Winter Storm Management of Arizona State Highways

OPERATIONS MANUAL

September 2014

ADOT

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TERMS AND ACRONYMS

Term/Acronym	Definition
%	percent
°F	degrees Fahrenheit, water freezes at 32 °F. Temperature scale used by ADOT Operations
AASHTO	American Association of State Highway and Transportation Officials
Abrasives	Volcanic cinders, sand, washed sand, and decomposed granite used to enhance traction on the roadway
ADA	Arizona Department of Agriculture
Adaptive Management	A structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reduce uncertainty over time via system monitoring.
ADEQ	Arizona Department of Environmental Quality
ADOT	Arizona Department of Transportation
ADT	Average Daily Traffic
AGFD	Arizona Game and Fish Department
AHMCT	Advanced Highway Maintenance and Construction Technology
All American Road	This designation means that these roads have features that do not exist elsewhere in the United States, and are unique and important enough to be tourist destinations unto themselves
ALT	Alternate route
AMP	Ambient Monitoring Program
ANOVA	"Analysis of Variance," a standard statistical analysis method
Anti-icing	The practice of applying a chemical additive to lower the freezing point of water on a highway surface to prevent snow and ice from bonding to the pavement, thus facilitating easy removal through snowplowing
ARS	Arizona Revised Statutes
ASLD	Arizona State Land Department
AVL	Automatic Vehicle Locating
BIA	Bureau of Indian Affairs
Black ice	Thin coating of clear, bubble-free, homogenous ice that forms on pavement with a temperature at or slightly above 32 °F
BLM	Bureau of Land Management
Blowing snow	Fallen snow is raised by the wind to a height of 6 feet or more and is transported across the road
BMPs	Best Management Practices
Brine	Water saturated (or nearly saturated) with salt. A strong saline solution (refer to definition of Salinity)
$CaCl_2$	Calcium chloride
CDEC	California Data Exchange Center

Term/Acronym	Definition
Chemical spread rate	The chemical application rate; for solid applications, it is the weight of the chemical applied per lane mile, and for liquid applications, it is the weight of the dry chemical in solution applied per lane mile
CMA	Calcium Magnesium Acetate
DEA	Draft Environmental Assessment
Deicing	The reactionary measure of applying chemical additives to snow- or ice-covered roads during or after a winter storm after anti-icing has become ineffective
DMS	Dynamic Message Sign
DoD	Department of Defense
DPS	(Arizona) Department of Public Safety
EA	Environmental Assessment
EC	Electrical Conductivity
EMS	Environmental Management System
EO	Environmental Overview
EOTEP	Equipment Operator Training and Evaluation Program
EPA	US Environmental Protection Agency
EQS	Equipment Services
ESP	Exchangeable Sodium Percentage
Eutectic Point	The point at which the freezing point temperature is the lowest for a solution at its optimal concentration. The lowest temperature is called the Eutectic Temperature and the optimal concentration is called the Eutectic Concentration
FHWA	Federal Highway Administration
ft	feet
Freezing rain	Supercooled droplets of liquid precipitation with a temperature near 32 °F
Frost	Ice crystals in the form of scales, needles, feathers, or fans deposited on surfaces cooled by radiation or other processes. The deposit may be composed of drops of dew frozen after deposition or ice formed directly from water vapor at a temperature below 32 °F (sublimation)
gal	gallon
gpm	gallons per minute
GIS	Geographic Information System
GPS	Global Positioning System
HCRS	Highway Condition Reporting System
Heavy snow	Snow falling at a rate of 0.5 inches per hour or greater. Visibility is less than ¼ mile
Historic road	Byways that have special uniqueness with regards to cultural heritage, historical contribution, and location in proximity to a historical area. There are currently three historic roads in Arizona. Refer to the definition of “Scenic road” for more information
I	Interstate

Term/Acronym	Definition
ITD	Intermodal Transportation Division (within ADOT)
KAc	Potassium acetate
KCl	Potassium chloride
lane-mi	lane-mile
lb	pound
Light rain	Small liquid droplets falling at a rate such that individual drops are easily detectable splashing from a wet surface, including drizzle
Light sleet	Scattered pellets that do not completely cover an exposed surface regardless of duration; visibility is not affected
Light snow	Snow falling at a rate of less than 0.5 inches per hour; visibility of motorists is not adversely affected. Visibility is greater than ½ mile
LOS	Level of Service
$MgCl_2$	Magnesium chloride
mi	mile
Moderate rain	Liquid drops falling are not clearly identifiable and spray from falling drops is observable just above pavement or other hard surfaces
Moderate sleet	Rain falls in sheets, individual drops are not identifiable, and heavy spray from falling rain can be observed several inches over hard surfaces
Moderate snow	Snow falling at a rate of 0.5 inches per hour or greater. Visibility is between ¼ to ½ mile
MOU	Memorandum of Understanding
MP	Milepost
mph	miles per hour
NaCl	Sodium chloride (salt)
National Scenic Byways	A road recognized by the Us Department of Transportation for one of the six "intrinsic qualities": archeological, cultural, historic, natural, recreational, or scenic.
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act (1970)
NOAA	National Oceanic and Atmospheric Administration
Nonadditive techniques	WSM methods employed by ADOT, including mechanical snow removal, snow fences, shade reduction, storm patrols, traffic controls, and public information
NPS	National Park Service
NWR	National Wildlife Refuge
NWS	National Weather Service
OAW	Outstanding Arizona Water
Orgs	Organizations within each ADOT Engineering District
OSHA	Occupational Health and Safety Administration
Parkways	Roads designated for protection due to geographic features, natural flora, or scenic value

Term/Acronym	Definition
PeCoS	Performance Control System, ADOT's maintenance management program
pH	Potential of hydrogen: the measure of the acidity or alkalinity of a solution
PM_{10}	Particulate matter less than 10 micrometers in diameter
PNS	Pacific Northwest Snowfighters
PPE	Personal Protective Equipment
ppm	parts per million
Pre-wetting	The practice of adding liquid chemicals to a granular additive before it is applied to the road
R/W	Right-of-way
rpm	revolutions per minute
RWIS	Road Weather Information System
Salinity	The relative concentration of dissolved salts in a given volume of water (see definition of Salt)
Salt	Refers to any compound consisting of the cation from a base and the anion from an acid and that is readily dissociated in water. Road salts may be applied to roadways as a liquid or solid and are used to lower the freezing point temperature and prevent ice from bonding to pavement or melt existing snow and ice. Although the primary salt used on Arizona roadways is sodium chloride (NaCl) or magnesium chloride ($MgCl_2$) compounds. Potassium acetate (KAc) and calcium magnesium acetate (CMA) are also salts
SAR	Sodium Adsorption Ratio
Scenic road	Roads designated to be preserved for the quality of the visual and historical environment. In 1982, the State of Arizona responded to this preservation movement by enacting into law ARS Sections 41-512 through 41-518. This law provides for the establishment of Parkways, Historic, and Scenic Roads. ADOT is the agency responsible for implementing these laws
SDS	Safety Data Sheet (replaces the MSDS under the Globally Harmonized System of Classification and Labelling of Chemicals [GHS])
Shade reduction	Entails thinning or removing trees and flattening slopes to reduce snow and ice accumulation and enhance melting of snow and ice
SHPO	State Historic Preservation Office
SHRP	Strategic Highway Research Program
SIPDE	Search, Identify, Predict, Decide, and Execute
Sleet	A mixture of rain and snow that has been partially melted after passing through an atmosphere with a temperature slightly above freezing
Slush	Accumulation of snow that lies on an impervious base and is saturated with water in excess of its freely drained capacity. Slush does not support the weight of traffic

Term/Acronym	Definition
Snow Desk	Staffed with administrative assistants familiar with all routes and resources; they contact WSM operators hourly for status updates; communicate with the Traffic Operations Center (TOC); coordinate with the TOC on dynamic message sign (DMS) messages; update information on the Highway Condition Reporting System (HCRS); and activate additional resources as directed by the shift or crew lead.
Snow fences	Long, fixed, standing structures that are strategically placed within the right-of-way to control drifting snow and improve motorist visibility by blocking snow
SR	State Route
TAC	Transportation Association of Canada
T.A.P.E.R. log	Log used to record the location and application of chemicals and abrasives. T.A.P.E.R. stands for: T - temperature of the pavement and air; A - application rate (pounds or gallons per lane/mile); P - product being applied; E - event type (heavy snow, sleet, dry snow, etc.); and R - results of the anti-icing and deicing efforts
TOC	Total Organic Carbon
TOC	Traffic Operations Center
US	United States. Also refers to “US Highway”
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USDOT	US Department of Transportation
USFS	US Forest Service
USFWS	US Fish and Wildlife Service
Visibility hazards	Visibility reduced to less than ¼ mile by fog, blowing dust/sand, volcanic ash, or smoke
VMT	Vehicle Miles Traveled
WSDOT	Washington State Department of Transportation
WSM	Winter Storm Management

National Weather Service Terms	Definition
Advisory	National Weather Service announcement issued for less serious conditions that are occurring, imminent, or have a high probability of occurrence and can cause significant inconvenience and, if caution is not exercised, could lead to situations that threaten life or property. See “Warning”, “Watch”, and “Winter storm warning”
Blizzard warning	National Weather Service announcement issued for sustained winds or frequent gust of 35 mph or more, visibility frequently below ¼ mile in considerable snow and/or blowing snow, and the above conditions are expected to prevail for 3 hours or longer

National Weather Service Terms	Definition
Blowing snow advisory criteria	National Weather Service announcement issued for visibility frequently at or below ¼ mile in blowing and drifting snow
Freezing rain/drizzle advisory criteria	National Weather Service announcement issued when freezing precipitation is light and when ice does not form on all exposed surfaces
Heavy snow warning criteria	National Weather Service announcement issued for elevations 5,000 to 7,000 feet, 6 inches/12 hours or 10 inches/24 hours, or elevations below 5,000 feet, 2 inches/12 hours or 4 inches/24 hours
High wind warning criteria	National Weather Service announcement issued for sustained winds greater than 40 mph and lasting longer than an hour, or wind gusts greater than 58 mph for any duration
Ice storm warning criteria	National Weather Service announcement issued for freezing rain, drizzle, or sleet that causes or is predicted to cause widespread, dangerous, and damaging accumulations of ice or sleet
Interim statements	National Weather Service announcements issued to provide updated information on the status of a watch, warning, or advisory (see definitions of each), and to provide the latest information available about winter weather affecting the area. Interim statements are issued using the product header of the original watch, warning, or advisory
Public zone forecast	The standard National Weather Service forecast used by the mass media. The zone forecast describes the weather forecast for the next 36 to 48 hours. The forecast is issued twice daily (4:00 AM and 4:00 PM) and updated as necessary
Snow advisory criteria	National Weather Service announcement issued for elevations 5,000 to 7,000 feet, 3-6 inches/12 hours or 6-10 inches/24 hours; elevations below 5,000 feet, 1-2 inches/12 hours or 2 inches/24 hours; or snow accumulation in any location that is a rare event
Warning	Highest priority issued by National Weather Service when hazardous winter weather or nonprecipitation event is occurring, is imminent, or has a high probability of occurrence. A warning is used for conditions posing a threat to life or property
Watch	National Weather Service announcement issued when conditions are favorable for hazardous winter weather or nonprecipitation hazard to develop, but its occurrence, location, and/or timing are still uncertain
Wind advisory	National Weather Service announcement issued for sustained winds 30 to 39 mph and lasting longer than an hour, or wind gusts 40 to 57 mph for any duration
Wind chill warning	National Weather Service announcement issued for a wind chill factor of -20 °F or colder

National Weather Service Terms	Definition
Winter storm warning	National Weather Service announcement issued when more than one winter hazard is involved producing life threatening conditions, such as a combination of heavy snow and windy conditions (causing widespread blowing and drifting snow), freezing rain, extreme wind chill, etc.
Winter weather advisory	National Weather Service announcement issued when more than one weather event is occurring or forecast that will cause significant inconvenience, such as advisory criteria snow accumulations combined with freezing drizzle

CHAPTER 1. INTRODUCTION

1.1 Introduction

Under federal and state statutes, the Arizona Department of Transportation (ADOT) is responsible for keeping state and federally owned/operated roadways safe and operational during winter months when snow and ice accumulate on these roadways, in a manner as safe and practical given winter storm conditions and available resources[1,2]. Maintaining these roads often requires active measures to remove snow and ice. Arizona is separated into nine Engineering Districts and ADOT's operations personnel within each District use a variety of winter storm management (WSM) techniques to ensure emergency services; commerce; and educational, employment, recreational, and leisure activities are not minimally disrupted during adverse weather conditions. Common practices include snowplowing, applying anti-icing/deicing chemicals, spreading abrasives to improve traction, removing trees to reduce roadway shading, installing snow fences to control drift, and providing traffic controls. ADOT also uses Road Weather Information System (RWIS) technology that provides weather-related information such as air and pavement temperatures, humidity, wind speed and direction, vehicle counts, and photographs.

While providing safe and operational transportation corridors, ADOT is also required to comply with various environmental laws, regulations, policies, and ordinances. ADOT completed a statewide environmental assessment (EA) of WSM techniques in 1992 (ADOT, 1992). The EA evaluated ADOT's use of road salts and abrasives and addressed public concerns and potential environmental impacts associated with these WSM activities. The EA included a list of recommended mitigation measures, and ADOT subsequently developed a Winter Storm Management Plan to minimize impacts associated with deicing chemicals (ADOT, 1996). In addition to the 1996 Winter Storm Management Plan, ADOT developed District-specific Snow Guides that are revised annually. In conjunction with the EA that was finalized in 1992, the ADOT Natural Resources Management Group initiated a program to monitor changes in soil conditions and evaluate possible environmental impacts associated with WSM activities. ADOT has modified the monitoring program, which is now referred to as the Ambient Monitoring Program (AMP). The earlier program was referred to as the Biological Monitoring Program.

Since the 1992 EA, ADOT's WSM Program has continued to evolve with industry advances in technology, materials, and application techniques. In 2001, a formal assessment of ADOT's WSM Program was deemed necessary to address concerns related to Environmental (i.e., groundwater, air quality) and socioeconomic impacts. ADOT released a Draft EA (DEA) during 2004 (ADOT, 2004) and public comments were received. ADOT reinitiated the WSM environmental review process in 2007 and determined that the final document should be an Environmental Overview (EO) rather than an EA. Because winter storm management did not require a federal decision, a National Environmental Policy Act (NEPA) document (e.g., an EA) was not required. The EO addressed the public comments received on the DEA and incorporated revised alternatives that reflected changes in ADOT WSM practices (ADOT, 2008).The objectives of the EO were to:

[1] Arizona Revised Statute [ARS] Title 28 Section 108
[2] 23 Code of Federal Regulations Section 635

- Update the 1992 EA and consider and analyze environmental and socioeconomic impacts related to current and potential future WSM practices.
- Discuss implementation of a WSM program based on a revised WSM Operations Manual that would result in Districts selecting the most successful techniques for safely operating and maintaining the beneficial uses of the roads based on site- and storm-specific conditions while maintaining compliance with environmental laws, regulations, polices, and ordinances.

The EO was prepared using scientific literature, documentation of existing WSM practices in Arizona, consultation with ADOT personnel involved in winter storm management, and coordination with agency and public stakeholders.

This WSM Operations Manual was prepared subsequent to approval of the EO. One of the strategies of the WSM Operations Manual is to use an adaptive management approach to optimize WSM operations and minimize environmental impacts.

In 2011, ADOT commenced a limited study to evaluate the validity of the AMP. The objectives of the 2011 study were to:

- Assess the current anti-icing/deicing chemical application guidelines based on analytical results of soil and vegetation samples collected from specific sites subject to ADOT WSM activities;
- Provide recommendations for implementing a WSM recordkeeping system of chemical usage and storm events; and
- Provide recommendations on monitoring and mitigating environmental impacts resulting from ADOT's WSM Program.

The research approach for this study began with a review of other western US states' WSM procedures and guidelines. A literature review was also conducted, focusing on previous work determining linkages (or lack thereof) between WSM activities in other Midwest and western US states and salt accumulation in roadside soil, vegetation, and bodies of water.

For this study, soil and vegetation samples were obtained across 16 sites along State Route (SR) 260 and United States (US) Routes 180 and 191, all within ADOT's Globe District. The relationship between salt applications and potential impacts to soil and vegetation were evaluated using data from WSM activities (frequency of application, quantity of salt applied, and adherence to ADOT WSM guidelines). The WSM data were compared to sodium and chloride concentrations in soil and vegetation samples collected at varying distances from the roadway.

This revised WSM Operations Manual incorporates the findings of the 2011 study and is designed to assist ADOT staff in making informed decisions regarding the use of appropriate WSM techniques. One of the strategies of the WSM Operations Manual is to use an adaptive management approach to optimize WSM operations and minimize environmental impacts.

1.2 Purpose and Need

The objectives of this WSM Operations Manual are to provide a foundation for ADOT's WSM Program; and to ensure that roadway level of service (LOS) remains high, impacts to environmental and socioeconomic resources are minimized, and compliance with various environmental laws, regulations, policies, and ordinances is achieved. Implementation of this WSM Operations Manual will support the goals of enabling a reasonable and cautious driver to safely travel ADOT's priority routes during the winter season. In addition, implementation of this WSM Operations Manual should facilitate the movement of goods, provide access for emergency vehicles, and maintain access to winter recreational sites before, during, and after freezing conditions or a winter storm, while maintaining environmental compliance.

The WSM Operations Manual was revised in 2008 because ADOT's 1996 Winter Storm Management Plan was no longer adequate for providing guidance to operations staff regarding the use of appropriate WSM techniques. Since implementation of the 2008 Plan, ADOT's practices for winter storm management have evolved to incorporate recent advances in equipment, the increased number of chemical additives available for the treatment of snow and ice, and techniques for their use. The greater flexibility provided in this WSM Operations Manual will allow ADOT operations staff to successfully manage variable winter storm conditions that occur across ADOT's climatically and geographically diverse Districts. This Manual also incorporates techniques for addressing public and agency concerns and the potential environmental and socioeconomic impacts identified in the EO and supported by the 2011 study. Recommendations supported by the 2011 study will provide for greater control of salt and abrasives usage, and continued and expanded monitoring of roadside soil and vegetation conditions through time.

1.3 Overview of Plan Area and Operations

This WSM Operations Manual addresses WSM activities statewide. It is intended to be a programmatic rather than site-specific document. The project area is defined as transportation corridors within Arizona where snow and ice occur and where ADOT conducts WSM activities. Transportation corridors include the roadway and the land adjacent to the roadway called the right-of-way (R/W). Generally, the R/W is the area extending parallel to both sides of the road, from the white line along the edge of pavement to the fence. Medians are typically considered part of the R/W. The project area also includes storage facilities situated at strategic maintenance yards associated with WSM activities. The transportation corridors, District offices, and maintenance yards are shown in **Figure 1 (refer to "Figures" tab following Chapter 7)**.

The Intermodal Transportation Division (ITD) oversees the construction and maintenance operations of the State Highway System (ADOT, 2007a). ADOT maintains and operates more than 28,970 lane miles that include travel lanes, ramps, passing lanes, paved shoulders, and unpaved roads (ADOT 2012 State Highway System Log, Table XV, 2012). This extensive network provides a safe, efficient, and affordable means of surface transportation and supports economic and social activities. Much of the northern and eastern portions of Arizona are located at elevations greater than 5,000 feet. Accumulations of snow and ice compromise the safety, efficiency, and beneficial uses of roads; therefore, ADOT must employ WSM techniques to maintain safe conditions for the traveling public, emergency services, and commerce.

The State Highway System is divided into nine Engineering Districts: Flagstaff, Globe, Holbrook, Kingman, Phoenix, Prescott, Safford, Tucson, and Yuma (ADOT website, 2014). The Districts are responsible for WSM activities in their respective areas. For maintenance purposes, each District is subdivided into multiple maintenance facility locations or organizations (Orgs), allowing operations personnel to focus activities on site-specific conditions.

ADOT strives to keep the roadways it manages safely open for motorists. However, winter storm conditions may require temporary closures or recommendations for use only by vehicles with special equipment (e.g., chains, studded tires) (ADOT, 1996). The Districts work to minimize such closures and recommendations through implementation of various WSM practices including:

- Anti-icing
- Deicing
- Pre-wetting
- Abrasives
- Nonadditive management

Materials used in anti-icing, deicing, and pre-wetting practices include various salts, commonly referred to as road salts. ADOT uses primarily sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Future references to salt or road salt in this document refer to these compounds. Calcium chloride ($CaCl_2$), potassium chloride (KCl), calcium magnesium acetate (CMA), and potassium acetate (KAc) are available for use in anti-icing and deicing operations, but not currently used on ADOT roadways.

Since incorporating chemical additives into winter storm management, ADOT has seen an improvement in roadway safety (i.e., increase in LOS) following winter storms. The improvement is supported by anecdotal evidence from the Arizona Department of Public Safety (DPS) and by a reduction in the need for roadway spot treatment (AMEC, 2007). The improvement in roadway conditions is consistent with results reported in studies conducted outside of Arizona (FHWA 1994, 1996; Marquette University, 1992).

Anti-icing is the practice of applying a chemical additive to a highway surface prior to snow or ice accumulation. Applying an anti-icing additive is a proactive technique that lowers the freezing point to the thawing point of water, thus facilitating easy removal through snowplowing during a winter storm. Anti-icing, when used in conjunction with snowplowing, is beneficial because of its potential to maintain bare pavement longer at the onset of and throughout a storm. Continued application throughout a storm lowers the freezing point and reduces snow accumulation and snowpack, allowing faster and easier removal through snowplowing following a storm. This allows a reduction in the overall amount of salt necessary to manage the roadway. Anti-icing is only used for paved roads.

ADOT uses both pre-wetted granular and liquid forms of anti-icing additives, although liquid $MgCl_2$ is the most commonly used additive. The additives are applied using computer-controlled mechanical spreaders and sprayers. Anti-icing additives are stored at maintenance yards.

Liquid additives are stored in tanks, and granular materials are stored in covered sheds or all-weather sacks.

Deicing is the reactionary measure of applying chemical additives (often the same chemicals used for anti-icing) to snow- or ice-covered roads during or after a winter storm. When deicing chemicals are applied to roadways covered in snow or ice, a brine solution is created. The brine solution lowers the freezing point of water and disrupts the bond between the pavement and the snow or ice. Once the bond is weakened, it is easier for equipment to remove the layers of accumulated snow or ice. Deicing alone may not be a sufficient method for snow and ice removal. The traditional method is often to wait until one inch or more of snow has accumulated before treating roads. This strategy may lead to a compacted snow/ice layer that is tightly bonded to the pavement surface. This layer will require additional deicing applications to work through the packed and bonded snow and ice and reach the pavement to destroy or weaken the bond. It takes more salt to melt ice than to prevent it. Deicing is only used for paved roads.

ADOT typically uses NaCl and $MgCl_2$ for deicing operations. These additives may be in liquid or granular form. Additives in liquid form are applied using spray or tank trucks. Granular deicing additives are applied using trucks equipped with spreader units. Deicing materials are stored at maintenance yards. Deicing and anti-icing differ in their technique, but generally use the same chemical additives; therefore, the chemicals for both are stored similarly. Liquid additives are stored in tanks, and granular materials are stored in covered sheds or all-weather sacks.

Pre-wetting is a commonly used practice to improve retention and keep salts and abrasives on the road by reducing the effects of bouncing, blowing, and sliding. This technique uses liquid $MgCl_2$, salt brine, or other liquid chemical to wet granular additives before they are applied to the road. Pre-wetting also increases the rate at which the granular chemicals penetrate snow and ice; therefore, it is used to enhance the performance of anti-icing and deicing chemicals. Pre-wet granules adhere to the road surface better and there is a faster and longer-lasting effect. Pre-wetting also eliminates “bounce loss.” Dry granular materials often bounce to the shoulder and require higher application rates to be as effective as materials that are used with pre-wetting. In addition to granular chemical additives, abrasives may also be pre-wet. Pre-wetting is only used for paved roads.

Methods for pre-wetting used below 25 Fahrenheit ($^{\circ}$F) or on snowpack include injecting a pre-wetting chemical (ADOT uses $MgCl_2$) into a material stockpile, spraying a pre-wetting chemical onto a loaded spreader or onto material as it is being loaded into a spreader, and distributing by an onboard spraying system mounted to a spreader as material is applied to a road (Ketchum et al, 1996).

Abrasives are beneficial at low pavement temperatures when chemical reactions occur slowly and snow and ice cannot be easily removed from the road. In addition, the dark color of cinders enhances melting of snow and ice by absorbing light energy and retaining heat. Abrasives used by ADOT include volcanic cinders, sand, washed sand, and decomposed granite. Salts (liquid or granular) may be added to abrasives to increase effectiveness. Granular salt may also serve as an abrasive before fully dissolving. Abrasives may also be used following application of anti-icing or deicing additives. ADOT applies abrasives using trucks equipped with a mechanical spreader. Abrasives are stored in bulk piles at maintenance yards and other strategic locations, such as the junction of highways. Abrasives are used on both paved and unpaved roads to improve traction and aid in removal of snowpack.

Nonadditive Practices – employed by ADOT include snowplowing, snow fences, weather monitoring, shade reduction, storm patrols, traffic controls, and public information. Nonadditive techniques can be used on paved and unpaved roads. Snowplowing can be used when a approximately one inch of snow or loose ice has accumulated on the roadway. Snowplowing may be performed alone or in conjunction with other WSM techniques such as anti-icing, deicing, and abrasive application.

In addition to snowplowing, ADOT makes use of snow fences and shade reduction. Snow fences are long, fixed, standing structures strategically placed within the R/W and off the R/W to control drifting snow and improve motorist visibility by decreasing the amount of snow blown onto roadways. Shade reduction (or daylighting) is the practice of removing trees to allow more sunlight to reach the roadway, or excavating cut slopes to accelerate the melting of snow and ice.

Weather monitoring tools used by ADOT include National Weather Service (NWS) Data, local forecasts, on-site visual observations, and RWIS. RWIS provides real-time weather reporting along transportation corridors and includes embedded pavement sensors that allow ADOT to predict the potential for icing before it occurs.

Storm patrols include on-call personnel who visually inspect roadways to assess local conditions and the need for action when weather events cannot be accurately predicted using NWS Data or local forecasts. Storm patrols are mobilized prior to the start of a storm.

ADOT and DPS share the responsibility for traffic controls. Traffic controls related to winter storm management include signing and closing roads (it does not include enforcing tire chain recommendations as Arizona has no regulation mandating chain use). Road closures occur only after ADOT determines a road can no longer be safely maintained or operated. Based on traffic volume and weather conditions, ADOT routinely closes some transportation corridors on a short-term basis (e.g., SR 89A, US 180), whereas others are closed for the entire season (e.g., SR 67, SR 473, SR 261, SR 273).

ADOT employs public information tools to notify the public of road conditions during winter storms. These tools include a traveler information system accessible by phone (511 within the state of Arizona), on Twitter at “arizonadot,” and on the web at www.az511.gov, stationary dynamic message signs (DMSs), portable DMSs, and the Highway Condition Reporting System (HCRS), which is a web-based notification. ADOT also developed the “Know Snow” campaign to educate the public about driving during winter storms. This campaign includes brochures, a website that provides tips for winter driving and resources for obtaining information on road conditions (ADOT, 2007c), and a media event hosted each fall in Phoenix.

1.4 Organization of the Winter Storm Management Operations Manual

This Manual consists of the following Chapters:

Chapter 1 Introduction – provides the background and history of ADOT's WSM operations. Chapter 1 also provides an overview of WSM practices, including anti-icing, deicing, pre-wetting, abrasives, and nonadditive practices.

Chapter 2 Winter Storm Management – discusses ADOT's organizational structure, roles, and responsibilities for winter storm management. Chapter 2.0 includes a brief summary of environmental regulations and requirements that may apply to WSM practices and outlines ADOT's roadway priority and LOS goals. ADOT's AMP and Adaptive Management strategy for WSM operations are also introduced.

Chapter 3 Geographical and Environmental Conditions – contains an overview of the geography, demographics, roadway system, land jurisdiction, climate, environmental concerns, and monitoring infrastructure within Arizona.

Chapter 4 Ice and Snow Science – provides the user with a background of the scientific principles behind snow and ice formation and melting, chemical bonding, deicing and anti-icing reactions, and pavement temperature dynamics.

Chapter 5 Operations Guidance and Best Management Practices – discusses ADOT's WSM planning, operation, and maintenance procedures. ADOT's chemical additive and nonadditive practices are described in detail, including operational safety tips and considerations. Chapter 5.0 also provides best management practices (BMPs) for equipment storage, maintenance practices, and chemical material storage and handling. This chapter explains weather monitoring and informational technologies that are critical to effective WSM operations, including weather forecasting, RWIS, truck-mounted sensors, traffic controls, storm patrols, and public education outreach. Other critical components of effective WSM operations, such as education, training, simulations, recordkeeping, and reporting, are also discussed in this chapter.

Chapter 6 Ambient Monitoring Program – describes ADOT's AMP, which is a revision of the Biological Monitoring Program that was first implemented in 1991. The AMP is designed to monitor environmental impacts in soil, biota, surface water, groundwater, and sediment. Results from the limited 2011 study to validate the AMP are incorporated in Chapter 6, detailing sampling strategies, ancillary data collection, data management and analyses, and reporting procedures.

