WINTER HIGHWAY MAINTENANCE OPERATIONS: CONNECTICUT

JULY 2015

A REPORT BY

THE CONNECTICUT ACADEMY OF SCIENCE AND ENGINEERING

FOR

THE CONNECTICUT DEPARTMENT OF TRANSPORTATION

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This study was initiated at the request of the Connecticut Department of Transportation on June 1, 2014. The project was conducted by an Academy Study Committee with the support of the UConn Transportation Institute, with James Mahoney serving as Study Manager. The content of this report lies within the province of the Academy's Transportation Systems Technical Board. The report has been reviewed on behalf of the Academy's Council by Academy Members John N. Ivan, PhD, Herbert S. Levinson, DrEng, PE, and external reviewer Ron Wright, Idaho Transportation Department. Martha Sherman, the Academy's Managing Editor edited the report. The report is hereby released with the approval of the Academy Council.

Richard H. Strauss
Executive Director

Disclaimer

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Partners: Connecticut Department of Transportation, and the Connecticut Department of Energy and Environmental Protection; Connecticut Academy of Science and Engineering; and the Connecticut Transportation Institute, UConn. Prepared in cooperation with USDOT, Federal Highway Administration.

16. Abstract: This study addresses issues identified in legislation adopted by the Connecticut General Assembly that directed the Commissioner of Transportation to conduct an analysis of corrosive effects of chemical road treatments, determine the cost of corrosion created by road treatments, and to provide an evaluation of alternative techniques and products, such as, but not limited to, rust inhibitors, with a comparison of cost and effectiveness. Primary conclusions of the study include that ensuring the safety and mobility of the traveling public requires the most effective winter highway maintenance practices possible. This is a shared responsibility—to achieve comprehensive and sustainable success, competing factors must be considered including safety, cost, corrosion, operating practices, materials and equipment, environmental and economic impacts, and communication with the general public, stakeholders, and government leaders. Balancing these factors presents a challenge that can be met through ongoing monitoring and continuous improvement based on evolving best practices. While use of chloride-based deicing chemicals for winter highway maintenance has raised concerns regarding impacts on vehicles, infrastructure and the environment, alternative products also have environmental, corrosion and expense impacts. Although corrosion inhibitors are available for use with deicers, evidence of their effectiveness in the field based on literature reviewed was not found. Research is needed to confirm their effectiveness before considering use. Further, CTDOT's participation in national initiatives, and ongoing communication with neighboring states, municipalities, and other stakeholders should continue and be strengthened to help balance the competing factors by using the most effective practices.

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LIST OF ACRONYMS AND ABBREVIATIONS

°F	Degrees Fahrenheit
2009/2010	Winter season crossing two calendar years
µS/cm	Electrical Conductivity (micro siemens per centimeter)
10:1	10 parts mixed with 1 part
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACR	Alkali Carbonate Reaction
AOT	Agency of Transportation (Vermont)
ASCE	American Society of Civil Engineers
ASR	Alkali Silica Reaction
ASTM	American Society of Testing and Materials
ATA TMC	American Trucking Association Truck Maintenance Council
AVL	Automatic Vehicle Location
BOD	Biochemical (or Biological) Oxygen Demand
$CaCl_2$	Calcium Chloride
CASE	Connecticut Academy of Science and Engineering
CASHO	Connecticut Association of Street and Highway Officials
CGA	Connecticut General Assembly
COD	Chemical Oxygen Demand
CRCOG	Capital Region Council of Governments
CMA	Calcium Magnesium Acetate
C-S-H	Calcium Silicate Hydrate
CTCDR	Connecticut Crash Data Repository
CTDOT	Connecticut Department of Transportation
CTI	Connecticut Transportation Institute, UConn
CY	Calendar Year
DAS	Connecticut Department of Administrative Services
DEEP	Connecticut Department of Energy and Environmental Protection
DOD	US Department of Defense
DOT	US Department of Transportation (also referred to as USDOT)
DPH	Connecticut Department of Public Health
EMS	Emergency Medical Services
EPA	US Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
F/T	Freeze-thaw Cycling
GIS	Geographic Information System
GPS	Geographic Positioning System
HMWM	High Molecular Weight Methacrylate
IPRF	Innovative Pavements Research Foundation
KABCO	Injury classifications system for crash victims (see Glossary of Terms)
KAc	Potassium Acetate
Lbs.	Pounds

LD_{50}	A lethal dose at which 50% mortality occurs
L	Liters
(LMC/OBPE)	Liquid Magnesium Chloride/Organic-based Performance Enhancers
MaineDOT	Maine Department of Transportation
MAIS	Maximum Abbreviated Injury Scale (see Glossary of Terms)
MassDOT	Massachusetts Department of Transportation
MCL	Maximum Contaminant Level
$MgCl_2$	Magnesium Chloride
MSDS	Material Safety Data Sheet
M-S-H	Magnesium Silicate Hydrate
NaCl	Sodium Chloride
NACE	National Association of Corrosion Engineers
NCHRP	National Cooperative Highway Research Program
NHDOT	New Hampshire Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NYSDOT	New York State Department of Transportation
OE	Original Equipment
PCA	Portland Cement Association
PCC	Portland Cement Concrete
PNS	Pacific Northwest Snowfighters Association
ppm	Parts per Million
QALYs	Quality-Adjusted Life-Years
Ref.	Reference
RCI	Road Condition Index
RIDOT	Rhode Island Department of Transportation
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
sq-mi	Square miles
STD	Standard (Volvo)
TMDLs	Total Maximum Daily Loads
TRB	Transportation Research Board
USDOT	US Department of Transportation (also referred to as DOT)
USGS	United States Geological Survey
UV	Ultra-violet light
VAOT	Vermont Agency of Transportation (also referred to as AOT and VTrans)
VMT	Vehicle Miles Travelled
W/D	Wet-dry Cycling
WSI	Winter Severity Index
WTI	Western Transportation Institute, Montana State University

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APPENDIX A
GLOSSARY OF TERMS

Anaerobic: An environment lacking oxygen

Anions: A negatively charged atom or group of atoms

Anti-icing: A non-mechanical process by which a liquid chemical, usually salt brine, is applied to a roadway prior to or very early in a winter weather event. The chemical is applied to prevent bonding of snow and ice to the pavement surface by lowering the freezing point at which this occurs [1]

Calcium Silicate Hydrate (C-S-H): Formed by Portland Cement within Portland Cement Concrete during initial curing after construction to add strength to the concrete

Capitol Region Council of Governments (CRCOG): A Connecticut planning region comprising 38 municipalities in the metropolitan Hartford area

Cathodic Protection: A technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell

Cations: Positively charged ions that are formed when an atom loses one or more electrons during a chemical reaction

Centerline Miles: The actual length of roadway in one direction of travel. Opposing travel lanes on some state highways are separated by large medians, this can result in the total length of highway differing for each direction. [53]

CTDOT Highway Operations Centers: CTDOT's operations centers, located in Newington and Bridgeport, monitor traffic and weather conditions 24/7 and support the CTDOT storm center during severe winter weather. These monitoring operations include utilizing 324 available traffic cameras statewide, as well as communicating with the State Police on weather related incidents that occur, and apprising the storm monitors and the operation managers.[4]

CTDOT Snow and Ice Control Standing Committee: This committee was formed in 2006 and named as a standing committee in 2015. The committee comprises personnel from the Bureau of Highway Operations and Maintenance, the Bureau of Policy and Planning, Environmental Planning Division, and the Bureau of Finance and Administration. The committee meets monthly to provide input and review of the winter maintenance process, including discussion and critique of snow and ice related issues and concerns, environmental policy and materials. [4]

CTDOT Storm Monitors: CTDOT Office of Maintenance staff serve as both the central point of contact for notification of pending winter weather events and coordinators for reporting staffing and equipment information and field weather conditions during winter weather events. [4]

CTDOT Storm Center: The CTDOT Storm Center, located at CTDOT Headquarters in Newington, CT serves as the center of operations during storms and events.[4]

Deicing: A strategy by which ice and/or compacted snow is removed from the roadway by either a chemical or mechanical means or a combination of the two. This includes chemical treatments, such as salt, which are applied later in a winter storm and continued past the end of the storm. [1]

Deliquescence: The process by which a substance absorbs moisture from the atmosphere until it dissolves in the absorbed water and forms a solution.

Echelon Plowing: Snow plowing in tandem, with plows staggered in a formation to cover all lanes of a roadway.

Endothermic Reaction: A reaction where heat energy is absorbed from surrounding materials

Eutectic Temperature: The optimum eutectic temperature for a given product is the lowest temperature at which a product will freeze when at the optimum ratio of chemical to water. This can also be stated as the lowest freeze-point achievable by a given chemical through an optimum ratio of chemical to water.

Evapotranspiration: The sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere.

Exothermic Reaction: A chemical reaction that releases energy in the form of heat.

Gore Area: A triangular-shaped boundary marked by white lines intended to help organize and protect traffic when vehicles enter or exit highways. Gore areas separate an exit ramp from the through lanes on a highway and assist drivers to safely merge on or off an exit ramp.

Ground Speed Controller: Systems that automatically change application rate with change in ground speed

Halite: Rock salt – sodium chloride

Hygroscopic: A substance that absorbs moisture from the air under certain conditions of humidity and temperature but not necessarily to the point of dissolution

Inorganic Chemical Deicer: All salts are inorganic and non-biodegradable. Three inorganic chloride deicers (magnesium chloride, sodium chloride and calcium chloride) are discussed in this report.

KABCO Injury Scale: A system to classify victims from crashes: *"where K–killed, A–incapacitating injury, B–non-incapacitating injury, C–possible injury, or O–no apparent injury"* used by many state public safety offices for accident coding [148]

Lane-Mile: A measurement of roadway distance based on a single lane of travel. For example, one mile of a two lane road would constitute two lane miles [53]

Level of Service: a qualitative measure used to relate the quality of traffic service defined by six levels:

A: Free flow, low traffic density

B: Minimum delay, stable traffic flow

C: Stable condition, movements somewhat restricted due to higher volumes, but not objectionable for motorists

D: Movements more restricted, travel speeds begin to decline

E: Traffic fills capacity of the roadway, vehicles are closely spaced, incidents can cause serious breakdown

F: Forced flow with demand volumes greater than capacity resulting in breakdown in traffic flow

Linear Referencing System: A method of spatial referencing, in which the locations of features are described in terms of measurements along a linear element, from a defined starting point; for example, a milepoint along a road. Each feature is located by either a point (e.g. a signpost) or a line (e.g. a no-passing zone). The system is designed so that if a segment of a route is changed, only those milepoints on the changed segment need to be updated.

Magnesium Silicate Hydrate (M-S-H): Formed in Portland Cement Concrete from a chemical reaction with magnesium chloride. MSH is a powder or gel substance with limited strength and is thus deleterious to the concrete. [21]

MAIS Injury Scale: The maximum Abbreviated Injury Scale (AIS) is an anatomically based, severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale (1=minor and 6=maximal). The AIS was developed by the Association for the Advancement of Automotive Medicine (AAAM). See www.aaam1.org/index.html [148]

Molal: One mole of solute in 1 kg of solvent

Molality: The number of moles of solute per kilogram of solvent. It is important that the mass of solvent is used and not the mass of the solution. Solutions labeled with molal concentration are denoted with a lower case "m". A 1.0 m solution contains 1 mole of solute per kilogram of solvent.

Molar: Relating to 1 mole of a substance (1.0 M = one mole per liter)

Molarity (*also known as molar concentration*)**:** The number of moles of a substance per liter of solution. Solutions labeled with the molar concentration are denoted with a capital M. A 1.0 M solution contains 1 mole of solute per liter of solution.

Necrosis: The death of living cells or tissue or the morphological changes indicative of cell death. When plants are subjected to abiotic stress they initiate rapid cell death with necrotic morphology.

Non-intrusive Remote Temperature Sensor: A hand-held or vehicle attached sensor that can read the surface temperature of pavement on a continuous basis.

Organic Chemical Deicer: Deicer compounds that contain carbon are organic. Organic biodegradable deicers described in this report include: urea, propylene glycol, potassium formate, sodium formate, potassium acetate, calcium magnesium acetate, sodium acetate, and agricultural by-products such as beet juice, molasses, corn syrups, and others.

Osmotic Stress: A sudden change in the solute concentration around a cell causing a rapid change in the movement of water across its cell membrane. Under conditions of high concentrations of salts, water is drawn out of the cells through osmosis.

Oxychlorides: A compound having oxygen and chlorine atoms bonded to another element

pH: A measurement of a solution's acidity or alkalinity

Pre-treating: The application of either a liquid chemical such as salt brine, a dry solid chemical salt or a pre-wetted solid mixture of chemicals to the pavement surface prior to the start of a winter weather event. Pre-treating is a proactive preventative strategy to decrease the possibility of snow bond, black ice from freezing rain or frost formation on pavement surfaces. Pre-treating is a form of anti-icing.

Pre-wetting: The process by which a liquid chemical (usually salt brine or water) is added to a [solid] deicer chemical prior to application to the roadway. Pre-wetting can occur at different points in the application process and different equipment options are used on the trucks. [1]

Road Weather Information Systems (RWIS): FHWA defines a RWIS as comprising environmental sensor stations (ESS) in the field, a communication system for data transfer, and central systems to collect field data from numerous ESS. ESS stations measure atmospheric, pavement and/or water level conditions. Central RWIS hardware and software are used to process observations from ESS to develop nowcasts or forecasts, and display or disseminate road weather information in a format that can be easily interpreted and used by road operators and maintainers to support decision making.

Rock Salt: Composed primarily of sodium chloride, and used as a deicer for snow and ice control

Salt Brine: A liquid solution of salt, most commonly sodium chloride and water; as used in this report salt brine is 23% sodium chloride with water in solution.

Salt Neutralizing Agent: A product applied to a vehicle surface to reduce corrosion from salts, and once left on to air dry, leaves a protective coating for further protection from corrosion. Can lengthen the life of assets by reducing corrosion damage and improving performance.

Salt Slurry Generation Applicator: A proprietary device attached to the back of a chemical application truck used for winter highway maintenance that reduces salt grain size, increases moisture and allows for deicers to be applied at more grains per square foot than conventional distributors.

Silane sealer: A penetrating sealer used to seal materials such as dense concrete to repel water

State Emergency Operations Center: The Center is located in Hartford. During storms and emergencies the Center is headed by Connecticut's Governor and staffed with state emergency management personnel and representatives of the state's major utility companies.

Toxicosis: Any diseased condition due to poisoning

Vehicle Miles of Travel (VMT): A measurement or sum of total miles traveled by all vehicles in a specified region for a specified time period. CTDOT usually reports VMT as average daily VMT or average annual VMT. For example if there are 3 million vehicles each travelling 10 miles per day, the daily VMT equals 3 million X 10 = 30 million daily VMT.

Winter Activity *(CTDOT def.)***:** Winter weather events are defined by CTDOT as activities and storms. Activities typically last less than six hours and involve less than 50% of the workforce.

Winter Storm *(CTDOT def.)***:** Winter weather events are defined by CTDOT as activities and storms. Storms are of longer duration than activities with more than 50% of the snow and ice control workforce activated.

APPENDIX B
STUDY COMMITTEE MEETINGS AND GUEST SPEAKERS

The following is a list of study committee meetings, including presentations by guest speakers and the CASE Research Team. In the electronic version of this report, links to meeting presentations are highlighted in blue.

