provide enough diversity to optimize the forecasts, run the MM5 and WRF models every hour and use a "time-lagged" ensemble technique to provide diversification of solutions to the RWFS data fusion engine. Using this technique may reduce the amount of cycle-to-cycle shock that can sometimes be generated by updating model cycles.
- Updating the main display to replace the color dots with digital values
- Adding the ability to view current RWIS observational data
- Designing a way to view recent history on the display (within 6 hours) so that more than just the latest 48 hours is viewable

Even after all of these changes are implemented, there will still be many challenges to overcome to create a truly comprehensive MDSS. However, the spirit of cooperation between the public and private sectors will move the entire industry closer to this goal.

5.0 Technology Transfer

Once the second field demonstration is complete, the laboratories will begin to compile new verification statistics and evaluation reports. The FHWA will also begin to work with different champions to see how this technology can be transferred to the private sector. One such champion is the AASHTO (American Association of State Highway and Transportation Officials) Technical Implementation Group. The MDSS project will be submitted as a new and promising technology during the spring of 2004. It is hoped that components of the MDSS will be integrated into the product lines of private companies so that the technology can be used to raise the level of service for all state DOTs.

A meeting of the MDSS stakeholder group will be held in July 2004 in Boulder, CO. At this meeting, the laboratories will be holding a workshop to provide a detailed engineering overview and exchange to any company that is interested in utilizing the MDSS technology.

Finally, CDs with all of the software and documentation associated with the winter 2004 demonstration will be distributed to interested parties during the fall of 2004 via the NCAR MDSS web site.

6.0 Summary

The FHWA has been funding and directing a team of national laboratories to create and refine a decision support system for the winter road maintenance community. A demonstration of the MDSS prototype was conducted in central Iowa during the winter of 2003. Reviews from this first demonstration were mixed. The system showed consistent improvement as the season progressed. However, there were some problems with obtaining ground truth observations both from automated stations and from paper log forms. There were problems with the weather models capturing some "light" precipitation events. And, because some of the weather forecasts missed their marks, some of the treatment recommends did too.

However, in a post demonstration presentation, the participating IADOT maintenance supervisors all agreed that the system had tremendous promise and was worth the effort to continue to work with the laboratories to make the system better.

A summary of the winter 2004 demonstration will be provided to this forum at the 2005 annual meeting.

Current documentation, progress reports and contact information for prospective stakeholders can be found on the NCAR web site:

http://www.rap.ucar.edu/projects/rdwx_mdss/index.html

7.0 Acknowledgment

The authors would like to acknowledge some of the major contributors to the MDSS project. First, this project would not be possible without the continuing support and leadership from the FHWA Office of Operations, the Joint Program Office and the Highway Research Division. These individuals include Jeff Paniati, Shelley Row (now of the Institute of Transportation Engineers), Mike Freitas, James Pol, Toni Wilbur, Rudy Persaud and Henry Lieu.

Major contributors from the laboratories include:

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- From MIT/LL: Robert Hallowell
- From FSL: Paul Schultz
- From CRREL: George Koenig

Contributors from the IADOT include Dennis Burkheimer, Paul Durham, Edward Mahoney and Richard Hedlund.

Verification support was lead by Dennis Kroeger of the Iowa State University's Center for Transportation Research and Education.

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Wolff, J.K., B.C. Bernstein, S. Linden, 2004: Case Study Verification of the Maintenance Decision Support System (MDSS) During the 2003 Operational Demonstration, Preprints, 20st Conf. on Interactive Information and Processing Systems, Seattle, WA, Amer. Meteor. Soc., 18.5.

APPENDIX B

SALT INSTITUTE – HIGHWAY SALT AND OUR ENVIRONMENT

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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Table of Contents

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

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[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

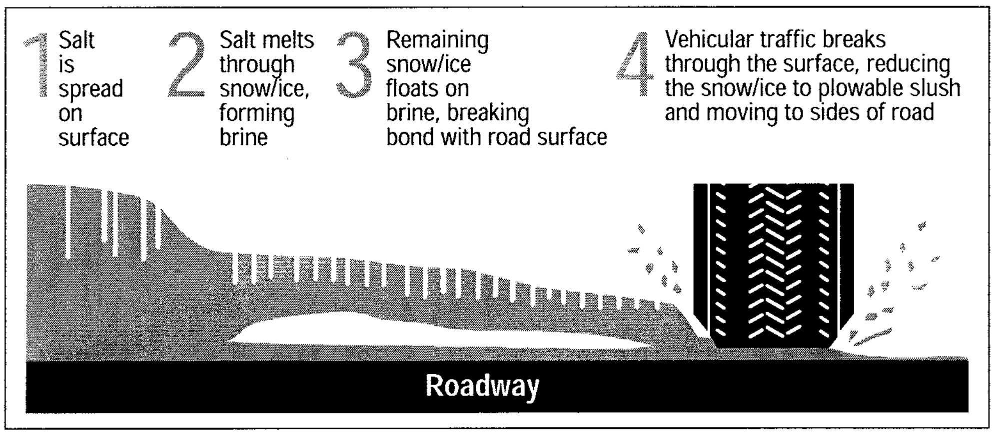
Most ice storms and snowstorms occur between 20° F and 32° F. Often after the storm breaks, high pressure systems move in and temperatures plummet, sometimes to well below freezing. So, it is important to apply salt early during the storm when salt will be most effective as a melting agent and will prevent 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.[12] [13] [14] 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 Are 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

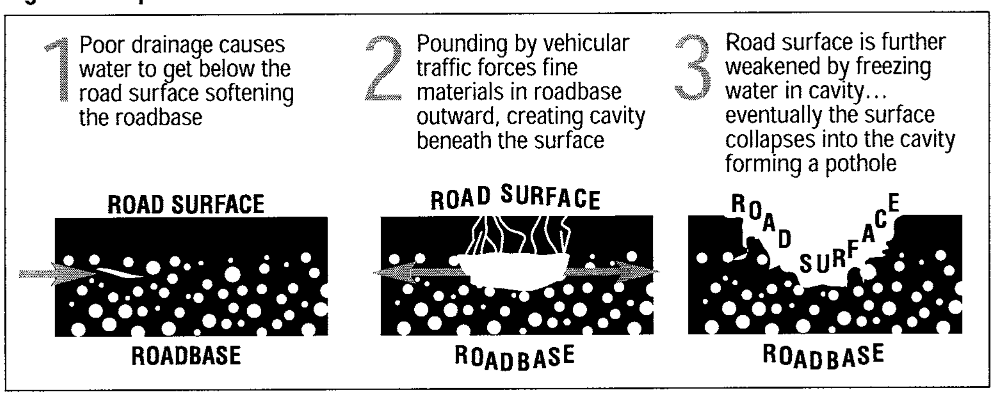
Of all "environmental" impacts, the greatest costs are associated with chloride-accelerated corrosion of man-made structures and vehicles. By comparison, impacts on water, vegetation and wildlife are relatively small.

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.

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[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. Futurists[29] 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.

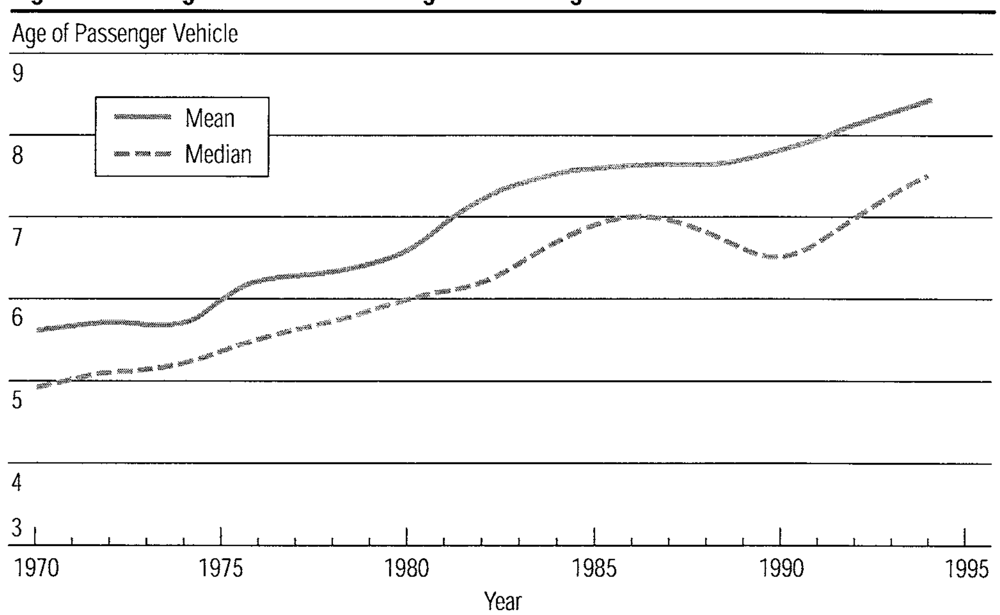
[27] CORROSION98 – Evaluation of Corrosion Protection on Recent Model Vehicles. NACE International, Paper 741, 1998.
[28] Society of the Plastics Industry website, http://www.plasticsindustry.org/industry/2118.htm, dowloaded March 23, 2003.
[29] Snyder, David, www.the-futurist.com.
[30] Burns, Lawrence 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 1994[34]



[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.

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[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.tfhrc.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	Scoth 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	Lantona	
	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 sacoton
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 publication[45] refers to a recent study by the Wisconsin Department of Transportation[46] 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 flavenscens*), fathead minnows (*Pimephales promelas*), brown trout (*Salmo trutta*), lake trout (*Salvelinus namaycush*) and walleye (*Stizostedon 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 $CaCO_3$). 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, $Na_4Fe(CN)_6 \cdot 10H_2O$ and Prussian blue, $Fe_4[Fe(CN)_6]_3$) 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, $Ca(CN)_2$).

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[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-Schmiedebergs 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 year [65] 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 affect 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.

APPENDIX C

NYCDOT – EVALUATION OF A

FIXED ANTI-ICING SPRAY TECHNOLOGY (FAST) SYSTEM

EVALUATION OF A FIXED ANTI-ICING SPRAY TECHNOLOGY (FAST) SYSTEM

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Abstract

This paper describes the in-house development (Phase I) of the Fixed Anti-Icing Spray Technology (FAST) systems to apply less corrosive liquid chemical freezing - point depressants on portions of the south-roadway (Manhattan-side span) of the Brooklyn Bridge. During the first phase of the project, several operational parameters were investigated, including spray pattern, spray angle and spray pressure. Two homegrown FAST systems were installed. The first system consisted of the installation of pipes on both sides of the roadway, with spraying activated simultaneously through nozzles spaced 20 feet apart and 6-8 inches above the roadway surface. The second system – which was installed on only one side of the roadway – was intended to achieve sequential spraying. During this phase, the FAST systems were manually activated. Phase II of this project describes the proposed extension of the FAST system and integration of a road weather information system (RWIS).

I. Introduction

The Brooklyn Bridge is the oldest of the East River bridges and connects the Boroughs of Brooklyn and Manhattan in New York City. It was opened to traffic in May 1883 and designated a Historic Landmark in 1967. It is a combination suspension/cable-stayed bridge with a main span of 1595.5 feet and two equal side spans 933.2 feet. At the time of construction, it was the longest suspension span in the world. The bride has four main cables (A, B, C, D north to south), each 15.75 inches in diameter. Granite masonry towers and anchorages support the cables. As the transportation mode changed over time, the bridge was reconfigured to accommodate the increasing transportation demand. In the late 1940's, the roadway was replaced with a concrete filled steel grid deck supported by steel I-beam stringers placed over the original truss floorbeams. Thus, the bridge, in its current configuration, has three vehicular lanes each way with an AADT of 140,000 (passengers car only).

In 1995 and 1996, the FHWA conducted a maintenance review of the Division's preventive maintenance program on the East River Bridges (ERB). The reports recommended that the Division develop and initiate aggressive short-term and long-term preventive maintenance strategies that would serve to extend and preserve the useful life of its bridges, and protect the highway community's investments. Years of heavy sodium chloride (salt) use on the ERB have resulted in extensive corrosion of the bridges' roadways and structures. This roadway de-icing method has resulted in costly and often premature roadway and structural repair. During the summer of 1998, when the overlay was being replaced, it was discovered that the concrete fill in the 50-year old deck was failing due to excessive salt in it, allowing the corrosion of steel grid members. Thus, the entire suspended span decks were replaced at the lowest bid price totaling $33,357,000.00 dollars.

The Objective

The objective of this paper is to provided an evaluation of the FAST system's (System 1) performance during the '98-'99 winter season and subsequent winter seasons. Also embedded within this objective is the evaluation of the following performance goals and criteria for the FAST system:

- Improve service delivery to the motoring public with the safe, timely and rapid application of chemical to the bridge's roadway.
- Monitor vehicles tire tracking and carry-over distance.
- Evaluate and monitor drivers' reaction to spraying via an automatic system.
- Evaluate the system's in-use reliability.
- Evaluate and compare conventional over-the-road method utilizing trucks
- Establish wide-scale implementation parameters and feasibility (cost and cost effectiveness) goals

Scope of Evaluation

This evaluation will investigate the operation and performance of the FAST system (system I) during the 1998-1999 winter season and subsequent winter seasons. Of primary technical concern in this investigation were the capabilities and reliability of the system's components: spray nozzles, PVC piping on the south roadway barrier and the check valves. A cost-comparison between the conventional over-the-road method utilizing spray trucks and the FAST system will be investigated.

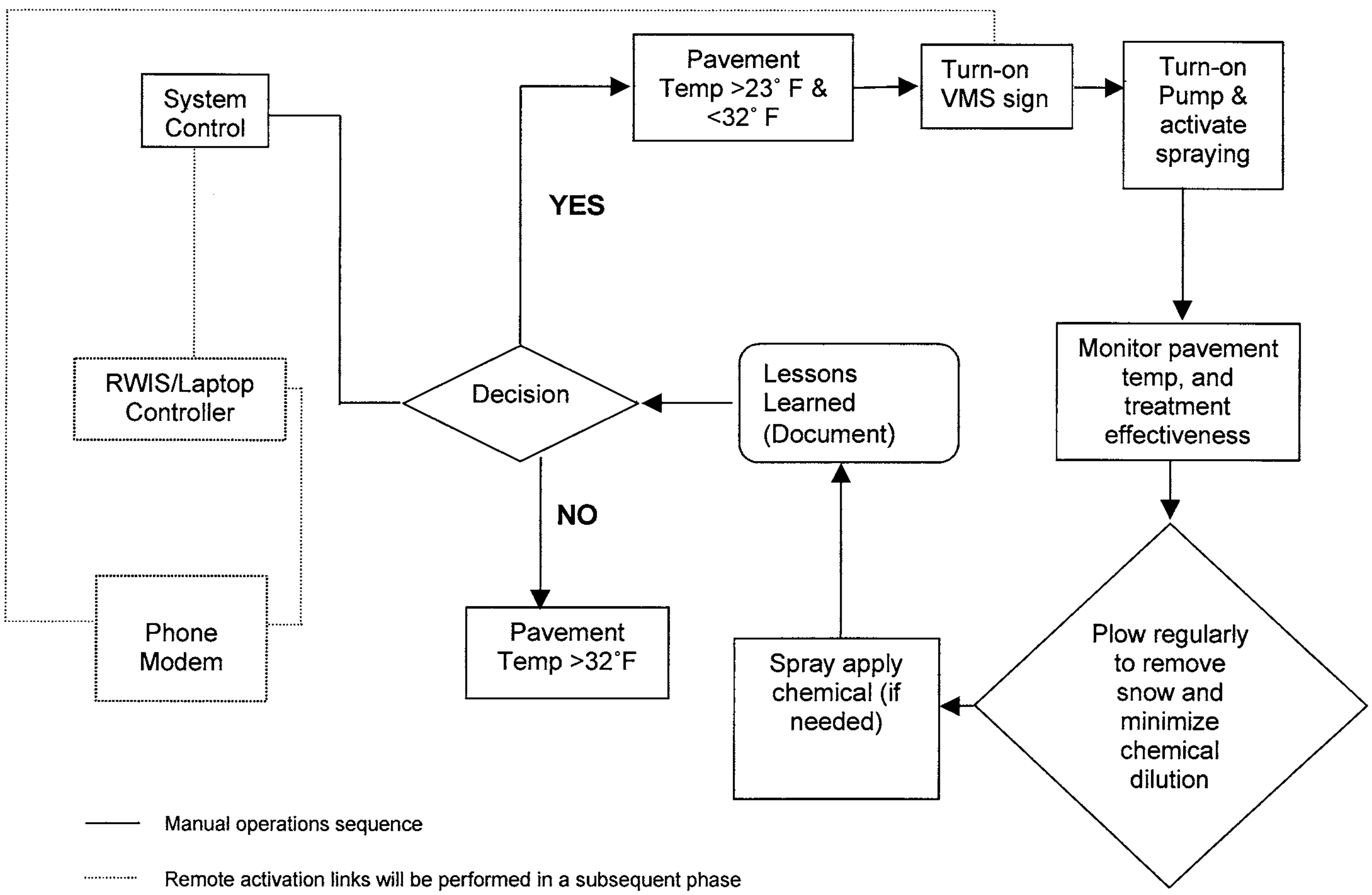
Methodology of Evaluation

The weather forecasting methods used were not site specific to the bridges' roadways. A Road Weather Information System (RWIS) was not integral into the decision making process during the season (the integration of a RWIS is discussed under *Phase II* of this project). As a result, weather forecasts and the decision to initiate anti-icing procedures were primarily based upon broadcast radio and television weather forecast reports. **Chart A** outlines the operational procedures adopted and followed during each weather event the FAST system was utilized. A designee from the Division's Maintenance Unit was assigned to coordinate operations with the Department of Sanitation (DOS). This person was further responsible for initiating call-out procedures for the Division's winter operation crews. Call-out procedures were initiated based on a forecast threshold of a >60% chance of precipitation occurring. The process consisted of the designee contacting (via telephone) and informing each respective operation managers/supervisors (FAST and Truck crew) of the decision to mobilize crews.

However, once the crews were mobilized, the on-site decision to initiate anti-icing techniques was determined by the respective operations' supervisor. This decision was generally based on the pavement temperature estimated to be 5°F-10°F lower than the ambient air temperature. The treatment recommendations outlined in the *Federal Highway Administration's Manual of Effective Anti-icing Practices* [1] were followed for the corresponding event type.
A Variable Message Sign (VMS) was utilized to provide advance warning and information to the motoring public with regarding the spraying. Also a CCTV system was utilized to monitor the site.

Supervisors followed and recorded field data based on the procedures outlined on the TAPER[1] logs. This information was later summarized and evaluated.

CHART 1: FAST OPERATIONAL PROCESS SEQUENCE



[1] TAPER is the acronym for: Ta=Time of Application; T=Low temperature since last application; A=Application rate (gallons/lane-mile); P=Product used; E=Event; R=Results

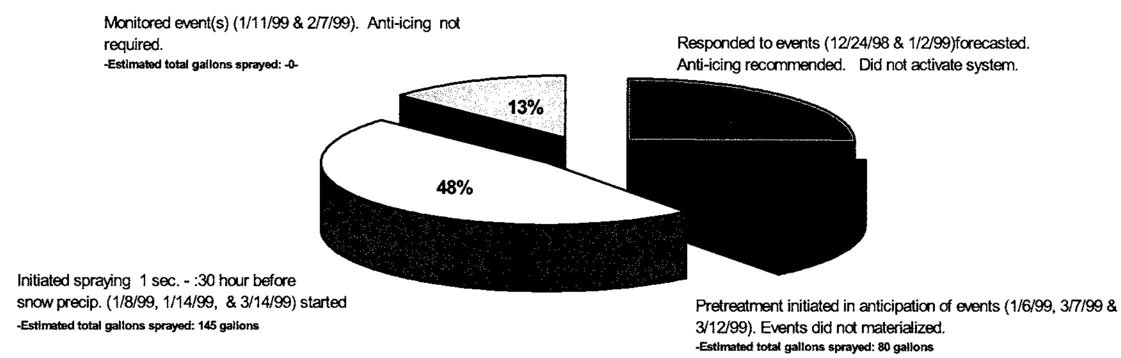
II. EVALUATION OF FAST SYSTEM'S PERFORMANCE GOALS AND INDICATORS

During the 1998-1999 winter an evaluation procedure was implemented in an effort to determine the effectiveness of the FAST system. The evaluation plan for this project *(submitted as part of the initial Project Proposal)* outlined and targeted the following performance goals and indicators for this phase (phase I) of the project:

- Mechanical Performance
- Chemical Performance
- Cost Analysis

An operation team consisting of two workers responded to ten separate weather events during the '98/'99 season. These events were categorized (see Chart 2) as follows:

Chart 2: 1998/99 Event-Response Categories



Note: Percentages are based on operation cost.

A site-specific weather forecast information system was not utilized in determining whether to initiate a treatment, and when to start. Overall, a total of seven events (52%) were classified as follows: delayed responses; events that did not materialized, and events not requiring anti-icing. This inability to accurately predict storm and pavement temperature and to communicate rapidly changing conditions before treatments were initiated resulted in unnecessary expenditures. The decision to pretreatment the roadway and average of thirty-two (32) hours before an event materialized occurred on three (14%) occasions during the season. However, these actions aided the evaluation by providing some critical information pertaining to the residual effects of a treatment on the roadway. As anticipated, the chemical (potassium acetate) was not as effective after this lapse of time before the event started. Based solely on observation, traffic volume was considered to be a major factor in "removing" the chemical from the roadway. In fact, treatment made >1hour before an event invariably required retreating. The converse to pre-treatment was the decision to delay treatments in an effort to ascertain if a storm is of sufficient magnitude before initiating spray treatment. This situation occurred during of the first two events (12/24/98 and 1/2/99) of the season. While the conditions warranted anti-icing treatments, treatments were made utilizing truck mounted spray units. Similar decision-making was followed for the events anticipated on 1/11/99 and 2/7/99. Fortunately, these events (13%) did not meet the threshold temperature required to initiate anti-icing techniques. As a result, no action was taken to spray the roadway. The total reliance on broadcast media or the operation managers' judgment was not adequate and specific enough for effective decision-making.

The forecast certainty (> 90% chance of precipitation) of the 1/8/99, 1/14/99 and 3/14/99 events resulted in spraying being initiated literally seconds before the events started. An analysis of these events and the treatments initiated indicate that the roadway section treated via the AISDS provided a higher level-of-service in comparison to the adjacent roadway sections treated with an over-the-road method utilizing truck mounted spray units. Photo exhibits A-G below illustrate the various pavement conditions observed during the events.

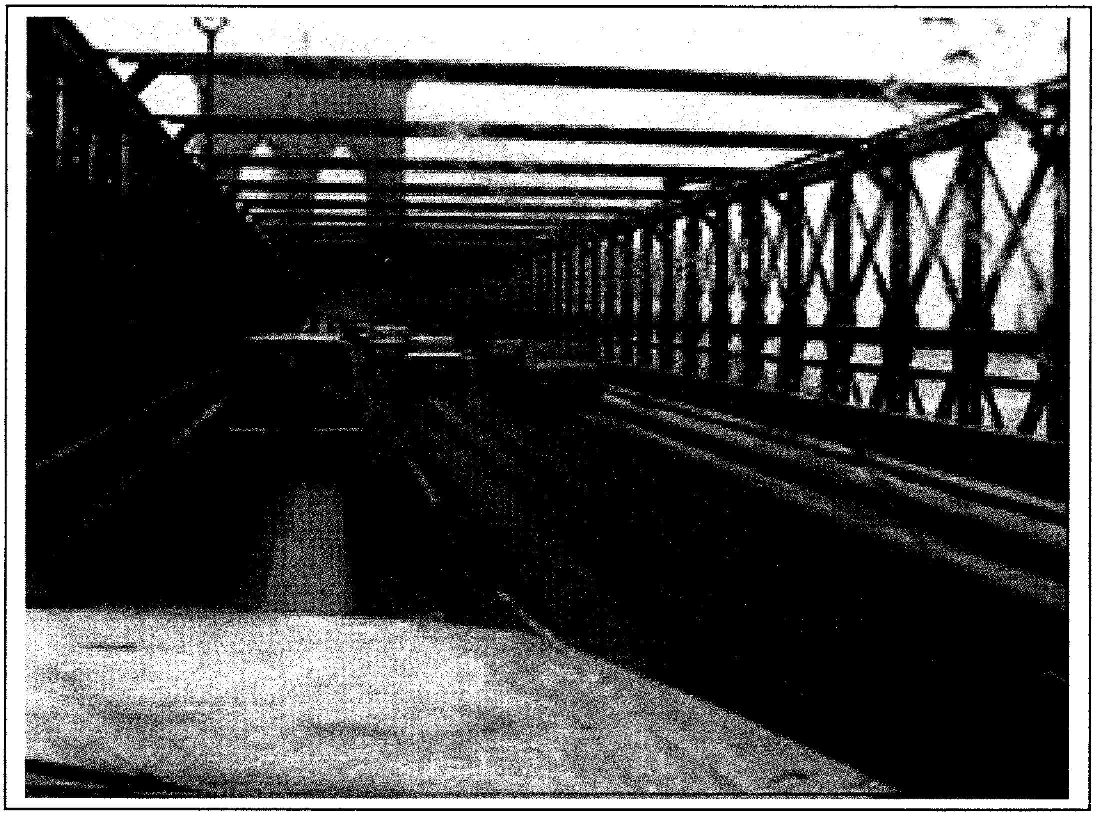


Photo Exhibit A: Pavement condition of roadway section sprayed with FAST system (3/14/99)

Note: Photos are for illustrative purposes.
Brooklyn Bridge south roadway

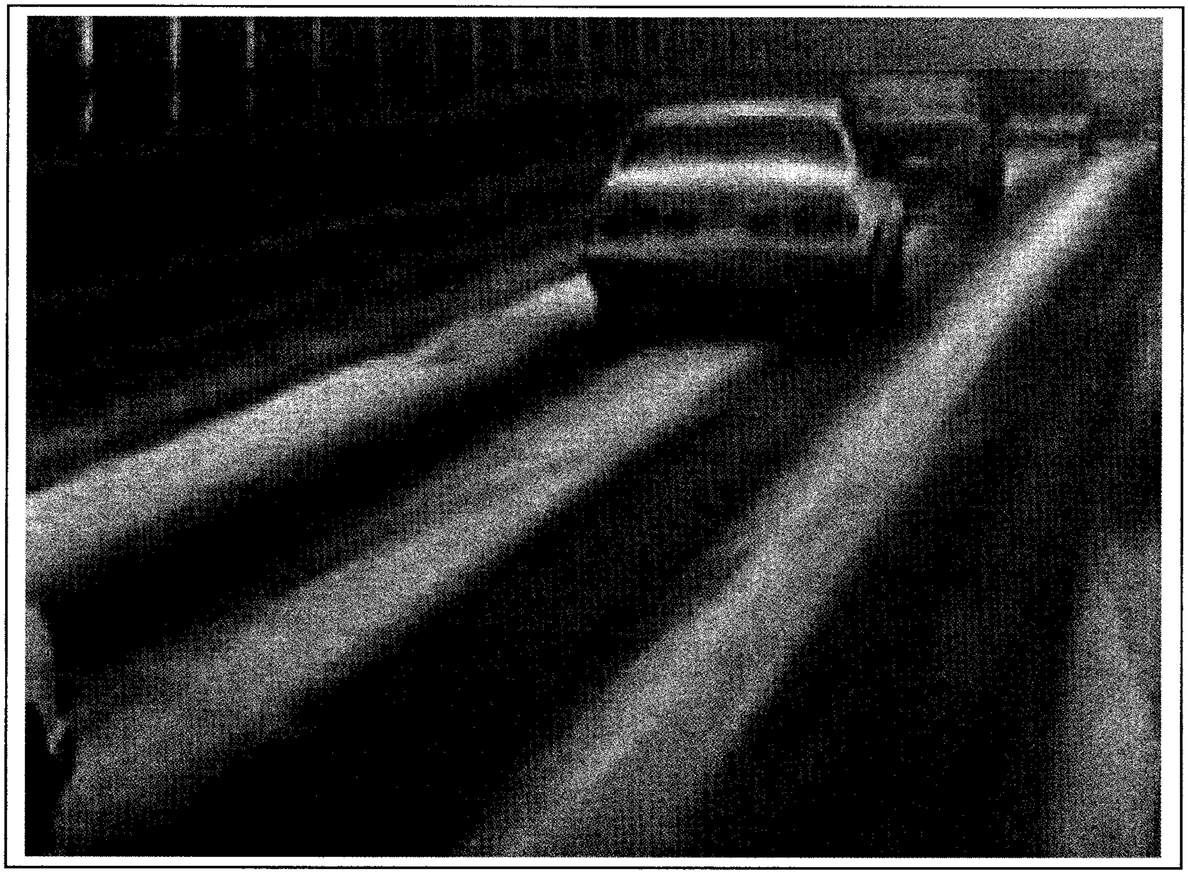


Photo Exhibit B: Location sprayed with Truck mounted spray unit (3/14/99)

Initially, the decision to initiate anti-icing during the March 14, 1999 event was marginal. This was partly due to the weather forecast prediction that temperature would be steadily increasing during the course of the event. Under these conditions, icing of the roadway was unlikely. However, snow precipitation was predicted to be moderate to heavy, with accumulations totaling 4.5 inches. In addition, the snow was of a wet[2] consistency. Nevertheless, a treatment was initiated second after the event started. Photo Exhibit A and B illustrates the pavement condition between the hours of 8am-10am. It is critical to note, that plowing is recommended for this type of event and accumulation total. However, none was observed during this period. A key consideration in the decision to spray the roadway under these conditions was an attempt to discourage the DOS's crews from salting the roadway by default. However, despite bare "black" pavement conditions, a DOS truck was observed salting the roadway (see photo exhibit C) despite the pavement condition.

The photo exhibit below depicts an event on March 7, 1999 where a DOS salt truck was observed salting the pavement (black pavement conditions). This event did not materialized.

[2] Wet snow is a 10:1 snow to liquid ratio; Dry snow is a 20:1 snow to liquid ratio

Photo Exhibit C: NYCDOS salt truck salting the Brooklyn bridge south roadway (3/7/99)

While the rationale for the treatments is unexplained for the conditions reported, a similar action was also observed during the January 14, 1999 event. Based upon the evaluation of the event, maintaining a bare "black" pavement condition required minimal snow removal. The information recorded indicated that the pavement temperature was estimated to be ~23°F; the ambient temperature was 27°F and snow precipitation was dry with accumulations totaling >2 inches. The pavement section treated with the FAST system achieved the best pavement conditions ("black conditions") compared to the other section treated by the spray truck (see Photo Exhibits D and E). As photo exhibit D illustrates, a dry slush-like residue (<<1 inch) remained on the roadway in comparison to the section treated with the spray truck (see Photo Exhibit E). A subsequent treatment was initiated during the event in an attempt to achieve black pavement conditions. However, the slush-like residue remained on the pavement as illustrated. DOS salt trucks were witnessed salting the roadway later into the event-day. Photo Exhibit G illustrates the pavement after the salting occurred.