Chapter 7 References and Resources – lists the references that were used to develop this Manual and additional resources that the user can refer to for additional information. These references and resources include existing ADOT guidance, US Department of Transportation (USDOT) and Federal Highway Administration (FHWA) resources, and other WSM operations guidance literature. This Manual also incorporates results from a survey of other Western states' Departments of Transportation and new references that were used in the 2011 study.

CHAPTER 2. WINTER STORM MANAGEMENT

2.1 Organizational Structure, Roles, and Responsibilities

ADOT Operations is ultimately responsible for implementing statewide WSM operations; however, each Engineering District manages the roadways within their respective District boundary. Each Highway Operations Superintendent is the primary decision maker on resource allocations and techniques to be used before, during, and after a winter storm. This information is passed on to the Org Supervisors who in turn pass it on to their crews. Annually, each District revises its District Snow Guide that states how their WSM operations will take place that year.

2.2 Summary of Environmental Requirements

Environmental agencies establish standards for protecting environmental resources. WSM activities are subject to various environmental requirements and numerous procedures and permits are available to ensure environmental compliance. The principal agencies that regulate or influence activities associated with ADOT's WSM activities are the FHWA, US Environmental Protection Agency (EPA), US Fish and Wildlife Service (USFWS), US Army Corps of Engineers (USACE), Arizona Department of Environmental Quality (ADEQ), and Arizona Game and Fish Department (AGFD).

ADOT's WSM activities are also affected by state and federal land management agencies. These agencies include the US Department of Agriculture's (USDA) US Forest Service (USFS); US Department of Interior's Bureau of Land Management (BLM), National Park Service (NPS), and Bureau of Indian Affairs (BIA); Arizona State Land Department (ASLD), and several tribal nations. In addition, the Arizona Department of Agriculture (ADA) is responsible for enforcement of regulations that protect native plants, and the Arizona Parks Board addresses historic resources through the State Historic Preservation Office (SHPO) that may impact ADOT's winter storm management.

Environmental laws related to winter storm management are outlined below.

Environmental Laws Influencing Winter Storm Management		
Law	**Agencies Responsible**	**Function**
Clean Water Act (1977)	EPA, USACE, ADEQ	Regulates water quality by establishing standards and permit programs.
Clean Air Act (1970)	EPA, ADEQ	Regulates air quality by establishing standards and permit programs.
Executive Order 11990 Protection of Wetlands (1977)	All federal agencies	Regulates impacts to wetlands.
Resource Conservation and Recovery Act (1976)	EPA, ADEQ	Regulates generation, handling, and disposal of hazardous materials and reporting of certain spills.

Environmental Laws Influencing Winter Storm Management		
Law	**Agencies Responsible**	**Function**
Comprehensive Environmental Response, Compensation, and Liability Act (1980)	EPA, ADEQ	Involves liability assessments for property acquisitions and disposals.
Endangered Species Act (1973)	USFWS	Established mechanism for listing threatened and endangered species and establishing species recovery programs.
Arizona Native Plant Law (1998)	ADA	Requires permits for removal or salvage of protected native species on state-owned or private land[1].
Department of Transportation Act (as amended by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, 2005)	FHWA	Involves any federal-aid highway program affecting Section 4(f) resources[2].
Arizona Historic Preservation Act (1982)	SHPO	Involves activities affecting historic properties on state land or through a state action.
Wild and Scenic Rivers Act (1968)	NPS, USFWS, BLM, USFS	Applies to activities with the potential to impact federally designated wild and scenic rivers.
Arizona Aquifer Protection Program	ADEQ	Applies to facilities with the potential to discharge to groundwater. These facilities include, but are not limited to, impoundments, on-site wastewater treatment facilities, underground storage facilities, and materials pits that intercept groundwater.

Environmental Laws Influencing Winter Storm Management		
Law	**Agencies Responsible**	**Function**
Arizona Pollutant Discharge Elimination System Statewide Permit (2002/2010)	ADEQ	Governs discharges of stormwater from activities associate with the municipal separate storm sewer system (MS4 operated by ADOT; construction activities initated and controlled by ADOT; and facilities associated with industrial and maintenance activities owned and operated by ADOT).
Safe Drinking Water Act (1974)	EPA, ADEQ	Involves facilities where drinking water is supplied to the public or that use non-stormwater dry wells for disposal. Also involves any projects that would potentially affect a sole source aquifer.

[1] The Arizona Native Plant Law includes an exemption for normal or routine maintenance of improvements that may cause the incidental or unavoidable destruction of native plants (ARS Title 3, Chapter 7, Article 1, Section 3-915 Exemptions).
[2] Section 4(f) resources include publicly owned land of a public park, recreation area, or wildlife and waterfowl refuge of national, state, or local significance, or land of an historic site of national, state, or local significance (as determined by the federal, state, or local officials having jurisdiction over the park, area, refuge, or site).

2.3 Coordination with Local Jurisdictions and Federal Agencies

ADOT coordinates with state and federal regulatory agencies, including ADEQ, EPA, and USFWS, to comply with applicable environmental regulations. ADOT also complies with Memoranda of Understanding (MOUs) and other agreements with stakeholders and other jurisdictions, including USFS, BLM, NPS, ASLD, tribal nations and the BIA, and local governments, such as municipalities and counties.

2.4 WSM Goals and Environmental Strategies

2.4.1 Roadway Priorities and Level of Service Goals

ADOT is responsible for keeping state and federally owned/operated transportation corridors safe and operational during winter months when snow and ice accumulate on these roadways. Each District has evaluated their roadway system and assigned each road a priority ranging from I through V. Roadways with higher priorities receive a quicker response and a greater allocation of resources to meet the desired LOS goals. Efforts have been made to coordinate priorities so that roads maintain similar priorities as they cross District boundaries. Note that, during light winter storms, all routes and priorities may be able to be addressed if the resources are available.

While each District is responsible for developing its District Snow Guide to describe practices that may be unique to each District in maintaining its LOS goals, the following outline provides the general outline on which the individual District Snow Guides are based. Due to climate, elevation, and road classifications, not all Districts address LOS Goals I through V in their District Snow Guide. The Kingman District addresses LOS Goals I through III. The Yuma District has no LOS goals defined because its low elevation and mild winters preclude the occurrence of freezing winter storm conditions; therefore, unlike other Districts, Yuma has no Snow Guide.

Roadway Priorities and LOS Goals		
Priority	**Definition**	**Resource Allocation and LOS Goals**
I	Highways carrying over 3,500 average daily traffic (ADT) and/or having great economic importance locally.	• Maintained at the highest LOS practical using all available resources. • Receives coverage until near normal surface conditions are restored. • LOS Goal – Substantially free of loose snow and ice pack (bare pavement).
II	Highways carrying 1,000 to 3,500 ADT or highways in extreme climate areas required to be open year round.	• Receives coverage during storms, during drifting conditions, or when road conditions require tire chains or four wheel drive. • Removal of snowpack and ice and the addition of abrasives are limited to available resources. • LOS Goal – Substantially free of loose snow and ice pack (bare pavement).
III	Highways carrying less than 1,000 ADT.	• Receives coverage during storms or drifting conditions as resources become available. • Removal of snow and ice pack and the addition of abrasives are limited to daytime coverage. • In cases of extreme weather conditions, coverage will be extended if additional resources become available. • LOS Goal – These routes may be closed until the storm passes if resources are needed for higher priority routes. If closed, the route will be patrolled to ensure no motorists are stranded.
IV	Highways that have very low ADT.	• No maintenance provided during the storm and snow and ice pack removed only during regular working hours. • LOS Goal – These routes may be closed until the storm passes if resources are needed for higher priority routes. If closed, the route will be patrolled to ensure no motorists are stranded.
V	Highways that are seasonal routes.	• Typically, these roads are closed during the winter.

2.4.2 Environmental Management

Although WSM activities, particularly anti-icing and deicing operations and the application of abrasives, are necessary to keep ADOT's roadways safe and operational, these activities do have an impact on the environment. ADOT is committed to implementing processes that will minimize impacts to the environment from the use of salts, abrasives, and other chemicals. This Manual provides guidance for all WSM techniques currently used by the Districts, including anti-icing, deicing, pre-wetting, abrasives application, and nonadditive practices; and describes when and how each technique should be used for maximum effectiveness.

In addition, this Manual allows for the evaluation and potential use of new techniques and chemicals as they are developed. This Manual is formatted in a way that allows Org Supervisors to select the techniques that are most successful for maintaining the beneficial uses of roads within their Districts based on site- and storm-specific conditions, while minimizing potential impacts to the environment.

ADOT is in the process of developing an Environmental Management System (EMS) to provide a systematic approach for identifying important issues, potential liabilities, and for achieving and measuring improved environmental performance. In order to provide the data necessary to support the EMS, an AMP is being implemented to monitor WSM impacts on the environment (i.e., soil, vegetation, and water). The monitoring results are intended to support defensible conclusions concerning the environmental fate of chemicals used during WSM operations and the potential impacts that these chemicals and other materials may have on local ecosystems.

Optimization of WSM operations to reduce their impacts on the environment will be managed through a strategy called adaptive management. Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs (British Columbia Forest Service, 1999). Adaptive management was specifically designed for ecological management and is particularly important when there is significant uncertainty about the possible outcomes of a program (WSM practices, in this case) and there is a potential for environmental, economic, or social impacts from the program.

Environmental impacts can be minimized through the implementation of BMPs. As discussed throughout this Manual and summarized in Chapter 2.4.2.4, ADOT has incorporated a number of BMPs into their WSM operations. Many improvements have been made in recent years, including the use of new equipment and techniques that facilitate a precise, controlled application of anti-icing and deicing chemicals to the roadway. In addition, ADOT has implemented a more proactive strategy of applying anti-icing chemicals to roadways to prevent snow and ice from bonding to the pavement. It has been documented that a well planned and implemented anti-icing strategy can result in a significant reduction in the use of chemicals (AASHTO, 2004a). Continual optimization of WSM operations will be realized by ensuring operations staff are thoroughly trained, chemical usage is closely monitored, and feedback systems are in place to monitor the effectiveness of treatment practices.

2.4.2.1 Potential Environmental Impacts

Much of the salt used during WSM operations eventually leaves the roadway and reaches the natural environment. This can occur in a number of ways (AASHTO, 2004a):

- Granular salts may land directly on or bounce onto areas adjacent to roads.
- Salt may be thrown off roads by passing vehicles or by wind.
- Liquid and granular salts may run off roads with snowmelt or be splashed or sprayed onto soil and vegetation adjacent to roads.
- Salted snow and ice pack may be blown or plowed onto areas adjacent to roads.

Roadside trees and other vegetation may be affected by (1) increased concentrations of salt on soil and water leading to greater root absorption and (2) salt accumulation by foliage and branches due to vehicle splash and windblown dry salt. Trees closest to the road (generally those within 20 feet) are the worst affected, and there is frequently a distinct injury gradient with distance from the road. Trees on the downhill side of the road tend to suffer more damage than those on the uphill side (AASHTO, 2004a).

Chloride-based chemicals have the potential to increase the salinity of rivers, streams, and lakes, especially slow-flowing streams and small ponds. The accumulation and persistence of salts in watersheds pose risks to aquatic ecosystems and the presence of salts on the roadways attracts wildlife, contributing to roadkill. The quality of shallow groundwater aquifers may also be impacted by the presence of anti-icing and deicing chemicals (AASHTO, 2004a).

Abrasives applied to roadways often end up in streams and lakes contributing to turbidity and sedimentation and resulting in impacts to fish and aquatic resources. Vehicles may grind abrasives into fine particles that can become airborne when dry, resulting in increased air pollution (AASHTO, 2004a). Finally, abrasives have the potential to block stormwater inlets, leading to localized flooding.

2.4.2.2 Ambient Monitoring Program

The AMP consists of a network of sites that are used to monitor environmental impacts resulting from ADOT's WSM operations. The AMP is described in detail in Chapter 6.0 of this Manual. Although the primary medium of concern is soil within the R/W, other media included in the AMP are vegetative tissues, sediment, and (if present) surface water. The AMP is an outgrowth of the Biological Monitoring Program that was initiated by ADOT in 1991. In conjunction with the AMP, ADOT Districts will maintain records on the dates, methods, type of chemical(s), application rates, and results of their WSM operations during each winter season (see Chapter 5.8 of this Manual). These records, combined with the AMP data, will be used to:

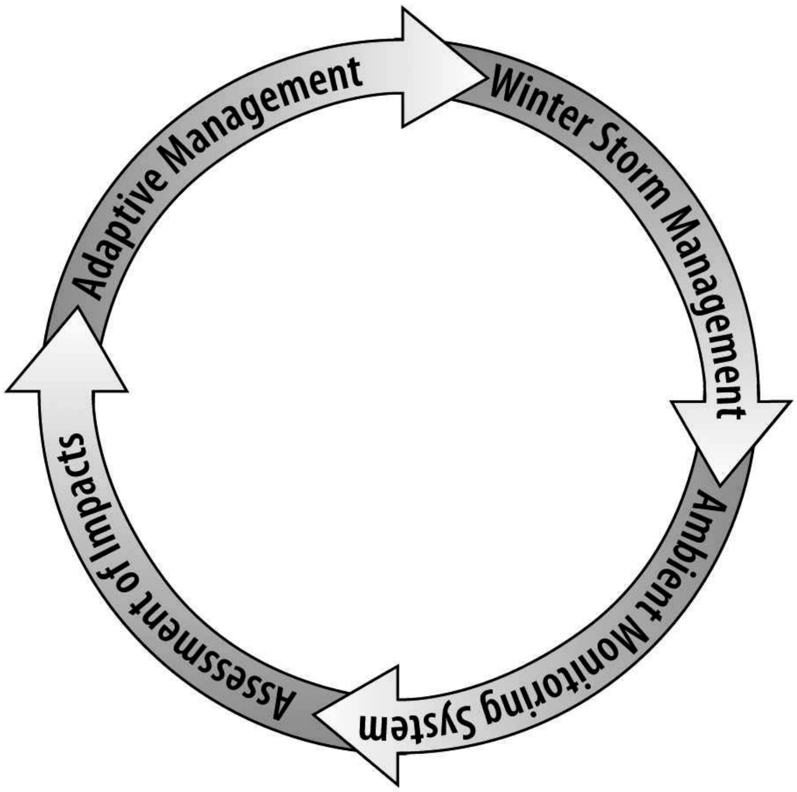
- Assess the current anti-icing/deicing chemical application guidelines based on analytical results of soil and vegetation samples collected from specific sites subject to ADOT WSM activities;
- Provide recommendations for implementing a WSM recordkeeping system of chemical usage and storm events; and
- Provide recommendations on monitoring and mitigating environmental impacts resulting from ADOT's WSM Program.

The operational records and monitoring data will be compiled and the data will be evaluated to assess long-term trends in the measured parameters and impacts to natural resources. Based on the results of these analyses, an adaptive management approach will be used to optimize WSM operations and minimize environmental impacts.

2.4.2.3 Adaptive Management

Adaptive management is a structured, iterative process of optimal decision making in the face of uncertainty, with an aim to reduce uncertainty over time via system monitoring.

Through the implementation of adaptive management based on environmental monitoring results, ADOT will adjust WSM practices to maintain environmental compliance as advances in WSM techniques occur, additional environmental monitoring data become available, and environmental regulations change. The adaptive management approach will balance practices by weighing LOS against environmental impacts resulting from WSM activities.



The adaptive management approach allows flexibility to make corrections or adjustments to WSM practices. Although this WSM Operations Manual provides consistent guidance across the state, each District is still allowed the opportunity to maintain independent WSM practices customized for specific District conditions. While this introduces a certain level of organizational variability and uncertainty into measuring and determining compliance, implementation of the AMP would mitigate much of this uncertainty through monitoring.

2.4.2.4 Best Management Practices

One of the key approaches to minimizing environmental impacts is the consistent use of the BMPs presented in this Manual. It is envisioned that new BMPs will be developed as a result of the detailed records of WSM activities that will be maintained by the Districts and the monitoring results of the AMP.

ADOT is implementing a number of BMPs to mitigate potential environmental impacts resulting from their WSM operations. Key practices include:

- Liquid chemical additives are stored in sealed containers or tanks and dry chemicals are stored in covered sheds or in all-weather sacks.
- Containment system areas are constructed around salt storage piles to collect contaminated runoff and protect nearby receiving storm drains and waterbodies.
- Equipment is washed at specified locations in District maintenance yards or at local contracted/approved car wash facilities. These facilities are equipped with infrastructure for collecting and disposing of pollutants.
- Chemical applicators are calibrated by Equipment Services (EQS) on an annual basis prior to the winter season and recalibrated if any errors are suspected.
- Chemical additives are procured through preapproved vendors and all products must meet specifications (including environmental specifications) established by the Pacific Northwest Snowfighters (PNS).
- All WSM operators receive training in WSM principles and practices. The training includes an initial 8 hours of training followed by an annual 2-hour refresher training course.
- RWIS and truck-mounted sensors are used to measure air and pavement temperatures to assist with making decisions regarding the proper timing and application of chemicals.
- Spreading speeds and patterns are controlled to reduce bounce and scatter and to concentrate material where it is most effective.
- ADOT has implemented a strategy of applying anti-icing chemicals to prevent snow and ice from bonding to the road. Anti-icing treatments have been shown to require less chemical usage than most deicing procedures and make it easier for snowplows to achieve bare pavement conditions by eliminating or reducing the bond between snow and ice and the pavement.

Adaptive management is a key component of ADOT's strategy to reduce environmental impacts. This Manual includes BMPs and/or programs that ADOT initiated during the 2008/2009 winter season and evaluated between 2011 and 2013. Key BMPs/programs include:

- ADOT initiated the AMP and evaluated its effectiveness on a limited basis as described in Chapter 6 of this Manual. The monitoring results will be used to support defensible conclusions concerning the environmental fate of chemicals used during WSM operations and the potential impacts that these chemicals and other materials have on local ecosystems. Based on the monitoring results, ADOT will use an adaptive management strategy to make changes to their WSM operations to maintain environmental compliance.

- Districts will be implementing a more stringent recordkeeping system than in the past. Each operator performing anti-icing and deicing activities will be required to accurately record their chemical usage through the use of T.A.P.E.R. logs[3] or automated logging methods. These logs will be used to record the types and application rates of chemicals, the locations where chemicals are applied, and the effectiveness of the applications. These logs will serve several purposes:
  - By measuring and recording the quantity of chemical applied, and observing and recording the effectiveness of the application, it should be possible to optimize the amount of chemical applied to the road (i.e., apply the least amount of chemical to achieve the desired effect). This philosophy can be summed up as delivering the right amount of chemical to the right location at the right time.
  - A review of the logs and accident data over time may result in the identification of trouble spots that consistently require higher quantities of chemical application. Based on these evaluations, it may be possible to target these areas for alternate control methods, such as shade reduction, message boards or signs, application of abrasives, or other nonchemical methods.
  - By evaluating data obtained from the logs and from the AMP, it may be possible to correlate changes in soil and plant tissue concentrations (i.e., calcium, magnesium, etc.) with specific chemical products and/or application rates. The results of these evaluations may be used to modify certain practices along specific segments of roadway.

ADOT's 2011 study in the Globe District compared salt accumulation in soil and vegetation adjacent to roadways with WSM activities at specific locations. The study also addressed the feasibility of using Automatic Vehicle Locating (AVL) systems on their WSM equipment as an alternate to T.A.P.E.R. logs. AVL uses global positioning system (GPS) technology to record in real time the location of the WSM equipment, plow status, vehicle speed, and application rates. The use of this equipment would limit the amount of information that the WSM operators would need to record and result in more accurate records. However, for those Districts that have not yet transitioned to automated recordkeeping such as AVL, T.A.P.E.R. logs will be used in the interim.

[3] ADOT records and retains data on the location and application rates of chemicals and abrasives through the use of T.A.P.E.R. logs as described in more detail in Section 5.8. T.A.P.E.R. stands for: **T** – Time; **A** – Application rate (pounds or gallons per lane mile); **P** – Product being applied; **E** – Event type (heavy snow, sleet, dry snow, wet snow, etc.); and **R** – Results of the anti-icing and deicing efforts.

CHAPTER 3. GEOGRAPHICAL AND ENVIRONMENTAL CONDITIONS

Within ADOT, operations and maintenance of roadways is divided into nine Engineering Districts: Flagstaff, Globe, Holbrook, Kingman, Phoenix, Prescott, Safford, Tucson, and Yuma (**Figure 1**). Each District is responsible for the management of roadways within their designated geographical area. Within each District, operational duties, including winter storm management, have been divided further into service areas, or Orgs, that have been designated throughout each District in a strategic manner based on geography, climate, and lane miles of roadway. As previously discussed, the Yuma District because of the unlikelihood for winter storm conditions to occur in this District.

The geographical diversity within the state results in a wide range of ecological, climatic, and demographic conditions. Because of these diverse conditions, each ADOT District tailors their management and maintenance requirements to their surrounding environment, particularly with regard to winter storm management. An overview of statewide characteristics is presented in the following sections.

3.1 Geography and Demographics

Arizona is located in the southwest region of the United States. The state is comprised of three physiographic provinces: the Colorado Plateau, Basin and Range, and Transition Zone. The Colorado Plateau province is located in the northern and northeastern portions of the state and is characterized by broad flat lands punctuated by isolated mountains and canyons. Much of this province is located at elevations averaging between 5,000 and 7,000 feet. The Basin and Range province is located in the western and southern portions of the state and is characterized by a series of mountain ranges separated by broad alluvial basins (valleys). The valleys generally range from 500 to 4,000 feet in elevation, with the higher elevations present in the southeastern part of the state and the lower elevations present in the southwestern part of the state. The mountain ranges generally are 2,000 to 5,000 feet higher in elevation than the surrounding valleys. The Transition Zone province occurs as a diagonal zone running from the southeast to northwest corners of the state and separates the Colorado Plateau province from the Basin and Range province. The Transition Zone province is characterized by rugged mountains separated by alluvial basins. The mountains generally range from 7,000 to 12,000 feet in elevation.

A nearly unbroken chain of ponderosa pines extends from the White Mountains, across the Mogollon Rim, to the San Francisco Peaks, and continues northward along the Kaibab Plateau into southern Utah. Located just northwest of Flagstaff, Humphreys Peak is the highest point within the state with an elevation of 12,611 feet. The Lower Colorado River Valley in the southwestern portion of the state has the lowest elevation at around 100 feet (**Figure 2**).

According to the US Census Bureau, Arizona is statistically one of the fastest growing states in the country. The total estimated population in 2013 was approximately 6,626,624 residents, up 22.6 percent since 2000. This is well above the national average growth rate of 8.8 percent. Total population and density among counties within the state can vary widely. Maricopa County has the largest population at approximately 4,009,412 residents and is fourth in terms of growth within Arizona, with a 23.4 percent population increase since 2000 (pop. 3,072,149, US Census Bureau, 2000). Between 2000 and 2013, Pinal County's population grew 53.8 percent from

179,727 to 389,350 residents, making it the fastest growing county in the state (US Census Bureau, 2000 & 2013).

3.2 Roadway System

Roadway use within the state is generally consistent with the population levels of individual areas; the higher the population, the higher the traffic levels. Data compiled by ADOT in 2012 compared the total miles that vehicles travel on major ADOT roadways, expressed in daily vehicle miles traveled (VMT), to the population of the county (ADOT, 2012a). As shown in the following table, Maricopa County has the greatest population density and the highest daily VMT. Conversely, Greenlee County has the lowest population density in the state and experiences the lowest daily VMT.

COMPARISON OF POPULATION AND VMT BY COUNTY

County	Total Population (2013)[1]	Total VMT on Major ADOT Roadways (2013)[2]
Apache	71,934	2,544,000
Cochise	129,473	4,017,000
Coconino	136,539	6,209,000
Gila	53,053	1,594,000
Graham	37,482	896,000
Greenlee	9,049	226,000
La Paz	20,324	2,396,000
Maricopa	4,009,412	90,393,000
Mohave	203,030	7,484,000
Navajo	107,322	3,682,000
Pima	996,554	22,868,000
Pinal	389,350	8,556,000
Santa Cruz	46,768	1,323,000
Yavapai	215,133	7,801,000

[1] US Census Bureau Quickfacts, 2013
[2] ADOT, Multimodal Planning Division, 2013

Primary routes in the state include Interstate (I)-8, I-10, and I-40, which run east to west, and I-17 and I-19, which run north to south. Other major roadways outside of the Phoenix area include SR 95 and US 93 in the western portion of the state, SR 87 and US 89 in the central and northern portions of the state, and SR 64 and SR 67, which provide access to the Grand Canyon National Park.

Roads designated as Parkways, Historic, or Scenic Roads, National Scenic Byways, and All-American Roads occur within the state and may be affected by WSM activities. Twenty roadways designated as Parkways, Historic, or Scenic Roads occur in areas where ADOT currently conducts WSM activities (**Figure 3**). There is one All-American Road and four National Scenic Byways in Arizona. Four of these roadways occur in areas where ADOT currently conducts WSM activities.

3.3 Land Jurisdiction

Transportation corridors within the state generally are located on or adjacent to land that is owned and/or operated by entities other than ADOT. In many cases the roadways are constructed on easements or R/Ws that are leased by the state. Public and private parties that have jurisdictional control over adjacent land have a vested interest in WSM activities that occur within the corridor. The major landholders in the state are the BLM, USFS, tribal governments, NPS, ASLD, Department of Defense (DoD), USFWS, state and local parks departments, and private owners. The distribution of land jurisdiction is shown in **Figure 4**.

ADOT provides winter storm management on over 756 miles of roadway located on lands administered by the BLM. These lands are mostly located in northern Arizona on the Colorado Plateau. The main route through this area is I-40, which can experience temporary closures due to blowing and drifting snow. Additionally, Arizona is located in USFS Region 3. Within Arizona, there are six designated national forests: Apache-Sitgreaves, Coconino, Coronado, Kaibab, Prescott, and Tonto. These forests encompass a total of 11.25 million acres of land, nearly 15 percent of the total area of the state. ADOT provides winter storm management on 2,288 miles of roadway located on lands under the jurisdiction of the USFS. ADOT in conjunction with FHWA, BLM, and USFS has developed guidelines for WSM activities on roads that pass through BLM and USFS land (ADOT/FHWA/BLM/USFS Steering Committee, 2008).

Within Arizona, there are 21 federally-recognized tribes that have established reservations (UA, 2007). These lands are officially owned by the federal government and entrusted to Native American tribes or nations. Activities that occur within these lands are federally controlled and fall outside the jurisdiction of the State of Arizona. ADOT provides winter storm management on 2,225 miles of roadway located on lands under the jurisdiction of Native American tribes and nations.

There are currently 25 designated parks, monuments, memorials, recreation areas, historic sites, and trails managed by the NPS within Arizona. ADOT provides winter storm management on over 184 miles of roadway located within 11 areas under the jurisdiction of the NPS.

Over nine million acres of land are currently in the State Land Trust under the jurisdiction of the ASLD (ASLD, 2007). ADOT provides winter storm management to over 1,032 miles of roadway in the State Land Trust.

The DoD operates a number of major facilities within Arizona, including Fort Huachuca and the Yuma Proving Grounds Army installations; the Marine Corps Air Station in Yuma; and Davis-Monthan and Luke Air Force Bases, the Barry M. Goldwater Air Force Range, and the Gila Bend Air Force Station. ADOT provides winter storm management on over 91 miles of roadway under the jurisdiction of the DoD.

There are eight National Wildlife Refuge (NWR) areas in Arizona that are under the jurisdiction of the USFWS: Bill Williams River, Buenos Aires, Cabeza Prieta, Cibola, Imperial, Kofa, Leslie Canyon, and San Bernardino. ADOT does not provide winter storm management on roadways within any of the NWR areas.

State and local park lands are those lands that have been designated for public recreation. These lands fall under the jurisdictions of Arizona State Parks, county park departments, and city or town park departments. ADOT provides winter storm management to 8.5 miles of roadway under the jurisdiction of state and local parks departments.

Lands that do not fall under the jurisdiction of federal, state, Native American tribe or nation, county, local municipality, or any other public organization are classified as private or “other” lands. Private lands are primarily owned by private individuals, groups of individuals, businesses, or large corporations. Other lands consist of everything else. ADOT provides winter storm management on over 3,480 miles of roadway located on or adjacent to privately owned or other lands.

3.4 Climate

ADOT maintains RWIS sites throughout the state in order to aid WSM activities. The RWIS sites are shown on **Figure 5**. Climate and weather patterns vary widely within Arizona. Climatic variations occur over geographical regions and over areas exhibiting extreme elevation changes. These variations make for unique and dramatic differences in average temperature, precipitation, and overall climatic characteristics. Climate and related information for this section was obtained from the Western Regional Climate Center (2007).

Temperatures within the state can vary widely depending on geographic location and elevation. Northern and higher elevation regions within the state generally experience cooler temperatures and larger amounts of precipitation, including snowfall. Mountainous and high plateau regions in the northern and eastern regions of the state can experience temperatures as low as -35 degrees Fahrenheit (ºF) during winter months. Winter temperatures in these regions of Arizona average 44 ºF during the day and 17 ºF at night. The central and southern portions of the state, particularly those areas at low elevations, have climatic conditions characteristic of the Sonoran Desert. During winter months, average high temperatures are in the mid-70s ºF and low temperatures are in the low 30s ºF.