JULY 17, 2014 – MEETING 1

- **Welcome and Introductions**
- **Previous CASE Study**
  Richard Strauss, CASE Executive Director
- **Guest Presenters**
  Mike Riley, President, Motor Transport Association of Connecticut
  Kim Pelletier, Truck Builders
  Topic: Truck Corrosion
- **CTDOT Presentation Introduction of Study Topic -**
  Charles Drda, Transportation Maintenance Administrator, Office of Maintenance
  Topic: Introduction of Study Topic – Presentation
- **Research Team – Plan for Study**
  Jim Mahoney (CASE Study Manager), Executive Program Director, Connecticut Transportation Institute, UConn – Presentation
- **Next Steps**

SEPTEMBER 17, 2014 – MEETING 2

- **Welcome and Introductions**
- **Guest Presenters**
  Mark Hammerlein, Water Quality Program Manager, New Hampshire DOT
  Topic: NHDOT Chloride Issues, Challenges and Solutions – Presentation
  Eric Williams, Watershed Assistance Section Manager, New Hampshire Department of Environmental Services – Presentation
  Topic: New Hampshire Road Salt Reduction Initiative
- **Study Committee Member Presenter**

  Paul Brown, Director of Snow and Ice Operations, Massachusetts Department of Transportation
  Topic: Massachusetts Winter Highway Maintenance Practices - Presentation

- **Research Team Update**
  Jim Mahoney, Study Manager – Presentation

- **Next Steps**

OCTOBER 21, 2014 – MEETING 3

- **Welcome and Introductions**

- **Guest Presenter**
  Joe H. Payer, Chief Scientist, National Center for Education & Research for Corrosion & Materials Performance, Corrosion and Reliability Engineering, University of Akron
  Topic: Corrosion Cost and Preventive Strategies in the US – Presentation, Appendix

- **Guest Presenter**
  David Darwin, Deane E. Ackers Distinguished Professor and Chair, Department of Civil, Environmental Architectural Engineering, University of Kansas
  Topic: Effects of Deicers on Concrete Deterioration – Presentation

- **Study Committee Member Presenter**
  Monty Mills, Maintenance & Operations Branch Manager, Washington State DOT
  Topic: Corrosion to Snow & Ice Material Application Equipment – Presentation

- **Research Team Update**
  Jim Mahoney, Study Manager

- **Next Steps**

NOVEMBER 14, 2014 – MEETING 4

- **Welcome and Introductions**

- **Study Committee Member Presenter**
  Brian Burne, Highway Maintenance Engineer, Maine Department of Transportation
  Topic: Maine Winter Highway Maintenance Practices – Presentation

- **Guest Presenter**
  Western Transportation Institute, Montana State University: **Laura Fay**, Research Scientist, Winter Maintenance & Effect Program Manager and **Mehdi Honarvar Nazari**, Postdoctoral Visiting Scholar
  Topic: Corrosion Inhibitor Research – Fay Presentation, Nazari Slide

- **CTDOT Presentation**
  Charles Drda, Transportation Maintenance Administrator, Office of Maintenance
  Topic: ConnDOT Winter Highway Maintenance Practices – Presentation

- **Research Team Update**
  Jim Mahoney, Study Manager – Presentation

DECEMBER 17, 2014 – MEETING 5

- **Welcome and Introductions**
- **Guest Presenter**
  Chelsea Monty, Assistant Professor, Chemical and Biomolecular Engineering, University of Akron
  Topic: Research on the Effectiveness of Salt Neutralizers for Washing – Presentation
- **Guest Presenter**
  Bob Hamilton, Director of Fleet Maintenance, Bozzuto's, Inc.
  Topic: Winter Weather Fleet Management – Presentation
- Guest Presenter
  Daniel Szczepanik, OE/Commercial Products Manager, Sherwin-Williams
  Topic: Protecting Vehicles from Corrosion – Presentation
- **Research Team Update**
  Jim Mahoney, Study Manager -- Presentation, Handout: Commercial Car Washes, Handout: Cargill MSDS, Handout: Sodium Chloride Health
- **Next Steps**

JANUARY 21, 2015 – MEETING 6

- **Welcome and Introductions**
- **Guest Presenter**
  J. Adam Hill, Vice President of Product Sales Engineering, Great Dane Trailers
  Topic: Corrosion Issues – Presentation
- **Research Team Update**
  Jim Mahoney, Study Manager – Presentation
- **Committee Discussion**
  Rick Strauss, Executive Director
  Topic: Brainstorming concepts for recommendations
- **Next Steps**

MARCH 11, 2015 – MEETING 7

- **Welcome and Introductions**
- **Guest Presenter**
  Stacey Spencer, Principal Engineer, Global Technology Specialist Materials Engineering, Volvo Group Trucks
  Topic: Effect of Deicers on Engineering of Class 8 Trucks – Presentation

- **Guest Presenter**
  Jeff Williams, Weather Operations Manager, Utah Department of Transportation
  Topic: Utah Severity Index – Presentation

- **Research Team Update**
  Jim Mahoney, Study Manager – Presentation, Handout 1, Handout 2

- **Guest Presenter**
  Michaela Cisowski, Northwestern Regional High School, District #7, Winsted, CT
  Topic: Rust in Peace – Uninhibited Magnesium Chloride Brine – Presentation

- **Committee Discussion**
  Richard Strauss, Study Manager
  Topic: Brainstorming findings and concepts for recommendations

- **Next Steps**

APRIL 10, 2015 – MEETING 8

- **Welcome and Introductions**

- **Guest Presenter**
  Bob Rossini, Incoming President, Connecticut Carwash Association
  Topic: Winter Road Maintenance Practices - Carwash

- **Research Team Update**
  Jim Mahoney, Study Manager – Presentation
  Kay Wille, Research Team
  Topic: Effects of Deicer Corrosion on Infrastructure – Presentation
  Tim Vadas, Research Team
  Topic: Environmental Impacts of Deicing Chemicals – Presentation

- **Committee Discussion**
  Richard Strauss, Executive Director, CASE
  Topic: Brainstorming findings and concepts for recommendations

- **Next Steps**

MAY 5, 2015

- **Welcome**

- **Committee Discussion**
  Richard Strauss, Executive Director, CASE
  Topic: Brainstorming draft findings and recommendations

- **Next Steps**

APPENDIX C
AN OVERVIEW OF SNOW AND ICE CONTROL OPERATIONS ON STATE HIGHWAYS IN CONNECTICUT

JUNE 2015

This overview is intended to provide basic information on advanced snow and ice control operation practices employed on the Connecticut State highway network. It is for informational purposes only, and does not constitute a standard, policy or guideline.

Connecticut Department of Transportation
Bureau of Highway Operations
Office of Maintenance

CONNECTICUT DEPARTMENT OF TRANSPORTATION

An Overview of Snow and Ice Control Operations on State Highways In Connecticut

June 2015

This overview is intended to provide basic information on advanced snow and ice control operation practices employed on the Connecticut State highway network. It is for informational purposes only, and does not constitute a standard, policy or guideline.

Bureau of Highway Operations

Office of Maintenance

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Introduction

Snow and ice covered roads can severely impact mobility and disrupt modern societies that depend upon government services to improve public safety, provide mobility and minimize the economic impact. Advancements in anti-icing technology and practices, weather information, operational methods, materials and equipment have transformed snow and ice control to provide both improved levels of service and efficiencies on our highway system.

This overview provides basic information on the many elements, technical decisions and proactive approaches currently employed by the Connecticut Department of Transportation (CTDOT) to achieve and maintain reasonable levels of service during winter weather-related events on Connecticut's highways.

Mission

Connecticut's General Statute 13a-93 requires that "the commissioner *(Transportation)* shall remove the snow from the traveled portions of any completed state highway when the accumulation thereof renders such highway unsafe for public travel"/1/. Also, CTDOT Policy No. HO-5 (4/8/11), states "The Department shall provide a standard of winter maintenance that provides for the motoring public reasonably safe roads during and after adverse weather conditions throughout the winter season"/2/.

Effective snow and ice control operations are essential for achieving CTDOT's mission "to provide a safe and efficient intermodal transportation network that improves the quality of life and promotes economic vitality for the State and the region"/3/.

Snow and Ice Control Operations

To address the challenges associated with winter weather on the State highway network, CTDOT has charged the Bureau of Highway Operations and Maintenance with snow and ice control operations. This responsibility includes maintaining a network of over 10,800 lane-miles[1]. Snow and ice operations involve many elements, including, but not limited to: planning and analysis of plowing routes, continuous review of practices and procedures of snow states, acquisition of equipment and materials, annual snowplow operator training, weather prediction and storm tracking, as well as a thorough understanding of anti-icing, deicing, highway monitoring, and plowing practice.

CTDOT staff prepare throughout the year for snow and ice deployment between November 1st and April 30th each year. The Department's deployment strategy seeks to:

[1] Comprises 10,300 mainline and ramp lane-miles /5/ (CTDOT Planning, 2013) as well as an additional 500 lane miles from miscellaneous plowed road segments. (i.e. turn-arounds, High Occupancy Vehicle (HOV) Lanes, climbing and turning lanes, etc.) Parking lots and facilities are not included in this quantity.

- pro-actively utilize weather information, anti-icing methods and manpower;
- prescribe road treatments, based on expected and actual conditions;
- provide for continuous plowing and critical operational support throughout storm events;
- balance effective treatment with public safety, environmental concerns and cost;
- prescribe road treatments, based on expected and actual conditions; and the following highway classifications:

  Class 1 – Limited Access Highways – Includes interstates, parkways and expressways with corresponding ramps. Continuous service throughout the storm with multi-truck echelon plowing and material applications; applications are made as necessary for reasonably safe travel and prior to rush hour periods. Lanes and shoulders scraped down to near bare pavement; snow accumulations will occur during periods of heavy snow; desired cycle time of two hours with a goal to have lanes cleared to bare and wet pavement within four hours following a winter event.

  Class 2 – Primary Routes – Includes major and minor collector highways; continuous service throughout the storm with two truck echelons; application on centerline with one wheel path of traction in either direction; lanes scraped down to near bare pavement; snow accumulations of 2 – 4 inches will occur during periods of heavy snow; desired cycle time three hours with a goal to have lanes cleared to bare and wet pavement 4-6 hours after a winter event.

  Class 3 – Secondary / Miscellaneous Routes – Includes low-volume, state-maintained roadways; continuous service throughout the storm with one assigned plow; application on centerline as needed, with attention to hills, curves and intersections; snow accumulations of over four inches may occur during periods of heavy snow; cycle time may exceed three hours; goal is to have the lanes cleared to bare and wet pavement within six hours following a winter weather event.

Anti-Icing

The anti-icing approach has been CTDOT's primary snow and ice control strategy since 2006. The goal of the anti-icing approach is to prevent the snow and ice from bonding to the pavement surface /6/. This approach actively employs weather information and utilizes the most effective methods and materials for road treatment based on specific conditions. Anti-icing treatments specifically include "Pre-Treating" and "Pre-Wetting" methods. Pre-Treating is the placement of anti-icing materials, specifically sodium chloride solution on state roads in CT, in advance of anticipated weather events. Pre-Wetting is the advanced activation of sodium chloride, commonly referred to as rock salt, by infusing a liquid chloride to the rock salt at the discharge chute /6/. The deployment strategy includes strategic timing of both the treatments and plowing, based on storm characteristics, treatment activation times, traffic patterns, and time of day. The anti-icing approach results in both improved level of service and the efficient use of chemicals /6/.

Weather Information

CTDOT receives contracted weather forecasting services that are paramount to effective decision-making. Weather reports are issued daily and in advance of adverse weather. Specific routine and emergency forecasts are provided for seven geographic zones in the State, as shown in Figure 1.

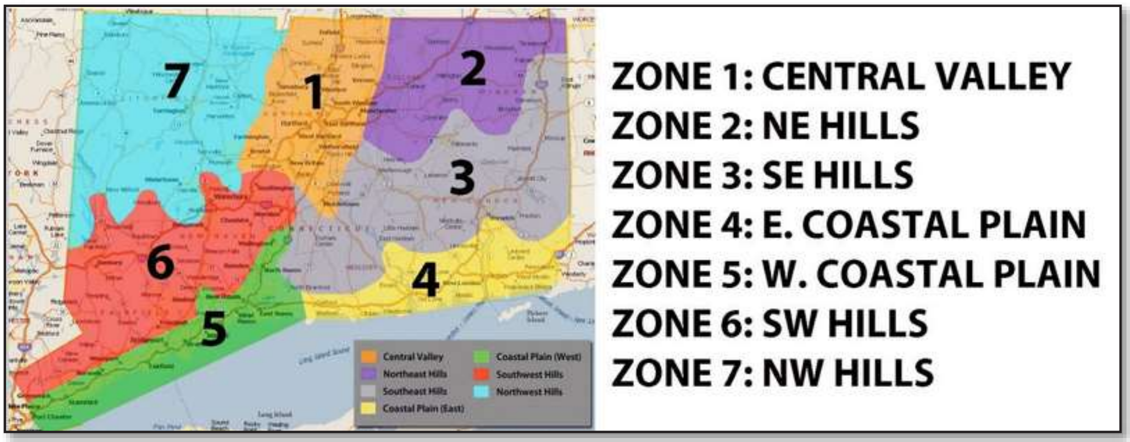

Figure 1: Map of Weather Zone Designations in Connecticut

The forecasting service report includes an array of forecasted data, including: maximum and minimum air temperatures, general cloudiness, precipitation type(s) and intensity, projected ground accumulation, timing, duration, wind direction and velocity, as well as other pertinent forecast information and remarks, including post-storm conditions. The weather service employees contact CTDOT storm monitors two hours in advance of snow and ice precipitation entering the state, and continue to issue updated advisories every four hours, or as required, until the storm event has ended. Weather forecasting information is also provided by the Division of Emergency Management and Homeland Security of the Department of Emergency Services and Public Protection during major storm events.

In addition to forecast services, actual field condition information is paramount. Pavement temperatures are essential to successful decision-making in the anti-icing deployment strategy. Field condition data are monitored from truck-mounted air and pavement temperature sensors and from Road Weather Information Systems (RWIS). There are currently thirteen RWIS installed on the Connecticut State highway network and more RWIS stations are proposed to be installed strategically throughout the network in the near future. Information from these systems provides road and bridge surface temperatures, relative humidity, dew point, air and subsurface temperatures, precipitation type and chemical concentration. Some RWIS stations are also equipped with cameras for visual verification of conditions. An RWIS weather station is shown in Figure 2 and an in-pavement sensor part of an RWIS is shown in Figure 3.

Figure 2: RWIS: Station, Route 2, Lebanon, CT (Left)

Figure 3: In-Pavement Sensor (Right)

Real-time weather conditions are observed 24/7 by highway operations personnel who have access to 324 highway traffic cameras located throughout the state. The CTDOT Highway Operations Centers are located in Newington and Bridgeport, CT.

Pre-Treating

CTDOT utilizes pre-treating in advance of winter weather events, including frost, freezing rain and snow. Pre-treating is conducted when conditions allow, as outlined by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) Guidelines /6, 7/. The decision flowchart used for pre-treatment is provided in Figure 4.

Trucks specifically equipped with tanks, called "tank trucks," are used to pre-treat bridge decks and high-risk areas with a sodium chloride brine solution. When placed under dry conditions, the brine solution, as designed, will dry and remain dormant on the treated surface for up to five days. It is activated by moisture to mitigate the ice bond at locations that may freeze first. Pre-treating serves as an immediate deployment at these locations. Without pre-treating, such a timely response is unattainable through traditional methods. In addition, this provides mobilization time and improved efficiency during non-work periods.