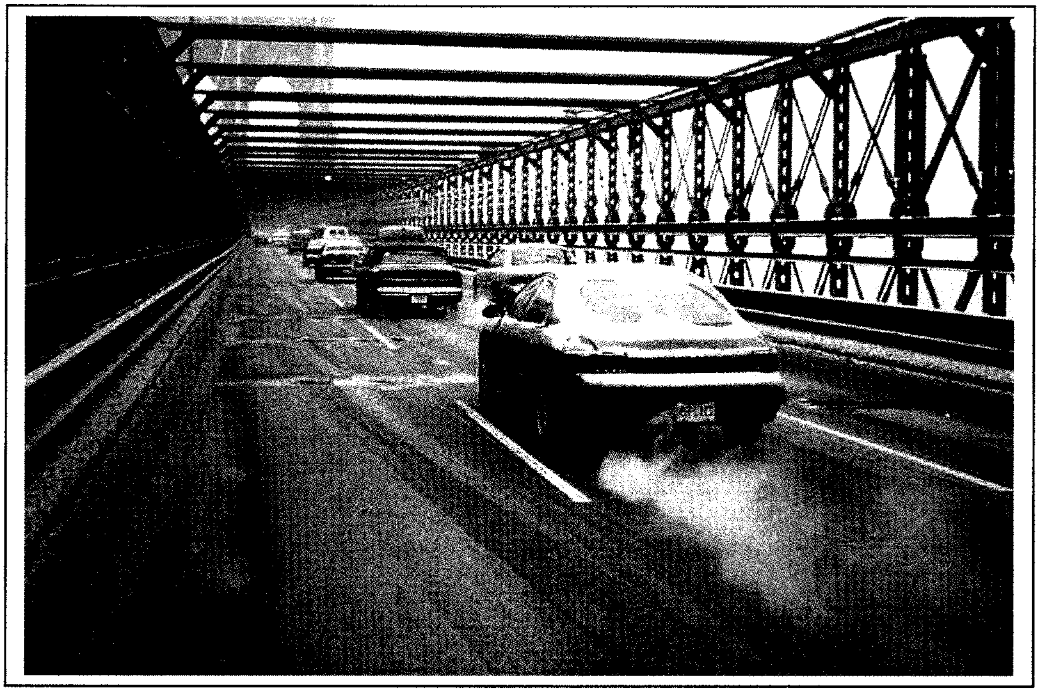


Photo Exhibit D: Pavement condition before re-treating (1/14/99)

Photo Exhibit E: Road section treated by spray truck (1/14/99)

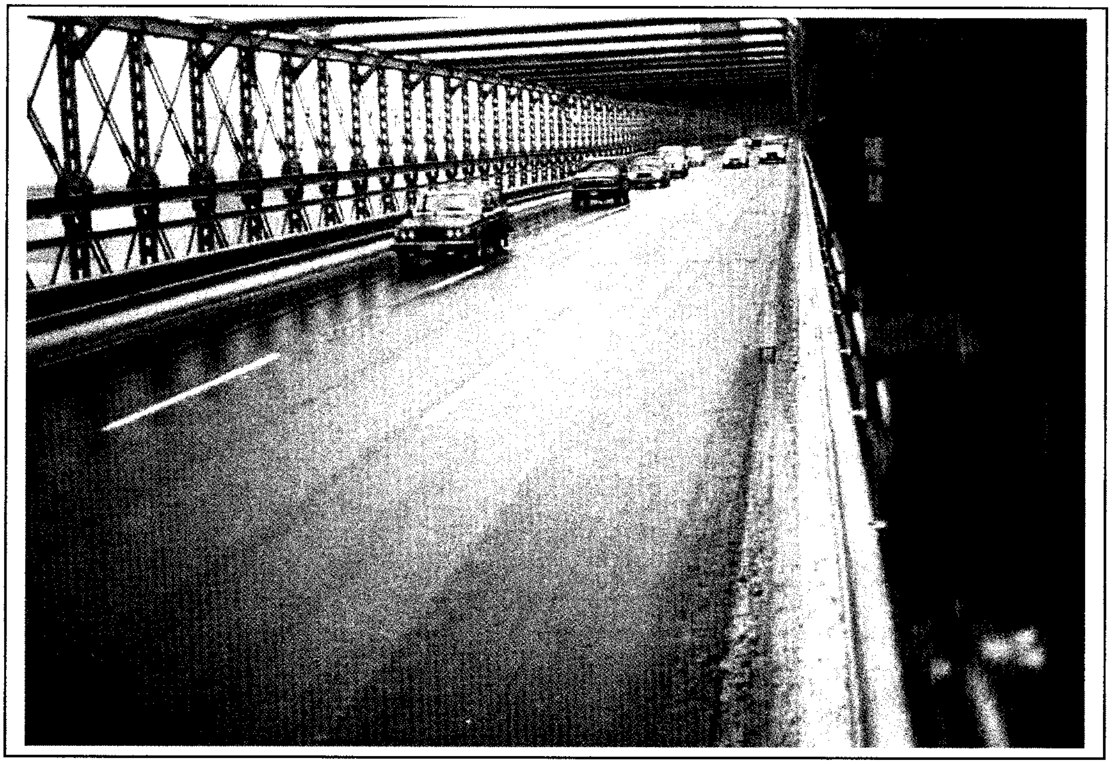


Photo Exhibit F: North roadway pavement after >4 passes of DOS salt trucks (1/14/99)

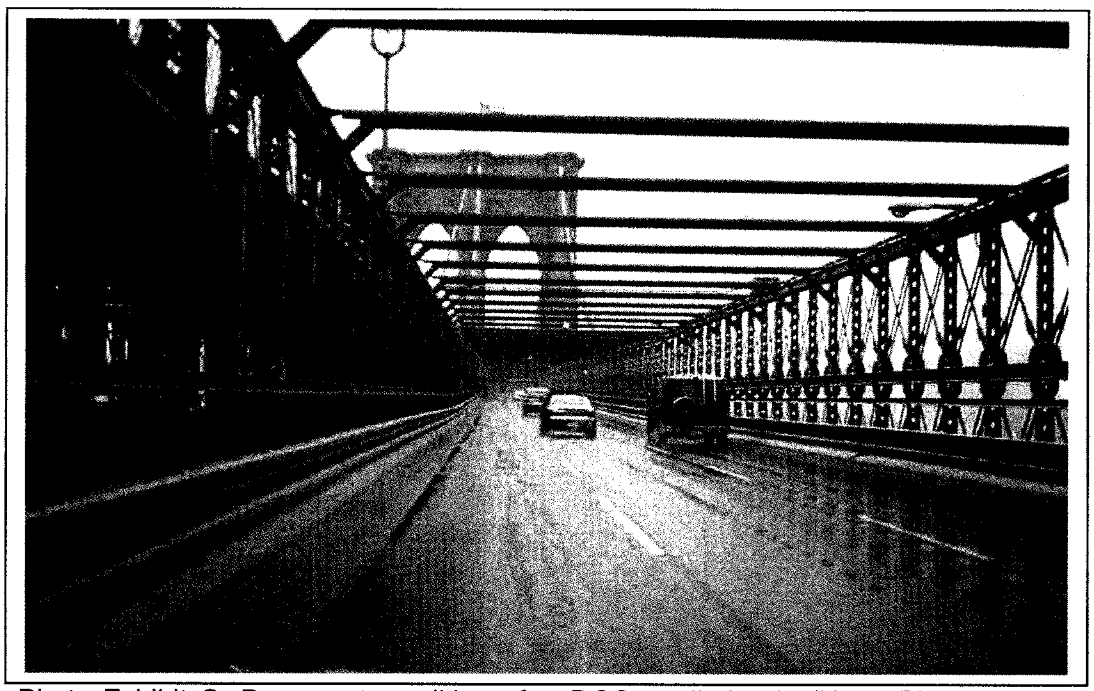


Photo Exhibit G: Pavement condition after DOS applied salt. (Note: Photo D illustrates the pavement condition before salting occurred (1/14/99).

Preliminary results indicate the effectiveness of timely and rapid spray applications utilizing the FAST system on the Brooklyn Bridge with a reported average daily traffic (ADT) volume of 147,898 to be safe and effective. Also, the integration of a RWIS and plowing equipment are necessary tools for an effective anti-icing program.

MECHANICAL PERFORMANCE

Evaluation of the AISDS mechanical performance has been broken-down into the following categories:

➢➢ FLUID DELIVERY: In order to spray the recommended quantity (0.5 gallons per 1000 sq. ft.), of potassium acetate (CF7) required for the initial application, a spraying time of 2-3 seconds was required. The spray time duration is based on the capacity of each nozzle (3-GPM) and the total number (50) of nozzles utilized. Photo Exhibit H provides an illustration of the FAST system spraying in progress.

Photo Exhibit H: FAST system spraying (1/14/99)

➢➢ **EFFICIENCY**: The efficiency of the FAST system was measured by the following:

► Spray area coverage

► Reliability of the system's components such as:
- Spray nozzles
- Check valves
- PVC piping on the south barrier

Spray area coverage

The initial goal established was to achieve a spray coverage distance of three wheel paths from the curb barrier. This goal was achieved as a result of the nozzle angle and spray pressure (70psi) established.

Reliability of the System's components

While each component is critical to the overall operation and performance of the FAST system, special focus was directed to the following components:

- Spray Nozzles: The nozzles' capacities are 3 gallons per minute (gpm) each, with a 15° degree spray angles. The nozzles were self-cleaning and generated negligible misting that would not impair drivers' visibility.

- Check Valves: The absence of an in-line filtration system had initially resulted in residual debris in the pipe being deposited in the valves spring mechanisms. This condition was initially observed and addressed during the early testing phases of the system. However, this occurrence was infrequent during the season.

- PVC Piping: Schedule 80 PVC pipe was installed on the south roadway barrier. A major concern has been the durability of this pipe exposed to the elements. The concern was would it become brittle and break as a result of extreme ambient weather conditions, and when: year-one, year-two or year five. This did not occur during the '98/'99 winter season- the second year of the system's installation- but it was observed that some of the joints were discolored and moist. The discoloration can be attributed to airborne dust and debris. The moisture at some of the joints was as a result of the glue's failure. Commercial PVC pipe glue was used. During subsequent winter seasons –'99/'00 and '00/'01- failure of the PVC pipe joints occurred.

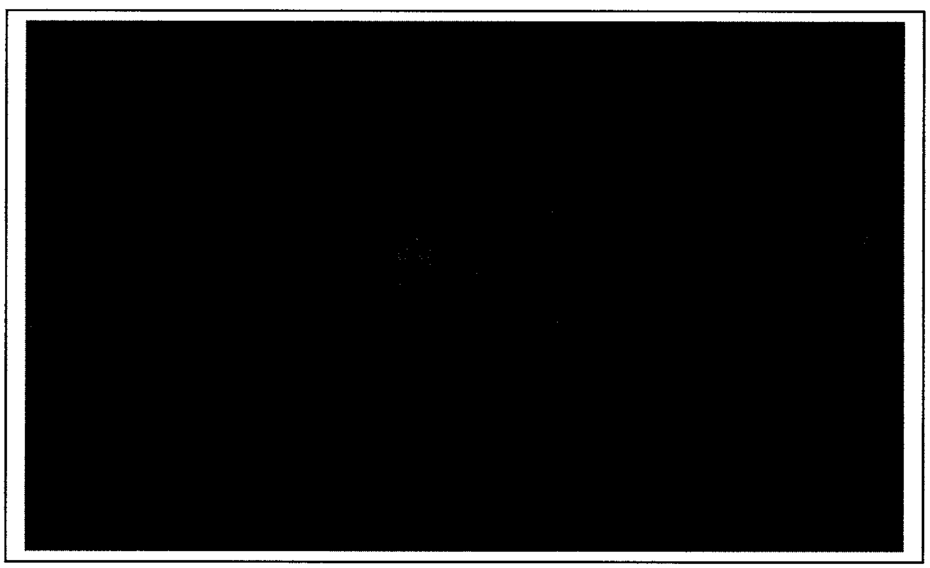


Photo Exhibit I: Typical joint failure

➢➢ **DRIVER REACTION:** There were no adverse reactions observed to the sprays.

➢➢ **MAINTAINABILITY OF SYSTEM:** Maintenance consisted primarily of scheduled and periodic cleaning of check valves. Repair of broken and leaky joints is accomplished by a worker easily saw cutting PVC pipe and using couplings, reconnect the jount.

Photo Exhibit J: Typical joint repair

➢➢ **LEVEL OF SERVICE**

It is important to note that a qualitative comparison of pavement conditions indicate that the level of service of the roadway treated with the FAST system had significantly less accumulated snow that the section tread via conventional methods utilizing a spray truck (see photo 1 and 2 for illustration).

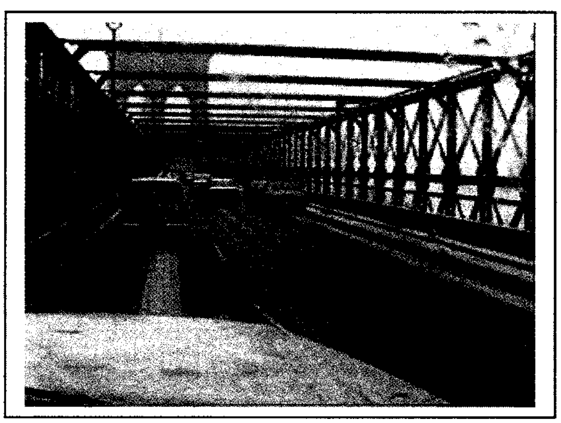


Photo 1: Road section sprayed by the FAST system

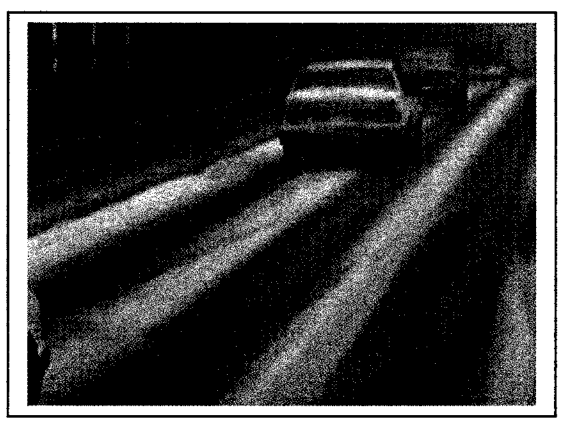


Photo 2: Road section sprayed with truck mounted spray unit

CHEMICAL PERFORMANCE

Potassium Acetate (CF7) (Chart 3: Phase diagram [1]) was utilized during the events the FAST system was utilized during the '98/'99 season. This chemical was effective as an anti-icer. Information pertaining to the residual concentration of the chemical on the roadway was not "scientifically" monitored and obtained. This information is generally obtained from solution detection sensors installed on the roadway as part of a RWIS. The installation of an RWIS is proposed as part of the Phase II of this project. In fact, the presence of these sensors will enhance the abilities of the decision-makers as to how far (time) in advance a treatments should be made considering deck and pavement types and the average daily traffic (ADT) volume on the bridge.

It should also be pointed-out that a different manufacture's brand of potassium acetate (no chemical phase diagram was provided by the manufacture/distributor) was purchased and introduced during the '98/'99 season and utilized during subsequent seasons. Initially, the truck mounted spray units sprayed this generic brand chemical product exclusively. However, with the depletion of CF7 in the FAST system's tanks, the use of this generic brand product during the '00/'01 season occurred. During a February 22, 1001 event, the application of this chemical was sprayed by the FAST system.

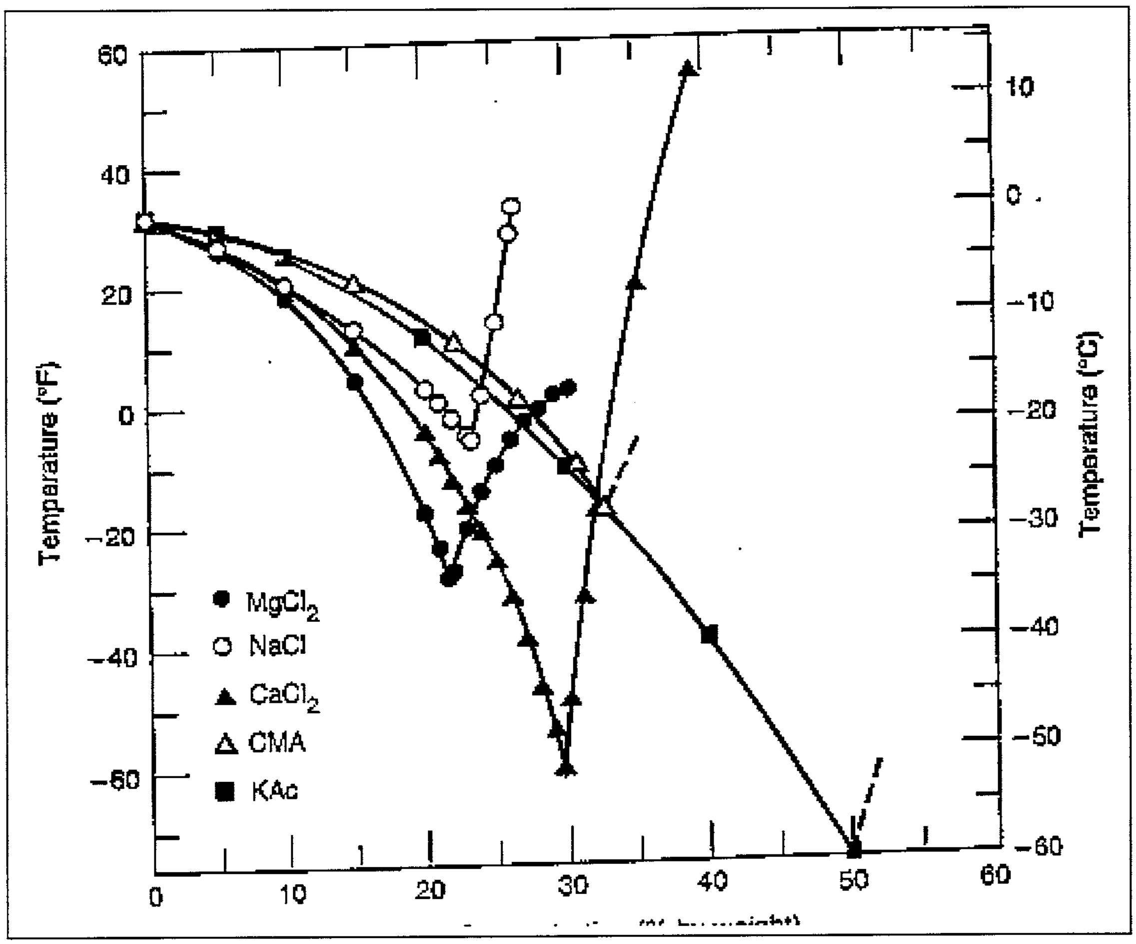


Chart 3: Phase Diagram [1]

It was observed that as the temperatures dropped below freezing and the snowfall precipitation rate increased, the roadway section sprayed (via FAST) with the chemical was comparatively more slippery than the adjacent sections not sprayed by the FAST system. Upon close examination of the roadway section, it was observed that the chemical – obviously diluted because of the wet pavement surface - was "freezing" on the bridge deck. Further application of this chemical utilizing the FAST system was discontinued. Test samples of the chemical were removed from the storage tanks for product analysis. The result of the analysis is forthcoming. Preliminary observations by some personnel suggest that the noticeable physical characteristics – vinegar-like odor of product, residual solution properties (slipperiness) on asphalt surfaces – were not as distinctive as the CF7.

COST ANALYSIS

Weather scenarios in '98/'99 occurred that ranged from moderate snow falling with pavement temperatures rising above freezing to snow falling with pavement temperatures below freezing or expected to fall below freezing. Regardless to the condition, calling out crews too soon was a large expense incurred by the truck operation. A practice and cost that is duplicated during subsequent winter seasons ('99/'00 and '00/'01).

The results of the two methods of treatments evaluated during the '98/'99 season suggests (see Chart 4) that the wide-scale installation of the FAST system offer the opportunity for:

- A significant return on investment;
- Significantly improves the service level on the brides roadways with the safe and rapid application of potassium acetate (CF7) to the bridges roadways; and
- Greatly reduce the frequency of decision error.

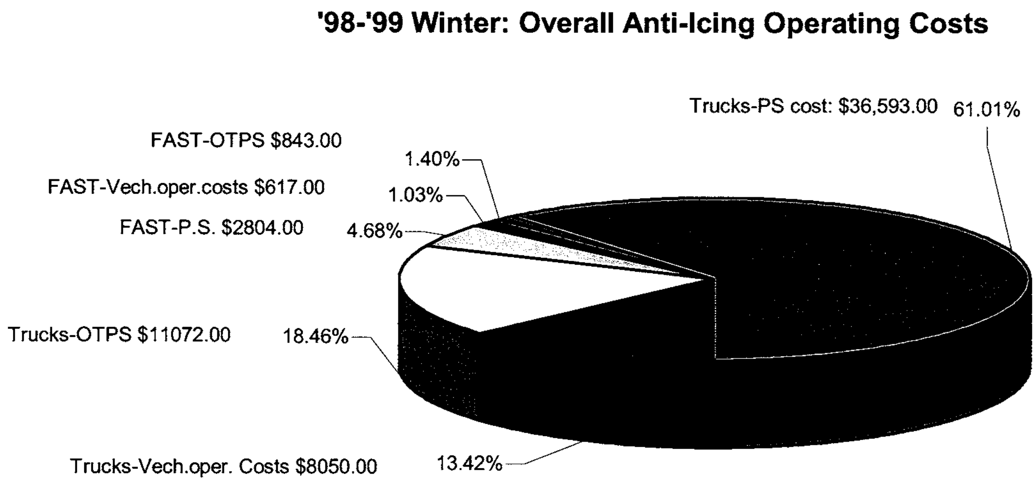


Chart 4: Operating Cost

SUMMARY

Observations and Conclusion

The homegrown development and utilization of the FAST system as part of an anti-icing evaluation program required more than bolting pipes and nozzles to the bridge and spraying the chemical onto the roadway when weather conditions deteriorated. In fact, an effective anti-icing program uses each tool as part of the larger winter road maintenance equation and decision-making process. The use and benefits of a FAST system are best optimized when the signals to activate the system are coupled with a Road Weather Information System (RWIS) that will incorporate knowledge of ambient and pavement temperatures, humidity, and precipitation type and amount. The absence of this technology in the decision-maker's toolbox has resulted in reliance on the radio, television, or in some instances, the reliance on intuition. This approach resulted in excessive and unnecessary operations expenditure totaling $8,409.00. A total of 42% of the events -responded to- did not materialized, and an additional 8% did not meet the threshold temperature recommended in the *Federal Highway Administration's Manual of Effective Anti-icing Practices* to initiate anti-icing techniques and principles.

This project verified that the FAST system can significantly and cost effectively enhance motorists safety during snow and icing conditions relative to the present over-the road (trucks) methods of application. The further development and linking of the FAST system to RWIS give winter managers added flexibility in performing their duties. Optimally, the use of the FAST systems has an inherent time advantages over calling-in maintenance crews, loading trucks, and sending them out to bridges to navigate high traffic volumes. This is especially the case in New York City[3].

The results of this investigation indicate that maintaining a bare pavement level-of-service was consistently improved by activating spray applications closest to the event start. In fact, it was noted that subsequent applications are often not required when the initial application is applied timely (the instant precipitation starts or immediately after) and rapidly. It should also be noted that in moderate to heavy snowfall (>2"), maintaining "black road" conditions is not likely without the support of a plowing operation. As an aside, during the '00/'01 winter season, two of the four significant snow events exceeded 4 inches. Plowing superseded the effective use of anti-icing. Post storm anti-icing was recommended during falling temperatures.

As illustrated by the January 14, 1999 event, a slushy-like residue (<<1") remained on the roadway that has the net effect of diluting any subsequent chemical treatments. Since plowing is generally not performed by DOS for accumulations less than (<) 2 inches, the response has been – salt the roadway. This response and action was observed on several occasions (1/8/99, 1/14/99, and 3/14/99) during the '98/'99 season. Ironically, these applications were observed being made to a roadway with "black pavement" conditions. To eliminate this response, plowing is required for snowfall ≥1 inches.

RECOMMENDATIONS

The widespread use of anti-icing techniques, supported by the increased use of FAST systems in the Untied States is a signal being received and advanced by highway and bridge owner/managers to proactively preserve and extend the useful life of the national infrastructure. In a similar manner, the City's $2.1 billion dollars investment to rehabilitate the East River Bridges must be maximized by maintaining and utilizing proven and cost-effective methods. Part of this maintenance will be the development and use of anti-icing application techniques. Implicitly, the development and use of FAST systems during the winter months provides the greatest value to augmenting the implementation of an anti-icing program. While this method of application is not a replacement for the traditional over-the-road winter methods using trucks, it provides added flexibility and safety to the Division's winter managers.

Based primarily on the Division's 1998-1999 winter performance to implement anti-icing on the ERB, the following recommendation are listed for consideration:

- Expand and develop the FAST system on the Brooklyn Bridge. This implementation should be performed in phases. One phase will address the remainder of the South roadway; another will focus on the North roadway and a final phase would be the on-ramps and approaches.

- Initiate initial treatment application closer to the event start. This is achieved via a FAST system. Trucks will be used for plowing, subsequent treatments (if needed), and spreading of solid (granulate) deicers.

- Implement plowing operation. This task should be performed utilizing plows with slush blades[3]. This approach and strategy would have the resultant effect similar to a squeegee-like cleaning (scraping) of the roadway. This "scraping" procedure is recommended for snow accumulation < 1 inch and performed utilizing an underbody scraper.

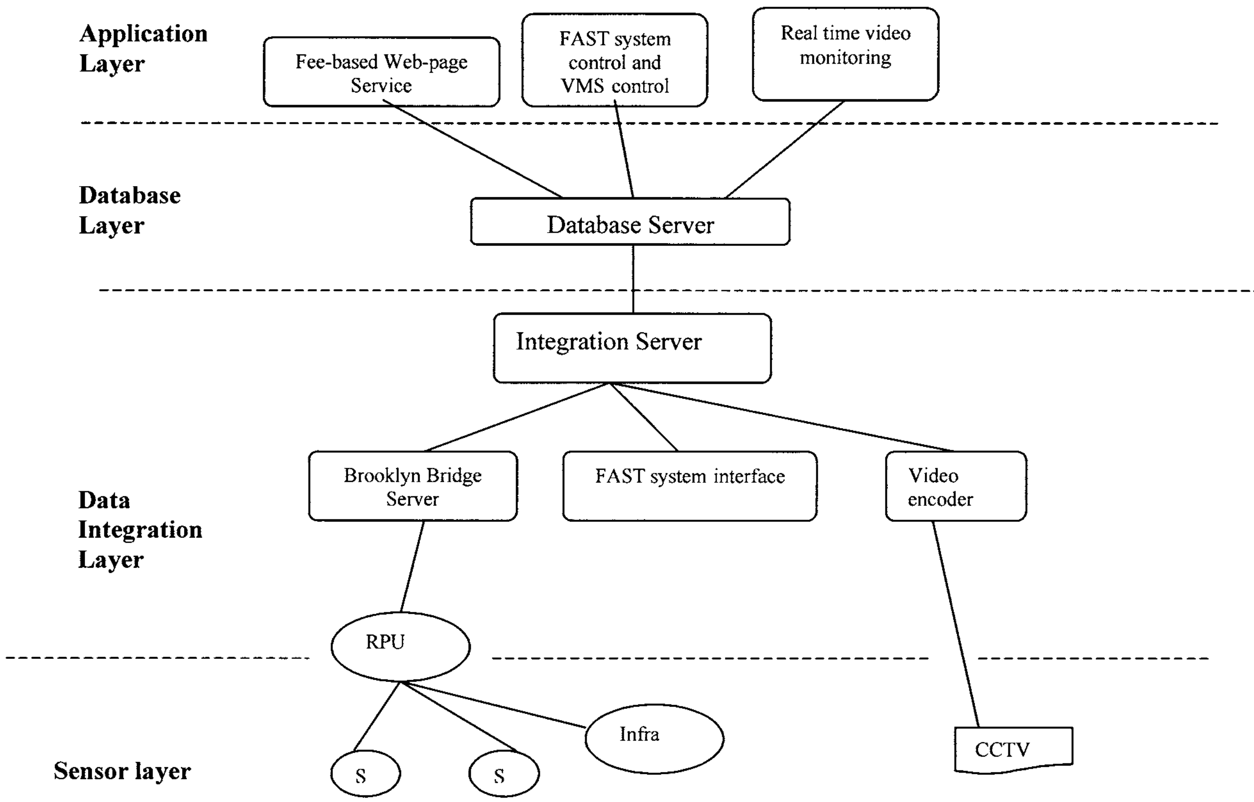
- Implement and use of a Road Weather Information System (RWIS). RWIS sensors provide a generally reliable means to monitor, detect and assist in the prediction of road temperatures and weather pavement conditions.