Winter precipitation rates in the state vary widely and generally follow the same geographical patterns seen in the state’s topography (**Figures 2 and 6**). Precipitation rates are greatly influenced by elevation and season. During winter months, Pacific storms tend to enter the state and produce significant precipitation events at elevations over 3,000 feet in the northern and central portions of the state. Areas higher than 7,000 feet in elevation receive a cumulative total of up to 100 inches of snow during the winter. The monsoon season generally occurs during the summer months of July, August, and September. During this time, heavy afternoon thunderstorms are produced from heat rising from the desert floor, primarily in the lower elevations of the central and southwestern portion of Arizona. Average annual precipitation ranges from 23 inches in Flagstaff to 3.1 inches in Lake Havasu City. Average annual snowfall ranges from 81.3 inches in Flagstaff to 0 inches in Phoenix, Lake Havasu City, and Yuma.

3.5 Environmental Concerns and Monitoring

Application of chemicals for winter storm management of roads may have an impact on the environment, including water resources. Water resources in Arizona include both surface water and groundwater. Surface water resources are comprised of lakes, rivers, streams, and wetlands; and they are important for a variety of reasons including economic, ecological, recreational, human health, and potable water consumption. Groundwater is commonly used as a source for drinking water, agricultural irrigation, and industrial applications.

Waterbodies that do not meet applicable numeric or narrative water quality standards or are not of a quality that enables them to be used in accordance with the state's explicit use are classified as "Impaired Waters" per Section 303(d) of the Clean Water Act. Arizona currently has 68 waterbodies classified as impaired, some of which are located near ADOT-maintained roadways (**Figure 7**).

Per Arizona Administrative Code Section R18-11-112, the Director of ADEQ may classify a waterbody within the state as an "Outstanding Arizona Water (OAW)." In so doing, site-specific water quality standards may be applied to the waterbody as a means of maintaining and protecting its existing water quality. Of the 19 waterbodies listed as OAWs by ADEQ, only two are in the general proximity of transportation corridors that receive winter storm management by ADOT. The entire section of Oak Creek, including the West Fork, is classified OAW and flows parallel to SR 89A from mileposts (MPs) 374.15 to 387.66 and parallel to SR 179 from MPs 312.82 to 313.44. In addition, Cienega Creek flows beneath I-10 at MP 289.22 (**Figure 7**).

In addition to impaired waters and OAWs, wild and scenic rivers must be considered with regards to winter storm management (**Figure 7**). Wild and scenic rivers are rivers deemed to have unique properties and characteristics, for which nearby development and preservation are balanced. The Verde River, which begins at Sullivan Lake in Yavapai County and empties into the Salt River near Fountain Hills, is the only designated wild and scenic river in Arizona. Approximately 40.5 miles of the 195-mile long river was placed in the National Wild and Scenic River program in 1984 due to its remarkable scenery, historical and cultural value, and threatened, endangered, sensitive, and special status species present in the river. Approximately 4.4 miles of ADOT-maintained roads (I-17 and SR 260) are located within 0.25 miles of wild and scenic portions of the Verde River. Biological resources, such as species of concern and those species addressed in the EO, are also considered in ADOT's AMP.

Winter storm management may also affect air quality. Traffic can pulverize abrasives to particulate matter less than 10 micrometers in diameter (PM_{10}), and once airborne, contribute to PM_{10} particulate air pollution. Within Arizona, 14 areas have been designated as nonattainment areas or attainment areas with maintenance plans for one or more criteria pollutant. These designated areas include those designated as nonattainment for PM_{10}. These areas include both urban and rural areas with roadways that receive winter storm management **(see Figure 8)**.

CHAPTER 4. ICE AND SNOW SCIENCE

To understand when and how WSM technologies and practices are effective, it is important to first understand the science behind ice and snow formation and deicing and anti-icing processes.

4.1 Ice and Snow

The term ice refers to the solid phase of water, which can take several forms, both on a micro-scale (i.e., molecular structure) and macro-scale (i.e., visible to the naked eye). Ice is considered a mineral, a naturally occurring crystalline solid made up of water, air, and impurities. Ice appears in many forms, particularly in the atmosphere. Hail, for example, is ice that forms in the atmosphere (typically forming around a dust particle nucleus) until it reaches a size at which it is no longer buoyant and falls from the atmosphere. Frost, another form of ice, is created in the atmosphere when water (in the vapor phase) cools directly to a solid phase without passing through the liquid phase. Snow is also a form of atmospheric ice; snowflakes are aggregates of small ice crystals that form in loose, hexagonally symmetrical structures (Klesius, 2007).

4.2 Ice and Snow Formation and Melting

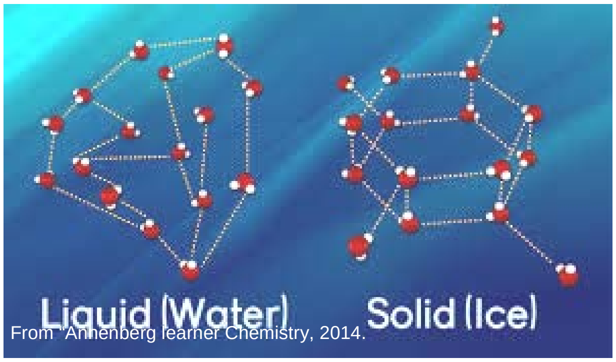
Ice forms when liquid water is cooled below 32 °F at standard atmospheric pressure and it most commonly arranges in a hexagonal crystalline structure. Once formed, ice is typically transparent or opaque bluish-white, but ice can also take on the color of other materials mixed in with it, such as vegetation, soil, or pavement[4]. Ice has an unusual property in that its density as a solid is 8 percent less than liquid water. In the form of snow, the density is *substantially* less than water (5 to 15 percent the density of water). When snow initially settles on the ground under its own weight, its density increases to approximately 30 percent of water, and as the winter season progresses (passing through multiple freeze-melt cycles), the density of accumulated snow gradually increases, typically to 50 percent the density of water (CDEC, 2007). Long-term accumulations of snow are referred to as snowpack.

Ice changes to the liquid phase (water) when its internal temperature surpasses its melting point[5] temperature. During the melting process, bonds between water molecules are broken (as discussed in further detail in the following section), which requires a substantial amount of energy or heat. Typically, the source of this heat comes from the underlying pavement or the friction between the pavement and tires from vehicular traffic.

[4] Ice referred to as “black ice” is not actually black. It is transparent in color and takes on the color of the underlying pavement (black). It is difficult for motorists to see because it lacks the glossy surface commonly seen on ice formed over light materials, such as water in a lake.

[5] Melting point and freezing point temperatures are the same. The correct usage depends on the phase change. For a liquid to solid phase change, the temperature is referred to as the freezing point. For a solid to liquid phase change, the temperature is referred to as the melting point.

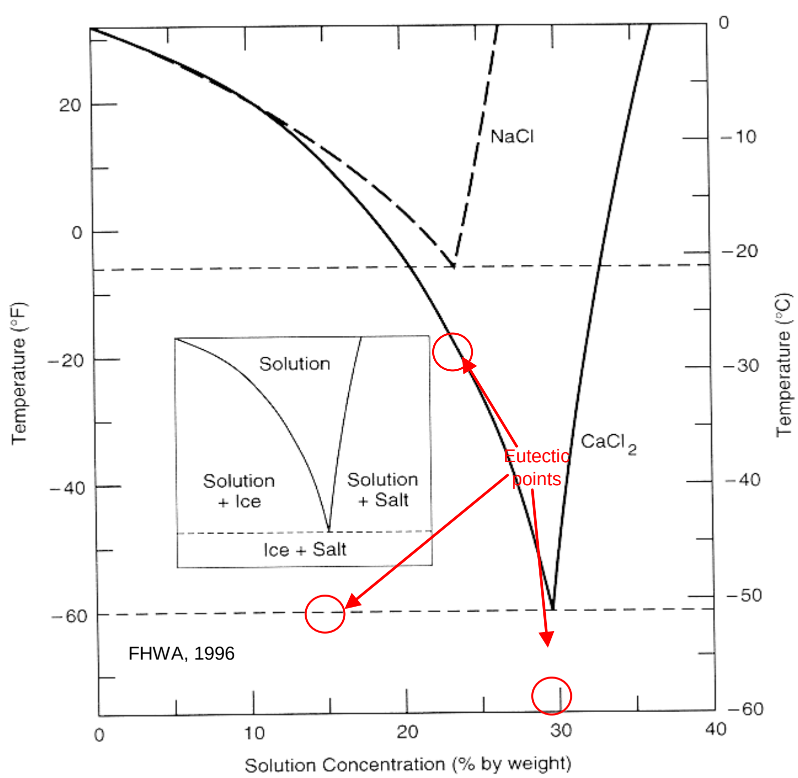
4.3 Chemical Bonding



The chemical bonding in ice has important implications in WSM operations. In the solid phase, water molecules form the maximum number of possible bonds (4), known as hydrogen bonds, among themselves, essentially locking the molecules in place (Nature, 2006). There are fewer available hydrogen bonds in the liquid phase than in the solid phase and the fewest number of hydrogen bonds, perhaps none at all, in the vapor phase. Ice has a slippery surface because the water molecules at the top of the ice layer (in contact with the air) have fewer bonds and can move more freely as a liquid.

4.4 Deicing and Anti-icing Science

The effect of deicing is based on the concepts of lowering the freezing point temperature and disrupting the four hydrogen bonds that keep water molecules rigid within the ice structure. Deicing chemicals (salt, for example) draw moisture and heat from the snow or ice[6], creating a solution of salt and water (brine). The brine solution has a lower freezing point than water alone; therefore, the ice on the road melts, changing from a solid to liquid phase (FHWA, 1996).



All deicing chemicals have an optimal brine concentration (see the graphic). For example, in the case of NaCl, designated by the dashed curve, the optimal (lowest) freezing point temperature is reached with a 23 percent brine solution concentration (by weight). When dry salt is initially applied to the ice, the brine concentration is very high (right side of the curve) and not very effective (i.e., high freezing point temperature). As the salt begins to draw moisture from the ice, the brine concentration decreases (moving left on the curve), because there is more water brought into the solution with the same amount of salt.

[6] Pre-wetting, as discussed in more detail in Section 5.3.4.1, assists in deicing because it establishes a volume of liquid water that the deicing agent can readily dissolve in, rather than drawing liquid water from the ice.

The brine concentration continues to decrease until it reaches an optimal concentration where the freezing point temperature is lowest (the bottom point of the curve). This point on the curve is referred to as the eutectic point (approximately -6 °F for NaCl). As more water from the surrounding ice is brought into the brine solution, the freezing point temperature begins to rise (moving further to the left on the curve). Thus, it is important to periodically reapply deicing agents to increase the brine concentration and decrease the freezing point temperature to an optimum point (moving to the right, back towards the eutectic point).

As one studies the freeze-point curve, it becomes apparent that the effect of deicing chemicals is not static and does not occur instantaneously. Instead, it is a dynamic process that occurs over time and is influenced by environmental conditions. The speed at which dilution takes place depends on several factors (Township of Cranberry, 2006). The three main factors are discussed below:

(1) Volume of water available. The more water, snow, or ice on the pavement at the time of treatment (left behind from plowing or pre-wetting) the faster the deicing chemicals will dilute. Note that excessive water, snow, or ice on the pavement will excessively dilute deicing chemicals beyond their effective concentration. Similarly, more dilution will occur if there is precipitation during treatment, and the more intense the precipitation the faster the rate of dilution will occur. Moreover, the higher the water content present in the snow or ice, the faster the rate of dilution. Therefore, freezing rain will dilute deicing chemicals faster than light snow.

(2) Deicing formulation and grain-size distribution. The dilution rate of a deicing agent strongly depends upon the original formulation and grain-size distribution. Liquid formulations of deicing chemicals (23 to 32 percent concentration) will dilute faster than solid (dry) formulations (100 percent concentration). For dry deicing chemicals, finer grained materials will dilute faster than coarser grained materials.

(3) Water temperature. The rate of dissolution (movement of deicing compounds into solution) slows down with decreasing temperatures and will hardly occur at all if there is only a mixture of salt and solid ice. This is one of the reasons that it is not advisable to apply dry deicing chemicals directly to ice, and that pre-wetting chemicals should be used.

As shown in the graphic, all deicing chemicals exhibit a similar behavior, although they each have their own specific eutectic concentrations and temperatures. For example, $CaCl_2$, shown with a solid line in the previous graphic, has a higher eutectic concentration (30 percent) and lower eutectic temperature (-60 °F) than NaCl. The eutectic concentrations and temperatures of common deicing chemicals are listed on the next page (FHWA, 1996).

Deicing Chemical		Eutectic temperature (°F)	Eutectic concentration (percent by weight)
Name	Formula or Abbreviation		
Sodium Chloride	NaCl	-6	23.0
Magnesium Chloride	$MgCl_2$	-28	21.6

Anti-icing works by the same physiochemical process as was described for deicing. The only difference from deicing is that the chemicals, which can be the same agents used for deicing (i.e., NaCl, $MgCl_2$), are applied prior to, or very shortly after, the start of a winter storm. In the anti-icing process, the chemicals establish and maintain the eutectic temperature on the pavement surface, thereby preventing ice formation at any temperatures above that point. Hence, the pavement remains free of ice formation during the storm. Refer to Chapter 5.3.4 for more details on the application of deicing and anti-icing chemicals.

4.5 Pavement Temperature and Effects

Pavement temperature is an important factor to understand from a WSM perspective because it controls the chemical additive solubility and resulting application effectiveness. It should be noted that pavement temperature and air temperature are not synonymous; pavement temperature typically lags the air temperature by a few hours. There are a number of factors that influence the pavement surface temperature and ice formation on the pavement (Township of Cranberry, 2006).

4.5.1 Solar Radiation

Solar radiation (sunshine) can warm surface temperatures significantly above the air temperature, particularly if the surface is dark like asphalt. Solar radiation is most intense at the highest sun angles relative to the horizon (i.e., midday), so as the sun rises, solar warming increases. Shady patches of roadway are the first to freeze and the last to melt as they are protected from solar radiation. Similarly, vertical sags (low points) and superelevated portions of roadways often preferentially form ice because they have the least exposure to solar radiation during the day. During clear nights with minimal winds, surface temperatures can rapidly cool to the point that the pavement surface temperature is colder than the adjacent air temperature. It is at this time that black ice or frost will form on the pavement surface. Solar radiation and nighttime effects are not instantaneous, since surface temperatures take longer to change than air temperatures. This is referred to as the temperature lag time.

4.5.2 Geothermal Effects

While solar radiation and nighttime effects influence pavement temperatures from above, the underlying soil temperature influences pavement temperatures from below. This influence is referred to as the geothermal effect. During the fall, pavement temperatures may not drop below the freezing point, because the underlying soil has not yet dropped below the freezing point and there are only short durations during the night at which the air temperature is below freezing. However, as the winter season progresses and air temperatures are consistently lower, the underlying soil temperatures will drop below the freezing point. Toward the end of winter and possibly into spring, depending on the climate, pavement temperatures may remain lower than air temperatures for some time because the soil temperatures still remain low.

Geothermal effects (or lack thereof) are also responsible for the differential freezing on bridge decks. In early winter months, bridge decks will freeze quicker than adjacent road surfaces because they lack an underlying earthen subsurface with a higher temperature than the surrounding air temperature. In contrast, toward the end of the winter season, bridge decks will not freeze as quickly or as often as adjacent road surfaces because the surrounding air temperature is warmer than the earthen subsurface.

4.5.3 Wind Speed

Although pavement temperatures tend to lag behind air temperatures (as discussed in Chapter 4.5.1), the presence of wind can shorten the lag time. The higher the wind speed, the faster the pavement temperature will change toward the air temperature.

4.5.4 Pavement Type

Roadway surfaces generally consist of concrete or asphalt pavements. The differences in these two materials have significant implications in terms of WSM operations (TAC, 2003). Because of its dark color, asphalt pavements are more sensitive to solar effects and can heat up quicker and to higher temperatures compared to light colored concrete during the day and vice versa during the night (as discussed in Chapter 4.5.1). Additionally, similar to geothermal effects from the underlying soil (Chapter 4.5.2), asphalt intrinsically has a lower thermal mass than concrete, which is another reason that it heats up and cools down faster than concrete.

Asphalt, particularly aged asphalt, is more pervious than concrete and tends to shed brine solutions slower than concrete pavements do. Moreover, concrete is often grooved to improve drainage and wet weather friction and reduce noise. Such grooving on concrete pavements increases the shedding of brine solutions; therefore, concrete pavements may require additional or more frequent application of deicing or anti-icing chemicals than asphalt pavements do.

Asphalt (flexible) pavements are more prone to wheel rutting than concrete (rigid) pavements, particularly as they age and carry heavier traffic loads. Wheel rutting causes the brine solution to accumulate and concentrate in the wheel track, which has both positive and negative impacts. The positive impact from wheel rutting and the accumulation of brine solution within the wheel track is that there is less likelihood of refreezing where vehicle tires are most commonly traveling. However, by the same token, this creates unsafe driving conditions outside of the wheel track where less brine solution has accumulated.

CHAPTER 5. OPERATIONS GUIDANCE AND BEST MANAGEMENT PRACTICES

5.1 Winter Storm Management Planning

Strategic planning is an integral component of successful winter storm management. Internal ADOT planning should be conducted at all levels, from the field operations crew to the management level. The ADOT Performance Control System (PeCoS) is used when strategic planning. WSM operations fall within Program 170 – Snow and Ice Removal. Specific activities within PeCoS Program 170 **(Appendix A-1)** are:

- Activity 171 – Plow Snow and/or Apply Abrasives/Deicers
- Activity 172 – Winter Storm Patrol
- Activity 173 – Spot Ice Control
- Activity 174 – Anti-Icing with Deicers
- Activity 175 – Cleaning of All Snow Related Equipment
- Activity 179 – Other Snow and Ice Control

Planning will be conducted externally to incorporate input from other government agencies, DPS, Native American tribes and nations, municipalities, public and private stakeholders, and the general public. Procurement and shipment of chemical additives and abrasives to ensure adequate inventories, and calibration and preparation of spreading, spraying, and plowing equipment by EQS shops will also take place at this time.

5.1.1 Winter Storm Management Meetings

Each District will conduct internal WSM meetings before and after each winter season. These meetings are critical for planning, management, trouble-shooting, and continuous improvement of the WSM Program. A general WSM meeting topic checklist is included in **Appendix A-2**.

Pre-winter season meetings are intended to prepare for WSM logistics and activities, including:

- Overview of WSM operations and procedures;
- Organization of WSM personnel and scheduling;
- Establish consistency with systems across Districts; and
- Address safety concerns and procedures.

Post-winter season meetings will be held to assess the overall success of the WSM operations and to evaluate methods of continuous improvement of work crews and administration, materials application, policies, health and safety concerns, and operational response procedures.

5.1.2 Coordination with Agencies and the Public

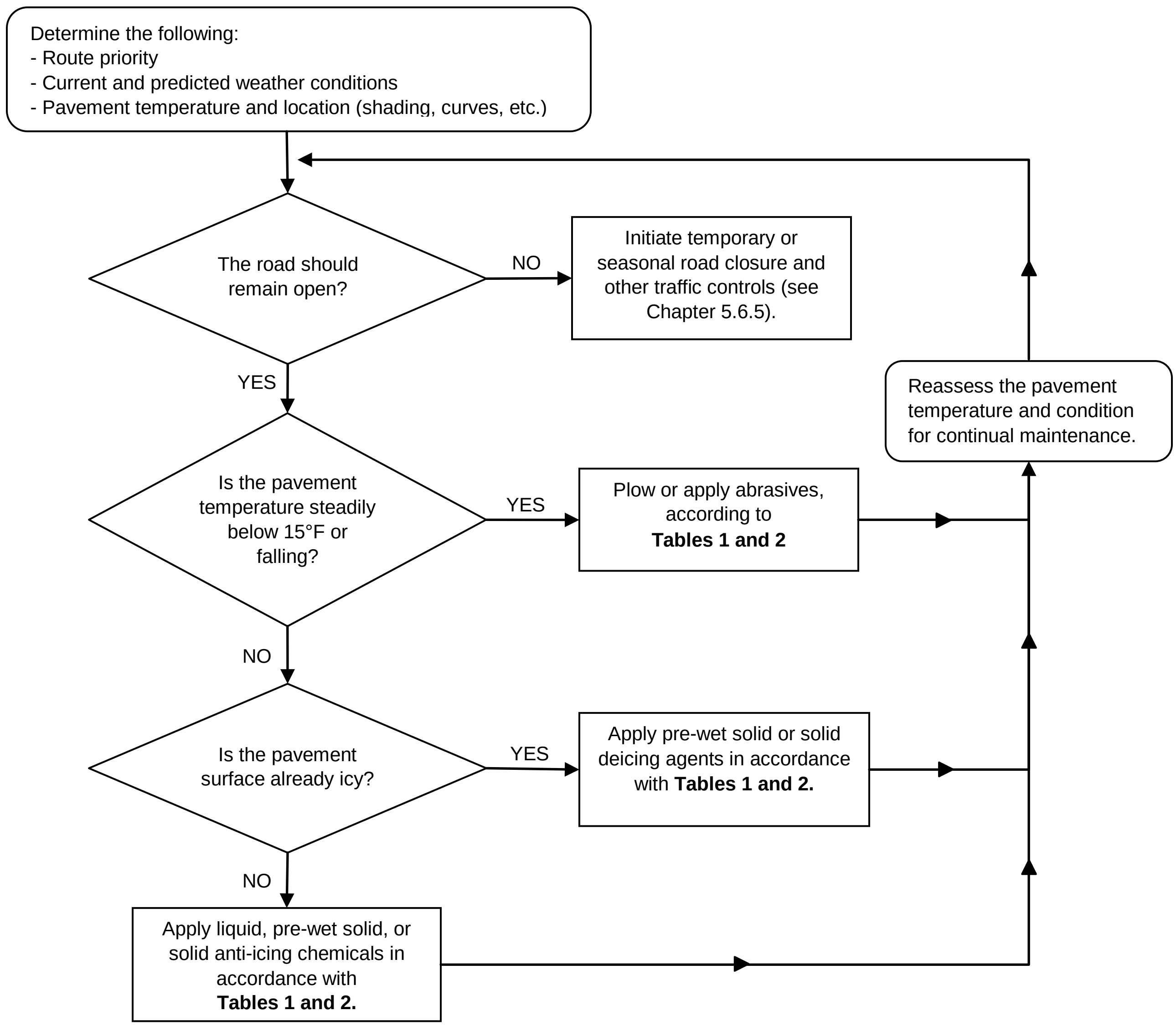
ADOT coordinates closely with the DPS, particularly for issues related to motorist safety recommendations. These include tire chain and snow tire recommendations, reduced speed limits, traffic controls, signage, road closures, abandoned vehicle removal, stranded motorist assistance, and other activities. Refer to Chapter 5.6.5 for more details on traffic controls. ADOT routinely invites stakeholders to participate in preseason forums to discuss upcoming WSM operations and to solicit input for improved operations.

5.1.3 Typical Winter Storm Management Strategy

As shown in the following schematic, the typical WSM strategy begins by assessing the route priority; and obtaining accurate information regarding current and predicted weather conditions, pavement temperatures and conditions, and other location-specific factors (pavement shading, road curves and hills, bridges, etc.). If, after gathering and assessing the necessary information, ADOT determines that the roadway can no longer be safely operated or maintained, the roadway will be closed (either temporarily or for the entire season), as discussed further in Chapter 5.6.5.

Anti-icing and deicing chemicals can be applied as a liquid, as a pre-wet solid, or directly as a solid. **Tables 1 and 2** provide recommended application rates for the anti-icing and deicing agents NaCl and $MgCl_2$. Regardless of the maintenance activity initiated, the weather and pavement conditions should be continually monitored and assessed. Depending on how the conditions change, subsequent operations may also change **(see Tables 1 and 2).**

Typical Winter Storm Management Strategy Schematic



5.1.4 Annual Updating of Snow Guides

Each ADOT District will update their Snow Guide annually. The Snow Guides are specific to the operations, routes, and needs of the District. In general, the Snow Guides include the following components:

- Overview of the purpose and objectives of winter storm management within the District;
- District map, including routes and maintenance yards;
- Guidance for recommending chain and snow tire usage;
- Closed roadway inspections;
- Recommended material spread rates;

- Safety tips and reminders for operating snowplows, spreaders, and other heavy equipment;
- Weather condition reporting and weather advisories;
- District personnel contacts and phone numbers;
- Identified route priorities;
- Accident reporting procedures and DPS contact numbers;
- Snow Desk and Traffic Operations Center (TOC) contact numbers;
- Org information; and
- Reporting/recordkeeping forms, including the T.A.P.E.R. log form.

Because it is likely that one or more of the above components of the Snow Guide will change from one year to the next, the Snow Guides are updated annually to reflect the conditions and operations for the upcoming winter season. This Manual serves as a resource for Districts to update their Snow Guides.

5.2 Equipment

5.2.1 Types of Equipment

The types of equipment used for WSM practices include automated and manually-controlled chemical additive and abrasives dispensers and spreaders and snowplows (AASHTO, 1999; Salt Institute, 1991; TAC, 2003). The equipment often has cab controls and/or temperature sensors to assist and guide the operator.

Solid Material Spreaders

Dry chemical additives and abrasives can be applied to the roadway with a hopper-type spreader or a dump body with spreader. Spreaders can be used to apply dry granular materials at widths ranging from 3 to 40 feet. Application rates can be controlled by: (1) the area of the gate opening on a hopper box; (2) the feed-belt or auger speed; and (3) the truck speed. Feed-belt and auger speed can be controlled manually or by a groundspeed oriented controller.

Liquid Material Spreaders

ADOT uses nozzle spreaders to distribute liquid additives. Nozzle spreaders are designed to be towed by a truck equipped with a liquid tank, and the nozzle spreader is powered by its own traction-driven wheel and groundspeed control. Nozzle spreaders should spray liquid at a low height above the roadway to minimize the effects of air turbulence behind the vehicle. Nozzle spreaders will experience problems if the nozzles become plugged. Also, if the droplets are too fine the mist can disperse before hitting the pavement surface. This problem can be mitigated by using a liquid filter. Nozzle spreaders can be chassis-mounted (a slip-in unit that can be placed temporarily in the bed of a dump truck) or they can be towed behind the vehicle.

Snowplows

Snowplows come in multiple forms: one-way, front, reversible, deformable moldboard, underbody, and side wing plows. Rubber blades are currently used by most Districts for slush removal. Snowplows are generally used when more than one inch of snow has accumulated on the pavement.

Automatic Vehicle Locating System

ADOT has equipped some WSM equipment with the AVL system to collect data related to their WSM operations. The AVL system is installed on vehicles used for snowplowing and the application of road salt and cinders. The AVL system uses GPS technology to track vehicle movements and application details. During vehicle operation, general information such as vehicle speed, location, and heading are recorded at short time intervals. The AVL system also records information related to the operation of the vehicle's equipment, such as plow setting (up versus down), spreader setting, material applied, application rate, pavement temperature, and air temperature. The AVL system provides the ability to track real-time material application rates for each piece of equipment. This provides ADOT with the ability to monitor and communicate important winter storm-related information, such as the number of applications and their associated rates over any section of roadway for a particular storm, month, or season, and evaluate resource requirements for seasonal planning. Of particular value is the ability to evaluate the rate at which winter storm applications are conducted as compared with guidelines provided in the ADOT WSM Operations Manual.

5.2.2 Equipment Inspection

In addition to the inspections conducted by ADOT EQS, WSM operators should check the following items on a daily basis (AASHTO, 1999; Salt Institute, 1991) and complete the daily commercial driver's license checklist (see District Snow Guide).

Spreaders

Inspect pumps, hoses, controls, and fittings. Mount, load, and test all spinners, augers, and auxiliary engines.

Gate Settings

Check low and high gate settings for the proper opening (2 inches for salt, 8 inches for cinders).

Hydraulic System

Inspect air and hydraulic pumps, hoses, and controls for proper operation at various settings.

Plows

Carefully inspect the moldboard and cutting edge of all snowplows for cracks or excessive wear. Thoroughly inspect all plow bits as outlined in the District Snow Guide to assess wear, and replace when necessary. Note that right-hand plows wear down most rapidly on the left side and left-hand plows wear down most rapidly on the right side. Inspect snowplow hoists and underbody blades for proper operation.

Electrical Equipment

Inspect and service all lighting and electrical equipment, including wiring, sockets, headlights, flashers, and strobe vehicle and spreader warning lights for proper operation. If any lighting or electrical equipment does not work, take the equipment to the closest EQS shop for repair. Faulty wiring and failure of alternators, generators, and batteries are a major cause of downtime in WSM vehicles.

Safety Equipment
Check that there is a flashlight, flares, flags, safety vests, a shovel, a fire extinguisher, and a first-aid kit in the truck cab. Test the handheld and two-way radio before leaving the yard. If they are used, apply tire chains with the proper tension.

AVL Equipment
Ensure properly functioning AVL system by implementing a periodic equipment maintenance protocol that includes calibration of the pavement temperature sensors, spreader rate control, and GPS to ensure accurate readings.