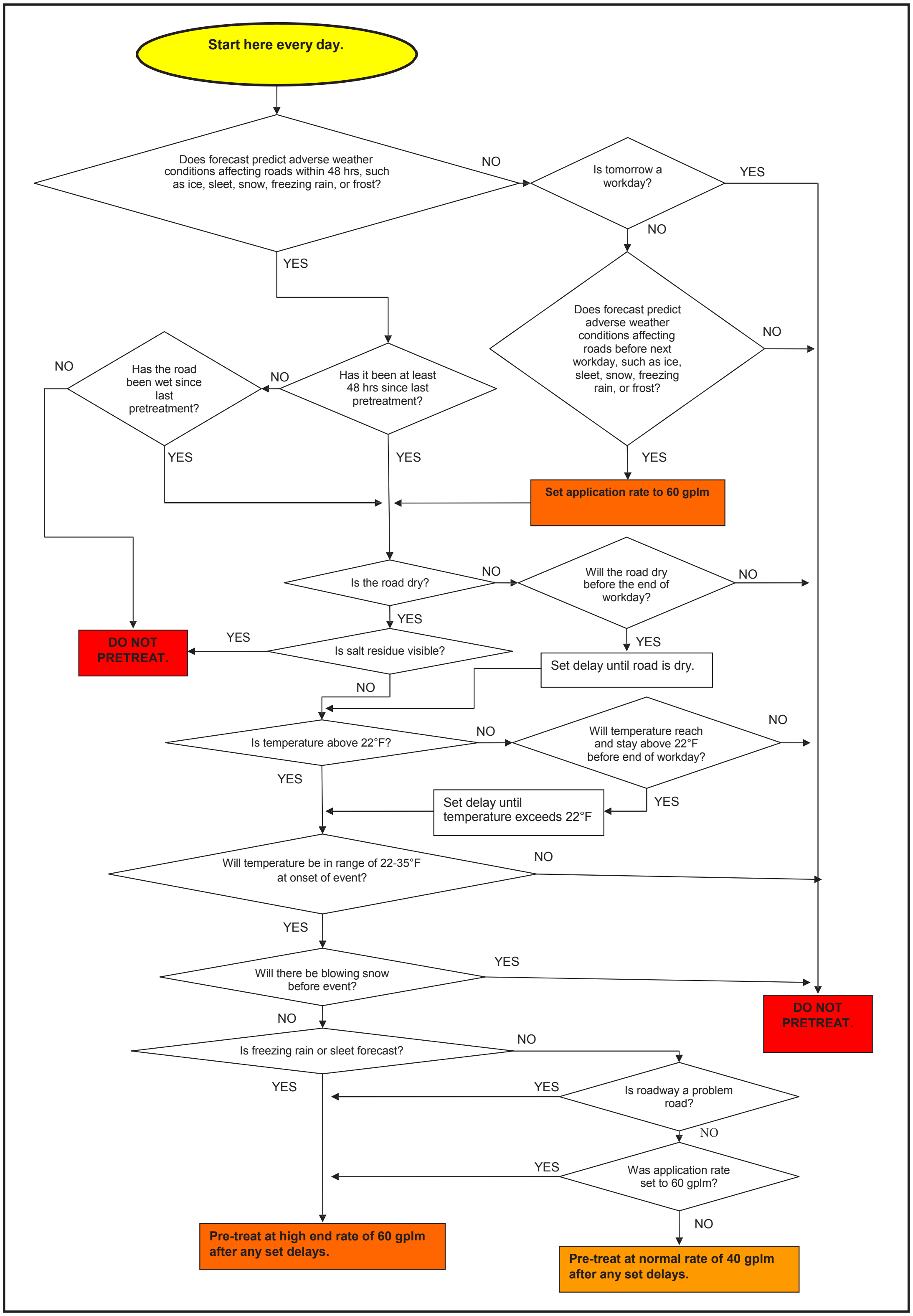

Figure 4: Decision Flowchart for Pre-Treatment in Connecticut

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Figure 5: Pavement Pre-Treated with Sodium Chloride Brine Solution

Figure 5 shows a roadway pre-treated with sodium chloride brine solution. Full application guidelines are outlined in the CTDOT Bureau of Highway Operations, Office of Maintenance Snow and Ice Guidelines /4/.The brine solution is produced at centralized maintenance facilities with water and rock salt to make a 23% sodium chloride solution. Scientifically, the 23% solution is the concentration that provides the lowest freezing point (i.e., eutectic composition) for sodium chloride/6 /. A mixing device and storage tanks used for the brine are shown in Figure 6. The amount of brine solution applied is by temperature, in accordance with CTDOT Guidelines /4/: Specifically, 30 gallons per lane-mile at 32°F[2], 40 gallons per lane mile at 22°F. It is not applied when the road temperature is below 22°F.

Figure 6: Brine Mixing (Sodium Chloride) and Storage (Sodium Chloride and Magnesium Chloride) Tanks, Putnam Garage

[2] All application temperatures refer to pavement temperatures.

During the Storm

The goal is to keep snow and ice from bonding to the pavement surface by applying sufficient material to break the ice/pavement bond. Salts are effective in breaking as well as preventing the bond of ice because of the capability to lower the freezing point of water/8/. As described by AASHTO, "salt is widely used because of its effectiveness at moderate subfreezing pavement temperatures, relatively low cost, availability, and ease of application..."/7/ (p. 31). The effectiveness of salts is temperature dependent. For most conditions (above 20°F), sodium chloride is placed at a rate of 200 pounds per lane-mile/4/.

Pre-Wetting

Pre-wetting (liquid) is a method where solution is applied to the sodium chloride (solid) to help keep the solid materials on the road by preventing bounce and scatter, and activate the salt more quickly to melt the snow and ice at lower working temperatures and reduce the overall amount of salt needed/8,9,10, 11/. The sodium chloride, rock salt, is pre-wetted at the time of placement with a magnesium chloride solution. This solution is purchased premixed and consists of 30% magnesium chloride (by weight) and 70% water (by weight)/4/. This solution is applied to the sodium chloride (rock salt), at the rate of one gallon per lanemile, as the sodium chloride is spread from the truck, as shown in Figure 7. By weight, this is approximately 3 pounds of magnesium chloride per lane-mile. A sodium chloride solution may also be used for pre-wetting at temperatures above 25°F, at the manager's discretion /4/. Calcium chloride solution was used for pre-wetting in 2006 – 2012 until supply issues were encountered.

Figure 7: Salt, Pre-Wetted as Dispensed, Using a Static Spinner to Create a Windrow Application

"Call-out" is deployment based on expected pavement temperatures, accumulation and precipitation type by geographic region(s). Deployments are most often enacted based on information received through the contracted weather service, but can also be initiated based on information from staff field reports, public safety offices or other agencies. At the core of the deployment process are staff designated as "Storm Monitors." They serve as both the central point of contact for notification of pending winter weather events and coordinators for reporting staffing and equipment information and field weather conditions during winter storms. They are notified two hours prior to the prediction of any precipitation in the form of snow or freezing rain entering the state and prior to a storm warning issued by the contracted weather service. The contracted weather service continues with four hour updates during an event. Four storm monitors are on-call 24 hours per day, seven days per week during the winter season.

It is the storm monitor's responsibility to notify the Highway Maintenance Managers of updated weather and roadway information, including air and road temperatures and other atmospheric conditions. Maintenance Managers are responsible for determining the type and extent of road treatment, as well as the labor and equipment needs for each deployment. The CTDOT Storm Center, located at CTDOT Headquarters in Newington, CT, serves as the center of operations during storms and events. Figure 8 shows the Storm Center during activation.

Figure 8: Activated Storm Center, Newington, CT.; (Insert) Storm Activation, Graphical Display

The State of Connecticut deploys 632 plow trucks, 120 loaders and other specialized equipment, including snow blowers, and uses over 1,100 essential employees during full activation. In addition, contractor-supplied plow trucks (approximately 200) can be called into service for additional support under Department of Administrative Services (DAS) contract, if conditions warrant. Repair facilities are activated and operational during snow and ice events to support continuous operations. The routing, lane coverage and synchronization of truck formations are well planned and orchestrated. Routings are established based on traffic volume, mileage, and round-trip cycle time. The routings are carefully planned by each district to address a variety of needs and are updated annually.

Skilled plow operators use various plow and blade configurations, spreading patterns and application rates, and planned and specific truck arrangements such as echelon plowing (depicted in Figures 9 and 10) to achieve best results.

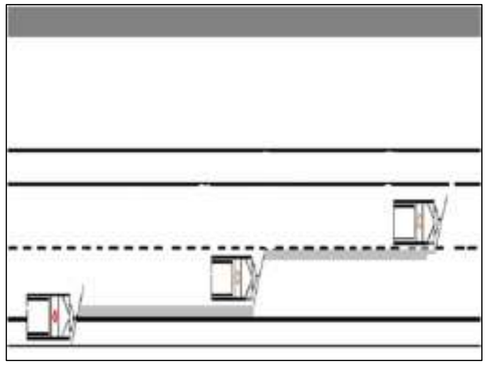

Figure 9: Echelon Plowing: Configuration

Figure 10: Trucks Deployed in Echelon

General practice is one application every three hours with variations based upon the weather conditions, traffic and time of day. For example, when the snowfall rate is extremely heavy, plows operate with the purpose of clearing travel lanes. During these conditions, it is most practical to plow the snow without applying the material. Key application times are at the beginning and ending of precipitation and prior to rush hour traffic. Contracted trucks are used to plow snow only and do not apply chemicals. A small fleet of two-axle dump trucks are also utilized to plow commuter parking lots.

Conditions during snow and ice season can vary considerably between seemingly minor to extreme weather events. It is a challenge to address the motoring public's needs based on the inexact science of weather prediction. For this reason, snow and ice professionals use various additional tools to address specific and immediate needs. When extremely severe winter conditions are encountered, the Governor may activate the Emergency Operations Center (EOC), which serves as the hub for all statewide emergency management personnel. The Governor may also declare travel bans, as necessary.

Post Storm

After precipitation has ended and the travel way is cleared, work continues to remove snow from other areas of accumulation. Such areas include pavement shoulders, bridges and viaducts,gore and ramp areas, impact attenuators, catch basins, median barriers, sidewalks which are the State's obligation for winter maintenance, and other locations where snow can melt and drain into the roadway. Department-maintained yards are cleared, and snow obscuring the visibility of warning and directional signs is removed. Removal is conducted using various equipment including industrial snow blowers, pay loaders and manual labor. Figure 11 shows industrial snow blowers in use. After each storm, all equipment is cleaned, checked, and repaired as necessary to get ready for the next winter event. Periodically during the winter season, a neutralizing agent is applied to all snow and ice equipment, per manufacturers' recommendations/12/.

Figure 11: Industrial Snow Blowers In-Use, Post Storm.

Detailed records on material usage are maintained and checked after each storm to ensure that application rates are in accordance with CTDOT guidelines. In addition, material supplies are inventoried and restocked and the budget is tracked. Figure 12 is an example of the truck operator activity log manually completed by each operator per shift. Information on material use from the truck operators' logs are summarized at the garage level into "Statewide Storm Summary Reports"/13/ (a.k.a. 'Maintenance 9 Form').

These Storm Summary Reports are submitted to staff maintenance for review as part of the maintenance management system. Tables 1 and 2 provide excerpts from the Summary Report, as examples. Table 1 details how the hours, sand, salt and chloride (magnesium) were recorded by section throughout the season (this example: Storm #8, 2012/2013 Season.) Summaries are also provided by District and by crew. Table 2 details how materials are recorded by crew. Further breakdown of these amounts are listed by two-lane, ramp, multi-lane and post-secondary categories. Table 3 lists the estimated material usage from CTDOT from 2000 - 2014. Material usage is highly dependent upon many factors that are not listed, including storm intensity, temperature and time of day. For example, the years 2007 – 2014 had less average snow than the period 2000 – 2006, but the Department used slightly more (15%) chlorides. In this case, “total snow” is an oversimplification for storm/winter characterization. Other factors, such as duration, ice accumulation, subfreezing temperatures when more chlorides are needed to be effective, and re-freezing events influence the severity of the winter and material needed.

As is common practice, all material spreaders are calibrated prior to the snow season and validated periodically by CTDOT Maintenance staff according to the procedures of the equipment manufacturer /4/. Figure 13 shows a material spreader calibration in-progress. Each truck is labelled with the calibration results as shown in Figure 14, for easy reference by different drivers and supervisors. Sodium chloride is purchased under contract and accepted according to: (1) Purity: as stated in AASHTO M—143-13 “Standard Specification for Sodium Chloride,” (ASTM D—632-12, Type 1)/14/; (2) Gradation: requirements set forth by the Department; and, (3) Moisture Content: not to exceed 3% by weight. Salt testing for material quality occurs every 10 calendar days and is administered by the CTDOT’s Material Testing Laboratory.

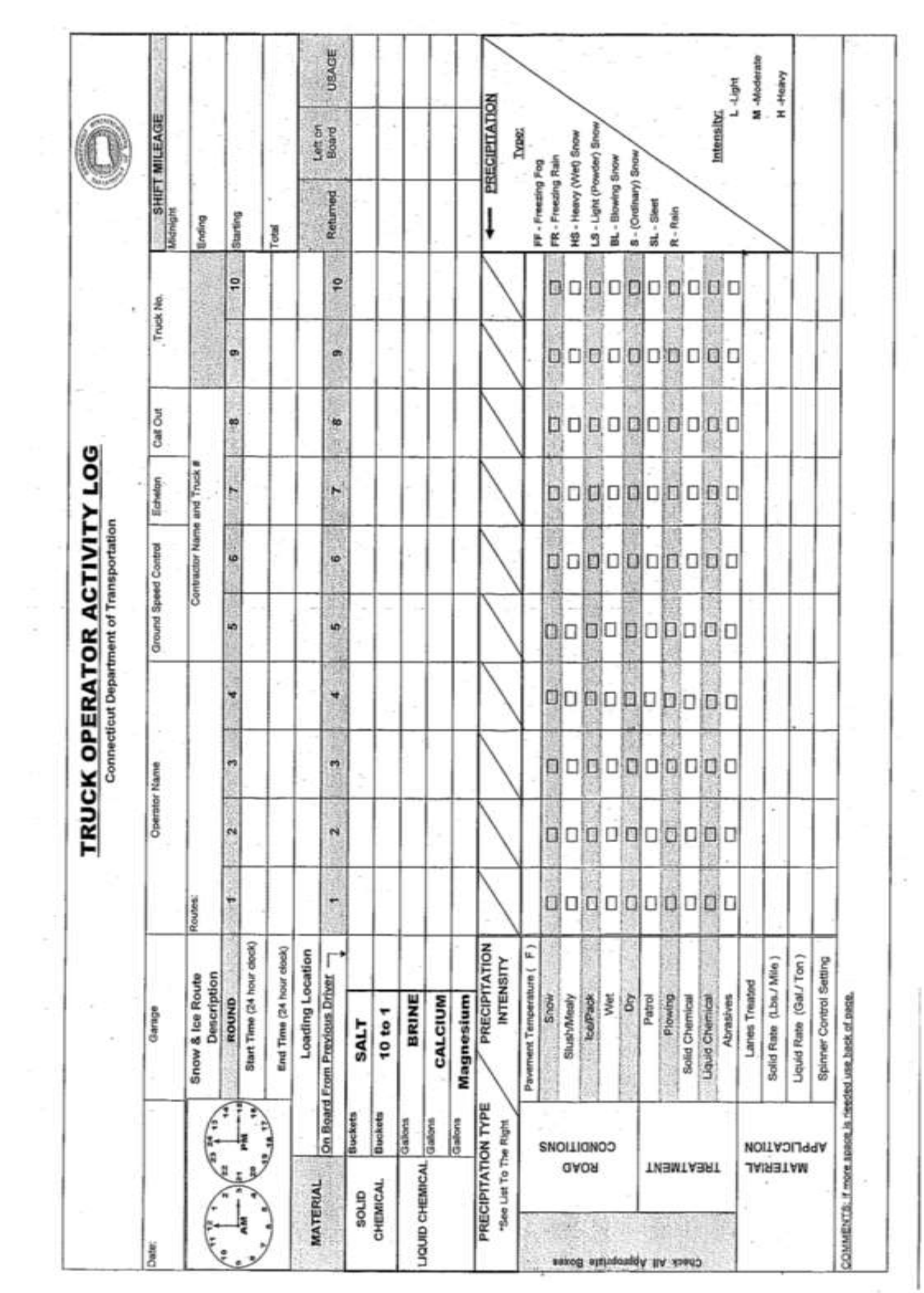

Figure 12: Example of Truck Operator Activity Log

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Table 1: Example of Material Reports Generated After Each Storm, by Section (Excerpt from Statewide Storm Summary Report)/13/