- Evaluate and implement the ERB Winter Incident Management Plan: Phase II

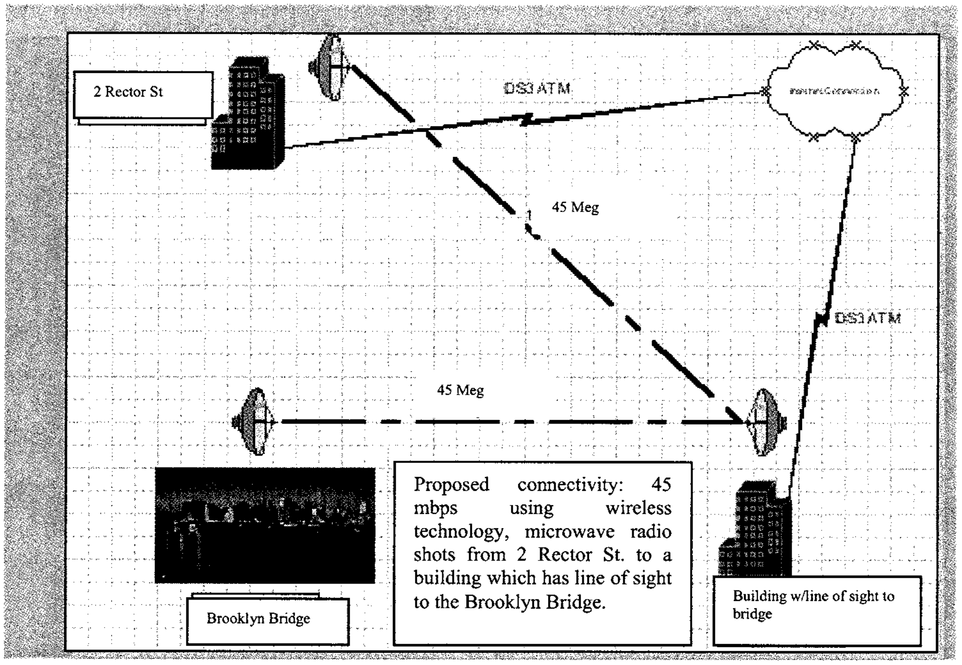
[3] A blade that uses two blades: the leading blade has a cutting edge of steel and the trailing blade having an edge of rubber.

PHASE II: The East River Bridges Winter Incident Management

This phase of the project (phase II) describes extension of the FAST system and integration the following road weather information system's next generation (RWIS) architecture [2] model.



The demonstration phase of the phase II project shall provide for the development of proven wireless high-speed connectivity of a road weather information system's (RWIS) sensors data and distribution of real time high quality video across a virtual private IP network and IP-applications utilizing the Internet. By combining wireless technologies with a fiber infrastructure, the Division will cost-effectively link pavement sensors, non-destructive structural stress-stain sensors' data and distribute high quality live video across a Virtual Private IP network which can handle 30 JPEG images per second over the LAN and internet.



Utilizing 45 Mbps RF wireless microwave communication technologies and radio shots between two sites- Brooklyn Bridge Manhattan Tower to New York City Department of Transportation's Division of Bridges office located at 2 Rector Street in lower Manhattan-this can be accomplished.

References

[1] Federal Highway Administration's *A Manual of Practice for an Effective Anti-icing: A Guide for Highway Winter Maintenance Personnel* June 1996
[2] Next Generation R/WIS: Concept and Prototype Implementation, Final Report-MN/RC-1999-19
[3] The Brooklyn Bridge: Fixed Anti-Icing Spray Technology, NYCDOT-January 2000 (Video file)

APPENDIX D

NYSDOT – HIGHWAY MAINTENANCE GUIDELINES:

SNOW AND ICE CONTROL

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

HIGHWAY MAINTENANCE GUIDELINES

SNOW AND ICE CONTROL

5.0000 SNOW AND ICE CONTROL ON STATE HIGHWAYS

5.0100 General Principles

Our State's, society and economy depend upon the all weather use of our streets and highways. When the State system is closed or the capacity reduced, industry and commerce are severely affected. Also, accidents due to snow and ice on our pavements can be very costly in terms of property damage, personal injuries and human life. The terms shall, must, should, recommended and may used in Section 5 have the following meaning:

Shall and Must - A required course of action

Should and Recommended -A recommended course of action

May - An optional course of action

5.0110 Goal

To provide a highway that is passable and reasonably safe for vehicular traffic as much of the time as is possible within the limitations imposed by climatological conditions and the availability of equipment, material and personnel resources. It is recognized that due to those resource limitations and climatological conditions, pavement surfaces will be snow covered and/or slippery some of the time. Vehicle operators must exercise caution and drive appropriately in those situations.

5.1000 Preparation For Snow and Ice Control

5.1100 Objective

The objective of planning for snow and ice control operations is to have sufficient resources and knowledge to effectively combat snow and ice conditions that routinely affect the State highway system, in accordance with budgetary and available resource considerations.

5.1200 Goal

The goal of the preparation effort is to provide for a reasonable response to snow and ice events that affect the State highway system.

5.1300 Methodology

5.1301 Rationale for a Traffic Based Level of Response

Traffic volume is selected as a basis for level of response primarily because it reflects (1) the degree of difficulty in snow and ice control, (2) the speed of vehicles using the facilities, (3) the relative skill and familiarity of the highway users generally traveling on the highways, and, (4) the number of people we are inconveniencing if our efforts are delayed.

5.1302 Highway Classifications for the Purpose of Snow and Ice Control

Class A1 - Expressways with low average running speeds. Examples: Long Island Expressway, Interurban, and Intercity State Routes with traffic volumes approaching or exceeding capacity. These highways are at, near, or, over the practical capacity of the highway at certain times during the day. Any interruptions delay some vehicles, thereby raising the volumes in a given section to or above the possible capacity. The speed then drops to near zero and complete congestion results. In cases like this, the speed of the Snow and Ice control vehicle is not governed by the operator or by the efficiency of the operation, but by forces completely beyond control. However, traffic must be kept moving before that complete congestion point is reached. This signifies that, so far as is practicable, priority attention be given to these highways.

Class A2 - Expressways with high average running speeds. Typically, these are Interstate type highways with a one-way design hourly volume of 500 or more vehicles per hour. The slowing of a few vehicles does not mean complete congestion of the highway. These highways give snow and ice control vehicles more freedom to maneuver, and plow speed can be controlled by the operator.

<u>Class B</u> - Major State highways with a one-way design hourly volume from 200 to 500 vehicles per hour. As with A2 highways, the immediate need for snow and ice control is not as critical since vehicles can normally travel without congestion at reduced speeds.

<u>Class C</u> - Minor State highways with a one-way design hourly volume less than 200 vehicles per hour. On these highways traffic volumes are low, motorists are more apt to be familiar with the highway, and the congestion point is rarely reached. Plowing speeds can, therefore, be controlled by the plow operator.

<u>Class D</u> - Minor State highways having very low traffic volume. On these highways there is little vehicle interaction and a lower level of service can be safely tolerated.

<u>5.1303 Locations that require special consideration when planning for snow and ice operations</u>.

In particular, locations such as steep grades, intersections, sharp curves, bridges, approaches, and railroad crossings should receive special consideration in planning for snow and ice control operations, regardless of the highway classification. Areas subject to the Great Lakes squalls, bridges and highway sections susceptible to sudden icing, and highways subjected to abnormal drifting are all special conditions that warrant individual consideration. Other special snow and ice removal areas include: ditches and culverts (to provide for proper drainage), bridges, intersections, signs, safety appurtenances, facility drives and loading areas, and certain commercial areas that could otherwise possibly impair traffic flow.

<u>5.1304 Design rate of snowfall</u>

A snowfall rate of 1.1 inches per hour has been determined as being exceeded only a few times each year in all areas of the State. It is considered the maximum rate of fall for which staffing is economically possible.

<u>5.1305 Average Truck Speeds (for planning purposes)</u>

Through research, it has been determined that the average plow truck speed (including deadheading and reloading) is 16.5 MPH for highway classes A2, B, C, and D and 14.5 MPH for class A1 highways.

5.1306 Assignment of Plow and Spread Trucks to the Various Classes of Highway

The distribution of plow and spread trucks to Regions shall be:

Highway Class	Lane Miles per Plow and Spread Truck	Lane Miles per Spread Only Truck
A1	20	45
A2	30	45
B	30	45
C	30	45
D	30	45

5.1307 Plowing Capability of Snow and Ice Trucks

The GVWR (Gross Vehicle Weight Rating) determines to a large extent the plowing capacity of the truck. A suggested minimum truck GVWR of 36,000 pounds will handle the rate and frequency of storms anticipated, spread sufficient material per trip, and minimize the possibility of complete impassability of State highways during less frequent but more severe storms.

5.1308 Spreading Capacity of Snow and Ice Trucks

Ideally, the spreading capacity of trucks used for Snow and Ice control on State highways should be at least 7 C.Y. This will minimize the labor and equipment cost per yard of material spread and provide sufficient materials coverage for normal beats. Time lost during reloading is not productive and necessitates increased use of equipment and personnel resources.

5.1309 Other types of Snow and Ice equipment that must be considered during planning

A. Loading Equipment

So far as possible, sufficient loading capability must be provided to load trucks without unreasonable delays. Additionally, plowed snow must be removed from certain areas on and around the highways. Front end loaders having a bucket capacity of about 2 C.Y. are suitable for this purpose.

B. Graders

Occasionally, in spite of reasonable effort, pack will form on the highway. Graders are suitable for mechanically removing this pack. However, they are too slow for efficient removal of ordinary snow from the highway. If equipped with a wing plow, they are suitable for benching and some post-storm cleanup.

C. Snowblowers

There are some drifting areas where accumulating snow exceeds our capacity to remove it with plow trucks. Here, snowblowers having sufficient size and capacity, are the only way to open or keep the highway open. They are also useful in loading and hauling operations.

D. Light Weight Equipment

There may be bridges on the highway system that cannot accommodate the weight of heavy plow trucks. A variety of lighter plow-equipped trucks, where possible, should be available to maintain these bridges.

E. Large Capacity Loaders

On Long Island, where traffic volume is extremely high, and there is an occasional heavy snowfall, highways can be closed due to large numbers of stranded vehicles. Availability of front end loaders having bucket capacities of 5 C.Y. or more is desirable. These loaders are capable of removing stranded vehicles from the highway as well as efficient snow removal.

5.1310 Equipment Readiness

Major repairs and overhauls of Snow and Ice equipment should be performed well in advance of the anticipated time of need. Stored equipment (plows, spreaders, snowblowers, etc.) should be given proper lubrication, protection and painting prior to storage. This stored equipment should be thoroughly checked and run prior to the time of anticipated need. Proper preventive maintenance and daily maintenance on multi-seasonal equipment is a good way to ensure readiness and proper performance.

5.1311 Personnel Readiness

The training of Snow and Ice personnel to safely and efficiently perform their duties should be a continuing effort. Basic Snow and Ice training for all new employees is essential. Snow Schools, mini-Snow Schools, Seminars, and preparation for snowplow competitions are available training forums.

5.1312 Facilities and Stockpiles

Facilities and stockpiles should be located so as to keep deadheading minimized.

5.1313 Weather Information

As accurate weather information is essential to effective Snow and Ice management, the possible sources of this information must be known well in advance of the Snow and Ice season. Possible sources include:

A. THE NOAA WEATHER RADIO NETWORK

NOAA Weather Radio is a service of the National Oceanic & Atmospheric Administration (NOAA) of the U.S. Department of Commerce. It provides continuous broadcasts of the latest weather information directly from National Weather Service offices. Most of the stations operate 24 hours daily. Residency radio scanners equipped to pick up the appropriate frequency can monitor NOAA Weather Radio broadcasts from the following stations:

NOAA STATION	FREQUENCY (M Hz)
Albany	162.550
Binghamton	162.475
Buffalo	162.550
Elmira	162.559
Kingston	162.475
Rochester	162.400

Syracuse	162.550
New York City	162.550
Burlington (Vermont)	162.400

B. Private Weather Forecasting Services

There are a number of private weather forecasting companies that offer a variety of service. NYSDOT has an agreement with a forecasting firm that provides for Regional notification of anticipated Snow and Ice events and other severe weather events.

C. In-House weather radar

Some Residencies have near real-time radar information from sites that cover their area. This provides excellent data on storm location and timing.

D. Knowledge, experience and communication with locations in the storm path.

Over time, people develop a sense of local weather patterns. Certain bridges and sections of highways tend to be possible problem spots. This information should be communicated to all employees that are likely to have snow and ice responsibility for those areas. When general storms are approaching, communication with Residencies closer to the storm will yield valuable information on the timing and character of the storm as well as information on the cessation of the storm.

E. Other Sources of Weather Data

Local radio and television stations provide some weather information. The amount and priority are a matter of local station policy. Computer access, of various kinds of weather information, is available through modem transmission by a variety of subscription vendors. Local and national newspapers contain varying amounts of weather information. Cable television provides access to a weather channel that provides forecasts 24 hours every day.

5.2000 Storm Watch

5.2100 Objective

The objective for storm watch is to have a set of communications procedures in place that will enable timely mobilization of sufficient personnel to effectively deal with snow, ice or other possible emergencies and provide the public and other agencies a forum for reporting potentially hazardous highway related conditions.

5.2200 Goal

The goal for storm watch is to effectively use the selected set of communications procedures to provide timely response to snow, ice and other winter emergencies.

5.2300 Methodology

The methodology will vary among Residencies and shall be based on such factors as traffic volume, historical rate and frequency of storms, population centers, working hours of large employers within the Residency, the necessity of maintaining access to vital services such as hospitals, fire, police protection, and the necessity of maintaining a consistent level of service on important highways. Continuous telephone watch shall be maintained during the snow and ice season in each Residency. Portions of this may be in the form of commercial services or arrangements with other municipal service agencies.

5.2301 Supervision and Preparedness

During periods when snow or ice events are predicted, it is recommended that supervisors, in light vehicles having communications capability, patrol areas likely to be affected by the event for the purpose of directing the appropriate response. This activity is termed supervision.

In situations where a snow or ice event has a high probability of occurring, it is recommended that trucks, carrying the appropriate material, be in position to begin spreading on their beat as soon as the event starts. This activity is called preparedness.

5.3000 Snow Control

5.3100 Snow Control Objective

The objective of snow control is to provide the traveling public with a passable highway as much of the time as possible - given the constraints of operational resources and the character of the snow event.

5.3200 Snow Control Goals

The snow control goals will vary with traffic volume and other considerations. Furthermore, the level of service provided will vary with the snow control goals determined to be appropriate given the existing conditions. Regular level of service should be provided on all classes of highway between 4:00 AM and 10:00 PM Monday thru Friday, and at all times on highways having Average Daily Traffic (ADT) of 50,000 vehicles per day or more. Modified level of service should be provided on all highways except those having ADT's of 50,000 vehicles per day or more in all time periods except those defined under "regular level of service".

The Regional Director may determine it to be appropriate, at his or her discretion, to provide certain highway sections with a higher than modified level of service. Such a determination may occur where it might be necessary to maintain a higher level of service because of unique travel or weather demands. These may include, but not be limited to, highway sections serving industrial or recreational areas, other highway sections important for economic activities, or highway sections which may historically receive heavy snowfalls such that the Maximum Goal Accumulation may routinely be exceeded. These variations must be approved by the Regional Director, as requested by the Resident Engineer and recommended by the Regional Highway Maintenance Engineer and documented at the beginning of each snow and ice season, and updated as appropriate during the season.

5.3201 Snow Control Goals - Regular Level of Service

Highway Class	Accumulation at which plowing should begin, Inches	Elapsed time after event end that full width of pavement should be plowed, hours
A	0.50 to 2.50	1.5
A2, B, C	1.00 to 3.00	2.0
D	1.50 to 4.00	3.0

5.3202 Snow Control Goals - Modified Level of Service

	Accumulation at which plowing should	Elapsed time after event end that full width of pavement should

Highway Class	begin, Inches	be plowed, hours
A	0.75 to 3.00	2.0
A2, B, C	1.50 to 3.50	3.0
D	2.00 to 4.50	4.0

5.3300 Snow Control Methodology

5.3301 Preparation for Snow Control Operations

A few plows should be mounted well in advance of the anticipated date of the first snowstorm. As more consistent winter weather approaches, additional units should be readied. All plows should be mounted by a date determined by the previous experience of the location. During the winter season, equipment shall be serviced at the end of each storm and at opportune times during a storm. The trucks and spreaders should be cleaned at the end of each storm.

Ballast, usually in the form of salt or abrasives, provides extra weight needed by the truck to obtain maximum traction for removing snow. The ballast must be removed when the truck is not needed for snow removal.

Blades (cutting edges) and shoes must be inspected by each operator on each shift and changed as necessary in order to prevent moldboard damage and wear.

Properly fit tire chains shall be carried on each snow and ice vehicle. Conditions such as ice storms often require the use of chains.

5.3302 Snowplowing Procedures - Mainline

A. General

There are a variety of acceptable procedures that will facilitate removal of snow from the highway and allow for reasonably safe traffic flow. They vary with local traffic conditions, the characteristics of the highway surface and available snow storage area. The paramount objective in all of these procedures is to avoid leaving a windrow or berm of plowed snow between adjacent mainline (travel) lanes where reasonably possible. However, there may be circumstances where insufficient equipment or other conditions may exist that preclude plowing without leaving windrows in certain areas. In such circumstances, windrows may be left, but should only remain in such an area for as brief a period of time as reasonably possible.

The following are examples of acceptable procedures:

B. TWO LANE - TWO WAY TRAFFIC

Plowing shall always be done in the direction of traffic. A one-way plow with right wing is typically used when plowing the snow to the right. The traffic lane and as much of the shoulder as is possible should be plowed clear of snow in this operation. When a plow truck is plowing to the right, without the right wing, as much of the pavement as possible should be cleared. Some reasonably small amount of plowing over the center line may be necessary to clear the pavement. However, plow trucks shall yield the right-of-way to oncoming traffic.

C. TWO LANE SECTION - ONE WAY TRAFFIC

1. Plowing shall always be done with trucks moving in the direction of traffic. Snow should not be plowed to the side of the truck on which traffic has an opportunity to pass unless it is done as part of a close echelon plowing operation that minimizes passing opportunities and will have plowed snow quickly removed from the pavement surface.

2. Typically, the entire passing lane will be plowed in one pass, by plowing the snow to the left if the median is of adequate width to store the snow. This should preferably be accomplished with a large dump truck equipped with reversible plow throwing left and a left-hand wing. This truck will typically be operated along the right-hand edge of the passing lane so that the plow cuts as close to the lane marking as possible.

3. The entire driving lane should be plowed in the second pass by plowing the snow to the right. The truck for this pass shall be operated more than approximately five hundred and fifty feet behind the truck of the first pass. The plowing of the driving lane should preferably be accomplished by a large dump truck equipped with a plow and a right-hand wing. This truck will typically be operated

along the left edge of the driving lane so as to permit removing the remaining snow, on the entire driving lane and any small area of unplowed snow that may be remaining on the passing lane, in one pass. If the trucks leave the mainline plowing operation to plow ramps, and intersections it is important that they return to the place they left off as quickly as possible in order to minimize the time sections between "off" and "on" ramps are in the unplowed condition.

4. If the median is too narrow to store snow, all plowing should be in close echelon and to the right as described in 1. above.

D. THREE LANE SECTION - ONE WAY TRAFFIC

1. Plowing shall always be done with trucks moving in the direction of traffic. The inside or left lane should be plowed toward the median or left shoulder if sufficient snow storage area is available.

2. The center and right-hand lane should be plowed with two trucks utilizing right-throwing plows and wings while traveling in echelon as close together as safely possible. The first truck should generally operate as close to the left-hand edge of the center lane as possible.

3. Should the trucks leave the mainline plowing operation to plow ramps and intersections, it is important that they return to the place they left off as quickly as possible in order to minimize the time sections between "off" and "on" ramps are in the unplowed condition.

4. Alternative sequencing of the plow trucks is acceptable as long as no windrows or berms of plowed snow are created between adjacent travel lanes and the distance between the close echelon pair of trucks and the single truck is a minimum of approximately 700 feet.

5. If the median is too narrow to store plowed snow, all plowing should be in close echelon and to the right.

6. There may be circumstances where insufficient equipment or other conditions may exist that preclude plowing without leaving windrows in certain areas. In such circumstances, windrows may be left, but should remain in such an area for as brief a period of time as possible.

5.3303 Plowing of Ramps and Intersections

In general, ramps and intersections should be plowed at about the same time as mainline sections. The character of the storm and traffic conditions may dictate that they be plowed earlier or later than the adjacent mainline sections.

5.3304 Plowing of Shoulders

After the pavement and ramps are cleared, the full width of the shoulders should be plowed. If weather predictions indicate that snow on the shoulders will not freeze solid, shoulder plowing may be delayed until it can be accomplished on a "Regular Time" basis. It is particularly important that snow be cleared beyond the shoulder high point on banked curves in order to minimize possible re-freeze of snow melt on the pavement.

5.3305 Crossovers, Turnarounds and Gore Areas

Crossovers, turnarounds and gore areas should be plowed after the storm is over and other elements of the highway have been cleared. These should be done when visibility is good and traffic volume is low.

The use of crossovers during mainline plowing operations is discouraged. Intersections should be used to the extent possible for the operational movement of plow trucks.

5.3306 Plowing Back and Benching

After the storm is over, plowed snow should be plowed back as far as possible to provide snow storage space in anticipation of the next storm. Additional snow storage can be provided by plowing high snowbanks with wing elevated. This is called benching. If the plow with wing elevated is unable to displace the snow, a snowblower should be used to clear the area. This operation should be accomplished on a "Regular Time" basis to the extent possible.

5.3307 Removal of Snow from Special Areas

A. General

After the storm is over, the shoulders, crossovers and gore areas have been plowed, and benching and pushing back operations are underway or complete, the removal of snow from special areas should commence. These operations require loading equipment and hauling vehicles. Front end loaders, snowblowers and heavy dump trucks are usually used for this purpose. If necessary, rental equipment should be considered. This may be available under a Municipal contract or through private rental.

B. Bridges

When possible, accumulated snow should be removed from locations that could melt during the day, drain across the deck, and freeze at night. Bridge drainage features should be cleared to facilitate the designed discharge of water. Also, bridges having features to prevent plowed snow from leaving the bridge should have the accumulated snow removed to make room for the next storm.

C. Impact Attenuators

When possible, accumulated snow should be removed from areas that could effect the performance of impact attenuators.

D. Banked Curves

When possible, accumulated snow on the high side of banked curves should be removed to minimize the risk of melt water freezing on the pavement.

E. Sags (Vertical Curves)

When possible, drainage channels should be created in the snowbanks on both sides of the highway at the low point in sag vertical curves to minimize the risk of melt water accumulating on the pavement.

F. Ditches and Culverts

When possible ditches and culverts having a history of snow melt-water runoff problems should be cleared of accumulated snow prior to anticipated thawing weather.

G. Closed Drainage Systems

The inlets to closed (underground) drainage systems should be cleared prior to anticipated thawing weather.

H. Narrow Median Areas

Accumulated snow should be removed from narrow median areas if it poses possible melt water problems or otherwise interferes with the traffic control function of the medians.

I. Guiderail and Median Barrier

Snow should be removed as close to guiderail and median barrier as reasonably possible with plow equipment. The complete removal of snow from the traffic side of guiderail and median barrier is not possible with available resources.

5.3308 Snow Removal from Municipal/Commercial Areas

Within Municipal and commercial areas, "reasonable passage and movement" may require loading and hauling snow. This work is to be done only to the extent necessary. Need will be determined by the Regional Highway Maintenance Engineer. State forces shall be used to the extent necessary and available. Any combination of State, County, Town and Village forces that is most practicable and applicable under current policy and contract agreements should be used. The clearing of Municipal sidewalks is not intended to be performed or paid for by the State.

Prior to disposing of snow removed from municipal/commercial areas, a check of local rules and ordinances relative to snow disposal should be made for reasonable cooperation. Additionally, a check should be made for applicable watershed rules and regulations made or approved by the New York State Department of Health (P.H.L. 1100) for required compliance purposes.

5.3309 Snow Control During Blizzard and White-Out Conditions

Some snow and wind events produce snowfall intensity that severely limits the visibility and performance factors of the plow operator(s). Temporarily curtailing operations under these conditions may be prudent to preserve the safety of plow operator(s) and other vehicles using or stranded on the highway and pedestrians that may be in the vicinity of the highway. Most of these events are associated with localized squalls of lake effect snow and are usually of relatively short duration. During these conditions, operators may drive their trucks to a safe location, well off the highway, turn all exterior lights off and contact a supervisor for further direction.

Some intense low visibility snowfall/wind events (blizzards) are more sustained and can last from several hours to several days. During these events the overall level of service may be limited to that necessary for supporting local emergency situation response. During this pullback phase, operators waiting for further direction should make appropriate preparations and equipment should be made ready for intense operations when the visibility and/or other difficult conditions improve. Generally, this pullback option should only be used in conjunction with declared states of emergency when non-essential highway travel is prohibited.

5.4000 Ice Control

5.4100 General

It is recognized that it is impossible to provide a "bare" or "wet" pavement surface all of the time. The characteristics of climatological events and finite available resources preclude this possibility. The interactive effects of pavement temperature, air temperature, event intensity, timing of initial treatment, operational cycle time, traffic volume, wind velocity, and solar energy have profound influences on the effectiveness of our ice control measures.

During those times when the pavement surface is not "bare" or "wet" it is incumbent on the driving public to perceive those conditions and operate their vehicles accordingly.

5.4200 Objective

The objective of ice control is to provide a reasonably safe pavement surface given the available resources and limitations imposed by climatological conditions.

5.4300 Goal

The goal of ice control is to provide the safest possible pavement surface that climatic conditions and available resources will allow.

5.4400 Methodology

5.4401 General Principles of Effective Ice Control

A. Prevent Pack - Don't Melt It

Timely application of salt very early in a storm, with appropriate follow-up applications, will generally prevent pack from forming. This strategy is much more cost effective and safe than trying to remove pack once it has formed.

B. If Salt Will Work - Use It

If the conditions are favorable, salt should be the first choice ice control material. The use of abrasives when salt will work encourages the formation of pack. The overall resource requirements for dealing with pack are far greater than preventing pack by the timely use of salt.

5.4402 Materials Used for Ice Control

A. General

There are a large number of chemicals and other treatments that are used for ice control. NYSDOT generally uses only three - salt (Sodium Chloride or Rock Salt), Calcium Chloride and Abrasives (sand). These are used singly or in combination depending on the climatological and pavement conditions. As newer ice control products become available they are carefully evaluated to see if they have a place in our ice control program.

B. Salt (Sodium Chloride or Rock Salt)

Salt is the most common and least expensive ice control chemical. There are at least two major salt mines within New York State that produce most of the salt used on State highways. This accounts for the relatively low cost.

The ability of salt to melt ice or form brine is highly temperature dependent. At 30 degrees Fahrenheit, one pound of salt will melt 46.3 pounds of ice. At 15 degrees Fahrenheit, one pound of salt will only melt 6.3 pounds of ice. This characteristic of salt primarily dictates when it is used.

C. Abrasives (Sand)

Abrasives may be natural sand, crushed rock or a variety of by-products from coal burning and other industrial processes. They have a low initial cost (about 1/5 that of salt) and provide immediate temporary improvement in the frictional characteristics of the pavement surface.

D. Calcium Chloride

Calcium Chloride has much better low temperature ice melting characteristics than salt. As a solid material it may be mixed with salt for use at low temperatures or used straight to open drainage facilities. However, it is about 5 times as expensive as salt. As a liquid it is added to salt to improve low-temperature ice melting characteristics, acceler- ate the working time, and reduce bounce and scatter.

5.4403 Guidelines for the Use of Salt

A. General Considerations

The effectiveness of salt is highly temperature dependent. Pavement temperature is the key temperature in this situation. Pavement temperature is seldom the same as air temperature. Starting about mid-morning, with solar warming, pavement temperature will exceed air temperature by as much as 40 degrees Fahrenheit. With nightfall, pavement temperatures will still be higher than air temperature for several hours. In early to mid-morning, pavement temperature will be lower than air temperature.

Absent the daily solar effects, seasonal geo-thermal factors do influence the relationship between air and pavement temperature. In early winter, pavement temperatures are generally warmer than air temperature. In late winter, pavement temperatures are generally colder than air temperature.

The ice content of a particular snow or ice event is another factor that influences the effectiveness of salt. There is a wide range in the ice or water content of snow and ice events. The ice content of snow can vary from about 10% to 90%. Sleet, freezing rain, pack and glaze all have ice contents in the range of 90%-100%. With increasing ice content per inch of snow or ice, more salt is required in order to be effective.

Salt is more effective with higher traffic volume. Frictional effects at the tire-pavement interface tend to warm the pavement. Also, the mechanical impact of traffic tends to break up the ice once the salt has prevented or broken ice/pavement bond.

Given the above, reasonable judgement has to be exercised in deciding when to use salt and how much salt to use. If the analysis of the various judgmental factors indicate that salt would be effective, salt should be used.

B. Specific Application Rate Guidelines

1. Light to moderately accumulating normal snow

The initial application shall be 225 pounds of salt per mile, per lane. Follow-up applications shall be as necessary, and at 115 pounds of salt per mile, per lane. If the pavement temperature is over 30 degrees Fahrenheit and/or traffic volume is high, the initial application rate may be reduced.

2. Rapidly accumulating dense snow, freezing rain, pack, glaze and sleet (high ice content)

The initial application shall be 270 pounds of salt per mile, per lane. Follow-up applications shall be as necessary, and the rate of application will vary with the observed condition of the snow or ice on the pavement surface. If surface is still glazed or packed, the follow-up application shall be 270 pounds of salt per mile, per lane (the same as the initial application). If the surface is mealy or slushy, the follow-up application shall be 115 pounds of salt per mile per lane.

C. Accuracy of Application Rates

The application rates specified above should serve as targets and actual application rates as determined from calibration data shall be within 7-1/2% of the target value.

D. Spreading Patterns

The spreading pattern is dictated by the type of highway, number of lanes being spread and the character of the event. Adjustments to spread pattern can be achieved by changing the spreader's baffle position, deflector position, spinner speed and direction of throw. The most common cause of wider than desired spread patterns is excessive spinner speed.

1. Two Lane - Two Way Traffic

The most efficient pattern is to spread salt in about the middle third of the pavement. The normal pavement crown will allow salt brine to flow across the remainder of the pavement.

In simultaneous plowing/spreading operations the spread pattern should be within the recently plowed area to prevent working brine from being plowed off. On out-and-return beats, spreading of both lanes associated with plowing may be done only on the return plow/spread run.

In situations where the salt does not appear to be working well, the spread pattern may be further narrowed around the center line of the road.

2. Multi-Lane - One Way Traffic

Multi-lane highways usually carry heavier traffic volume. With the heavier volume, the spread pattern should be nearly full-width of the lane(s) being treated. If traffic volume is low or the salt does not appear to be working well, the salt should be distributed in relatively narrow bands around adjoining lane lines.

E. Spreading Speed

The traffic characteristics of the highway will to some extent determine the speed of the spreading truck. On high speed-high volume highways the speed will be faster than on low speed-low volume highways. This is to reduce the risk of being rear-ended.

With increasing speed, "bounce" and "scatter" of salt becomes greater. The actual spread pattern should be checked periodically to be sure the salt is being distributed as intended. Depending on road and traffic condition, speeds should be in the range of about 15 MPH to 35 MPH.

5.4404 Guidelines for the Use of Abrasives

A. General Considerations

Abrasives should generally be used where low traffic volume and/or low temperature will preclude salt from working properly.