5.2.3 Equipment Maintenance

Proper equipment maintenance is essential for a successful WSM Program (AASHTO, 1999; Salt Institute, 1991). In anticipation of a winter storm, conduct maintenance and fueling before the storm. After each storm, all equipment should be cleaned, dried, and refueled to be ready for the next storm. Components such as chains, sprockets, hinges, spinners, bearings, and other moving parts should be properly lubricated once they are dry. The pump and spray nozzle assemblies should be drained and flushed. The hydraulics and quick disconnects should be checked for leaks. If repairs are needed, ADOT EQS should be notified. During winter storm operations, ADOT WSM equipment takes precedence over all other ADOT equipment requiring maintenance or repairs.

Wash equipment after each winter storm with pressure washers and hot water at the Org wash station, local contracted wash facility, or approved car wash. This includes all snowplows, loaders, etc. used in the handling of anti- and deicing chemicals. Refer to PeCoS “Activity 175 – Cleaning of All Snow Related Equipment” in **Appendix A-1** for specific operational details regarding the cleaning of WSM equipment and refer to the activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.2.4 Equipment Calibration

Solid and liquid spreader calibrations should only be performed by a trained EQS technician. It is important to calibrate all chemical additive and abrasive spreaders to ensure that the desired quantity of material is being applied (AASHTO, 1999; Salt Institute, 1991). All equipment should be calibrated before the winter season begins and recalibrated if any maintenance or repair is performed during the season. Also, if an error in calibration/application rates is suspected, the spreader should be checked by a trained EQS technician as soon as possible. It is also recommended to check the manufacturer’s calibration instructions for all new equipment. For liquid spreaders, the controller application rate setting should be compared to the actual amount of liquid applied several times throughout the winter season. Refer to **Appendix A-5** for procedures to manually verify or calibrate liquid and granular application rates.

5.2.5 Equipment Storage and Maintenance Best Management Practices

Refer to the following applicable equipment storage and maintenance BMPs from the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013):

ADOT Maintenance and Facilities BMP Manual		
Facilities BMP Program No. – Title	**Facilities BMP Activity No. – Title**	**Applicable WSM Materials/Activities**
2 – Sites, Yards, and Grounds	2.6 – Sediment Control – Track-in/Track-out	Control sediment and track-out from the maintenance yard during winter months. Snow and slush typically create more potential for track-out.
3 – General Automotive Activities	3.0 – Fueling Stations	Fueling WSM vehicles.
	3.1 – Outdoor Vehicle and Equipment Storage	Storage of WSM vehicles and other equipment.
	3.2 – Vehicle Fluid Management	General maintenance of WSM vehicles and other equipment.
	3.3 – Vehicle/Equipment Wash Facilities	Washing WSM vehicles and other equipment during the winter season.

5.3 Chemical Additives and Abrasives

The application of chemical additives and abrasives has become a common WSM practice. The following subsections describe procedures for purchasing, storing, handling, and applying chemical additives and abrasives.

5.3.1 Procurement

ADOT procures chemical additives and abrasives from vendors through a contract for a period of 12 months, which may be extended for supplemental periods of up to a maximum of 48 months. Current vendors are listed in **Appendix B**. At the time of the annual extension of each contract, the ADOT Procurement Officer will contact the end-users (e.g., Highway Operations Superintendents and other operations personnel) for approval to renew the contracts, and to discuss any issues they may have with the products or contractors. Approximately five months before the five-year expiration of the contracts, the Procurement Officer will begin the rebid process for new contracts. The Procurement Officer will form a focus team of Highway Operations Superintendents and other end-users to discuss any concerns regarding the products, contractors, new products, or changes in user requirements. Typically, multiple chemicals are combined into a single solicitation and each chemical may be awarded to one or more vendors, depending on the solicitation specifications and contract requirements.

When procuring new product types, the ADOT Procurement Officer develops a new solicitation and the old contract must be cancelled and replaced with the new award. However, in some cases, when it is known in advance that new products will be coming on the market, wording can be included in the original contract that allows for the new products. If a chemical is not on contract, ADOT Districts can purchase products (under a $5,000 limit) for research and testing purposes. However, if a product is going to be tested for several years, this may be construed as eventually going over the $5,000 limit, and may require the Procurement Officer to go out for an electronic bid or a not practicable to quote award. In all instances, competitive bidding should be encouraged to ensure that ADOT obtains a fair price on all products.

It is extremely important to monitor the chemical and abrasive material inventory closely throughout the winter season. Maintenance yards often have limited space, so materials (chemicals and abrasives) may need to be replenished at some point during the winter season. Replacement orders should be made with appropriate lead times (as defined in the contract) to avoid depleting inventories during large storms.

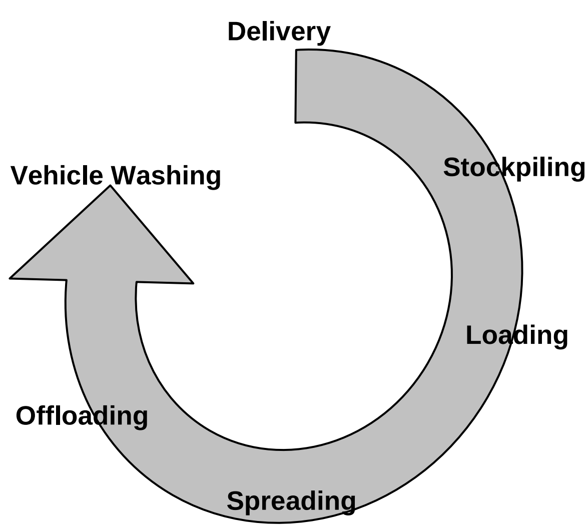
5.3.2 Storage and Handling

Each Org has a maintenance yard that serves as the operational center for the Org. Many Orgs also have satellite yards/camps to facilitate operations. WSM storage sites (for both equipment and additive materials) are situated in the maintenance yards and satellite yards/camps to minimize nonproductive travel time of WSM vehicles, and so that storage sites can serve multiple crews (AASHTO, 1999).

The storage method of chemical additives and abrasives depends on the formulation (liquid or granular). Dry (granular) chemical formulations should be stored in piles or bins under cover, which may include enclosed buildings, open sheds, or tarps. Abrasive stockpiles pre-wetted with liquid chemical additives should also be covered. From an operational standpoint, covering dry chemicals also helps prevent loss of material through leaching and caking (which will hinder the spreading process). Liquid chemical additives should be stored in sealed containers or tanks. Liquid chemical additive containers or tanks should be stored under protective covers, such as enclosed buildings or open sheds.

Storage areas should have proper pollution prevention and drainage controls in place to protect nearby receiving storm drains and waterbodies. Ideally, storage areas should be shielded from prevailing winds and have a permanent roof (or some other form of protection from direct precipitation), adequate space for loading and unloading, an impervious floor, and a containment system for contaminated runoff. Containment systems should be designed to contain all contaminated runoff, and the runoff should be reused for treating abrasive stockpiles or pre-wetting solid chemicals during snow and ice control operations. Note that controlling contaminated runoff from the source is more effective than installing a collection and disposal system.

The typical handling cycle for additive (chemical and abrasive) materials is shown in the graphic on the right:



Material transfers should be minimized as much as possible within this cycle because excessive handling of materials increases the chance of spillage, material degradation, and worker exposure to unnecessary risks involving lifting, working in and around machinery, slipping, tripping, and falling. Loading of spreader trucks should be conducted carefully to minimize spillage of material outside of the truck. Handling of anti- and deicing chemicals should occur on concrete slabs within the sheds, except where no slabs or sheds have been constructed. Shake the loader bucket over the storage pile to avoid overloading and spills. Immediately clean up any spills noticed after the winter storm.

5.3.3 Material Storage and Handling Best Management Practices

Refer to the following applicable material storage and handling BMPs from the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013):

<table>
<tr><th colspan="3">ADOT Maintenance and Facilities BMP Manual</th></tr>
<tr><th>Facilities BMP Program No. – Title</th><th>Facilities BMP Activity No. – Title</th><th>Applicable WSM Materials/Activities</th></tr>
<tr><td>1 – Buildings</td><td>1.5 – Shipping/Receiving/ Loading Docks</td><td>Receiving and loading of abrasives and chemical additives.</td></tr>
<tr><td>2 – Sites, Yards, and Grounds</td><td>2.1 – Vehicle Parking Areas (Snow and Ice Removal)</td><td>Public and ADOT vehicle parking lots and yards – management of snow and ice.</td></tr>
<tr><td rowspan="3">6 – Storage and Handling of Chemicals</td><td>6.1 – Storage and Handling of Chemicals</td><td>General (nonadditive) chemicals used during WSM operations.</td></tr>
<tr><td>6.3 – Liquid and Solid Deicer Management</td><td>Handling and storing liquid and solid deicing and anti-icing chemicals.</td></tr>
<tr><td>6.6 – Material Stockpile Management</td><td>Handling and storing sand and cinder abrasives.</td></tr>
<tr><td>7 – Waste Disposal and Debris Management</td><td>7.6 – Dewatering of Material Containment Facilities and Structures</td><td>Discharge of accumulated stormwater and sediments in scale pits, manholes, basins, vaults, containments, etc.</td></tr>
<tr><td rowspan="4">8 – Good Housekeeping Practices</td><td>8.0 – Scheduling and Planning</td><td rowspan="4">Good housekeeping practices to apply at the maintenance yard for WSM material storage and handling.</td></tr>
<tr><td>8.1 – Preventative Maintenance</td></tr>
<tr><td>8.2 – Product Substitution and Inventory Control</td></tr>
<tr><td>8.3 – Training</td></tr>
</table>

ADOT Maintenance and Facilities BMP Manual		
Facilities BMP Program No. – Title	**Facilities BMP Activity No. – Title**	**Applicable WSM Materials/Activities**
9 – Spill Prevention and Control	9.0 – Yard and Facility Spills	Handling and storing liquid and solid deicing and anti-icing agents as well as other (nonadditive) chemicals at maintenance yards.
	9.1 – Small Spill Response Procedures	

5.3.4 Application

Anti-icing and deicing chemicals are available in both granular (dry) and liquid form (abrasives by themselves are dry). Depending on road conditions, one or the other may be better suited for use, and in some cases, these chemicals are mixed (i.e., liquid chemical is added to granular material or abrasives to achieve desired results).

5.3.4.1 Pre-wetting

Pre-wetting is a technique used to enhance the capabilities of anti-icing, deicing, and abrasive applications by ensuring that more material stays on the roadway surface and increasing the rate at which chemical additives penetrate snow and ice layers on the pavement (TAC, 2003; ADOT, 2004). Pre-wetting is accomplished by adding liquid chemicals to granular chemicals or abrasives before they are applied to the road. Pre-wetting can be performed by (1) injecting a liquid chemical into a material stockpile at a specified dosage, (2) spraying a liquid chemical onto a loaded spreader or on the material as it is being loaded into the spreader, or (3) adding a liquid chemical to granular materials at the time of spreading. Pre-wet dry granules to optimize the application results and help the material stay on the roadway surface. For specific pre-wetting instructions, refer to the product instructions.

5.3.4.2 Anti-icing Chemicals

Anti-icing chemicals are used to lower the freezing point of water on a highway surface to prevent snow and ice from *initially* bonding to the pavement (TAC, 2003; ADOT, 2004). Anti-icing chemicals should be applied prior to, or very shortly after, the start of a winter storm to prevent snow and ice from bonding to the pavement. Liquid $MgCl_2$ is typically used for anti-icing operations, although solid or liquid NaCl can also be used. Recommended chemical concentrations range from 21 to 33 percent, with higher concentrations needed at lower pavement temperatures. Recommended anti-icing application rates range from 10 to 90 gallons per lane per mile (75 to 400 pounds per lane per mile), depending on pavement temperatures and conditions and the type of chemical used. Application rates of $MgCl_2$ are typically lower than other anti-icing chemicals at 15 to 40 gallons per lane per mile. Higher application rates of $MgCl_2$ may result in slippery conditions. Refer to **Tables 1 and 2** for the recommended anti-icing application rates of NaCl and $MgCl_2$, respectively, for specific storm and roadway conditions.

Anti-icing chemicals are best applied on shady areas, grades that historically have caused difficulties for motorists during storms, roadway curves, approaches at the bottom of hills, and bridge decks. The FHWA recommends the use of anti-icing on high priority routes to achieve high LOS (interstates and key state routes or US highways). Depending on the material composition (liquid or granular), anti-icing chemicals can be applied to the pavement via spray, tank, and/or plow trucks. Preferably, liquid chemicals should be applied using nozzles to achieve the best coverage.

Anti-icing Tips

Be careful not to over apply anti-icing chemicals because this can create a slippery road surface. The greatest potential for slippery roads appears to occur when air temperatures are above -40 °F and the relative humidity is 45 to 50% or greater (WSDOT, 2007).

ADOT Lessons Learned/ADOT Winter Storm Training –

- Application rates depend on the product formulation and roadway weather conditions. Operators should consult with their shift or crew lead for specific application rates.
- Liquid anti-icing chemicals are only to be used prior to a winter storm to address known trouble spots (shady areas, grades that historically have caused difficulties for motorists during storms, roadway curves, approaches at the bottom of hills, and bridge decks). Note that bridge decks and large culvert crossings are particularly prone to ice formation because air temperatures above streams and rivers are typically lower than temperatures above ground surfaces.
- Dry granules should be pre-wetted to optimize the results of the application and help the material stay on the paved surface.
- Dry snow can absorb anti-icing chemicals and will dilute the applied concentration over time.
- When using anti-icing chemicals, the exhaust heater should be disconnected from the V-box spreaders to avoid drying out (and hardening) the chemicals. For more tips on spreaders and truck vibrators, refer to those in the "Deicing Tips."

Refer to PeCoS "Activity 174 – Anti-Icing with Deicers" and "Activity 173 – Spot Ice Control" in **Appendix A-1** for specific operational details regarding anti-icing application and refer to this activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.3.4.3 Deicing Chemicals

Deicing chemicals are used to create a brine solution that disrupts the bond that ice has already made with the pavement surface (TAC, 2003; ADOT, 2004). Once the ice/pavement bond is broken, it is easier for equipment to remove accumulated layers of ice.

Deicing chemicals are applied during and/or after the start of a winter storm once snow and ice have accumulated on the road, and typically consist of NaCl, $MgCl_2$, and $CaCl_2$. NaCl is an effective deicer for pavement temperatures above 22 °F. $CaCl_2$ and $MgCl_2$ are very effective deicing chemicals at pavement temperatures between -5 and 22 °F. However, these chemicals are more expensive than NaCl.

The use of non-salt based deicers is becoming more widespread in states that have WSM programs. Two of these chemicals, calcium-magnesium acetate (CMA) and potassium acetate (KAc) are less environmentally invasive and will generally prevent ice from bonding to the pavement for days following the initial application (ADOT, 1994). However, both require high application rates, are currently prohibitively expensive for widespread use, and are not very effective at pavement temperatures below 22 °F. ADOT does not currently use CMA or KAC for deicing activities.

The recommended chemical application concentration for deicing chemicals ranges from 21 to 33 percent. As with anti-icing chemicals, higher concentrations are required at lower pavement temperatures. Recommended deicing application rates range from 10 to 90 gallons per lane per mile (75 to 400 pounds per lane per mile), depending upon pavement temperatures and conditions and the type of chemicals used. Refer to **Tables 1 and 2** for the recommended deicing application rates of NaCl and $MgCl_2$, respectively, for specific storm and roadway conditions.

Deicing chemicals are applied statewide by all Districts (with the exception of the Yuma District). Depending on the material composition (liquid or granular), deicing chemicals can be applied to the pavement via spray, tank, and/or plow trucks. Liquid formulations are applied with spray and/or tank trucks that are generally equipped with saddle tanks, motorized pumps, computer controls, and spray bars. Solid-stream nozzles should be used to apply deicing chemicals. Granular materials are applied using trucks equipped with spreader units. Some trucks are also equipped with pre-wetting units so solid chemical additives can be wetted prior to application for improved adhesion to the road surface. Deicing chemicals can also be mixed with abrasives to improve traction.

Deicing Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- Avoid applying deicing agents during extreme cold and falling temperatures (below 15 °F). Cold, dry pavement will not retain deicing chemicals and will not contain enough latent heat to activate the salt.
- Use solid stream nozzles and lower pump pressures to prevent splashing.
- Avoid plowing/removing active brine off of the pavement and periodically keep the active brine fresh with additional deicing chemicals. It takes approximately half as much deicing agent to “freshen” an active brine on the pavement.
- Note that even if the road starts to ice over, it may be possible to apply additional deicers to form a brine instead of switching over to abrasives.
- When backing up use extreme caution and be aware of hazards. Whenever possible, have another person provide direction when backing.
- Consider the weight of the material being loaded so as to avoid overloading the truck. Any material that falls off the sides can injure pedestrians or cause damage to passing vehicles and should be cleaned up as soon as possible.
- Use truck dump-bed vibrators to keep material from sticking to the inside of the spreader. Note: excessive use of the vibrator will cause the material to compact and cake up.

Refer to PeCoS “Activity 170 – Plow Snow and/or Apply Abrasives/Deicers” and “Activity 173 – Spot Ice Control” in **Appendix A-1** for specific operational details about deicing and refer to this activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.3.4.4 Abrasives

Abrasives are applied to roadways during winter storms to improve vehicle traction (TAC, 2003; ADOT, 2004). Abrasives are not used to melt snow and ice. Abrasives application is most effective when pavement temperatures are below 15 °F. At these temperatures, chemical additives are not effective. Abrasives will not be incorporated into ice unless deicing chemicals are mixed with them. In Arizona, abrasives generally consist of volcanic cinders or sand. Because of availability and proximity, cinders are most often used in the northern half of the state, whereas sand is most often used in the southern half of the state. A limitation of volcanic cinders, however, is that they are friable and break down into finer particles that provide less traction. In contrast, sand grains do not break down into finer particles as easily. Regardless of the composition, both types of abrasives must be clean, hard, sharp, and free of clay lumps to provide maximum traction.

Abrasives are distributed by trucks equipped with a mechanical spreader that is operated by a power take-off control mechanism in the truck cab. The amount of abrasives applied can vary greatly and depends on weather conditions and the amount of snow and ice that has accumulated on the roadway. Abrasives are most effective after excess, loose snow has been plowed away (see Chapter 5.4.1).

Abrasive Application Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- Use abrasives when conditions deteriorate to the point where other snow and ice treatment methods are not effective.
- Consider the likelihood of needing to use abrasives without spreader box heaters on certain trucks when assigning trucks and routes.
- In general, apply abrasives to improve traction on hills, curves, and stopping/starting areas.
- Snowplow first, then apply abrasives.
- Adjust vehicle and spinner speed and shields to keep the material where needed.
- Use abrasives when snowplows cannot keep up with the snowpack.
- Pre-wet abrasives with $MgCl_2$ or brine solution of NaCl (and $MgCl_2$) to improve adhesion to the roadway surface.
- Consider oncoming traffic when applying abrasives.
- In PM_{10} nonattainment and maintenance areas, minimize the use of abrasives if possible (**see Figure 8**).
- Refer to spreader box and truck vibrator tips in the "Deicing Tips."

Refer to PeCoS "Activity 170 – Plow Snow and/or Apply Abrasives/Deicers" and "Activity 173 – Spot Ice Control" in **Appendix A-1** for specific operational details about applying abrasives and refer to this activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.4 Nonadditive Practices

Nonadditive WSM practices include mechanical removal (snowplows and blowers), control measures (snow fences and shade reduction), and other techniques.

5.4.1 Snowplowing

The primary function and purpose of a snowplow is to physically remove as much snow and/or loose ice from a roadway as possible without damaging the integrity of the pavement (TAC, 2003). Plowing typically is performed when snow or ice inhibits functional traffic flow or when a sufficient amount of snow or ice has accumulated on the pavement (generally agreed to be approximately one inch thick). In addition to plowing snow away from the roadway, snowpack or ice can be fractured and subsequently removed with a blade. Plowing can be accompanied by additive practices, depending on the intensity of the winter storm and roadway conditions.

Snowplowing Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- Regulate vehicle speed based on the type of work being done, weather and roadway conditions, and prevention of injury or damage to nearby pedestrians, motorists, vehicles, or property.
- Conduct snowplowing with the direction of traffic to avoid snagging guardrails and other structures.
- Always be aware of how far the wake of snow is traveling from the plow to the edge of the road. Wet snow is heavier and can be thrown further distances than dry snow, and can cause injuries or property damage.
- In areas with consistently high snowfall, push snow further away from the roadway to make room for future snowplow piles.
- Do not plow private drives, driveways, or business parking lots. These are the responsibility of the owners. The only exception to this is if it is necessary for emergency or rescue operations.
- Be aware of bridge deck joints, manhole covers, cattle guards, curbs, gutters, downdrains, parked cars, driveways, sidewalks, landscape features, and other roadway obstructions before and during plowing operations.
- Stay just off of the curb or gutter by bumping and then moving just away from it. Know where curb or gutter sections begin, end, or change height along a route.
- Check corner bits regularly.

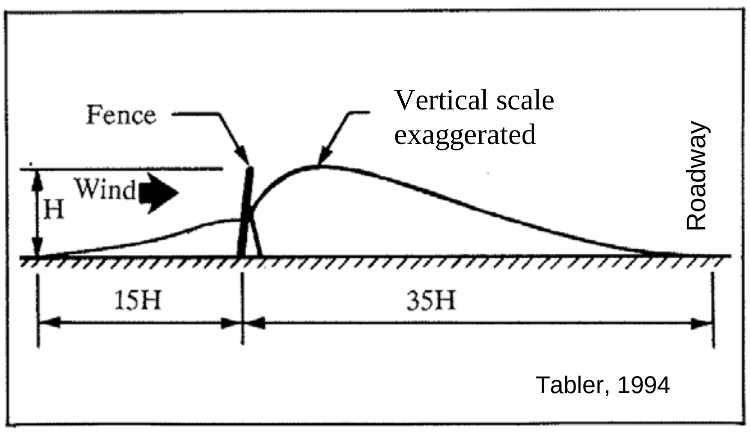
Refer to PeCoS "Activity 170 – Plow Snow and/or Apply Abrasives/Deicers" in **Appendix A-1** for specific operational details about snowplowing and refer to this activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.4.2 Snow Fences

The quantity of snow that blows onto a road can be much greater than the amount that falls directly on the road (Tabler, 1994). To address this issue, ADOT uses snow fences to control windblown snow or snowdrift. Snow fences are long, fixed, standing structures that are strategically placed within the R/W to control drifting snow and improve motorist visibility. Snow fences can minimize the amount of chemical additives or abrasives required and/or the amount of snow to plow. There are several design considerations that should be taken in account, including:

- Location of drift or reduced visibility area;
- Prevailing wind direction(s) and velocity;
- Terrain characteristics; and
- Fence height, length, aesthetics, orientation, and setback distance.

Snow fences should be placed perpendicular to the prevailing wind direction (which is not necessarily parallel to the roadway alignment). Tabler (1994) recommends that fences be placed a distance of at least 35 times the height of the fence from the roadway, as shown in the schematic below.



Snow fences can be made of wood, metal, plastic, or even vegetation like trees, shrubs, and agricultural crops. Plastic or metal fences are generally considered more effective than traditional wood fences.

Refer to PeCoS “Activity 179 – Other Snow and Ice Control” in **Appendix A-1** for specific operational details about snow fences and refer to this activity in the ADOT Maintenance and Facilities BMP Manual (ADOT, 2013) for appropriate BMPs.

5.4.3 Shade Reduction

Sunlight is a natural method of accelerating snow and ice melt and can be enhanced by reducing shade and trimming canopies that overhang the roadway (ADOT, 2004). Shade reduction may entail thinning trees and/or flattening slopes to increase the amount or duration of sunlight that reaches the road. Thinning trees also has the benefit of reducing fire fuel loads and increasing driver and animal visibility. However, the potential for a decrease in roadway aesthetics should be a consideration before deciding to thin trees. Tree removal should be targeted for those sections of roadway that have a history of developing patches of ice or being the last sections of road where ice melts. Affected land management agencies (e.g., BLM, USFS) should be contacted to develop appropriate shade reduction plans.

5.4.4 Other Techniques

There are other snow and ice control techniques. These techniques include loading, hauling, and dumping. This is the most basic form of snow removal; however, ADOT rarely uses this.

5.5 Safety

Snow and ice, poor visibility, and wind present hazards to WSM operators. The safety and well-being of WSM personnel and the traveling public is of paramount importance to ADOT and should not be compromised under any situation. ADOT WSM safety procedures include minimizing driving and operating hazards, using personal protective equipment (PPE), maintaining delineations, and following communication protocols.

Safety Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- **Vehicle speed** - Regulate vehicle speed based on the type of work being done and weather and roadway conditions, and prevention of injury or damage to nearby pedestrians, motorists, vehicles, or property.
- **Climbing on or off of equipment** - As with all construction equipment, maintain three points of contact at all times when climbing on or off of equipment.
- **Clothing** - Dress for winter conditions, and bring PPE including hard hat, reflective safety vest, gloves, ear protection, safety glasses, steel toed shoes or boots, and a high visibility reflective jacket or coat.
- **Communication** - Operators should check in with the Snow Desk or TOC every one to two hours. Operators should also notify the the Snow Desk or TOC anytime they decide to leave (or work away from) the primary route or when they step out of the truck and cannot be reached.
- **Chemical hazards** - All personnel who handle hazardous material must be current on their Occupational Health and Safety Administration (OSHA)-required Hazard Communication training before they are assigned to handle chemical additives and abrasives. Ensure that Safety Data Sheets (SDSs) for all chemicals in use are accessible to all personnel who are exposed to these materials. All personnel who work with any chemicals must review and become familiar with the SDSs. All personnel handling these chemicals must wear appropriate PPE for all chemicals in use. Appropriate PPE will be listed in the specific product’s SDS. Ensure that all tanks, bins, or other containers used to store or transport chemical additives and abrasives are correctly and legibly labeled. Prior to mixing any chemicals, refer to the SDS to ensure the compatibility of the chemicals, and wear appropriate PPE.
- **Safety equipment** - During the vehicle daily inspection, check that a flashlight, flares, flags, safety vests, a shovel, a fire extinguisher, and a first-aid kit are in the truck cab and test the handheld and two-way radio before leaving the yard. Apply tire chains with the proper tension, if used.

5.6 Monitoring and Information Technologies

The decision to initiate WSM practices is largely dependent on road weather data. The more accurate and site-specific the data, the more effective WSM decisions can be made.

5.6.1 Weather Forecasting

One basic method of monitoring weather conditions for WSM purposes is to continuously check weather forecasts via the internet and other media sources. Examples of weather forecast websites include, but are not limited to:

AccuWeather: www.accuweather.com

National Weather Service (NWS): http://radar.weather.gov/

National Oceanic and Atmospheric Asministration (NOAA), Western Region Headquarters: www.wrh.noaa.gov

The NWS issues winter storm warnings when more than one winter hazard is involved in producing life threatening conditions and winter weather advisories when one or more weather event is occurring or forecast to cause significant inconvenience. These winter warnings and advisories are described in the Terms and Acronyms section of this document.

5.6.2 Road Weather Information Systems (RWIS)

RWIS is a weather reporting system used along transportation corridors (AASHTO, 1999). RWIS monitors are equipped with embedded pavement sensors that allow weather forecasters to predict icing before it occurs. ADOT currently has RWIS sites throughout the state along I-40, US 93, SR 87, SR 377, SR 77, SR 264, and I-10 (refer to **Figure 4**), which can be viewed at: http://www.az511.com/adot/files/traffic/. ADOT's web based interactive 511 Geographic Information System (GIS) map. RWIS data are also communicated through the DPS microwave network, although ADOT is developing a separate communications network devoted to RWIS. ADOT Districts forecast, monitor, and use real-time weather data to assist in WSM resource allocation and treatment decisions. In addition to RWIS monitors, real-time Arizona weather information is available at remote locations, such as ports of entry. The weather information includes current data on local conditions (for example, pavement and air temperature[7], type of precipitation, pavement condition, wind speed and direction, dew point, humidity, and solar radiation).

Operations crews use this information to assess whether treatment is necessary, when the optimal time to apply chemicals is, what chemical additives or abrasives should be used, and how much chemical additive is required. Accurate pavement condition forecasts (such as RWIS) are essential for identifying conditions in which anti-icing will be most effective. When assessing weather information it should be noted that concrete pavements are more susceptible to

[7] Pavement temperature is the most important factor to obtain because it controls the chemical additive solubility and resulting effectiveness; anti-icing and deicing chemicals must form a solution in water in order to depress the freezing point. Air temperature is secondary to pavement temperature since there is usually a lag between air and pavement temperature. Nonetheless, air temperature can be an important indicator of pavement temperature (if specific pavement data are not available); pavement temperature will usually follow the air temperature within a few hours.

freezing than asphalt pavements due to their light color and higher thermal mass. In addition, concrete pavements are more impervious and shed runoff more readily than asphalt pavements. Because of this, the conditions of concrete pavement surfaces should be monitored closely.

5.6.3 Truck-mounted Sensors

In general, ADOT plow trucks are equipped with temperature sensors capable of reading air and pavement temperatures. Sensors can also be installed on equipment to record plow position(s), material spread rate and distribution, equipment loading characteristics, and hydraulic pressure, as well as other parameters (e.g., vehicle speed, engine temperature, braking system).