Snow & Ice Control Material Usage: 2012-2013 Season

Through Storm # S08

Section	Hours						Sand (Cubic Yards)					
	Storm Total	% of Bud.	Previous Total	Total to Date	Hours Budgeted	% Exp	Storm Total	% of Bud.	Previous Total	Total to Date	Amount Budgeted	% Exp
11	24.00	9.27	143.00	167.00	259.00	64.48	0.00	0.00	0.00	0.00	7,375.00	0.00
13	20.00	7.72	141.50	161.50	259.00	62.36	0.00	0.00	216.00	216.00	6,239.00	3.46
21	21.00	8.24	133.50	154.50	255.00	60.59	0.00	0.00	0.00	0.00	6,870.00	0.00
23	22.00	8.56	137.00	159.00	257.00	61.87	0.00	0.00	0.00	0.00	5,604.00	0.00
31	24.00	9.49	141.00	165.00	253.00	65.22	0.00	0.00	0.00	0.00	4,737.00	0.00
33	24.00	9.45	141.00	165.00	254.00	64.96	0.00	0.00	0.00	0.00	6,008.00	0.00
41	24.00	8.96	138.50	162.50	268.00	60.63	0.00	0.00	0.00	0.00	8,839.00	0.00
43	24.00	8.82	149.00	173.00	272.00	63.60	0.00	0.00	0.00	0.00	7,204.00	0.00

Section	Salt (Tons)						Chloride (Gallons)					
	Storm Total	% of Bud.	Previous Total	Total to Date	Amount Budgeted	% Exp	Storm Total	% of Bud.	Previous Total	Total to Date	Amount Budgeted	% Exp
11	1,739.88	7.13	9,505.51	11,245.39	24,389.00	46.11	12,185.00	10.18	58,634.00	70,819.00	119,741.00	59.14
13	1,868.40	6.88	8,401.89	10,270.29	27,155.00	37.82	16,385.00	12.20	64,935.00	81,320.00	134,311.00	60.55
21	1,962.31	10.47	7,864.63	9,826.93	18,746.00	52.42	20,702.00	20.83	68,204.00	88,906.00	99,382.00	89.46
23	1,828.44	11.04	7,059.67	8,888.11	16,566.00	53.65	21,145.00	21.89	64,505.00	85,650.00	96,578.00	88.68
31	1,069.20	6.52	7,651.98	8,721.18	16,409.00	53.15	9,364.00	12.49	43,619.00	52,983.00	74,946.00	70.69
33	1,669.68	8.90	6,114.61	7,784.29	18,754.00	41.51	13,008.00	16.81	40,224.00	53,232.00	77,391.00	68.78
41	1,775.52	7.07	7,856.86	9,632.38	25,125.00	38.34	15,179.00	15.19	50,998.00	66,177.00	99,936.00	66.22
43	1,926.56	8.61	8,989.43	10,915.99	22,373.00	48.79	16,159.00	16.46	66,255.00	82,414.00	98,144.00	83.97

Note: Column Title annotated to 'Chloride' (Gallons), refers to Magnesium Chloride Solution.

Table 2: Example of Material Report by Crew, (excerpt from Statewide Storm Summary Report) /13/

...Total Amounts...

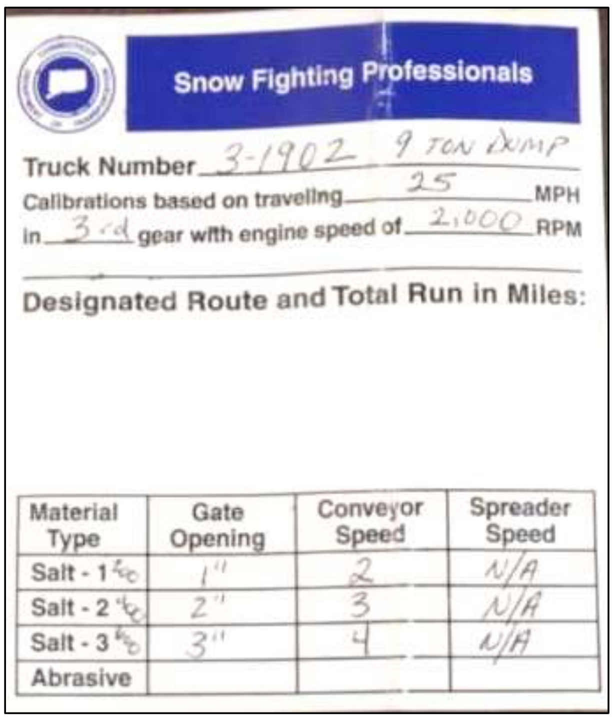
Crew	10:1	Sand	Salt	Brine	CalC
111	0	0	220	0	810
112	0	0	269	0	2600
113	0	0	310	0	2700
114	0	0	338	0	2837
116	0	0	244	0	1052
117	0	0	230	0	2186
Total	0	0	1611	0	12185

Table 3: Estimated Winter Storm and Material Use Totals, 2001 – 2014

Season (Years)	Storms (No.)	Activities (No.)**	Total Snowfall (Range, Inches) ***	Sand (Tons)	Sodium Chloride (Tons)	Calcium Chloride* (Tons)	Magnesium Chloride* (Tons)	Total Chlorides Applied (Tons)
2000/ 2001	17	11	25-71	307,310	140,850	-	-	140,850
2001/ 2002	9	5	5-26	94,260	40,220	-	-	40,220
2002/ 2003	16	10	50-98	303,110	140,110	-	-	140,110
2003/ 2004	12	9	46-79	225,310	103,820	-	-	103,820
2004/ 2005	18	4	51-77	317,130	161,900	-	-	161,900
2005/ 2006	11	6	25-62	198,310	107,930	-	-	107,930
2006/ 2007	9	6	6-30	6,790	104,760	481	-	105,241
2007/ 2008	14	10	13-70	2,860	185,000	1,240	-	186,240
2008/ 2009	13	8	33-58	4,230	179,710	1,492	-	181,202
2009/ 2010	12	5	22-67	60	131,040	1,333	-	132,373
2010/ 2011	15	5	52-87	10	179,490	1,092	748	181,330
2011/ 2012	6	4	9-31	-	62,550	141	422	63,113
2012/ 2013	11	9	35-74	-	160,930	-	1,727	162,657
2013/ 2014	17	11	40-62	-	225,170	-	2,341	227,511

Notes: Sand and sodium chloride values rounded to the nearest 10 ton.
Shaded area indicates seasons prior to deployment of anti-icing practices.
*Applied in Solution: $CaCl_2$ (32%) Solution,(3.54lbs/gal); $MgCl_2$ (30%) Solution,(3.23lbs/gal).
**Activities are precipitation events, do not include applications from 're-freeze' events.
***Snowfall amounts, as measured at CTDOT Maintenance Facilities.

Figure 13: Spreader calibration



Snow Fighting Professionals

Truck Number 3-1902 9 TON DUMP

Calibrations based on traveling 25 MPH

in 3rd gear with engine speed of 2,000 RPM

Designated Route and Total Run in Miles:

Material Type	Gate Opening	Conveyor Speed	Spreader Speed
Salt - 1 200	1"	2	N/A
Salt - 2 400	2"	3	N/A
Salt - 3 600	3"	4	N/A
Abrasive			

Figure 14: Calibration ticket, displayed in each vehicle

During the Off-Season

During the off-season, work is done to facilitate the snow and ice operations for the next winter season. This includes:

- Equipment is cleaned and a neutralizing agent is applied.
- Snow plowing routes are reviewed annually for the purposes of optimization and efficiency:
- Potentially hazardous trees and brush are removed;
- Structures, drainage areas and other roadside obstacles are identified and staked before the next season.

Tree and branch (canopy) removal is critical to reduce the risks of falling trees and limbs, as well as accumulated snow and ice dropping from overhead canopy. Reduced canopy improves sun exposure to naturally aid in the snow and ice removal process/15/. As such, this also results in reducing the amount of materials needed to combat both storm and re-freezing events. Additionally, during the off-season stockpiles are replenished, equipment and supplies are replaced and contracts needed for the next winter's activities are executed.

Storm Characterization

Snow and ice events are designated and tallied as storms or activities. Storms and activities are categorized based on the duration, percent of workforce activation and distribution statewide. As such, activities are typically less than six hours with less than 50% of the workforce activated statewide, and storms are longer in duration with 50% or more of the snow and ice control workforce activated statewide. For planning purposes, CTDOT budgets for 12 storms per year based on past averages.

During the 2013/2014 season, the average storm was 20 hours. Figure 15 provides a graphical depiction of how the number of storms varies from year to year. As shown, these range between as many as 18 storms in the 2004/2005 season, and 17 in 2013/2014 season, to as few as six in the 1999/2000 and 2011/2012 seasons. State work-forces are also called to action when isolated weather conditions occur. These necessary actions, such as spot treatments in the case of possible "re-freeze," are not reflected in storm and activity tallies.

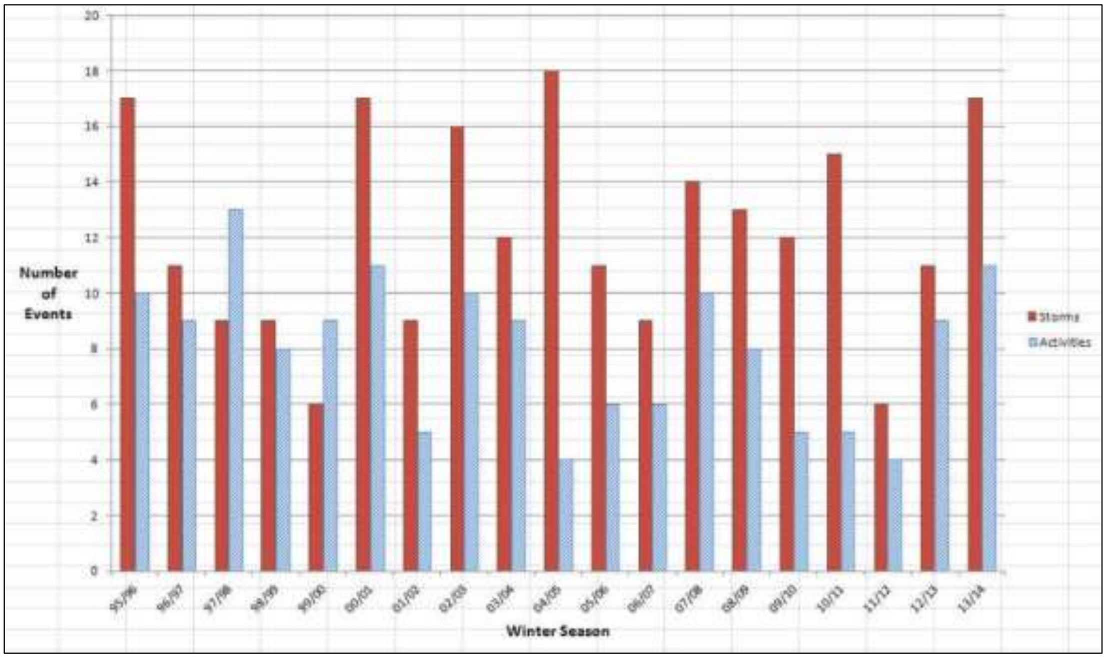


Figure 15: Number of Storms and Activities, by Winter Season (1996 – 2014)

A Decade of Advancements

“Agencies are continually seeking better ways to handle snow and ice problems”/7/. During the last decade there have been important improvements to snow and ice maintenance operations in Connecticut. These include adoption of anti-icing, pre-treating and pre-wetting practices and strategies, as well as advancements in equipment, data for decision-making and weather forecasting. Table 4 provides information on the progression of practices in a maturity chart format.

The change from deicing to anti-icing was described as “revolutionary” in a FHWA’s Public Road article in 1995 entitled, “New Strategies Can Improve Winter Road Maintenance”/16/. Based on national field trials, significant input from other agencies, recommendations in the 2006 study entitled, “Improving Winter Highway Maintenance – Case Studies for Connecticut’s Consideration”/18/, and recommendations from the 2005 NTSB Highway Accident Report, “Multiple Vehicle Collision on Interstate 95, Fairfield, CT January 17, 2003” /19/, CTDOT adopted improved approaches and technologies for winter highway maintenance, including anti-icing for the winter season 2006/2007. As described by FHWA in 1995, anti-icing is a “new strategy for preventing a strong bond from forming between snow or frost and the pavement surface”/16/. Advanced anti-icing methods represent a paradigm shift from traditional deicing methods. “Deicing is familiar to most agencies since it has been the most widely used strategy in the past”/16/. Traditional deicing methods allow snow to accumulate prior to removal and often resulted in “snow pack” that bonded to the road surface for hours and days, creating safety concerns. In the past, a sand and salt (sodium chloride) mixture (mixed at a ratio of 7:2) was spread behind the plows with the intent of improving vehicle traction to the snow pack. Numerous studies showed that abrasives (i.e., sand) have little friction-enhancing value on a road with any substantive level of traffic /17/. In addition to the limitations on effectiveness, use of sand required extensive cleanup, contributed to airborne particles and impacted the environment (example: water flow at streams)/15,17/. AASHTO and FHWA documented best practices indicate that sand should not be used for routine snow and ice operations/7, 6/. Hence, sand is only prescribed on Connecticut State highways during specific circumstances where ice or hilly terrain warrant remediation.

CTDOT began programming the pre-treating of select locations during the winter of 2006-2007 as part of the overall anti-icing strategies. Pre-treating had documented benefits by other states /6/ including:

- significantly reduces accidents on major river crossings;
- mitigates snow and ice from bonding to pavement;
- provides plow drivers more time at the onset of a storm;
- reduces salt use;
- promotes bare pavement sooner after storm; and,
- reduces overall cost of snow operation.

As indicated in Table 4, CTDOT also began "pre-wetting" in 2006. CTDOT opted for pre-wetting to improve the effectiveness of the salt being applied. It is a commonly used practice to improve salt activation, retention of the salt on the road by reducing the effects of bouncing, blowing and sliding of the salt, and this improved performance can result in an overall reduction in salt use /7,6/. The application rate was derived from a National Cooperative Highway Research Program (NCHRP) study 577,/20/, experience and the capabilities of the CTDOT fleet and equipment. Initially, a calcium chloride solution was used (2006 – 012), until availability of the material became problematic. For this reason, CTDOT began using a magnesium chloride solution for pre-wetting, beginning during the 2010 season, and changed to all magnesium chloride solution for pre-wetting in 2012. Correspondingly, facilities and equipment received the necessary upgrades to accommodate the new practices. Facilities were equipped with liquid chloride storage tanks and trucks with saddle-tanks for the purpose of pre-wetting. Since 2007, new fleet trucks are pre-equipped when purchased with larger tanks (125 gallon) integrated on the vehicle.

Weather technology advancements include the use of RWIS/21, 22/ and vehicle-mounted pavement (surface) temperature monitors. The improved temperature and field data enable improved application of anti-icing methods and storm management decision-making.