Abrasives may be used initially in some circumstances where salt will work. These include steep grades and other situations where the normal working time associated with salt could result in road blockage caused by vehicles stranded due to lack of traction.

The use of "sweetened" mixtures like 50-50 (1 part abrasives and 1 part salt) is wasteful and inefficient. If spread at the normal application rate for abrasives, this mixture will place 40% more salt on the road than a normal application of pure salt. The effectiveness of that salt is reduced by the presence of the abrasives.

Abrasives, overall, are more costly (based on initial application, reapplication, cleanup and other factors) and less safe to use than salt (if abrasives were used where salt would otherwise work). Abrasives are applied at 3-1/3 times the rate of salt. When the cost of necessary salt in the abrasives and mixing costs are considered, the per application cost of abrasives is about equal to that of salt.

Although snow and ice surfaces that have been treated with abrasives are safer than untreated snow or ice surfaces, they are not as safe as bare pavement. Traffic quickly diminishes the effect of abrasives and frequent re-application is necessary. This adds significantly to the overall cost and still provides a less safe surface than the bare pavement that could have been achieved with pure salt.

B. Specific Abrasives Application Rate Guidelines

Abrasives shall be applied at 750 pounds of abrasives (natural sands) per mile, per lane. If cinders or bottom ash are used, the application rate is 500 pounds of abrasives (cinders or bottom ash) per lane mile. These rates may be increased by up to 20% for hills, curves and intersections and decreased by up to 20% for tangent (straight) sections.

C. Accuracy of Application Rate

The actual application rate as determined from calibration data shall be within 7-1/2% of the target value.

D. Spreading Patterns

Abrasives shall be spread as near to full pavement or lane width as possible.

E. Spreading Speed

The spreading speed should be in the range of about 15 MPH to 35 MPH, depending on traffic and highway surface conditions.

5.4405 Mixing Salt with Abrasives

A. General

A small amount of salt must be added to abrasives in order to keep them in a workable or spreadable condition and have them adhere to the snow or ice. The amount of salt necessary will vary with the normal winter temperatures of the area. For most of the State, 5% salt is sufficient. In normally colder areas, 10% salt may be necessary. In milder areas as little as 2-1/2% salt will be satisfactory.

B. Density of Abrasives and Salt

For computational purposes, the following uncompacted densities are considered standard or average:

Material	Density, Lbs./C.Y.
Salt	2,000
Natural Sand	2,700
Cinders, or Bottom Ash	1,800

For abrasives having densities significantly different from those listed above, the application rate may be adjusted to yield the same volume of abrasives applied to the highway.

C. Guidelines for Mixing Salt with Abrasives

Using the densities in B. above, the following is a guide for mixing abrasives with salt:

NUMBER OF BUCKETS	
Natural Sand	Cinders

% Salt	Sand	Salt	Cinders	Salt
2.5	30	1	45	1
5.0	15	1	23	1
7.5	10	1	15	1
10.0	8	1	12	1

5.4406 Procurement and Quality of Abrasives

A. Procurement of Abrasives

Unless an in-house abrasives mine is available, abrasives should be procured through the competitive bidding process. The contract should be for abrasives delivered to the stockpile site. Studies have determined this is a more cost effective approach than having users pick up the material F.O.B. mine.

B. Quality of Abrasives

Abrasives should be comprised of granular material that is relatively free of organic impurities. The grain size distribution is important as it influences workability and the amount of salt that must be added to keep the abrasives spreadable. Gradation requirements vary around the State depending on product availability. The target or desired gradation is:

Sieve Size	% Passing
3/8 in.	100
#4	80-100
#50	0- 15
200	0- 3

Particles passing the #50 sieve do not have much abrasive quality and particles passing the #200 sieve have a detrimental effect on spreadability and storability.

Particle shape is also important. Abrasives containing substantial amounts of flat and/or elongated particles do not store and spread well.

5.4407 Guidelines for the Use of Calcium Chloride

A. Solid or Flake Calcium Chloride

In low temperature situations where it is imperative to achieve bare pavement quickly, a mixture of 3 parts salt to 1 part Calcium Chloride may be spread at the rate of 200 lbs. of salt-Calcium Chloride mixture per mile per lane.

B. Liquid Calcium Chloride

Liquid Calcium Chloride is added to salt to improve the low temperature characteristics, reduce bounce and scatter and accelerate working time. It should not be used on pavement temperatures above 20 degrees Fahrenheit unless there is a special need to accelerate working time or penetrate pack.

There are two systems for adding liquid Calcium Chloride to salt. The shower spray or load saturation system sprays liquid Calcium Chloride on salt that has already been loaded into the hopper. The spinner spray system sprays liquid Calcium Chloride on salt after it comes out of the hopper and before it reaches the spinner. The latter system is much more efficient.

Application rates for the two systems are:

System	Gal. of Calcium Chloride Per Ton of Salt
Load Saturation	11
Spinner Spray	6

The application rates for salt treated with liquid Calcium Chloride are the same as for pure salt.

Caution with late-in-the-day application is necessary. there is a tendency for water/brine to re-freeze at night if traffic does not dry the pavement.

5.4408 Special Considerations in Ice Control

A. General

Good judgement in the application of salt is a must. Salt can be very effective under certain apparently adverse conditions or it may possibly be very dangerous under some seemingly ideal conditions.

B. Time of Day

The time of day when salt is applied can greatly affect the action of salt. If it is 9 or 10 o'clock in the morning, 18 -20 degrees and sunny, salt will work as the day warms up and traffic will dry the pavement. However, if it is 25 degrees at 3 p.m. - use salt with caution - as temperatures will usually fall after sundown and the roads may re-freeze. If necessary, abrasives should be applied in this situation.

C. Traffic Volume

The traffic volume greatly affects salt action. Also, heavy traffic during the mid-part of the day will whip slush from the pavement, leaving it dry. On lightly traveled roads, traffic may only rut the slush, leaving it to freeze as temperatures drop at night.

D. The No Treatment Situation

Salt or abrasives should not be applied in conjunction with plowing operations at very low temperatures or when plowing blowing and drifting snow at very low temperatures. Usually snow will not bond to the pavement and can be effectively substantially removed by plowing. Traffic will whip the rest of the snow away. In this situation salt, or the salt in abrasives, may make the snow stick to the pavement causing icy spots.

E. Spot Treatment

In situations where conditions are present that require intermittent (spot) treatment (pavement or bridge icing potential, blow-overs, drifting or other snow or ice conditions that do not effect the entire State highway system in a given area) it is recommended that only a portion of the "normal" response capability be utilized during this activity. This activity is called spot treatment. Depending on existing conditions, lighter vehicles equipped with plows and spreaders may be more cost effective for this purpose.

5.4409 Spreading Equipment and Calibration

A. Spreading Equipment

Most spreading is accomplished with "V" box spreaders that mount in the box of heavy dump trucks. There are three different capacity spreaders in common use. The capacity and approximate range are listed below:

Spreader Capacity, Cubic Yards	Range, Lane Miles	
	Salt	Abrasives*
6	53	18-26
7	62	20-30
10	89	29-43

* Depends on proportion of hills, curves and intersections.

B. Ground Speed Controllers

Systems that automatically change application rate with changes in ground speed should be operational on all spreader trucks. These systems are relatively inexpensive and can pay for themselves in materials savings in a short period of time.

C. Calibration of Spreaders

All spreaders and ground speed controllers should be calibrated each year prior to the snow and ice season and after a major repair on the spreader. There are separate calibrations for salt and abrasives. Detailed calibration procedures are available from the NYSDOT Highway Maintenance Division.

D. Back-Up Calibration for Non-Automated Spreading

In addition to the calibration described in C. above, each spreader/truck should have established a back-up calibration to be used when the automatic system is not functioning. The details of this procedure are available from the NYSDOT Highway Maintenance Division.

5.5000 Stockpiling and Storing Salt and Abrasives

5.5100 Objective

The objective of providing stocks of salt and abrasives is to have these materials available and ready for use at locations that will facilitate a reasonable response time to snow and ice events.

5.5200 Goal

The goal of stockpiling and storing salt and abrasives is to assure an adequate supply of these necessary materials throughout the snow and ice season while minimizing adverse effects on the environment.

5.5300 Methodology

5.5301 Sites for Stockpiling and Storing Salt and Abrasives

A. Preliminary Investigation

Prior to locating stockpile and storage areas, a check should be made of local ordinances for reasonable cooperation. In addition, a check should be made of watershed rules and regulations made or approved by the N.Y.S. Department of Health (Section 1100 of the New York State Public Health Law) for compliance purposes. Sites should be selected to minimize "dead-heading". They should also be as centrally located as possible. This will minimize the number of sites required. Joint stockpiles or reciprocal agreements can be made with other agencies (e.g., County or Town Highway Departments) to minimize duplication of facilities and reduce the cost of loading equipment. This necessitates close cooperation and accounting with the other agency involved.

B. Site Characteristics

1. Highway Access

Since trucks and other equipment will be using stockpile and storage sites during storms and at times of poor visibility, they should be easily accessible. Access roads to the site, where possible, should not open directly onto heavily traveled highways and should be located to provide ample sight distance for the equipment operators. Signs should be erected to warn motorists that trucks enter and leave the area.

2. Drainage

Sites should be selected or graded to provide positive drainage away from the stockpile or storage facility. The area selected should not drain directly into a stream, reservoir, well, well aquifer, or adjacent residential property.

3. Size

Storage areas should be large enough for front-end loaders and trucks to maneuver safely.

4. Doors to Buildings

Building doors and other openings should be large enough to permit access for loading and unloading.

5. Driveway Areas

The surface of the driveway and maneuver area should be such that there are no low or weak spots.

6. Access Platforms and Loading Ramps

Access platforms and loading ramps should be provided to make loading operations safer.

7. Lighting

Yard areas should be adequately lighted and lights should also be available inside the storage buildings.

8. Housekeeping

All work areas should be as unobtrusive as possible. They should be kept neat and orderly. Screening with trees and shrubs makes the area more aesthetically appealing.

5.5302 Guidelines for Storing Salt

All pure salt shall be stored, covered and housed on an impermeable pad in an acceptable structure. Where acceptable structures are not available or there is insufficient storage capacity in structures, pure salt shall be stored on impermeable pads and covered with secured waterproof tarpaulins - year-round.

5.5303 Guidelines for Storing Abrasives that Contain Salt

All stockpiles of abrasives that contain salt shall be placed on an asphalt concrete pad (having an impermeable membrane) and be completely enclosed in: (1) A structure that effectively keeps rain and snow off the abrasives, or, (2) waterproof tarpaulins that are effectively secured. This requirement is effective year-round.

There are two exceptions to this policy:

A. Small working piles of abrasives containing salt may remain uncovered during the winter season as long as they are on an impermeable pad and have a berm of unsalted abrasives around the stockpile and within the confines of the impermeable pad. At the end of the winter all abrasives on the pad (including the berm) shall be mixed together and moved within an appropriate structure or securely covered with a waterproof tarpaulin on an impermeable pad.

B. During the colder portions of the winter, the working face of <u>unsalted</u> abrasives stockpiles may have a small amount of salt mixed in the topmost portion. However, the working face must be protected by a small containment berm of unsalted abrasives. As with A. above, at the end of the winter, any abrasives containing salt must be removed and stored in an appropriate structure or securely covered with a waterproof tarpaulin on an impermeable pad.

If stockpiles are to be covered with tarpaulins, low, elongated shaped piles are much easier to manage. Old guiderail installed on either side of an elongated pile provides excellent lashing points to secure the tarpaulins.

5.5304 Guidelines for Managing Unsalted Stockpiles of Abrasives

Unsalted stockpiles of abrasives having the proper grain size distribution, can be effectively managed. This is usually done in conjunction with "mix-and-go" (mixing salt with abrasives and immediately loading the spreading truck) operations or where small amounts of abrasives containing salt are stored in a structure or in a small covered stockpile. There are some techniques that facilitate the management of unsalted stockpiles of abrasives:

A. There must be sufficient extra material to compensate for material that will become frozen into chunks and be unusable during the colder portions of the winter. A frozen chunk factor of about 20% is an average condition for most of the State.

B. Build the stockpiles relatively low so the loading equipment can safely remove bridges and overhangs of frozen material that form on top of the working area.

C. Orient the working face of the stockpile to face south. This will take maximum advantage of solar heat and reduce the severity of frozen material on the working face.

D. Obtain abrasives that have:

1. Smaller proportions of minus #50 sieve size particles.

2. A small proportion of particles having flat and/or elongated shapes.

E. Mixing salt with abrasives at the working face of the unsalted stockpile and removing the mixed material to smaller working piles or structural shelter has proven to be effective.

F. Utilize sunny days to the extent possible when mixing salt with abrasives.

G. Backblading with loaders or dozers can sometimes break up frozen chunks of abrasives.

5.5305 Stockpiling and Mixing Salt with Abrasives

Abrasives are usually delivered to the site in dump trucks. Depending on management strategy, salt may or may not be mixed with abrasives during the stockpiling process.

A. Conveyors

Conveyors are the most efficient type of equipment for creating uncompacted stockpiles. If salt is being added to the stockpile, a second conveyor for salt will provide a well-mixed stockpile.

B. Cranes

Cranes with clamshell buckets may be used for creating both salted and unsalted stockpiles of abrasives. They are capable of creating reasonably well mixed uncompacted piles of salted material.

However, they are not capable of a high rate of production and the stockpiling process could be lengthy and costly.

C. Other Equipment

Loaders, dozers, hydraulic excavators, power shovels and even trucks may be used singly or in combination to create stockpiles. None of these methods are capable of efficient mixing and most will produce a compact stockpile. However, in most cases, stockpiling must be accomplished with the available equipment, and these types of equipment are frequently used. Care must be exercised when utilizing trucks, loaders and dozers on inclined surfaces. If not utilized properly, this equipment could easily tip over during the stockpiling operation. Hydraulic excavators and power shovels should always operate from a flat surface.

5.6000 Snow Stake Installation

5.6100 Objective

The objective of snow stake installation is to identify possible obstructions within the plowing and winging area that may interfere with the snow removal process.

5.6200 Goal

Install snow stakes at locations of possible obstructions within the plowing and winging area that may interfere with the snow removal process.

5.6300 Methodology

A. Timing

Snow stakes that must be driven into the ground should be installed before the ground freezes and well in advance of the first anticipated snowfall.

B. Materials

Material for snow stakes may vary from trimmed tree limbs to delineator posts. Uniformity of material is desirable and the type of material used should reflect the class of highway.

C. Functional Characteristics

Snow stakes should be long enough to extend above the anticipated depth of snow in the area. The top six inches of the stake should be painted, flagged or taped to provide better visibility.

D. Obstructions that should have snow stakes

Generally, all solid objects within the plowing and winging area that are likely to be covered by snow, should be identified by snow stakes. These include, but are not limited to: Guide posts, ends of guiderail runs, culvert headwalls, traffic channelization devices, hydrants, gutters and isolated curb sections.

E. Snow stakes to identify drainage features

Catch basins, drop inlets and other drainage structures, particularly in median areas, should be marked with snow stakes to permit location of the structure when it is snow covered.

F. Snow Stakes used as shoulder and median markers

On divided highways snow stakes should be used to delineate the shoulder and median area. The stakes should be about 5 feet above the ground and be placed 1 to 2 feet beyond the shoulder. Spacing on tangent sections should be 200 feet. Closer spacing on curves may be utilized. When snow stake median markers are used in conjunction with permanent delineators on the right shoulder, they should be placed directly opposite every other (alternate) permanent right shoulder delineator post.

5.7000 Maintaining the Capability of Drainage Features

5.7100 Objective

The objective of maintaining critical drainage features is to minimize flooding during thaw conditions.

5.7200 Goal

Maintain the functional capability of critical drainage features so that flooding and ponding on the highway are minimized during periods of thaw.

5.7300 Methodology

A. General

Through knowledge and experience, the critical drainage features should have been identified. It is important to maintain their functionality throughout the snow and ice season.

B. Closed Drainage Systems

In order to maintain safe roadways and protect against flooding and freezeovers, the tops of catch basins and drop inlets should be cleared of snow and provided with reasonable means to prevent possible development of ice. If a system is likely to freeze up, salt or Calcium Chloride should be applied periodically to critical catch basins and drop inlets, subject to existing conditions in the area involved.

C. Open Drainage Systems

Prior to thaws and the subsequent runoff, it is advisable to remove packed snow and ice from the ends of culverts and their inlet and outlet ditches. At the beginning or middle of winter, if the water is flowing adequately underneath the snow, the snow should not be removed since this might allow the water to freeze and block the culvert. As the weather moderates and a continued thaw is anticipated, the snow and ice should be removed as indicated above. Weather forecasts will aid in making the decision whether or not to remove the snow. Generally, a forecast of two or more days of thaw indicates need for snow removal at known, troublesome locations.

D. Structures

Finger joints, expansion joints and the bridge deck drainage system should be kept functional during the winter. Removal of surface snow and ice and the thawing of drainage and expansion features with salt or Calcium Chloride may be necessary.

E. Thawing Drainage Features

Frozen drainage features are usually cleared by adding liberal amounts of salt or Calcium Chloride to the upstream frozen surface subject to existing conditions in the are involved. A Steam Jenny may also be used if available and deemed reasonably effective given existing conditions in the area involved and can be used from both upstream and downstream sides of the frozen location. The steam approach is more environmentally sound and should be used to the extent possible.

5.8000 Passive Snow Control

5.8100 Objective

The objective of passive snow control is to reduce or eliminate persistent snow drifting on roadways and to improve visibility during blowing snow conditions by installing snow fence, planting shelterbelts, or altering the roadway cross section.

5.8200 Goal

The goal of passive snow control is to reduce or eliminate areas of persistent drifting and/or low visibility where resources, right-of-way and cost effectiveness will permit.

5.8300 Methodology

5.8301 General

Use of passive snow control techniques will improve roadway safety and reduce supplementary snow removal in areas of recurrent drifting. The erection of snow fence or the establishment of shelterbelts in areas of frequent drifting and/or whiteouts can dramatically improve or eliminate the condition. Drifting problems may also be mitigated by reconstructing the roadway cross section to provide a windswept aerodynamic cross section which will remain drift free. Partial improvement should be considered at locations where total mitigation measures are not possible.

5.8302 Snow Fence

Snow fences may be permanent or temporary. Permanent fences erected on private property will require the acquisition of a permanent easement. The Regional Real Estate Officer should be contacted for easement procedures. Temporary fences may be erected on private property under Article 3, Section 45 of the Highway Law.

Snow fences should be of adequate height to store the usual expected amount of snow that will be transported (blown) through the location. The snow transport will vary by location. The Regional Design Group may be consulted for an accurate estimate of this snow transport. The required fence height is given by **H** in the following equation:

$\mathbf{H} = 0.065\ (Q^{0.454})$, where Q = average snow transport (lbs.)

The length of the upwind drift created by a snow fence is equal to 15 x height. The downwind drift length is equal to

35 x height. For this reason, snow fences should be placed at a distance of 35 x height from the road to ensure that the drift generated by the fence will not encroach onto the roadway. The fence may be placed closer to the road only if there are topographic features, such as a ravine, which will provide significant additional storage. If the fence becomes full during most winters, the height should be increased and the distance from the highway adjusted accordingly. Although additional rows of fence will increase the amount of available snow storage, it is much more cost effective to increase the height and use a single fence. Fence heights should generally exceed six (6) feet except in limited areas.

All fences should have a gap at the bottom to prevent the fence from becoming buried. The gap should be 10% of the total fence height and should be measured from the top of the expected winter vegetation.

Fences should be oriented parallel to the road except when the prevailing wind direction is more than 30 degrees from perpendicular to the road.

Fences should extend a distance of 50 feet beyond the area to be protected to prevent snow from being blown around the ends.

<u>5.8303 Shelterbelts</u>

Shelterbelts are single or multiple rows of plantings. There are many advantages to shelterbelts as compared to snow fences. They include: lower costs, roadside beautification, wildlife benefits, little or no maintenance after establishment, and long service life.

Placement of shelterbelts is similar to that of snow fences, since shelterbelts will perform similar to a snow fence during the first several years of growth. After crown closure is attained, the trees will perform more like a solid barrier. The trees should be placed no closer than 3 times their mature height from the road.

Generally two or more staggered rows of trees should be planted to provide full coverage and to prevent gaps caused by plant loss or damage. Shelterbelts should be comprised of coniferous trees, such as Austrian Pine. They should be spaced so that crown closure will be achieved within five to ten years. Temporary snow fence may be used to protect the plantings during the first few years. Care should be taken to ensure that the trees do not become buried by the fence drift.

An effective shelterbelt may also be achieved by having farmers leave five to seven rows of cornstalks standing through the winter.

This may be accomplished by using appropriate real estate procedures of the N.Y.S.D.O.T. Real Estate Division.

5.8304 Modifications of Roadway Features

Providing an aerodynamic cross section will allow the roadway to be swept clear by the wind. It should be recognized that this is not a solution where whiteouts are a problem. In some areas it may be possible to alter the cross section to provide for additional snow storage upwind from the road. Minor grading on private property may be accomplished with appropriate real property procedures. The details of these procedures are available from the N.Y.S.D.O.T. Real Estate Division.

The following guidelines will improve drift prone areas:

- Backslopes and foreslopes should be flattened to a 1:6 slope or flatter.
- Ditches should be widened as much as possible.
- The profile of the road should be raised to two feet above the ambient snow cover.
- Provide a ditch adequate for storing the snow plowed off the road.
- Widen cuts to allow for increased snow storage.
- Eliminate the need for guiderail.
- Replace W-beam guiderail with cable guiderail where possible. W-beam will perform like a miniature snow fence and should be removed or replaced with cable whenever possible.

APPENDIX E

USEPA – STORM WATER MANAGEMENT FACT SHEET:
MINIMIZING EFFECTS FROM HIGHWAY DEICING

United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-016 September 1999

Storm Water Management Fact Sheet
Minimizing Effects from Highway Deicing

DESCRIPTION

The United States is critically dependent on its road system to support the rapid, reliable movement of people, goods, and services. Even in the face of winter storms, we expect roads and highways to be maintained to provide safe travel conditions. In many states, this requires substantial planning, training, manpower, equipment, and material resources to clear roads and streets throughout the winter.

The dependency on deicing chemicals has increased since the 1940s and 1950s to provide "bare pavement" for safe and efficient winter transportation. Sodium chloride (common table salt) is one of the most commonly used deicing chemicals. Concern about the effects of sodium chloride on the nation's environment and water quality has increased with this chemical's usage. Automobile and highway bridge deck corrosion has also become a concern. However, in most cases sodium chloride is the most cost effective deicing chemical. Such concerns have led to major research efforts by the Strategic Highway Research Program (SHRP), the highway community, industry, government, and academia. This ongoing research is exploring many different areas in an effort to maintain the safest roads possible in the most economical way while protecting the environment.

This fact sheet summarizes research addressing water pollution and associated effects from deicing chemicals, and describes the methods used to control snow and ice on roadways while minimizing impacts on the environment. Because of this topic's breadth, sources for research and alternative methods are listed and can be referenced for more detail. This fact sheet emphasizes methods and practices for snow removal that are feasible and cost effective for local governments to implement and that are also consistent with sound environmental quality goals.

APPLICABILITY

Beginning in the late 1940s and 1950s, the "bare pavement" policy was gradually adopted by highway agencies as the standard for pavement condition during inclement weather. The policy provided safer travel conditions on roadways and became a useful concept for roadway maintenance because it was a simple and self-evident guideline for highway crews. Dispersion of city populations into suburbs, higher travel speeds, and growing dependence upon automobiles for commuting and commerce increased the need for snow and ice removal for safer roadways (Lord, 1988). Salt was first used on roads in the United States for snow and ice control in the 1930s (Salt Institute, 1994). In the 1960s, the use of salt as a deicing chemical became widespread in the United States because salt was readily available, effective on ice and snow, and the lowest cost alternative (Salt Institute, 1994).

A common perception that "more is better" led to practices of high application rates of salt. By the late 1950s, however, damage to roadside sugar maples (a salt- intolerant species) in New England had given rise to concern about the widespread use of salt. Shortly thereafter, contamination to drinking water from wells located near unprotected salt storage areas heightened this concern (Lord, 1988). Other adverse effects from the runoff of road salts, including the pitting and "rust out" of automobiles and corrosion of highway structures, especially bridge decks (Lord, 1988) were also becoming apparent.

These environmental concerns have spawned a number of research programs. The goal of this research has been to minimize the environmental effects of deicing while still providing a cost effective means of clearing roadways for safe travel. Early in the 1960s, research began on alternative deicing chemicals, reduced chemical use, improved operational practices, pavement heating, pavement modification, and mechanical approaches (Lord, 1988). More recently, a "Snow and Ice Control" study was conducted by the SHRP, a unit of the National Research Council that was authorized by Section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987 (SHRP, 1994b). The snow and ice control research included five major initiatives: improved operational procedures; road weather information systems; alternative deicing chemicals; pretreatment; and mechanical approaches. These are discussed further in the Implementation section below.

ADVANTAGES AND DISADVANTAGES

Highway ice and snow removal is essential both to public safety and to local and interstate commerce. However, the traditional method of deicing roads through the use of salt has several drawbacks. First, the use of salt has led to degraded habitats in areas where salt accumulates in runoff. Second, the storage and use of salt can be expensive. In a 1988 paper, Lord estimates that 400,000 tons of salt, approximately 5 percent of the 8 million tons used annually in the United States is lost from uncovered stockpiles. An estimate of $30 per ton of salt equates to a monetary loss of $12 million dollars each winter (Lord, 1988). A well planned and operated snow and ice removal program is essential to ensure public safety and to minimize environmental effects and costs.

IMPLEMENTATION

Many initiatives have been taken to control ice and snow on roadways while minimizing any associated environmental effects. Several of these initiatives are discussed below

Improved Operational Practices

Clearing roadways after winter storms accounts for a large portion of the highway maintenance budget for many northern states. According to the Salt Institute's 1991 Snowfighter's Handbook, snow removal in 33 snow belt states accounted for 16.2 percent of total highway maintenance costs and 3.6 percent of all highway expenditures (Salt Institute, 1991).

To aid highway management personnel in improving operational practices, the Salt Institute initiated a "sensible salting" program in 1967 (Lord, 1988). These guidelines have evolved with technology to include the following: planning; personnel training; equipment maintenance; spreader calibration; proper storage; proper maintenance around chemical storage areas; and environmental awareness (Salt Institute, 1994). Further information on the "sensible salting" program can be obtained from the Salt Institute, located in Alexandria, Virginia.

While all of these guidelines reflect key concerns, proper storage is considered one of the most effective in source control of deicing chemicals (U.S. EPA, 1974a). Guidelines for siting and designing deicing chemical storage facilities are provided in the Manual for Deicing Chemicals: Storage and Handling (U. S. EPA, 1974b).

In addition to reducing the amount of salt lost due to runoff, the actual amount of salt used on the roads can be reduced. The Regional Groundwater Center (1995), estimated that 10 million tons of salt are used each winter in the United States to melt snow and ice on roads and surface streets (Regional Groundwater Center, 1995; Salt Institute, 1994). Salt application rates range from 300 to 800 pounds per two-lane mile, depending on road, storm, and temperature conditions (Salt Institute, 1994).

One of the most effective measures for reducing chemical application has been the use of a calibrated spreader using the optimal application rate. Automatic controls on spreaders are recommended to ensure a consistent and correct application rate. The spreader should be calibrated prior to and periodically during the snow season, regardless of whether automatic or manual controls are used.

Uncalibrated controls and poor maintenance are often responsible for excessive salt use (Salt Institute, 1994). Guidelines for the calibration of spreaders and determination of application rates are given in the Salt Institute's Snowfighter's Handbook (1991) and in the EPA document *Manual for Deicing Chemicals: Application Practices* (U. S. EPA, 1974a).

Road Weather Information Systems

In an effort to maximize the effectiveness of control efforts and to reduce costs, the SHRP has sponsored research using road weather information systems (RWIS) for highway snow and ice control. Components of the RWIS include meteorological sensors, pavement sensors, site-specific forecasts, temperature profiles of roadways, a weather advisor, communications, and planning (SHRP, 1993b, 1993c).

The RWIS can maximize the effectiveness of icing and plowing efforts by pinpointing and prioritizing roadways that need attention. It can also eliminate unnecessary call-outs and improve scheduling of crews based on estimates of the extent and severity of the storm. Research indicates that the use of the RWIS technologies can improve efficiency and effectiveness as well as reducing the costs of highway winter maintenance (SHRP, 1993b). Thus, RWIS may improve snow and ice removal service. This report concludes that road weather information system technology may improve service. The report recommends that every agency that regularly engages in snow and ice control consider acquiring some form of road weather information systems; at a minimum, forecast services should be used.

The SHRP has also pointed out that additional research beyond the scope of the original RWIS project would be helpful (SHRP, 1993b). Additional information about RWIS and intelligent and localized weather prediction is provided in the following SHRP manuals: Road Weather Information Systems, Volumes 1 and 2 (SHRP, 1993b, 1993c); and Intelligent and Localized Weather Prediction (SHRP, 1993a).

Alternative Deicing Chemicals

The most commonly used salts for deicing are sodium chloride (NaCl) and calcium chloride (CaCl) (Salt Institute, 1994). The eastern and north-central sectors of the country use more than 90 percent of the approximately 10 tons of salt used each year (Lord, 1988). However, sodium chloride has several drawbacks, including its harmful environmental effects. Therefore, due to both environmental concerns and the importance of snow and ice removal programs in terms of public safety and economic factors, there has been an abundance of research on alternative deicing chemicals.

An acceptable alternative deicer must have an effective melting range similar to salt's, and must be cost-comparable or less expensive. One such chemical is calcium magnesium acetate (CMA). CMA is made from delometric limestone treated with acetic acid. While CMA does not overcome all the undesirable characteristics of salt, it is still an effective deicer. CMA is frequently used because it has less potential to affect the environment and is not as corrosive as salt. However, to achieve the same deicing effectiveness as salt, CMA materials need to be applied in larger quantities. In addition, CMA's cost exceeds salt's by a factor of 10 to 20 (Lord, 1988). Continual efforts are being made to find a more effective production technology to lower the cost of CMA, but these efforts have had limited success (Lord, 1988).

Because of the growing interest in deicing technology, the SHRP published a handbook to standardize testing procedures used to evaluate deicing chemicals (SHRP, 1992). Deicing chemicals are evaluated based on their fundamental properties (e.g., ice melting potential, thermodynamic factors), physicochemical characteristics, deicing performance (e.g., ice melting, ice penetration, ice undercutting), materials compatibility, and additional engineering parameters. Additional information on these testing procedures is provided in the *Handbook of Test Methods for Evaluating Chemical Deicers* (SHRP, 1992).