5.6.4 Ambient Monitoring Program

Sampling and analysis of roadside soils and vegetation can be used to monitor environmental changes that may result from WSM activities. The AMP (AMP) is designed to provide ADOT with a comprehensive database of the environmental effects of WSM activities so that impacts can be identified and modifications to WSM activities can be made by individual Districts to mitigate impacts. The AMP will provide the data necessary to implement adaptive management and allow Districts to customize their WSM practices to minimize environmental impacts. Refer to Chapter 6 for more information about ADOT's AMP.

5.6.5 Traffic Controls

Traffic controls and responsibilities for various situations are shared by ADOT and the DPS during snow and ice conditions. These controls and responsibilities include coordinating message boards and signs, administering and closing transportation corridors, aiding motorists, and coordinating the removal of abandoned or disabled vehicles (ADOT Flagstaff District, 2013).

Road closures are specific to a particular section of roadway and are coordinated within ADOT with the District Engineer, Maintenance Engineer or Highway Operations Superintendent prior to road closure. Each District has developed its closure procedures in their District Snow Guide. Road closures are only made after ADOT determines that the road can no longer be safely maintained and the public has been notified. The entire length of closed roadways is patrolled via snowplows or all-terrain vehicles, (and in extreme conditions via snowmobile or aircraft) for stranded vehicles and/or motorists. Based on traffic volume and weather conditions, some roadways are routinely closed on a short-term basis (i.e., SR 89A and US 180), whereas others are typically closed for the entire season (i.e., SR 67). Each District will coordinate the road closure with local and county authorities, who may need to establish emergency shelters for stranded travelers. Road inspections start as soon as conditions permit and must be documented in writing on a Crew Work Report.

During a storm, WSM operators may encounter a traffic incident (collision, slide-offs, rollovers, or stranded vehicle). Operators will need to decide whether to call in the accident and continue on or to stop and assist the motorist(s). The decision should be based on the roadway conditions, severity of the storm, the type of incident encountered, and safety. Refer to the tips in the box on the next page.

Roadway Incident Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- ALWAYS dial 911 if there are severe injuries or severe damage to vehicles.
- After summoning emergency services (if necessary), call the incident in to the Snow Desk or TOC.
- Do not push or pull any private vehicle UNLESS the vehicle is blocking the roadway or there is a request to move the vehicle by the local law enforcement agency.
- Keeping the roads open and passable is the operator's primary function. Do everything possible to minimize time away from the primary function. Assist with roadway incidents only as long as absolutely required to secure the area and then return to the primary function.

ADOT uses a variety of techniques to disclose information pertaining to winter weather and road conditions, for example fixed signs, DMSs, social media, telephone hotlines, and the "Know Snow" campaign. Fixed signs are strategically placed along roadways to warn motorists of known hazard spots. They include messages such as "Watch for Snow and Ice" or "Snow and Ice May Accumulate on the Road." Districts inform the public about road closures and provide real-time weather and pavement condition information through the use of DMSs and www.AZ511.gov. ADOT is responsible for the maintenance of DMSs and updating the AZ511 website, social media, and telephone hotlines.

5.6.6 Storm Patrols

If a major winter storm is anticipated, the initial winter storm patrol should take place at least two hours prior to the expected onset of the storm. If a winter storm patrol is required, it should be coordinated District-wide by operations personnel. The following technologies can minimize the need for winter storm patrols:

- Current and forecasted temperatures from one of the weather information sources listed in Chapter 5.6.1;
- Radio communications from Org to Org and/or District to District; and
- Visual observations.

Visual observations of weather and pavement conditions may be used to assess the need for snow and ice control if weather data are not available (ADOT Flagstaff District, 2007d). Refer to PeCoS "Activity 172 – Winter Storm Patrol" for specific operational details about snow patrols (**Appendix A-1**).

5.6.7 Snow Desk

The Snow Desk can be used when winter storm conditions are expected to be widespread (affecting two or more Orgs) with significant accumulation or significant duration and additional resources may be required. Each District designates its own Snow Desk. The Snow Desk requires 24-hour coverage until the storm is over, and is staffed with Administrative Assistants familiar with all routes and resources. The Snow Desk provides the following functions:

- Contacts WSM operators hourly for status updates;
- Communicates with the TOC;
- Coordinates with the TOC on DMS messages;
- Updates information on the HCRS; and
- Activates additional resources as directed by the shift or crew lead.

If a Snow Desk has not been established, then the Org should coordinate all communications between the WSM operators and the TOC.

5.6.8 Public Education and Outreach

Educating motorists and the general public about winter driving safety is essential for a successful WSM program. ADOT developed the “Know Snow” campaign to educate and assist the public about driving in winter storms and lists eight topics for safe winter driving:

- Planning travel in advance;
- Winter road closure advisory;
- Vehicle supplies;
- Preparing your vehicle;
- Driving on wet or icy roadways;
- Stalled or stopped vehicles; and
- Respect the plow.

The “Know Snow” brochure describes vehicle preparation tips and lists essential supplies that should be kept in the vehicle when driving during the winter. The “Know Snow” brochure provides the hotline telephone number, 511, and the internet address, www.az511.com, for snow updates (ADOT website, 2014).

5.7 Education and Training

Education and training of WSM personnel are critical components of implementing a sufficient WSM Program (AASHTO, 1999). ADOT WSM personnel are trained and maintain currency in the following WSM topics: basic meteorology principles; recommended chemical additive and abrasive usage practices; an overview of equipment operation, calibration verification, and maintenance; winter storm safety; the RWIS network; and case studies. Training should be focused to ensure that participants understand key WSM concepts and issues. A broad outline of a WSM training curriculum is included in **Appendix A-3**, and also lists some of the key learning goals. Training consists of an initial 8 hours of training followed by an annual 2-hour refresher training course. This training is provided as part of ADOT’s Equipment Operator Training and Evaluation Program (EOTEP). In addition, crews prepare annually by attending the Annual Winter Readiness Workshop.

Most Districts have a computer controlled simulator that provides WSM personnel with practical training on snowplow and spreader equipment operation (AMEC, 2007). The simulator training is based on the Search, Identify, Predict, Decide, and Execute (SIPDE) process to teach sound decision-making processes during real operations. The simulator allows WSM operators to practice and test their reaction time to oncoming traffic and other road hazards, weather conditions, shifting, and other operational procedures. Those Districts that do not have simulators should train with those Districts that do.

5.8 Recordkeeping and Reporting

Many WSM decisions are based on reviewing data and result from previous winter storms and seasons. For effective snow and ice control, it is important to continuously evaluate data and results on treatment, location, time, road and bridge conditions, weather and storm conditions, material and equipment usage, cost, policies and procedures, and operational problems. These data are used to improve future management policy, planning, and practices, and are also necessary to correlate with environmental data collected from local AMP sites. As such, properly completing and retaining records and reports are essential to ADOT's WSM Program.

ADOT records and retains data on the location and application rates of chemicals and abrasives through the use of T.A.P.E.R. logs:

T – Temperature of the pavement and air;
A – Application rate (pounds or gallons per lane mile);
P – Product being applied;
E – Event type (heavy snow, sleet, dry snow, wet snow, etc.);
R – Results of the anti-icing and deicing efforts.

A statewide version of the T.A.P.E.R. log form is included in **Appendix A-4**. These data will be used in conjunction with data obtained through the AMP and AVL system to correlate the application of chemical additives to roadways with measured changes in environmental conditions adjacent to the roadways.

Recordkeeping Tips

ADOT Lessons Learned/ADOT Winter Storm Training –

- Each operator is accountable for accurate reporting of routes and MPs covered, materials used, application rates, and miles plowed.
- All information recorded on the forms should be based on facts, not opinions.

CHAPTER 6. AMBIENT MONITORING PROGRAM

In 2008, ADOT developed the AMP to determine to what degree there was a linkage between the use of WSM chemicals and concentrations of these chemicals (or their constituents) in roadside soil and vegetation. Before deploying this program in each District, ADOT commenced a limited study in 2011 to evaluate the AMP. The objectives of the 2011 study were to:

- Assess the current anti-icing/deicing chemical application guidelines based on analytical results of soil and vegetation samples collected from specific sites subject to ADOT WSM activities;
- Provide recommendations for implementing a WSM recordkeeping system of chemical usage and storm events; and
- Provide recommendations on monitoring and mitigating environmental impacts resulting from ADOT's WSM Program.

The study looked at the three winter seasons 2010-2011, 2011-2012, and 2012-2013. Because physiographic characteristics and roads within ADOT's Globe District are representative of all roads within the state that are subjected to winter storm-related conditions, this study was initially located entirely within the Globe District. For the purpose of this study, 16 sites were chosen for evaluation based on vegetation and soil types, and whether or not vegetation was showing any signs of stress that might be attributed to WSM chemicals.

While originally the AMP was concerned with four media (soil, vegetation, sediment, and surface water), the 2011 study focused on two: soil and vegetative tissue within the travel corridor R/W. Samples of soil and vegetation were collected twice a year during the 2011-2012 and 2012-2013 winter seasons. AVL data for all winters between 2010 and 2013 were used to determine salt application rates.

6.1 Sampling Strategy

Based on the results of the 2011 study, ADOT determined that more data are needed to fully understand the relationship (or lack thereof) between WSM chemical applications and WSM chemical accumulation in adjacent soil and vegetation. In order to carry the AMP forward and develop a more comprehensive body of data, the following sections provide guidance on how soil and vegetation should be sampled in support of the AMP. Each District should establish their own monitoring sites, and include those that:

- show probable indications of WSM impacts to vegetation; and
- represent a variety of conditions – forested, shrubland, grassland, and level of priority for WSM applications.

In order to determine suitable locations for AMP monitoring sites, District personnel should perform semiannual roadside visual surveys to identify areas showing indications of WSM impacts. Priority should be given to sampling of soil and vegetation from areas showing the highest degree of impact. Sites should be permanently marked for location and identification.

6.1.1 Soil Samples

The periodic sampling of soils for chemical and physical analyses is a key element of the AMP. It is critically important that the sampling of soil at chosen monitoring sites and subsequent data collection be sufficient to support defensible conclusions concerning the environmental fate of chemical constituents of road salt—especially sodium—used in WSM operations and the potential impacts that these chemicals and other materials may have on local ecosystems.

When choosing a monitoring site, one soil sample should be collected and submitted to a soils laboratory for proper classification (e.g., sieve analyses and plasticity index).

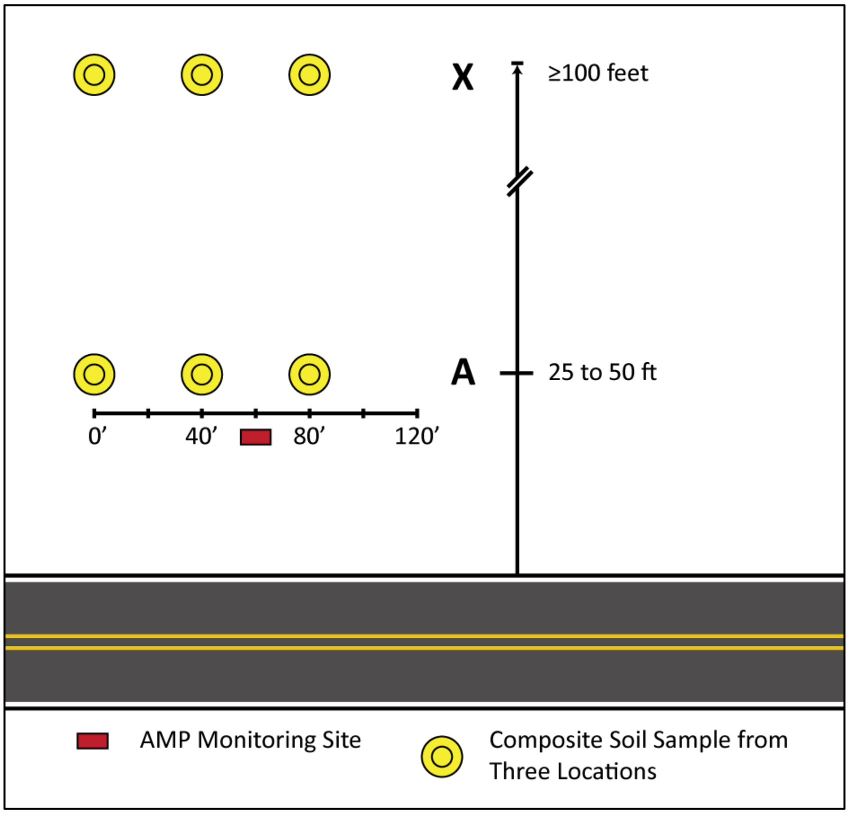
6.1.1.1 Sampling Locations and Method

One composite soil sample should be collected from each AMP site annually in the following manner. Once a monitoring point has been established, three discrete soil samples (named “A” samples) would be collected on a 10-foot spacing at 25 to 50 feet from the edge of pavement. The exact distance from the edge of pavement would be determined during the first sampling event and would remain the same during subsequent sampling events. The distance from the edge of pavement should be based on site-specific characteristics (e.g., slope grade and topography, presence of rockfall containment ditch, drainage characteristics, condition of vegetation). If the monitoring site is located in a cut, the soil samples should be collected from within the rockfall containment ditch near the toe of the cut. In areas where vegetation shows signs of stress, the soil samples should be obtained from areas beneath the impacted foliage. The rationale for establishing the sampling distance from the edge of pavement should be documented on the initial sampling form.

A second composite soil sample should be collected in the same manner, except that this composite of three soil samples (named “X” samples) would be collected 100 feet or more away from the edge of pavement. This composite soil sample would be used to establish “background” soil chemistry, assuming negligible effects from WSM chemicals. New background samples will be collected at each site at two-year intervals after the first sample is collected. The samples will be analyzed for the same suite of parameters as the samples obtained adjacent to the roadway.

For each monitoring site, once the sampling distance from edge of pavement has been established, the sampling distance should remain the same for all discrete samples and subsequent sampling events. The recommended sampling design is depicted in the following schematic.

Soil Sampling Design Schematic



At all monitoring sites, discrete soil samples that make up the composite samples should be obtained with a hand auger or thin-walled tube sampler to represent the most immediate area of salt accumulation. These samples would consist of continuous cores of soil extending from the surface to a depth of 18 inches below ground surface.

Soil samples should be collected from only one side of the road at each AMP site. In general, the side of the road with vegetation showing the greatest degree of impact should be sampled. In cases where impacts on vegetation are not discernible, other factors such as slope gradient, water, salt encrustation, wind direction, and/or traffic volume should be used to decide which side of the road to sample.

If the sampling strategy is altered at a future date, the rationale for making the change must be thoroughly documented. If the sampling locations extend beyond ADOT's R/W, permission should be obtained from the landowner prior to collecting samples.

6.1.1.2 Soil Sampling Season

Soil samples should be collected each spring after WSM operations have been completed. The timing of sampling may vary by District, with sampling in the southern Districts occurring earlier than in the northern Districts. Whenever possible, soil sampling and vegetation sampling should be performed concurrently.

6.1.1.3 Analytical Parameters

Soil should be analyzed for sodium concentration and other constituents, such as chloride, at ADOT's discretion.

6.1.2 Vegetation Samples

Vegetation should be sampled at each monitoring site, with preference given to vegetation showing signs of stress. Signs of stress could include discoloration of foliage, stunted growth, and death of individual twigs or branches, or of the entire tree.

Vegetation sampling can include any species in which significant effects are observed, but should primarily focus on woody species, including evergreens (e.g., junipers, pinyon pine, and Douglas-fir) and deciduous trees and shrubs (e.g., Gambel oak, quaking aspen, and sumac).

In general, the vegetation samples should consist of mature or fully developed leaves or needles that are exposed to direct sunlight just below the growing tip on main branches or stems. Vegetation samples should be collected in the spring just prior to or at the time the plant begins its reproductive stage of growth. When feasible, vegetation sampling should be conducted at the same time soil samples are collected. However, in some cases a separate trip may be necessary to collect vegetation samples at the correct time. Prior to collection, the entire surface, both top and bottom, of the leaves or needles should be sprayed with distilled water and shaken dry (or blotted with a paper towel) to remove dust and other foreign material (including salt that may have splashed onto the cuticle of the leaf). The samples should then be partially air dried, placed in a plastic bag, and sealed. The samples would be placed in a cooler with icepacks and shipped to the laboratory for analyses. Vegetation samples should be tested for sodium in parts per million (ppm) and other constituents, such as chloride, at ADOT's discretion.

Sampling of impacted vegetation and the soil directly below the plants would allow for the possible correlation of bioaccumulation with total salt concentrations in the soil.

6.1.2.1 Vegetation Sampling Season

Vegetation samples should be collected in the spring after WSM operations have been completed and after new leaves or needles have emerged on trees. The timing of sampling may vary by District, with sampling in the southern Districts occurring earlier than in the northern Districts. Whenever possible, vegetation sampling and soil sampling should be performed concurrently.

6.1.3 Air Samples

The potential for significant impacts to air quality from WSM operations is considered minimal. Therefore, routine monitoring of air quality parameters (e.g., PM_{10} particulate loads) at the monitoring sites is not deemed necessary. However, more detailed evaluations may be warranted if a significant entrainment of dust by passing vehicles is observed or reported on any roadway receiving WSM treatment, or as changes are made to air quality rules. If PM_{10} particulates are collected, they should be analyzed for the same parameters as those listed for the soil samples in Chapter 6.1.1.3.

6.1.4 Surface Water and Sediment Samples

The potential for transport of chemical additives and abrasive materials by surface water could vary from location to location. In some cases, this potential may be minimal due to the presence of flat terrain. However, at some locations, surface water collects in roadside ditches and drains into an intermittent stream channel (e.g., an arroyo) or drains from a bridge into an intermittent stream channel. In rare cases, the receiving channel may contain perennial or seasonal surface flows or water-related resources, such as impoundments or vegetated wetlands, downstream of the roadway.

ADOT is fully committed to coordinating and collaborating with USFWS and AGFD to identity sites to monitor surface water quality as it relates to winter storm management. The process by which these sites are selected, the proposed monitoring details, the assessment of the resulting analytical data, and potential partnerships would be documented in a separate document. Given the variability in climatic conditions across the state, as well as the need to assess both short-term and long-term impacts of WSM activities to aquatic environments, ADOT recognizes that different monitoring objectives may be necessary.

6.2 Ancillary Data and Information

Ancillary data are data collected in support of the analysis and interpretation of the monitoring data. These data will include, but are not limited to, the application of chemicals or other treatments to routes along which AMP sites are located; meteorological data from sources as near to the AMP sites as possible; photographs taken from fixed locations and in prescribed directions to show the conditions at the AMP sites at the time of sampling; and other pertinent observations made at the sites at the time of the visit.

6.2.1 Application Data

Key to interpreting the monitoring data is knowledge of the frequency, intensity, and methods used to manage snow and ice on ADOT’s adjacent roadways during the winter season. It is the responsibility of District personnel to maintain records of the dates, methods, types, and application rates of chemicals and abrasives used along their routes during each winter season. ADOT collects copies of these records, possibly supplemented by interview information from WSM operators, for use in the interpretation of monitoring site data. Key operations personnel (including operators) should be trained on the goals of the AMP, the monitoring sites established in their District, and the importance of maintaining records on WSM operations performed along their routes.

6.2.2 Automatic Vehicle Location Data

The AVL system uses GPS technology to record real-time location of the WSM equipment, plow status, vehicle speed, and application rates. The use of AVL equipment would limit the amount of information that the WSM operators would need to record and result in more accurate records. However, for those Districts that have not yet transitioned to automated recordkeeping such as the AVL system, T.A.P.E.R. logs will be used in the interim.

6.2.3 Weather Data

Annual precipitation (both snowfall and rainfall), daily air temperature, wind speed, and wind direction data will be collected from weather monitoring stations (either public or privately operated) located as near to the monitoring sites as possible. The decision as to which weather monitoring station will be used for an individual monitoring site will be based on both proximity to the site and the quality and completeness of the data available from that station. If feasible, site-specific weather monitoring stations will be employed; however, the cost of installing and maintaining on-site measuring devices and the threat of vandalism may be prohibitive factors in using such an approach.

6.2.4 Photographic Log

A photographic log will be kept for each AMP site. During each sampling event, a series of high resolution digital photographs will be taken of each monitoring site. These photographs will include four shots from the signpost (to the left and right, parallel to the roadway, and directly toward and away from the roadway) and from the equivalent location on the opposite side of the roadway. Additional photographs will be taken of any notable observances, such as dead or browning vegetation, salt crusting or water ponding on the soil, deep accumulation of cinders, etc. When feasible, photographs will also be obtained following a winter storm to depict winter storm conditions at the sites. A log will be kept of the photograph number, sampling date, sampling site, GPS coordinates, subject information, and any additional information that will enhance the interpretation of the photograph.

6.2.5 Field Observations

During the initial site visit, a record of pertinent field observations will be made. These will include roadway characteristics (e.g., number of lanes, presence of roadway crown, type of pavement); soil conditions (e.g., variations in soil type and texture); slope grade and topography; slope class (e.g., steep, gentle, flat, uphill, or downhill); the condition of vegetation (e.g., browning, reduced growth, death, or observed changes in species composition that may be due to increased soil salinity); observable effects in the soil (e.g., salt crusts, fluffy soils, water ponding); unexpected disturbances to the site (e.g., erosion, fire, oil spills); and other factors that might influence the results, or interpretation of the results, of the monitoring effort. During each subsequent site visit, the record will be updated with observable changes. Some of the site characteristics will remain the same (e.g., number of lanes, site topography); however, some characteristics may change through time (e.g., condition of vegetation, unexpected disturbances to the site).

6.3 Data Management

A key aspect of the monitoring program is the importance of keeping consistent records of the sampling operations and monitoring results. Changes in personnel can be expected, but it is important that the critical pieces of information for all samples be recorded regardless of such changes. To this end, standard data management practices should be followed. Some of these practices are described below.

6.3.1 Standardized Data Forms

Standardized data forms should be developed for the sample collection effort at each site. The forms should include the date and time of the visit, the AMP site reference name, GPS coordinates, the personnel present, a list of the samples collected and their location (on a sketch map), the photograph log, and other field observations. A chain-of-custody form should be used for the transfer of samples to the analytical laboratory. Partial or complete automation of data recording through electronic devices should also be employed as feasible.

6.3.2 Laboratory Data Review and Validation

Data received from the laboratory should be reviewed for anomalous results and validated based upon EPA criteria for the purposes of quality assurance and quality control. Subsequent records of the data should include qualifiers that result from the validation process.

6.3.3 Database Management

Data should be entered into an electronic database (preferably a relational database, such as Microsoft Access®) for storage and analysis. Entered data should be checked for transcription errors, errors in units, etc. Standard data entry forms and report pages should be developed to facilitate data management processes and quality assurance. If feasible, the data should also be incorporated into ADOT’s EMS, once implemented.

6.3.4 Geographical Information System

AMP data that are spatially oriented will be evaluated using GIS. GIS layers should include the AMP monitoring sites, GPS coordinates, the key routes being evaluated in the AMP, meteorological stations where snowfall and precipitation data are being measured, locations where samples of media other than soil and vegetation (water, sediment, or air) were collected.

6.3.5 Statistical Analyses

Statistical treatment of the monitoring data should be based on defined questions and subsequent testable hypotheses underlying the goals of the monitoring program. These might include the following:

- Is sodium concentration in the soil changing with time?
- Can sodium concentration in the soil be correlated to WSM practices?
- Are salt concentrations in soil and vegetation samples correlative?
- Are salt levels impacting soil quality?
- Are chemical concentrations in soil, biota, or water approaching or exceeding established thresholds or levels known to be detrimental?

A standard set of statistical analyses should be applied to the monitoring data to evaluate these questions and test the underlying hypotheses. These methods might include control charting and trend analysis, regression analysis, correlation analysis, analysis of variance (ANOVA), or equivalent techniques. Descriptions of these techniques are presented in most introductory statistical references. Gilbert (1987) provides details for the applications of most of these techniques to environmental monitoring data. Most of the techniques (in simple form) can be performed with Microsoft Excel®; however, as data are accumulated and more complex analyses become feasible, an integrated statistical software package (e.g., Statistica®) should be used to maintain consistency and quality. **Appendix C** provides general descriptions of these methods and how they may be applied to the types of hypotheses listed above.

6.4 Reporting

Results from each year's sampling will be compiled in an annual summary report. The report would include statistical analyses of the year's sampling data, as well as meteorological data, chemical and material application data, and a photographic log of the AMP sites sampled. Every six years, ADOT should prepare a report that describes the long-term trends in the measured parameters. This interval would allow for three complete cycles of annual sampling at each AMP site (six samples each of soil and vegetation adjacent to the roadway and three samples each of soil and vegetation background samples≥100 feet from the roadway). The focus of this report would be to identify trends indicating the accumulation of chemicals or materials along roadway R/W, and the observed or potential impacts to natural resources associated with these accumulations. These reports could include recommendations for refinements to the AMP and/or the implementation of additional BMPs for WSM operations.

CHAPTER 7. REFERENCES AND RESOURCES

AMEC Environment and Infrastructure, Inc. (AMEC), 2007, Personal Communications and Winter Storm Management Workshops with ADOT Engineering Districts.

American Association of State Highway and Transportation Officials (AASHTO), 1999, Guide for Snow and Ice Control, Washington D.C.

American Association of State Highway and Transportation Officials (AASHTO), 2008, Update of the Guide for Snow and Ice Control, Washington D.C.

American Association of State Highway and Transportation Officials (AASHTO), 2004a, Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance, prepared by Veneer Consulting and Parsons Brinckerhoff, NCHRP Project 25-25 (04), September.

American Association of State Highway and Transportation Officials (AASHTO), 2004b, Snow and Ice Control: Guidelines for Materials and Methods, prepared by Blackburn, R.R., Bauer, K., Amsler, D.E., Boselly, S.E., and McElroy, A.D., NCHRP Report 526.

Arizona Commission of Indian Affairs, 2012, Arizona Tribal Lands Map, http://azcia.gov/Documents/TribalLandsMap.pdf.

Arizona Department of Transportation (ADOT), 2013, Daily Vehicle Miles, ADOT website. http://mpd.azdot.gov/planning/DataandAnalysis/highway-performance-monitoring-system.

Arizona Department of Transportation (ADOT), 2014, District Contacts, www.azdot.gov/Highways/Districts.asp.

Arizona Department of Transportation (ADOT), 1992, Final Environmental Assessment Report, Deicing of State Highways, January.

Arizona Department of Transportation (ADOT), 2008, Guidelines for Highways on Bureau of Land Management and U.S. Forest Service Lands, Prepared by Wheat Scharf Associates, Landscape Architects under the direction of LeRoy Brady, RLA, FASLA, Chief Landscape Architect, ADOT Roadside Development and ADOT/FHWA/BLM/USFS Steering Committee. Available for download at http://www.azdot.gov/Highways/RdwyEng/RoadsideDevelopment/ADOTGuidelinesForHighwaysOn BLM_USFSLands.asp.

Arizona Department of Transportation (ADOT), 2014, Interactive Maps, ADOT website. http://www.azdot.gov/highways/index.asp.

Arizona Department of Transportation (ADOT), 2014, Know Snow and Ice website. http://www.azdot.gov/CCPartnerships/KnowSnow/tips.asp.

Arizona Department of Transportation (ADOT) Maintenance Section, 1994, Snow and Ice Control Handbook, August.

Arizona Department of Transportation (ADOT), 2005, Procedures for Winter Storm Maintenance Operations, Final Report 461, October.

Arizona Department of Transportation (ADOT), 2013, Maintenance and Facilities Best Management Practices Manual.

Arizona Department of Transportation (ADOT), 2013, Flagstaff District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Globe District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Holbrook District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Holbrook District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Kingman District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Prescott District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2013, Tucson District 2013-2014 Snow Guide.

Arizona Department of Transportation (ADOT), 2008, Final Environmental Overview, Winter Storm Management of Arizona State Highways.

Arizona Department of Transportation (ADOT), 2008, Winter Storm Management of Arizona Highways Operations Manual.

Arizona Department of Transportation (ADOT), 1996, Winter Storm Management Plan.

Arizona Office of the Auditor General, 2007, Arizona Department of Transportation Highway Maintenance Report Highlights Performance Audit Report, June.

Arizona State Land Department (ASLD), 2007, GIS Web Portal. http://www.azland.gov/webapps/parcel/.

British Columbia Forest Service, Forest Practices Branch, 1999, An Introductory Guide to Adaptive Management.

California Data Exchange Center (CDEC), 2007, Department of Water Resources, http://cdec.water.ca.gov/snow/misc/density.html, December.

Federal Highway Administration, (FHWA), 1994, Focus-Strategic Highway Research Program Implementation, Anti-Icing: A Bold New Strategy, December-January.

Federal Highway Administration (FHWA), 1996, Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel, FHWA-RD-95-202.

Gilbert, R.O., 1987, *Statistical Methods for Environmental Pollution Monitoring,* Van Nostrand Reinhold Company, New York.

Hunt, Charles B., 1974, Natural Regions of the United States and Canada, San Francisco: W.H. Freeman and Company.

Jouyban, Zeinolabedin, "The Effects of Salt Stress on Plant Growth," *Technical Journal of Engineering and Applied Sciences*, Journal-2012-2-1/7-10 (2012).

Ketchum, S.A., Minsk, L.D., Blackburn, R.R. and Fleege, E.J., 1996, The Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel, prepared for USDOT FHWA, June.