Table 4: CTDOT Snow and Ice Control Maturity Chart

Prior to 2006	2006 – 2013	2013-2014 Season and Beyond
Strategy : Deicing	**Strategy: Anti-Icing**	**Strategy: Anti-Icing**
• Sand & Sodium Chloride (7:2 Ratio) Rate: 1564 lbs./2-lane mile (LM), (non-multi-lane) • Sodium Chloride Rate: 432 lbs./2-LM	Sodium Chloride Rate: 200 lbs./LM	Sodium Chloride Rate: 200 lbs./LM
CT Patent on Brine Truck Technology; 1979	Programmed Pre-treating at Select Locations: Brine Solution (23% Sodium Chloride); 2007 – 2013	Programmed Pre-treating at Select Locations: Brine Solution (23% Sodium Chloride)
Pre-treating and Brine Application Field Trial; 1997 – 1998	Pre-Wetting: (All Pre-mixed, uninhibited, unless indicated.) • Inhibited Calcium Chloride Solution (32%); 2006 – 2008 • Calcium Chloride Solution (32%); 2008 – 2010 • Calcium Chloride (32%) or Magnesium Chloride Solution 30%); 2010 – 2012 • Magnesium Chloride Solution (30%); 2012 – 2013	Pre-Wetting : 1 gallon Magnesium Chloride Solution/LM; Magnesium Chloride Solution (30% by weight)
First Road Weather Information System (RWIS) installed, Route 2, Lebanon, CT; 1997	Additional RWIS Installed	RWIS Network • 13 Existing RWIS Systems • 23 Additional Proposed
Fleet: • Began installing air and temperature sensors on maintenance vehicles; 1999	Fleet/Facilities: • Acquired Trucks and updated facilities for pretreating; 2006 • Continued to deploy air/pavement temp sensors on vehicles • Trial Rear-Center Vehicle Salt Application Spreader; 2009-2013 • Developed CT Rear Truck-Mounted Discharge Chute; 2012 • Underbody scraper blades, 6 Trucks	Fleet/ Facilities: • Increased salt brine capabilities at various maintenance garages. • Purchased Vehicles Rear-Center Vehicle Salt Application Spreader for use on multi-lane highways • Purchased industrial snow blowers; 2013 • Composite blades • Trial of Salt-Slurry Generation Applicator; 2013 • Purchase of three Salt-Slurry Generators

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The fleet, facility features and capabilities have continued to develop and evolve over time. Recent fleet advancements include methods of dispensing the salts, and snow-plowblade material (e.g. composites), designs (e.g., flexible blade systems), as well as addition of the "underbody scraper." The underbody scraper is an attachment used for removal of snow pack in high volume urban areas. This attachment is mounted mid-truck. The Department added industrial snow blowers to its fleet after the Blizzard of 2013 to improve the rate and efficiency of accumulated snow removal. CTDOT is currently developing a linear reference system (LRS) for the Connecticut highway network. This system will provide the ability to spatially link routing and other roadway attribute data for road network management purposes. It is envisioned that this technology will be utilized for snowplow route optimization, as well as providing the opportunity for further advances in snow and ice operations.

Innovation, Pilots and Trials

CTDOT has explored new methods to improve practices and conducted field trials and pilot studies. Some of the most recent methods tested include use of a corrosion inhibitor (2006/2007); non-intrusive sensor technology for RWIS data collection in 2013, bridge rinsing in 2012, the CTDOT rear-mounted discharge chute (2012) and the salt-slurry generator (2013).

- Vehicle Surface Temperature Sensors

Surface pavement temperature sensors were initially installed on several vehicles in 2000. Use of these devices proved to be reliable and instrumental to decision-making. Widespread implementation was adopted, resulting in all supervisory vehicles and lead echelon plow trucks being equipped with both air and pavement surface temperature sensors.

- Pre-Wetting

For pre-wetting, a calcium chloride liquid anti-icing agent solution with corrosion inhibitor was used on the state highway network for the 2006/2007 and a portion of the 2007/2008 seasons. It was purchased pre-mixed. Problems were encountered with the bulk storage of the corrosion inhibited calcium chloride resulting from settlement and coagulation within the tanks and in the clogging of the application nozzles. These problems were attributed to the corrosion inhibitor. In addition, there were concerns regarding the impact to the environment, specifically, the detrimental impact to aquatic life by increasing the biochemical oxygen demand and degrading the overall water quality. Little evidence was available to support the product effectiveness. Use of this product was discontinued. An uninhibited calcium chloride solution was then used for pre-wetting during remainder of the 2007/2008 winter season. Storage and nozzle clogging were not issues with the uninhibited solution.

- Advanced RWIS Technologies

Recent advancements in RWIS employ non-intrusive sensor technologies. This type of RWIS is being used at one location, and is proposed for additional sites. Its initial use during the winter of 2013/2014 appears to provide reliable information, and provides the benefit of being independent of pavement condition and repairs. Other states report similar results/23/.

- Bridge Rinsing

A pilot program was conducted to rinse residue and debris from non-lead bridge structures not located over watercourses. Methods and protocols, based on those employed in other states, were developed in cooperation with the Department of Energy and Environmental Protection (DEEP) for pre-stressed concrete and lead-free multi-beam steel structures. Discussions were held with New England states through the AASHTO Northeast Bridge Preservation Partnership (NEBPP) (https://tsp2bridge.pavementpreservation.org/). The pilot consisted of the rinsing of 25 structures and was completed on June 5, 2012.

- CTDOT Rear-Mounted Discharge Chute

In winter 2012/2013, CTDOT District II Maintenance employees developed a rear truck-mounted discharge chute for improved application of salt onto the centerline of the roadway. Figure 16 shows this innovative device. This innovation was awarded the Connecticut Transportation Institute's Creative Solutions Award in 2013. These devices have been successfully installed on the CTDOT rear-gate vehicle fleet, when applicable.

Figure 16: The Connecticut Rear Truck-Mounted Discharge Chute

- Salt-Slurry Generator

During the winter of 2013/2014, a trial of a salt-slurry generator was conducted. The salt-slurry generator, shown in Figure 17, is a vehicle-mounted device that provides greater efficiency to the pre-wetting and salt application process. This is accomplished by reducing the gradation of the salt for quicker activation; and is a better method for infusion of the deicing liquid. In addition, it provides the ability for increased pre-wetting rates /24/. The trial was conducted on a plow route selected in proximity to the CTDOT headquarters for visual evaluation. Adjustments were conducted as needed for the operation. Initial indications, based on visual observations, are that the technology shows the potential for benefit. The Department currently has three of these units in operation. Work is being undertaken to determine and adjust spreader control parameters as well addressing mechanical and operational items. Additional field testing is ongoing.

Figure 17: Salt-Slurry Generator

Operational Coordination and Oversight

Before, during and after a storm there is considerable operational coordination and oversight. As part of this process, there are strategically planned meetings, post-storm critiques, to review the effectiveness of the snow and ice control. These include a meeting after the first storm, every other storm, special conditions and major storm events, as well as after the season. There are weekly status reports during the season. Items that are reviewed include: material usage, transactions and balances, road conditions, contractor results, equipment performance and weather reporting. “Tailgate talks” are routinely held at garages to communicate with plow operators and maintenance personnel regarding issues, storm critique and safety topics.

An informal Snow and Ice Control Committee was formed in 2006 in an effort to strategize and develop the transition protocol and training from a deicing to an anti-icing priority. This committee was formalized into a Departmental Standing Committee in 2015. Personnel from the Bureau of Highway Operations and Maintenance, with representatives from the Bureau of Policy and Planning, Environmental Planning Division, Office of Engineering and the Bureau of Finance and Administration serve on the Committee. This committee typically meets on a monthly basis to provide valuable input and review of the process, including discussion and critique of snow and ice-related issues and concerns, environmental policy and materials. As a Standing Committee, this committee will produce an annual report describing their activities, deliberations and information from assessing the state-of-the-practice.

Training, Outreach and Collaboration

The Department conducts training on snow and ice control. New and experienced workers comprising employees from CTDOT Maintenance, as well as other areas of CTDOT and DEEP, receive annual classroom and field instruction. Field training includes area and route-specific instructions in conjunction with the staking and marking activities for the upcoming season.

Educational programs and resources are provided to staff from municipal agencies through the Connecticut Technology Transfer Program (T^2), funded jointly by FHWA and CTDOT through UConn's Connecticut Transportation Institute (CTI). Numerous educational programs are provided by T^2 that are designed to address snow and ice operations. These include: a "Public Works Academy" for new municipal public works employees, with one day designated "Safe Operation of a committtt and Winter Operations," typically taught by CTDOT staff; The "Road Master Program," designed for participants from municipal agencies and CTDOT, that includes instruction on "Planning and Managing Snow and Ice Operations;" and the "Road Scholar Program," that includes roundtable discussions on the topic of winter operations for attendees from municipal and state agencies (CTDOT, DEEP, etc.). In addition, informal "Winter Operations Roundup(s)" are held periodically after the winter season to debrief while issues are fresh. Resources and outreach include technical and safety briefs, /25, 26/ as well as opportunities to be informed on practices through surveys (T^2 CT Winter Operational Survey, [2012]), demonstration of new techniques and equipment at T^2 Expos and T^2 Newsletter articles. In addition, T^2 provides a very successful "Public Works Online Forum" that is used routinely during storms to share information, request mutual aid, and as well as a mechanism for state agencies to disseminate information to the public works community.

CTDOT seeks opportunities to improve practice by having discussions with other state agencies. As part of this effort, Connecticut joined the FHWA Pooled Fund Project TPF-5(218), "Clear Roads Winter Highway Operations." This research program focuses on practical research for winter highway maintenance. It has 29 member states /26/. Extensive information is available on the project's website, www.ClearRoads.org.

CTDOT Office of Maintenance staff are actively engaged in seeking out information on best practices to employ in Connecticut through dialogue, webinars and literature /27/. Snow and ice operations are the focus of discussions at AASHTO meetings, as well as regional sessions. Connecticut has had ongoing dialogue with practitioners in New York State who have similar weather and challenges.

Integrated Operations

Improved snow and ice operations are achieved through coordinated efforts with other functional areas, agencies and organizations. CTDOT's operations centers, located in Newington and Bridgeport, monitor traffic and weather conditions 24/7 and support the storm room during severe winter weather. These monitoring operations include utilizing 324 available traffic cameras statewide, as well as communicating with the State Police on any weather-related incidents that occur and apprising the storm monitors and the operation managers. To facilitate mobility, traffic signal timing on specific routes is adapted to winter weather conditions to improve operations.

The referenced highway traffic cameras are available for public access and media use. The traffic camera images are routinely broadcast to the public as part of television news reports, where they are instrumental in providing the public visual condition information for travel decisions. CTDOT provides weather information on their website, in a section entitled, "Weather Round-up," (http://www.dotdata.ct.gov/WeatherRoundUp/WRU_Index.HTM). Information shared on the "Weather Round Up' is often used by towns and contractors for operations and is available for use by travelers for up-to-date information on temperatures, precipitation types and accumulations from around the state during winter weather events.

CTDOT is affiliated with TRANSCOM (Transportation Operations Coordinating Committee) (http://xcm.org) which is a coalition of 16 transportation and public safety agencies in the New York, New Jersey, and Connecticut metropolitan region. The aim of TRANSCOM is to update the coalition for the purpose of coordination with regard to accidents, road closures, traffic bans and any other traffic impacts related to storm or construction events. Through this program, conference calls are usually held throughout a specific event to get updates on road and public transportation conditions throughout the region. This facilitates the exchange of important information regarding cross-state road conditions for highway, transit and freight movement.

During extreme weather, the Governor may activate the State Emergency Operations Center (EOC) to conduct additional coordination with other state agencies. CTDOT will have staff representatives at the EOC during this time to address concerns as they arise. The Governor has the authority to declare travel bans.

Summary

CTDOT conducts snow and ice operations to keep the highway network reasonably safe and passable during winter weather events and to provide the best level of service within the limitations imposed by weather conditions; the availability of equipment, material and personnel; and environmental concerns. Snow and ice operations are essential for public safety, mobility and to minimize negative economic impacts. Advancements in technology and knowledge gained from operations and research have improved the state's winter maintenance practices. These include the anti-icing approach, pre-treating and pre-wetting methods, as well as new technologies for improved assessment of road conditions, material placement and fleet operations. CTDOT has adopted advancements and continues to actively seek improved practices to address the complex challenges of winter highway maintenance.

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APPENDIX D
QUESTIONS ASKED IN SURVEY OF CONNECTICUT MUNICIPALITIES

Thank you for taking time out of your busy schedule to complete this survey regarding salt usage in your agency, as well as your current practices. The survey is being conducted as part of a research study in conjunction with the Connecticut Academy of Science and Engineering.

This research study is in response to Public Act 14-199 that requires the Connecticut Department of Transportation to conduct an analysis of corrosion effects of chemical road treatments.

The results from this survey will not be published with your Municipality's name associated to the data, so it will not be possible to connect any specific practices with a particular Municipality.

The information from this survey will be used as part of the report to respond to the requirements of Public Act 14-199.

If you have at hand the salt and/or sand usage statistics for your Municipality for the winter seasons 2009-2010 through 2013-2014, the time to complete this survey should be under 15 minutes. If you need to gather information on salt and sand use quantities, we greatly appreciate your efforts in doing so. We realize that completing this survey is an additional task that consumes your valuable time, but we believe the information is quite important for optimizing use of resources for winter maintenance in Connecticut in the future.

Thank you in advance for your participation.

If you have any questions, please feel free to contact me:

Jim Mahoney
Connecticut Transportation Institute
University of Connecticut

james.mahoney@uconn.edu
860.486.9299

Please provide the following General Information

***1. Municipality Name**

***2. Name of Person Responding**

3. Title of Person Responding

***4. Email Address**

5. Telephone Number

***6. Number of Center Lane Miles Maintained in Your Municipality?**

Information about Quantities of De-Icing Chemicals Used During the Past 5 Years (Winter Seasons), Starting with 2009-2010, should be entered below.

7. Please enter the annual estimated tons of straight salt (sodium chloride) and solar salt used by your municipality for each of the five winter seasons indicated.

(There is a later question (Q8) about proprietary salt products such as, for example, Magic Salt and Clearlane. Please do not include those quantities here in Q7)

Tons of Salt Used 2009/2010

Tons of Salt Used 2010/2011

Tons of Salt Used 2011/2012

Tons of Salt Used 2012/2013

Tons of Salt Used 2013/2014

8. During any of the five Winter seasons indicated, did you use any proprietary, treated or alternative salt products? If so, could you please list them by season, and enter the approximate tonnage of each product used? If you used more than one proprietary product in a given year, please list all of them, including tonnage.

(Please be as specific as possible with the names as there are minor differences in the names some companies use, and yet it has a big impact on what is contained in the product)

Alternative Product(s) Used in 2009/2010

.......and Tons Used 2009/2010

Alternative Product(s) Used in 2010/2011

.......and Tons Used 2010/2011

Alternative Product(s) Used in 2011/2012

.......and Tons Used 2011/2012

Alternative Products(s) Used in 2012/2013

.......and Tons Used 2012/2013

Alternative Products(s) Used in 2013/2014

.......and Tons Used 2013/2014

9. In the five winter seasons indicated below, did you use any sand? If so, could you please indicate the approximate quantity of sand you used in tons, by year.

Tons of sand used 2009/2010 [ ]

Tons of sand used 2010/2011 [ ]

Tons of sand used 2011/2012 [ ]

Tons of sand used 2012/2013 [ ]

Tons of sand used 2013/2014 [ ]

The next seven questions refer to newer or "innovative" techniques such as pre-treating, pre-wetting, and use of biodegradable non-chloride products, which might affect the amount of salt you use.

10. Do you pre-wet solid salt before you apply it to the roads? If yes, what is your application rate in gallons per-ton-of-solid-applied?