Pretreatment

Limited experience (mainly in Scandinavian and other European countries) has shown that applying a chemical freezing-point depressant on a highway pavement prior to, or very shortly after, the start of accumulation of frozen precipitation minimizes the formation of an ice-pavement bond (SHRP, 1994a). A liquid salt solution has been applied prior to a snowfall in Scandinavia and has proven successful for pretreatment (SHRP, 1994a). This anti-icing or pretreatment practice reduces the task of clearing the highways and decreases the amount of chemical applied from that required when deicing chemicals are applied after snow and ice have begun to accumulate.

When properly implemented, pretreatment practices may reduce costs and be more effective than conventional practices. However, most state highway agencies have not adopted pretreatment because they are uncertain how and when to implement it. Other concerns with pretreatment practices include the imprecision with which icing events can be predicted, the uncertainty about the condition of the pavement surface, and the public's perception of wasted chemicals. Some early attempts to utilize pretreatment practices in the United States have failed because of these problems (SHRP, 1994a).

Technological improvements in forecasting weather and in assessing pavement surface conditions, as previously mentioned, offer the potential for successful implementation of pretreatment. Research during the winters of 1991-92 and 1992-93 by the SHRP indicated that a 40 percent and 62 percent reduction, respectively, in chemical usage was possible using pretreatment (SHRP, 1994a). Pretreatment's success depends on accurate RWIS, a technology that is still evolving. Development of spreaders specifically designed or retrofitted to distribute prewetted solid material or liquid chemicals, calibration and evaluation of spreaders, training of maintenance personnel, and effective communication also need further attention to ensure the success of a pretreatment program (SHRP, 1994a). Additional information on pretreament is available in the SHRP manual entitled *Development of Anti-Icing Technology* (SHRP, 1994a).

Mechanical and Structural Approaches

Many mechanical and design approaches have been and are being evaluated in an effort to improve snow and ice control practices. Some of these attempts have been very successful, while others have had limited success or need additional research. This section examines several mechanical and design approaches, including pavement heating, pavement coatings, mobile thermal deicing equipment, snow fences, and snowplows. This list is not comprehensive.

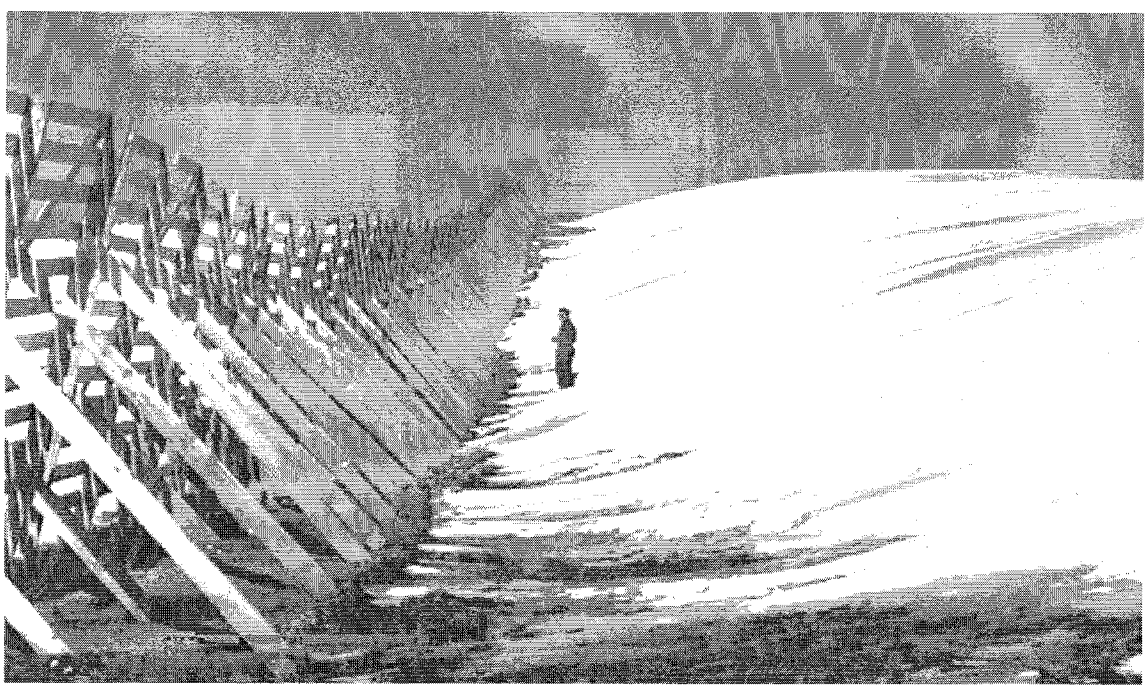
Because of cost or feasibility, pavement heating and pavement coatings have had limited success in snow and ice removal. Pavement heating systems are costly to install, and operational costs exceed those of salt on the order of 15 to 30 times (Lord, 1988). Pavement coatings involve using hydrophobic or icephobic coatings to reduce the adhesion of ice and snow to the roadway. Pavement coatings are required to weaken or prevent bonding, while not decreasing vehicle traction in no-snow conditions. They are also required to persist in extremely harsh conditions. Pavement coatings were generally unsuccessful because they were unable to meet these goals (Lord, 1988 and U. S. EPA, 1976b). A 1976 EPA Manual, *Development of a Hydrophobic Substance to Mitigate Pavement Ice Adhesion* (U. S. EPA, 1976b), describes this research. Mobile thermal deicing equipment has also been evaluated and determined to be impractical.

Snow fences are used to keep snow from being blown into drifts. Studies show that snow fences minimize costs associated with snow clearing, reduce the formation of compacted snow, and reduce the need for chemicals. Mechanical snow removal costs approximately 100 times more than trapping snow with fences (SHRP, 1991).

One concern regarding snow fences focuses on their position and design. About 20 years ago, it was very common to find that 4 foot picket snow fences had buckled under the weight of accumulated snow (SHRP, 1991). When properly designed and positioned, a taller snow fence is more effective than the traditional low picket snow fence. Not only is size relevant to the fence's performance, but so is its weight. A lightweight plastic, for example, allows for the construction of a portable fence up to 8 feet tall (SHRP, 1991). A 15-foot-tall snow fence used in Wyoming is shown in Figure 1. To minimize improper positioning and design of snow fences, the SHRP has provided publications such as *Design Guidelines for the Control of Blowing and Drifting Snow* (SHRP, 1994b), *Snow Fence Guide* (SHRP, 1991), and a 21-minute video entitled "Effective Snow Fences."

Snowplow designs in the United States have evolved empirically. These designs, however, have neglected to incorporate the effects of the physical properties of the materials handled by the plow and the aerodynamic and hydrodynamic principles involved in the flow of fluidizing snow. Consequently, more energy is expended in displacing snow than is necessary, and the short cast distance necessitates rehandling of the snow (Lord, 1988). The SHRP has funded research at two universities to improve development of plow blade design and cutting edges for the plow blades (SHRP, 1991). The first research project, conducted by the University of Wyoming Department of Mechanical Engineering, focused on developing an improved snowplow blade that minimizes energy needed to throw snow clear of the roadway. The plow design, based on analytical methods and laboratory scale experiments, showed a 20-percent improvement in efficiency over conventional plows. The plow underwent testing in West Yellowstone, Montana during the winter of 1990-1991 (SHRP, 1991). Research for additional technological advances in plow design is ongoing.

Another research project, conducted by the University of Iowa Institute of Hydraulic Research, sought to improve snowplow efficiency by improving cutting edges of plow blades (SHRP, 1993e). Laboratory tests were performed with a hydraulic ice-cutting ram to determine the effects of the geometry of the cutting edge of a snow plow blade on the force required to remove ice from a highway pavement surface. Results of this research indicate that changes in the cutting edge geometry result in substantial improvements in ice cutting; cutting edge performance may still benefit from further studies (SHRP, 1993e). An Iowa



Source: Reprinted with permission, Tabler and Associates, 1972.

Department of Transportation "plowing truck" cutting ice is shown in Figure 2. Additional information can be obtained in the SHRP manual entitled "Improved Cutting Edges for Ice Removal" (SHRP, 1993e).

COSTS

The United States and Canada spend over $2 billion dollars each year on snow and ice control (SHRP, 1993b). However, very little cost data has been generated to show the direct costs of, or the cost reductions due to, the specific snow removal alternatives and process improvements discussed in this fact sheet. Some cost information has been generated for alternative deicing chemicals. NaCl is both the most common and the most cost-effective deicing agent, with costs per ton ranging from $17 to $30 (Lord 1988; Jesperson, 1995). The Michigan Department of Transportation drew this conclusion in a recent evaluation. The evaluation examined the costs of sodium chloride (road salt), CMA, CMS-B (also known as Motech), CG-90 Surface Saver (a patented corrosion-inhibiting salt), Verglimit (patented concrete surface containing calcium chloride pellets), and calcium chloride (MDOT, 1993). Most of the alternative deicers ranged in cost from $200 to $700 a ton (Jesperson, 1995), and were thus significantly more expensive than sodium chloride.

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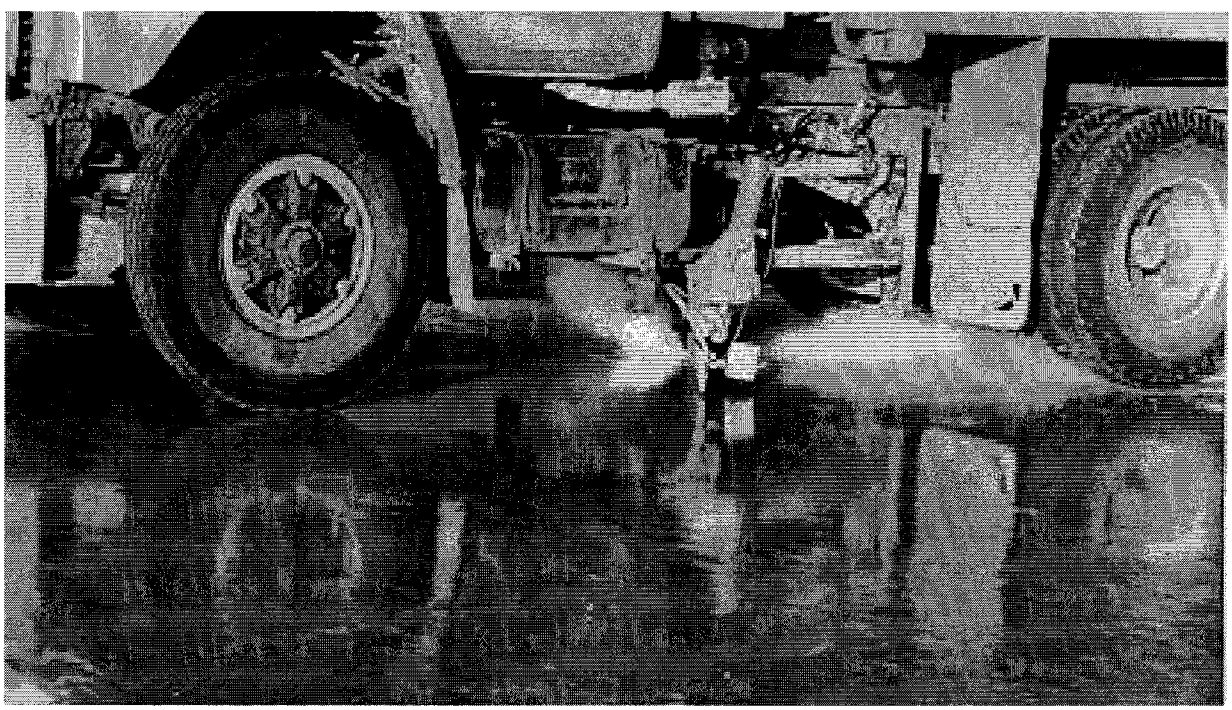

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FIGURE 2 A PLOWING TRUCK CUTTING ICE

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APPENDIX F

USEPA OFFICE OF WETLANDS, OCEANS AND WATERSHEDS –
STORM WATER BMP DESIGN SUPPLEMENT FOR COLD CLIMATES –
CHAPTER 8: POLLUTION PREVENTION

Stormwater BMP Design Supplement for Cold Climates

December 1997

for: US EPA Office of Wetlands, Oceans and Watersheds
and US EPA Region 5

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8. Pollution Prevention

This section focuses on cold climate modifications of non-structural BMPs, or pollution prevention measures. Specifically, it discusses options for controlling pollution from sand and other abrasives, road deicers and airport deicers. It also discusses snow storage techniques to minimize pollutant loads and encourage infiltration of snowmelt.

8.1 Sand (Abrasives)

Abrasives retain traction on roads in icy or snowy conditions. Sand is the most commonly used abrasive, but other materials such as crushed stone or furnace slag are also used. Three measures are proposed to reduce pollution from sand application: use of a clean sand source, street sweeping during and immediately after the spring runoff and operator training focusing on application of the minimum amount of sand necessary.

8.1.1 Clean Sand Source

One way to reduce the water quality impacts of sand application is to use "clean" sand (e.g., free of fine materials). Sand itself can cause water quality and habitat impacts, such as filling in of ponds and wetlands and destruction of downstream habitat. The fine particles mixed in with sand can further increase stream turbidity and carry the majority of pollutants such as phosphorous and metals.

8.1.2 Street Sweeping

Street sweeping during the spring snowmelt can reduce pollutant loads from road sanding. Seventy percent of cold climate stormwater experts (CWP, 1997) recommend street sweeping during the spring snowmelt as a pollution prevention measure. The Minnesota Pollution Control Agency (1989), for example, recommends street sweeping two times per year for pollution prevention: after the spring snowmelt and after leaves fall in the autumn.

8.1.3 Operator Training

One method to reduce unnecessary sand application is to train sand application operators to apply only the amount necessary for the given conditions. Many states offer guidance on the amount of sand necessary for a given amount of snow and road traffic.

8.2 Road Deicers

Deicers, chemicals designed to melt ice and snow on pavement, are another pollutant source in cold climates. Road salt (NaCl) is the most commonly used deicer, primarily because of its low cost (Ohrel, 1995). Several changes can be made to traditional deicing to decrease the impacts to the environment. These include: apply less salt, apply alternate deicers, use additives to reduce deicer application, change the timing of application, modify spreaders and implement salt storage regulations.

8.2.1 Application Rate

Decreasing the application rate can significantly decrease environmental impacts. This measure is controversial because of safety concerns, however (i.e., slippery roads). To avoid applying too much ice to lightly traveled roads, some northern states have adopted specific guidance for road salt application, based on the type of road. For example, Michigan practices a three-tiered system based on road traffic (Gales and Vander Meulen, 1992).

8.2.2 Alternative Deicers

Depending on the environmental problems of an area, deicers other than salt may be used. Unfortunately, most deicers have some negative environmental impacts, and many are more costly than road salt (See Table 8.1).

TABLE 8.1 CHARACTERISTICS OF DEICERS (SOURCE: OHREL, 1995)

Characteristics	Sodium Chloride ($NaCl$)	Calcium Chloride ($CaCl_2$)	CG-90 Surface Saver (Mg, Na and Cl)	CMA ($CaMgC_2H_3O_2$)
Soils	Cl complexes release heavy metals; Na can break down soil structure and decrease permeability	Cl complexes release heavy metals; Ca can exchange with heavy metals, increase soil aeration and permeability	Same as NaCl; Mg can exchange with heavy metals	Ca and Mg can exchange with heavy metals. Ca increases soil aeration and permeability.
Vegetation	Salt spray/splash can cause leaf scorch and browning or dieback of new plant growth up to 50' from road; osmotic stress can result from salt uptake; grass more tolerant than trees and woody plants.			Little effect
Groundwater	Mobile Na and Cl ions readily reach groundwater and concentration levels can increase in areas of low flow temporarily during spring thaws. Ca and Mg can release heavy metals from soil.			
Surface Water	Can cause density stratification in small lakes having closed basins, potentially leading to anoxia in lake bottoms; often contain nitrogen, phosphorous and trace metals as impurities, often in concentrations greater than 5 ppm			Depletes O2 in small lakes and streams when degrading
Aquatic Biota	Little effect in large or flowing bodies at current road salting amounts; small streams that are end points for runoff can receive harmful concentrations of Cl; Cl from NaCl generally not toxic until it reaches levels of 1,000 to 36,000 ppm; eutrophication from phosphorous in Cg-90 can cause species shifts			Can cause oxygen depletion
Cost ($/lane mile/ season)	$6,371-$6,909	$6,977-$7,529 plus storage and equipment costs	$5,931-$6,148	$12,958-$16,319
Minimum Operating Temperature	12°F	-20°F	1°F	23°F
Comments	Most commonly used deicer nationwide.	More effective and less harmful than salt. However, overall expense is much higher. CaCl2 is most often used in very low temperature conditions.	Provides some corrosion protection and is cost-competitive. Must be applied in much lower concentrations than salt.	This material is very expensive and starts to act at a slower rate than salt. Most often used on bridges because it is less corrosive than salt.

8.2.3 *Deicer Additives*

In the past, metals have been added to deicers to improve their performance. This practice has been discontinued, however, because of harmful environmental effects (Gales and Vander Meulen, 1992). Recently, an organic additive has been developed that appears to improve the effectiveness of road salt. The additive, Ice Ban, is derived from the beer brewing process. Although the product has not been widely used, evidence from Webster, New York, suggests that it is a cost-effective additive. During the winter of 1995-96, the town saved $58,000 by using this additive (Strable, 1996). Some concern has been raised about the potential BOD loading of this product (Smith, 1997).

8.2.4 *Timing of Application*

By applying deicers at the appropriate time, the amount of deicing material needed can be decreased. One proposal is to apply deicers before snow falls, based on forecasts. If the forecasted storm does occur, it will take less deicing material to melt snow in this condition. The drawback to this method is that, if forecasting is inaccurate, deicers are applied unnecessarily.

More elaborate data can be used to determine the rate of deicer application. For example, Irondequoit Bridge near Rochester, New York, has sensors in the pavement that record the pavement temperature and moisture content. This data is combined with local weather data to decide how much deicer should be applied (Tallie, 1997). Although this type of system is expensive, it is recommended for bridges that cross a sensitive water body or where corrosion is a particular concern.

8.2.5 *Modified Spreaders*

Deicers are often over-applied because much of the material bounces off the road surface. One solution to this problem is the use of "zero velocity" spreaders. These spreaders sense the velocity of the spreader compared to the pavement. The salt is spread so that it lands with a velocity of zero relative to the ground. Another modification is to adjust the rate of application based on ground speed. That is, when the truck is moving slower, deicers will be applied at a lower rate.

8.2.6 *Salt or Deicer Storage*

Many states have developed regulations regarding the storage of deicers, particularly salt. Salt should be stored on an impervious surface to prohibit groundwater contamination. Furthermore, salt piles should be placed in a structure protected from rainfall, eliminating contamination of runoff by exposed salt.

8.3 Airport Deicers

Airports use different deicers than those applied to roads because the corrosion caused by salt-based deicers (e.g., $NaCl$, $CaCl_2$) raises concerns about safety and damage to airplane parts. Environmental impacts of deicer alternatives are discussed in this section, along with methods to reduce deicer impacts. These include limiting application, treating deicer runoff and deicer recycling.

8.3.1 Airport Deicer Alternatives

The two deicers commonly used on airport runways are glycols and urea. Alternative acetate deicers have been proposed as well (e.g., CMA). The deicer alternatives are described in Table 8.2.

TABLE 8.2 AIRPORT DEICER ALTERNATIVES

(SOURCE: SILLS AND BLAKESLEE, 1992)

	Glycol	Urea	Acetates
Description	Petroleum-based organic compounds, similar to anti-freeze.	Nitrogen-based fertilizer product.	Petroleum-based organic chemicals, such as CMA.
Environmental Impacts	• Extremely high BOD_5 concentrations (Stormwater concentrations between 500 and 5,000 mg/l) • Trace carcinogenic compound (1,4-dioxane in some glycols)	• Toxicity concerns from ammonia formation • Increased nitrogen in water bodies may contribute to algal blooms	• High BOD_5
Comments	Most commonly used airport deicer.	Sometimes used as a glycol alternative, but nitrogen concerns can limit use.	Recently proposed alternative. Pelletized CMA is difficult to apply because jets blow pellets of the runway.

8.3.2 Limit Application

Reducing deicer application rates on airport runways is controversial because of safety risks. There are, however, a few options for deicer application. Hot water can be used to melt ice, but there is a risk of refreezing. When this method is used, a glycol spray should be used immediately after application to prevent refreezing. In addition, anti-icing (i.e., applying deicers prior to ice formation) can reduce required deicer application rates.

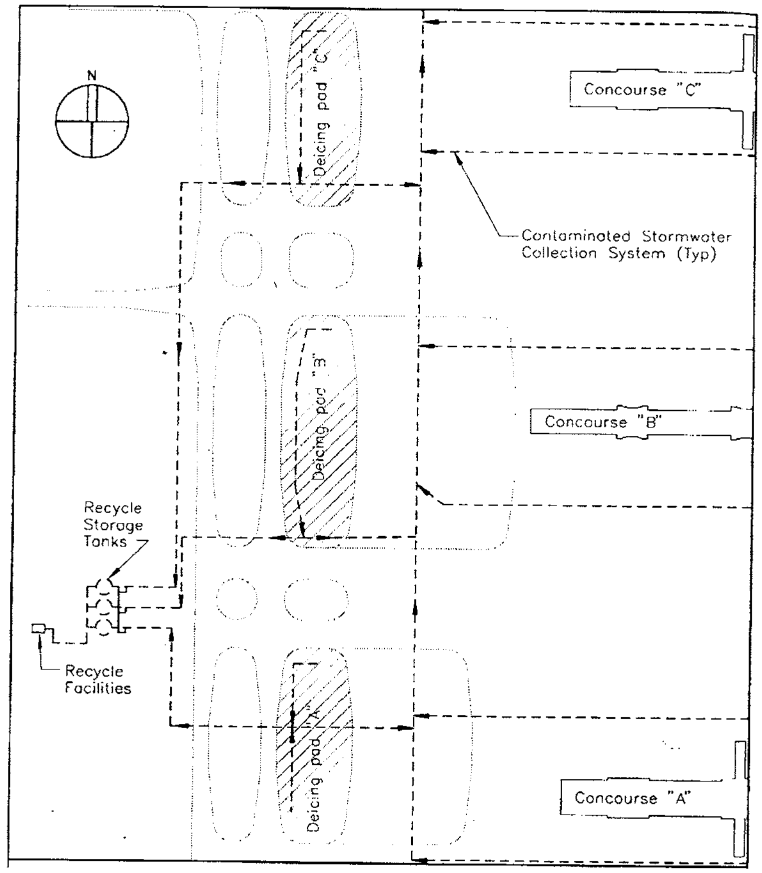
8.3.3 Treatment

One option to treat runoff is the use of aerated basins to reduce the BOD demand and treat nutrients in deicers. Unfortunately, this option is often space-prohibitive, especially in established airports. A second treatment method is to remove deicers from pavement. For example, at Calgary International Airport, absorbent material is applied to pavement immediately after aircraft are sprayed with glycol. This material is then vacuum swept and land filled. This process prevents 40% of glycol from entering stormwater (Sills and Blakeslee, 1992).

8.3.4 Deicer Recycling

Glycol recycling systems have only been used in a few airports worldwide. One example is the Denver International Airport (Figure 8.1; Backer et al., 1993). Glycol used for airplane deicing is captured and recycled. Airplanes are deiced at central facilities (deicing pads) so that the glycol levels will be substantially elevated to make recycling practical. Glycol concentrations greater than 15% need to be maintained at the recycling facility. During the winter season, runoff mixed with glycol from deicing pads is routed to storage tanks and then recycled by boiling off the water in the runoff. During the summer, runoff is pumped to a runoff collection system that leads to a treatment pond.

FIGURE 8.1 AIRPORT DEICER RECYCLING (SOURCE: BACKER *ET AL.*, 1993)



8.4 Snow Storage

The impacts of snowmelt runoff on aquatic systems can be minimized by storing snow in upland areas to promote infiltration, more nearly approaching pre-development hydrology. It also provides an alternative to disposing of snow directly into streams, reducing the capacity for "shock" loadings. A sample snow storage sizing and location example is included in Appendix C.

APPENDIX G

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM –

REPORT 526: SNOW AND ICE CONTROL:

GUIDELINES FOR MATERIALS AND METHODS

NCHRP

REPORT 526

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Snow and Ice Control: Guidelines for Materials and Methods

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 526

Snow and Ice Control: Guidelines for Materials and Methods

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SUBJECT AREAS
Maintenance

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2004
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Amir N. Hanna
Staff Officer
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This report provides guidelines for selecting roadway snow and ice control strategies and tactics for a wide range of winter maintenance operating conditions. These guidelines apply to highways, roads, streets, and other paved surfaces that carry motor vehicles—under state or local jurisdictions. The guidelines will assist winter maintenance personnel in selecting the appropriate level-of-service (LOS)-driven roadway snow and ice control operations and will help effectively manage snow and ice control resources. The report is a useful resource for state and local highway agency personnel and others involved in snow and ice control.

Snow and ice control on the U.S. highway system consumes billion of dollars—in direct costs and costs associated with corrosion and environmental impacts—each year. Strategies and tactics that employ solid and liquid chemicals, abrasives, and mechanical methods—individually or in combination—have been used by state and local agencies. In spite of many studies of issues associated with snow and ice control treatments, widely accepted guidelines for selecting roadway snow and ice control strategies and tactics for specific climatic, site, and traffic conditions have not emerged. Without such guidelines, the process of selecting treatment strategies and tactics that meet highway agency objectives can be difficult and costly. NCHRP Project 6-13 was conducted to address this need.

Under NCHRP Project 6-13, "Guidelines for Snow and Ice Control Materials and Methods," Midwest Research Institute of Kansas City, Missouri was assigned the objective of developing guidelines—applicable to state and local agencies—for selecting roadway snow and ice control strategies and tactics for specific ranges of climatic and traffic conditions found in the United States. These strategies and tactics refer to the combinations of materials, equipment, and methods—both chemical and physical—used in snow and ice control to achieve a defined LOS; they also include road-weather information systems and weather forecasting. To accomplish this objective, the researchers performed the following tasks:

1. Identified the climatic, site, and traffic conditions that affect the selection of snow and ice control strategies and tactics to achieve agency objectives (e.g., LOS) and listed in a rank-order the criteria necessary to assess the performance of treatments.
2. Identified the snow and ice control strategies and tactics in current use that may be applicable to U.S. conditions and highlighted for each strategy and tactic the conditions of use, selection criteria, evaluation methods, effectiveness, and related problems.
3. Identified specific snow and ice control strategies and tactics that merited further evaluation and developed a plan for their field evaluation in different environments under different site and traffic conditions.

4. Conducted investigations of several potential snow and ice strategy and tactic combinations during three winter seasons and collected information necessary to relate the effectiveness of each of these combinations to the climatic, site, and traffic conditions.
5. Developed guidelines that can be used for selecting appropriate snow and ice control strategies and tactics for specific climatic, site, and traffic conditions to achieve agency objectives.

The following five primary combinations (1 through 5) were evaluated at different locations over three winter periods under a variety of weather and traffic conditions:

1. Anti-icing strategy with appropriate chemical forms (e.g., solids and prewetted solids) on lower-volume primary highways and local roads followed by a subsequent strategy of mechanical removal of snow and ice together with friction enhancement, if necessary.
2. Anti-icing strategy with appropriate chemical forms (e.g., solids, prewetted solids, and liquids) at selected highway locations such as hills, curves, intersections, grades, and selected bridge decks.
3. Anti-icing or deicing strategy with appropriate chemical forms on lower-volume primary highways and local road systems.
4. Anti-icing strategy with liquid chemical applications on bridge decks to prevent preferential icing.
5. Mechanical snow and ice removal strategy with abrasives prewetted with liquid chemicals.

A total of 24 highway agencies (13 state, 1 provincial, 4 county, and 6 city or town) made an attempt at testing the five strategy/tactic combinations at a total of 51 site locations over the three-winter periods; three highway agencies provided test data for the same location over all three winters. However, adjustments were made by some highway agencies to the assigned strategy/tactic combinations during some winter weather events because of weather-related circumstances and other limitations. These adjustments resulted in the following three additional strategy/tactic combinations (6 through 8):

6. Chemical priority strategy with straight chemicals (solid, prewet solid, or liquid) throughout an event to the extent possible and an occasional application of abrasives/chemical mixture.
7. Abrasive priority strategy with abrasives (pure or mixed with chemicals) throughout an event to the extent possible and an occasional application of straight chemicals (solid, prewet solid, or liquid).
8. Plowing only strategy without the use of snow and ice control materials (chemicals and/or abrasives) throughout the entire winter weather event.

To evaluate alternative strategy/tactic combinations, the researchers considered possible indicators/measures of effectiveness and developed a condition index—termed Pavement Snow and Ice Condition (PSIC) index—that describes the road condition in one of seven levels. These levels range from a pavement surface that remains in a bare/wet condition at all times (Condition 1) to a pavement surface that is covered with a significant buildup of packed snow and ice (Condition 6) and even a pavement surface that is exposed to drifting and excessive unplowed snow to warrant temporary closure (Condition 7). The index was used to evaluate both within-event and end-of-event LOS achieved by the winter maintenance treatments for comparing the effectiveness of the different strategy/tactic combinations. The researchers also investigated the factors influencing the choice of materials, their form, and associated application rates.

The findings of this research pointed out the importance of (1) ensuring that snow and ice control strategy/tactic combinations are LOS driven; (2) using nowcasting results, materials characteristics, traffic volume, and cycle time considerations in the treatment decision making; and (3) providing flexible winter maintenance operations to deal with the variety of precipitation types, especially those occurring within a given weather event.

Results of the analytical and field investigations conducted in this research were used to develop the guidelines for winter maintenance materials and methods presented in this report. These guidelines will assist in selecting materials and methods that best address LOS, weather, site, and traffic conditions and, therefore, be useful to highway agencies and contracting firms involved in snow and ice control work.

CONTENTS

CHAPTER 1

INTRODUCTION

Snow and ice control on the U.S. highway system consumes over $2 billion in direct costs each year (*1*). Indirect costs associated with corrosion and environmental impacts add at least $5 billion (*1*). Strategies and tactics that employ solid and liquid chemicals, abrasives, and mechanical methods—individually or in combination—have been used by different state and local agencies. Research by the Strategic Highway Research Program (SHRP), the Federal Highway Administration (FHWA), the American Association of State Highway Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), and other organizations in the United States and other countries has addressed many of the issues associated with snow and ice control treatments (*2–5*). However, widely accepted guidelines for selecting level-of-service (LOS)-driven roadway snow and ice control strategies and tactics for specific climatic, site, and traffic conditions have not been developed. Without this information, the process of selecting treatment strategies and tactics that meet highway agencies LOS objectives is difficult.