Klesius, Michael, 2007, "The Mystery of Snowflakes", *National Geographic,* Issue 211 (1): 20.

Marquette University, 1992, Salt Saves Lives, The Marquette Report, Accident Analysis of Ice Control Operations, conducted by Department of Civil and Environmental Engineering.

Nature, 2006, "Ultrafast Superheating and Melting of Bulk Ice," Issue 439, pp. 183-186, January 12.

New York Times (NY Times), 2006, "Explaining Ice: The Answers are Slippery," February 21, www.nytimes.com/2006/02/21/science/21ice.html.

Salt Institute, 1991, The Snowfighter's Handbook: A Practical Guide for Snow and Ice Control, SI-1991R.

System Innovations, Inc., 2003, ADOT Arizona Road Weather Information System (RWIS) Communications Plan - Final Report 525, April.

Tabler, Ronald D., 1991, Strategic Highway Research Program (SHRP) National Research Council, Snow Fence Guide SHRP-W/FR-91-106.

Township of Cranberry, Pennsylvania (Cranberry), 2006, Cranberry Township's Snow and Ice Control Plan: General Information Guidelines and Operational Procedures for the Public Works Operations Materials Management Plan, November.

Transportation Association of Canada (TAC), 2003, Syntheses of Best Practices Road Salt Management.

United States Census Bureau, Quickfacts, http://quickfacts.census.gov/qfd/states/04000.html.

Washington State Department of Transportation (WSDOT), 2007, Statewide Snow and Ice Plan, October 1.

Western Regional Climate Center, 2014, Climate Information Home Page http://www.wrcc.dri.edu.

TABLES

TABLE 1
SODIUM CHLORIDE (NaCl) APPLICATION RATES AND NOTES
(FHWA, 1996; WSDOT, 2007)

ADOT

Pavement Temperature, Range, and Trend	Winter Storm Event	Pavement Surface	Initial Operation (typically anti-icing)			Subsequent Operations (typically deicing)			Comments
			Maintenance Action	Chemical Spread Rate		Maintenance Action	Chemical Spread Rate		
				Liquid, gal/lane-mi	Solid or Pre-Wetted Solid, lb/lane-mi		Liquid, gal/lane-mi	Solid or Pre-Wetted Solid, lb/lane-mi	
Above 32 °F, steady or rising	Any type	Dry, wet slush, or light snow cover	None	Not Required	Not Required	None	Not Required	Not Required	1) Monitor pavement temperature closely. Begin treatment if temperature falls below 32 °F and is at/below dew point. 2) Treat icy patches if needed with pre-wetted solid chemical at 100 – 150 lb/lane-mi or liquid chemical at 40 – 65 gal/lane-mi; plow as necessary.
Above 32 °F, but falling	Light to heavy snow storm, frost, or black ice	Dry	Apply liquid or pre-wetted solid chemical	40 – 65	75 – 150	Plow as necessary. Reapply pre-wetted solid chemical when needed	40 – 65	75 – 200	1) Applications will need to be more frequent at lower temperatures and higher snowfall rates. 2) Not advisable to apply liquid chemical at the indicated spread rate when the pavement temperature drops below 23 °F. 3) Do not apply liquid chemical onto heavy snow accumulation or packed snow. 4) Reduce chemical rate to 100 lb/lane-mi after heavier snow periods and during light snowfall; continue to plow and apply chemicals as necessary. 5) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 200 lb/lane-mi to accommodate longer operational cycles.
	Freezing rain storm	Wet	Apply solid chemical	N/A (solid chemical only)	100 – 200	Reapply solid chemical as needed	N/A (solid chemical only)	100 – 200	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential.
	Sleet storm	Any	Apply pre-wetted solid chemical	N/A (solid chemical only)	125	Plow accumulation as needed. Reapply pre-wetted solid chemical as needed	N/A (solid chemical only)	125	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential. Increase spread rate with increasing freezing rainfall intensity. Decrease spread rate with decrease in freezing rainfall intensity.
20 to 32 °F, remaining in range	Light snow storm	Wet, slush, or light snow cover	Apply liquid or solid chemical	40 – 90	100 – 210	Plow as necessary. Reapply liquid or solid chemical when needed	40 – 90	100 – 210	1) Application rates will depend on dilution potential.
	Moderate to heavy snow storm	Wet, slush, or light snow cover	Apply solid chemical	N/A (solid chemical only)	175 – 200	Plow as necessary. Reapply pre-wetted solid chemical when needed	80 – 90	190 – 200	1) Do not apply liquid chemical onto heavy snow accumulation or packed snow. 2) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 400 lb/lane-mi to accommodate longer operational cycles.
	Frost or black ice	Any	Apply pre-wetted solid chemical	N/A (solid chemical only)	175 – 225	Reapply pre-wetted solid chemical as needed	N/A (solid chemical only)	175 – 225	1) Monitor pavement temperature closely. 2) Application rates will depend on dilution potential. If pavement becomes wet or if ice forms, reapply chemical at a higher rate.

TABLE 1 (Cont.)
SODIUM CHLORIDE (NaCl) APPLICATION RATES AND NOTES
(FHWA, 1996; WSDOT, 2007)

Pavement Temperature, Range, and Trend	Winter Storm Event	Pavement Surface	Initial Operation (typically anti-icing)			Subsequent Operations (typically deicing)			Comments
			Maintenance Action	Chemical Spread Rate		Maintenance Action	Chemical Spread Rate		
				Liquid, gal/lane-mi	Solid or Pre-Wetted Solid, lb/lane-mi		Liquid, gal/lane-mi	Solid or Pre-Wetted Solid, lb/lane-mi	
20 to 32 °F, remaining in range (Cont.)	Freezing rain storm	Any	Apply solid chemical	N/A (solid chemical only)	200 – 300	Reapply solid chemical as needed	N/A (solid chemical only)	200 – 300	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential. Increase spread rate with increasing freezing rainfall intensity. Decrease spread rate with decrease in freezing rainfall intensity.
	Sleet storm	Any	Apply pre-wetted solid chemical	N/A (solid chemical only)	125 – 325	Plow accumulation as needed. Reapply pre-wetted solid chemical as needed	N/A (solid chemical only)	125 – 325	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential. Increase spread rate with increasing freezing rainfall intensity. Decrease spread rate with decrease in freezing rainfall intensity.
20 to 28 °F, remaining in range and equal to or below dew point	Frost or black ice	Any	Apply liquid or pre-wetted solid chemical	65 – 80	165 – 200	Reapply liquid or pre-wetted solid as needed	65 – 80	165 – 200	1) Monitor pavement closely. If thin ice forms, reapply chemical at higher rate. 2) Applications will need to be more frequent at higher levels of condensation. If traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency. 3) It is not advisable to apply a liquid chemical at the indicated spread rate when the pavement temperature drops below 23 °F.
15 to 20 °F, remaining in range	Light to heavy snow storm	Dry, wet, slush, or light snow cover	Apply pre-wetted solid chemical	May use pre-wet @ a rate of 7-10 gal/lane-mi	200 – 240	Plow as necessary. Reapply pre-wetted solid chemical when needed	May use pre-wet @ a rate of 7-10 gal/lane-mi	200 – 250	1) If sufficient moisture is present, solid chemical without pre-wetting can be applied. 2) Application rates will depend on dilution potential. Reduce chemical rate to 200 lb/lane-mi after heavier snow periods and during light snowfall; continue to plow and apply chemicals as necessary. 3) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 500 lb/lane-mi to accommodate longer operational cycles.
	Frost or black ice	Any	Apply pre-wetted solid chemical	May use pre-wet @ a rate of 7-10 gal/lane-mi	175 – 225	Reapply pre-wetted solid chemical when needed	May use pre-wet @ a rate of 7-10 gal/lane-mi	175 – 225	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate. 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency.
	Freezing rain storm	Any	Apply solid chemical	N/A (solid chemical only)	250 – 400	Reapply solid chemical as needed	N/A (solid chemical only)	250 – 400	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential. Increase spread rate with increasing freezing rainfall intensity. Decrease spread rate with decrease in freezing rainfall intensity.

TABLE 1 (Cont.)
SODIUM CHLORIDE (NaCl) APPLICATION RATES AND NOTES
(FHWA, 1996; WSDOT, 2007)

ADOT

Pavement Temperature, Range, and Trend	Winter Storm Event	Pavement Surface	Initial Operation (typically anti-icing)			Subsequent Operations (typically deicing)			Comments
			Maintenance Action	Chemical Spread Rate: Liquid, gal/lane-mi	Chemical Spread Rate: Solid or Pre-Wetted Solid, lb/lane-mi	Maintenance Action	Chemical Spread Rate: Liquid, gal/lane-mi	Chemical Spread Rate: Solid or Pre-Wetted Solid, lb/lane-mi	
15 to 20 °F, remaining in range (Cont.)	Sleet storm	Any	Apply pre-wetted solid chemical	N/A (solid chemical only)	250 – 400	Plow accumulation as needed. Reapply pre-wetted solid chemical when needed	N/A (solid chemical only)	250 – 400	1) Monitor pavement temperature and precipitation closely. 2) Application rates will depend on dilution potential. Increase spread rate with increase in freezing rainfall intensity. Decrease spread rate with decrease in freezing rainfall intensity.
Below 15 °F, steady or falling	Light to heavy snow or sleet storm	Dry or light snow cover	Plow as needed	Not Required	Not Required	Plow as needed	Not Required	Not Required	1) It is not recommended that chemicals be applied in this temperature range. 2) Abrasives can be applied to enhance traction.
	Freezing rain storm, frost, or black ice	Any	Apply abrasives	Not Required	Not Required	Apply abrasives as needed	Not Required	Not Required	

GENERAL NOTES

Chemical Applications – These application rates are starting points. Local experience should refine these recommendations. Time the chemical applications in order to prevent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

Chemical Rates – The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Plowing – Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.

WINTER STORM EVENT DEFINITIONS

Black Ice – Thin coating of clear, bubble-free, homogenous ice that forms on pavement with a temperature at or slightly above 32 °F.

Freezing Rain – Supercooled droplets of liquid precipitation with a temperature near 32 °F.

Frost – Ice crystals in the form of scales, needles, feathers, or fans deposited on surfaces cooled by radiation or other processes. The deposit may be composed of drops of dew frozen after deposition or ice formed directly from water vapor at a temperature below 32 °F (sublimation).

Heavy Snow – Snow falling at a rate of 0.5 inches per hour or greater. Visibility is less than ¼ mile.

Light Rain – Small liquid droplets falling at a rate such that individual drops are easily detectable splashing from a wet surface, including drizzle.

Light Sleet – Scattered pellets that do not completely cover an exposed surface regardless of duration; visibility is not affected.

Light Snow – Snow falling at a rate of less than 0.5 inches per hour; visibility of motorists is not adversely affected. Visibility is greater than ½ mile.

Moderate Rain – Liquid drops falling are not clearly identifiable and spray from falling drops is observable just above pavement or other hard surfaces.

Moderate Sleet – Rain falls in sheets, individual drops are not identifiable, and heavy spray from falling rain can be observed several inches over hard surfaces.

Moderate Snow – Snow falling at a rate of 0.5 inches per hour or greater. Visibility is between ¼ to ½ mile.

Sleet – A mixture of rain and snow that has been partially melted after passing through an atmosphere with a temperature slightly above freezing.

TABLE 2
MAGNESIUM CHLORIDE ($MgCl_2$) APPLICATION RATES AND NOTES
(FHWA, 1996; WSDOT, 2007)

Pavement Temperature, Range, and Trend	Winter Storm Event	Pavement Surface	Initial Operation (typically anti-icing)		Subsequent Operations (typically deicing)		Comments
			Maintenance Action	Chemical Spread Rate (30%), gal/lane-mi	Maintenance Action	Chemical Spread Rate, gal/lane-mi	
Above 32 °F, steady or rising	Light to heavy snow storm, frost, or black ice	Dry, wet slush, or light snow cover	None	Not Required	None	Not Required	1) Monitor pavement temperature closely. Begin treatment if temperature falls below 32 °F and is at/below dew point. 2) Treat icy patches if needed with pre-wetted solid chemical at 15 – 35 gal/lane-mi; plow as necessary.
	Freezing rain or sleet storm	Any	None	Not Required	None	Not Required	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
Above 32 °F, but falling	Light snow storm	Dry	Apply $MgCl_2$	15 – 35	Plow as necessary. Reapply $MgCl_2$ when needed	15 – 35	1) Application rates will depend on dilution potential. 2) Do not apply $MgCl_2$ onto heavy snow accumulation or packed snow.
	Moderate or heavy snow storm	Dry	Apply solid NaCl pre-wet with $MgCl_2$	N/A (NaCl pre-wet with $MgCl_2$)	Plow accumulation and reapply NaCl pre-wet with $MgCl_2$	N/A (NaCl pre-wet with $MgCl_2$)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Frost or black ice	Any	Apply $MgCl_2$	15 – 35	Reapply $MgCl_2$ as needed	15 – 30	1) Application rates will depend on dilution potential.
	Freezing rain storm	Wet	Apply solid NaCl	N/A (solid NaCl only)	Plow accumulation and reapply solid NaCl	N/A (solid NaCl only)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Sleet storm	Any	Apply solid NaCl pre-wet with $MgCl_2$	Apply solid NaCl pre-wet with $MgCl_2$	Plow accumulation and reapply solid NaCl pre-wet with $MgCl_2$	N/A (NaCl pre-wet with $MgCl_2$ only)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
20 to 32 °F, remaining in range	Light snow storm	Wet, slush, or light snow cover	Apply $MgCl_2$	20 – 40	Plow as necessary. Reapply $MgCl_2$ when needed	20 – 40	1) Application rates will depend on dilution potential.
	Moderate to heavy snow storm	Wet, slush, or light snow cover	Apply solid NaCl pre-wet with $MgCl_2$	N/A (pre-wet solid NaCl only)	Plow accumulation and reapply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$ only)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Frost or black ice	Any	Apply $MgCl_2$	20 – 40	Reapply $MgCl_2$ as needed	20 – 40	1) Application rates will depend on dilution potential.

TABLE 2 (Cont.)
MAGNESIUM CHLORIDE ($MgCl_2$) APPLICATION RATES AND NOTES
(FHWA, 1996; WSDOT, 2007)

Pavement Temperature, Range, and Trend	Winter Storm Event	Pavement Surface	Initial Operation (typically anti-icing): Maintenance Action	Initial Operation (typically anti-icing): Chemical Spread Rate (30%), gal/lane-mi	Subsequent Operations (typically de-icing): Maintenance Action	Subsequent Operations (typically de-icing): Chemical Spread Rate, gal/lane-mi	Comments
20 to 32 °F, remaining in range (Cont.)	Freezing rain storm	Any	Apply solid NaCl	N/A (solid NaCl only)	Plow accumulation and reapply solid NaCl	N/A (solid NaCl only)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Sleet storm	Any	Apply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	Plow accumulation and reapply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
20 to 28 °F, remaining in range and equal to or below dew point	Frost or black ice	Any	Apply $MgCl_2$	20 – 40	Reapply $MgCl_2$ as needed	20 – 40	1) Application rates will depend on dilution potential.
15 to 20 °F, remaining in range	Light snow storm	Dry, wet, slush, or light snow cover	Apply $MgCl_2$	15 – 40	Plow as necessary. Reapply liquid chemical when needed	45 – 70	1) Application rates will depend on dilution potential.
	Moderate to heavy snow storm	Dry, wet, slush or light snow cover	Apply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	Plow accumulation and reapply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Frost or black ice	Any	Apply $MgCl_2$	25 – 40	Reapply $MgCl_2$ as needed	25 – 40	1) Application rates will depend on dilution potential.
	Freezing rain storm	Any	Apply solid NaCl	N/A (solid NaCl only)	Plow accumulation and reapply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
	Sleet storm	Any	Apply solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	Plow accumulation and solid NaCl pre-wet with $MgCl_2$	N/A (solid NaCl pre-wet with $MgCl_2$)	1) Refer to Table 1, Sodium Chloride (NaCl) Application Rates and Notes.
Below 15 °F, steady or falling	Light to heavy snow or sleet storm	Dry or light snow cover	Plow as needed	Not Required	Not Required	Plow as needed	1) It is not recommended that chemicals be applied in this temperature range. 2) Abrasives can be applied to enhance traction.
	Freezing rain storm, frost or black ice	Any	Apply abrasives	Not Required	Not Required	Apply abrasives as needed	

GENERAL NOTES

Chemical Applications – These application rates are starting points. Local experience should refine these recommendations. Time the chemical applications in order to prevent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

Chemical Rates – The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Plowing – Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.

WINTER STORM EVENT DEFINITIONS

Black Ice – Thin coating of clear, bubble-free, homogenous ice that forms on pavement with a temperature at or slightly above 32 °F.

Freezing Rain – Supercooled droplets of liquid precipitation with a temperature near 32 °F.

Frost – Ice crystals in the form of scales, needles, feathers, or fans deposited on surfaces cooled by radiation or other processes. The deposit may be composed of drops of dew frozen after deposition or ice formed directly from water vapor at a temperature below 32 °F (sublimation).

Heavy Snow – Snow falling at a rate of 0.5 inches per hour or greater. Visibility is less than ¼ mile.

Light Rain – Small liquid droplets falling at a rate such that individual drops are easily detectable splashing from a wet surface, including drizzle.

Light Sleet – Scattered pellets that do not completely cover an exposed surface regardless of duration; visibility is not affected.

Light Snow – Snow falling at a rate of less than 0.5 inches per hour; visibility of motorists is not adversely affected. Visibility is greater than ½ mile.

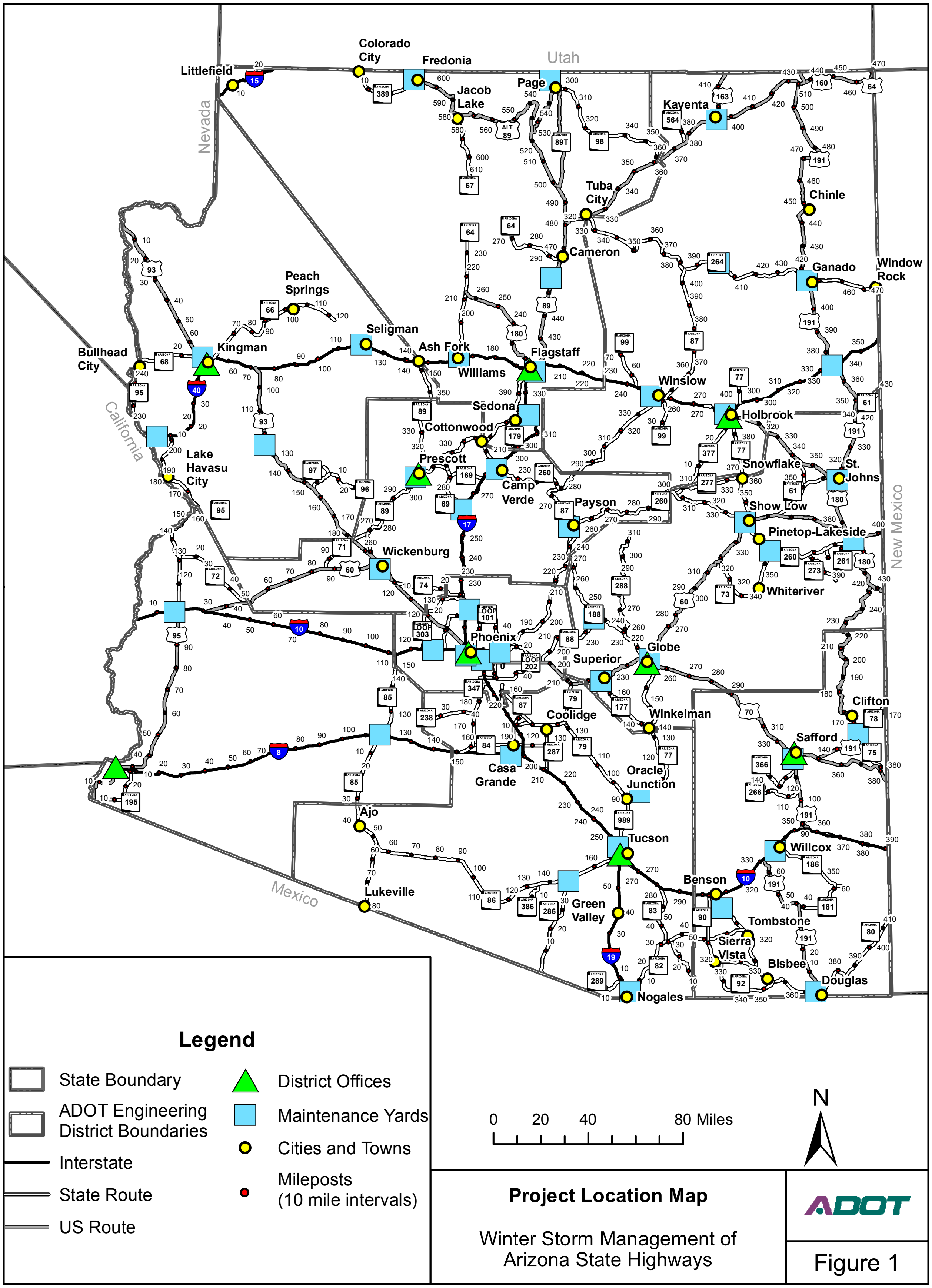
Moderate Rain – Liquid drops falling are not clearly identifiable and spray from falling drops is observable just above pavement or other hard surfaces.

Moderate Sleet – Rain falls in sheets, individual drops are not identifiable, and heavy spray from falling rain can be observed several inches over hard surfaces.

Moderate Snow – Snow falling at a rate of 0.5 inches per hour or greater. Visibility is between ¼ to ½ mile.

Sleet – A mixture of rain and snow that has been partially melted after passing through an atmosphere with a temperature slightly above freezing.