11. Do you pre-treat roadways with liquids before storms? If yes, what is your application rate in gallons per center-line mile?
Note: If you pre-treat with solid chemicals, that information is captured in a later question (Q12).

12. Do you pre-treat roadways with solids before storms? If yes, what is your application rate in pounds per center-line mile?

13. If you use a liquid or solid pre-treatment, please indicate where this is accomplished (for example, bridges treated only, intersections only, hills and trouble spots only, selected roads, or entire road network)

- ☐ Bridges pre-treated
- ☐ Intersections pre-treated
- ☐ Hills and trouble-spots pre-treated
- ☐ Selected routes pre-treated
- ☐ Entire road network pre-treated
- ☐ Other

14. If you selected "Other" for question 13, please explain here; otherwise skip to question 15.

15. If you pre-treat (i.e., answered questions 11 or 12), please describe below when and how you apply the pretreatment materials.

16. Do you use non-chloride biodegradable liquid by-products? If yes, what products have you used?

(Biodegradable by-products may include beet juice, molasses, corn derivatives, etc.)

17. If there are any other innovative techniques that you utilize that you care to share information about, please do.

You are almost done with the survey. The final six questions refer to equipment and winter maintenance procedures. And you are then welcome to provide any additional comments to us.

18. Have you noticed an increase in the corrosion rate of your plowing/chemical spreading equipment over the past five years? Please rate on a scale of 0 to 10 for severity.

(0 being no noticeable increase, 5 being a moderate increase, up to 10 being a major increase in corrosion).

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

19. What is the approximate average age of your winter maintenance plowing/chemical spreading equipment fleet?

Age in Years

20. What is your anticipated average service life for winter plowing/chemical spreading maintenance equipment, in years?

○ 5 years ○ 6 years ○ 7 years ○ 8 years ○ 9 years ○ 10 years ○ 15 years ○ 20 years ○ Other

21. How often do calibrate your salt spreading equipment?

22. Do you use ground speed control to spread chemicals?

○ Yes

○ No

23. Approximately what percentage of your fleet equipment contains ground surface temperature sensors?

Percent

24. Any other comments about winter maintenance or this survey are welcome here.

You are finished. THANK YOU for participating in this survey!

APPENDIX E
ADVANTAGES AND DISADVANTAGES OF DEICERS

Deicer Type	Advantages	Disadvantages
Abrasives	• Provides traction on ice • Provides color delineation for travel lanes for public assurance that a product has been applied to the road surface • Use is independent of temperature	• Does not lower freezing/melting point of ice (However, dark color of abrasive may help accelerate ice melting with sunshine) • Traffic causes migration of abrasives from roadways into ditches off roadways • Can increase water turbidity and be detrimental to the surrounding environment • Clogs drainage systems and accumulates in runoff areas, including streams and ponds • Can increase air pollution • Clumps together and freezes when damp, unless mixed with deicers • Absorbs and impedes effectiveness of deicers • Causes buildup on road shoulder areas precluding sheetflow runoff often requiring additional road maintenance • Material must be removed in the spring and summer at significant cost, both time and expense
Sodium Chloride	• Least expensive deicer for Connecticut and most states • Most prevalent deicer product (i.e., widespread availability) • Causes less deterioration of Portland Cement Concrete compared to other chlorides [21] • Can be used for anti-icing, deicing and pre-wetting • Not as hygroscopic (moisture absorbing) as other chlorides at moderate levels of relative humidity(which is beneficial for storage of solid form, and for pretreating roads with brine)	• Detrimental to surrounding environment (particularly for degradation of water quality in surface and groundwater, build up in soil and negative effects on some types of roadside vegetation from surface runoff, aerosols from vehicle spray, and wind) • Not very effective as a deicer when ambient temperatures are below 15°F, unless large quantities are used • Accelerates corrosion of metals including steel reinforcement in pavements and bridge structures • Corrosive to some motor vehicle components • Attracts animals to roadsides, which can be a safety hazard to motorists and animals • Can raise sodium levels in drinking water, adversely affecting human health

Deicer Type	Advantages	Disadvantages
Magnesium Chloride	• Lowers the freezing/melting point of water to approximately 5°F • Even at low temperatures solid magnesium chloride works quickly due to its ability to absorb moisture from the atmosphere (hygroscopic nature) • Can be used for anti-icing, deicing and pre-wetting	• Causes corrosion of metals including steel reinforcement in pavements and bridge structures • Corrosive to some motor vehicle components • Can accelerate corrosion (compared to sodium chloride) due to moisture absorption (magnesium chloride absorbs moisture from the atmosphere when relative humidity is as low as 30%, [22] which keeps surfaces on which it has adhered to wet) • Moisture attraction can make a pavement wet and potentially slick when the magnesium chloride is at a high enough concentration such as when it is used for anti-icing (pre-treating) • Magnesium ions can cause more severe concrete deterioration than sodium chloride [21] • In solid form, straight magnesium chloride is considerably more expensive than sodium chloride (> $150/ton)
Calcium Chloride	• Works effectively to lower the freezing/melting point of water to at least 25°F below that of sodium chloride and water • Works quickly due to its hygroscopic nature • Can be used for deicing, as brine for pre-wetting or anti-icing • Releases heat (exothermic) when applied as a solid and combines with moisture	• The calcium in calcium chloride can react with other elements in concrete and cause deterioration of the concrete • Can cause corrosion of metals in reinforced concrete for roads and bridges • Corrosive to some motor vehicle components • Considerably more expensive than sodium chloride (> $160/ton) • Its ability to attract moisture can make a pavement wet and potentially slick when present in high concentrations such as when it is used in anti-icing pretreatments • It is so hygroscopic that as a solid it eventually dissolves in the water it absorbs; this property is called deliquescence. To prevent this it must be kept in tightly-sealed containers
CMA	• Low toxicity to plants • Biodegradable • Main ingredient, dolomitic lime is abundant throughout the United States • Does not cause corrosion to most metals • Low toxicity to fish • Assists in prevention of surface water re-freezing • Reduces snow crystal tendency to stick together	• Only effective above 20° F • Can potentially lower dissolved oxygen concentrations in soils and receiving waters,[24] • Cost is at least 20 times that of sodium chloride (> $1,500/ton) [10] • Uses large quantities of energy in its production process (i.e., greater life cycle cost) • Due to lower density and greater quantity required to be effective, CMA requires more storage space than chlorides [23] • Requires a higher application rate than salts • Can cause deterioration of concrete due to calcium's chemical reaction with cement • Does not ionize as readily as sodium chloride, slowing initial reaction time, and therefore, is less successful than sodium chloride in melting snow and ice accumulations (particularly fluffy, dry snow)

Deicer Type	Advantages	Disadvantages
Sodium Acetate	• Exothermic (i.e., gives off heat when reacting with water) and therefore, helps prevent melted snow from re-freezing • Non-toxic (used in food and medical products) • Biodegradable • Generally non-corrosive to vehicles, bridges and utilities, which is especially critical for use in connection with aircraft operations and electronic runway lighting • Lowers the freezing point of water to 0°F	• Much more expensive than sodium chloride (>$ 1,900/ton) • May cause eye or skin irritation in solid form • Inhalation of dust during handling may cause respiratory tract irritation and coughing • May be corrosive to galvanized steel, zinc and brass • Quantities could become limited if selected for wider use such as on roadways • Decomposition can reduce dissolved oxygen in bodies of water
Potassium Acetate	• Low toxicity to fish, mammals and vegetation • Biodegradable • Biodegrades at low temperatures, and thus produces relatively low increase in BOD during spring thaw when temperatures rise • Generally non-corrosive to vehicles, bridges and utilities • Melts snow and ice twice as fast as sodium chloride at 20°F [3] and unlike most chlorides is active below zero degrees • Lowers the freezing point of water to -75°F at specific concentrations • Meets FAA approved specifications	• Corrosive to stainless steel • Expensive compared to sodium chloride ($2,000/ton; $5.50/gallon at 50% concentration) • May cause gel-like precipitate when mixed with sodium chloride for pre-wetting [20] • Decomposition can reduce dissolved oxygen in bodies of water • Dry compound is combustible so it is typically sold in liquid form for highway uses
Sodium Formate	• Relatively non-toxic • Similar deicing characteristics to sodium chloride	• Very limited usage experience in the United States — possibly at some airports • Data pertaining to a sodium acetate /sodium formate-based deicer suggests that during the spring thaw runoff, short periods of oxygen depletion in receiving waters may occur, with potential danger in warmer weather (Bang and Johnston, 1998) [30]
Potassium Formate	• Makes snow softer and less sticky • May be less detrimental to the environment than sodium chloride	• May be corrosive to electrical connectors • Not used very extensively in the United States • Limited information is available about this deicer • Decomposition can reduce dissolved oxygen in bodies of water

Deicer Type	Advantages	Disadvantages
Carbohydrates / Agricultural or Organic Byproducts	• Enhances performance of other deicers when mixed with them, thus, allows for potentially less deicer use per mile, which can reduce the amount of chlorides released into the environment • Helps sodium chloride "stick" to the road, (i.e., less bounce and scatter) • Dark color assists melting when in sunlight • Dark color provides for color delineation of travel lanes during snowy conditions	• Sticky when handling and applying • Expensive • Does not have significant ice melting capacity when used alone • The organic contents of byproducts when broken down may cause temporary anaerobic soil conditions as well as oxygen depletion in surface waters • Stickiness could cause chlorides (such as sodium chloride and magnesium chloride) to adhere to metals for longer periods of time.
Urea	• Non-corrosive to steel reinforcement • Fertilizes plants	• Is not very effective as a deicer below 25°F • Can cause sinus respiratory and eye irritation • Corrosive to some metals • Can burn (damage) vegetation in high quantities • Urea, by itself, has a high BOD and decreases the available oxygen to aquatic organisms • Costs approximately 500% as much as sodium chloride
Propylene Glycol	• Non-toxic • Biodegradable • Non-corrosive to metals • Works at very low temperatures • Safe for handling	• Expensive • Depletes oxygen in waters which can adversely affect aquatic life
Treated Road Salt (Proprietary)	• Performance at low temperatures (due to presence of magnesium chloride) • 70% less corrosive to steel (per PNS test as stated by manufacturers) than plain sodium chloride (due to the inclusion of corrosion inhibitors) • Less bounce and scatter (due to presence of water and biodegradable additives) • Potential lower total use of sodium chloride as a result of faster and lower temperature melting capabilities	• Degradation of Portland Cement Concrete (PCC) is possible in the presence of magnesium chloride (Magnesium ions cause more severe concrete deterioration than other constituents of common deicing chemicals) [2] • Detrimental to surrounding environment (particularly for degradation of water quality in surface and groundwater, build up in soil and negative effects on roadside vegetation from surface runoff, aerosols from vehicle spray, and wind) due to presence of sodium chloride • Products containing sodium chloride attract animals to roadsides, which can be a safety hazard to motorists • Products containing sodium chloride, can raise sodium levels in drinking water, adversely affecting human health

APPENDIX F
PACIFIC NORTHWEST SNOW FIGHTERS QUALIFIED PRODUCT LIST – PRODUCTS

Pacific Northwest Snow Fighters (PNS) Qualified Product List - PRODUCTS
Date of Listing: November 24, 2014

Category 1 - Corrosion Inhibited Liquid Magnesium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Iceban 200*	Earth Friendly Chem.	8.4	26%	8/15/2002
Caliber M1000 AP	Envirotech Services Inc.	20.8	28%	8/2/2004
Meltdown with Shield AP	Envirotech Services Inc.	25.9	30%	8/2/2004
Hydro-Melt Green	Cargill	24.3	28.5%	8/1/2005
Meltdown APEX with Shield AP	Envirotech Services Inc.	25.1	30%	1/25/2006
FreezGard CI Plus	North American Salt	12.2	30%	8/28/2006
Ice B'Gone II HF	Sears Ecological Appl.	28.6	25%	8/9/2007
FreezGard LITE CI Plus	North American Salt	12.3	27%	6/13/2011
HydroMelt Liquid Deicer	Cargill	28	28.6%	8/15/2011
FreezGard CI Plus Sub Zero	North American Salt	14.1	27.5%	10/11/2011
Ice Ban 305	GMCO Corporation	25.3	26.6%	1/10/2013
FreezGard 0 CCI	GMCO Corporation	21.2	30.0%	1/10/2013
Meltdown Apex	Envirotech Services Inc.	22.4	30.0%	4/16/2014
Meltdown Inhibited	Envirotech Services Inc.	24.1	30.0%	4/29/2014

Note-Iceban 200 was formerly Iceban Performance Plus M
Those products marked with an asterisk (*) indicates that the stratification can be seen and agitation is required.

Category 2 - Corrosion Inhibited Liquid Calcium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Liquid Dow Armor	Dow Chemical	26	30%	6/25/1999
Winter Thaw DI	Tetra Technologies	16.5	32%	9/13/1999
Corguard TG	Tiger Calcium Services	27.7	29%	1/9/2001
Road Guard Plus	Tiger Calcium Services	16	25%	6/5/2006
Calcium Chloride with Boost (CCB)	America West	18.4	32%	4/10/2014

Category 3 - Non Corrosion Inhibited Liquid Calcium Magnesium Acetate

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Liquid CMA 25%	Cryotech	-11	25%	5/19/1998
SC CMA 25%	Sure Crop Farm Services	-2.8	25%	9/13/1999

Category 4 - Corrosion Inhibited Solid Sodium Chloride

Category 4A- Corrosion Inhibited Solid Sodium Chloride (Corrosion Percent Effectiveness of 30% or less)

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Inhibited Ice Slicer	Envirotech	30	N/A	5/19/1998
CG-90 Non-Phosphate 2.8%	Cargill	27	N/A	5/19/1998
IMC CI SALT A 3.5	North American Salt	28	N/A	8/21/2001
IMC CI SALT B 4.5	North American Salt	18.6	N/A	8/21/2001
Clear Lane PNS Enhanced Deicer	Cargill	28.9	N/A	8/1/2005
Ice Slicer Elite	Envirotech	16	N/A	8/1/2005

Category 4B- Corrosion Inhibited Solid Sodium Chloride (Corrosion Percent Effectiveness 31% to 85%)

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Ice Slicer RS	Redmond	80	N/A	10/13/2009
Ice Slicer Super Blend Plus	Redmond	60.4	N/A	10/13/2009

Category 5 - Corrosion Inhibited Sodium Chloride Plus 10% Magnesium Chloride (Solid)

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
CG-90 Surface Saver 10%	Cargill	15	N/A	5/19/1998
Meltdown 10	Envirotech	30	N/A	5/19/1998
Surface Saver PNS 10%	Cargill	27.2	N/A	8/21/2001

Category 6 - Corrosion Inhibited Sodium Chloride Plus 20% Magnesium Chloride (Solid)

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
CG-90 Surface Saver 22%	Cargill	26	N/A	5/19/1998
Meltdown 20	Envirotech	27	N/A	8/8/2000
Surface Saver PNS 20%	Cargill	22	N/A	8/21/2001

Category 7 - Calcium Magnesium Acetate (Solid)

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
CMA	Cryotech	-7	96%	5/19/1998

Category 8 - Non Corrosion Inhibited Solid Sodium Chloride

CATEGORY 8A-B Standard Gradation, Brining Salt, Insoluble Material less than 1%, and Moisture less than 0.5%.

Product Name	Manufacturer			Date Approved
DriRox Coarse Salt*	North American Salt			9/21/2012
Bulk Coarse Solar	Morton Salt			4/21/2006
Intrepid Coarse Salt	Intrepid Potash			6/3/2010

* Product was renamed from NASC Salt (Coarse). The product has been approved since 8/2000.

CATEGORY 8A-R Standard Gradation, Road Salt, Insoluble Material less than 10%, and Moisture less than 0.5%.