This report presents a realistic set of guidelines for selecting roadway snow and ice control strategies and tactics for a wide range of climate, site, and traffic conditions found in the United States. These guidelines apply to both state and local highway agencies. The term "roadway" used in this document refers to any highway, road, street, or other paved surface that carries motor vehicles.

The guidelines were developed from appropriate existing documentation plus data collected from field testing of selected snow and ice control strategies and tactics over three winters.

In the general sense, a strategy is a careful plan or method directed at achieving a specific goal or goals. Tactics, on the other hand, are the systematic employment of available means or resources to accomplish a desired end condition of a strategy. For purposes of these guidelines, strategies and tactics refer to the combination of material, equipment, and methods, including both chemical and physical, that are used in snow and ice control operations to achieve a defined level of service.

The various roadway snow and ice control strategies used in winter maintenance operations in the United States can be classified into four general categories:

- Anti-icing,
- Deicing,
- Mechanical removal of snow and ice together with friction enhancement, and
- Mechanical removal alone.

Roadway anti-icing is a snow and ice control strategy of preventing the formation or development of bonded snow and ice to a pavement surface by timely applications of a chemical freezing-point depressant. The tactics employed during anti-icing operations consist of chemical applications that are coordinated with plowing.

Deicing is a snow and ice control strategy of destroying the bond between snow and ice and the pavement surface by chemical or mechanical means or a combination of the two.

Mechanical removal of snow and ice together with friction enhancement is a strategy in which abrasives or a mixture of abrasives and a chemical are applied to a layer of compacted snow or ice already bonded to the pavement surface that may or may not have been partially removed by mechanical means (plowing and scraping). This strategy is used to provide an increase in the coefficient of friction for vehicular traffic, although this increase may be short lived. Abrasives, by themselves, are not ice control chemicals and will not support the fundamental objective of either anti-icing or deicing.

Mechanical removal alone is a strategy that involves the physical process of attempting to remove an accumulation of snow or ice by means such as plowing, brooming, blowing, and so on, without the use of snow and ice control chemicals. This strategy is strictly a physical process that has some merit during and/or after frozen precipitation has occurred at very low pavement temperatures, say below 15°F, and on very low volume and unpaved roads.

The guidelines were developed to assist maintenance managers, local maintenance supervisors, and other field personnel in selecting LOS-driven roadway snow and ice control strategies and tactics. The guidelines focus on the snow and ice control materials and methods that best address such items as LOS, weather, site, and traffic conditions.

Following this Introduction, the guidelines are divided into seven major chapters:

- **Chapter 2: Level of Service**—This chapter describes the various winter-time LOS definitions used by highway agencies in the United States. Stressed is the need to define LOS in terms of measures of effectiveness that can be used by the agencies in their evaluation process. Factors affecting LOS are discussed in general and then more specifically in later chapters. The discussion includes the need for describing within-storm, end-of-storm, and post-storm conditions when developing LOS.

- **Chapter 3: Snow and Ice Control Operational Considerations**—This chapter describes the various climatic, site, and traffic conditions found in the United States that are considered important in the selection of appropriate roadway snow and ice control strategies and tactics. Described are the various types and distribution of winter weather conditions within the general climates of the United States. and their relationship to snow and ice control. This chapter also contains a description of microclimates and their importance in selecting appropriate strategies and tactics for snow and ice control. Those site conditions that influence snow and ice control are discussed. Major influences include the area development setting, roadway features, and solar influences. Also described are the influences of site considerations on LOS goals that are achievable with various resources. This chapter also describes the traffic-related influences on snow and ice control. The influences include traffic volume, vehicle mixes, essential or functional traffic patterns, and vehicle speeds. The influence of traffic considerations on LOS is presented. Finally, this chapter concludes with a summary of the important factors of these three considerations that influence the choice of snow and ice control strategies and tactics.
- **Chapter 4: Performance-Based Level of Service**—This chapter describes a process for use by agencies in developing a performance-based LOS. This discussion includes the use of Pavement Snow and Ice Condition (PSIC) indices, a suggested set of PSIC definitions, and the establishment of LOS classes using PSIC for various highway classifications and for within-storm and end-of-storm conditions.
- **Chapter 5: Strategies and Tactics and Their Application to Support Level of Service Choices**—This chapter describes the four snow and ice control strategies: anti-icing, deicing, mechanical removal of snow or ice with traction enhancement, and mechanical removal of snow or ice. For each of these strategies, the guidelines describe the effects of climate, site, and traffic considerations. In addition, and considering PSIC and LOS, the guidelines discuss the strategies with respect to pre-storm, within-storm, and end-of-storm operations. Various tactics that can be used to support each of the strategies are also discussed. The chapter concludes with special discussions of traction enhancement and the use of combinations of strategies and tactics.
- **Chapter 6: Factors Influencing the Choice of Materials, Their Form, and Associated Application Rates**—In order to attain LOS classes, managers must select appropriate resources. This chapter first describes the influence of pavement temperatures and the dilution potential of winter weather events. Then discussed are the properties of materials used in support of strategies and tactics and the effects of dilution with respect to attaining LOS goals.
- **Chapter 7: Recommended Snow and Ice Control Practices**—This chapter describes a recommended process and sets of procedures to follow for snow and ice control operations for various LOS goals. The recommended practices are based on the results of the strategies and tactics evaluated in this project, supplemented by data assembled from various sources. A discussion on treatment decision making concludes the chapter.
- **Chapter 8: Recommended Operational Guidelines for Winter Maintenance Field Personnel**—This chapter contains tables that suggest appropriate maintenance actions to take during various strategy and tactic operations for winter weather events. These tables are suitable for reproduction and use by field personnel.

CHAPTER 2

LEVEL OF SERVICE

Level of service (LOS) in the context of roadway snow and ice control operations is a set of operational guidelines and procedures that establish the timing, type, and frequency of treatments. The maintenance actions are directed toward achieving specific pavement condition goals for various highway sections. Examples of LOS for highways, roads, and streets under snow and ice control conditions are given in AASHTO's "Guide for Snow and Ice Control" (*5*). How highway agencies characterize LOS, how they assign LOS goals, and how they measure the performance of maintenance operations in achieving the LOS goals are very important topics. These are briefly described below.

HOW AGENCIES CHARACTERIZE LEVEL OF SERVICE

There are several ways (singularly and in combination) by which highway agencies characterize the LOS they provide. These include level of effort, priority of treatment, types of treatments, and results in terms of pavement conditions at various points in time during and after snow and ice events.

The level of effort category includes assigning more people and equipment to higher priority routes, providing more or less effort during certain time frames, varying the number of people and equipment providing treatment in relationship to the predicted severity of the event, and so on.

The priority of treatment category includes giving first and/or more frequent treatment to higher traffic routes, high accident/problem locations, commercial/business locations, school bus routes, transit routes, health facilities, fire house locations, and schools. Some highway agencies use a system of providing treatment on a highway priority basis whereby the next lower category of highway is not treated until higher category roads are in "satisfactory" condition.

In the type of treatment category, the treatments at various locations are specifically defined. Examples include sanding hills and intersections, plowing-only on certain roads, using nonchloride or reduced chloride applications in certain areas, anti-icing areas, pre-treating areas, applying chemicals only at the beginning and end of the event, and so on.

RECOMMENDED LEVEL OF SERVICE GOALS

A good way to define LOS is in terms of results at various points in time. Examples include maximum accumulation of snow on highways during a storm, absence of pack or bond during a storm, bare/wet pavement (x) hours after end-of-event, plowed and sanded (x) hours after end-of-event, friction number > (y) (x) hours after end-of-event, road plowed, and road passable.

ASSIGNING LEVEL OF SERVICE GOALS

There are two fundamental approaches for highway agencies to use when assigning their LOS goals. The first is to evaluate existing resources and direct them toward providing a balanced LOS on a priority of treatment basis. This is realistically the more common approach. The second, and preferred, approach is to assign pavement condition goals at intervals within and after a "design storm" of "X" inches of snow per hour to the various priority elements of the highway system. Using this, and production rate (lane-miles per hour) of equipment (including deadheading and reloading) in both the plowing and materials spreading modes, the necessary personnel and equipment can then be determined to provide the desired LOS.

PERFORMANCE MEASURING OF LEVEL OF SERVICE

A variety of performance measures are being tried and used relative to LOS. These include (in order of popularity) pavement conditions (visual) at various points in time (some agencies use pictorial reference templates as an aid to condition observers); performance indices that relate the amount of time pavement areas are snow/ice covered to total storm time (visual); report cards (customer satisfaction surveys); and friction measurements at various points in time and rating slipperiness at various points in time based on vehicle handling characteristics.

The visual approach appears to be gaining in popularity in the United States and abroad. Examples of visual characterization of roadway surfaces include the following:

- Centerline bare,
- Wheel path bare,
- Loose snow covered (percent area and depth),
- Packed snow covered (percent area and depth),
- Bare (percent area),
- Thin ice covered (percent area),
- Thick ice covered (percent area),
- Dry,
- Damp,
- Slush (percent area and depth),
- Frost, and
- Wet.

Using the descriptors above together with traffic flow and other visual information, a Pavement Snow and Ice Condition (PSIC) can be established for any point in time. The descriptions of the various PSICs appear in Table 1.

Whatever performance measure is chosen, it must be part of a continuing evaluation plan that addresses individual winter weather events; early, mid, and late winter season events that tend to have similar characteristics; and full winter seasons. This will allow critical judgment to be made on resource levels, strategies and tactics, materials choices and materials application rates.

SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS RELATING TO LEVEL OF SERVICE

The primary snow and ice control operational considerations relating to LOS are cycle time, available material treatments, weather conditions, site conditions, and traffic considerations.

Cycle time is primarily a function of the number of personnel and the amount of equipment available to treat the assigned roadway system or route. Other factors, including traffic volume/speed, traffic control devices, roadway geometry/complexity, and the location of material stockpiles also contribute to achievable cycle time.

LOS and cycle time of maintenance treatment operations are clearly interconnected. The LOS and cycle time for a facility will largely be determined by the importance or functional classification of the road, which may be strongly related to the roadway's average daily traffic volume (ADT) (*5*). High winter maintenance LOS requirements are described many times as "bare pavement" policies. Anti-icing strategies with appropriate tactics have been shown to be consistent with the requirements of a high-LOS facility (*3*).

The type of material treatments an agency is capable of delivering has a major impact on achievable LOS. Agencies capable of providing appropriate liquid and/or solid chemi-

TABLE 1 Descriptions of pavement snow and ice conditions (PSIC)

Condition 1: All snow and ice are prevented from bonding and accumulating on the road surface. Bare/wet pavement surface is maintained at all times. Traffic does not experience weather-related delays other than those associated with wet pavement surfaces, reduced visibility, incidents, and "normal" congestion.
Condition 2: Bare/wet pavement surface is the general condition. There are occasional areas having snow or ice accumulations resulting from drifting, sheltering, cold spots, frozen melt-water, etc. Prudent speed reduction and general minor delays are associated with traversing those areas.
Condition 3: Accumulations of loose snow or slush ranging up to (2 in.) are found on the pavement surface. Packed and bonded snow and ice are not present. There are some moderate delays due to a general speed reduction. However, the roads are passable at all times.
Condition 4: The pavement surface has continuous stretches of packed snow with or without loose snow on top of the packed snow or ice. Wheel tracks may range from bare/wet to having up to (1.5 in.) of slush or unpacked snow. On multilane highways, only one lane will exhibit these pavement surface conditions. The use of snow tires is recommended to the public. There is a reduction in traveling speed and moderate delays due to reduced capacity. However, the roads are passable.
Condition 5: The pavement surface is completely covered with packed snow and ice that has been treated with abrasives or abrasive/chemical mixtures. There may be loose snow of up to (2 in.) on top of the packed surface. The use of snow tires is required. Chains and/or four-wheel drive may also be required. Traveling speed is significantly reduced and there are general moderate delays with some incidental severe delays.
Condition 6: The pavement surface is covered with a significant buildup of packed snow and ice that has not been treated with abrasives or abrasives/chemical mixtures. There may be (2 in.) of loose or wind-transported snow on top of the packed surface due to high snowfall rate and/or wind. There may be deep ruts in the packed snow and ice that may have been treated with chemicals, abrasives, or abrasives/chemical mixtures. The use of snow tires is the minimum requirement. Chains and snow tire equipped four-wheel drive are required in these circumstances. Travelers experience severe delays and low travel speeds due to reduced visibility, unplowed loose, or wind-compacted snow, or ruts in the packed snow and ice.
Condition 7: The road is temporarily closed. This may be the result of severe weather (low visibility, etc.) or road conditions (drifting, excessive unplowed snow, avalanche potential or actuality, glare ice, accidents, vehicles stuck on the road, etc.).

cal treatment will achieve higher LOS than those who provide only mixtures of chemicals and abrasives or no material treatment at all.

The character and intensity of particular winter weather events influence how long chemical snow and ice control treatments will remain effective and the amount of snow/ice accumulation on the roadway between plowing cycles. The climatology of a particular area defines the historical average (usually over a 30-year period) of the type and amount of frozen precipitation the area can be expected to receive in an average winter. What is important for winter maintenance operations in a given area is not so much climatology, but the distribution of precipitation types associated with winter weather events. Winter maintenance forces across the United States need to be prepared to treat a wide variety of precipitation types, even within a given winter weather event. Only the distribution of the likelihood of precipitation type occurrence changes from area to area, or agency to agency.

The three site conditions of major importance are (1) pavement temperature, (2) the amount of snow/ice remaining on the roadway after plowing and/or before chemical treatment, and (3) most significantly, the presence or absence of ice/pavement bond. Other site conditions that relate more to operational difficulty include curvature, variable pavement widths, and many of those variables listed in next chapter. These latter items directly or indirectly can contribute to the presence of ice/pavement bond because of special needs imposed on snow and ice control field operations.

Traffic considerations include those relating to operational difficulty (e.g., slow- and fast-moving traffic, stranded blocking vehicles); timing (e.g., rush-hour, congestion); and influences on treatment effectiveness and longevity. The variation of traffic rate throughout a 24-hr period is an important consideration in the operational decision-making process.

Vehicular traffic can affect the pavement surface in several ways. Tires compact snow, abrade it, displace, or disperse it. Heat from tire friction, engine, and the exhaust system can add measurable heat to the pavement surface. Traffic wheel passages can help in the deicing of local streets when treated in the early morning hours. Traffic can also result in applied chemicals and abrasives being blown from the pavement surface when applied before precipitation. Thus, traffic can have both positive and negative influences on the effectiveness of snow and ice control operations. However, most of the influences are difficult to quantify. Further research is needed to quantify the effects of traffic.

CHAPTER 3

SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS

The major snow and ice control operational considerations, exclusive of agency resources, are climate, weather, site conditions, and traffic. Each has a profound effect on some aspect of operations.

CLIMATE CONDITIONS

Climate can be defined as the weather that occurs averaged over a specified period of time, normally 30 years. The climate is also defined by statistics about the frequency of extreme events. Climate elements are the averaged meteorological elements.

Table 2 provides a listing of major climate-related issues. Most of these have value in the planning phase of operations. LOS goals are to some extent climate driven in terms of what is and is not possible. Strategies and tactics that support LOS goals are similarly climate driven. Certain recurring site conditions (microclimates) are climate driven and require specific recurring operational responses. These include cold spots, high humidity locations, persistent windy areas, etc.

In any climate, the achievable LOS is limited by the rate of precipitation, cycle time capability, sustainability of the maintenance effort, site conditions that may cause road closure, and materials options. Higher LOS for similar weather conditions can be provided with shorter cycle times and the use of straight ice control chemicals.

WEATHER CONDITIONS

Field winter maintenance personnel in a given area are mostly concerned with anticipated winter weather conditions and not with climate considerations. "Weather" usually refers to the measurable or identifiable meteorological events that occur at a given site or in a given area at a particular point in time. Weather can be characterized by describing the meteorological elements associated with those events (e.g., precipitation type and amount, visibility, wind speed and direction, temperature, and relative humidity).

Precipitation is arguably the most important weather condition. Having a working knowledge of precipitation definitions is essential when designing a snow and ice control treatment. Those definitions appear in Table 3 and are taken from the *Federal Meteorological Handbook (FMH)* No. 1 (*6*).

Other important meteorological variables that have an impact on winter pavement conditions are sky, or cloud cover conditions (solar radiation effects); air temperature, to the extent it establishes the trend in pavement temperature; dew point temperature; condensation; pavement temperature; relative humidity; wind speed and direction; and evaporation.

Condensation occurs when the pavement, or bridge deck, temperature is above 32°F and below the dew point temperature. Frost, on the other hand, occurs when the pavement temperature is at or below 32°F and below the dew point temperature. It is common for bridge deck surfaces to develop frost when the adjacent highway surfaces do not. This typically happens in the fall and spring when these temperature conditions are satisfied, the sky is free of cloud cover, and the wind speed is calm (0 to 3 mph). The early morning hours, just before sunrise, are ideal times for bridge deck icing/frosting to occur. The prediction of these icing conditions is particularly difficult, especially for rural areas with elevation changes and varied roadside vegetation coverage. Location of Road Weather Information Systems (RWIS) sensors in these sensitive areas has been most helpful in detecting the onset of frost conditions.

Crosswind speeds in excess of about 15 mph may cause local snow drifting and inhibit anti-icing operations. Also, liquid chemical sprayers should be set closer to the pavement during windy conditions to avoid spray loss.

SITE CONDITIONS

Site conditions are those local situations that affect how snow and ice control operations are conducted. They influence type of equipment, materials choices, materials application rate, priority and sequence of treatment, and type of treatment. Table 4 is a listing of important site conditions.

TRAFFIC CONDITIONS

The influence of traffic was discussed in the Chapter 2 section on Snow and Ice Control Operational Considerations Relating to Level of Service. The traffic conditions of possible importance are listed in Table 5.

TABLE 2 Climate-related items

- Frequency of Snow and Ice Events
  - Low
  - Moderate
  - High
- Severity of Winter Pavement Exposure
  - Mild
  - Moderate
  - Severe
- Wintertime Precipitation
  - Type
  - Rate
- Urban Influence
  - Small
  - Medium
  - Large
  - Industrial
- Water Influence
  - Minor
  - River
  - Lake
  - Ocean
- Elevation/Large Scale Topography
  - Plain
  - Rolling
  - Mountainous

SUMMARY OF SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS

Climate is an issue that is primarily of importance in the planning phase of snow and ice control operations. With minor exception, the various snow belt climate zones in North America all experience similar types of winter weather events with mixtures of precipitation classes. The difference among the climate zones is in the distribution of expected precipitation class events. Mountain climates, for example, see very few freezing rain events; however, they may see more snow events with high accumulations. The bottom line is that all snow belt maintenance forces have to be prepared to deal with all types of precipitation events.

The ability to forecast and recognize the various types of precipitation is extremely important. This influences to a large degree the type of treatment, material choice, and material application rate.

Site conditions, especially pavement temperature, snow/ice on the highway surface, and ice/pavement bond, are major factors when deciding on material type and application rate. Traffic characteristics appear to be less important than weather and site conditions; however, higher traffic volume and speed can displace snow and ice control materials from the highway surface.

TABLE 3 Precipitation definitions

Light Rain. Small liquid droplets falling at a rate such that individual drops are easily detectable splashing from a wet surface. Include drizzle in this category.
Moderate Rain. Liquid drops falling are not clearly identifiable and spray from the falling drops is observable just above pavement or other hard surfaces.
Heavy Rain. Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray from falling rain can be observed several inches over hard surfaces.
Freezing Rain. When rain freezes upon impact and forms a glaze on the pavement or other exposed surfaces.
Sleet (Ice Pellets). Precipitation of transparent or translucent pellets of ice, which are round or irregular in shape.
Light Intensity of Sleet: Scattered pellets that do not completely cover an exposed surface regardless of duration. Visibility is not affected.
Moderate Intensity of Sleet: Slow accumulation on ground. Visibility reduced by ice pellets to less than 7 mi (13 km).
Heavy Intensity of Sleet: Rapid accumulation on ground. Visibility reduced by ice pellets to less than 3 mi (5.6 km).
Light Snow. Snow alone is falling and the visibility is greater than ½ mi (0.9 km).
Moderate Snow. Snow alone is falling and the visibility is greater than ¼ mi (½ km) but less than or equal to ½ mi (0.9 km).
Heavy Snow. Snow alone is falling and the visibility is less than or equal to ¼ mi (½ km).
Blowing Snow. When fallen snow is raised by the wind to a height of 6 ft (1.8 m) or more and is transported across a road.
None. No precipitation or blowing snow.
NOTE: An estimate can be made of the moisture content of falling snow as follows: 1 = powder snow; 2 = ordinary snow; 3 = wet/heavy snow

[a] Definitions taken from *Federal Meteorological Handbook (FMH)* No. 1 (*6*).

TABLE 4 Site conditions

- Area Type
  - Urban
  - Suburban
  - Rural
- Special Highway Segment Areas
  - Hills
  - Curves
  - Grades
  - Intersections
  - Bridges
  - Sags
  - Ramps
  - Crosslopes
  - Weaving Areas
  - Narrowings
  - Roadway Widenings
  - Elevated Roadways
  - Pavement Surface Types
  - Tangents
- Shadings from Solar Influence
  - Forest/vegetation
  - Buildings/structures
  - Cuts
- Pavement Conditions
  - Temperature
  - Ice/pavement bond
  - Frost or thin ice
  - Slush, loose snow, packed snow, thick ice

TABLE 5 Traffic conditions

- Traffic Volume
  - Very low
  - Low
  - Medium
  - High
  - Very high
- Commercial Vehicle Mix
  - Low
  - Moderate
  - High
- Vehicle Speeds
  - Low
  - Moderate
  - High

CHAPTER 4

PERFORMANCE-BASED LEVEL OF SERVICE

The definition of terms, concepts, and a suggested Pavement Snow and Ice Condition (PSIC) rating system were described in Chapter 2 in the section entitled Performance Measuring of Level of Service (LOS). When defining LOS goals, two time frames relative to a winter weather event need to be considered:

- Within-winter weather event and
- After-end-of-winter weather event.

Higher LOS are associated with "better" within-event pavement ice conditions and more rapid achievement of "better" or "bare" pavement conditions after the event ends.

THE "DESIGN" WINTER WEATHER EVENT

A winter weather event having a snowfall rate of "X" inches per hour should be chosen as a basis for determining what level of service can be provided with existing resources or determining the necessary resources to provide a desired level of service. "X" should be a rate that is only exceeded in "Y" percent of snowfall records in an average year (from climatological records). "Y" of about 20 percent can be selected (*7*).

WITHIN-WINTER WEATHER EVENT LEVEL OF SERVICE

A within-winter weather event has two intertwined components—the amount of loose snow/ice/slush that is allowed to accumulate between plowing cycles and the condition of the ice/pavement interface in terms of bond and packed snow/ice.

The amount of loose snow allowed to accumulate on the roadway between plowing cycles is usually the driving force for plowing resource requirements. Plowing operations are limited to one lane at a time while material spreading operations can treat more than one lane at a time. Once the allowable amount of loose snow/ice is established, the necessary equipment resource can be determined. First, the local plowing production rate in terms of lane miles per hour (including reloading and deadheading) has to be determined. This, in conjunction with design snowfall rate, yields the cycle time required to meet the "accumulation" goal. Sufficient equipment has to be provided to achieve the desired cycle time(s).

The second issue is the condition of the snow/ice pavement interface in terms of bond or packed snow/ice. This is largely a function of pavement temperature, the type of materials treatment being provided, materials application rate, and cycle time. Generally, cycle times shorter than 1.5 hours using straight chemicals and plowing will allow a high within-event level of service.

AFTER-END-OF-WINTER WEATHER EVENT LEVEL OF SERVICE

The after-end-of-event LOS is usually expressed as a time to achieve particular pavement surface conditions in terms of ice or snow coverage, or PSIC level.

ESTABLISHING LEVEL OF SERVICE GOALS

The first step in the process of establishing LOS goals is to prioritize the roadway system and particular locations within the system into some type of LOS system. This is typically a numeric, alphabetic, or color system. The next step is to assign both within-winter weather event and after-end-of-winter weather event LOS goals. These goals may be described in terms of a PSIC as shown in Table 6 or a variety of other descriptors. The final step is a reality check to ensure that sufficient capability to meet the goals for the "design" conditions is available. Table 6 is an example of LOS goals for a small roadway system.

TABLE 6 Example of level of service assignment

Highway segment		LOS class[a]	Within-event LOS		After-end-of-event LOS	
Route	Mile post		PSIC	Maximum snow accumulation (in.)	PSIC	Hours after end-of-event
15	2-25	2	3	1.5	1	2.0
8	175-186	4	5	2.0	2	6.0
16	37-51	3	4	1.5	2	3.0
5	256-271	3	4	1.5	2	3.0
2	0-4	2	3	1.5	1	2.0
10	277-291	4	5	2.0	2	6.0
10	291-315	3	4	1.5	2	3.0
4	26-32	1	2	1.0	1	1.5
4	32-50	3	4	1.5	2	3.0
Main Street	–	1	2	1.0	1	1.5
Baxer Bridge	–	1	1	0.0	1	0.0

[a] "1" is the highest; 4 is the lowest LOS class.

CHAPTER 5

STRATEGIES AND TACTICS AND THEIR APPLICATION TO SUPPORT LEVEL OF SERVICE CHOICES

As stated in the Introduction, the various roadway snow and ice control strategies used in winter maintenance operations can be classified into four general categories and are discussed in details in this chapter:

- Anti-icing,
- Deicing,
- Mechanical removal of snow and ice together with friction enhancement, and
- Mechanical removal alone.

ANTI-ICING

Roadway anti-icing is a snow and ice control strategy of preventing the formation or development of bonded snow and ice to a pavement surface by timely applications of a chemical freezing-point depressant. The tactics employed during anti-icing operations consist of chemical applications that are coordinated with plowing.

Anti-icing is suitable for use during most weather, site, and traffic conditions. It is particularly beneficial as a pretreatment using liquid chemicals for anticipated frost and preferential icing situations. Anti-icing with a liquid chemical is a good strategy when the pavement temperatures are above about 20°F at the onset of a snowfall event. It is not a good strategy when the pavement temperatures are below about 20°F at the onset of a snowfall event, or at any freezing pavement temperatures when the snowfall event is preceded by rain. Anti-icing with liquid chemicals is not recommended during freezing rain or sleet events. Anti-icing with solid or prewetted solid chemicals is not a good strategy when the pavement temperatures are below about 15°F at the onset of a winter weather event. The use of chemicals below these minimum pavement temperatures will require excessive amounts of chemicals to be used as shown in Attachment 1.

Anti-icing can be initiated before a winter weather event or very early in the event. By continuing the strategy throughout the event there should be a very rapid recovery or achievement of a satisfactory pavement condition after the end of the event. Anti-icing produces very high within-winter weather event and after-winter weather event LOS.

DEICING

Deicing is a snow and ice control strategy of removing compacted snow or ice already bonded to the pavement surface by chemical or mechanical means or a combination of the two.

Deicing is a suitable strategy for most weather, site, and traffic conditions except when the pavement temperatures are below 20°F. Deicing operations can be accomplished at temperature lower than 20°F, but the number of chemical applications and/or chemical application rates will be excessive, as shown in Attachment 1, and the time to accomplish deicing will be long. Chemical treatments are usually initiated later in a winter weather event and continued well after the end until a satisfactory pavement condition is reached. Deicing usually produces lower within-winter weather event and after-winter weather event levels of service. Deicing usually will require more chemicals than anti-icing to produce the same LOS.

MECHANICAL REMOVAL OF SNOW AND ICE TOGETHER WITH FRICTION ENHANCEMENT

Mechanical removal of snow and ice together with friction enhancement is a strategy in which abrasives or a mixture of abrasives and a chemical are applied to the plowed or scraped roadway surface that may have a layer of compacted snow or ice already bonded to the pavement surface. This strategy is used to provide an increased level of friction for vehicular traffic, although this increase may be short lived. Abrasives, by themselves, are not ice-control chemicals and will not support the fundamental objective of either anti-icing or deicing.

This strategy has been used for many years in most snow and ice situations; however, its only real applications are in very low pavement temperature situations (about 12°F) where chemical treatments are not likely to be effective and on roads having a low traffic volume and a LOS designation. This strategy is sometimes used when agencies run out of chemical deicers.

The LOS expectation (within-event and after-end-of-event) for this strategy cannot be high unless there are significant amounts of ice control chemicals in the mixture, unless there are numerous applications of mixtures containing smaller amounts of chemicals, or unless there are very high application rates of mixes containing smaller amount of chemicals. This strategy is a viable option for unpaved roads if there is no, or very little, ice control chemical in the mixture.

MECHANICAL REMOVAL ALONE

Mechanical removal alone is a strategy that involves the physical process of attempting to remove an accumulation of snow or ice by means such as plowing, brooming, or blowing without the use of snow and ice control chemicals. This strategy is strictly a physical process.

This strategy is suitable for use in a variety of situations. It may be the only treatment rendered on unpaved or very low LOS roads. On higher LOS roads, it is effective when pavement temperatures are above freezing and snow is not bonding to the pavement. Similarly, when pavement temperatures are lower than about 12°F and snow is not bonding to the pavement, this is an effective treatment. This also may be the final treatment for a winter weather event after ice control chemicals or warming pavement temperatures have loosened any bonded snow or ice from the pavement.

TRACTION ENHANCEMENT

There are some techniques for enhancing the traction of snow/ice surfaces. Mechanical roughening, grooving, or texturing provides a small level of traction and directional stability enhancement. This technique is not suitable for higher volume roads as the effect is short lived. It may provide an option in environmentally sensitive areas with low traffic volume.

The most common technique for enhancing friction on a snow/ice surface is to apply abrasive materials such as sand, cinders, ash, tailings, and crushed stone/rock. These materials may be applied straight or with varying amounts of ice control chemical in a mixture. This is thought to make them "adhere" a little better to the surface and last a little longer. A solid form of ice control chemical may be mixed into the abrasive stockpile and allowed to age (to form a brine and coat some of the abrasive particles). A liquid chemical may be sprayed onto the abrasives while they are being applied to the road or while the stockpile is being created. Another technique for enhancing the "retention" and longevity properties is to spray the abrasives with warm water as they are being dispensed onto the road. This is reported to be quite effective.