FIGURES



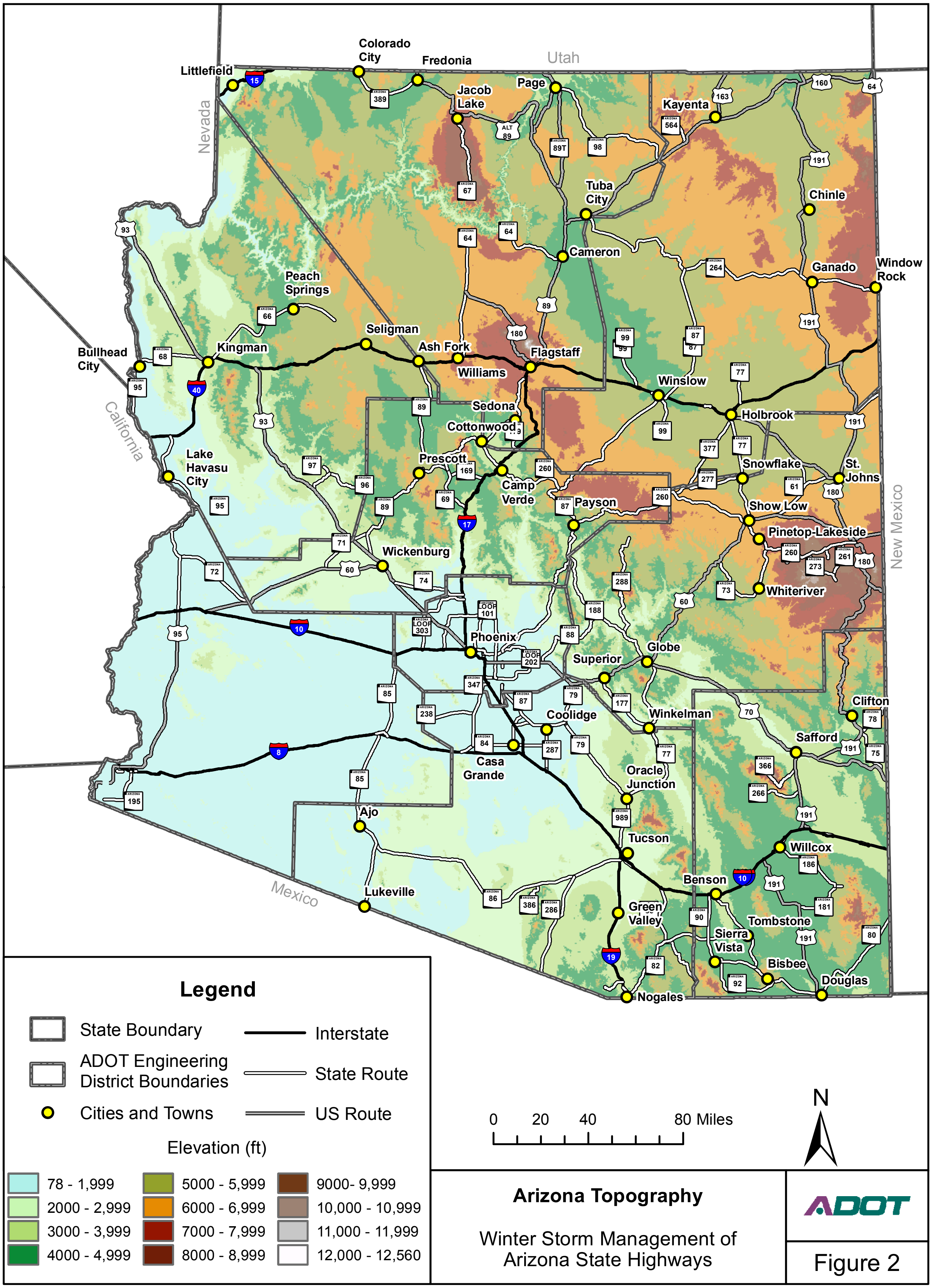
Project Location Map

Winter Storm Management of Arizona State Highways

ADOT

Figure 1

Source: ADOT 2014

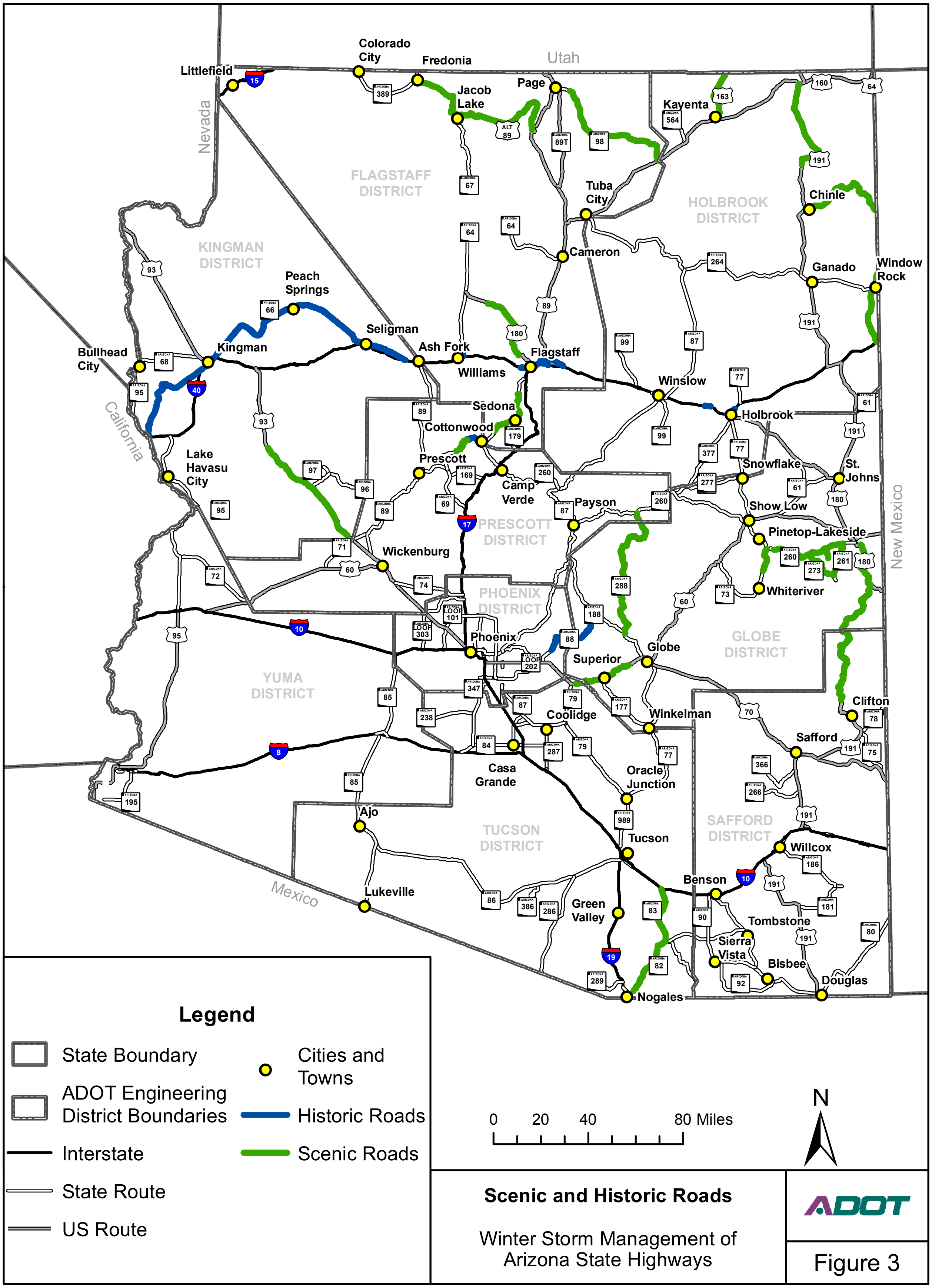


Arizona Topography

Winter Storm Management of Arizona State Highways

Figure 2

Source: ADOT 2014, USGS DEM

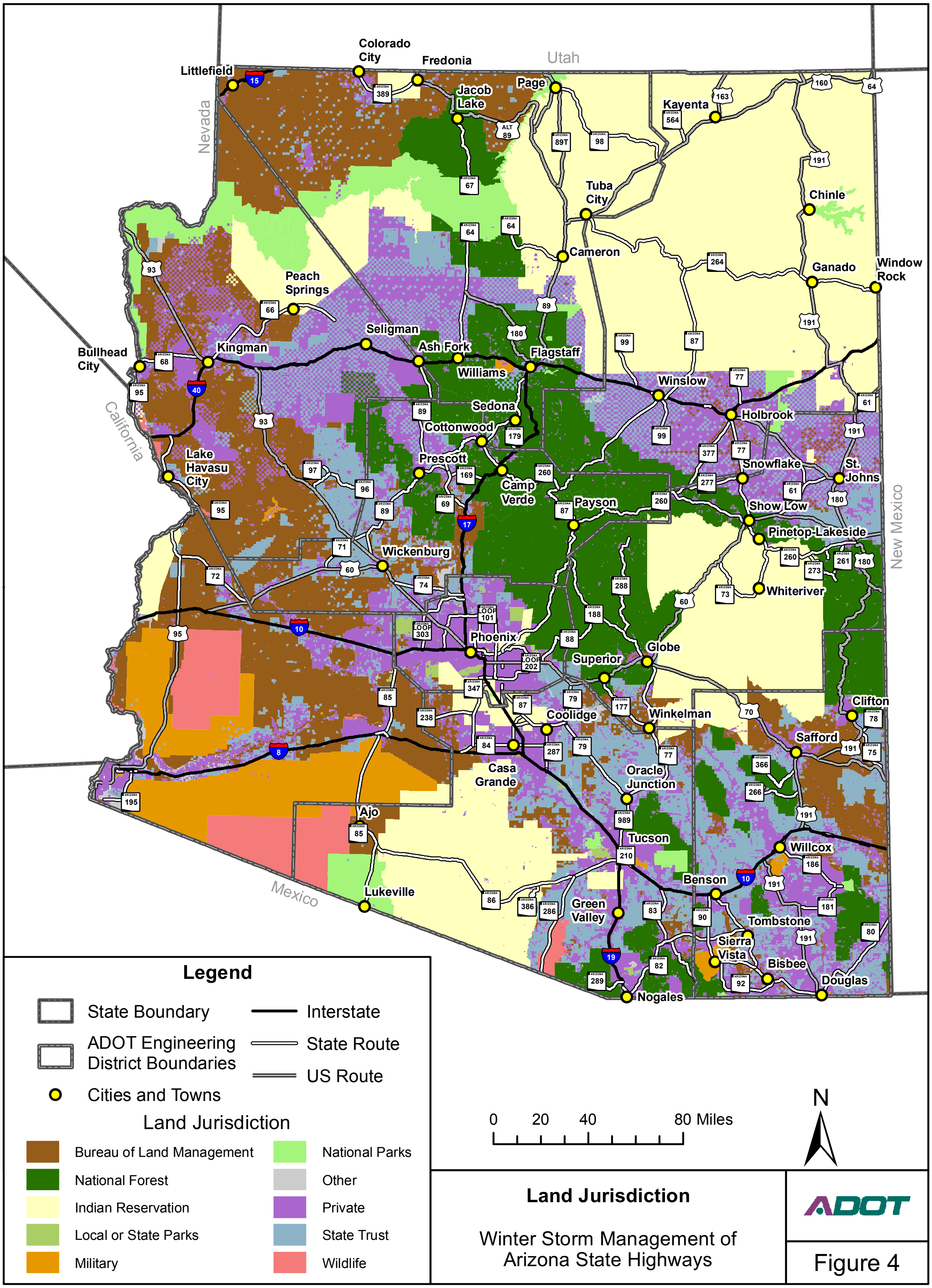


Scenic and Historic Roads

Winter Storm Management of Arizona State Highways

Figure 3

Source: ADOT 2014

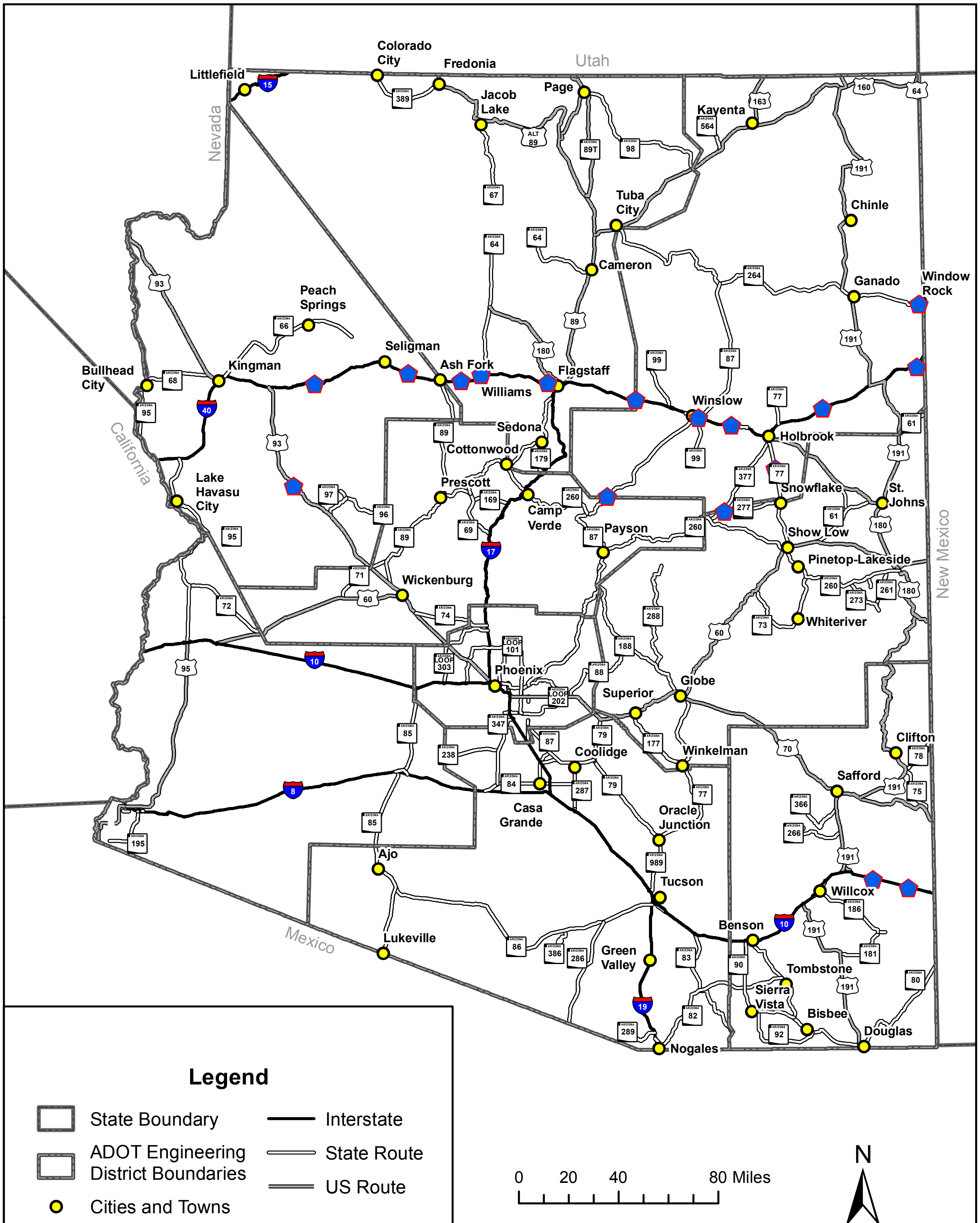


Land Jurisdiction

Winter Storm Management of Arizona State Highways

Figure 4

Source: ADOT 2014, ASLD 2014



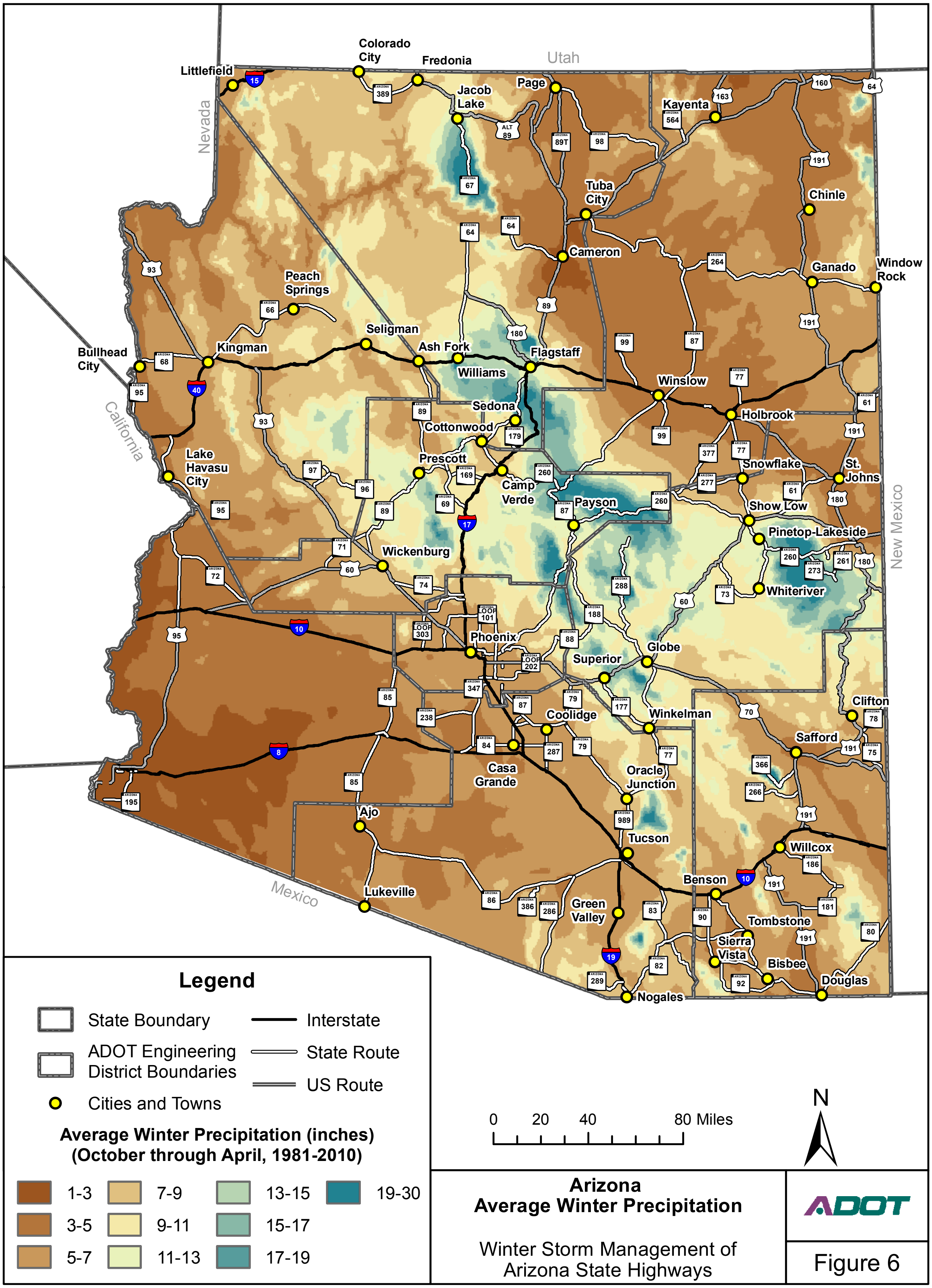
Road Weather Information System (RWIS) Locations

Winter Storm Management of Arizona State Highways

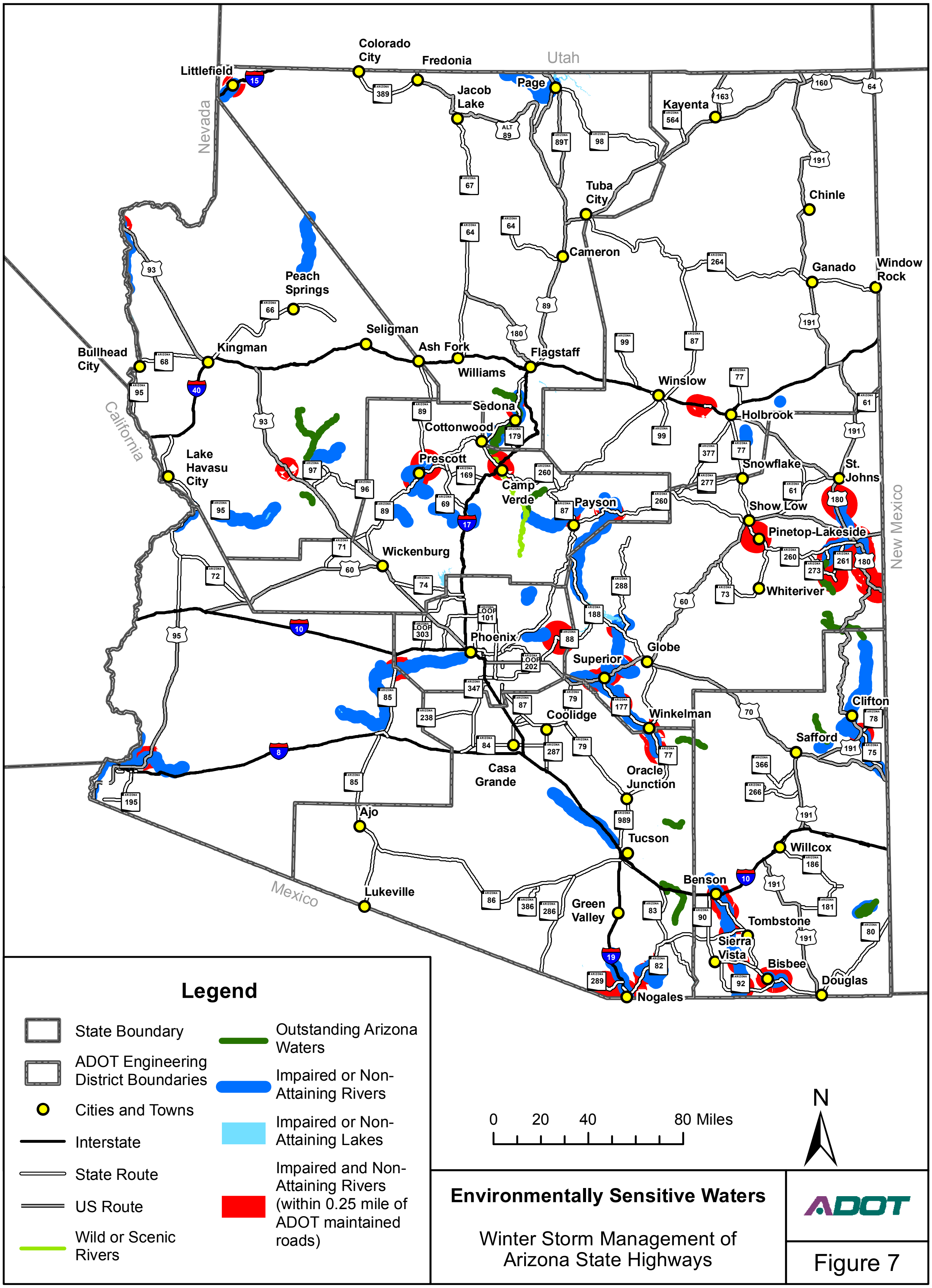
ADOT

Figure 5

Source: ADOT 2014



Source: ADOT 2014, PRISM 1981-2010

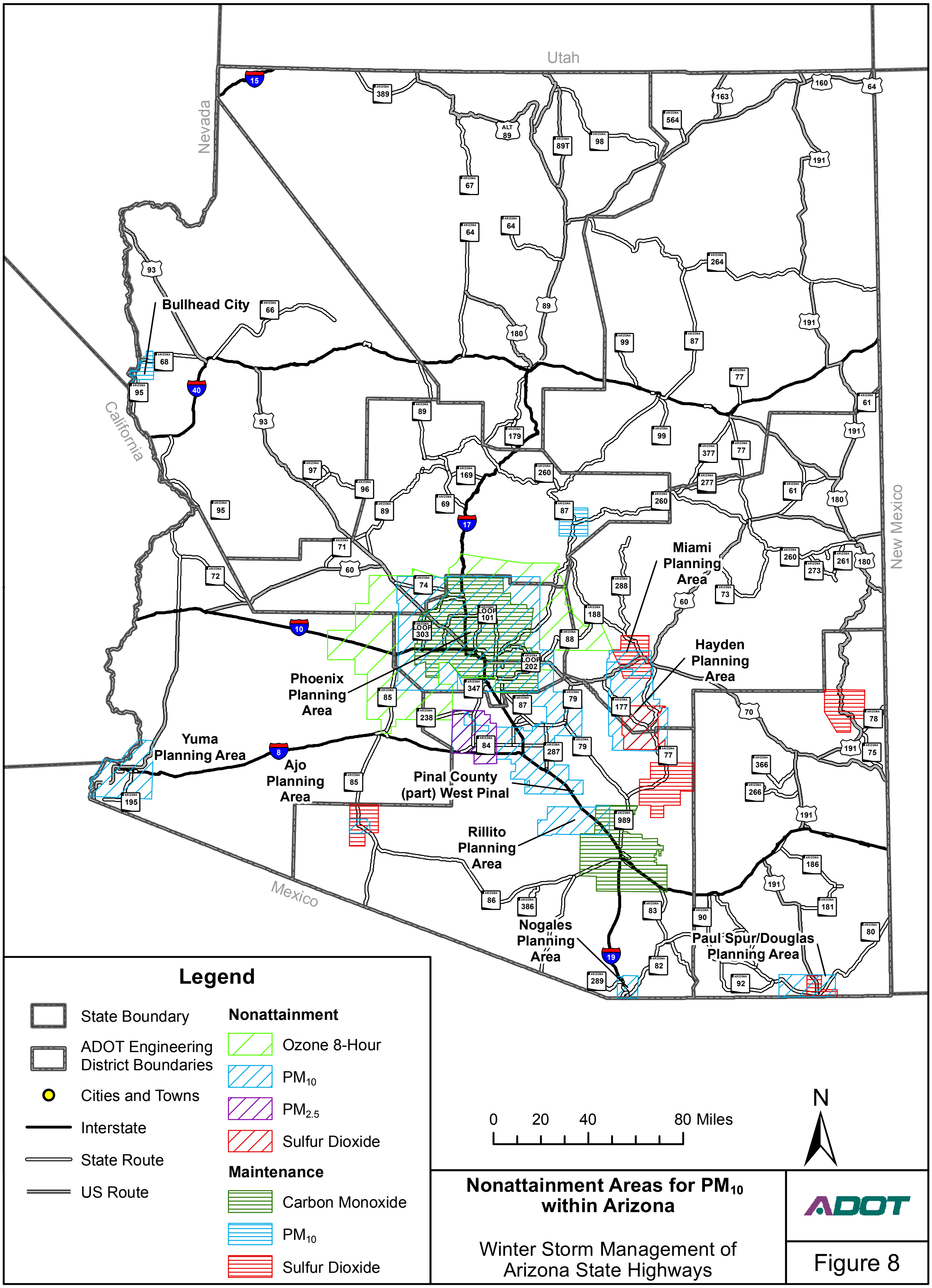


Environmentally Sensitive Waters

Winter Storm Management of Arizona State Highways

Figure 7

Source: ADOT 2014



Nonattainment Areas for PM_{10} within Arizona

Winter Storm Management of Arizona State Highways

ADOT

Figure 8

Source: ADOT 2014

APPENDIX A

OPERATIONAL GUIDANCE AND BMP MATERIALS

APPENDIX A-1

PECOS SNOW AND ICE ACTIVITIES

Arizona Department of Transportation ITD - Highway Maintenance **Performance Guideline - PeCoS**	Program Number: 170 Activity Number: **171** Effective Date: **7/1/13**

Activity:

Plow Snow and/or Apply Abrasives / De-icers — Check Environmental BMP

Description and Purpose:

Plow snow and/or apply de-icing agents to the roadway as conditions warrant under the ADOT District Snow and Ice Control Plan. **(Stipend Activity)**

Performance Guideline:

Plow and/or apply abrasives / de-icers to locations where needed. Abrasive material may be treated with de-icing agents.

Statewide Average Crew Size

Highway Operations Worker
HOT 1 / 2 / 3 / 4 / **Supvr.**

Average Crew Size: 1

Work Method

1. Plow and/or apply abrasives or de-icer to assigned routes.
2. Warning signs shall be placed or erected as needed.

Equipment Options

Code	Description	Code	Description
01	Pickup	42	Spreader
02/03/04	Truck	50	Water Tank
09	Truck, Misc.	56	Arrow / Message board
10	Grader		
11	Loader		
13	Dozer		
40	Snow Blower		
41	Snow Plow		

Material Options

Code	Description	Code	Description	Code	Description
03M	Sand Produced	12M	Cinders Purchased	21X	Magnesium Chloride-Dry
04M	Sand Purchased	03X	Salt	22X	CMA (Calc. Mag. Acetate)
05M	Cinders (Course)	16X	Calcium Chloride	23X	Misc De-Icer - Liquid
11M	Cinders (Fine)	20X	Magnesium Chloride-Liq.	24X	Misc De-Icer - Dry
				29X	Brine

Accomplishment - Miles

Notes:

1. One employee will be designated at the start of each shift to perform PM (Preventative Maintenance) check list on the loader to be used and to record usage hours.
2. Mileage will begin upon leaving the yard, and will end upon entering the yard at the end of the shift.
3. When more than one shift is necessary to accommodate snow activity, report under the appropriate suffix letter:
   171-A: First Shift 171-B: Second Shift
4. Drift control to be reported as **Activity 171-T**.

Arizona Department of Transportation
ITD - Highway Maintenance
Performance Guideline - PeCoS

Program Number:	170
Activity Number:	**172**
Effective Date:	**7/1/13**

Activity:

Winter Storm Patrol **Check Environmental BMP**

Description and Purpose:

Conduct winter patrol of snow and ice areas of the road to determine the possible development of hazardous conditions requiring maintenance attention. **(Stipend Activity)**

Performance Guideline:

Winter storm patrol shall be used as weather forecasts and conditions warrant.

Statewide Average Crew Size

Highway Operations Worker
HOT 1 / 2 / 3 / 4 / **Supvr.**

Average Crew Size: 1

Work Method

1. Patrol snow and ice areas.
2. Determine maintenance required.
3. Call out assistance, if needed.
4. Place warning signs as needed.

Equipment Options

Code	Description
01	Pickup
02/03/04	Truck

Material Options

Code	Description
	N/A

Accomplishment - Miles

Notes:

1. This Activity is for patrolling only in anticipation of a winter storm. If plowing snow and/or applying abrasives is required, use **Activities 171 or 173**.
2. Mileage will begin upon leaving the yard, and will end upon entering the yard at the end of the shift.
3. When more than one shift is necessary to accommodate snow activity report under the appropriate suffix letter:

171-A: First Shift **171-B: Second Shift**

Arizona Department of Transportation ITD - Highway Maintenance **Performance Guideline - PeCoS**	Program Number: 170 Activity Number: **173** Effective Date: **7/1/13**

Activity:

Spot Ice Control Check Environmental BMP

Description and Purpose:

The application of abrasives, treated abrasives, de-icing or anti-icing agents to areas where ice exists.
(Stipend Activity)

Performance Guideline:

This activity is to be used when weather or storm conditions are such that require the application of abrasives, treated abrasives, de-icing or anti-icing agents to ice spots on roadways.

Statewide Average Crew Size

Highway Operations Worker
HOT 1 / 2 / 3 / 4 / **Supvr.**

Average Crew Size: 1

Equipment Options

Code	Description
1	Pickup
02/03/04	Truck
10	Grader
11	Loader
41	Snow Plow
42	Spreader
50	Water Tank

Work Method

1. Apply abrasives, treated abrasives, and/or liquid deicers/anti-icing agents where needed along assigned routes.
2. Warning signs shall be placed, erected, or dropped as needed.

Material Options

Code	Description	Code	Description	Code	Description
03M	Sand Produced	12M	Cinders Purchased	21X	Magnesium Chloride-Dry
04M	Sand Purchased	03X	Salt	22X	CMA (Calc. Mag. Acetate)
05M	Cinders (Course)	16X	Calcium Chloride	23X	Misc De-Icer - Liquid
11M	Cinders (Fine)	20X	Magnesium Chloride-Liq.	24X	Misc De-Icer - Dry
				29X	Brine

Accomplishment - Miles

Notes:

1. When more than one shift is necessary to accommodate snow activity report under the appropriate suffix letter.
   173-A: First Shift 173-B: Second Shift
2. Mileage will begin upon leaving the yard, and will end upon entering the yard at the end of the shift.
3. For Spot Ice Control required on Bridge Decks, report as **Activity 173-D**.
4. One employee will be designated at the start of each shift to perform PM (Preventative Maintenance) check list on the loader to be used and to record usage hours.
5. Drift control to be reported as **Activity 173-T**.

Arizona Department of Transportation
ITD - Highway Maintenance
Performance Guideline - PeCoS

Program Number:	170
Activity Number:	**174**
Effective Date:	**7/1/13**

Activity:

Anti-Icing w/ Deicers

Check Environmental BMP

Description and Purpose:

The application of Anti-icing agents to Roadway in advance of winter storms or when weather conditions warrant. **(Stipend Activity)**

Performance Guideline:

Activity should be used to reduce chances of ice forming on roadway.

Statewide Average Crew Size

Highway Operations Worker
HOT 1 / 2 / 3 / 4 / **Supvr.**

Average Crew Size: 1

Equipment Options

Code	Description
01	Pickup
02/03/04	Truck
50	Water Tank
57	Attenuator

Material Options

Code	Description
20X	Magnesium Chloride - Liquid
23X	Misc. De-Icier - Liquid
29X	Brine

Work Method

1. Apply anti-icing agents to areas where needed along assigned routes. Use pre-determined calibrated amounts.

2. Warning signs shall be placed, erected, or dropped as needed.

Accomplishment - Miles

Notes:

1. Supervisors are encouraged to perform in daytime for visibility.

Arizona Department of Transportation
ITD - Highway Maintenance
Performance Guideline - PeCoS

Program Number:	170
Activity Number:	**175**
Effective Date:	**7/1/13**

Activity:

Cleaning of All Snow Related Equipment

Check Enviromental BMP

Description and Purpose:

To remove de-icer from equipment to prevent excessive corrosion. **(Non Stipend Activity)**

Performance Guideline:

Clean and inspect equipment. As washed, perform adjustments to equipment as needed. (Plow bits, spreader chain, etc.)

Statewide Average Crew Size

Highway Operations Worker
HOT 1 / 2 / 3 / 4 / **Supvr.**

Average Crew Size: 2

Equipment Options

Varies

Material Options

Code	Description
	N/A

Work Method

1. Wear all Personal Protection Equipment as required for cleaning.
2. Unload de-icer to stockpiles
3. Wash all equipment.
4. Remove spreader & plow. Store in proper areas.

Accomplishment - Labor Hours

Notes:

1. Equipment Unit = 1 piece of equipment (w/ ADOT Equipment Services #)
2. When accounting for Equipment units being washed account for them by checking the "equipment was transported via this CWR and not used" box located on the equipment tab.

Arizona Department of Transportation ITD - Highway Maintenance **Performance Guideline - PeCoS**	**Suffix Required**	Program Number: 170 Activity Number: **179** Effective Date: **7/1/13**

Activity:

Other Snow and Ice Control (Non Stipend Activity) Check Environmental BMP

Performance Guideline:

This activity shall be used only for snow and ice control and related support work which cannot be performed as **Activity 171 - 175**. Proper safety devices and signs shall be used in every case where work exposure to traffic.

The following suffix letters shall be used:

- **A.** **First Shift**
- **B.** **Second Shift**
- C. Transport of Anti De-Icing Materials to Location
- D. Prepare Equipment Before Storm (Mount Plows, Spreaders, Calibrate Equip, etc.)
- E. Remove Equipment After Storm
- F. Emergency Radio Operation
- G. Set up, Man, and/or Maintain Temporary Road Blocks.
- H. After Storm Clean Up Using Loader, Snowblower, Grader, etc.
- I. Mix De-Icing Agents with Abrasives
- J. Erect, Dismantle, Repair and otherwise Maintain Snow Fence
- K. Sweep / Remove Cinders / Sand Related to Snow and Ice Control
- L. Open or Close Snow, Ice and other Related Warning Signs (includes Maintenance Supervisor's Time)
- M. Snow Marker Maintenance / Snow Signs (if Work is Performed by Hwy Maint ORG)
- N. Close, Barricade and/or Inspect Closed Highway *****
- Q. Production of Brine
- S. Shift Supervisor
- **TR.** **Travel Between Orgs**
- U. Fuel and Service Equipment in Field
- V. Receiving and Stockpiling Snow Related Materials

Accomplishment - Labor Hours

Suffix letter "N" shall be used when any highway or portion of a highway is closed and barricaded because of heavy snow. The entire length of the closed highway shall be inspected for stranded vehicles and motorists following the closure. Inspection will start as soon as conditions permit, utilizing any form of transportation, including air transportation.*****

Inspection of a closed highway will be documented in the comment section of the completed Daily Work Report. The comments shall include the following:

Date of inspection; Route inspected with the beginning and ending mileposts; Name of employee(s) making the inspection, and results of this inspection.

"CONSULT DISTRICT SNOW PLAN"

Notes:

1. Enter "YARD" as **Sort #** on Crew Work Report when suffix letter is used for work not being accomplished on the roadway. Report the nearest location to the yard on the Crew Work Report.
2. NOTE: Use multiple suffixes when shifts are involved.

APPENDIX A-2

WSM PRE-WINTER SEASON MEETING AGENDA

Winter Storm Management Pre-Winter Season Meeting Agenda

1. Introductions

2. Overview of WSM Activities
   a. Objectives
   b. Material Storage and Handling
   c. General WSM Practices (anti-icing, deicing, abrasives, plowing, and other techniques)
   d. Shift or Crew Lead Role During Winter Maintenance Activities

3. Summary of Previous Season
   a. Successes
   b. Issues and Lessons Learned

4. Anti-Icing, Deicing, and Abrasives Application Procedures
   a. When to Use Anti-icers, Deicers, and Abrasives
   b. Application Products and Rates
   c. Priority Locations
   d. Truck Vibrators

5. Plowing Procedures and Hazards
   a. Operation and Driving
   b. Hazards: Bridges, Curb/Gutters, and Sidewalk Sections
   c. Responding to Accidents and Stranded Vehicles
   d. Temperature Sensors

6. Equipment Care
   a. Inspection Procedures
   b. Maintenance Procedures
   c. Calibration Procedures
   d. Wash Facilities and Procedures

7. Safety Concerns and Procedures
   a. Driving and Operating Hazards (speed, turning around, throwing snow, etc.)
   b. PPE and Safety Supplies
   c. Communication Protocols
   d. Chemical Hazards
   e. Motorist Traffic Safety and Assistance

8. Winter Storm Patrols

9. On-the-job Training Requirements
   a. Time in the truck
   b. Simulator
   c. Winter Readiness Workshop
   d. EOTEP
   e. Obtain All Certifications Required to Drive a Snowplow

10. Snow Desk Procedures

11. Shifts and Shift Changes

12. Other

APPENDIX A-3

WSM TRAINING CURRICULUM OUTLINE

Winter Storm Management Operations Training Curriculum Outline

LEARNING GOALS

1. Increase knowledge of safety policies and practices
2. Increase knowledge of proper use of equipment
3. Increase knowledge of proper/optimal application of chemicals to be effective in winter storm management, while minimizing adverse effects on the environment
4. Improve efficiency and effectiveness of winter storm management

Lesson Plan Outline

1. **Introduction to Winter Storm Management**
    a. Goals of winter storm management
    b. Federal regulations and requirements
        - Importance of winter storm management
    c. Objectives of this training
        - Present learning goals

2. **Legality**
    a. Agency personnel, CDL and staffing policies, including drug and alcohol policy
    b. Legal rights and responsibilities as a snow removal agency
    c. Any restrictions on shift length, for instance, 12-hour shifts

3. **Basic Meteorology and Winter Weather Events**
    a. Specifically, how weather events relate to snow control activities
    b. Present a few scenarios (temperature falling, whiteout, wind, etc.) and how the operator's behavior would have to be modified to deal with them
    c. Emergency situations
        - Agencies available to help with winter storm emergencies
    d. Tools used by ADOT
        - To get weather forecasts and current information
        - To alert drivers to weather conditions
    e. RWIS network in Arizona
        - Visual, if available

4. **Priority Routes**
    a. Define priority routes (I, II, III, etc.)
    b. Map of different routes within the District. If possible, include the following:
        - Known obstacles in the roadway
        - Bridges & bridge seams
        - Turn-around points
        - Pipes, drainage inlets, culverts, and cattle guards
        - Speed bumps
        - Low overhead clearance features
        - Safe areas for use during blizzards or whiteout conditions
    c. Are there any route-specific issues that should be addressed?
        - Environmentally-sensitive areas
        - Challenging areas, like bridges or densely-populated urban areas
    d. Define the level of service that the District must meet for each route

5. **Fundamental Snow and Ice Control Concepts**
    a. Explain chemical additives
    b. Explain abrasives
    c. Explain snowplow techniques, applications, and safety

6. **Recommended Chemical Additives and Abrasives**
    a. How anti-icing and deicing agents work
        - Difference between preventing the road/ice bond and breaking it
        - Commonly-used chemicals
        - Which chemicals does the specific District use?
        - Which chemicals are most effective per situation / condition?
    b. Application rates and timing
        - Cite manufacturer's recommendations for that particular District's vehicles
    c. Special storm conditions
        - How the operator can respond to them
        - When would it be inappropriate to apply chemicals, abrasives, etc.
    d. Special deicing problems (bridges, elevated curves, ramps, and intersections)
        - Where specifically within the District will these problems be encountered?
    e. When to reapply
        - Bring out manufacturer's recommendations for the products that district will be using

7. **Recommended Nonadditive Practices**
    a. What they are
    b. When these are applicable

8. **Equipment—Operation, Calibration, and Maintenance**
    a. Plows
        - Preinspection and operation of equipment
        - Proper plowing techniques
    b. Spreaders and controls
    c. Loaders
    d. Emergency repair and refueling stations
    e. Preventative maintenance
    f. Lighting and signage of equipment

9. **Winter Storm Safety**
    a. Agency safety policies
    b. Defensive driving techniques
    c. Winter survival in open rural country

10. **Case Studies**

11. **Conclusion**
    a. Reiterate important points
        - Priority routes
        - When to use chemicals, abrasives, and plows
        - Importance of equipment calibration, inspection, and maintenance
    b. Questions

12. **Training Evaluation**

APPENDIX A-4

T.A.P.E.R. LOG
(Record of Chemical Application)

T.A.P.E.R. LOG

Date: ____/____/____

Day: ______________

Drivers	Start Time	End Time	Reg Time	Overtime

Unit	Plow No.	Spreader	Start Miles	End Miles	Total Miles

Loaders	Begin	Ending	Total

Equipment			Capacity
Komatsu Loader	Heaping bucket	4.750 lbs	2.25 c.y.
CAT Loader	Heaping bucket	5.250 lbs	2.60 c.y.
CAT 928G			2.2 c.y
Volvo L70G			3 c.y.
Deere 544G			2.5 c.y.
Komatsu			2.7 c.y.

Route	Milepost	
(1)	A	B
(2)	B	C
(3)	C	D
(4)	D	E
(5)	E	F

Route	Milepost to Milepost
	-
	-
	-
	-
	-

MATERIAL USED: ____

	Beginning Milepost	Ending Milepost	Lane Direction		Total Mileage	Application Rate	Pounds Used	Air Temp.	Surface Temp.
			R	L					
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

TOTAL WEIGHT USED (shift): __________________ lbs

Comments:

APPENDIX A-5

EQUIPMENT CALIBRATION PROCEDURES

Manual Calibration Procedures

Deicing and anti-icing spreading equipment may initially be calibrated in the factory, but it is important to periodically recalibrate equipment, especially prior to the winter season or after damage is suspected to have occurred to the spreader equipment any spreader failure, regardless or type, and repair. Solid and liquid spreader calibrations should only be performed by a trained EQS technician. The following procedures can be used to check the calibration of solid and liquid material spreaders. Different dry and liquid materials will spread at different rates at the same setting, so calibration rates must be checked with the material that will be used.

I. Solids Spreader Calibration

Spreader calibration is a necessary part of a successful preventive maintenance program. Spreader calibrations must be checked annually to ensure proper application rates, as determined in the District Snow Guides. Due to normal wear and tear of the spreader system components throughout the course of the snow removal season, it is essential that the spreader's calibration settings be verified and adjusted, if necessary, annually.

Manual calibration of spreaders requires calculating the pounds per mile discharged at various spreader control settings and truck speeds by counting the number of auger shaft revolutions per minute, measuring the material discharged in one revolution, and monitoring the vehicle speed.

With hopper-type spreaders, each spreader must be calibrated individually at a specified gate opening; even the same models can vary widely at the same setting. Measurements should be made from the floor of the conveyor to the bottom edge of the gate.

Equipment needed:

- Scale for weighing
- Clean canvas bag or bucket to collect material
- Chalk, crayon, or other marker
- Stopwatch (or a watch with a second hand)
- Calculator

Calibration steps

1. Warm truck's hydraulic oil to normal operating temperature with the spreader system running.
2. Place a partial load of salt on the truck.
3. Mark shaft end of the auger or conveyor.
4. Dump salt on auger or conveyor.

5. Accelerate the truck engine to operating speed, at least 2,000 revolutions per minute (rpm).
6. Count and record the number of shaft rpm at each spreader control setting.
7. Collect salt for several revolutions and divide by this number of turns to get the weight for one revolution. This can be accomplished at idle or very low engine rpm.
8. Multiply shaft speed (rpm) by the discharge per revolution (lbs) to get discharge rate (lbs/min), then divide the discharge rate by the planned vehicle travel speed (miles/min).

Example Calculation:

Measured parameters
Determine the discharge rate (lbs/mile) for:

- Shaft rotation speed = 30 rpm
- Weight of salt collected in a single revolution = 7 lbs
- Planned vehicle travel speed = 20 miles/hour (mph) = 0.33 miles/min

Calculations

- Discharge rate (lbs/min) = [30 rpm] x [7 lbs/revolution] = 210 lbs/min.
- Discharge rate (lbs/mile) = [210 lbs/min] / [0.33 mile/min] = 630 lbs/mile at 30 rpm.
- The above two calculations can be repeated for other spreader control settings.

II. Automatic Control Solids Spreader Calibration

Automatic controls come with factory calibration cards that indicate the proper rate of spread for each setting. However, when there is a need to check the calibration of the automatic controls, the following procedure can be used, which consists of collecting and measuring the material discharged over a known distance.

Equipment needed:

- Scale for weighing
- Clean canvas bag or other heavy-duty sack to collect material
- Cone, signpost, spray paint, or other visible object to mark specified distances
- Calculator

Calibration steps:

1. Remove or turn off the spinner.
2. Set the auger on a given number, such as No. 2.
3. Tie the canvas bag under the discharge chute.

4. Mark a known or measured distance, such as 100 or 1,000 feet. Note the trade-off: an easier, more manageable quantity of salt is collected in 100 feet, but the calibration may be more accurate if collected over 1,000 feet.
5. Drive that distance with the spreader operating at a constant speed.
6. Weigh the salt collected in the canvas bag.
7. Multiply weight of salt by 5.28 (in case of 1,000 feet) or 52.8 (in case of 100 feet).

This will be the amount of salt discharged per mile, which remains constant regardless of speed, but a calibration check must be done for each control setting.

Example Calculation:

Measured parameters

Determine the discharge rate (lbs/mile) for:

- Auger setting = No. 2
- Distance traveled = 1,000 feet
- Weight of salt collected = 120 lbs

Calculations

- Discharge rate (lbs/mile) = [120 lbs] x [5.28 (converts from 1,000 feet to 1 mile)] = 634 lbs/min at Auger Setting No. 2.
- The above calculation can be repeated at other auger settings.

III. Liquid Spreader Calibration

Liquid calibration checks are similar in concept to solid calibration checks. To avoid having to work with liquid deicing or anti-icing solutions, liquid calibration can be performed using water instead.

Equipment needed:

- Clean 5-gallon bucket, marked in 0.5 gallon intervals
- Stopwatch (or a watch with a second hand)
- Calculator

Calibration steps:

1. Fill the storage tank about half full.
2. Start the pump and let it run for a few minutes. Record the pressure. Spray some water to ensure that all nozzles are working properly and equally.

3. With the pump on, measure the amount of time required to collect a known volume of water (i.e., 1 gallon, 5 gallons). If the time is measured in seconds, convert to minutes.
4. Divide the volume collected by the measured time and then multiply this value by the total number of nozzles on the spray bar.

The following equation can be used to determine (or confirm) the correct truck application speed (for a given application rate).

$$AS = \frac{NFR \times 60\,min}{AR}$$

where:

AS = Application speed to be driven by the truck (mph)

NFR = Nozzle flow rate in gallons per minute (gpm), calculated as:
= [volume collected (gal)] / [measured time (min)] x [number of nozzles on the spray bar]

AR = Application rate (gallons per mile, g/mi)

Example Calculation:

<u>Measured parameters</u>
Determine the truck application speed (mph) for:

- Time to collect 1 gallon = 30 seconds = 0.5 minutes
- Number of nozzles on the spray bar = 3
- Application rate (desired) = 40 g/mi

<u>Calculations</u>

- NFR = [1/0.5] x [2] x [3] = 12 gpm

$$AS = \frac{[12\,gpm] \times [60\,min]}{[40\,g/mi]} = 18\,mph$$

Based on the calculation, the operator should maintain the truck at 18 mph to apply 40 g/mi of liquid deicing or anti-icing solution.

APPENDIX B

PROCUREMENT OF CHEMICAL ADDITIVES AND ABRASIVES

PROCUREMENT OF CHEMICAL ADDITIVES AND ABRASIVES

Chemical additives and abrasives used for winter storm management of ADOT roadways are acquired through ADOT Procurement. Contracts with vendors typically last 12 months and may be extended for supplemental periods of up to a maximum of 48 months based on a review of the products, vendors, and contracts. Often, multiple chemicals are combined into a single solicitation and each chemical may be awarded to one or more vendors, depending on the solicitation specifications and contract requirements. Procurement of new products or those not under contract requires development of a bid solicitation that includes specific environmental, health, and safety requirements. Some of these requirements include meeting the standards and specifications set forth by the Pacific Northwest Snowfighters (PNS) Association. Acceptable products must be qualified by PNS and approved ADOT.

The PNS is comprised of representatives from transportation agencies in Washington, Oregon, Montana, Idaho, and the Canadian province of British Columbia. The committee was formed to develop specifications for chemicals used in snow and ice control and includes experts in the fields of chemistry, the environment, maintenance operations and management, law, public affairs, and purchasing. Through development of these specifications, PNS helps to maintain a balance between minimizing environmental impact and providing a safe and mobile transportation system during snow and ice events, while taking into consideration budgetary and product performance needs.

PNS specifications for deicing chemicals require that trace constituents do not exceed the following concentration limits:

Constituent	Maximum Concentration (ppm)
Arsenic (As)	5.00
Barium (Ba)	100.00
Cadmium (Cd)	0.20
Chromium (Cr)	1.00
Copper (Cu)	1.00
Lead (Pb)	1.00
Mercury (Hg)	0.05
Selenium (Se)	5.00
Zinc (Zn)	10.00
Phosphorus (P)	2,500.00
Cyanide (CN)	0.20

Sources: a) 2010 PNS Snow and Ice Control Chemical Products Specifications and Test Protocols for the PNS Association of British Columbia, Idaho, Montana, Oregon, and Washington.

Corrosion inhibited products must also meet standards set forth by PNS (which includes the National Association of Corrosion Engineers standard for chemical product testing) and nutrient contents and chemical toxicity are taken into consideration.

In addition to the development of specifications, PNS has developed a list of qualified products (including the manufacturer) that meet the association specifications. This list is included as **Appendix B-1**. ADOT has awarded contracts to vendors for supply of PNS-qualified products. WSM chemicals are currently provided to ADOT through contracts with EnviroTech Services, Inc. and GMCO Corporation. **Appendix B-2** details the vendor name, product name, chemical name, and trace constituents.

Miller Mining, Inc. is under contract with ADOT to provide cinders and cinder fines. Cinders must meet ADOT Specification 1 and cinder fines must meet ADOT Specification 3. Cinders and cinder fines must be black in color and meet the following specifications, in addition to ADOT Standard Specifications for Road and Bridge Construction:

Specification	Type	Sieve Size	Percent Passing
1	Cinders	½”	100%
1	Cinders	#8	5-25%
3	Cinder Fines	No.4	100%
3	Cinder Fines	No. 200	2-8%

ATTACHMENT B-1

PACIFIC NORTHWEST SNOWFIGHTERS (PNS) QUALIFIED PRODUCTS LIST

Pacific Northwest Snow Fighters (PNS) Qualified Product List - PRODUCTS
Date of Listing: September 19, 2013

Category 1 - Corrosion Inhibited Liquid Magnesium Chloride

Product Name	Manufacturer	Corrosion Rate % Effectiveness	% Concentration	Date Approved
Magnum*	America West	17	29%	5/19/1998
Iceban 200*	Earth Friendly Chem.	8.4	26%	8/15/2002
Meltdown - Shield LSW*	Envirotech Services Inc.	23.5	30%	10/8/2002
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
Meltdown Wendover AP	Envirotech Services Inc.	25.9	29%	6/22/2005
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

Note-Iceban 200 was formerly Iceban Performance Plus M.
Those products marked with an asterisk (*) indicate 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
Calcium Chloride with Boost	America West	12.6	32%	6/5/2006
Road Guard Plus	Tiger Calcium Services	16	25%	6/5/2006

**Product has been re-qualified.
Those products marked with an asterisk (*) indicate that the stratification can be seen and agitation is required.

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	SPL	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

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

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
ESB	America West	25.4	19.2/2.6(2)	2/6/2013
Beet Heet Severe	K-Tech Specialty Coatings	21.1	15.3/5.4(3)	7/13/2011

1 - 20% NaCl and 2% $CaCl_2$

2- 19.2% NaCl and 2.6% $CaCl_2$

3 - 15.3% NaCl and 5.4% $CaCl_2$

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
ThermaPoint IB 7/93	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 (*) indicate that the stratification can be seen and agitation is required.

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(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

1 - 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 - Potassium Acetate
5 - 15% 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 pre-wet material to solid salt and 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% .

Those products marked with an asterisk (*) indicates that the stratification can be seen and agitation is required.

Pacific Northwest Snow Fighters (PNS) Qualified Product List - INHIBITORS
Date of Listing: September 19, 2013

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

Product Name	Manufacturer	% NaCl	% Additive	Class	% Effectiveness	Date Approved
ArtiClear CI Plus	North American Salt	21.2	5	1	21.3	12/3/2010
Watershed CI	Rivertop Renewables	22.1	5	1	23.2	3/21/2012

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	19.2	2.6	20	I / 2	25.4	2/6/2013

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

ATTACHMENT B-2

ADOT WINTER STORM MANAGEMENT CHEMICALS

ADOT Winter Storm Management Chemicals					
Distributor[1]	**Product Name[1]**	**Chemical Name**	**Trace Constituents**	**PNS Qualified Product?**	**Recommended Application Rates (and References)**
Envirotech Services, Inc.	Ice Slicer RS	Complex Chloride - Sodium Chloride, Potassium Chloride, Magnesium Chloride	Sulphur Iron Iodine Zinc Copper Manganese Phosphorus 60+ Trace Minerals and Micronutrients (Other)	Yes	No application rate specified. References: www.envirotechservices.com/products/display.php?id=65 www.iceslicer.com
Envirotech Services, Inc.	Corrosion Inhibited MeltDown Liquid with AP	Corrosion Inhibited Liquid Magnesium Chloride	Exact constituents were not provided. Envirotech Services reports that chemicals meet PNS standards.	Yes	No application rate specified. References: www.envirotechservices.com/docs/pdf/products/Meltdown_Liquid_Brochure.pdf
Envirotech Services, Inc.	Caliber M-1000 AP	Enhanced and Corrosion Inhibited Magnesium Chloride Solution	Barium Cyanide Lead Zinc Phosphates All other constituents measured were below the minimum detection limit	Yes	Caliber M1000 is specifically designed for anti-icing, direct application deicing, frost prevention, and/or prewetting of solids: <u>Anti-icing operations</u> - application rates of 20 -30 gallons per lane mile are typical (40 gallons per lane mile should be considered the maximum in any anti-icing situation). <u>Direct application deicing</u> - 40-60 gallon per lane mile applications are used. <u>Frost prevention</u> - application rates of 15-20 gallons per lane mile are employed. These rates can vary depending upon storm conditions and service level goals. <u>Prewetting agent</u> - Caliber M1000 can be used at rates from 5-15 gallons per ton of substrate, depending upon the solid used and the performance objective. References: www.envirotechservices.com/products/display.php?id=18 www.anti-icers.com/images/m1000nl.pdf
Envirotech Services, Inc.	APEX	Magnesium Chloride Solution plus Proprietary Additive	Exact constituents were not provided. Envirotech Services reports that chemicals meet PNS standards.	Yes	No application rate specified. Reference: www.envirotechservices.com/products/display.php?id=17
GMCO Corporation	FreezeGuard $MgCl_2$	Corrosion Inhibited Liquid Magnesium Chloride	Arsenic Zinc Ammonia Phosphate All other constituents measured were below the minimum detection limit	Yes	No application rate specified. References: www.gmcocorp.com/deicing.htm http://nasalt.com/products/magchloride/freezgard/freezgard.htm
GMCO Corporation	RapidThaw (Ice Slicer Equivalent)	Complex Chloride - Sodium Chloride, Potassium Chloride, Magnesium Chloride	Arsenic Barium Copper Zinc Total Phosphate Cyanide All other constituents measured were below the minimum detection limit	No	150 lbs per lane mile Reference: www.gmcocorp.com/deicing.htm
GMCO Corporation	Road Salt[2]	Sodium Chloride	Iron, Magnesium, and Potassium not to exceed 5.0 percent	N/A	No application rate specified. Reference: www.gmcocorp.com/deicing.htm

[1]Trade or manufacturer names that appear herein are cited only as examples of manufacturer products used by ADOT currently or previously. ADOT does not endorse individual products or manufacturers.
[2]Sodium Ferrocyanide (YPS) is used as an anti-caking agent.

APPENDIX C

STATISTICAL ANALYSIS METHODOLOGIES

Statistical Analysis

WSM sampling data, once analyzed, should be run through a series of statistical analyses to make useful correlations between samples, time, and data. The following statistical methods are recommended.

Control Charts and Trend Analysis: Control charts provide a basic, graphical method for detecting inconsistencies or trends in data. The graphs are easily maintained and can provide a variety of information for subsequent data analysis or quick response. Control charts are based on time-series plots of raw data (i.e., a simple plot of the data against time) as they are acquired. Various control limits or action response thresholds may also be plotted on the graphs. For the AMP, these limits should include the mean and maximum value for that site (if available) and a toxicity threshold value (once established) for the parameter (in this case, sodium). Control charts should be established for each site. The time increments should be years, with data plotted independently on the same plot. After five-years of data collection, a five-year running mean of the data (i.e., the mean of the current year and the four previous years) should also be plotted.

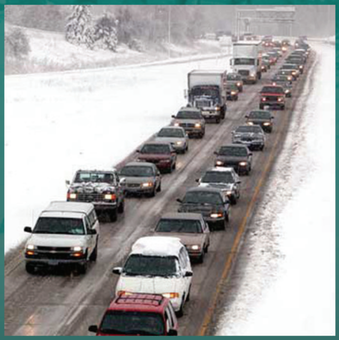
Results from the monitoring sites showed wide variations in soil data between years; however, this may be due to the collection of a single sample from each site, reflecting both spatial and temporal variability. The use of a three-sample composite in the AMP should reduce some of the variability found in the monitoring sites, making the temporal variability more discernible in the control charts. The running means also eliminate some of the “noise” in the data, again making temporal trends in the data more discernible. Trend analysis can be applied to these data to statistically determine whether trends (increasing, decreasing, or fluctuating) exist in the data. Gilbert (1987) provides a detailed description of these techniques and their application to environmental monitoring data.

Regression and Correlation Analysis: Regression analysis techniques are used to evaluate the relationship between two variables and can be used to establish a quantitative model for predicting the value of one (the dependent variable) from the measured value of the other (the independent variable). For example, the question as to whether the amount of NaCl applied to a roadway over the course of a winter season will result in predictable changes in the measured soil parameters related to NaCl (e.g., sodium and chloride concentrations, Sodium Absorption Ratio [SAR], Exchangeable Sodium Percentage [ESP]) can be addressed by regression analyses between the chemical application data and each of the potentially affected parameters. Other possible relationships that can be explored through the application of regression analysis would be the relationship between the concentration of a particular element in soil and its concentration in plant tissues; between distance from the roadway and the soil concentration; and between the salt concentration of a soil and other soil parameters such as potential of hydrogen (pH), electrical conductivity (EC), and total organic carbon (TOC). In general, regression analysis is applied to data where there is a known or reasonably expected cause-and-effect relationship between the selected independent and dependent variables. If a more complex relationship is suspected, such that there may be two or more independent variables affecting the value of the dependent variable, multiple regression techniques may be required to fully evaluate the relationships. A possible example of this would be the relationship between both the chemical application rate and the amount of roadway traffic on the lateral distribution of the chemical in soil. The simplest form of a regression relationship is a straight line (with a mathematical model of the form Y = mX + b, where Y is the dependent variable, X is the independent variable, and m and b are the slope and y-intercept of the line, respectively). Regression analysis that assumes linearity is referred to as linear regression. Nonlinear relationships of raw data can sometimes be linearized by a mathematical transformation of one or both variables (a logarithmic transformation is often used for this purpose).

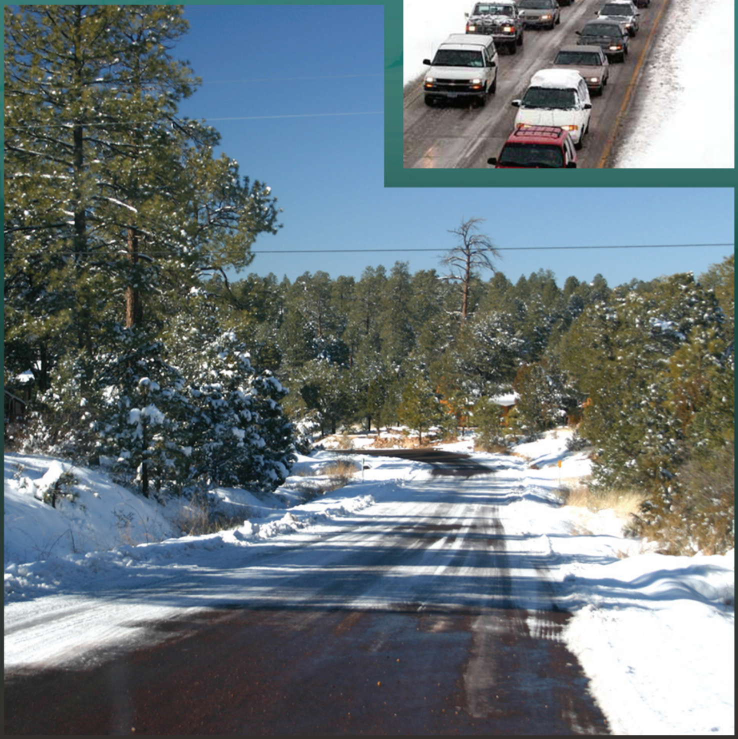
In contrast to regression analysis, correlation analysis is used for the evaluation of the relationship between two variables when it is unlikely that there is a cause-and-effect relationship between them. A simple example would be the relationship between sodium and chloride ion concentrations in the soil. Because sodium and chloride are typically applied together as NaCl salt, it can be expected that their concentrations in soil would vary together, yet one is not the cause of the other. Such a relationship can be elucidated quantitatively through a correlation analysis. As data are accumulated in the AMP, it is expected that several such relationships will present themselves for evaluation. Simple linear regression and correlation analyses can be performed using Microsoft Excel® or equivalent software packages. For more complex analyses (e.g., multiple regression), statistical software packages are recommended.

ANOVA and Equivalent Methods: ANOVA is a hypothesis-testing technique that is used to test for statistically-significant differences in the means of a response variable between multiple treatment groups. For example, a question as to whether the mean sodium concentrations from three distances from the road (sample locations A, B, and C) are statistically different can be addressed through ANOVA, provided certain data requirements are met. The most critical of these is having a sufficient number of data points in each treatment group (in this case, the three distances, A, B, and C) to validly conduct the test. It is recommended that a minimum of five data points per group be available for performing ANOVA. Therefore, this comparison could not be made for a single AMP site until five-years of data collection has been achieved. However, the comparison could be made with the combined data from five or more separate AMP sites provided they are equivalent in general characteristics of chemical application, traffic, soil, etc.

A second critical requirement is that the underlying data in each group are normally distributed (i.e., ANOVA is a parametric hypothesis-testing technique). Tests for normality are often included in statistical software packages; however, the EPA's ProUCL software (available online at *www.epa.gov/esd/tsc/software.htm*) can be used for testing for either normality or lognormality in a data set. If the data are lognormally distributed, the ANOVA can be performed on the log-transformed data. If the data (or transformed data) do not meet the requirement for normality, an equivalent, nonparametric test (e.g., the Kruskal-Wallis rank test) should be used. It should be noted that for comparisons between only two groups (e.g., differences between distance A and B or differences between surface and subsurface soil), the ANOVA reduces to the Student's t-test (to be used if the data are normally distributed) and the Kruskal-Wallis rank test reduces to the Mann-Whitney U-test (or equivalently, the Wilcoxon rank sum test).




ROAD




WATCH
FOR
ICE