Product Name	Manufacturer			Date Approved
Cargill Dry Salt	Cargill			6/1/1998
Mineral Melt	NSC Minerals			6/1/1998
DriRox Coarse Salt*	North American Salt			9/21/2012
Kayway Salt (Coarse)	Kayway Industries			12/23/2003
Bulk Coarse Solar	Morton Salt			4/26/2005
Ice Slicer Super Blend	Redmond Mineral			8/2/2006
ISCO Bulk Rock Salt	K+S			6/23/2008
Natural Alternative Ice Melt	NaturaLawn of America			5/17/2010
Intrepid Coarse Salt	Intrepid Potash			6/3/2010

* Product was renamed from NASC Salt (Coarse). The product has been approved since 8/2000.

CATEGORY 8B - Insoluble Material less than 10%, and Moisture less than 5.0%.

Product Name	Manufacturer		%Moisture	Date Approved
Ice Slicer RS	Redmond Mineral		1.95	2/9/2003
QwikSalt	North American Salt		2.54	6/30/2004
Type C Treated Salt	Broken Arrow		2.94	8/2/2004
SS-5.0	Shelton's Salt		0.90	9/16/2004
Bulk Type C Road Salt	Morton Salt		2.63	4/26/2005
ESSA Salt	ESSA		0.84	6/26/2007
Rapid Thaw	Broken Arrow		2.49	3/4/2009
Bulk Deicing Salt	Central Salt		2.39	6/24/2013

CATEGORY 8C-B Fine Gradation, Brining Salt, Insoluble Material less than 1%, and Moisture less than 0.5%.

Product Name	Manufacturer			Date Approved
Mineral Melt	NSC Minerals			3/1/2006
Quick Brine RF	NSC Minerals			3/1/2006
Rocanville Standard Road Salt	NSC Minerals			10/6/2006
Medium Solar Salt	North American Salt			8/12/2009
Mixing Solar Salt	North American Salt			8/12/2009
Intrepid Medium Salt	Intrepid Potash			6/3/2010

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CATEGORY 8C-R, Fine Gradation, Road Salt, Insoluble Material less than 10% and Moisture less than 0.5%.

Product Name	Manufacturer			Date Approved
Mineral Melt	NSC Minerals			3/1/2006
Quick Brine VS	NSC Minerals			3/1/2006
Quick Brine RF	NSC Minerals			3/1/2006
Rocanville Standard Road Salt	NSC Minerals			10/6/2006
Medium Solar Salt	North American Salt			8/12/2009
Mixing Solar Salt	North American Salt			8/12/2009
Intrepid Medium Salt	Intrepid Potash			6/3/2010
Ice Slicer Near Zero	Redmond Minerals			12/3/2010

Category 9 - Corrosion Inhibited Liquid Sodium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Salt Brine + Brine CI	Cargill	25.4	23.3	8/12/2009
Brine with Headwaters Inhibitor	Rivertop Renewables	25.6	22.5	11/24/2014
Brine with Headwaters 10F Inhibitor	Rivertop Renewables	26.7	22.4	11/24/2014

Category 10 - Corrosion Inhibited Liquid Sodium Chloride Plus Calcium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
TC Econo*	Tiger Calcium Services	20.5	20/2(1)	8/12/2009
Beet Heet Severe	K-Tech Specialty Coatings	21.1	15.3/5.4(2)	7/13/2011
ESB	America West	21.0	18.8/2.3(3)	4/14/2014
SO-CAL	Custom Spray Services	27.8	20.8/2.5 (4)	4/14/2014

1 - 20% NaCl and 2% $CaCl_2$

2 - 15.3% NaCl and 5.4% $CaCl_2$

3- 18.8% NaCl and 2.3% $CaCl_2$

4 - 20.8% NaCl and 2.5% $CaCl_2$

Category 11 - Corrosion Inhibited Liquid Chloride Blended Brines

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Road Guard Plus*	Tiger Calcium Services	16	27 (1)	8/12/2009
Road Guard TC	Tiger Calcium Services	21.3	32.1 (2)	8/12/2009
Road Guard XCEL	Tiger Calcium Services	20.3	33.2 (3)	8/12/2009
IB 7/93-Thermapoint	Millennium Roads	24	26.7(4)	5/1/2013

1 - 25% Calcium Chloride and 2% Magnesium Chloride
1 - 27.3% Calcium Chloride and 4.8% Magnesium Chloride
2 - 28.5% Calcium Chloride and 4.7% Magnesium Chloride
4 - 17.8% Calcium Chloride, 5.4% Sodium Chloride, and 3.5% Magnesium Chloride
Those products marked with an asterisk (*) indicates that the stratification can be seen and agitation is required.

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PNS Experimental Category - Approved Liquid Corrosion Inhibited Products

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
CF-7	Cryotech	0.0	50(1)	6/20/2001
CMAK	Cryotech	0.0	12.5/25(2)	6/20/2001
NC 3000	Glacial Technologies	-3.5	25(3)	3/13/2002
Alpine Ice-Melt	Nachurs Alpine Sol. Ind.	-4.8	50(4)	6/23/2008
Fusion 60/40	Eco Solutions	22.1	15.0(5)	11/23/2009
Beet Heet Concentrate***	K-Tech	14.8	21.7(6)	9/26/2012
AquaSalina+	Nature's Own Source	26.4	22.5(7)	9/19/2013
Isoway	Omex Environmental	-5.1	25.0(8)	4/15/2014
Geomelt S7	SNI Solutions	25.9	18.1(9)	4/17/2014
SOS AP***	Envirotech Services	21.0	26.0(10)	4/18/2014
SOS Inhibited***	Envirotech Services	25.3	26.0(11)	8/28/2014
AQ+IceBite Liquid Brine Deicer	Nature's Own Source	11.4	20.4(12)	8/28/2014
Ecolution Liquid Deicer	State Industrial Products	26.5	24.6(13)	8/28/2014
Ice Bite S	Road Solutions Inc.	15.0	22.1(14)	10/21/2014
XO-Melt$_2$	K-Tech	22.9	24.5(15)	11/3/2014
Husker Plus***	Smith Fertilizer and Grain	10.2	36(16)	11/24/2014

1 - 50% Potassium Acetate
2 - 12.5% Calcium Magnesium Acetate and 25% Potassium Acetate
3 - The product contains a 25% Potassium Acetate concentration. The product also contains 30% Carbohydrate material which is still under consideration as an active ingredient but at this time has not be included.
4 - 50% Potassium Acetate
5 - 15.0% Sodium Chloride, blend of 60% Fusion/ 40% Salt Brine
6 - Total Chloride Salt Blend with $CaCl_2$-11.9%, $MgCL_2$- 3.4%, KCL-2.7%, NaCl-3.7% . Carbohydrate content-28.8%. ***Material approved as a pre-wet material to solid salt. Not for direct application as a liquid deicer.
7 - Total Chloride Salt Blend with $CaCl_2$-9.0%, $MgCL_2$- 2.5%, and NaCl-11.0% .
8 - 25% Potassium Acetate
9 - 18.1% Sodium Chloride, blend of 30% Geomelt 55/ 70% Salt Brine.
10 - 26.0% $MgCl_2$ with a thicking additive. ***Material approved as a pre-wet material to solid salt. Not for direct applications as a liquid deicer.
11 - 26.0% $MgCl_2$ with a thicking additive. ***Material approved as a pre-wet material to solid salt. Not for direct applications as a liquid deicer.
12 - Total Chloride Salt Blend with NaCL-13.0% and $CaCl_2$-7.4%, blended with 15% IceBite.
13 - Total Chloride Salt Blend with $CaCl_2$-9.8%, $MgCL_2$- 2.3%, and NaCl-12.5% .
14 - 22.1% Sodium Chloride.
15 - Total Chloride Salt Blend with CaCl2-12.3%, MgCL2- 2.1%, and NaCl-10.1% .
16 - 36% Mixed Matrix Organic Salt Compounds derived from Sugar. ***Material approved as a pre-wet material to solid salt. Not for direct application as a liquid deicer.

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Pacific Northwest Snow Fighters (PNS) Qualified Product List - INHIBITORS
Date of Listing: July 18, 2014

Category A1 - Corrosion Inhibitor for Sodium Chloride Brine (Minimum 21% NaCl)

Product Name	Manufacturer	% NaCl		% Additive	Class	% Effectiveness	Date Approved
ArctiClear CI Plus	North American Salt	21.2		5	1	21.3	12/3/2010
Headwaters Corrosion Inhibitor	Rivertop Renewables	22.5		3.5	1	24.9	4/15/2014
Shield GLT Plus	Paradigm Chemical	22.6		5	1	28.7	4/15/2014
Headwaters 10F Corrosion Inhibitor	Rivertop Renewables	22.4		4.5	1	26.7	7/18/2014

Category A2 - Corrosion Inhibitor for Sodium Chloride and Calcium Chloride Brine (Minimum 15% NaCl & 2% $CaCl_2$)

Product Name	Manufacturer	% NaCl	% $CaCl_2$	% Additive	Type/Class	% Effectiveness	Date Approved
Boost SB	America West	18.8	2.3	20	I / 2	21.0	4/14/2014

Category A3 - Corrosion Inhibitor for Sodium Chloride (Minimum 15% NaCl)

Product Name	Manufacturer	% NaCl		% Additive	Class	% Effectiveness	Date Approved
ArtiClear Gold	North American Salt	18.8		15	2	26.6	12/3/2010
Beet 55 Concentrate	Smith Fertilizer & Grain	17.2		35	2	23.1	9/19/2013
Geomelt 55	SNI Solutions	18.1		30	2	25.9	4/17/2014

APPENDIX G

SUMMARY OF LABORATORY STUDY LITERATURE FOR DEICER CHEMICALS AND PORTLAND CEMENT CONCRETE

Lab Study (reference) Location	Test Type	Description of Test Performed	Official Test Method(s)	Specimens Used	Solutions Used (and Explanation)	Study Results
Peterson **[95]** **Sweden**	Soak	Immerse in 29 liters of solution **at 41**°F for 22 to 32 months (checked each month)	Not cited	**48 mortar prisms** **0.8 in x 0.8 in x 11 in** length change 24 at w/c 0.45 and 24 at w/c 0.60 Air content not given	• 25.9% NaCl • 42.7% $CaCl_2$ • 30.7% CMA • 26.7% Calcium Acetate	*Primary study objective was to test CMA in non-freeze soak* *Tests:* • Length change (monthly) • Mass change (monthly) • pH (monthly) • flexural strength (at end of study) • compressive strength (at end of study) Results: **calcium chloride solution**. Solutions with very low and very high concentration do not attack the concrete, but solutions with an intermediate concentration may destroy the concrete by strong expansion within a few days. Note, a calcium chloride solution on a concrete surface will constantly change concentration due to relative humidity. **CMA**: The attack of the CMA product according to our sample was so severe that this product should not be used for deicing of bridges and concrete roads. An essential condition for this attack is, however, that the temperature of the solution has the opportunity to rise well above the freezing temperature.
	Soak	Immerse in 29 liters of solution **at 68**°F for 22 to 32 months (checked each month)	Not Cited	**48 mortar prisms** **1.6 in x 1.6 in x 6.3 in** Mass and strength change 24 at w/c 0.45 and 24 at w/c 0.60 Air content not given	• 25.9% NaCl • 42.7% $CaCl_2$ • 30.7% CMA • 26.7% Calcium Acetate	
Cody et al **1996** **[96]** **Iowa State University**	Soak	Immerse in 100 ml solutions at 140°F for 222 days; test cycle observations performed every 132 hrs (5.5 days)	Not Cited	*All Iowa highway cores contained dolomite aggregate from the Silurian Hopkinton Formation or the Ordovician Galena Formation* (air content not given) • Rectangular **blocks** **0.5 in. x 0.5 in. x 1 in.** cut from **High** durability **PCC cores** from in-service highways • Rectangular **blocks** **0.5 in. x 0.5 in. x 1 in**. cut from **Low** durability **PCC cores** from in-service highways	• 17.6% NaCl = 3 M • 33.3% $CaCl_2$ = 3 M • 28.6% $MgCl_2$ = 3 M • Distilled Water • Magnesium Acetate • Magnesium Nitrate	The experiments document that the substitution of magnesium and/or calcium deicers for rock salt may have unintended consequences in accelerating concrete deterioration. Long-term, carefully controlled field experiments with magnesium and calcium deicers are essential in order to fully determine the effects of long-term use of these deicers under highway conditions and to determine if they are suitable substitutes for rock salt.

Continued **Cody et al 1996 [96] Iowa State University**	W/D	• Wet at 140°F; dry at 194°F; 4 cycles (each complete test cycle = 6.5 days) • Wet at 140°F; dry at 140°F; 6 cycles		• Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **High** durability PCC cores from in-service highways • Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **Low** durability PCC cores from in-service highways	• 17.6% NaCl = 3 M • 33.3% $CaCl_2$ = 3 M • 28.6% $MgCl_2$ = 3 M • Distilled Water	The most severe deterioration occurred in wet/dry experiments with 3M solutions and 194°F drying. Only four cycles (26 days) were required for observable visible damage.
	W/D	Wet at 140°F; dry at 140°F; 16 cycles		• Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **High** durability PCC cores from in-service highways • Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **Low** durability PCC cores from in-service highways	• 4.40% NaCl = 0.75 M • 8.33% $CaCl_2$ = 0.75 M • 7.15% $MgCl_2$ = 0.75 M • Distilled Water	The least damaging conditions were wet/dry cycling with 0.75M solutions and 140°F drying, and freeze/thaw cycling with 0.75M solutions and 32°F freezing. Each required 16 cycles (104 days) to produce significant deterioration.
	F/T	Freeze at -94°F; thaw at 77°F; 9 cycles		• Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **High** durability PCC cores from in-service highways • Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **Low** durability PCC cores from in-service highways	• 17.6% NaCl = 3 M • 33.3% $CaCl_2$ = 3 M • 28.6% $MgCl_2$ = 3 M • Distilled Water	
	F/T	Freeze at 32°F; thaw at 77°F; 16 cycles		• Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **High** durability PCC cores from in-service highways • Rectangular blocks **0.5 in. x 0.5 in. x 1 in.** cut from **Low** durability PCC cores from in-service highways	• 4.40% NaCl = 0.75 M • 8.33% $CaCl_2$ = 0.75 M • 7.15% $MgCl_2$ = 0.75 M • Distilled Water	The least damaging conditions were wet/dry cycling with 0.75M solutions and 140°F drying, and freeze/thaw cycling with 0.75M solutions and 32°F freezing. Each required 16 cycles (104 days) to produce significant deterioration.

Lee et al 2000 [97] Iowa DOT	W/D	Immerse at 136.4°F for 132 hrs; dry at 136.4°F for 24 hrs; cool to 77°F; immerse at 77°F; store at 136.4°F for 132 hrs.	Not Cited	**Blocks cut from PCC cores** removed from Iowa highways (air content not given) **1.2 in. x 0.6 in. x 0.6 in.**	• 4.40% NaCl =0.75 M • 8.33% $CaCl_2$ = 0.75 M • 7.15% $MgCl_2$ = 0.75 M • CMA (5 ratios)=0.75M • Calcium Acetate=0.75M • Magnesium Acetate = 0.75M	This study observed that magnesium in any form was very damaging to the concrete. **Magnesium chloride** produced significant concrete crumbling because of widespread replacement of calcium silicate hydrate (C-S-H) with non-cementitious magnesium silicate hydrate (M-S-H). **Calcium magnesium acetate** solutions were the most damaging of all solutions tested. Wet/dry and freeze/thaw cycling in CMA produced widespread and severe damage with scaling from replacement of C-S-H with non-cementitious M-S-H. **Magnesium acetate** produced similar damage and **calcium acetate** solutions produced much less alteration. **Calcium chloride** deicing salts caused characteristic deterioration in concrete containing reactive dolomite coarse aggregate by enhancing dedolomitization reactions that release magnesium to form destructive brucite and M-S-H. For the experimental conditions utilized herein, **NaCl solution** was the least deleterious to the cement paste and aggregate. The validity of extrapolating the results obtained in our experimental conditions to those occurring under road use conditions is uncertain, and that our results and conclusions should be taken as cautionary only.
	F/T	Immerse at 135°F for 132 hrs.; air cool to 77°F; place in freezer at 25°F for 24 hr; air warm to 77°F; immerse at 77 F, store at 135°F for 132 hrs.	Not Cited	**Blocks cut from PCC cores** removed from Iowa highways (air content not given) **1.2 in. x 0.6 in. x 0.6 in.**	• 4.40% NaCl =0.75 M • 8.33% $CaCl_2$ = 0.75 M • 7.15% $MgCl_2$ = 0.75 M • CMA (5 ratios)=0.75M • Calcium Acetate=0.75M • Magnesium Acetate = 0.75M *NOTES: The solutions used were 0.75 M CaCl2·2H2O, MgCl2 ·6H2O, NaCl, calcium acetate Ca(CH3COO)2·H2O, magnesium acetate Mg(CH3COO)2·4H2O, and CMA based on a molar ratio of 3:7, i.e. 3[Ca(CH3COO)2·H2O] :7[Mg(CH3COO)2·4H2O], and distilled water. Experiments were also conducted with five solutions of 0.75 M CMA with different molar ratios of Ca-acetate and Mg-acetate (5:3, 7:3, 1:1, 3:5, and 3:7).*	

Sutter et al 2006 [98] Michigan Technological University **SD DOT**	Soak	Immerse at -15°F for 20 hours; Air dry at 135° F for 20 hours	Not Cited	**Mortar cylinders** (Ottawa Sand, cement and water only) **2 in. diam. X 4 in. H** w/c 0.40 w/c 0.50 w/c 0.60 air content not given	• 15% $MgCl_2$=1.85 m Mg2+ & 3.7 m Cl- *This $MgCl_2$concentration was chosen to represent the immediate dilution that occurs when salt solutions are applied to a road surface.* • 17% $CaCl_2$= 1.85 m Ca2+ & 3.7 m Cl- • 17.8% NaCl = 3.7 m Na & 3.7 m Cl-	***Not Successful, test stopped*** *Molality offers the advantage of equal numbers of moles of each deicer cation per volume solution, providing a basis for comparison of deicer chemicals in terms of the chemical interaction only.*
	Soak	Immerse at 40°F for 7, 14, 28, 56, 84 or 112 days	Not Cited	**Mortar cylinders** **2 in. diam. X 4 in. H** w/c 0.40 w/c 0.50 w/c 0.60 air content not given	• 15% $MgCl_2$ • 17% $CaCl_2$ • 17.8% NaCl	***Successful, but ended at 84 days*** Exposures of the various mortar specimens to calcium and magnesium chloride solutions at 40°F led to severe expansion, with deterioration first noticed at 56 days. Petrographic analysis and quantitative microanalysis were used to positively identify the presence of $Mg(OH)_2$ (brucite) formation in the outer layers of the specimens. Furthermore, the results presented clear evidence of calcium oxychloride formation in the specimens analyzed. Further research Phase 2 is being conducted, including the same immersion test at 40°F on Portland Cement Concrete specimens, to identify whether this distress mechanism is of concern for structures such as roads and bridges.
	Soak	Immerse at 135°F for 7, 14, 28, 56, 84 or 112 days	Not Cited	**Mortar cylinders** **2 in. diam. X 4 in. H** w/c 0.40 w/c 0.50 w/c 0.60 air content not given	• 15% $MgCl_2$ • 17% $CaCl_2$ • 17.8% NaCl	***This test Resulted in minimal deterioration of all specimens***

Wang, Nelson and Nixon, 2006 [99]Iowa State university	W/D	Immerse and store at 40°F for 15 hrs; air dry at 73°F (50% RH) for 9 hrs (solution changed every 20 cycles)	Not Cited	**Paste sample** **2 in. x 2 in. x 2 in.** Air entrainment 6% **Concrete sample** **4 in. x 4 in. x 4 in**. Air entrainment 6%	• 26.5% NaCl • 37.9% $CaCl_2$ • 39.9% $CaCl_2$ + inhibitor • 54.5% KAc • Agricultural = ?? • Distilled Water	Studied physical (mass loss and scaling), mechanical (strength), chemical (ion penetration and crystalline reaction products), and micro-structural properties of the paste and concrete were evaluated.
	F/T	Immerse and freeze at -4°F for 15 hrs; thaw for 9 hrs (not in solution) (solution changed every 10 cycles)	Not Cited	**Paste sample** **2 in. x 2 in. x 2 in.** Air entrainment 6% **Concrete sample** **4 in. x 4 in. x 4 in**. Air entrainment 6%	*DILUTED TO ALLOW FOR FREEZE to OCCUR in LAB* • 13.3% NaCl • 9.5% $CaCl_2$ • 10.0% $CaCl_2$ + inhibitor • 13.6% KAc • Agricultural (1:3) (chem:water) • Distilled Water	Results indicated that the various deicing chemicals penetrated at different rates into a given paste and concrete, resulting in different degrees of damage. Among the deicing chemicals tested, two **calcium chloride** solutions caused the most damage under both W/D and F/T conditions. Addition of a **corrosion inhibitor** into the calcium chloride solution delayed the onset of damage, but it did not reduce the ultimate damage. **Agricultural deicing product** resulted in the least chemical penetration and scaling damage of paste and concrete.
Darwin et al, 2008 [100] **University of Kansas**	W/D	Immerse at 73°F for 4 days; air dry at 100°F for 3 days (solutions replaced every 5 weeks) tested up to 95 cycles(weeks) *(Each 10 weeks is supposed to represent 10 years in field)*	Not Cited ***SEE NOTE***	**Prismatic PCC Specimens** **3 in. x 3 in. x 12 in.** w/c 0.45 air entrainment 6+/-1%	*Report states: Ice melting capability of a deicer is more closely related to the number of ions in a given quantity of water than to either the weight or molar concentration. Each test solution is molal ion concentration* • 15% NaCl = 6.04m • 16.9% $CaCl_2$ = 6.04m • 16.1% $MgCl_2$ = 6.04m • 22.7% CMA= 6.04m • Water • Air	• Visual Condition (physical appearance) • Change in Dynamic Modulus of Elasticity (ASTM C 215 based on ASTM C 666 for freeze/thaw)) At high concentrations, **calcium chloride, magnesium chloride, and calcium magnesium acetate** cause significant changes in concrete that result in loss of material and a reduction in stiffness and strength. The application of significant quantities of calcium chloride, magnesium chloride, and calcium magnesium acetate over the life of a structure or pavement will negatively impact the long-term durability of concrete.
		Immerse at 73°F for 4 days; air dry at 100 F for 3 days (solutions replaced every 5 weeks) tested up to 95 cycles(weeks)	Not Cited	**Prismatic PCC Specimens** **3 in. x 3 in. x 12 in.** w/c 0.45 air entrainment 6+/-1%	• 3% NaCl = 1.06m • 3.25% $CaCl_2$ = 1.06m • 3.76% $MgCl_2$ = 1.06m • 4.9% CMA = 1.06m • Water • Air	At lower concentrations, **sodium chloride and calcium chloride** have a relatively small negative impact on the properties of concrete. At high concentrations, **sodium chloride** has a greater but still relatively small negative effect. At low concentrations, **magnesium chloride and calcium magnesium acetate** can cause measurable damage to concrete.
NOTE*: Wet/dry cycles continue for a total of 95 weeks or until the relative dynamic modulus of elasticity (wet/dry) Pw/d drops below 0.9, at which point the tests are terminate*						

Poursaee, Laurent, and Hansson, 2010 [101] **Purdue University**	W/D	A ponding well was filled with a salt solution corresponding to a 3% Cl– (weight percent) concentration for 2-week periods followed by 2 weeks without solution (cycled for 130 weeks)	Not Cited ***SEE NOTE***	**Mortar prisms (containing steel)** **6 in. × 6 in. × 4 in.** Contain four 9 in. lengths of #5 (6.35 mm or 0.25 in ø) steel reinforcing bars. Air content not reported	• 4.94% NaCl (3% Cl-) • 4.70% $CaCl_2$ • 4.03% $MgCl_2$	Determine the effect of each of these salts on the **corrosion of steel rebar and their impact on the durability of the mortar.** The results show that $CaCl_2$ has the most negative effect on the steel and, in high concentrations, on the integrity of the mortar. $MgCl_2$ also deteriorates the mortar if used in high concentration, while NaCl has no apparent effect on mortar durability even in high concentration.
University of Waterloo	W/D	A ponding well was filled with a salt solution corresponding to a **30%** Cl– (weight percent) concentration for 2-week periods followed by 2 weeks without solution		**Mortar prisms (containing steel)** **6 in. × 6 in. × 4 in.** Contain four 9 in. lengths of #5 (6.35 mm or 0.25 in ø) steel reinforcing bars	• 49.4% NaCl (30% Cl-) • 47.0% $CaCl_2$ • 40.3% $MgCl_2$	By increasing the salt concentration from 3% to 30%, severe deterioration was observed in the mortar specimens exposed to $CaCl_2$ and, to a lesser extent, in those exposed to $MgCl_2$. No damage was seen on the specimens exposed to NaCl.
NOTE: *The vertical surfaces were coated with epoxy resin to prevent access of oxygen from those surfaces; (ii) a ponding well was mounted on the top surface; and (iii) the three bottom bars were connected together and then connected to the top bar through a 100 Ω resistor.*						
Shi et al 2010[102] **Montana State University**	F/T	Freeze at -0.04°F for 16-18 hrs; thaw at 74.4°F (RH 45-55%) for 6-8 hr; repeat cycle 10 times	Modified SHRP H-205.8 freeze thaw test FESEM EDX	**PCC Cylinders** **1-1/2 in. dia x 1-7/8 in. H** Used four specimens per solution plus control = total of 32 test specimens Air entrainment 6+/- 1% 3% after compaction	*BELOW diluted 100 to ~3 with dionized water* • 99% Solid NaCl diluted to **3% solution** • 99% Solid Potassium Formate diluted to **3% solution** • 50% Liquid Potassium Acetate diluted to **1.5% solution** • 96% Solid CMA diluted to **3% solution** • 27-29% Liquid $MgCl_2$ diluted to **0.85% solution** • ?% Solid Ice-Slicer ™ (NaCl) diluted to **3% solution** • Solid Sodium Acetate, & Sodium Formate Blend (50:50) diluted to **3% solution**	"This work investigated the effect of diluted deicers on the durability of a Portland cement concrete. Based on the gravimetric and macroscopic observations of freeze/thaw specimens following the modified SHRP H205.8 laboratory test, de-ionized water, the CMA solid deicer, and the CDOT $MgCl_2$ liquid deicer were benign to the PCC durability, whereas KFm and the NaAc/NaFm blend deicer showed moderate amount of weight loss and noticeable deterioration of the concrete. NaCl, the NaCl-based deicer (IceSlicerTM), and the KAc-based deicer (CF7TM) were the most deleterious to the concrete. Our data indicated much more deleterious impacts by 3% NaCl than 0.85% $MgCl_2$ on PCC durability. The key was the difference in the deicer solution concentration." This finding from diluted deicers differed from the study of concentrated deicers [3], where NaCl seemed to be more chemically benign to concrete than $MgCl_2$. It should be cautioned that in the field environment, the deicer impact on the durability of concrete may not follow a similar pattern, as it is further complicated by the concentration and longevity of the deicer and its additives, the chemical composition and microstructure of the concrete, and the temperature regimes experienced by the concrete."

Shi et al 2011 [103] **Montana State University**	Soak	Ponded at room temperature for 330-347 days	Modified (NACE) Standard TM0169-95 for corrosion of carbon Steel	**Cores** removed from 1980s style **PCC** design (WADOT) **2.3 in. x 2.2 in. H** Pavement samples Air content 5.7% Bridge samples Air content 5.1%	*BELOW diluted 100 to ~31 with dionized water* • 23% NaCl diluted to **7.7% solution** • 23% NaCl+inhibitor (Shield GLT ^{TM}) diluted to **7.8% solution** • 30% $CaCl_2$ + inhibitor (Geomelt CT ^{TM}) diluted to **8.2% solution** • 30% $MgCl_2$ + inhibitor (Freezgard C1 Plus ^{TM}) diluted to **8.8% solution**	"To determine relative effect of various corrosion-inhibited deicers on the concrete durability, relative to the ''straight salt" (non-inhibited sodium chloride)."ASTM C873/C873M – 04e1 Standard Test Method for compressive Strength of Concrete Cylinders. The comparison between non-inhibited and inhibited NaCl suggests little benefits of corrosion inhibitor in preserving the concrete integrity in the case of continuous exposure to deicers at room temperature. One possible reason is provided as follows. The inhibitors added in deicer products were designed to mitigate the corrosive attack of chloride to metals (instead of concrete). For the pavement mix, the continuous exposure to non-inhibited NaCl, inhibited NaCl and the inhibited $CaCl_2$ deicer led to limited levels of strength gain of the concrete, whereas that to the inhibited $MgCl_2$ led to significant strength loss. For the bridge mix, the continuous exposure to the four deicers led to significant strength loss of the concrete, with the inhibited $CaCl_2$ deicer being the least affected. These results suggest the deleterious role of Mg_2+ cations and the beneficial role of Ca_2+ cations when it comes to their effect on the concrete integrity.
Jain et al 2012 [104] Purdue University	W/D	Immerse at 39.2°F for 16 hrs; dry at 50% RH 73.4 F for 8 hrs. 168-350 days (cycles) (1 cycle = 24 hrs)	Not Cited	1. **Plain Portland Cement Concrete** Air content 6.8% w/c = 0.42 2. **Fly Ash (20%) PCC** Air content 5.8% w/c = 0.42 • Prisms **3x3x11.5 in**. • Cylinders **4x8 in.** • Cylinders **3x6 in.**	• 23% NaCl = 10.20 molal ions • 28% $CaCl_2$ = 10.51 " " • 25% $MgCl_2$ = 10.5 " " • Deionized Water	Ultrasonic pulse velocity measurements after every two weeks of exposure until the end of the test (ASTM E1876). At the end of the W-D exposure period, the same test cylinders were used to obtain the (AASHTO T22-07) compressive strength of the concrete. In summary, based on the visual observations of Type I specimens exposed to W-D and F-T cycles, it can be concluded that the greatest physical changes resulted from exposure to $CaCl_2$ deicers, whereas the exposure to NaCl deicer and to the deionized water did not create any visible signs of distress. The visual damage induced by the exposure to the $MgCl_2$ was less extensive than that induced by exposure to $CaCl_2$ under both W-D and F-T conditions. The 20% Fly Ash concretes displayed better performance (less reduction in relative dynamic modulus of elasticity) than Type I concretes during the reported period of testing in both exposure regimes. This can be attributed to pozzolanic reaction and higher chloride-binding capacity of fly ash concretes.
	F/T	9 hrs cooling from 71.6°F to -4°F; 5 hrs at -4°F; 6 hrs heating from -4°F to 71.6°F; 4 hrs at 71.6°F; 168-350 days (cycles)		1. **Plain Portland Cement Concrete** 2. **Fly Ash (20%) PCC** • Prisms **3x3x11.5 in. (only)**	• 14% NaCl = 5.48 molal ions • 17% $CaCl_2$ = 5.54 " " • 15% $MgCl_2$ = 5.56 " " • Deionized Water	

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