Traction enhancement's primary role is limited to lower volume roads, situations where ice control chemicals will not likely "work," and in environmentally sensitive situations where the use of ice control chemicals must be limited. There are potential environmental impacts associated with the (excessive) use of abrasives just as there are potential environmental impacts associated with the (excessive) use of chemicals in deicing operations. Winter maintenance field personnel, as stewards of the highway and its environment, must be ever vigilant in resisting the temptation to use more snow and ice control materials than are needed for the operational conditions.

COMBINATIONS OF STRATEGIES

Combinations of strategies are almost always used. Many winter weather events present a variety of weather and pavement conditions. To deal effectively with these changes, strategies and tactics need to be adapted. The most common scenario requiring changes is when pavement temperatures fall to a low level during a winter weather event. As ice control chemicals become much less effective in colder temperatures, agencies often switch from straight chemical treatments to treatment with abrasives or mixtures of abrasives and chemicals.

Achieving stated LOS goals may require using different strategies and tactics during a single winter weather event. An example is where an agency wants a low within-winter weather event LOS and a high LOS at or after the end of a winter weather event. In this case, an agency may initially do anti-icing with ice control chemical, use only mechanical removal techniques during the event, and utilize deicing at the end of the event. The early anti-icing treatment makes the later deicing treatment more effective.

SUMMARY

Higher LOS can only be provided if snow/ice is not bonded to the pavement. There are only two mechanisms that will achieve this: (1) the use of ice control chemicals and (2) favorable pavement temperatures. Using the right amount of chemical for the operational, weather, and pavement conditions is the most efficient and effective way to meet most higher LOS goals.

Warm pavement temperatures above 32°F will usually not allow light to moderate rates of precipitation to bond. Very cold pavement temperatures, lower than about 12°F, together with dry or powder snow will usually not produce ice/pavement bond. In either case, mechanical removal alone may be all that is necessary to achieve a high LOS.

There is always the potential danger of chemical residuals becoming diluted and resulting in a refreeze condition, whether at elevated or low temperatures. The material treatment design process which follows considers the impact of weather and road conditions that occur after a given treatment and before the next scheduled treatment in order to prevent refreezing of chemical solutions.

CHAPTER 6

FACTORS INFLUENCING THE CHOICE OF MATERIALS, THEIR FORM, AND ASSOCIATED APPLICATION RATES

The major factors to consider when choosing a snow and ice control materials treatment are pavement conditions, weather conditions, and the performance characteristics of the materials.

DILUTION POTENTIAL

Dilution potential is a term that relates precipitation, pavement conditions, pavement surface conditions, and operational conditions to the choice of snow and ice control material and application rate that will generally produce a "successful" result. For simplicity, dilution potential is divided into three categories: low, medium, and high.

Precipitation Dilution Potential

Precipitation dilution potential is the contribution to overall dilution potential caused by the type and rate of precipitation of a winter weather event in progress. The higher the moisture content of the event per unit or time, the higher the dilution potential.

Pavement Conditions

Pavement conditions are the properties of the pavement itself that influence snow and ice control operations. The most important of those is pavement surface temperature. Other factors that sometimes warrant consideration are severely textured pavement surfaces such as open-graded asphalt concrete surfaces and grooved or heavily textured Portland cement concrete surfaces.

Pavement surface temperature has a major effect on how ice control chemicals perform and ultimately, on the treatment decision itself. As pavement temperatures decline below about 12°F, most ice control chemicals become very inefficient because of the slow melting rate and the amount of ice melted per unit of chemical applied. Pavement temperature therefore drives the decision to plow only, plow and apply chemicals, or plow and apply abrasives (depending also on LOS goals).

Severe pavement surface texture is another factor that influences the choice of chemical application rates. It is widely known from operational experiences that chemical application rates need to be increased for severely textured pavement surfaces such as found with open-graded asphaltic concrete and newly grooved/tined Portland cement concrete. How much of an increase in chemical application rate is required for these surfaces compared to smoother surfaces for equivalent chemical performance for a range of operating conditions is a subject for further research.

Pavement type can influence solar heat absorption and ultimately pavement surface temperature at the time of treatment. Unpaved or gravel roads are not suitable for chemical treatment.

Pavement Surface Conditions

Pavement surface conditions describe any accumulations of snow and ice that may remain on the pavement at the time of treatment (after plowing). These include loose snow, packed snow, and ice. A critical surface condition is whether or not the snow or ice is bonded to the pavement surface.

Any remaining snow or ice on the roadway surface after plowing will cause chemical treatments to dilute more quickly (in addition to the dilution caused by precipitation). If the snow or ice is bonded to the pavement, considerably more chemical will have to be applied in order to achieve an unbonded condition.

Operational Conditions

The most important operational conditions influencing dilution potential are treatment cycle time and traffic. Longer cycle times allow more precipitation to accumulate on the roadway between treatments. For equivalent effectiveness, more chemical must be applied for longer cycle times.

The two traffic characteristics thought to influence dilution potential are traffic volume and traffic speed. Higher speeds and higher volume will displace ice control chemicals from the roadway.

PROPERTIES OF ICE CONTROL MATERIALS

The four basic types of ice control materials are (1) abrasives, (2) solid ice control chemicals, (3) prewet solid ice control chemicals, and (4) liquid ice control chemicals.

Abrasives

Abrasives are a vital part of most snow and ice control programs. They support lower LOS and can provide at least some measure of traction enhancement when it is too cold for chemicals to work effectively. They are suitable for use on unpaved roads and on thick snow pack/ice surfaces that are too thick for chemicals to penetrate.

When mixed with enough ice control chemical, abrasives will support anti-icing and deicing strategies; however, this is very inefficient and costly as the abrasives for the most part are "going along for the ride" while the chemical portion of the mix is doing the "work."

Solid Ice Control Chemicals

Solid ice control chemicals are a very popular treatment option for most highway maintenance agencies. They support high LOS and both anti-icing and deicing strategies. When anti-icing, they are most effective when applied early in a winter weather event, before ice/pavement bond has a chance to develop. Some snow/ice/water on the pavement will minimize bouncing and scattering of the chemicals. Field observations indicate solid chemicals may be used as a pretreatment, especially when applied at traffic speeds under about 30 mph and traffic volumes under 100 vehicles per hour.

Solid chemicals, particularly those with a "coarser" gradation or particle size distribution, are well suited to deicing operations. The larger particles are able to "melt" through snow/ice on the surface and continue to cause melting at the ice/pavement interface until the ice/pavement bond is broken and the snow/ice can be removed mechanically.

The use of fine graded salt during anti-icing operations generally is not cost effective compared to the use of coarse graded salt (*8*). This is true for most forms of frozen precipitation, including freezing rain and sleet. Fine graded salt dilutes faster than coarse graded salt and has to be reapplied more often and at greater rates during a winter weather event than does coarse graded salt to achieve a similar chemical effectiveness. The fast brine generation of fine graded salt when applied to a pavement will produce a wet pavement sooner than coarse graded salt, but the condition will not be long lasting. This situation can quickly lead to a refreeze of the brine solution unless additional salt applications are made.

The use of fine graded salt is better suited for the treatment of thin ice and, when prewetted, as a pretreatment for frost conditions when applied just prior to daylight.

Fine graded salt applications are not well suited for deicing operations because of the high dilution potential.

Solid ice control chemicals are often mixed in small quantity (less than 10 percent) with abrasives to prevent "chunking" and freezing in stockpiles. They are also mixed with abrasives in sufficient quantity (greater than 20 percent) to do some ice melting.

Prewet Solid Ice Control Chemicals

Prewet solid ice control chemicals are used in the same way as solid chemicals except they are generally not mixed with abrasives. They consist of solid ice control chemicals that have been "coated" with liquid ice control chemicals by a variety of mechanisms. The water in the liquid ice control chemical starts the process of allowing the solid chemical to generate "brine" more quickly than "uncoated" solid chemical the coating also allows the solid chemical to better "stick" to the surface. This reduces bounce and scatter and accelerates deicing.

Liquid Ice Control Chemicals

Liquid ice control chemicals are generally a solution of solid ice control chemicals with water being the predominant component. They support high LOS and anti-icing strategy. They are particularly well suited to pretreating for anticipated frost/icing/black ice situations. Here, the water evaporates and the residual dry chemical is relatively immune to dispersal by traffic. Liquid chemicals are also used to pretreat roadways prior to a general snow or ice event. This is an effective way to initiate the anti-icing strategy.

Since liquid ice control chemicals are mostly water, they are already fairly well diluted. They are not well suited to deicing operations as they have little ability to penetrate thick snow ice. However, they may be used in limited situations for deicing if the treatment is immediately followed by an application of solid chemicals or the process is reversed. The Illinois DOT has reported success with a deicing strategy that utilizes approximately 250 lb/LM (lane mile) dry salt applied on top of compacted snow followed immediately by 30 to 50 gal/LM of liquid salt or calcium chloride with air temperatures above 10°F and sunny conditions (*9*). This is a variation of prewetting.

Liquid chemicals are probably not a good choice at pavement temperatures below about 20°F. Here, the limited ice melting ability of most chemicals would make application rates excessive and potentially cause refreeze if the pavement was not dried by traffic or other atmospheric mechanisms.

Liquid chemicals, as a within-winter weather event treatment, should be limited to lower moisture content events, pavement temperatures above 20°F, and cycle times less than about 1.5 hours. This will minimize the risk of ice/pavement bond formation. It is not advisable, however, to use liquid chemicals during moderate or heavy snow, sleet, and freezing rain events.

At pavement temperatures higher than about 28°F, liquid chemicals are a very effective treatment for thin ice in the absence of precipitation. The ice melting process in this situation is almost immediate.

CHAPTER 7

RECOMMENDED SNOW AND ICE CONTROL PRACTICES

The goal of effective snow and ice control programs should be to provide the highest LOS possible within the constraints of available resources and environmental responsibility. LOS goals are viewed from the time frames of within-winter weather event and after-end-of-winter weather event. After-event LOS is sometimes a moving target due to blowing and drifting snow conditions. In this case, those conditions may be considered to be part of the event.

In general, higher within-event LOS can be produced with an anti-icing strategy and relatively short operational cycle times of less than 1.5 hours. As cycle times increase, there are opportunities for higher accumulations of snow and ice on the roadway prior to plowing and retreating. Thus, maintaining an unbonded pavement/snow/ice interface becomes increasingly more difficult as cycle times increase.

For the purpose of the following discussion, pavement condition LOS is divided into three categories of low, medium, and high that can be related to PSIC defined in Table 1 in the following way:

Pavement condition LOS	PSIC
Low	5 and 6
Medium	3 and 4
High	1 and 2

With respect to after-event LOS, most agencies provide treatment until "bare" pavement is achieved. The measure of LOS then becomes the time, in hours, needed to reach a high LOS (a PSIC of 2 or 1). Again, for the purpose of this discussion, after-end-of-event LOS is divided into the three categories of low, medium, and high in the following way:

After-event LOS	Time (hr) to achieve a PSIC of 2 or 1
Low	>8.0
Medium	3.1–8.0
High	<3.1

STRATEGIES AND LEVEL OF SERVICE

Table 7 shows the expected LOS levels that can be achieved within- and after-winter weather events from various snow and ice control strategies and from tactics. For convenience, each strategy/tactic is described again below. It must be recognized that these are general approaches and changing conditions within an event often necessitate changes in strategies and tactics.

Anti-icing

Anti-icing is a general strategy that attempts to prevent the formation of ice/pavement bond by the timely application of ice control chemicals. Chemicals may be applied before the event (pretreating), early in the event, and as necessary throughout the event. This strategy generally produces high LOS during and after the event.

Deicing

Deicing is a strategy of allowing ice/pavement bond to form during an event and periodically treating it with chemicals until the ice/pavement bond is broken and snow/ice can be mechanically removed or displaced by traffic. This strategy generally produced low to medium within- and after-event LOS.

Mechanical

Mechanical removal is the displacement of snow/ice from the roadway by plows, rotary plows (snow blowers), brooms, and other mechanical means. This approach, as a strategy, is capable of producing low within- and after-event LOS. At pavement temperatures above 32°F and below about 12°F, higher LOS may be possible with mechanical removal.

Mechanical and Abrasives

The practice of plowing snow and spreading abrasives (either straight or mixed with a small amount of chemical) is common on lower-volume roads. It also may be a necessary treatment due to low pavement temperatures. As a strategy by itself, it only is capable of producing low within- and after-event LOS unless a very warm pavement temperature above 32°F is involved that does not allow ice/pavement bond to occur.

TABLE 7 Strategies and tactics and LOS expectations

Strategies and Tactics	Within-event LOS			After-event LOS		
	Low	Medium	High	Low	Medium	High
Anti-icing			X			X
Deicing	X	X		X	X	
Mechanical	X			X		
Mechanical and Abrasives	X			X		
Mechanical and Anti-icing			X			X
Mechanical and Deicing	X	X		X	X	
Mechanical and Prewetted Abrasives	X			X		
Anti-icing for Frost/Black Ice/ Icing Protection			X			X
Mechanical and Abrasives Containing > 100 lb/LM of Chemical	X	X	X	X	X	X
Chemical Treatment Before or Early in Event, Mechanical Removal During Event, and Deicing at End of Event	X				X	

Mechanical and Anti-icing

Timely mechanical removal of snow/ice within an event, in conjunction with an overall anti-icing strategy, will produce the highest possible LOS within and after events.

Mechanical and Deicing

Mechanical removal in conjunction with a deicing strategy within an event will produce low to medium LOS within and after winter weather events. This primarily results from controlling the depth of loose snow and ice on the roadway.

Mechanical and Prewetted Abrasives

Mechanical removal plus treatment with abrasives that have been prewetted with liquid chemical is capable of producing low within- and after-event LOS. Pavement temperatures above 32°F that will not allow ice/pavement bond may allow higher LOS to be achieved. Limited research shows prewetting abrasives might produce a slightly higher LOS than a stockpile mix alone.

Anti-icing for Frost/Black Ice/Icing Protection

Use of a liquid ice control chemical for pretreating areas susceptible to frost/black ice/icing that may occur in the absence of precipitation is a proven effective anti-icing tactic that prevents ice formation. Since the ice does not form, the LOS is always high.

Mechanical and Abrasives Containing More than 100 lb/LM of Chemical

"Rich" abrasives/chemical mixtures containing more than 20 percent chemicals by weight have been used for many years. They are capable of providing all ranges of LOS, depending on pavement and weather conditions. The LOS provided is generally in proportion to the amount of chemical in the mix and the application rate. Research has shown that to produce a high LOS, a strategy of using chemicals alone will be more effective and less costly than using mixtures of chemicals and abrasives.

Chemical Treatment Before or Early in an Event, Mechanical Snow/Ice Removal During an Event, and Deicing at the End of an Event

This is a hybrid strategy suitable for lower priority roads that produces a medium after-event LOS for a small chemical investment. The initial chemical application seems to prevent a strong ice/pavement bond. This, in conjunction with the later chemical application and any solar pavement warming, leads to a fairly quick recovery. This is particularly effective when the chemicals are placed in a narrow band around the center of a two-lane crowned roadway.

TREATMENT SELECTION

When selecting treatments, the most important consideration is LOS goals. Depending on a variety of factors, the goals may change during an event.

Every snow and ice control treatment should be individually designed to produce an effect that is consistent with the LOS goals, weather conditions, pavement conditions, and available resources of the moment. Weather and pavement conditions are continually changing and may require tactical adjustments. LOS goals may be changing with the time of day and pavement conditions. Available resources may be changing with equipment breakdowns and mandatory personnel rest periods.

The actual formula or process for making wise and appropriate treatment decisions is simple. It involves using timely information on weather and pavement conditions plus having an understanding of the LOS goals and capabilities of available resources. These resources include snow and ice control strategies and tactics, materials, equipment, and manpower. Attachment 1 provides recommended guidelines for using road and weather information to make snow and ice control treatment decisions. Chapter 8 provides recommended operational guidelines for winter maintenance field personnel.

CHAPTER 8

RECOMMENDED OPERATIONAL GUIDELINES FOR WINTER MAINTENANCE FIELD PERSONNEL

This chapter presents operational guidelines for winter maintenance field personnel on the selection of appropriate snow and ice control materials and associated application rates for various combinations of operating conditions. These conditions include precipitation type and rate, pavement temperature, pavement wheelpath area condition, treatment cycle time, traffic volume, and ice/pavement bond conditions. The information presented is discussed in terms of snow and ice control strategies, and tactics and their application to support LOS choices. It also complements the previous chapters describing the factors influencing the choice of materials, their forms, and associated application rates; and the recommended snow and ice control practices.

The snow and ice control materials discussed in this chapter are solid chemicals, liquid chemicals, prewetted solid chemicals, abrasives, abrasive/chemical mixtures, and prewetted abrasives including abrasive/chemical mixtures. Plowing and other mechanical removal methods are necessary to support LOS goals and allow material treatments to be more effective. If needed, plowing and other mechanical removal methods should precede any material applications so that excess snow, slush, or ice is removed and the pavement is left wet, slushy, or lightly snow-covered when treated.

This chapter is intended as a companion and background to Attachment 1, which presents specific recommendations for using road and weather information to make snow and ice control treatment decisions. Attachment 2 then provides an example of how to select a snow and ice control treatment using the treatment design procedure in Attachment 1.

The guidance presented in this chapter and in Attachment 1 is based upon the results of the three winters of field testing of various strategy/tactic combinations by 24 highway agencies as described in the main part of this report. The guidance has been augmented with practices developed within the United States, where necessary, for completeness. State and local highway agencies engaged in snow and ice control operations on highways, roads, and streets are encouraged to use the guidance in this document as a starting point for their operations. They are encouraged also to modify the recommendations when necessary in order to accommodate local experience, specific site concerns, and highway agency objectives.

SOLID ICE CONTROL CHEMICALS

Solid ice control chemicals serve a number of functions in snow and ice control operations. They are used in anti-icing, in deicing, in mixing with abrasives, and in the production of liquid ice control chemicals.

Anti-icing with Solid Ice Control Chemicals

Solid chemicals have been used for many years in anti-icing operations. They are typically applied early in an event before ice/pavement bond forms and then periodically throughout the event. The first application is made when there is just enough precipitation on the roadway to minimize "bounce and scatter" and displacement by traffic.

Dry solid chemicals can be used to pretreat roadways before a snow or ice event if applied at traffic speeds below 30 mph and with traffic volume less than about 100 vehicles per hour. The prewetting of a solid chemical prior to spreading can improve the effectiveness of the solid chemical and help the granules adhere better to the road surface. In theory, only a sufficient amount of liquid to wet every particle of a dry chemical is required for prewetting. The actual rate to achieve this wetting will vary with the particle size distribution. In practice it has been found that 10 to 12 gallons of a sodium chloride (NaCl) solution will be sufficient for 1 ton of dry chemical of coarse gradation *(3)*. Some agencies have used three times this quantity so that the material is applied as a slurry in order to reduce losses by traffic action. Prewetted finer gradations of a solid chemical will also adhere better to the road surface. Prewetted finer gradations of a solid chemical may be successfully applied at traffic speeds below 40 mph and with traffic volumes below about 250 vehicles per hour.

The role of a gradation size of solid ice control chemicals during anti-icing operations is discussed earlier under the section dealing with properties of solid ice control chemicals.

Application rate guidance for the use of solid NaCl with anti-icing operations (unbonded case) can be found in Attachment 1.

Deicing with Solid Ice Control Chemicals

With the exception of very thin ice situations, solid chemicals are the most effective treatment for packed/bonded snow and ice. Prewetting dry solid chemical with a liquid ice control chemical further enhances performance. Coarser graded chemicals do a better job of deicing thicker snow/ice accumulations.

Application rate guidance for the use of solid NaCl with deicing operations (bonded case) can be found in Attachment 1.

Mixing Solid Ice Control Chemicals with Abrasives

The mixing of solid chemicals with abrasives has been a popular practice for many years. The primary reason for this practice is to keep stockpiles of abrasives from freezing or chunking. The amount of chemicals in stockpiles is usually less than 10 percent by weight.

It is also a common practice to mix higher amounts of chemicals with abrasives in order to improve LOS. A popular practice is to mix equal volumes of abrasives and chemical. This mixing ratio will produce a chemical content by weight of about 42 percent with most naturally occurring abrasives. This mixture is used with anti-icing and deicing operations in some circumstances; however, anti-icing and deicing can be accomplished more effectively and more cost effectively by using straight chemicals.

Producing Liquid Ice Control Chemicals with Solid Ice Control Chemicals

Liquid ice control chemicals are becoming increasingly popular with highway maintenance agencies. In most cases a significant part of the cost of the liquid chemical is in the transportation from the point of production to the maintenance facility. As liquid chemicals are typically 50 percent to 77 percent water, much of the cost is for transporting water. By purchasing solid chemicals and mixing them with water on site, significant savings can often be realized. There are systems for making "brine" that range from site-fabricated manual operations to commercially available fully automated systems. Instructions for preparing salt brine are given in the *Manual of Practice* (*3*).

Application of Solid Snow and Ice Control Chemicals

The appropriate solid chemical application rate can be selected for the prevailing conditions using the guidance in Attachment 1. However, several special factors need to be considered in the operational treatments with solid snow and ice control chemicals. The following application techniques can help optimize the treatment effectiveness for each of these factors.

Two-Lane, Two-Way Traffic Highways (One-Lane Each Way)

The most effective way to treat this highway is to spread the ice control chemical in about the middle third of the highway. The slope of the highway and traffic will distribute the chemical fairly quickly across the entire pavement. When doing simultaneous plowing operations, care must be taken not to plow chemicals off too quickly. The spreader should be set to spread only in the plowed path. If plowing is not anticipated, spread the entire middle third on the "out" run of an "out and return" route.

Multi-Lane Highways

Most agencies spread ice control chemicals on multi-lane highways at as nearly full width as possible. Care must be taken not to spread beyond the pavement limits. Narrow bands of material spread near the high edge of each lane are also effective.

Hills, Curves, and Intersections

Because of the higher traction requirements on hills, curves, and intersections, many agencies use a higher application rate on these special sections than on straight sections of highway. On lower LOS highways, these are sometimes the only areas that receive treatment. When making special treatment at intersections, it is important to carry the treatment beyond the point where traffic normally backs up in snow and ice conditions.

Bridges and Other Elevated Structures Not Resting on Earth

In the fall, bridges and other elevated structures are likely to be colder than the adjacent pavement on earth. These situations can occur when the structures are cooled by outgoing radiation to the clear night sky even as the air temperature in the vicinity is above freezing. At other times in the fall when there is a rapid, severe decrease in air temperature, the elevated structures also are likely to be colder than the adjacent pavement on earth. It is appropriate to increase the application rate on these structures so refreezing will not occur or will occur at about the same time as the surrounding pavement. Toward spring, when air temperatures are warming, structure temperatures are likely to be warmer than the surrounding pavement. Higher application rates on these structures are not necessary in these situations.

Banked or Superelevated Curves

The spread pattern should be kept on the high side of superelevated curves. As the chemical goes into solution, the brine will migrate over the remainder of the roadway.

Strong Crosswinds

When spreading in strong crosswinds situations, the spreader should be kept upwind of the intended spread location. Spreading may not be appropriate on downwind lanes when crosswind speeds are in excess of about 25 mph.

Parking Areas

Spreading ice control chemicals as evenly as possible over the entire paved area is recommended for parking areas. These areas present a unique opportunity for anti-icing with solid chemicals because traffic generally will not displace them from the surface.

Changes in Maintenance Jurisdiction or Level of Service

Sometimes, where maintenance jurisdiction or mandated LOS changes, there will be a dramatic change in pavement conditions, including slipperiness. This is a dangerous condition as it is usually unexpected. Appropriate signing should be used to alert motorists of the situation, or more correctly, transitioning of the LOS treatment should be used by maintenance.

Worst-Case Scenarios

The worst cases usually occur when the chemical treatment is quickly overwhelmed (diluted) by excessive amounts of water or ice. Blizzard conditions (i.e., intense snowfall, wind, very cold temperatures) quickly dilute ice control chemicals and render them virtually useless. If the pavement temperature going into and coming out of a blizzard is expected to be below about 12°F, then plowing–only is probably the best strategy. If it is still very cold after the blizzard, abrasives should be used as necessary until warmer temperatures will allow chemical deicing to work. If the pavement temperature throughout and after the blizzard is likely to be above 12°F, a treatment with an ice control chemical before or early in the winter weather event followed by plowing–only throughout the winter weather event, will make deicing at the end of the winter weather event more efficient and cleanup will be accomplished much quicker.

Rapidly accumulating freezing rain is another maintenance nightmare. The best strategy is to apply solid ice control chemicals, at a high rate, in very narrow bands in the high-side wheel path of each lane. This approach should produce a location in each lane that will provide enough traction to allow vehicles to stop and steer.

Getting the Application Right

Application rates for ice control chemicals are usually specified in pound-per-lane-mile (lb/LM) or kilogram-per-lane-kilometer (kg/Lkm). Spreaders are usually calibrated to deliver pounds per mile or kilograms per kilometer (the discharge rate). It is important to understand that relationship in order to ensure that the proper application rate is being used. The application rate is the number of pounds or kilograms dispensed per mile or kilometer (the discharge rate) divided by the number of lanes being treated. Table 8 demonstrates the relationship between discharge rates and application rates.

LIQUID ICE CONTROL CHEMICALS

Liquid chemicals serve a number of functions in snow and ice control operations. They are used to prewet solid ice control chemicals, abrasives, and abrasive/solid chemical mixtures to make those applications more effective. Liquid chemicals are used to pretreat and treat "colder highway spots" for frost, black ice, and localized icing. They are used as a pretreatment for general storms to facilitate higher LOS in the initial storm phase and to "buy time" until treatments with solid chemicals can be made. They may be used also as a treatment within certain low moisture winter weather events. Liquid chemicals should generally not be used for freezing rain and sleet events nor as a treatment when pavement temperatures are expected to fall below about 20°F during the period of treatment effectiveness.

Prewetting with Liquid Ice Control Chemicals

Most commercially available liquid ice control chemicals can be used for prewetting solid ice control chemicals, abrasives, and abrasive/solid chemical mixtures. The primary function of the liquid in prewetting is to provide the water necessary to start the brine generation process for the solid chemicals. When used on abrasives, they help them adhere to the ice surface and provide some ice control chemical to

TABLE 8 Correspondence between discharge rate and application rate

Discharge rate in lb/mi (kg/km)	Application rate in lb/LM (kg/Lkm) Number of lanes being treated 1	2	3
100 (28)	100 (28)	50 (14)	33 (9)
200 (56)	200 (56)	100 (28)	67 (19)
300 (84)	300 (84)	150 (42)	100 (28)
400 (112)	400 (112)	200 (56)	133 (37)
500 (140)	500 (140)	250 (70)	167 (47)
600 (168)	600 (168)	300 (84)	200 (56)
700 (196)	700 (196)	350 (98)	233 (65)
800 (224)	800 (224)	400 (112)	267 (75)

the roadway that may at some point improve LOS. Organic based chemicals provide some corrosion protection properties and environmental friendliness.

Pretreating for and Treating Frost, Black Ice, and Icing with Liquid Chemicals

This tactic provides arguably the best use of liquid ice control chemicals. A 23-percent solution of liquid NaCl applied at 40 to 60 gal/LM (or equivalent effective amount of other chemical) has proven to provide protection from these conditions that are nonprecipitation events. Table 9 provides the multipliers based on a liquid NaCl application rate to achieve equivalent results with other chemicals. In the absence of precipitation, these treatments are effective for at least 3 days and possibly up to 5 days depending on traffic volume. If the liquid treatment is allowed to dry before the event, it will be slightly more effective.

To use the equivalency table shown in Table 9, simply multiply the rate of a 23-percent solution of NaCl by the appropriate multiplier corresponding to the temperature range and specified chemical. For example, if the treatment were to require 100 lb/LM of dry NaCl in a 23-percent solution and assuming a temperature in the range of 20° to 18°F, then it would only take 85 lb/LM of a 32-percent solution of $CaCl_2$. However, the same temperature condition would require a rate of 194 lb/LM of a 25-percent CMA solution.

Treating frost/black ice/icing that has already occurred with liquid chemicals is an excellent tactic. Using application

TABLE 9 Multipliers for liquid chemical application rates, normalized to 100 lb/LM of dry NaCl in a 23-percent solution

Temperature range (°F)	23% NaCl	32% $CaCl_2$	27% $MgCl_2$	50% KAc	25% CMA
32-30	1.00	1.11	0.94	1.58	1.64
30-28	1.00	1.06	0.90	1.50	1.69
28-26	1.00	1.02	0.86	1.42	1.74
26-24	1.00	0.98	0.82	1.34	1.79
24-22	1.00	0.94	0.78	1.25	1.84
22-20	1.00	0.89	0.74	1.17	1.89
20-18	1.00	0.85	0.70	1.09	1.94
18-16	1.00	0.81	0.66	1.01	1.99
16-14	1.00	0.76	0.62	0.92	2.04
14-12	1.00	0.72	0.59	0.84	2.09
12-10	1.00	0.68	0.55	0.76	–
10-8	1.00	0.63	0.51	0.67	–
8-6	1.00	0.59	0.47	0.59	–
6-4	1.00	0.55	0.43	0.51	–

rates for sodium chloride found in Attachment 1 for a low adjusted dilution potential and bonded condition will provide almost immediate results.

Pretreating for and Treating General Snow and Ice Events with Liquid Chemicals

The use of liquid chemicals during general snow and ice events requires more caution and information in order to achieve satisfactory results. Liquid chemicals are more sensitive to pavement temperature, dilution, and ice/pavement bond than solid chemicals. Analytical results were generated during the study to define the time to freeze of chemical brines as a function of application rate, pavement temperature, and rate and moisture content of precipitation. A discussion of time to freeze for chemical brines follows.

Relationships Between Time to Freeze of a Chemical Brine and Controlling Variables

The nature of the relationships between the time to freeze of a chemical brine and the controlling variables can be summarized as follows:

- The time to freeze increases proportionally with chemical application rate for a given pavement temperature and rate of precipitation. This relationship is a straight-line relationship.
- The time to freeze decreases with increasing rate of precipitation for a given chemical application rate and pavement temperature. However, this relationship is not a straight-line relationship. It is of the type shown in Figures 1 through 4, where the rate of decrease is high at low precipitation rates and tapers off as the rate of snowfall increases.
- The time to freeze decreases nonlinearly with decreasing pavement temperature for a given chemical application rate and rate of precipitation. This relationship is similar to the one described in the second point above.

Sample plots of the time to freeze of liquid NaCl versus snowfall precipitation rates in terms of meltwater equivalent (WE) in inches per hour and snowfall rate in inches per hour were generated to illustrate the second point above. The times to freeze for a 23-percent concentration of NaCl versus snowfall rate are presented in Figures 1 and 2. An application rate of 100 lb/LM equivalent dry NaCl was used in both figures. Figure 1 applies to a pavement temperature range of 28°F to 31.5°F. Figure 2 applies to a pavement temperature range of 20°F to 27°F.

The times to freeze for the dried case of NaCl versus snowfall rate are presented in Figures 3 and 4. Again, an application rate of 100 lb/LM equivalent dry NaCl was used in both figures. Figure 3 applies to a pavement temperature range of

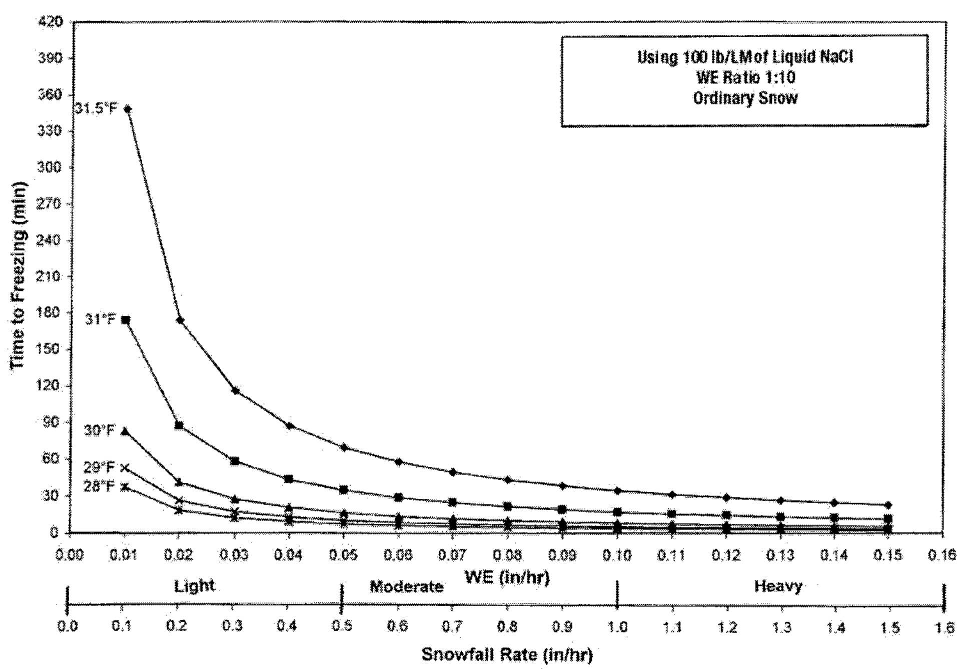

Figure 1. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 28°F to 31.5°F using 23-percent concentration liquid NaCl.

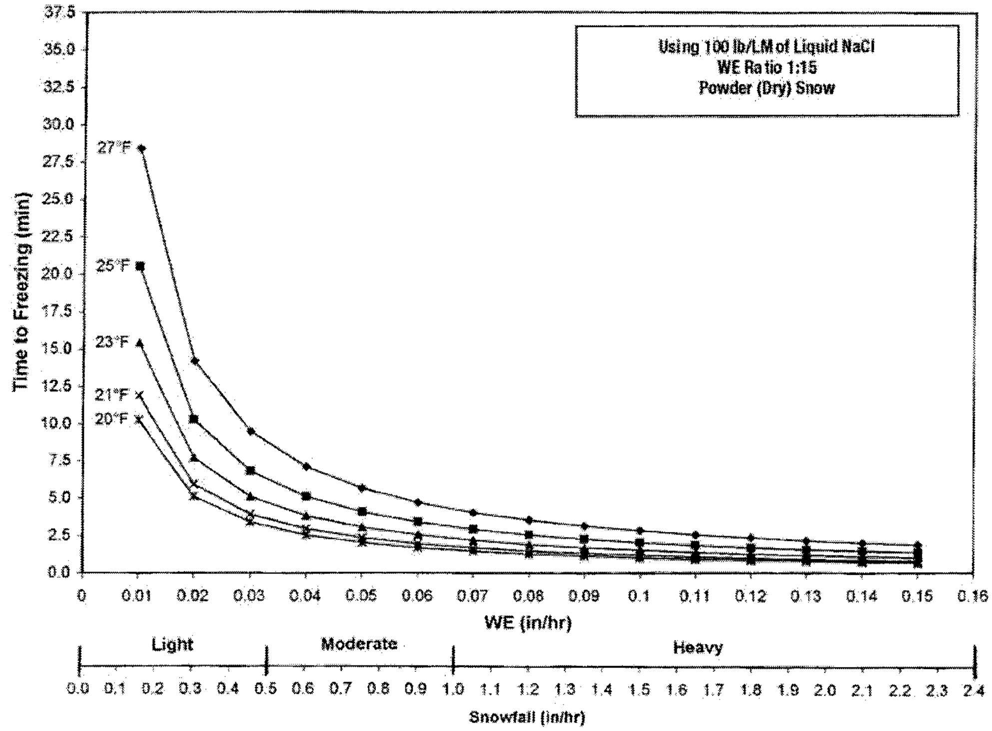

Figure 2. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 20°F to 27°F using 23-percent concentration liquid NaCl.

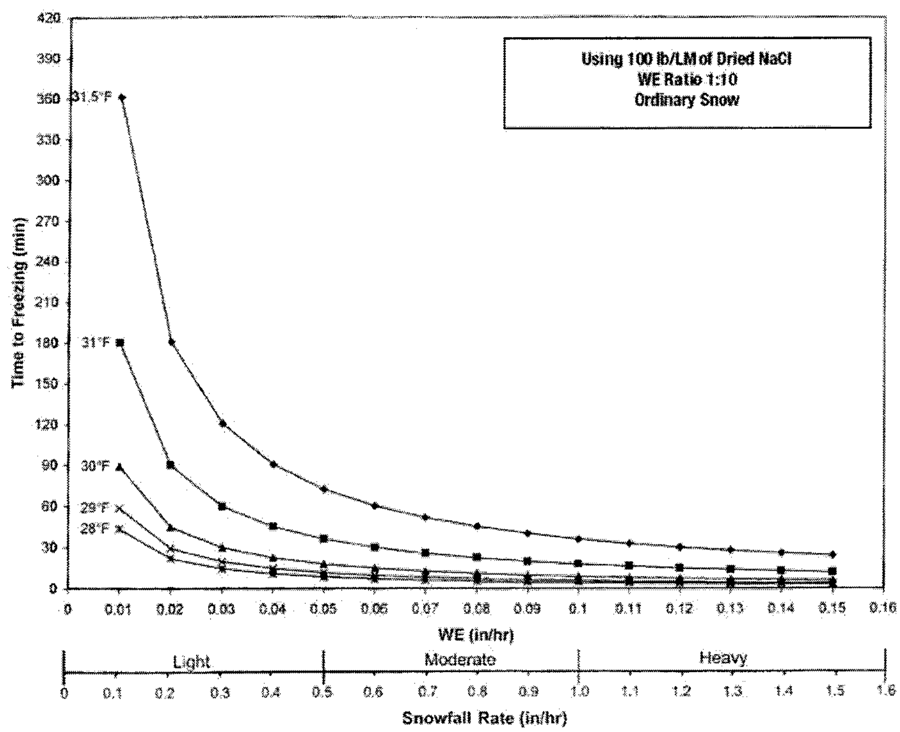

Figure 3. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 28°F to 31.5°F using dry NaCl.

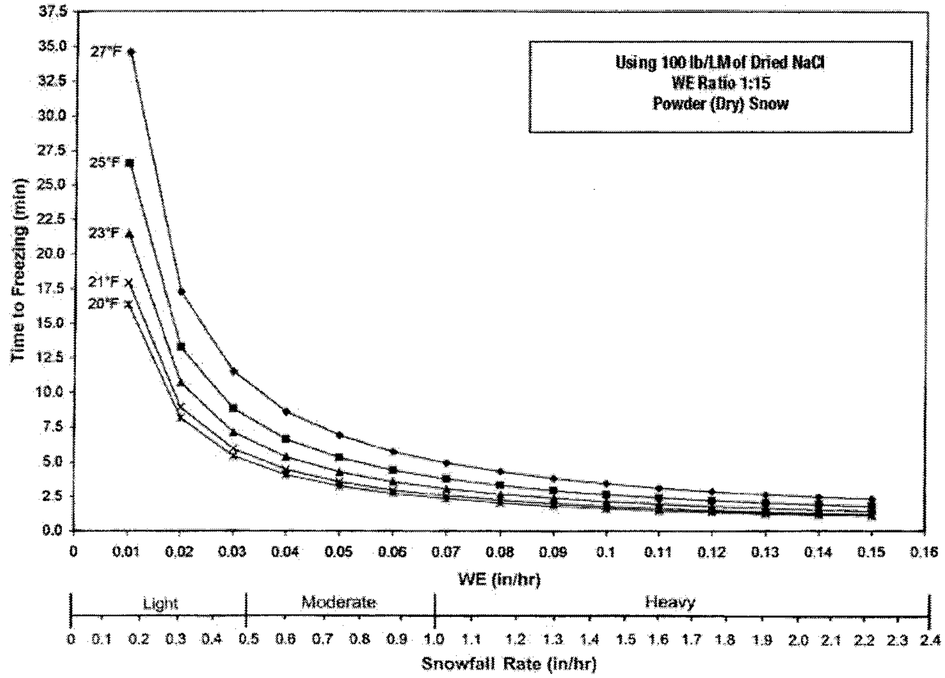

Figure 4. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 20°F to 27°F using dry NaCl.

28°F to 31.5°F. Figure 4 applies to a pavement temperature range of 20°F to 27°F.

Figures 1 through 4 clearly show the limiting role that liquid chemicals play in snow and ice control operations as the pavement temperatures drop and application rates associated with anti-icing are used. The role of liquid chemicals for a given pavement temperature also diminishes as the snowfall rate increases.

The times to freezing for the "dried" state of NaCl are longer than those for the "liquid" state, all conditions being equal. The time differences between the two chemical states do not appear to be significant from an operational consideration at the upper temperature range of 28°F to 31.5°F. The time differences increase as the pavement temperature decreases. How significant the time differences are in the 20°F to 27°F temperature range is uncertain because of the small magnitude of the freezing times.

Conversion of NaCl Application Rates to Application Rates of Four Other Snow and Ice Control Chemicals

Calculations were performed to develop application rate data for calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), and calcium magnesium acetate (CMA), that were normalized with respect to the application rate data for dry solid NaCl. The ice melting characteristics of each chemical were used in the computations. The equivalent application rates for each of the five ice control chemicals are given in Table A-6 of Attachment 1 for a range of pavement temperatures. The application rates are normalized to 100 lb/LM of dry solid NaCl. The application rates corresponding to a dry solid NaCl rate other than 100 lb/LM are determined by multiplying the equivalent chemical application rates for a given temperature by the ratio of the desired dry solid NaCl rate to 100 lb/LM. For example, if a 200 lb/LM of dry solid NaCl application rate were recommended at a temperature of 20°F, then switching to a 90- to 92-percent concentration of solid $CaCl_2$ would require a slightly higher application rate of 216 lb/LM.

With the previous discussion in mind, liquid ice control chemicals can be effectively used in the treatment of general snow and ice events if the methodology given in Attachment 1 is utilized.

Applying Liquid Chemicals to Roadway Surfaces

Liquid chemicals are usually applied to the highway with spray bars or spinners. Spray bars may simply have holes in them or nozzles having various spray patterns. When using chemicals other than liquid NaCl, it is recommended that "streamer" or "pencil" nozzles or just holes in the spray bar be used to apply "strips" of chemical to the surface. The spacing of nozzles or holes should be in the range of 8 in. There have been rare circumstances when using a liquid chemical has resulted in slippery conditions in the absence of precipitation or freezing pavement temperature. This phenomenon seems to be related in many instances to the combined effect of relative humidity, pavement temperature, and chemical type. The untreated areas between strips should help minimize the potential for this type of slipperiness.

ABRASIVES

The primary function of abrasives is to provide temporary traction (friction) improvement on snow/ice surfaces. It should be realized that snow/ice covered roadways that have been treated with abrasives provide friction values that are far less than "bare" or "wet" pavement. The application rate for abrasives varies considerably among maintenance agencies. Application rates for most agencies fall within the 500 lb/LM to 1,500 lb/LM range with the overall average centering around 800 lb/LM.

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Attachment 1

Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions

ATTACHMENT 1

USING ROAD AND WEATHER INFORMATION TO MAKE CHEMICAL ICE CONTROL TREATMENT DECISIONS

This Attachment contains recommended steps for using road and weather information to make snow and ice control treatment decisions. Its purpose is to define a step-by-step procedure that winter maintenance field personnel can follow in determining an appropriate treatment action to take in response to a variety of conditions.

Snow and ice control material rate guidelines are presented. These application rates are based upon results of three winters of field testing various strategy/tactic combinations by 24 highway agencies. The recommended rates apply to both state and local highway agencies engaged in snow and ice control operations on highways, roads, and streets. Appropriate application rates for solid, prewetted solid, and liquid sodium chloride are given as a function of pavement temperature range, adjusted dilution potential level, and the presence or absence of ice/pavement bond. The adjusted dilution potential level accounts for precipitation type and rate, snow and ice conditions on the road, and treatment cycle time and traffic volume conditions. The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) prior to the next anticipated treatment.

Implicit in the recommended treatment steps is the requirement that plowing, if needed, should be performed before chemical applications are made. This is necessary so that any excess snow, slush, or ice is removed and the pavement surface is wet, slushy, or lightly snow covered when treated.

When applying solid, prewetted solid, or liquid snow and ice control chemicals, the usual intent is to achieve or maintain an unbonded, bare, or wet pavement condition. The following procedure will provide a generally successful result.

STEP 1

The first step in the procedure is to determine the pavement temperature at the time of treatment and the temperature trend after treatment. A judgment, either estimated or predicted by modeling techniques, will need to be made of what the pavement temperature will be in the near term, 1 to 2 hours after treatment. This is one aspect of what is commonly called "nowcasting." Nowcasting refers to the use of real-time data, or best information available, for very short-term forecasting. It relies on the rapid transmittal of data from RWIS installations, weather radar, patrols, and other information sources for making a judgment of the probable weather and pavement condition/temperature over the next hour or two. Nowcasts can be provided by a private weather service or performed within the maintenance agency.

The end result of this step in the procedure will be the determination of the "pavement temperature and trend."

STEP 2

The second step in the procedure is to establish the dilution potential that a chemical treatment must: (1) endure before another treatment is made during a winter weather event, or (2) produce a satisfactory result in the absence of precipitation at the end of an event. The establishment of the dilution potential for each treatment includes consideration of precipitation type and rate (including none), precipitation trend, the presence of various wheel path area conditions, treatment cycle time, and traffic speed and volume.

The dilution potential for the precipitation at the time of treatment and its anticipated trend in the short-term is determined from Table A-1. The level of precipitation dilution potential will be either low, medium, or high. In the absence of precipitation, the dilution potential is determined from the wheel path area condition and is shown in Table A-2.

STEP 3

In the third step, an adjustment to the precipitation dilution potential shown in Table A-1 may have to be made for various wheelpath area conditions. These adjustments are given in Table A-3.

STEP 4

In the fourth step, an additional adjustment to the precipitation dilution potential may have to be made for treatment cycle time. This is the time between anticipated successive treatment passes. In the case of pretreating, it is the time between the onset of precipitation and the next anticipated treatment. These adjustments are given in Table A-4.

STEP 5

In the fifth step, an extra adjustment to the precipitation dilution potential may have to be made for traffic speeds greater than 35 mph and traffic volume greater than 125 vehicles per hour. These adjustments are also given in Table A-4. No adjustment is made for traffic volume when traffic speeds are 35 mph or below.

When making additional level adjustments to the precipitation dilution potential, an adjustment level of 1 would change a low level to a medium level or a medium level to a high level. An adjustment level of 2 would change a low level to a high level. The end result of adding various factor adjustment levels to the precipitation dilution potential is termed "adjusted dilution potential." The final adjusted dilution potential level cannot exceed "high."

STEP 6

The sixth and final step in the procedure is to make a judgment of whether an ice/pavement bond condition exists. This determination (yes or no) is made based on field observations or sensor data.

TABLE A-1 Precipitation dilution potential in the presence of precipitation

	Precipitation type	Precipitation rate			
		Light	Moderate	Heavy	Unknown
1.	Snow 1 (powder)	Low	Low	Medium	Low
2.	Snow 2 (ordinary)	Low	Medium	High	Medium
3.	Snow 3 (wet/heavy)	Medium	High	High	High
4.	Snow U (unknown)	–	Medium	–	–
5.	Rain	Low	Medium	High	Medium
6.	Freezing rain	Low	Medium	High	Medium
7.	Sleet	Low	Medium	High	Medium
8.	Blowing snow	–	Medium	–	–
9.	Snow with blowing snow	(Same as type of snow)			
10.	Freezing rain with sleet	Low	Medium	High	Medium

TABLE A-2 Precipitation dilution potential in the absence of precipitation for various wheel path area conditions

Precipitation	Wheel path area condition	Precipitation dilution potential
None	Dry or damp	Not applicable ("NA")
	Wet	Low
	Frost or black ice (thin ice)	Low
	Slush or loose snow	Medium
	Packed snow or thick ice	High

TABLE A-3 Adjustment table to precipitation dilution potential for the presence of various wheel path area conditions

Precipitation	Wheel path condition	Increase precipitation dilution potential by number of levels
Yes	Bare	0
	Frost or thin ice	0
	Slush, loose snow, packed snow, or thick ice	1

TABLE A-4 Cycle time and traffic volume adjustments to precipitation dilution potential (final level not to exceed "high")

Cycle time, hours	Increase precipitation dilution potential by number of levels:
0 – 1.5	0
1.6 – 3.0	1
More than 3.0	2
For traffic speeds > 35 mph Traffic volume (vehicles per hour)	
Less than 125	0
More than 125	1

The appropriate application rates for solid, prewetted solid, and liquid sodium chloride can then be determined from Table A-5 using the results from the previously described steps.

Calculations were performed to develop application rate data for calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), and calcium magnesium acetate (CMA), that were normalized with respect to the application rate data for dry solid NaCl. The ice melting characteristics of each chemical were used in the computations. The equivalent application rates for each of the five ice control chemicals are given in Table A-6 for a range of pavement temperatures. The application rates are normalized to 100 lb/LM of dry solid NaCl.

A word of caution is in order concerning the use of the application rates in Table A-6. The equivalent application rates for a 23-percent concentration solution of NaCl determined from the use of Table A-6 are more conservative (larger) than those in Table A-5 for unbonded ice-pavement conditions. The liquid application rate data in Table A-6 were derived from freezing point (ice melting) data of the five chemical solutions. The liquid application rate data in Table A-5 for unbonded ice-pavement conditions were derived from field test data and include the influence of such variables as precipitation type and rate, pavement wheel path conditions, maintenance treatment cycle time, and traffic volume. As such, the equivalent application rates for the five ice control chemicals in Table A-6 should be considered as starting points in determining the appropriate rates for snow and ice control operations. Local experience should refine these values.

Two forms were developed to assist in the process of selecting an appropriate treatment chemical application rate. Form 1 shown in Figure A-1 is a weather and pavement condition sheet. Here, all relevant weather and pavement data are arrayed for various points in time of interest. These time points may be:

- shortly before a winter weather event begins
- at the onset of precipitation
- at the beginning of each treatment cycle
- at the end of an event
- at various points in time after the winter weather event

The data may come from a variety of sources. The form is intended to display all relevant weather and pavement condition data in one convenient location and format. The form could be used as a format for private sector weather forecasters to deliver their products.

Form 2 shown in Figure A-2 is a snow and ice control treatment design worksheet. It was developed to assist in determining an appropriate treatment and application rate by arraying the necessary data in a logical order.

Both forms could be easily computerized to assist in the treatment decision-making process in support of level of service requirements. An example of how to select a treatment using the treatment design procedure is given in Attachment 2.

TABLE A-5 Application rates for solid, prewetted solid, and liquid sodium chloride

Pavement Temperature (°F)	Adjusted dilution potential	Ice pavement bond	Application rate	
			Solid (1) lb/LM	Liquid (2) gal/LM
Over 32° F	Low	No	90 (3)	40 (3)
		Yes	200	NR (4)
	Medium	No	100 (3)	44 (3)
		Yes	225	NR (4)
	High	No	110 (3)	48 (3)
		Yes	250	NR (4)
32 to 30	Low	No	130	57
		Yes	275	NR (4)
	Medium	No	150	66
		Yes	300	NR (4)
	High	No	160	70
		Yes	325	NR (4)
30 to 25	Low	No	170	74
		Yes	350	NR (4)
	Medium	No	180	79
		Yes	375	NR (4)
	High	No	190	83
		Yes	400	NR (4)
25 to 20	Low	No	200	87
		Yes	425	NR (4)
	Medium	No	210	92
		Yes	450	NR (4)
	High	No	220	96
		Yes	475	NR
20 to 15	Low	No	230	NR
		Yes	500	NR
	Medium	No	240	NR
		Yes	525	NR
	High	No	250	NR
		Yes	550	NR
15 to 10	Low	No	260	NR
		Yes	575	NR
	Medium	No	270	NR
		Yes	600	NR
	High	No	280	NR
		Yes	625	NR
Below 10°F	A. If unbonded, try mechanical removal without chemical. B. If bonded, apply chemical at 700 lb/LM. Plow when slushy. Repeat as necessary. C. Apply abrasives as necessary.			

NR = Not recommended.

Specific Notes:

1. Values for "solid" also apply to prewet solid and include the equivalent dry chemical weight in prewetting solutions.
2. Liquid values are shown for the 23-percent concentration solution.
3. In unbonded, try mechanical removal without applying chemicals. If pretreating, use this application rate.
4. If very thin ice, liquids may be applied at the unbonded rates.

General Notes:

5. These application rates are starting points. Local experience should refine these recommendations.
6. Prewetting chemicals should allow application rates to be reduced by up to about 20% depending on such primary factors as spread pattern and spreading speed.
7. Application rates for chemicals other than sodium chloride will need to be adjusted using the equivalent application rates shown in Table A-6.
8. Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.

TABLE A-6 Equivalent application rates for five ice control chemicals

	NaCl		$CaCl_2$		$MgCl_2$		KAc		CMA	
Temperature (°F)	100%* Solid lb/LM	23%* Liquid gal/LM	90-92%* Solid lb/LM	32%* Liquid gal/LM	50%* Solid lb/LM	27%* Liquid gal/LM	100%* Solid lb/LM	50%* Liquid gal/LM	100%* Solid lb/LM	25%* Liquid gal/LM
31.5	100	45	109	32	90	31	159	30	159	69
31	100	46	111	32	91	32	161	31	161	72
30.5	100	47	111	33	91	32	155	30	155	71
30	100	48	107	33	94	33	158	31	158	74
29	100	49	109	34	91	33	155	31	155	79
28	100	52	109	34	91	33	152	31	152	81
27	100	54	109	35	90	34	153	31	153	86
26	100	56	104	34	96	36	161	33	161	95
25	100	57	102	34	99	35	167	35	167	108
24	100	61	108	38	102	41	167	35	167	114
23	100	62	112	41	102	41	164	35	164	117
22	100	65	110	41	102	42	160	35	160	121
21	100	68	107	40	101	42	155	35	155	125
20	100	70	108	42	98	42	150	34	150	129
15	100	90	103	44	96	44	142	34	142	170
10	100	120	101	49	95	47	138	35	138	265
5	100	165	104	57	96	51	139	37	139	630

NaCl: Sodium chloride.
$CaCl_2$: Calcium chloride.
$MgCl_2$: Magnesium chloride.
KAc: Potassium acetate.
CMA: Calcium magnesium acetate.

* Typical percent concentrations of the solid and liquid forms with the balance being largely water.

General Notes:

1. The above application rates are normalized to 100 lb/LM of dry solid NaCl. The application rates corresponding to a dry solid NaCl rate other than 100 lb/LM are determined by multiplying the equivalent chemical application rates for a given temperature by the ratio of the desired dry solid NaCl rate to 100 lb/LM. For example, if a 200 lb/LM of dry solid NaCl application rate were recommended at a temperature of 20°F, then switching to a 90 to 92 percent concentration of solid $CaCl_2$ would require a slightly higher application rate of 216 lb/LM.
2. The above application rate data were derived from the freezing point (ice melting) data of the five chemical solutions. As such, the data are more conservative (larger) than field data would suggest for anti-icing operations.

Weather and Pavement Condition Sheet											
Weather Data	Date										
	Time										
	Forecast (F) or Actual (A)										
	Precipitation Type										
	Precipitation Intensity (H, M, or L)										
	Percent Clouds										
	Cloud Density (H, M, or L)										
	Radiational Effects (0, + or –)										
	Air Temperature (°F)										
	Air Temperature Trend (0, + or –)										
	Wind Velocity (mph)										
	Wind Direction										
	Relative Humidity (%)										
	Dewpoint (°F)										
Pavement Condition Data	Pavement Temperature (°F)										
	Pavement Temperature Trend (0, + or –)										
	Treatment Cycle Time (hr)										
	Traffic Speed (mph)										
	Traffic Volume (vph)										
	Slush, Loose Snow, or Packed Snow in Wheelpath (Yes or No)										
	Ice Pavement Bond (Yes or No)										
Text Forecast and Other Operational Data											

Figure A-1. Form 1—Example weather and pavement condition worksheet.

Agency________________ Date________________

Route________________ Operator________________

Date											
Time											
Dilution Potential	Precipitation and Trend (L, M, or H)										
	Cycle Time (0, +1, or +2)										
	Wheel Path Condition (0 or +1)										
	Traffic (0 or +1)										
	Final (do not exceed H)										
Pavement Temperature and Trend											
Ice/Pavement Bond (Yes or No)											
Recommended Treatment											

Figure A-2. Form 2—Example snow and ice control treatment design worksheet.

Attachment 2

Example of Designing a Chemical Snow and Ice Control Treatment

ATTACHMENT 2

EXAMPLE OF DESIGNING A CHEMICAL SNOW AND ICE CONTROL TREATMENT

This Attachment provides an example of how to select a snow and ice control treatment using the treatment design procedure given in Attachment 1—Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions.

Assume a snow and ice winter weather event is in progress on January 16, 2002. It is 1100 hours and a treatment is being designed for immediate implementation. The available weather and pavement condition data are arrayed on Form 1 (Figure B-1).

Using the data in the column for 1100 hours on Form 1 and the data in Table A-1, go to Form 2 (Figure B-2) and complete the column for 1100 hours.

Precipitation and Trend: The precipitation is ordinary snow falling at a moderate rate. The trend is toward lighter intensity; however, we will choose the conservative approach and call it ordinary snow falling at a moderate rate. From line 1 of the Precipitation Dilution Potential Table A-1, the dilution potential is "medium." This is entered on Form 2.

Cycle Time: From Form 1, the anticipated cycle time is 2 hours. From Table A-4, the cycle time adjustment is "1." This is entered on Form 2.

Wheelpath Condition: On Form 1, there is no slush, loose snow, or packed snow in the wheelpath. From Table A-3, the adjustment for this is "0." This value is entered on Form 2.

Traffic Volume: From Form 1, the maximum traffic volume is likely to be 100 vph and the maximum speeds will be in the range of 50 mph. From Table A-4, the traffic adjustment is "0." This value is entered on Form 2.

Adjusted Dilution Potential: There is only one required adjustment of +1 level to the precipitation dilution potential of "medium." This comes from the cycle time effect and makes the adjusted dilution potential to "high." Note that even though the sum of the adjustment may exceed "high," the adjusted dilution potential cannot exceed "high."

Pavement Temperature and Trend: From Form 1, the projected pavement temperature for 1 to 2 hours after treatment is 28°F; this is entered for pavement temperature and trend on Form 2.

Ice/Pavement Bond: From Form 1, the ice/pavement bond has been determined from field reports to be "no." This is entered on Form 2.

Treatment: Using the data on Form 2 for Adjusted Dilution Potential, Pavement Temperature and Trend, and Ice Pavement Bond, go to Table A-5 and determine the proper application rate for solid sodium chloride. In this case, the appropriate application rate is 190 lb/LM of solid NaCl.

Weather and Pavement Condition Sheet

Weather Data	Date 2002	1/16	1/16	1/16	1/16	1/16	1/16	1/16			
	Time	1100	1200	1300	1400	1500	1600	1700			
	Forecast (F) or Actual (A)	A	F	F	F	F	F	F			
	Precipitation Type	OS[1]	OS[1]	OS[1]	PS[2]	None	None	None			
	Precipitation Intensity (H, M, or L)	M	L	L	L	–	–	–			
	Percent Clouds	100	100	100	100	90	70	50			
	Cloud Density (H, M, or L)	H	H	M	M	L	L	L			
	Radiational Effects (0, + or –)	0	0	0	0	+	0	–			
	Air Temperature (°F)	25	25	25	24	23	22	21			
	Air Temperature Trend (0, + or –)	0	0	–	–	–	–				
	Wind Velocity (mph)	6	7	8	8	9	10	12			
	Wind Direction	SE	S	SSW	SSW	W	W	NW			
	Relative Humidity (%)										
	Dewpoint (°F)										
Pavement Condition Data	Pavement Temperature (°F)	28	28	27	27	26	26	25			
	Pavement Temperature Trend (0, + or –)	0	–	0	–	0	–				
	Treatment Cycle Time (hr)	2.0									
	Traffic Speed (mph)	50									
	Traffic Volume (vph)	100									
	Slush, Loose Snow, or Packed Snow in Wheelpath (Yes or No)	No									
	Ice Pavement Bond (Yes or No)	No									

Text Forecast and Other Operational Data

[1] Ordinary snow.
[2] Powder snow.

Figure B-1. Completed Form 1—Example weather and pavement condition worksheet.

Agency____________________ Date_______________

Route____________________________ Operator__________________________

Date		1/16/02									
Time		1100									
Dilution Potential	Precipitation and Trend (L, M, or H)	M									
	Cycle Time (0, +1, or +2)	1									
	Wheel Path Condition (0 or +1)	0									
	Traffic (0 or +1)	0									
	Adjusted (do not exceed H)	H									
Pavement Temperature (°F) and Trend		28									
Ice/Pavement Bond (Yes or No)		No									
Recommended Treatment		**190 lb/LM of solid sodium chloride**									

Figure B-2. Completed Form 2—Example snow and ice control treatment design worksheet.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation