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# Development of ADOT Application Rate Guidelines for Winter Storm Management of Chemical Additives through an Ambient Monitoring System

Arizona Department of Transportation Research Center

# Development of ADOT Application Rate Guidelines for Winter Storm Management of Chemical Additives through an Ambient Monitoring System

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16. Abstract

The Arizona Department of Transportation (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 roads. A common practice is the application of anti-icing and deicing chemicals, primarily sodium chloride (salt). ADOT's Winter Storm Management Operations Manual (WSMOM) presents guidelines for the application of anti-icing and deicing chemical based on specific storm events and roadway conditions. Sodium and chloride can be dispersed to areas adjacent to roadways though melting snow and ice and by vehicle splash and spray. Upon reaching vegetation and soil, these compounds can negatively impact the environment. To evaluate the relationship between salt applications and potential impacts to soil and vegetation, data from winter storm management activities (frequency of application, quantity of salt applied, and adherence to ADOT WSMOM guidelines) were compared to sodium and chloride concentrations in soil and vegetation samples collected at varying distances from the roadway. Data collection and review included 16 sites along State Route 260 and U.S. Routes 180 and 191, all in ADOT's Globe District. Analyses of soil and vegetation samples show that sodium concentrations are greatest nearest the roadway and decrease with increasing distance from the roadway. There is no evidence that sodium concentrations in the soil exceed levels considered tolerable for vegetation, nor is there a significant seasonal difference between fall readings and spring readings of sodium and chloride concentrations in soil and vegetation. Additionally, sodium concentrations in soil samples did not appear to have a statistically significant impact on the level of sodium in vegetation samples. Therefore, it cannot be concluded that sodium concentrations in soil are directly impacting sodium concentration in vegetation near the roadway. There is no evidence to support that ADOT should deviate from its current chemical application rate guidelines.

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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oF$ | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | $^oC$ |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oC$ | Celsius | 1.8C+32 | Fahrenheit | $^oF$ |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ADOT | Arizona Department of Transportation |
| ANOVA | analysis of variance |
| AVL | Automatic Vehicle Location |
| bgs | below ground surface |
| BMP | best management practices |
| BMS | biological monitoring site(s) |
| $CaCl_2$ | calcium chloride |
| CDOT | Colorado Department of Transportation |
| CMA | calcium magnesium acetate |
| DOT | Department of Transportation |
| dS/m | deciSiemans per meter |
| ° F | degrees Fahrenheit |
| FHWA | Federal Highway Administration |
| ft | foot, feet |
| GPS or gps | geographic positioning system |
| IDOT | Idaho Department of Transportation |
| kg | kilograms |
| lb/lane-mile | pounds per lane-mile |
| LOS | Level of Service |
| MDOT | Montana Department of Transportation |
| mg | milligrams |
| $MgCl_2$ | magnesium chloride |
| mg/kg | milligrams per kilogram |
| NaCl | sodium chloride |
| NCHRP | National Cooperative Highway Research Program |
| NDDOT | North Dakota Department of Transportation |
| ppm | parts per million |
| ROW | right-of-way |
| RWIS | Road Weather Information System |
| SAR | sodium adsorption ratio |
| SDDOT | South Dakota Department of Transportation |
| SOV | source of variation |
| TAPER | Temperature, Application rate, Product used, Event duration and precipitation amount, and Results |
| U.S. | United States or United States Route |
| WASHTO | Western Association of State Highway and Transportation Officials |
| WSMOM | Winter Storm Management Operations Manual |
| WSM | winter storm management |
| WSDOT | Washington Department of Transportation |
| WSMP | Winter Storm Management Program |

# EXECUTIVE SUMMARY

The Arizona Department of Transportation (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 roads. A common practice is the application of anti-icing and deicing chemicals, primarily sodium chloride (salt) in both brine solution and solid form. ADOT's Winter Storm Management Operations Manual (WSMOM) presents guidelines for the application of anti-icing and deicing chemicals based on specific storm events and roadway conditions (ADOT 2008b). Upon reaching vegetation and soil, salt compounds can negatively impact the environment. Sodium and chloride can be dispersed to areas adjacent to roadways though melting snow and ice, by vehicle splash and spray, or through misapplication.

To evaluate the relationship between salt applications and potential impacts to soil and vegetation, data from winter storm management (WSM) activities (frequency of application, quantity of salt applied, and adherence to ADOT WSMOM guidelines) were compared to sodium and chloride concentrations in soil and vegetation samples collected at varying distances from the roadway. Data collection and review included 16 sites along State Route 260 and U.S. Routes 180 and 191, all within ADOT's Globe District.

**RECOMMENDATIONS**

Assuming that a consultant performs future monitoring, there will be annual costs as outlined in Chapter 6. Should the monitoring be continued or repeated in other districts in the future, changes could be made to increase the quality of the data and efficiency of the monitoring program. Recommended changes include:

- Select monitoring sites that represent a variety of vegetation types—forest, shrubland, grassland—and levels of priority for WSM applications.
- Monitor sites that show probable indications of WSM impacts to vegetation.
- Reduce the sampling interval of vegetation and soil to once per year, preferably in the spring.
- Reduce the number of sampling locations and intervals at each monitoring site to two: one sample between 25 and 50 feet (ft) from the edge of the pavement to be tested annually, and one sample more than 100 ft from the edge of the pavement to be tested once every two years.
- Analyze soil and vegetation samples only for sodium concentrations.
- Perform semiannual roadside visual surveys to identify areas showing indications of WSM impacts, and plot these areas on maps that show the total amount of chemical application. Collect samples of soil and vegetation from areas showing the highest degree of impact for comparison with biological monitoring site (BMS) results.
- Once baseline data have been established for trees showing no impact from WSM activities at a BMS that includes stressed vegetation, sample only vegetation showing signs of stress at that BMS.

## CONCLUSION

Analyses of soil and vegetation samples show that while sodium concentrations are greatest nearest the roadway and decrease with increasing distance from the roadway, there is no evidence that sodium concentrations in soil exceed levels considered tolerable for vegetation, nor is there a significant difference in sodium and chloride concentrations in soil and vegetation between fall and spring. Additionally, sodium concentrations in soil samples did not appear to have a statistically significant correlation to the level of sodium in vegetation samples. Therefore, it cannot be concluded that sodium concentrations in soil are directly impacting sodium concentrations in vegetation near the roadway. Though there currently is no supporting evidence to suggest that ADOT should deviate from its current chemical application rate guidelines, ADOT may consider performing the scaled-down monitoring in select locations in the future where needed.

# CHAPTER 1. INTRODUCTION

The mission of the Arizona Department of Transportation (ADOT) is "…to provide a safe, efficient, cost-effective transportation system..." To do so requires planning, building, operating, maintaining, and improving a complex highway system in one of the fastest growing areas in the country. ADOT is committed to enhancing the sustainability of the community and environment while ensuring accountability for its actions and upholding the highest technical and ethical standards. A prime goal of ADOT operational standards is to ensure a safe system of transportation year-round, while minimizing impact on the surrounding environment. Maintaining highway safety is a priority and includes the management of roadway conditions during winter storm conditions.

Newly available technology and resources for chemical treatment for anti-icing and deicing roadways provide departments of transportation (DOTs) with an expansive toolbox from which to choose when and how best to combat winter storm precipitation. The primary tools used by DOTs nationwide include physically removing snow and ice through plowing, and chemically treating roadway surfaces. The latter includes the use of "road salt" or "salt," a collective name that includes sodium chloride, magnesium chloride, calcium chloride, and potassium chloride. Other non-salt-based materials gaining traction in other states include calcium magnesium acetate (CMA), potassium acetate, and agricultural by-products.

Road salt is used as both an anti-icer and a deicer. Anti-icing involves applying a brine solution or pre-wetted solid chemicals to the pavement surface prior to the onset of a winter storm to provide a barrier that prevents snow and ice from forming a bond with the pavement. This makes mechanical removal of snow and ice quicker and more efficient. In contrast, deicing involves treating the roadway surface to melt snow and ice after they have accumulated and prior to mechanical removal. Deicing does not prevent snow and ice from bonding with pavement surfaces.

Research has shown that winter storm management (WSM) strategies that focus on anti-icing and physical removal can be more effective than those that rely more on deicing. Benefits include the reduction of chemicals used, improved roadway conditions, and overall lower costs (NCHRP 2007). Regardless of the method chosen by a DOT, the selection of the proper application rate is important to obtain the desired outcome in the most economically sustainable way.

## PURPOSE OF STUDY

This study examines several aspects of ADOT's WSM anti-icing and deicing efforts in order to solve four key problems:

1. Recommended initial application rate guidelines.

   Anti-icing and deicing chemicals should be applied at a rate that is sufficient to effectively treat the accumulation of snow and ice on road surfaces but at the same time is economical and minimizes stress on the surrounding environment. Application rates typically are dictated by chemical selection and a variety of environmental factors such as air and pavement temperatures, precipitation type, and rate of accumulation.

2. Implementation of a WSM recordkeeping system.

   Tracking of winter storm events and response activities is imperative to measuring the effectiveness of the WSM program. Knowing how, when, and what type of data are collected is fundamental in implementing and evaluating a recordkeeping system.

3. Analysis of data collected to mitigate environmental impacts.

   The goal of the data collection, how data will be used, and what actionable items are likely to stem from these data must be considered during development of the data collection process.

4. Identification of trends indicating accumulation of chemicals along a roadway.

   Evaluate whether there is evidence of salt accumulation in soil and vegetation along ADOT corridors that receive chemical anti-icing and deicing treatments. If evidence does exist, identify key relationships between chemical usage (type, application rate) and accumulation in soil and vegetation.

**STUDY AREA**

The area chosen for this study lies entirely within the ADOT Globe District (Figure 1). Physiographic characteristics and roads within the Globe District are representative of all roads within the state that are subjected to winter storm-related conditions. Sixteen individual sites within the Globe District were chosen for detailed analysis, correlated to a unique, previously established ADOT biological monitoring site (BMS). These sites are described in detail in Appendix A and are mapped in detail in Appendix B.

ADOT replaced its Biological Monitoring Sites program with a more comprehensive Ambient Monitoring program and has dropped the usage of the term BMS. However, the term was still in use as of this study's initiation, and sites in the field are still identified by BMS signage; therefore, this study will reference the monitoring sites using the previous BMS naming convention.

Weather data were monitored using online websites, including www.weather.com and www.weatherunderground.com, and locations that these websites monitored were as closely correlated to BMS as possible; however, these data proved to be problematic, as will be discussed.

**ADOT WINTER STORM POLICIES AND PROCEDURES**

Current ADOT procedures for managing winter storm conditions include the application of road salt as anti-icing and deicing practices. The applications are based on several factors that include categorized level of service (LOS), temperature ranges and trends, pavement conditions, and other such factors. In 2008, ADOT finalized the Winter Storm Management of Arizona State Highways Operation Manual (WSMOM) which serves as a standard for ADOT roadway management during winter conditions. Among other things, detailed application rates are outlined in the manual. The application rates are based on

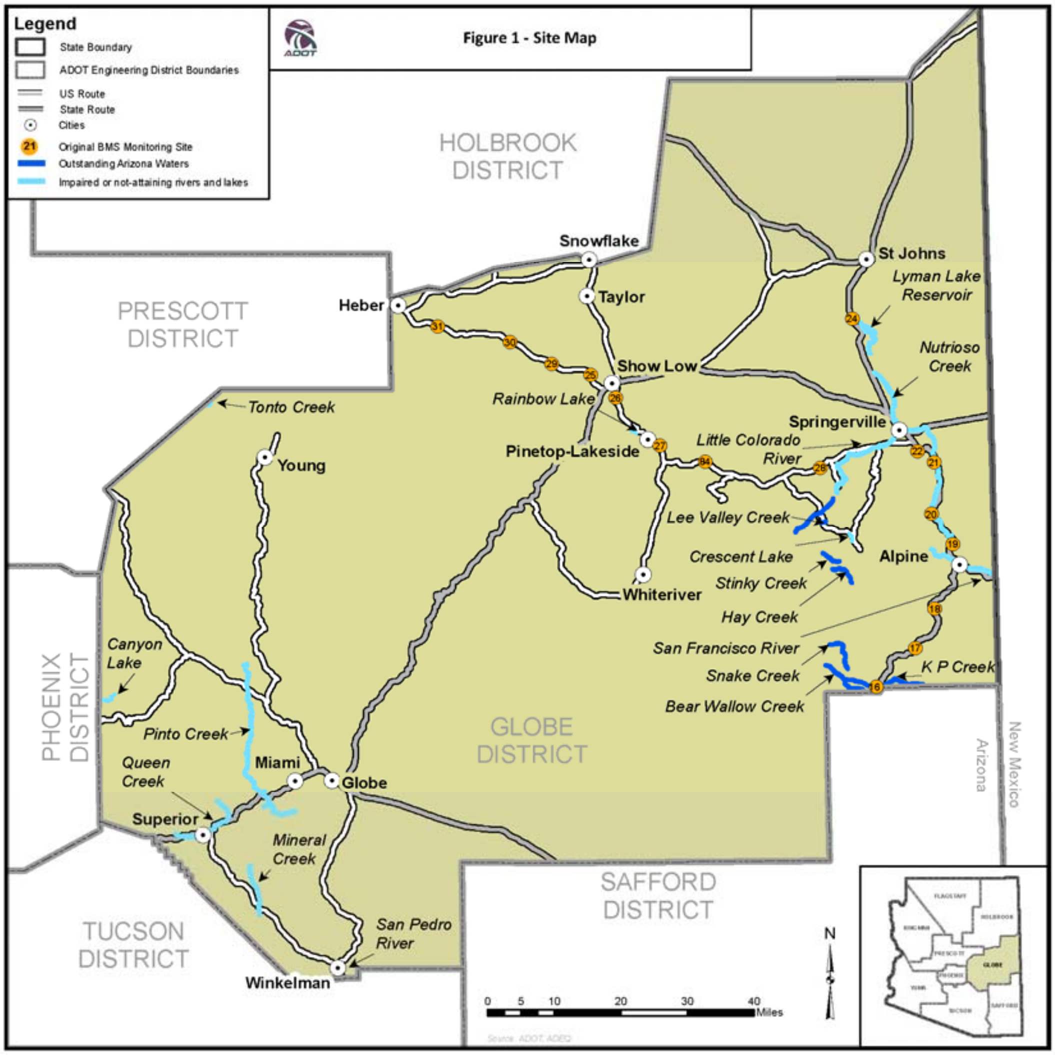


**Figure 1. Map of Study Sites in ADOT Globe District**

the combined guidance from two studies: one produced by the Federal Highway Administration (FHWA) in 1996 that outlines a basis for recommended salt application rates (FHWA 1996), and one by the National Cooperative Highway Research Program (NCHRP) in 2004 that provided guidelines for materials and methods in relation to snow and ice control (NCHRP 2004). The guidance bases recommended application rates on pavement temperature and trend, precipitation type and intensity, roadway conditions, and timing of application (before versus after onset of a winter storm). Additional considerations are included to enable the decision maker to identify an ideal application rate from a range outlined within the guidelines.

**ENVIRONMENTAL CONCERNS**

The use of chemical anti-icing, deicing, and pre-wetting control measures on roadways has become the preferred method of promoting safe motor vehicle travel during winter weather. However, the use of road salt comes at a cost. Studies conducted in other states show that soil, vegetation, water, infrastructure, and human health are all adversely affected by the use of road salt. Road salt has been shown to leach into soil adjacent to roadways, where the ions may accumulate and may eventually become toxic to organisms and plants growing in these soils (Cunningham et al. 2008). Road salt reaching water bodies, especially those with long turnover times, can deplete oxygen and accelerate eutrophication in small lakes and streams, degrading water quality and harming aquatic species (Public Sector Consultants, Inc., unpublished data, December 1993). Road salt annually causes significant damage to vehicles, bridge decks, and road surfaces. For example, Michigan may spend $5 billion over the next ten years on depreciation of its infrastructure due to salt-induced corrosion (Cornwell 2011). Road salt contaminants in drinking water supplies, especially sodium chloride (NaCl), have been demonstrated to pose adverse effects on human health (Siegel 2007).

To address public concern over potential environmental and socioeconomic impacts from its use of road salts as an anti-icer and deicer, ADOT initiated a formal assessment of its Winter Storm Management Program (WSMP) in 2001. The resulting draft environmental assessment was released in 2004 for public comment (ADOT 2004) ADOT renewed its review process of its WSMP in 2007, leading to the release of its environmental overview in August 2008 (ADOT 2008a). ADOT released a revised WSMOM in October 2008 to reflect the findings of the environmental overview and provide guidance regarding the use of appropriate WSM techniques (ADOT 2008b).

# CHAPTER 2. BACKGROUND

DOTs use a wide variety of strategies to effectively maintain roadways during the winter. These strategies include a number of factors: LOS, infrastructure and environmental impacts, varying weather conditions, and costs. DOTs have historically relied heavily on the use of road salt, both as deicing and anti-icing agents, to keep roadways clear of ice and snow. As part of this study, a review was conducted of the practices and policies of DOTs in other western states, and their best management practices (BMPs) for snow and ice removal. This review focused on two areas:

1. Chemical application guidelines currently being used by State DOTs belonging to the Western Association of State Highway and Transportation Officials (WASHTO).
2. Studies identifying BMPs and procedures for the selection and application of chemicals in a manner that minimizes negative impacts to the surrounding environment.

Results of the review are presented in the following sections.

## WESTERN REGION DOT GUIDELINES

A review of the latest chemical application guidance being implemented by WASHTO members was performed by searching the subject DOT websites, performing broader Internet searches, and contacting the DOTs directly by phone. The literature search provided relevant documentation for 12 of the 18 members. The six members for which relevant literature was not available are noted with an asterisk in Table 1.

**Table 1. WASHTO Member DOTs Selected for Literature Review**

| | | |
|---|---|---|
| Washington | Montana | South Dakota |
| Oregon* | Wyoming* | Nebraska |
| California | Utah | Colorado |
| Idaho | Arizona | New Mexico* |
| Nevada* | North Dakota | Oklahoma |
| Alaska* | Texas | Hawaii* |
| * No significant WSM documentation available . | | |

The review of state DOT guidelines for chemical applications identified several consistent practices that either were used by a majority of DOTs or were notable in their potential for providing a more accurate application of chemicals. Specific practices include the following.

### Level of Service

A common approach among WSM programs is the development of a LOS system for the state transportation system. The LOS system assigns a level of priority and treatment method for individual roadway segments depending on typical traffic patterns, population, and other factors. The LOS system identifies the priority in which roadway segments are treated and identifies those segments of roadway where chemical treatment during winter storm events is considered an option. Identifying priority roadways eliminates chemical treatment of roadways that are not considered vital, thus reducing the overall volume of chemicals applied throughout a DOT's jurisdiction.

### District Level Implementation

While winter storm policy and management guidance appears to have been consistently developed at high levels within the DOTs to provide a uniform plan for the entire state, the actual implementation of the policy typically is delegated to individual districts. Most DOT guidelines on WSM—and chemical applications specifically—indicated that specific decisions regarding application rates, timing of applications, the use of anti-icing agents, etc., should be refined at the local level. The primary intent of this approach is to let districts use their historical knowledge of site-specific weather and road conditions to make decisions about chemical application.

### Application Decision Matrix/Table

Several DOTs employed a decision matrix or table to provide guidance for when chemical application are appropriate and at what rates the chemicals should be applied. The guidance typically lists a number of factors, including:

- Level of service
- Temperature ranges and trends
- Pavement surface conditions
- Traffic conditions
- Precipitation types and intensities
- Chemical dilution potential
- Areas of shade/sun

While many DOTs rely on a matrix/table, the level of detail varies greatly. Selected DOT application guidance matrices/tables are presented in Appendix C, followed by a summary of notable chemical application guidelines for specific states.

## SUMMARY OF DOT GUIDELINES

### California Department of Transportation (Caltrans)

- Caltrans provides guidance for application of dry salt (sodium chloride), abrasives, and brine solution. The guidance, presented in tabular form, is based on air temperature, sun versus shade, and the intended action (prevention, removal, etc.). The table is presented in Appendix C (California Department of Transportation 2006).
- The guidance prescribes the use of a 25 percent salt brine solution to be applied with the application of abrasives.

- The guidance recommends that abrasives be applied at a rate of up to 1,000 pounds per lane-mile (lb/lane-mile) for normal roadways and up to 2,000 lb/lane-mile for roads with “super-elevations” or under unusual conditions.

**Washington Department of Transportation (WSDOT)**

WSDOT provides extensive guidance (presented in Appendix C) for making application decisions based on pavement temperature, pavement conditions, and traffic for the following specific weather events; WSDOT annually updates its statewide snow and ice plan and makes it available online (Washington Department of Transportation 2007):

- Black ice
- Freezing rain
- Frost
- Light snow
- Moderate or heavy snow
- Sleet
- Slush

The guidance provides:

- Detailed definitions of each weather event for which there is specific application guidance.
- Details for both an initial chemical application and subsequent maintenance actions (physical removal) and applications.
- Recommendations for applying magnesium chloride, calcium chloride, sodium chloride, and calcium magnesium acetate.

The guidance is based on FHWA studies.

**North Dakota Department of Transportation (NDDOT)**

- NDDOT provides guidance for physical removal and application rates based on five weather conditions that take into consideration temperature, precipitation type, and road surface conditions. The guidance is presented in Appendix C (North Dakota Department of Transportation 2012).
- Granular application recommendations are provided only as pounds of “salt.” Rates for specific dry chemicals are not provided.
- NDDOT provides recommendations for the application of potassium acetate solution for anti-icing. The guidance recommends that applications be based on the manufacturer’s specifications.

**South Dakota Department of Transportation (SDDOT)**

- SDDOT provides guidelines for the application of salt, salt brine, and liquid magnesium chloride by providing a range of product per lane-mile (e.g. 100 to 400 lb/lane-mile). The guidance is presented in Appendix C (South Dakota Department of Transportation 2010).
- The guidance provides application rates based on pavement temperature and weather conditions that are limited to either light snow or freezing rain.
- The guidance provides an application rate range based on factors that include pavement temperature and weather conditions.
- The guidance states that the maintenance supervisor or his/her designee has the discretion to select winter storm chemicals and adjust application guidance as needed, depending on specific weather events or road conditions.

**Idaho Department of Transportation (IDOT)**

- IDOT provides a general discussion of chemical applications, but no specific application rates are provided.
- IDOT recommends that maintenance managers determine specific application rates and frequency based on individual site conditions and historical information documented through TAPER (Temperature, Application rate, Product used, Event duration and precipitation amount, and Results) logs.

**Montana Department of Transportation (MDOT)**

- MDOT provides an outline of winter maintenance activities in the state DOT maintenance manual (Montana Department of Transportation 2002).
- The manual states that detailed application specifications can be developed through the use and review of TAPER logs and experience.
- MDOT has developed BMPs to protect environmentally sensitive areas. The BMPs are outlined in the *MDOT Maintenance Environmental Best Management Practices* (relevant sections of this document are presented in Appendix C).
- MDOT defines "environmentally sensitive areas" as those where highway maintenance may impact fish or fish habitat. BMPs for protecting these areas include:
    - Minimizing chemical applications within sensitive areas.
    - Applying magnesium chloride, alone or in combination with abrasives, within sensitive areas.
    - Employing physical barriers to prevent the discharge of winter storm chemicals into receiving waterways.
    - Maintaining an accurate inventory of environmentally sensitive areas.
    - Educating maintenance staff on water quality and fishery resource issues.

**Colorado Department of Transportation (CDOT)**

CDOT provides a general discussion of chemical applications, but no specific application rates are provided.

**BEST MANAGEMENT PRACTICES**

On the national level, research has identified practices and procedures for the selection and application of chemicals in a manner that minimizes negative impacts to the surrounding environment. Two particular studies were reviewed in detail to provide information for developing effective and environmentally sustainable winter storm maintenance procedures. The findings of these studies are summarized below.

Chapter Eight in *National Cooperative Highway Research Program: Project 25-25(04) – Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* (NCHRP 2004) provides practices for reducing the amount of road salts and other deicing chemicals used. Noteworthy items include:

- Benefits are seen in the transition to a program focused on anti-icing and physical removal rather than deicing. With timely application of anti-icing agents, the bond that develops between the roadway and precipitation (rain, snow, etc.) can be minimized or prevented, allowing for effective physical removal through plowing.
- Decisions on application should be based on pavement temperature conditions rather than air temperature conditions. This results in a better understanding of impending roadway conditions due to precipitation, whereas air temperatures do not provide the same level of information.
- The chemicals, application rates, and use of BMPs should be altered in areas known to be environmentally sensitive. Using alternative chemicals, reducing plow speeds, implementing physical barriers between roadways and critical environmental resources, and educating DOT staff can lessen impacts in environmentally sensitive areas.
- Precise applications can be ensured by using new application technologies, properly calibrating equipment, properly maintaining equipment, and following other best practices.
- Proper tracking of materials can be ensured through electronic material monitoring, which includes truck scales, Automatic Vehicle Location (AVL) systems, and TAPER logs.
- Established environmental performance measures reinforce the importance of environmental protection in developing and implementing an integrated WSM program. Such measures are not only beneficial to the roadside environment, but also tend to produce economic benefits by reducing excessive application or waste.
- Training programs on topics that include proper application methods, material handling, calibration techniques, recordkeeping, and DOT policies and procedures reinforce personnel familiarity with key aspects of WSM procedures and goals.

*National Cooperative Highway Research Program: Report 577 – Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts* (NCHRP 2007) identifies criteria for choosing appropriate chemicals to mitigate environmental impacts. In addition to calling for additional research into the issue, the study provides a generalized rating system (low, moderate, and high) for a chemical's impact on water quality, air quality, soil, vegetation, and animal life. The rating system provides a way to base chemical selection on known environmental issues or sensitive areas within a DOT's maintenance area. A decision tool was developed from the rating system to provide a basis for selecting chemicals according to weighted factors including cost, performance, environment, and corrosion. The tool assigns scores to the chemicals being evaluated that can be used to determine which chemicals should be chosen. Specific agency input regarding cost and performance is required.

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# CHAPTER 3. REVIEW OF CASE STUDIES

A number of studies have investigated impacts to roadside vegetation resulting from the use of salt for snow and ice removal. Some of the earliest studies were performed in the 1960s and focused on sugar maples in the northeastern United States. Some of these early studies determined that the most severe damage to foliage occurs on plants within 30 ft of the road (Holmes and Baker 1965; Lacasse and Rich 1964) and that plants that do not come into direct contact with sodium from salt spray are not injured as severely as plants that do (Holmes 1961). Many subsequent studies attempted to evaluate the primary mechanism for impacts to foliage and the distance from the road at which these impacts were noticeable. Barrick and Davidson (1980) and Sucoff et al. (1975) noted that salt spray injury is usually greater on the side of the plant that faces the road. Resource Concepts, Inc. (1990) noted that, although uptake of salts from the soil is most often invoked as the mechanism of salt movement from the environment into plants, foliage absorption of aerially deposited ions can cause significant leaf damage. Pederson and Fostad (1996) found that of the salt deposited on the road, 10 to 25 percent was spread through the air and was found within 30 ft of the road. Blomqvist (1999) reported that 90 percent of salt in roadside soil is detected within 40 ft of the road. Although researchers all agree that impacts of salt decline with distance from the roadway, the extent of the zone of influence is not clear, ranging from less than 10 ft (Pederson et al. 2000) to greater than 100 ft, with 30 to 50 ft reported as the mean values (Resource Concepts, Inc., unpublished data, 1990; Barker et al. 2003). Subsequent studies concluded that pine trees are the least tolerant species of trees with regard to salt damage (Scharpf and Srago 1974; Resource Concepts, Inc., unpublished data, 1990).

## LITERATURE REVIEW

Three of the studies reviewed were particularly pertinent to this research project because of their sampling and testing methodologies and, for the latter two, their focus on pine trees: Bryson and Barker (2002), Nowak et al. (2009), and Traecker and Ball (2011). The studies are summarized in the following subsections of this report.

### "Sodium Accumulation in Soils and Plants along Massachusetts Roadsides" (Bryson and Barker 2002)

Samples of soil and vegetation were collected from sites along Massachusetts roadsides that showed visible signs of salt damage to vegetation, and from sites that showed no visible signs of salt damage to vegetation. The soil samples were obtained at 5- to 10-ft increments perpendicular to the edge of the roadway up to a distance of 30 ft from the edge of the road. Each soil sample consisted of three sub-samples of soil obtained from a depth of 12 inches below ground surface (bgs) and thoroughly mixed to form one composite sample. The soil samples were analyzed for sodium content, pH, and electrical conductivity. Leaf samples were obtained both from vegetation that showed signs of salt damage and from healthy plants that showed no signs of salt damage. Vegetation that was sampled included both coniferous and deciduous trees and mixed grasses. Vegetative samples were analyzed for sodium content.

Analyses of laboratory results indicated that the concentration of sodium in the soil decreased as the distance from the road increased, with mean sodium concentrations ranging from 101 milligrams per kilogram (mg/kg) in samples taken 5 ft from the edge of the road to 16 mg/kg in samples taken 30 ft from the edge of the road. A marked decrease in sodium concentrations occurred beyond a distance of 15 ft, suggesting that most of the sodium in the soil was the result of salt spray. The pH of the soil decreased as the distance from the road increased, with sample results ranging from a mean of 7.6 units 5 ft from the edge of the road to a mean of 5.78 units 30 ft from the edge of the road. The electrical conductivity of the soil had a mean of 0.16 deciSiemans per meter (dS/m) at 5 ft from the edge of the road, increased to a mean of 0.23 dS/m at 15 ft, and then decreased to a mean of 0.12 dS/m at 30 ft.

Coniferous species, especially pines, appeared to be highly susceptible to salt damage. The damage to needles appeared as browning or burning and mainly occurred on the side of the tree facing the road. The average concentration of sodium in the needles of damaged pines was about 75 times greater than the average concentration of sodium in healthy needles. Samples of healthy pine needles averaged 28 mg/kg of sodium, compared to an average of 2,130 mg/kg in samples of damaged pine needles. The concentration of sodium in pine needles decreased as the distance of the tree from the road increased, ranging from a concentration of 3,356 mg/kg at a distance of 10 ft to a concentration of 1,513 mg/kg at a distance of 20 ft. Sumac showed widespread damage along the roadways; however, the concentration of sodium in leaves of severely damaged sumac and the leaves of healthy sumac did not vary greatly. This is likely because most of the damaged sumac leaves had fallen. The sodium concentration of sumac leaves decreased with distance from the road, ranging from a mean of 340 mg/kg at a distance of 10 ft to a mean of 150 mg/kg at a distance of 25 ft. Salt damage was evident on mountain laurel and spruce trees, but oak and maple species appeared to be salt tolerant. No damage was noted on any of the grasses, even in areas where salt damage was evident on other plant species.

The study concluded that the most severe cases of salt damage occurred in plants within 15 ft of the edge of the road and that the majority of the damage was caused by salt spray. Most of the damage to foliage was on the side of the tree facing the road. Deciduous species tended to be more tolerant to salt spray or soil-borne salt than coniferous species. The concentration of salt was greater in plants that exhibited damage than in plants that appeared to be healthy, regardless of species. Likewise, sodium levels in plant leaves decreased as the distance from the edge of the road increased, regardless of species.

The authors noted that high concentrations of salt in the soil can affect plant species in ways other than direct toxicity. High concentrations of sodium in the soil can reduce soil structure and have an adverse effect on the microenvironment of the rhizosphere (the narrow region of soil that is directly influenced by root secretions and associated soil microorganisms) by reducing oxygen to the roots and causing puddling of water on fine-textured soil. High sodium concentrations can affect the fertility of the soil by exchanging with available nutrients in the soil complex, leading to nutrient deficiencies and subsequent leaching of cations. When plants are stressed by low fertility, reduced oxygen at the roots, or damaged foliage, they can become susceptible to diseases.

**"Effects of Deicing Salts on Vegetation in the Lake Tahoe Basin – Draft" (Nowak et al. 2009)**

The Department of Natural Resources and Environmental Studies of the University of Nevada in Reno conducted a study on the effects of deicing on vegetation in the Lake Tahoe Basin along the border between California and Nevada. Vegetation in the basin is dominated by coniferous trees consisting of Jeffrey pine, lodgepole pine, white fir, and red fir. The study was conducted over a two-year period in 2006 and 2007. As part of the study, 216 plots were established in three types of areas: 1) along roads in urban areas, 2) along roads in rural areas, and 3) in control plots more than 1,000 ft from the edge of highways and plowed roads. Each plot measured 100 ft by 100 ft, encompassing an area of 0.23 acres. Where possible, plots were placed directly across from each other on both the upslope and downslope sides of the roadway for direct comparison of salt accumulation and damage. Baselines were established for each plot along the edge of the pavement (or along a slope contour for the control plots). Within each plot, all trees with trunks greater than four inches in diameter were measured, identified by species, and permanently tagged.

The following data were collected as part of the study:

- The amount of salt, sand, and salt brine applied to the roads.
- The type of equipment used to plow and apply deicing materials, the speed of the plows, and the number of passes each plow made along a segment of road.
- Traffic count information, where available.
- Posted speed limits of roads.
- Weather data, including temperature, precipitation, and snowfall.
- Soil types present in the plots as classified by the Natural Resource Conservation Survey.
- The condition of trees within each plot, including an assessment of salt damage; pathogen, insect and abiotic injury; and overall health rating. Tree damage was categorized into four types: 1) not damaged; 2) damaged by salt only; 3) damaged by both salt and other diseases or insects; and 4) damaged by diseases or insects only.

Soil samples were collected from 80 of the 216 plots. The sampled plots were selected randomly and were stratified across the three types of plots (urban roads, rural roads, and control plots). Within each selected plot, four soil samples were collected from a depth of six inches bgs at distances of 10, 30, 60, and 90 ft from the baseline (essentially the edge of the roadway for plots located adjacent to roads). The soil samples were collected in early spring, immediately before or immediately after snowmelt, and analyzed for electrical conductivity and pH. Samples of foliage were also collected from 25 percent of the trees in the same plots, both from trees exhibiting symptoms of salt damage and from trees that appeared healthy. The foliage samples were analyzed for total sodium and chloride content.

Data sets included: 1) pH and electroconductivity of soil samples; 2) sodium and chloride content from collected vegetation samples; 3) data from salt surveys of vegetation; and 4) data from surveys of other disease and insect damage to vegetation. Data sets were analyzed using analysis of variance (ANOVA) methods. Because soil pH and electrical conductivity values did not vary significantly between rural and urban plots, the urban and rural plots were grouped into a single category called "roadside" plots for further analyses. In roadside plots, pH and electrical conductivity values decreased with increasing distance from the edge of the road, but in control plots, these values did not change significantly with distance from the baselines. In roadside plots, pH levels declined by 0.5 to 0.6 units with increasing distance from the edge of the road, and electrical conductivity levels declined by 0.08 dS/m with increasing distance from the edge of the road. Soil pH values in samples collected from roadside plots typically were slightly acidic (6.5 to 7.0 units) and almost always above 5.0 units; toxicity of minor nutrients may become a problem for plants when the pH drops below 5.0 units. The electrical conductivity of soil samples collected from roadside plots typically averaged less than 0.35 dS/m, which is well below the value deemed detrimental to vegetative health. Neither the slightly acidic pH values nor the very low electrical conductivity values were deemed detrimental to the plants growing along the roadsides.

The sodium and chloride content of conifer foliage, both symptomatic and asymptomatic of salt damage, were compared among rural, urban, and control plots. No significant differences were found between rural roadside and urban roadside data, so the urban and rural roadside plots were combined into a single category called "roadside" plots for further analyses. As may be expected, conifer needles that were symptomatic of salt damage had significantly greater sodium and chloride content than asymptomatic foliage within the same plot. The sodium content was typically about four times as great and the chloride content was typically about 2.2 times as great in symptomatic foliage as in asymptomatic foliage. Larcher (1995) indicates conifers that are sensitive to salt damage display damage when chloride concentrations reach levels of between 2,000 and 4,000 mg/kg. In this Lake Tahoe Basin study, chloride concentrations in symptomatic foliage were near the upper level of 4,000 mg/kg, and chloride concentrations in asymptomatic foliage were below the lower limit of 2,000 mg/kg. Symptomatic and asymptomatic foliage samples from roadside plots had significant differences in both sodium and chloride content within the first 40 ft from the edge of the road and declined thereafter. Sodium and chloride contents of both symptomatic and asymptomatic foliage samples from roadside plots tended to be greater on steep downhill slopes than uphill slopes, although differences were significant only for chloride content.

As with other data sets, there was no significant difference in the percentages of trees with various types of damage between rural roadside and urban roadside plots, so the urban and rural roadside plots were grouped into a single category called "roadside" plots for further analyses. Over both years of monitoring, salt damage was never observed on trees located in control plots. Additionally, when compared to control plots, roadside plots had smaller percentages of healthy trees (i.e., trees with no damage) and smaller percentages of trees damaged by diseases and insects only. Distance from the roadside and slope appeared to have a strong influence on the extent of salt damage. The percentage of trees with salt damage declined significantly as the distance from the edge of the road increased. Plots with steep, downhill slopes (60 to 90 degrees) had a significantly greater percentage of salt-damaged trees compared to plots with gentle downhill slopes (0 to 30 degrees) and plots with uphill slopes. Results for measurements made in 2007 indicate that less than 50 percent of trees had salt-only damage or salt-plus-other damage when located more than 21 ft from the edge of the road, and less than 5 percent of trees had salt damage when located more than 101 ft from the edge of the road. However, results for measurements made in 2006 exhibited salt impacts at greater distances from the road. The percentage of trees with salt-only damage or salt-plus-other damage did not drop below 50 percent until a distance of 41 ft or greater from the edge of the road, and 25 percent of trees still exhibited salt damage at distances of greater than 101 ft from the edge of the road. Although nearly 53 percent of roadside trees displayed salt damage, less than one-third of the tree crown was affected by salt damage in most of these trees. Data indicate that of trees affected by salt damage, a smaller percentage were on uphill slopes than were on downhill slopes, and those trees that were affected on both slopes had less severe crown damage.

Soil type and elevation had only small effects on the percentage of trees with salt damage. Pine trees, especially Jeffrey pines, lodgepole pines, and ponderosa pines, had the greatest percentage of salt damage. Trees with the least amount of salt damage were incense cedar, red fir, and white fir. Study results also suggest that smaller-diameter trees are slightly less susceptible to salt damage. For both years of measurements, the proportion of trees that had both salt and other damage was significantly lower than the proportion of trees with only salt damage. Disease or insect damage did not appear to negatively interact with salt damage. Within roadside plots, salt damage decreased with distance from the road, but disease/insect damage increased, suggesting that salt damage may partially displace other types of damage from diseases or insects.

**"Assessment of Chloride Deicing Impacts to Roadside Vegetation in the Black Hills – Final Report – Draft" (Traecker and Ball 2011)**

The purpose of this project was to assess the extent of dieback of pine trees along roads within the Black Hills and to assess whether the degradation of tree appearance as caused by deicing salts. The study included a driving survey of state highways, with detailed surveys performed at one-mile intervals; collection and analyses of soil and foliage samples; and collection of ozone levels at selected locations within the study area. The study area included 13 major state highways and 376 observation points, typically located at one-mile intervals along the highways. The surveys extended 60 ft from the centerline of the road. Data collected from the observation points included slope percent, tree species, average canopy height, pine foliage percent color, and canopy dieback. "Canopy dieback" is defined as the mortality of branches that begins at the terminals and proceeds toward the trunk, and it is used as an indicator of the severity of recent stress (Schomaker et al. 2006).

Four sites with ponderosa pines exhibiting symptoms commonly associated with deicing salt injury (needle discoloration and dieback) were paired with four sites located within one mile that did not contain trees showing symptoms of deicing. The paired sites had similar slopes, orientations, and number of trees. Soil samples and pine needle foliage were obtained from both sides of the roads at all eight sites. Soil samples were obtained at distances of 3 ft and 20 ft from the edge of the road and 60 ft from the centerline of the road. Pine foliage was obtained from the nearest pine at the 20-ft and 60-ft sampling points. This resulted in the collection of samples from six locations at each site, for a total of 48 sampling locations.

Soil samples were collected with shovels, soil probes, and Pulaski bars at depths of zero to six inches, six to 12 inches, and 12 to 24 inches bgs at each sampling site. The soil samples were analyzed for pH, extractable soil chloride, sodium, and magnesium. Needle samples were collected from the outer branches of the trees at mid-canopy twice during the year, once during the months of May or June, and again in August or September. The first round of sampling consisted of the previous year's needles, and the test results were used to assess how trees were affected by deicing salts used during the previous winter. Pine needles collected in August-September were tested to provide information on salt uptake, storage, and accumulation within the vegetation during the current growing season. Needle samples were analyzed for chloride, sodium, and magnesium.

Because the pattern of dieback of ponderosa pine was not entirely consistent with patterns reported for deicing salts (i.e., discolored needles and dieback concentrated in the spray zone at the base of the canopy closest to the road), active and passive ozone instruments were used to measure ozone levels during 2008 and 2009. Passive samplers provide an indirect measurement of ozone loading based on nitrate concentrations; the results can be related to data from continuous (active) ozone monitors if co-located. Five passive samplers and one active monitor were deployed in 2008 at six individual sites. The passive samplers were all located 6.5 ft above the ground surface for a two-week period. In 2009, passive samplers were installed at four sites, and an active monitor was co-located at one of the sites. At two of the sites, passive monitors were installed at three different heights within the canopy: 6.5 ft, 16.4 ft, and 26 ft. Nine samples were collected from each passive sampler at two-week intervals from mid-May through mid-October.

Six SDDOT maintenance units perform snow and ice removal operations within the Black Hills: Spearfish, Deadwood, Sturgis, Rapid City, Custer, and Hot Springs. The primary deicing salt used by SDDOT is sodium chloride, commonly mixed with sand to provide traction. Magnesium chloride is used to prevent abrasives from freezing and is also used as a pre-wetting agent. Three of the maintenance units (Sturgis, Spearfish, and Deadwood) were able to provide documentation of deicing salt use for the period of 2002 through 2007; the remaining units could not provide documentation.

Approximately two-thirds of the 376 observation points had trees within 60 ft of the roadway, and 97 percent of these forested sites contained ponderosa pines. Pine trees within 70 percent of the forested sites exhibited less than 5 percent dieback. In 5 percent of the forested sites, pines exhibited moderate (15 to 30 percent) dieback. None of the observation points had pines that exhibited more than 30 percent dieback. Many of the sites had symptomatic pines on the uphill side of the road, something that was also noted by Goodrich et al. (2008) along roads in Colorado. Goodrich et al. (2008) did not find symptoms specific to aerial spray such as necrotic specks, crystallized salt deposits, or dust particles on foliage; they speculated that trees on the upslope side of the road were symptomatic because they had absorbed magnesium chloride through roots that extended beneath and beyond the roads. However, other researchers have reported increased foliar damage only on the downslope side of the roadway (Hofstra and Hall 1971, Piatt and Krause 1974, and Fleck et al. 1988).

Chloride, magnesium, and sodium concentrations in needle samples were compared with four Sources of Variation (SOVs): 1) sample time; 2) symptoms (symptomatic versus asymptomatic); 3) orientation (upslope versus downslope); and 4) distance from the road. ANOVA statistical methods with a probability level of 0.05 were used as the criteria for determining significance. Chloride, maganesium, and sodium concentrations were all found to be slightly higher in needle samples obtained from symptomatic sites versus those obtained from asymptomatic sites, and slightly higher in needle samples obtained from trees 20 ft from the road versus those obtained from trees 60 ft from the road. For sodium concentrations, sample results ranged from a low of 0.001 percent to a high of 0.095 percent, with only a few samples exceeding 0.08 percent, the level at which Hofstra and Hall (1971) observed minor damage in pine trees. In general, it was thought that the sodium levels were too low to produce symptoms attributed to application of sodium as a deicing salt (Hofstra and Hall 1971). For magnesium, needles obtained from symptomatic sites had significantly higher concentrations than needles obtained from asymptomatic sites, but the overall concentrations of magnesium were quite low, ranging from 0.11 to 0.14 percent. This falls within the range of magnesium concentrations (0.1 to 0.7 percent dry weight) necessary for normal plant growth (Brady and Weil 2008). For chloride, Hagle (2002) reports that the normal level in pine foliage is approximately 0.1 percent dry weight, and Hofstra and Hall (1971) report that 10 percent injury occurs when chloride levels in foliage exceed 0.8 percent dry weight. The concentration of chloride in needle samples ranged from 0.01 percent to 0.28 percent dry weight, and chloride concentrations declined markedly with distance from the road (20 ft versus 60 ft). However, as with sodium and magnesium, the levels of chloride in pine needles from the site were thought to be too low to account for the symptoms expressed by the pine trees.

ANOVA was also used to measure the influence of the SOVs (sample time, symptoms, orientation, and distance) on chloride, magnesium, and sodium levels in two soil profiles (zero to six inches and zero to 24 inches). There was no significance relationship between the SOVs and the chloride concentrations measured in the two soil profiles, possibly because of the high leaching ability of chloride (Viskari and Karenlampi 2000). Magnesium concentrations ranged from approximately 15 parts per million (ppm) to 40 ppm, but magnesium is generally not toxic to vegetation, even at high concentrations. Magnesium concentrations at symptomatic sites were slightly elevated at the 20-ft sample distance (but not the 60-ft sample distance), but the difference was not significant. Sodium concentrations ranged from approximately 35 ppm to 225 ppm and were found to vary significantly with sample time and distance. The highest levels of sodium occurred in samples collected from the edge of the road, indicating that deicing salts were the likely source. Sodium levels declined rapidly with distance from the road, returning to normal levels in samples collected 60 ft from the road. Although sodium and chloride concentrations at sample distances of 20 and 60 ft from the road were slightly higher at symptomatic sites than at asymptomatic sites, the differences were not significant.

Ozone, a secondary pollutant caused by the action of ultraviolet radiation in sunlight on hydrocarbons and oxides of nitrogen, is a major abiotic stressor and has been associated with a decline of numbers of ponderosa pines in some locations. Monitoring data collected during 2008 and 2009 indicate that ozone levels may have peaked in the “ozone damaging” range several times, but that no prolonged high ozone levels occurred. This suggests that levels of ozone were generally not high enough to be responsible for the foliar symptoms noted on the ponderosa pines in the study area.

The Black Hills experienced drought for much of the decade of 2001 through 2010, with normal precipitation only returning in 2008. The June precipitation from 2002 through 2007 was generally less than half of the long-term average. Shoot expansion on ponderosa pines generally occurs during May and June and may be adversely impacted by a lack of moisture. Symptoms associated with drought typically begin in the upper canopy and outer branch tips and gradually spread lower into the canopy with time. Deicing injury on pines is usually expressed as discoloration of foliage at the lower canopy and on the side facing the road. Needles are often yellow at the tips with an abrupt transition between dead and green portions. Many of the trees in the study area that were identified as symptomatic had affected upper canopies, whereas the foliage in the lower canopy remained green or was only slightly affected, suggesting that drought may have played a significant role in the poor appearance of pines along the highways in the Black Hills.

In summary, even though mean extractable levels of chloride, magnesium, and sodium were slightly elevated at symptomatic sites as compared to asymptomatic sites, the overall nonsignificance of the least significant difference analysis would indicate there was no direct connection between the higher levels of soil nutrients and the needle discoloration and dieback present in the ponderosa pines. Additionally, the levels of sodium and chloride were generally too low to be a primary stress factor. The study concluded that the dieback along the highways was most likely the result of a number of stress agents, with the long-term drought being the primary factor. Many of the trees in the symptomatic sites have improved since the drought ended in 2008.

# CHAPTER 4. METHODOLOGY

This study looked at data related to ADOT WSM activity and environmental field observations. Initially, the study was to focus on the 2011 and 2012 winter seasons. As the data will show, there was relative consistency in application rates during these two seasons. The study was expanded to include the 2010 winter season application rates to better establish trends in the data and provide for more robust analysis. The methodology for collecting the samples and analyzing the data is described in this section.

## STUDY SAMPLING AND ANALYSIS PLAN

Data gathered as part of ADOT's AVL tracking system were reviewed to gather information related to winter storm applications, their tendencies, and correlation to other factors. The data were collected, solely out of ADOT's Globe District, for the following three consecutive winter storm seasons: 2010 (spanning 2010-2011); 2011 (spanning 2011-2012); and 2012 (spanning 2012-2013). A total of 16 BMS along State Route 260 and U.S. Routes 180 and 191 were selected for data collection and sampling for this study (Figure 1 in Chapter 1). Specific site descriptions for each BMS are presented in Appendix A, and map locations are presented in Appendix B. The BMS are each marked with a unique bar-coded signpost. Environmental data and soil samples were collected at each BMS at various distances from the roadway and at two depth intervals below ground surface. Vegetation, in-stream sediment, and surface water samples were collected at selected monitoring sites using strategies and procedures discussed in the following sections. Weather data were also recorded using information from the websites www.weatherunderground.com and www.weather.com; forecast locations were correlated as closely as possible to BMS. Geographic locations for each site are listed in Table 2**.**

**Table 2. Revised Geographic Location of Monitoring Sites in the Globe District**

| BMS | Name | Route | Mile Post | Latitude | Longitude |
|---|---|---|---|---|---|
| 24 | Alamo Wash | US 180* | 378.5 | 34.3835 | -109.4055 |
| 19 | Alpine | US 180* | 423.0 | 33.8873 | -109.1575 |
| 18 | Campbell Blue Ridge | US 191 | 243.8 | 33.7472 | -109.2077 |
| 29 | Fornsworth Ranch | SR 260 | 330.5 | 34.2994 | -110.1949 |
| 28 | Greer | SR 260 | 383.3 | 34.0609 | -109.4970 |
| 17 | Hannigan Creek | US 191 | 235.7 | 33.6628 | -109.2621 |
| 16 | KP Cienega | US 191 | 226.1 | 33.5808 | -109.3644 |
| 27 | Latigo Wall | SR 260 | 355.0 | 34.1166 | -109.9162 |
| 84 | McNary | SR 260 | 364.0 | 34.0795 | -109.7991 |
| 25 | Mogollon Rim Trail | SR 260 | 336.9 | 34.2733 | -110.0937 |
| 21 | Nelson Reservoir | US 180* | 408.7 | 34.0666 | -109.1998 |
| 20 | Nutrioso | US 180* | 416.9 | 33.9541 | -109.2111 |
| 31 | Phoenix Park Wash | SR 260 | 311.6 | 34.3840 | -110.4936 |
| 22 | Picknick Creek | US 180* | 403.9 | 34.0914 | -109.2428 |
| 30 | Rogers Lane | SR 260 | 323.3 | 34.3481 | -110.3040 |
| 26 | Show Low | SR 260 | 344.1 | 34.2228 | -110.0292 |
| *Combined routes US-180 and US-191 | | | | | |

**AVL Technology Data**

ADOT has equipped WSM equipment with AVL systems to collect data related to their WSM operations. The AVL systems are installed on vehicles used for plowing snow and applying road salt and cinders. The AVL systems use global positioning system (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 ambient temperature. The AVL system provides the ability to track real-time material application rates for each piece of equipment. ADOT can track 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 purposes. Of particular value is the ability to evaluate, to some extent, the rate at which winter storm applications are conducted within the guidelines provided in the ADOT WSMOM.

The ADOT WSMOM provides guidance on appropriate application rates for different formulations of road salt, including sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), and calcium magnesium acetate (CMA). A commercially available anti-icing and deicing product, Ice Slicer® (90 percent NaCl, 10 percent other proprietary components), was the only granular deicer/anti-icer applied in the Globe District during the three winter seasons evaluated, and therefore is the only product application that was evaluated as part of this study. The application rate guidance provides several ranges of appropriate rates depending on a variety of physical factors at the time of application. These factors include pavement temperature ranges and trends, type of precipitation, and pavement surface condition (wet, dry, light snow covering, etc.). Additional comments provided with each entry can be used to further define the most appropriate application rate within the given range.

AVL data were provided by ADOT for all WSM operations conducted within the study area during the three winter seasons analyzed. These data were provided in an ESRI file geodatabase format. Within the geodatabase, the point data set containing AVL data is the "PowerTripRecords" data layer. This data layer contains individual records for any changes in both Power and Trip information. Power records contain information on ignition status and other vehicle settings, including plow, wing, low-gate, and high-gate settings. Trip records contain information related to the application of chemicals and environmental conditions, such as pavement temperature.

In order to focus the data analysis on the areas surrounding each BMS, the AVL data were limited to any PowerTripRecords occurring within 0.2 miles of a BMS using a spatial selection tool in ESRI ArcGIS software. Once the PowerTripRecords within a radius of 0.2 miles of each BMS were extracted, the data were exported to Microsoft Access for preparation and analysis.

On any given pass through the 0.2-mile buffer, a vehicle's AVL system may record several trip records containing duplicate information. For the analysis of chemical application rates, it was necessary to remove any duplicate data records. First, the records were sorted by AssetName, a unique identifier for each vehicle. Next the records were sorted by AVLID, a unique record identifier generated by the AVL system. This provided a record list for each truck showing the sequential ordering of all AVL data records. A cardinal direction of travel (N, S, E, or W) was assigned to each record according to the route being traveled and the azimuthal value of the AVL heading field (0°-360°). For example, on all north-south routes, vehicle travel with a heading greater than 270° and less than 90° was assigned a travel direction of north; all records with a heading greater than 90° and less than 270° were assigned a travel direction of south. The record date/time information was then used to calculate the elapsed time between each record for a given vehicle. It was determined that at a slow plowing speed of four mph, a vehicle may spend as much as six minutes making a single pass through a BMS buffer area. Therefore, any trip record at a given BMS occurring less than six minutes after the previous record, for travel in the same direction, was considered a duplicate record and was removed from analysis. By removing duplicate records in this manner, multiple passes at the same BMS during a storm event are still captured for analysis. The final data set used in this study is presented in Appendix D.

**AVL Analytical Approach**

The AVL data were evaluated with the intent of quantifying the total salt applied at each BMS and assessing any associated correlations with salt accumulations in the environment. These values were used to determine statistical correlations between salts added to the environment through winter storm applications and the levels of sodium and chloride in soil and vegetation material. This analysis is discussed in Chapter 5.

The AVL data were also used to evaluate the tendency for field applications to deviate from ADOT WSMOM guidance and to identify trends in the deviations. In this evaluation, the AVL application rate and the pavement temperature at the time of the application were compared to the ranges provided in the WSMOM guidance. Several parameters that were needed for a more robust and valuable analysis of the AVL data were unavailable for this study. To conduct a complete evaluation of the consistency of individual applications with the guidance, information must be available for all parameters that factor into the application guidance. These include observations regarding the type, intensity, and accumulation of precipitation; roadway surface conditions; and anticipated weather trend. These data are not collected as part of the AVL system.

Weather information proved to be problematic. Weather was monitored for general areas within the study area using the websites www.weatherunderground.com/ and www.weather.com. However, because weather forecast locations could not be precisely correlated with any specific BMS, it was not possible to correlate weather conditions at any specific BMS with specific weather data, geographically or temporally. Weather information from these websites provided ambient air temperature, which is less of a determinant in application rates than pavement temperature; the ambient air temperatures may or may not have correlated with pavement temperatures. Furthermore, determining precipitation amounts from frozen snow and ice is imprecise, and precipitation amounts can vary considerably over short distances as a function of elevation, local geography, or tree cover. Snowfall collected in weather station gauges will not provide a recordable precipitation volume until the snow melts. Since the water makeup of snow is variable, converting the water-based precipitation volumes to a snowfall equivalent would be imprecise and would leave much room for error. For these reasons, it was determined that the ambient weather conditions provided by weather forecast locations were not useful in this study.

During AVL data evaluation, several limitations were encountered, including the completeness of individual records. After evaluating 6,366 records associated with individual applications within the 16 BMS, approximately 1,386 records were omitted from analysis because reliable pavement temperature data were lacking. These records all exhibited pavement and ambient temperatures equal to zero. While equal ground and ambient temperatures are a likely possibility, the excessively high number of records with both temperatures equal to zero suggests that instruments measuring these temperatures were not operating correctly at the time of the application. An additional 43 records were excluded because of excessively high pavement temperatures (65° F to 3,645° F). These temperature readings were assumed to be caused by malfunctioning equipment. The remaining 4,937 records were included in the analysis.

**FIELD SAMPLING**

Four media were sampled as part of this study: soil, sediment, water, and vegetation, as described in detail below. Field data were recorded on a standardized "ADOT WSM Field Sampling Data" form that included location, site observations, photographic log, and sampling information. Forms completed for this study are located in Appendix E. Field notes were also recorded during each sampling event. Copies of all field notes are located in Appendix F.

**Soil Sampling Approach**

Soil types varied across the study area, dependent largely on local bedrock geology. While these different soil types may influence chemistry at individual sample sites, this possible influence was assumed to be minimal, and it was therefore not assessed as a part of this study. For a more complete description of soil types across the study area, refer to Appendix G.

The soil sampling strategy was developed to investigate potential trends in the spatial buildup of salts in soil at each site, both laterally from the roadway and at different depths. Soil samples were collected from one side of the road at each BMS. Composite soil samples consisting of three discrete samples were collected by hand auger within one or more separate sampling zones at each site, except where rocky substrate precluded the collection of deeper samples. Once obtained, samples were properly identified and submitted to TestAmerica for analysis. The laboratory results are presented in Appendix H.

*Sampling Zones*

Three soil sampling zones were established at each site and relate to the distance of a sample from the edge of the pavement (Figure 2). Soil samples collected from the distances listed below were designated as Zone A, B, or C samples:

- Zone A is between 10 and 50 ft from the edge of the pavement.
- Zone B is between 50 and 75 ft from the edge of the pavement.

- Zone C is between 75 and 125 ft from the edge of the pavement.

The specific distance from the edge of the pavement at which soil samples were collected within each sampling zone varied because of site-specific conditions such as slope, vegetation, drainage features, and other characteristics. This sampling design allowed discrete samples within a particular sampling zone to be collected at similar distances from the roadway, while providing some flexibility to accommodate site-specific constraints. As a general guideline, discrete samples were not collected from localized depressions or drainage features, in an attempt to minimize the impact of concentrated runoff on soil salt concentrations.

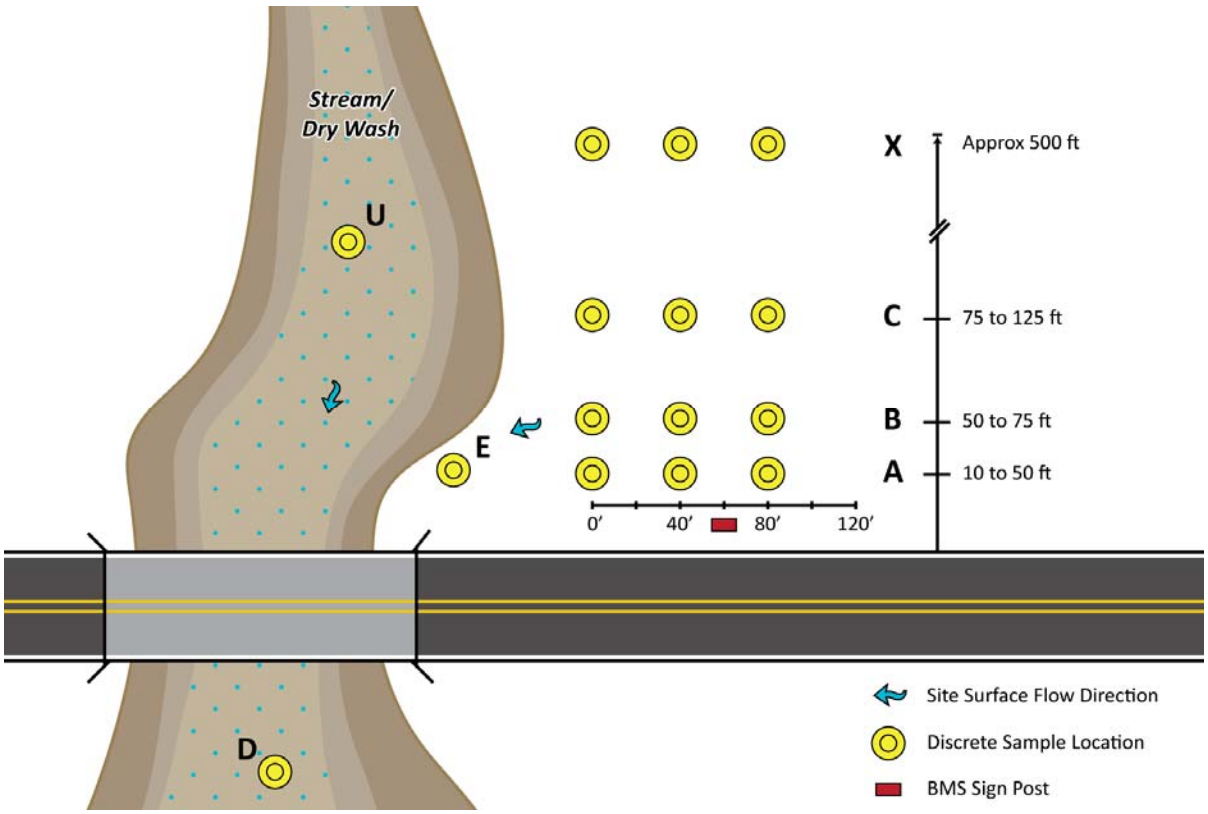



**Figure 2. Research Sampling Methodology**

Composite soil samples were collected from Zone A at each site during all sampling periods in order to provide a set of repeated measures at each site and to allow comparisons among sites. Composite soil samples were collected from Zones B and C if site conditions implied the buildup of salts in or on the surface of the soil, salt-related damage to vegetation, or the presence of various drainage features and conditions.

*Background Samples*

In addition to the A, B, and C composite samples, composite background samples were collected at each site in the spring of 2012. One background sample, designated X, was collected at each site from an extended distance (up to 500 ft) from the road surface. The X samples were collected to characterize soil conditions in areas that were not impacted by winter storm activities.

*Discrete Sample Locations*

Discrete soil samples were obtained at distances no greater than 60 ft on either side of the BMS signpost. This established a total sampling length of 120 ft parallel to the roadway. The starting point of the sampling area was defined as 60 ft to the left of the signpost (facing away from the roadway; Figure 2). Discrete soil samples were collected at 40-ft intervals within the 120-ft-long sampling area. For example, during the fall of Year 1, discrete soil samples were collected at distances of 1, 41, and 81 ft from the starting point. During the spring of Year 1, discrete soil samples were collected at distances of 2, 42, and 82 ft from the signpost, with this pattern continuing for each sampling period.

*Soil Sampling Procedures*

Discrete soil samples were collected during both fall and spring sampling periods. Soil samples were collected with a hand auger from two different depth ranges:

- Samples collected from a depth of 2 to 12 inches bgs were designated with “1.”
- Samples collected from a depth of 12 to 18 inches bgs were designated with “2.”

Soil samples generally were collected within the same column created by the hand auger. Therefore, a “2” sample would be collected immediately below a “1” sample. However, where the presence of rocky substrate prohibited continued downward progress with the hand auger, a second hole immediately adjacent to the first hole would be attempted in order to gain sufficient depth for the required soil sample. At times, the substrate would prohibit collection of a “2” sample. When this happened, sampling at that location would cease and the sample team would move on to the next discrete location within the same sampling zone. Within each sampling zone, soil samples from “1” depths were combined in one bucket and soil samples from “2” depths were combined in a second bucket.

After soil samples were collected at all three discrete sample locations, soil samples collected from the same sampling zone and depth were thoroughly mixed to form a composite sample. The composite samples were then placed in sample jars provided by the test laboratory and labeled appropriately (e.g., A1, A2, B1, B2, etc.). Samples were identified and labeled as described in the work plan and as required by the analytical laboratory. The hand auger and buckets used to collect and hold the composite soil samples were emptied of excess soil before being used for the next sampling zone. The soil sampling procedure was repeated for additional sampling zones.

**Sediment Sampling Approach**

Discrete sediment samples were collected at BMS where surface water features either intersect or closely parallel the site. Up to three discrete sediment samples were collected, based on the following conditions.

- Stormwater discharge point or channel off the site or outside of the right-of-way (ROW).
  - Designated "E" in samples.
- Surface water bisecting the site or the roadway down gradient of the site.
  - Upstream from this point, designated "U" in samples.
  - Downstream of this point, designated "D" in samples.

The point at which the "E" sample was collected varied from site to site but was either a channel or an indiscriminate spot where surface conditions would suggest the presence of a stormwater runoff discharge point. For sites where a surface drainage bisected the site or the roadway, sediment samples were collected up gradient (U) and down gradient (D) of the assumed chemical-laden flows resulting from winter storm activities. Sampling within the drainage and surface water features was conducted to assess the buildup of salt ions in the soil and the impact of drainage features on concentrations. Sampling nomenclature is summarized in Table 3.

**Table 3. Sampling Nomenclature**

| Type | Sample | Location |
|---|---|---|
| Composite | A | 1 –50 ft from edge of pavement |
| | B | 50–75 ft from edge of pavement |
| | C | 75–125 ft from edge of pavement |
| | X | Up to 500 ft from edge of pavement |
| Single Discrete | E | Discrete sample at approximate point of discharge for surface drainage into receiving water |
| | U | Point within surface drainage, upstream of BMS discharge at point E |
| | D | Point within surface drainage, downstream of BMS discharge at point E |
| Depth | 1 | 2–12 inches (2–6 inches for stream sediment) |
| | 2 | 12–18 inches (6–12 inches for stream sediment) |

*Sediment Sampling Procedures*

Sediment samples were collected during fall and spring sampling periods. Sediment samples were collected with a hand auger at up to two depths:

- Samples collected between 2 and 6 inches bgs were designated "1."
- Samples collected between 6 and 12 inches bgs were designated "2."

Sediment samples were collected as discrete samples for each depth within each zone (i.e., a discrete E1 sample or a discrete D2 sample). Sediment samples were collected from along the channel banks if surface water was present, or from within the channel if no water was present. Hand augured samples were placed in a bucket to hold the entire sample column (e.g., from two to six inches depth), mixed, and then placed in sample jars provided by the analytical laboratory. Samples were identified and labeled as described in the work plan and as required by the test laboratory. The hand auger and buckets were cleaned of excess sediment before the next sediment sample was collected.

**Vegetation Sampling Approach**

Vegetation types vary across the study area, depending largely on elevation and annual precipitation. Within the 16 BMS included in this study, vegetation types include pinyon-juniper mixed scrub/shrub grassland, open grassland near pasture lands, mixed conifer forest (spruce, fir, aspen), and ponderosa pine forest (Appendix B). Ponderosa pine communities, either with or without a grassy or shrub understory, were present at the majority of sites. For the purposes of this study, sampling and analyses were limited to coniferous species as described below. Sampled vegetation was provided to TestAmerica for analysis; they in turn subcontracted the analytics to A & L Analytical Laboratories, Inc., of Memphis, Tennessee. Analytical results for vegetation testing are presented in Appendix H (refer to Section 13, "Subcontractor Data").

Initially, vegetation was to be sampled only during spring sampling periods if indications of salt-related stress or damage were visible. Such indications were not visible or were very limited; therefore, such indicators were not used to determine which plants to sample. Instead, vegetation samples were collected during the spring sampling periods from trees near the road at 10 forested sites.

*Vegetation Sampling Procedures*

Vegetation samples were collected at random from two individual trees near the road (generally within 50 ft of the edge of the pavement) and labeled V1.0 and V1.1. Additional vegetation samples were collected at random from two individual trees at least 100 ft from the road and labeled V2.0 and V2.1. (Distance from the roadway may be reduced if the elevation change provides equivalent distance from the impacts of roadway drainage.) Often the V2.0 and V2.1 samples were taken from the same location as the background X soil samples. This method allowed for comparison of two samples from an area where chemical runoff may be expected, and two samples from an area where chemical runoff would be expected to be nonexistent or less prevalent and less concentrated.

In general, the vegetation samples were taken from coniferous trees (e.g., ponderosa pine, pinyon pine, spruce, fir) and consisted of outer branches of the plant that appeared representative of the entire plant. Approximately one quart of vegetative material was collected per sample. After collection, each sample was immediately placed in a brown paper bag (large lunch size) and labeled as appropriate. The samples were placed in a dry cooler and delivered to the laboratory for analysis.

### Water Sampling Approach

A straightforward water sampling approach was used. Water sampling was performed at BMS 17, 18, and 19 because perennial drainages parallel to each site were present.

*Water Sampling Procedures*

Water samples were collected from locations upstream and downstream from the locations where site runoff discharged to the perennial drainage. Surface water samples were collected during the fall and spring sampling events and were identified and labeled according to the work plan and instructions received by the analytical laboratory.

### Sampling Variability

The work plan developed for this study called for a combination of strict repeated measures at each site as well as collection of samples based on evidentiary information. It also called for the collection of an A1 sample at each site for all four sampling periods. Deeper samples (level 2) as well as B- and C-samples were to be collected only in the event that site conditions implied either the buildup of salts in or on the surface of the soil or salt-related damage to vegetation. X samples were to be collected only once for each site. For sites with surface water features, the related samples (E, U, and D) were to be collected and analyzed throughout the study.

The initial field observations for each site did not provide any clear visual indication of salt buildup or vegetation injury or desiccation. Vegetation at two sites, BMS 17 and 19, showed signs of injury that could be related to salt. Signs of leaf necrosis were observed on pine needles at BMS 17 and on grasses at BMS 19. While leaf necrosis can be attributed to a variety of causes, including nutrient and water imbalances, salt injury was assumed to be a potential cause. As a result, A2 and B samples were collected at both BMS 17 and 19. C samples were also collected at BMS 19. C samples were not collected at BMS 17 because of the limited distance between the roadway and Hannagan Creek.

After the initial sampling event (fall 2010), it was apparent that limiting the collection of deeper samples and B and C samples to sites with observed salt impacts would restrict the collection of these samples and limit the size of the data set available for analysis. To increase the sample population and provide additional data for analyses, A2 samples were obtained from all sites beginning in the second sampling period (spring 2011), and B1 samples were obtained from all sites beginning in fall 2011. It should be noted that deeper samples (level 2) and B and C samples were not collected at every site due to excessive rockiness of the soil at depth or limited access for sampling at distances greater than 50 ft perpendicular from the roadway.

### Analytical Approach

*Evaluation of AVL Data*

AVL data were obtained and reviewed for the winter seasons 2010 (fall 2010 to spring 2011), 2011 (fall 2011 to spring 2012), and 2012 (fall 2012 to spring 2013). A winter season was considered to begin with the first recorded winter storm application in the fall or the date of the fall soil sampling event conducted as part of this research project. The season was considered to continue through the final winter storm application in the spring or the date of the spring soil sampling conducted as part of this research, whichever occurred first. A winter storm application was defined as a recorded application of salt to the roadway within any of the 16 BMS. While ADOT routinely applies cinders to roadway surfaces to increase traction on the roadway surface, the focus of this evaluation was limited to salt applications.

*ADOT Application Guidance*

The ADOT WSMOM application rate guidance is a robust decision-making tool that provides recommended application rates based on six temperature ranges and trends (e.g., steady, rising, falling) and a variety of winter storm events (e.g., light snow, sleet, freezing rain, frost, black ice). The combination of temperature range and trend and winter storm event type can be used to select a recommended application rate (see Table 4).

Information related to temperature trends, precipitation type, and roadway surface conditions is not recorded by the AVL system and therefore not available for inclusion in the analyses performed for this study. As a result, four temperature and application rate ranges were delineated to reflect the data available for this research. The categories included in the ADOT WSMOM guidance were placed into one of the four research-delineated temperature and application rate ranges, as shown in Table 4.

Temperature trends were assumed to be steady, and details regarding precipitation and roadway conditions are not taken into account within each research-delineated range. The result is a more broadly defined application range. In comparison, ADOT application guidelines provide more detailed application ranges based on precipitation type and intensity in addition to temperature. For example, with a pavement temperature of 25 degrees Fahrenheit (°F), an application rate of 100 lb/lane-mile would be acceptable if the weather conditions included light snow. However, under any other winter precipitation conditions (moderate to heavy snow, freezing rain, etc.), this application rate would be considered low. Without data for real-time weather conditions, it is not possible to make a definitive judgment on an individual application.

In examining the AVL data, the broadest application rate range was applied to the defined pavement temperature range. As a result, this hypothetical application would always be considered to be an acceptable application rate in the analysis herein. The resultant analysis errs toward accepting an application as being within ADOT guidelines. Therefore, the overall results presented in Section 5 equate to a best-case scenario for overall conformance with ADOT WSMOM guidelines.

**Table 4. ADOT WSMOM and Research-Delineated Application Guidance Categories**

| Temperature Range Reviewed for this Study* | ADOT Temperature Range** | Winter Storm Event** | Solid or Pre-wetted Solid, lb/lane-mile** | Prescribed Application Rate Range, lb/lane-mile* |
|---|---|---|---|---|
| Above 32º F | Above 32º F, steady or rising | Any type | Not Required | 75–200 |

| Temperature Range Reviewed for this Study* | ADOT Temperature Range** | Winter Storm Event** | Solid or Pre-wetted Solid, lb/lane-mile** | Prescribed Application Rate Range, lb/lane-mile* |
|---|---|---|---|---|
| | Above 32º F, but falling | Light to heavy snow storm, frost or black ice | 75–200 | |
| | | Freezing rain | 100–200 | |
| | | Sleet storm | 125 | |
| 20º F to 32º F | 20º F to 32º F, remaining in range | Light snow | 100–210 | 100–325 |
| | | Moderate to heavy snow | 190–200 | |
| | | Frost or black ice | 175–225 | |
| | | Freezing rain storm | 200–300 | |
| | | Sleet storm | 125–325 | |
| | 20º F to 28º F, remaining in range and equal to or below dew point | Frost or black ice | 165–200 | |
| 15º F to 20º F | 15º F to 20º F, remaining in range | Light to heavy snow | 200–250 | 175–400 |
| | | Frost or black ice | 175–225 | |
| | | Freezing rain storm | 250 – 400 | |
| | | Sleet storm | 250 – 400 | |
| Below 15º F | Below 15º F, steady or falling | Any type | Not Required | Not Required |

*Acceptable for this study
**FHWA and ADOT WSMOM Guidance

**Soil Analysis**

*Distribution of Salt Levels in Sampling Areas*

The variation of salt concentrations between the sampling zones was examined to evaluate the impact of WSM activities versus distance from road on the surrounding environment. The focus of the analysis was on the levels of sodium and chloride, as they are the primary components of roadway winter storm chemicals used by ADOT. The concentrations of sodium and chloride were evaluated for the A1 and X samples to assess the impact that distance from the road has on the ion levels. Sodium and chloride concentrations for the A1 samples were averaged across the four sampling events. Only one X sample was obtained from each of the BMS. The results of the spring 2012 X sample were assumed to be an acceptable representation of the soil in that sampling region. This was based on an assumption that the soil in the X sample region had not been significantly impacted by ADOT WSM activities. The results for A1 and X samples were compared for the spring 2012 sampling event as well as the average across all four sampling events for the A1 samples. The difference in the mean concentrations was evaluated through Student's t-Test. Assumptions regarding normalcy and independence were evaluated to ensure the appropriateness of the test. The analysis tested the significance between the sample means to evaluate whether the location of the samples played a significant role in impacting the mean concentration of sodium and chloride. The null hypothesis is that the true difference between the means is equal to zero, with the alternative hypothesis being that the true difference is not zero. With a p-value of less than 0.05, the null hypothesis would be rejected in favor of the alternative. Rejecting the null hypothesis would indicate that the distance from the roadway has a statistically significant impact on the mean concentrations.

In addition to comparing soil near the roadway (A1 samples) and those a considerable distance from the roadway (X samples), the soil concentrations of sodium and chloride were evaluated for difference over a lesser perpendicular distance from the roadway. Site characteristics at 11 BMS provided the opportunity to evaluate the difference in salt concentrations between the A and B sampling regions, which are defined as 10 to 50 ft and 50 to 75 ft from the edge of the pavement, respectively. Whereas X samples were assumed to not be significantly impacted by WSM activities, an assumption that the result of this study would seem to support, B1 samples are close enough to the roadway that impacts from WSM activities can be assumed as a distinct possibility. By comparing the difference in A1 and B1 samples, we are able to further evaluate how far the impacts of WSM activities extend perpendicular to the roadway.

While A1 samples were obtained for all four sampling events, B1 samples were obtained only in the fall 2012 and spring 2013 sampling periods, as a result of the change in research procedures discussed previously. To evaluate the difference between A1 and B1 sample sodium concentrations, a two-factor ANOVA model with replication was fit to the data. The two factors evaluated were the distance from the roadway (A1 versus B1) and the season (fall 2012 versus spring 2013). The null hypothesis was understood as there being no difference between the mean sodium concentrations of A1 and B1 samples, or between fall 2012 and spring 2013, or some combination of the two. Conversely, the alternative hypothesis was understood as a difference in sodium concentrations between factors. A significance level of 0.05 (p=0.05) was used to assess the significance of the two factors and their interaction with each other. The null hypothesis is only rejected in favor of the alternative, with a p-value of 0.05 or less. All common assumptions for ANOVA were verified as well.

*Impact of Drainage on Soil/Sediment Levels*

The effect of site drainage characteristics on the distribution, concentration, and accumulation of salt was measured at seven BMS where perennial or intermittent surface drainages ran perpendicular to the sites. At these sites, the impact of distance was evaluated along with the location of the sample relative to surface drainage. The mean concentrations for each sample were evaluated for each BMS. General observations of the difference in the mean concentrations were noted between samples and BMS. While the main factor investigated between these samples was their location within the site drainage system, proximity to the roadway was considered as well.

*Seasonal Fluctuations in Salt Concentrations and the Impact of Roadway Application Rates*

A key part of the research was to evaluate salt concentrations in roadside soil, the impact of various amounts of chemical applied within the ROW, and the extent to which salt concentrations fluctuate between seasons. To assess these relationships, sodium and chloride concentrations in the A1 samples were evaluated over the four sampling periods. As discussed in Section 3, past research has indicated that soils closer to the roadway tend to have higher salt concentrations, due to chemical application to the roadway. Concentrations of sodium and chloride in the A1 samples were tracked over time to assess the total change in concentrations over the span of the four sampling events. The change in soil concentrations was tracked by BMS. The difference in the mean concentration was measured through Student's t-Test, which measured the significance in the mean difference between seasons. The null hypothesis, that there is no difference between seasons in the mean concentrations of sodium and chloride, would be rejected in favor of the alternative hypothesis with a p-value less than 0.05. The alternative hypothesis is understood that there is a significant difference in the mean concentrations between seasons and that therefore the seasonal activities have a significant impact on sodium and chloride concentrations.

To measure the impact the chemical applications levels have on salt concentrations in the soil, a linear regression model was used to evaluate the relationship between the total seasonal chemical application and the sodium and chloride concentrations for the A1 samples from the adjacent BMS. Since existing salt concentrations have been impacted by past activities and are likely to vary from site to site, the analysis also measured the impact of the seasonal chemical total on the difference between the A1 samples' sodium and chloride concentrations in the fall and spring sampling events.

The chemical application totals were gathered from ADOT AVL data and expressed as pounds per lane-mile. The chemical totals were calculated from lane-mile total, drainage-weighted lane-mile total, and roadway total. A regression analysis was conducted for each total. The lane-mile total was calculated for each BMS by summing the total amount of chemical applied to the side of the roadway that was adjacent to the BMS. Thus, for a BMS adjacent to the northbound travel lane, all northbound applications applied to the segment of roadway associated with the BMS were summed. Southbound applications were then disregarded. For the drainage-weighted application totals, the pitch of the roadway was determined to factor in how many lanes would drain to the BMS. Most BMS received drainage from either the northbound or southbound (eastbound or westbound) lanes. However, at a few sites, the entire roadway drained to the BMS. In these cases, the seasonal chemical application totals for all lanes were summed. The roadway total was calculated by summing all applications made to all roadway lanes at the BMS.

To evaluate the relationship between salt concentrations in the soil and chemical applications, the data were plotted and applied to a linear regression model. The model measures the significance that chemical application rates have on predicting soil sodium and chloride concentrations.

**Vegetation Analysis**

Mean concentrations of sodium and chloride were compared between vegetation less than 50 ft from the roadway (V1 samples) and vegetation 100 ft or more from the roadway (V2 samples) to evaluate the impact that distance from the roadway has on the salt concentrations. The difference in the means was evaluated through a Mann-Whitney-Wilcoxon Test, because the vegetation data did not meet assumptions regarding normality. The difference between the mean concentration of sodium and chloride in the V1 and V2 samples was compared by season (spring 2012 and 2013) and for all samples combined.

Correlations between sodium concentrations in V1 (vegetation) samples and chemical applications and sodium concentrations in A1 (soil) samples were measured using a linear regression model. The model measured whether chemical applications or A1 sample sodium concentrations could be used to predict a response in the levels of sodium in vegetation.

# CHAPTER 5. RESULTS

## ROAD SALT APPLICATION RATES

Anti-icing and deicing chemicals are ideally applied at a rate that is sufficient to effectively treat the accumulation of snow and ice on road surfaces but at the same time is economical and minimizes stress on the surrounding environment. Application rates typically are dictated by chemical selection and a variety of environmental factors such as air and pavement temperatures, precipitation type, and rate of accumulation.

Application rates over the three winter seasons considered in this study were compared to the pavement temperatures at the time of application to assess the general adherence to the application rate guidance in the ADOT WSMOM. Trends in applications rates and guidance about application rates were also evaluated. Results and observations are discussed in the following sections.

### Application Rates versus Pavement Temperature Guidelines

All applications for the three winter seasons included in this study were categorized in order to analyze adherence to application rate guidelines. Each application was categorized as acceptable (within the application guidance range), high (above the application guidance range), or low (below the application guidance range). For the three-year study period, 65 percent of all granular chemical applications were considered acceptable, meaning that they were applied at a rate that was appropriate for the pavement temperature at the time of the application. Figure 3 provides the breakdown of percent acceptable, high, and low applications across the study period. Overall, 14 percent of applications were considered high, and 21 percent were low.

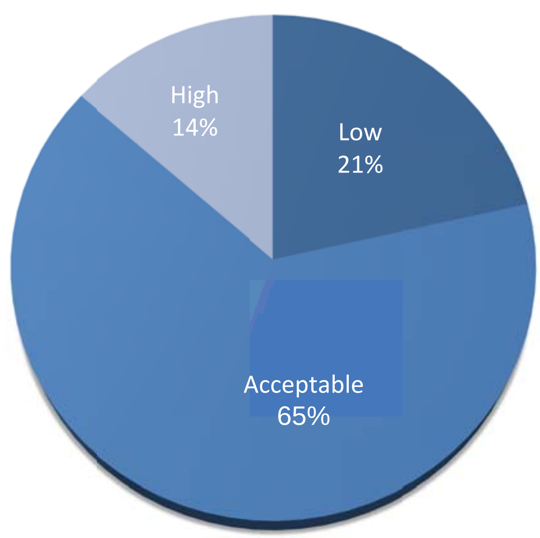
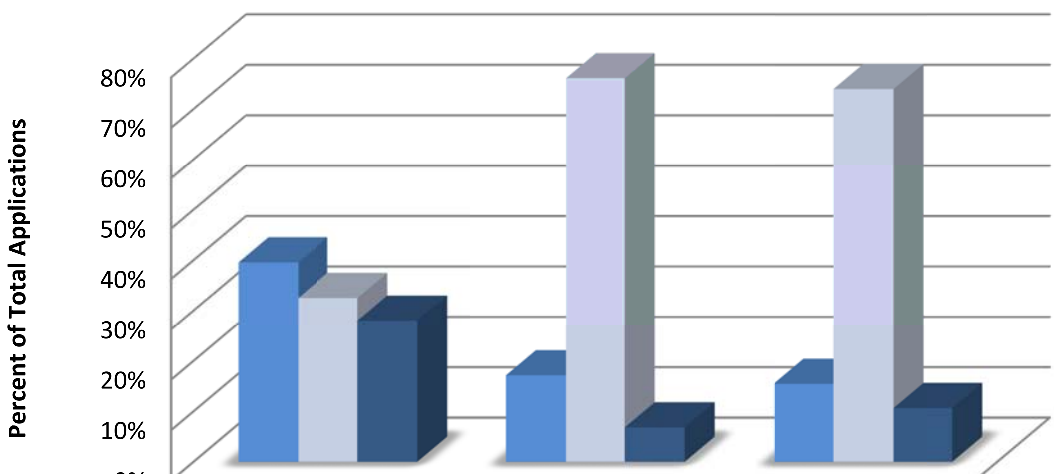



**Figure 3. Percent Acceptable, High, and Low Salt Applications Across the Study Period**

*Trends in Application Rates*

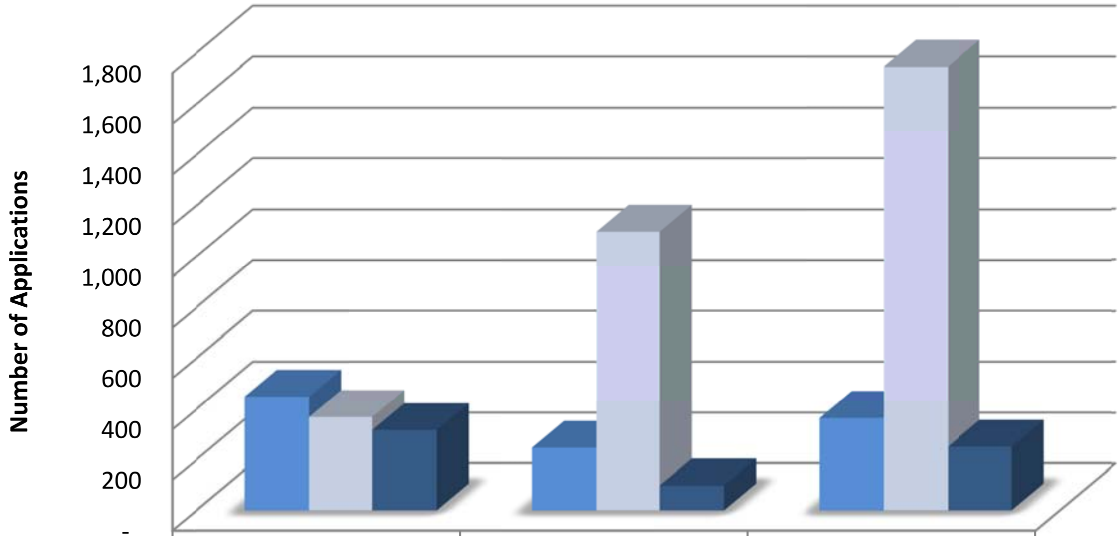
Figure 4 and Figure 5 provide a breakdown of acceptable, high, and low applications by percentages and totals for each of the three winter seasons. The percentage of acceptable applications increased from 32 percent in 2010 to 76 percent in winter 2011, and dropped slightly in 2012 to 74 percent (Figure 4). The percentage of low applications decreased steadily each year, from 40 percent in 2010 to 17 percent in 2011 and 15 percent in 2012. High application rates followed a similar downward trend over the study period, from 28 percent high applications in 2010, decreasing to 7 percent in 2011, before slightly increasing to 11 percent in 2012. The total number of applications categorized as acceptable increased steadily over the study period, while high and low applications decreased from 2010 to 2011, but increased from 2011 to 2012 (Figure 5). Despite this increase between 2011 and 2012, both high and low applications were lower in 2012 than in 2010.

The number and percentage of acceptable applications was higher in winters 2011 and 2012, as compared to 2010. Consequently, the percentage and total number of high and low applications was lower in 2011 and 2012, as compared to 2010. The number and percentage of high applications increased from 7 percent (98 applications) in 2011 to 11 percent (251 applications) in 2012. This resulted in a decrease in the percentage of acceptable applications from 76 percent in 2011 to 74 percent in 2012.




| | 2010 | 2011 | 2012 |
|---|---|---|---|
| Low | 40% | 17% | 15% |
| Acceptable | 32% | 76% | 74% |
| High | 28% | 7% | 11% |

**Figure 4. Percent Distribution of Total Application Conformance with ADOT WSMOM Guidance**



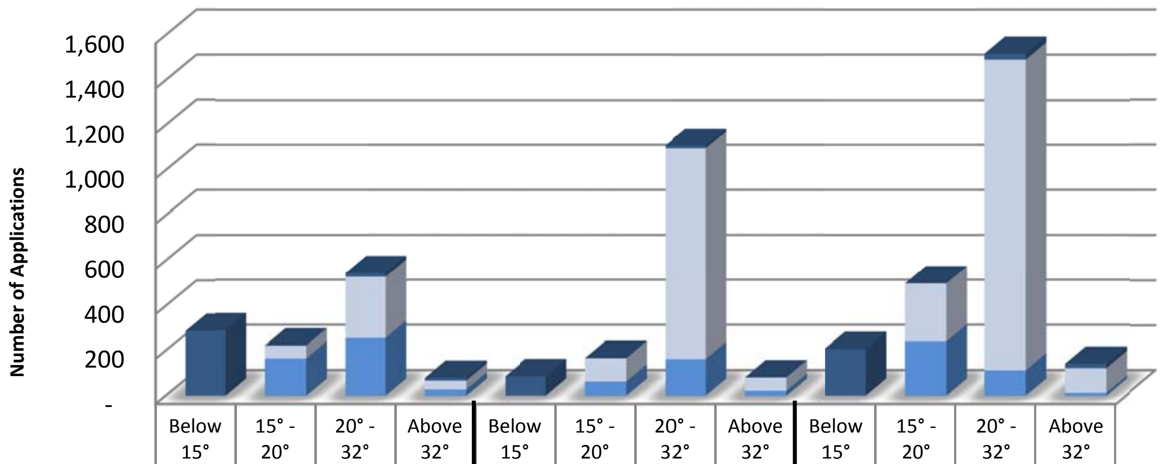

| | 2010 | 2011 | 2012 |
|---|---|---|---|
| Low | 448 | 247 | 364 |
| Acceptable | 368 | 1,098 | 1,746 |
| High | 317 | 98 | 251 |

**Figure 5. Application Conformance with ADOT WSMOM Guidance**

*Pavement Temperatures and Acceptable Application Rates*

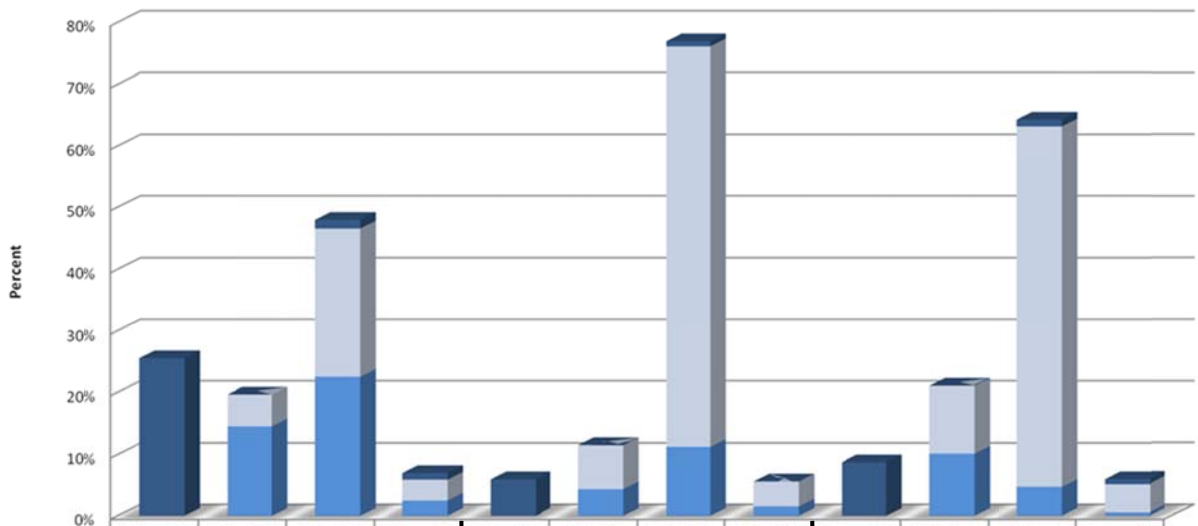
The ADOT WSMOM application rate guidance recommends application rates on the basis of six temperature ranges and trends. One factor that appears to directly influence the number and percentage of acceptable applications is the frequency of applications that correspond to pavement temperatures below 15° F. ADOT guidance for pavement temperature below 15° F is that snow and ice should be removed from the roadway via physical means only (e.g., plowing), applications of cinders can be made to provide traction, and no chemicals should be applied. Therefore, any chemical application that corresponds to this temperature range would be considered high.

In 2010, 317 applications were categorized as high (Figure 5). Of that total, 289 applications (or 91 percent) corresponded to pavement temperatures below 15° F (Figure 6). Only 28 applications corresponding to pavement temperatures above 15° F were considered high. In 2011, the number of high applications fell to 98, down from 28 percent of all applications in 2010 to 7 percent of all applications in 2011 (Figure 7). Of the 98 applications that were high, 88 percent, or 86 applications, corresponded to pavement temperatures below 15° F. In 2012, the percentage of applications that were considered high increased to 11 percent, or 251 total applications. The percentage of all applications that corresponded to pavement temperatures below 15° F increased as well, from 6 percent in 2011 to 9 percent in 2012. Of the 251 applications that were considered high in 2012, 82 percent (or 206 applications) corresponded to pavement temperatures below 15° F. The similarity of Figures 6 and 7 reinforces the idea that individual applications tend to fall within ADOT WSMOM guidance when pavement temperatures are within a range of 20° F and 32° F. The frequency of application versus temperature ranges for the study period are compiled in Figure 8.



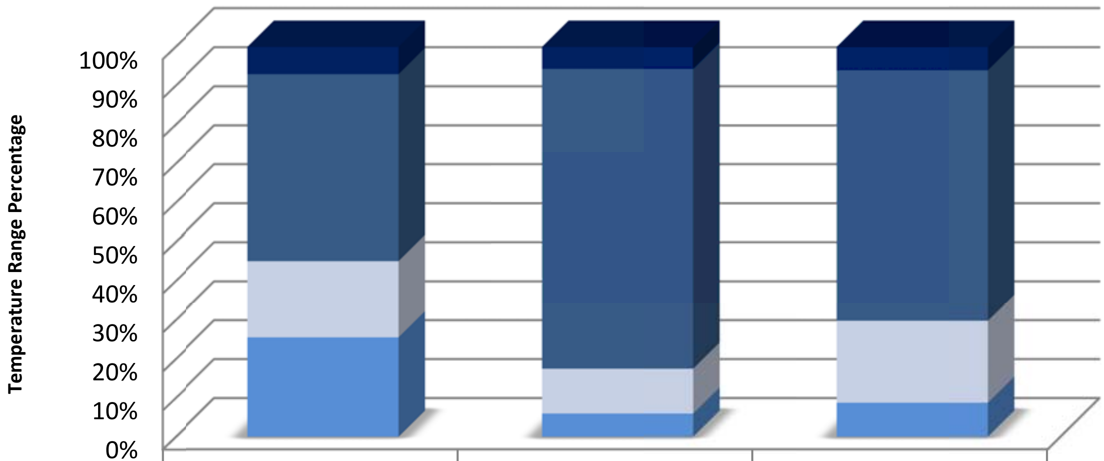

| | 2010 | | | | 2011 | | | | 2012 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Below 15° | 15° - 20° | 20° - 32° | Above 32° | Below 15° | 15° - 20° | 20° - 32° | Above 32° | Below 15° | 15° - 20° | 20° - 32° | Above 32° |
| High | 289 | - | 16 | 12 | 86 | - | 12 | - | 206 | - | 26 | 19 |
| Acceptable | - | 57 | 272 | 39 | - | 103 | 936 | 59 | - | 258 | 1,379 | 109 |
| Low | - | 165 | 255 | 28 | - | 63 | 162 | 22 | - | 239 | 112 | 13 |

**Figure 6. Total Application Conformance with ADOT WSMOM Guidance, by Year and Pavement Temperature Range**




| | Below 15° | 15° - 20° | 20° - 32° | Above 32° | Below 15° | 15° - 20° | 20° - 32° | Above 32° | Below 15° | 15° - 20° | 20° - 32° | Above 32° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | | | | 2011 | | | | 2012 | | | |
| High | 26% | 0% | 1% | 1% | 6% | 0% | 1% | 0% | 9% | 0% | 1% | 1% |
| Acceptable | 0% | 5% | 24% | 3% | 0% | 7% | 65% | 4% | 0% | 11% | 58% | 5% |
| Low | 0% | 15% | 23% | 2% | 0% | 4% | 11% | 2% | 0% | 10% | 5% | 1% |

**Figure 7. Percentage of Chemical Applications Below, Within, and Above ADOT Guidance Rate, by Year and Pavement Temperature Range**




| | 2010 | 2011 | 2012 |
|---|---|---|---|
| Above 32° | 7% | 6% | 6% |
| 20° - 32° | 48% | 77% | 64% |
| 15° - 20° | 20% | 12% | 21% |
| Below 15° | 26% | 6% | 9% |

**Figure 8. Frequency of Application versus Pavement Temperature Ranges, by Year**

During 2010, applications corresponding to a pavement temperature range of 20° F to 32° F accounted for 48 percent of all applications evaluated. During this period, 33 percent of the total applications fell outside of the acceptable category (below 15° F and above 32° F), the highest percentage of applications out of the acceptable range for the entire study period. In 2011 and 2012, these percentages shifted significantly, as the frequency of applications corresponding to pavement temperatures below 15° F decreased and those corresponding to pavement temperatures between 20° F and 32° F increased. For 2011 and 2012, applications at temperatures below 15° F accounted for only 6 and 9 percent, respectively, whereas applications at pavement temperatures between 20° F and 32° F rose to 77 and 64 percent, respectively. This shift is attributed to the range of application rates prescribed under the ADOT WSMOM guidance.

The shift in overall frequency of applications away from the "below 15° F" pavement temperature range to the "20° F to 32° F" pavement temperature range has a direct impact on the percentage of applications that are within ADOT WSMOM application guidelines. This impact is due not only to a reduction in the frequency of applications within an unacceptable low or high temperature range, but also an increase in the frequency of applications within a temperature range that was shown to have a high percentage of applications deemed acceptable. As shown in Figure 9c, 81 percent of the applications were made when pavement temperatures were between 20° F and 32° F. These applications fall within ADOT WSMOM guidance and are therefore deemed acceptable. ADOT WSMOM guidance provides a recommended application rate that ranges between 100 lb/lane-mile to

325 lb/lane-mile when temperatures are between 20° F and 32° F. Of the 4,937 applications reviewed, 3,992 (or 81 percent) were between 100 and 325 lb/lane-mile.

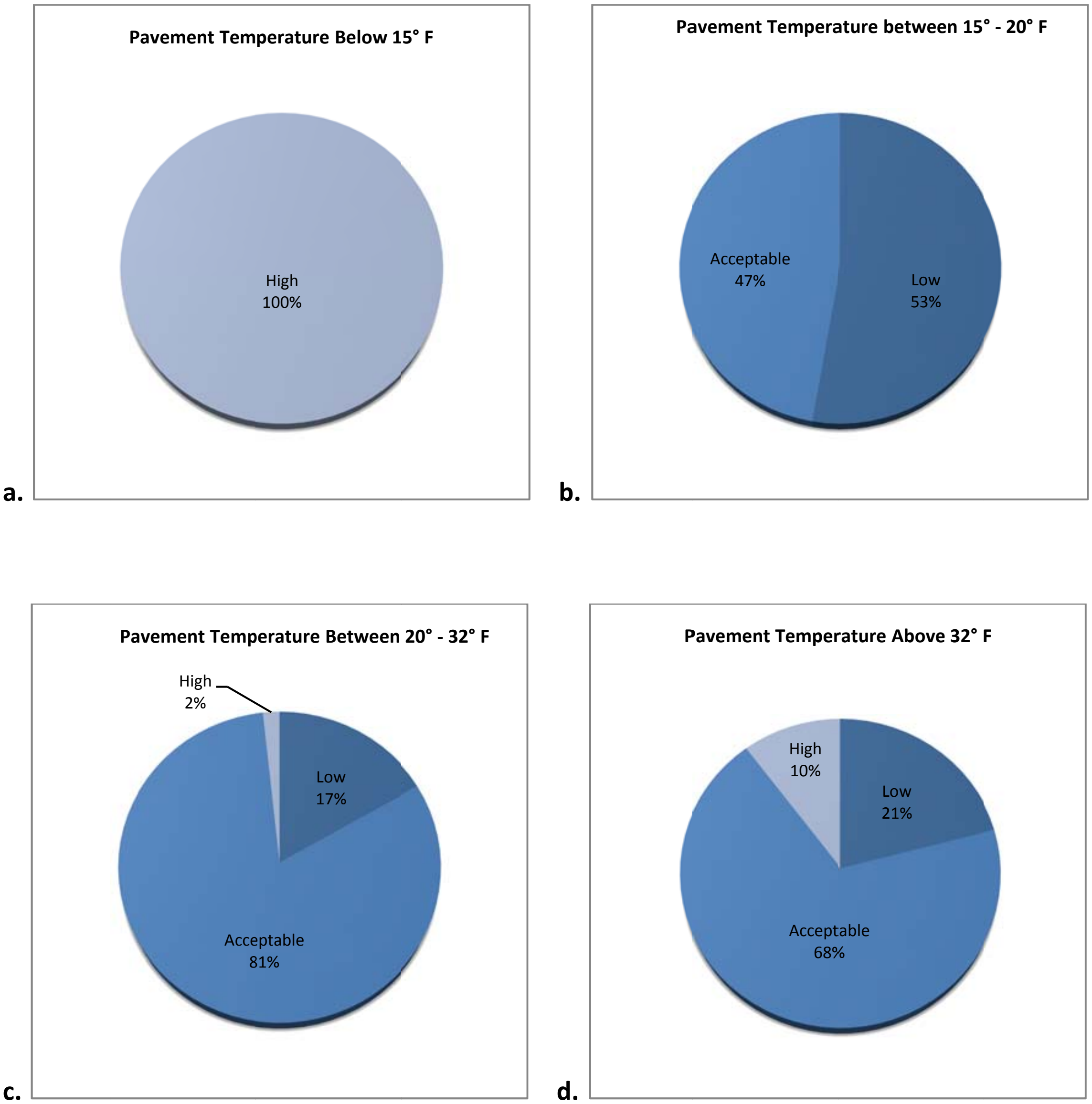



**Figure 9. Application Rate Conformance to ADOT WSMOM Guidance, by Pavement Temperature During the Study Period**

The correlation between the frequency of applications that correspond to the "below 15° F" and the "20° F to 32° F" pavement temperature ranges, and the tendency of the applications to be considered acceptable or high is illustrated in Figure 10. The increase in acceptable applications and decrease in high applications from 2010 to 2011 is clearly shown to correlate to the decreased percentage of applications that corresponded to pavement temperatures below 15° F and the subsequent increase in applications that corresponded to pavement temperatures from 20° F to 32° F. The slight increase in high applications between 2011 and 2012, from 7 percent to 11 percent, is also clearly correlated to a slight increase in frequency of applications corresponding to pavement temperatures below 15° F, from 6 percent in 2011 to 9 percent in 2012.

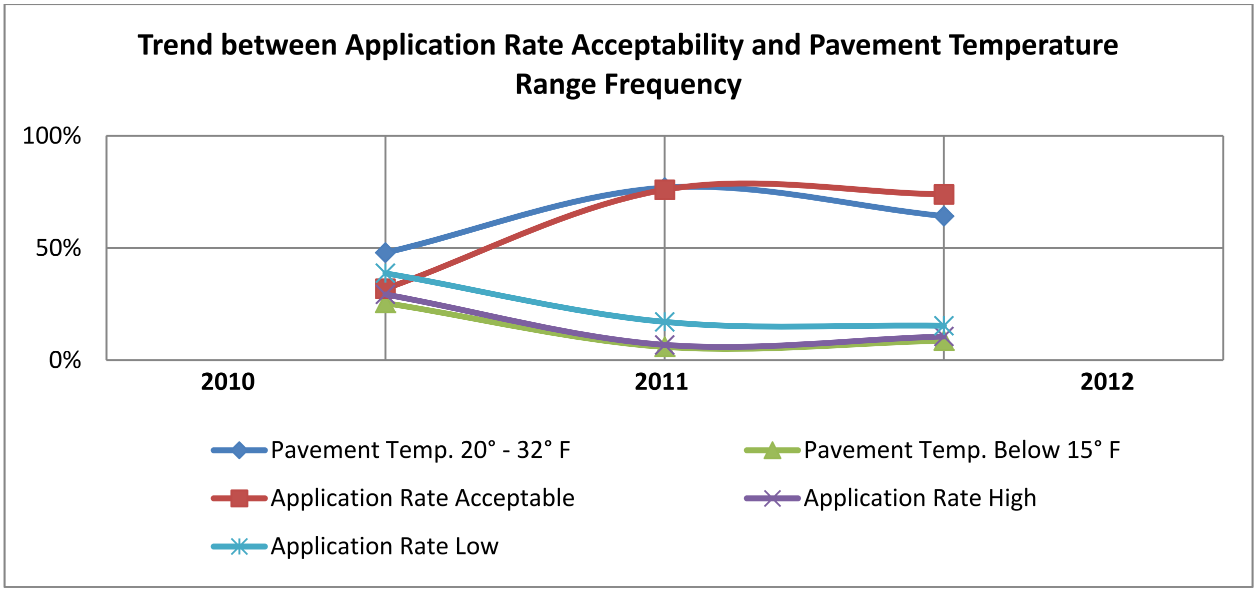
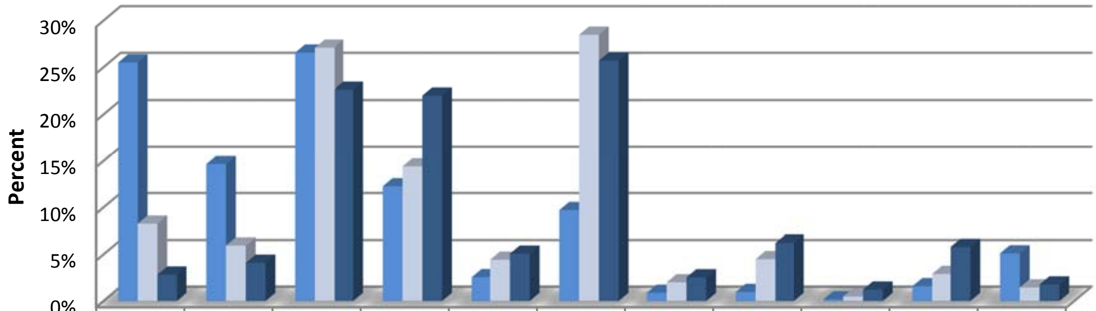



**Figure 10. Trend Between Application Rate Acceptability and Pavement Temperature Range Frequency**

*Application Rates Below ADOT WSMOM Guidance*

Applications categorized as low showed a decreasing trend over the three winter seasons, from 40 percent in 2010 to 17 and 15 percent in 2011 and 2012, respectively. An evaluation of the frequency of low applications across the three winter seasons reveals a shift in the application rates (application rates as outlined by the ADOT WSMOM guidelines). Figure 11 illustrates the percentages of categorized applications for each of the three seasons, by application rate (in lb/lane-mile).




| | 50 (lb/lane-mile) | 75 (lb/lane-mile) | 100 (lb/lane-mile) | 150 (lb/lane-mile) | 175 (lb/lane-mile) | 200 (lb/lane-mile) | 225 (lb/lane-mile) | 250 (lb/lane-mile) | 275 (lb/lane-mile) | 300 (lb/lane-mile) | 400 (lb/lane-mile) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 26% | 15% | 27% | 12% | 3% | 10% | 1% | 1% | 0% | 2% | 5% |
| 2011 | 8% | 6% | 27% | 14% | 4% | 28% | 2% | 5% | 0% | 3% | 1% |
| 2012 | 3% | 4% | 23% | 22% | 5% | 26% | 3% | 6% | 1% | 6% | 2% |

**Figure 11. Seasonal Application Frequency, by Year**

In 2010, 26 percent of all chemical applications were at a rate of 50 lb/lane-mile. This rate is below the lowest application rate prescribed by ADOT guidance for any temperature range; therefore, it is always categorized as a low application unless applied in correlation to a pavement temperature below 15° F, in which case it would be categorized as high. Recall from Figure 4 that in winter 2010, 40 percent of all applications were categorized as low. The majority of low applications consisted of applications using a rate of 50 lb/lane-mile. As the percentage of applications at the 50 lb/lane-mile rate decreased in subsequent seasons, so did the total percentage of low applications. As shown in Figure 11, the percentage of the season total applications at the 50 lb/lane-mile rate declined from 26 percent to 8 and 3 percent, sequentially. As a result, the total percent of applications categorized as low declined from 40 percent to 17 and 15 percent, sequentially (refer back to Figure 4).

In summary, the pavement temperature range of 20° F to 32° F has the highest percentage of acceptable application rate associated with it, with 81 percent of applications associated with this temperature range being acceptable. In a given season, the percentages of acceptable and high applications are directly related to the number of applications associated with pavement temperatures of 20–32° F and below 15° F, respectively.

## DISTRIBUTION OF SALT LEVELS IN SOIL

Concentrations of chloride were higher in the A1 samples than in the X samples when averaged across all BMS. However, the difference in chloride concentrations between the A1 and X samples was minor. The average of the four A1 samples across all BMS was less than the spring 2012 A1 sample. The averages of all A1 samples and the spring 2012 A1 sample were 83 mg/kg and 102 mg/kg, respectively. The average chloride concentration of the X samples was 62 mg/kg. A two sample t-test was conducted on the chloride level for the spring 2012 A1 samples and the X samples. The t-test indicated that the mean difference between the chloride levels of the spring 2012 A1 samples and the X samples was not significantly different ($p = 0.058$). These data are summarized in Table 5.

**Table 5. Summary of Chloride Concentrations for A1 and X Samples**

<table>
<tr><th>Sample</th><th>No.</th><th>No. Non-Detect</th><th>Min. (mg/kg)</th><th>Max. (mg/kg)</th><th>Median (mg/kg)</th><th>Mean (mg/kg)</th><th rowspan="2">Statistical Significance</th></tr>
<tr><td>A1: F11–S13</td><td>59</td><td>5</td><td>21</td><td>320</td><td>68</td><td>83</td></tr>
<tr><td>A1: S12</td><td>16</td><td>0</td><td>34</td><td>320</td><td>70</td><td>102</td><td rowspan="2">p = 0.058</td></tr>
<tr><td>X</td><td>16</td><td>0</td><td>33</td><td>91</td><td>65</td><td>62</td></tr>
</table>

The difference in the mean concentration of sodium in the A1 and X samples was more pronounced. The sodium concentrations of all A1 samples and the spring 2012 A1 samples were 512 mg/kg and 584 mg/kg, respectively. The mean sodium concentration of all X samples was 96 mg/kg. Sodium levels for seven X samples were non-detect, indicating that the sodium levels in the samples were lower than the laboratory's minimum detection level of 49 mg/kg. These data are summarized in Table 6.

**Table 6. Summary of Sodium Concentrations for A1 and X Samples**

| Sample | No. | No. Non-Detect | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) |
|---|---|---|---|---|---|---|
| A1: F11–S13 | 64 | 0 | 65 | 3,100 | 340 | 512 |
| A1: S12 | 16 | 0 | 98 | 2,900 | 410 | 584 |
| X | 9 | 7 | 53 | 280 | 78 | 96 |

An examination of individual A1 sample results for each sampling event and BMS indicated that the concentrations for three of the four samples at BMS 27 were significantly higher than for other samples. The A1 sample at BMS 27 is 15 ft from the edge of the pavement and at an even grade with the roadway. In addition, BMS 27 is adjacent to a five-lane roadway (two lanes in each direction and one turning lane), which receives higher salt applications compared to other BMS. These conditions may contribute to the excessively high concentrations at BMS 27. As a result, the sodium concentrations at BMS 27 skewed the overall mean for sodium concentrations in A1 samples, for both the entire A1 sample dataset and the spring 2012 data used to compare result to X samples. The individual sodium concentration results are presented in Figure 12.

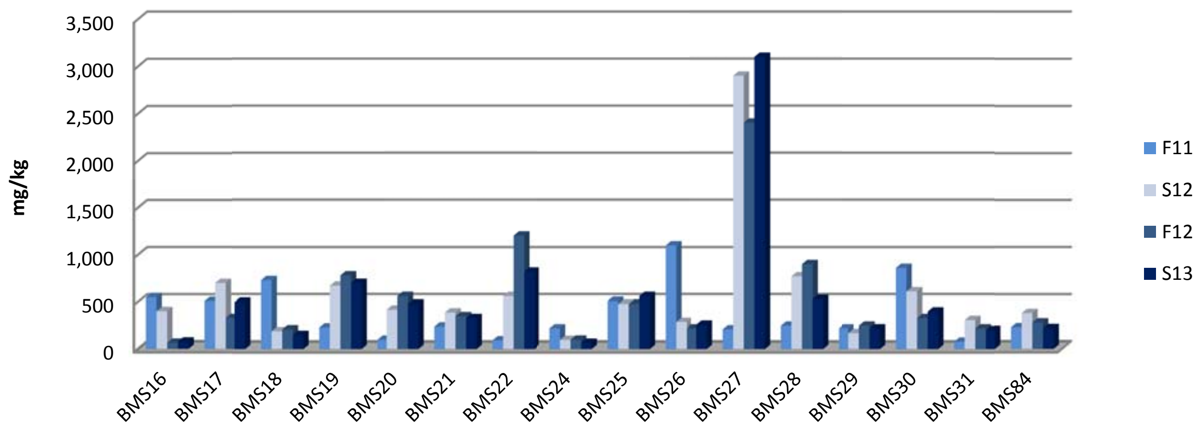



**Figure 12. A1 Sample Sodium Concentrations, by BMS**

To isolate the impact of the BMS 27 results on the rest of the dataset, the results for BMS 27 were excluded from the analysis of sodium concentrations within A1 and X samples. While the values changed, the mean concentrations remained significantly higher for the A1 samples than for the X samples. A two-sample t-test was conducted to evaluate the significance of the difference in the mean values of sodium between all A1 and X samples, and the spring 2012 A1 and X samples. The resulting p-values were 0.000, which is less than the minimum level of significance (0.05). On this basis, we can conclude that the sodium values were significantly higher in soil close to the roadway (A1 samples) than in soils that are considered background (X samples). The data are summarized in Table 7.

**Table 7. Summary of Sodium Concentrations for A1 and X Samples Without BMS 27**

| Sample | No. | No. Non-Detect | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) | Statistical Significance |
|---|---|---|---|---|---|---|---|
| A1: F11–S13 | 60 | 0 | 65 | 1,200 | 330 | 402 | $p = 0.000$ |
| A1: S12 | 15 | 0 | 98 | 770 | 400 | 429 | $p = 0.000$ |
| X | 8 | 7 | 280 | 811 | 82 | 101 | |

**Comparison of A1 and B1 Samples**

The concentrations of chloride in the A1 and B1 samples, for the 11 BMS where B1 samples were collected in both fall 2012 and spring 2013, were relatively similar. Two A1 and four B1 samples reported values below the laboratory detection limit (20 mg/kg). The mean concentrations in the A1 and B1 samples were 89 mg/kg and 80 mg/kg, respectively. These data are summarized in Table 8. An ANOVA was conducted on the dataset to measure the impact that the sample location and season, as well as their interaction, have on the mean concentrations of chloride in the soil. The analysis did not indicate a significant difference. As a result, we cannot reject the null hypothesis, that the difference in the mean concentration of chloride between A1 and B1 samples is insignificant.

**Table 8. Concentrations of Chloride in A1 and B1 Samples, F12-S13**

| Sample | No. | No. Non-Detect | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) | Statistical Significance by Factor | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Sample Location | Season | Sample Season |
| A1 | 20 | 2 | 21 | 190 | 84 | 89 | p= 0.633 | p=0.92 | p=0.136 |
| B1 | 18 | 4 | 40 | 320 | 60 | 80 | | | |

Sodium concentrations were found to be higher in the A1 samples on average than in the B1 samples. The average sodium concentration in the A1 samples for fall 2012 and spring 2013 were 385 mg/kg and 358 mg/kg, respectively, for a combined average of 371 mg/kg. The sodium concentrations in the B1 samples for the fall 2012 and spring 2013 sampling periods averaged 166 mg/kg and 156 mg/kg, respectively, with a combined average of 161 mg/kg. These data are summarized in Table 9. The difference in the mean concentrations of A1 and B1 samples was found to be significant, with a p-value of 0.0002. As a result, we can reject the null hypothesis, that the difference in the mean sodium concentrations between the A1 and B1 sample regions is not significantly different. On this basis, we can conclude that WSM activities, namely the application of salts, have an impact on the sodium concentrations in soil along ADOT ROWs.

**Table 9. Concentrations of Sodium in A1 and B1 Samples, F12-S13**

| Sample | No. | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) | Statistical Significance by Factor | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Sample Location | Season | Sample Season |
| A1 | 22 | 67 | 900 | 330 | 371 | p= 0.0002 | p=0.72 | p=0.87 |
| B1 | 22 | 49 | 440 | 135 | 161 | | | |

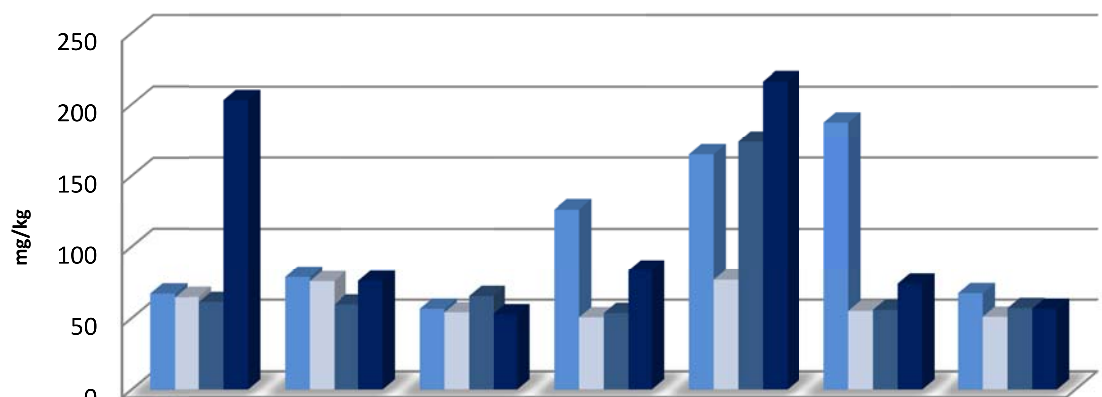
**Impact of Drainage**

The impact that drainage may have on the distribution of salts within the BMS was evaluated though the stream-related sampling at BMS 20, 21, 22, 24, 26, 30, and 31. The sampling was conducted on a consistent basis throughout the entire course of the research. In contrast to other relationships evaluated in the research, the impact of drainage on the distribution of salts throughout the BMS was assessed on an individual BMS level rather than across all BMS. Drainage characteristics are quite site specific, and the relationship between the samples varies from site to site. Combining all drainage-related samples may cause some factors to be ignored in the analysis.

Impacts due to drainage conditions were assessed using both chloride and sodium concentrations. Concentrations of chloride in drainage-related samples showed patterns similar to those observed for concentrations of sodium in drainage-related samples. Concentrations of sodium and chloride varied between sample locations and sites. Chloride concentrations were highest in A1 samples at three sites, and highest in E1 samples at two sites. Only one BMS, Site 22, showed the highest relative chloride concentrations in the D1 samples. The same BMS showed inequal chloride concentrations in the U1 and E1 samples. These data are summarized in Table 10 and Figure 13. The results suggest that proximity to the roadway plays a larger role in the spatial distribution of chloride concentrations at a given site than the site's location within a drainage system. These results do not show that chloride concentrations are significantly related to drainage characteristics at a BMS.

**Table 10. Spatial Comparison of Sample Chloride Concentrations for Select BMS**

| BMS | Sample | No. | Min. mg/kg | Max. mg/kg | Median mg/kg | Mean mg/kg | BMS | Sample | No. | Min. mg/kg | Max. mg/kg | Median mg/kg | Mean mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | A1 | 3 | 58 | 73 | 71 | 67 | 26 | A1 | 4 | 100 | 260 | 150 | 165 |
| | U1 | 3 | 64 | 65 | 65 | 65 | | U1 | 4 | 42 | 140 | 63 | 77 |
| | D1 | 4 | 49 | 74 | 61 | 61 | | D1 | 4 | 59 | 290 | 174 | 174 |
| | E1 | 3 | 110 | 330 | 170 | 203 | | E1 | 4 | 65 | 360 | 220 | 216 |
| 21 | A1 | 4 | 21 | 130 | 82 | 79 | 30 | A1 | 4 | 100 | 320 | 165 | 188 |
| | U1 | 4 | 42 | 120 | 71 | 76 | | U1 | 4 | 33 | 68 | 59 | 55 |
| | D1 | 4 | 37 | 77 | 62 | 59 | | D1 | 4 | 35 | 68 | 60 | 56 |
| | E1 | 3 | 68 | 84 | 76 | 76 | | E1 | 4 | 41 | 100 | 78 | 74 |
| 22 | A1 | 4 | 47 | 64 | 57 | 56 | 31 | A1 | 4 | 34 | 130 | 53 | 67 |
| | U1 | 4 | 51 | 56 | 54 | 54 | | U1 | 3 | 35 | 63 | 54 | 51 |
| | D1 | 4 | 52 | 76 | 67 | 65 | | D1 | 4 | 32 | 82 | 57 | 57 |
| | E1 | 3 | 47 | 56 | 54 | 52 | | E1 | 4 | 37 | 73 | 58 | 56 |
| 24 | A1 | 4 | 85 | 160 | 130 | 126 | | | | | | | |
| | U1 | 4 | 35 | 60 | 53 | 50 | | | | | | | |
| | D1 | 4 | 49 | 58 | 53 | 53 | | | | | | | |
| | E1 | 4 | 52 | 140 | 71 | 83 | | | | | | | |

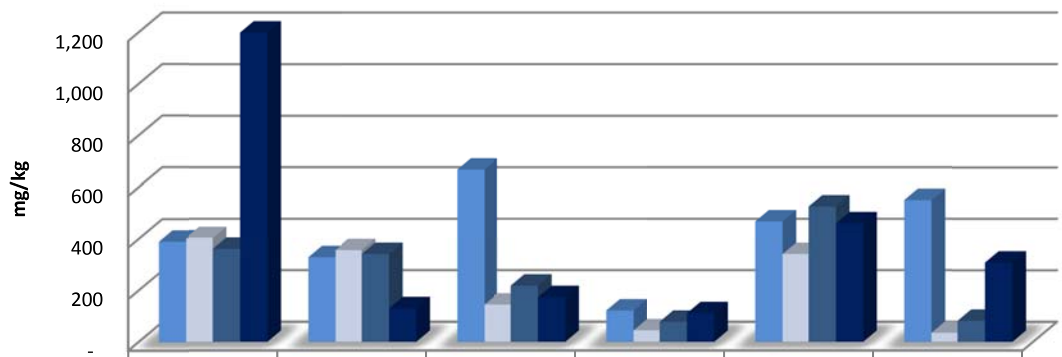



| | BMS20 | BMS21 | BMS22 | BMS24 | BMS26 | BMS30 | BMS31 |
|---|---|---|---|---|---|---|---|
| A1 | 67 | 79 | 56 | 126 | 165 | 188 | 67 |
| U1 | 65 | 76 | 54 | 50 | 77 | 55 | 51 |
| D1 | 61 | 59 | 65 | 53 | 174 | 56 | 57 |
| E1 | 203 | 76 | 52 | 83 | 216 | 74 | 56 |

**Figure 13. Comparisons of Chloride Concentrations in A1, U1, D1, and E1 Samples for Select BMS**

Mean concentrations of sodium in the drainage-related samples varied between BMS and among samples. A1 samples had the highest mean concentration of sodium at three of the six BMS (22, 24, and 30); this supports the conclusion that sodium concentrations are higher in closer proximity to the roadway (also supported by the analysis between A1 samples and B1 and X samples). A meaningful analysis of sodium concentrations at BMS 31 was not possible because the majority of U1, D1, and E1 samples were reported to have concentrations of sodium below the laboratory detection limit of 49 mg/kg.

Comparisons of sodium concentrations in various sampling points at select BMS are presented in Figure 14. The E1 sample had the highest sodium concentration at BMS 20, whereas the D1 sample had the highest sodium concentration at BMS 26. Two factors must be considered when evaluating the significance of the relatively high E1 and D1 samples. With regard to the D1 sample at BMS 21, while the mean sodium concentration was higher than for the A1 sample, the D1 sample was averaged over three samples that reported above the laboratory detection limit of 49 mg/kg. The fall 2011 D1 sample for BMS 21 was reported as non-detect, meaning the sample contained less than 49 mg/kg of sodium. Taking the mean value of all four D1 samples for BMS 21, and assuming the fall 2011 sodium concentration was just below the laboratory detection limit, the mean concentration of the D1 samples would be less than or equal to 352 mg/kg, which is nearly equal to the A1 and U1 sample means.




| | BMS20 | BMS21 | BMS22 | BMS24 | BMS26 | BMS30 |
|---|---|---|---|---|---|---|
| A1 | 390 | 328 | 668 | 121 | 468 | 550 |
| U1 | 403 | 355 | 144 | 45 | 340 | 35 |
| D1 | 360 | 340 | 218 | 78 | 525 | 82 |
| E1 | 1,200 | 130 | 173 | 111 | 460 | 308 |

**Figure 14. Comparisons of Chloride Concentrations in A1, U1, D1, and E1 Samples for Select BMS**

In Table 11, the relatively high mean concentrations in two drainage-related samples, namely E1 and D1 at BMS 20 and 26, suggest that proximity to the roadway was more important than drainage conditions.

Table 12 shows sampling distances from the roadway for all drainage-related sampling locations: the E1 sample at BMS 20 and all drainage-related samples at BMS 26 were all less than 50 ft from the edge of the roadway, which is within the A1 sampling range. The extremely high mean concentration for the E1 sample at BMS 20 was taken at approximately 5 ft from the roadway.

**Table 11. Spatial Comparison of Sample Sodium Concentrations for Select BMS**

| BMS | Sample | No. | Min. mg/kg | Max. mg/kg | Median mg/kg | Mean mg/kg | BMS | Sample | No. | Min. mg/kg | Max. mg/kg | Median mg/kg | Mean mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | A1 | 4 | 100 | 560 | 450 | 390 | 24 | A1 | 4 | 67 | 220 | 99 | 121 |
| | U1 | 4 | 250 | 550 | 405 | 403 | | U1 | 3 | 57 | 64 | 57 | 59 |
| | D1 | 4 | 120 | 470 | 425 | 360 | | D1 | 4 | 61 | 91 | 79 | 78 |
| | E1 | 4 | 320 | 2,300 | 1,090 | 1,200 | | E1 | 4 | 69 | 160 | 107 | 111 |
| 21 | A1 | 4 | 240 | 390 | 340 | 328 | 26 | A1 | 4 | 220 | 1,100 | 275 | 477 |
| | U1 | 4 | 230 | 330 | 315 | 355 | | U1 | 4 | 290 | 400 | 335 | 340 |
| | D1 | 3 | 250 | 750 | 360 | 453 | | D1 | 4 | 340 | 690 | 535 | 525 |
| | E1 | 3 | 110 | 150 | 130 | 130 | | E1 | 4 | 300 | 620 | 460 | 460 |
| 22 | A1 | 4 | 93 | 1,200 | 690 | 668 | 30 | A1 | 4 | 330 | 860 | 505 | 550 |
| | U1 | 4 | 76 | 200 | 150 | 144 | | U1 | 1 | 140 | 140 | 140 | 140 |
| | D1 | 4 | 140 | 260 | 235 | 218 | | D1 | 4 | 55 | 140 | 66 | 82 |
| | E1 | 4 | 92 | 390 | 105 | 173 | | E1 | 4 | 64 | 1,000 | 84 | 308 |

**Table 12. Distance from Edge of Pavement (in ft) for Select BMS Samples**

| Site | A1 | U1 | D1 | E1 |
|---|---|---|---|---|
| BMS 20 | 31 | 82 | 84 | 5 |
| BMS 21 | 18 | 68 | 78 | 50 |
| BMS 22 | 18 | 68 | 106 | 58 |
| BMS 24 | 25 | 30 | 88 | 36 |
| BMS 26 | 20 | 46 | 38 | 39 |
| BMS 30 | 22 | 130 | 91 | 77 |

### Seasonal Fluctuations in Salt Concentrations

The mean sodium concentrations of the A1 samples have been shown to be significantly different from the mean sodium concentrations of B1 and X samples, indicating that WSM activities are resulting in higher sodium accumulations in soil nearer to the road. To examine the extent to which WSM activities have short-term or immediate impacts on the soil near the roadway, sodium concentrations were evaluated between individual sampling events and seasons. A comparison of the seasonal mean sodium concentrations provides an indication as to whether winter applications of chemical are causing an increase in sodium concentrations from fall to spring, and whether summer rainfall is effectively leaching sodium from the top 12 inches of the soil profile.

The mean concentrations of sodium in A1 samples are listed in the tables below. Table 13 presents the mean concentrations per sampling event across all BMS (including BMS 27, considered an outlier) and shows a significant increase of nearly 200 mg/kg from fall 2011 to spring 2012; Table 14 excludes the mean concentrations for BMS 27 and shows that the increase was due primarily to the excessive jump in concentrations attributed to BMS 27. When BMS 27 results are removed from the analysis, the mean sodium concentration varies by only 61 mg/kg over the course of the study. The values provided in these two tables show that sodium concentrations in the A1 samples did not vary considerably.

**Table 13. Concentrations of Sodium Within A1 Samples, by Sampling Event**

| Season | No. | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) |
|---|---|---|---|---|---|
| Fall 2011 | 16 | 78 | 1,100 | 235 | 383 |
| Spring 2012 | 16 | 98 | 2,900* | 410 | 584 |
| Fall 2012 | 16 | 65 | 2,400* | 330 | 542 |
| Spring 2013 | 16 | 67 | 3,100* | 365 | 538 |

*BMS 27

**Table 14. Concentrations of Sodium Within A1 Samples, by Sampling Event, Excluding BMS 27**

| Season | No. | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) |
|---|---|---|---|---|---|
| Fall 2011 | 15 | 78 | 1,100 | 240 | 395 |
| Spring 2012 | 15 | 98 | 770 | 400 | 429 |
| Fall 2012 | 15 | 65 | 1,200 | 330 | 418 |
| Spring 2013 | 15 | 67 | 810 | 330 | 368 |

The mean sodium concentrations calculated for fall and spring sampling events, both with and without the BMS 27 sodium results included in the analysis, are presented in Table 15. A paired t-test was conducted on the mean sodium concentrations for fall and spring seasons to evaluate the null hypothesis, which assumes that there is no difference in the mean sodium concentrations between seasons. The t-test produced p-values of 0.3286 (with BMS 27) and 0.8758 (without BMS 27) for the comparison between fall and spring mean concentrations. Therefore, it cannot be assumed that the mean sodium concentrations were different between the fall and spring seasons.

**Table 15. Concentrations of Sodium Within A1 Samples, by Season**

| Sample | No. | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) | Statistical Significance |
|---|---|---|---|---|---|---|
| Fall | 32 | 65 | 2,400 | 265 | 463 | p=0.3286 |
| Spring | 32 | 67 | 3,100 | 400 | 561 | |
| Fall (less BMS 27) | 30 | 65 | 1,200 | 265 | 407 | p=0.8758 |
| Spring (less BMS 27) | 30 | 67 | 820 | 395 | 398 | |

*Impact of Variable Chemical Applications*

While the analysis of sodium concentrations between fall and spring seasons indicates that the mean concentrations were not significantly different, the impact of winter applications was examined further to assess whether the rate of application had an impact on the sodium concentrations within A1 samples. Total chemical applications at each BMS were calculated as an application rate per lane-mile in three ways: the total across all roadway travel lanes at the BMS (Figure 15); the total applied to the lane adjacent to the BMS (Figure 16); and the total applied to the lanes that slope toward the BMS (Figure 17).

The total chemical applications were plotted against the A1 sample concentration in the spring season that followed the winter application, and against the change in the A1 sample sodium concentration from fall to spring (Figure 18, Figure 19, and Figure 20). These plots do not indicate a linear relationship between the total material applied to the roadway and the concentration of sodium in the A1 samples immediately after the application season. While it is likely that chemical applications in the past have played an impact on the current levels of sodium in the soil adjacent to the roadways, a similar impact is not clear within the short timeframe of this study.

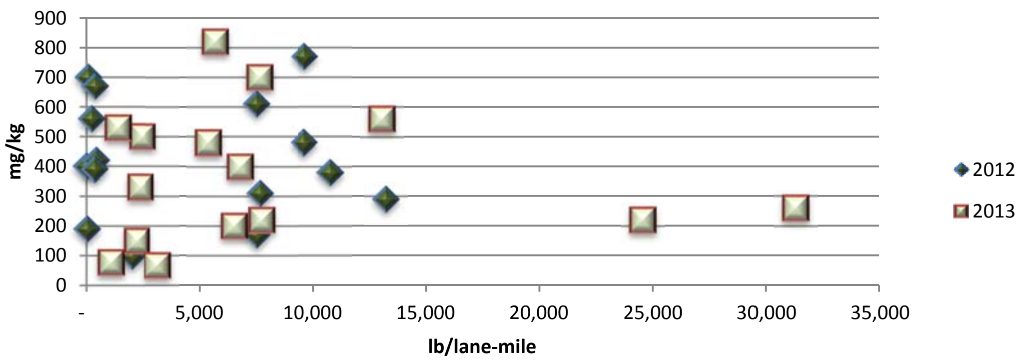



**Figure 15. Chemical Application per Lane-mile at BMS and Spring A1 Sample Sodium Concentrations**

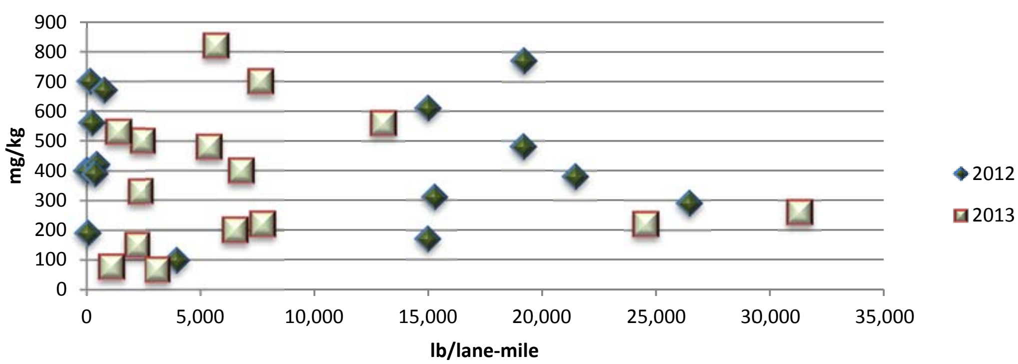



**Figure 16. Chemical Applications to Lanes Adjacent to BMS and Spring A1 Sample Sodium Concentrations**

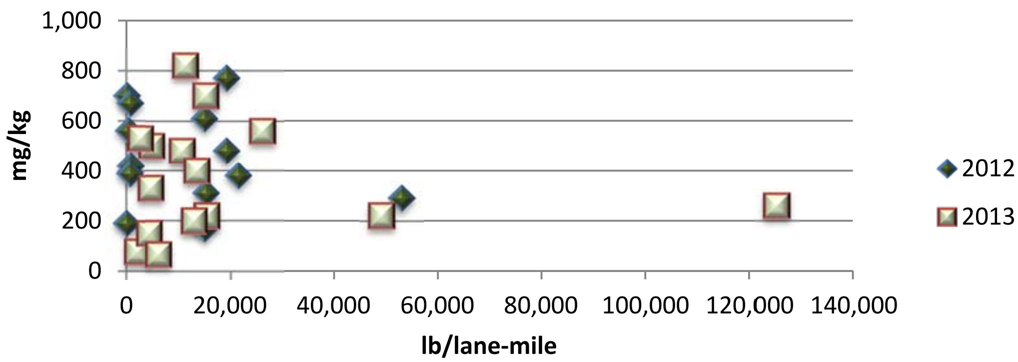



**Figure 17. Chemical Applications to Lanes Draining to BMS and Spring A1 Sample Sodium Concentrations**

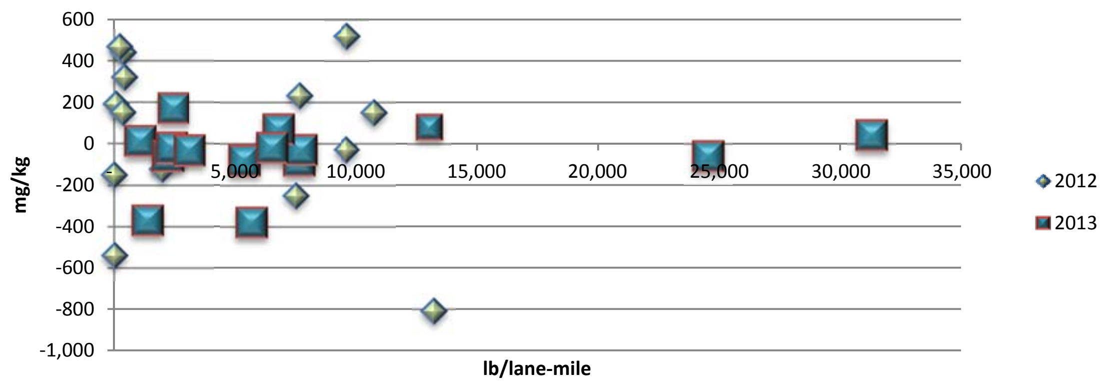



**Figure 18. Chemical Application per Lane-mile at BMS and the Change in A1 Sample Sodium Concentrations from the Fall-to-Spring Sampling Season**

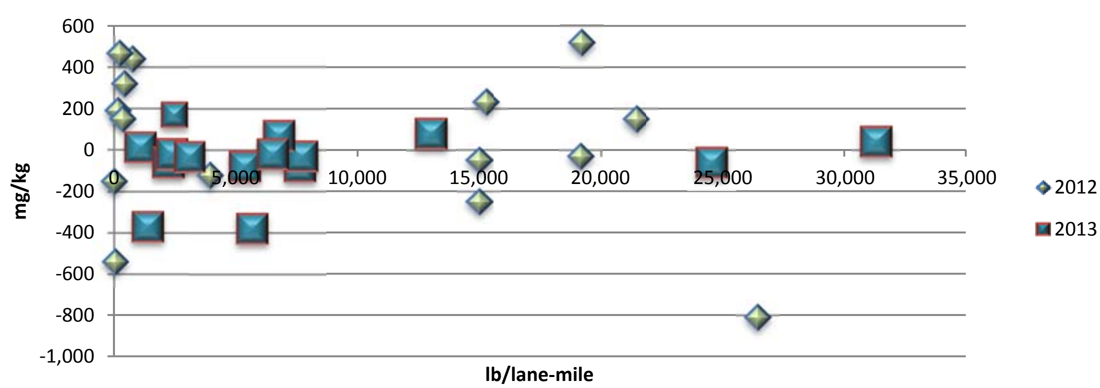



**Figure 19. Chemical Application to Lanes Draining to BMS and the Change in A1 Sample Sodium Concentrations from the Fall-to-Spring Sampling Season**

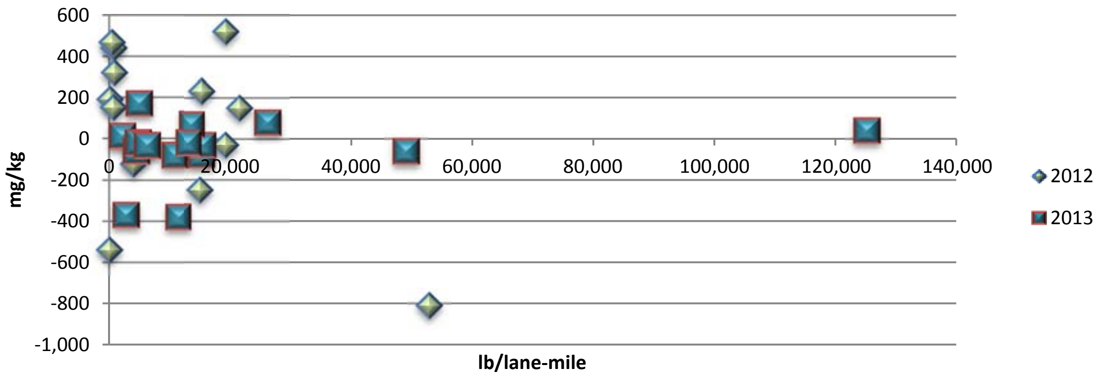



**Figure 20. Total Chemical Application to All Lanes at BMS and the Change in A1 Sample Sodium Concentrations from the Fall-to-Spring Sampling Season**

*Sodium Adsorption Ratio*

When soil becomes overloaded with sodium, a myriad of issues can occur that include nutrient deficiencies, toxicity to plants, and a breakdown of soil structure. This overloaded soil is generally referred to as sodic soil. Sodic soil is characterized by high concentrations of sodium in comparison to calcium and magnesium and by a sodium adsorption ratio (SAR) of 13 or greater (Davis et al. 2012). While a considerable number of soil samples analyzed as part of this study had levels of sodium above background levels, only one of the 347 samples analyzed had a SAR value greater than 13. BMS 27-S12-A2 had a SAR of 240; however, the SAR fell to 0.8 and 1.3 in subsequent sampling events. It is suspected that the sodium concentration that resulted in a SAR of 240 was a laboratory error. All other samples collected throughout the course of this study had a SAR of less than 4, with the vast majority of SARs less than one (Figure 21). Therefore, while many areas sampled as part of this study indicated levels of sodium above background levels, there was no indication that the soil had reached sodic levels considered unhealthy for plant growth.

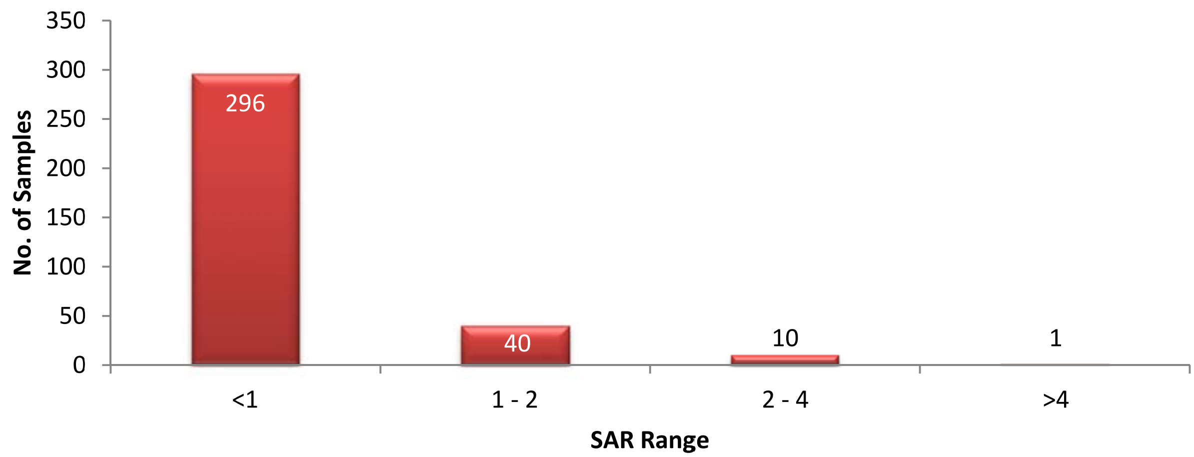



**Figure 21. Histogram of SAR Results for All Samples**

## Vegetation Analysis and Results

*Impact of Distance from the Roadway*

The mean concentrations of sodium and chloride in plant tissue were compared for V1 and V2 samples collected at BMS 16, 17, 18, 19, 25, 26, 27, 28, 29, and 84. For each BMS, two discrete V1 and V2 samples were collected to increase the amount of data available for analysis. The mean concentrations were compared by year and across the entire study timeframe. The effect that the distance from the roadway had on the difference in the mean percentages of sodium and chloride in the vegetation was evaluated through a Mann-Whitney-Wilcoxon Test. Results of the analyses are presented in Table 16 and Table 17.

**Table 16. Percent Sodium in Vegetation Tissue by Sample and Year**

| Year | Sample | No. | Min. (percent) | Max. (percent) | Median (percent) | Mean (percent) | Statistical Significance |
|---|---|---|---|---|---|---|---|
| 2012 | V1 | 20 | 0.02 | 0.1 | 0.045 | 0.052 | p = 0.000 |
| | V2 | 20 | 0.01 | 0.07 | 0.02 | 0.026 | |
| 2013 | V1 | 20 | 0.02 | 0.28 | 0.04 | 0.055 | p = 0.029 |
| | V2 | 20 | 0.02 | 0.09 | 0.03 | 0.033 | |

**Table 17. Percent Chloride in Vegetation Tissue by Sample**

| Year | Season | No. | Min. (mg/kg) | Max. (mg/kg) | Median (mg/kg) | Mean (mg/kg) | Statistical Significance |
|---|---|---|---|---|---|---|---|
| 2012* | V1 | 20 | 0.06 | 1.52 | 0.09 | 0.214 | p = 0.366 |
| | V2 | 20 | 0.04 | 0.29 | 0.085 | 0.1045 | |

*Missing 2013 data due to lab error

The percentage of sodium in vegetation tissue was roughly twice as high for V1 samples as for V2 samples. While precise proximity to the roadway varied for vegetation sampling, the V1 samples were generally obtained from vegetation within 50 ft of the roadway, whereas V2 samples were obtained from vegetation 100 ft or more from the roadway. A comparison of the means indicates a significant difference in the sodium percentages between V1 and V2 samples for both sampling periods. This indicates that proximity to the roadway has a significant impact on the sodium percentage in the vegetation. On average, trees closer to the roadway were found to have a higher concentration of sodium in their leaf tissue compared to trees at a greater distance from the roadway.

In light of the impact that proximity to the roadway has on the concentration of sodium in roadside vegetation, the relationship between the percentage of sodium in the vegetation and the concentration of sodium in the soil was evaluated for evidence of a link between the two. All observations from BMS 27 results are considered outliers, due to extremely high sodium concentrations in A1 samples, and were excluded from the dataset. In addition, one V1 sample from BMS 26 was excluded from the dataset as an outlier because of an extremely high vegetation sodium percentage. The relationship between V1 (vegetation) and A1 (soil) samples is plotted in Figure 22.

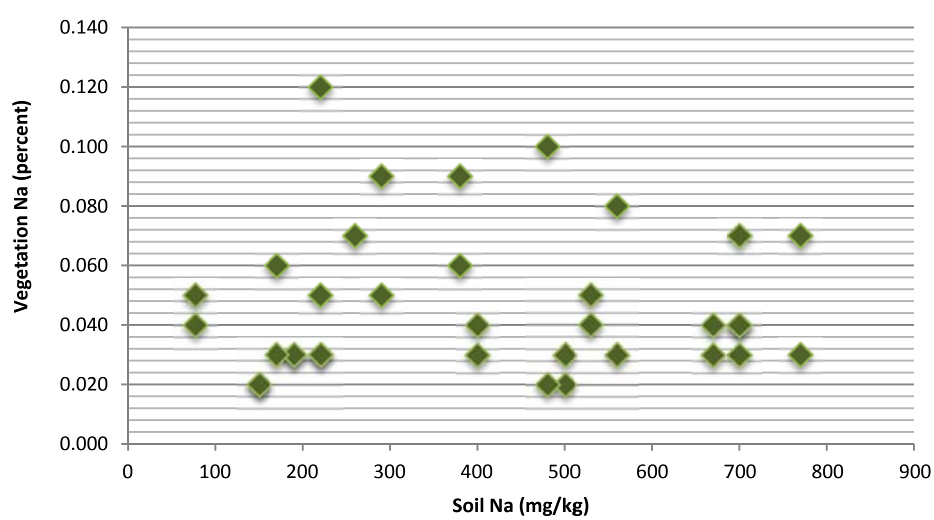



**Figure 22. Relationship Between Sodium Percentage in V1 Samples and the Corresponding Sodium Concentrations in the A1 Sample**

The plotted relationship between sodium percentages in V1 vegetation samples and sodium concentrations in A1 soil samples indicates that no discernible linear relationship existed between the sodium concentrations in the soil and the sodium percentage in vegetation at the time of sampling.

The relationship between sodium percentages in V1 samples and total roadway chemical application to the travel lane adjacent to the BMS from the previous spring was compared. The relationship was examined to evaluate whether the chemical application over the winter period had any measurable impact on the roadway vegetation the following spring. The data for chemical applications and sodium concentrations in V1 samples are plotted in Figure 23. Results for BMS 27 and one V1 sample result from BMS 26 were excluded from the dataset as outliers because of extremely high sodium concentrations.

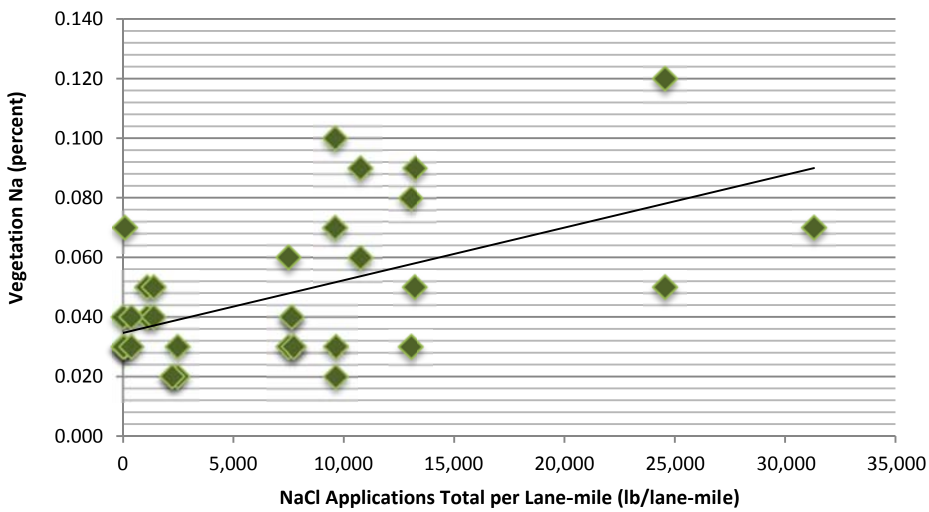



**Figure 23. Relationship Between Sodium Percentage in V1 Samples and the Corresponding Chemical Roadway Application (per Lane-mile) from Previous Winter Season**

The plot of sodium percentages in V1 samples and the corresponding chemical application to the roadway adjacent to the BMS indicates a weak potential linear relationship between the two factors. The result of a linear regression analysis on the data is provided in Table .

**Table 18. Summary of Regression Analysis for Sodium Concentrations in V1 Samples and Corresponding Chemical Roadway Application**

| Regression Predictor | Coefficient | Standard Error | t-value | p-value | Adjusted $R^2$ |
|---|---|---|---|---|---|
| NaCl | 1.768e-06 | 4.751e-07 | 3.72 | 7.4e-04 | 0.274 |

The regression analysis indicates a statistically significant linear relationship between sodium concentrations in V1 samples and the previous winter application of chemical. This is based on the p-value of 0.00074 (less than 0.05) associated with the analysis. The adjusted $R^2$ is an estimate of the percent of variation in the dependent variable that can be explained by the independent, or predictor, variable. At 0.274, the $R^2$ value for this regression is considered fairly low and can be interpreted to mean that the independent variable (NaCl) would account for only 27.4 percent of the variability of the dependent variable (percent sodium in vegetation). Therefore, while the relationship is statistically significant, it is quite weak.

A significant difference in sodium concentrations was observed between V1 and V2 samples. To a lesser extent, a potential linear relationship between springtime sodium concentrations in vegetation near the roadway and the total chemical application from the previous winter was identified as well. Another significant finding of the study was that, while roadside vegetation exhibited higher sodium concentrations than vegetation farther from the roadway, the vegetation within the subject BMS did not indicate symptoms of injury or stress from salts or other factors at the time of sampling. As indicated by Figure 24, of the 80 vegetation samples collected, only one had a sodium concentration that was above 200 mg/kg, the documented level of toxicity for evergreens (Midwest Laboratories 2013). Therefore, while vegetation within the BMS examined as part of this study indicated impacts from roadway chemical applications, the impact was not found to be detrimental.

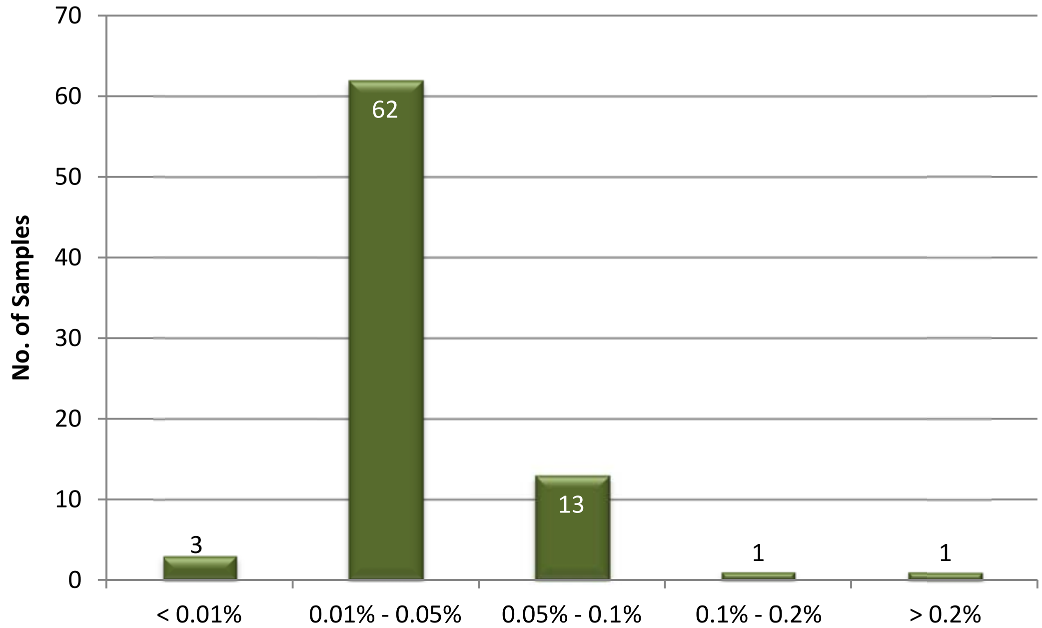



**Figure 24. Histogram of Sodium Concentrations in All Vegetation Samples**

# CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Conclusions drawn from this study are presented first, followed by recommendations on initial application rate guidelines, a WSM recordkeeping system of chemical usage and storm events, and improvements to the ambient monitoring program. These recommendations are based upon results from this study and previous studies performed by others.

As discussed in Chapter 5, chemical application rates can be categorized as:

- Acceptable – an acceptable rate within the ADOT WSMOM application guidance range that is given for a specific pavement temperature range;
- High – a rate above the ADOT WSMOM application guidance range that is given for a specific pavement temperature range; and
- Low – a rate below the ADOT WSMOM application guidance range that is given for a specific temperature range.

A number of factors (precipitation type, intensity, and accumulation rates; pavement temperature trends; pavement conditions; etc.) should be considered when choosing an application rate; however, only a few of these inputs are currently recorded by the AVL system. The conclusions presented below regarding adherence to ADOT's WSMOM application guidance are based on a review of available data.

## OBSERVED RESULTS

### WSM Application Rates Based on AVL Data

- For the three years of AVL data used (2010 through 2012), 65 percent of all chemical applications were considered acceptable.
- The percentage of acceptable applications increased from 32 percent in 2010 to 76 percent in 2001 and 74 percent in 2012.
- The percentage of low applications decreased each year, from 40 percent in 2010 to 17 percent in 2011 and 15 percent in 2012.
- The percentage of high applications was 28 percent in 2010, 7 percent in 2011, and 11 percent in 2012.
- Applications at pavement temperatures below 15° F comprised a high number of the unacceptable applications during the study period. ADOT WSMOM guidance recommends no chemical application when the pavement temperature is below 15° F. As a result, all applications performed when the pavement temperature is below 15° F are considered high.
- Aside from applications that coincided with pavement temperatures below 15° F, less than 2 percent of all other applications were categorized as high.
- The decrease in the percentage of high applications was found to correspond to a decrease in the percentage of applications associated with pavement temperatures below 15° F and a subsequent increase in the percentage of applications that coincided with pavement temperatures between 20° F and 32° F, which have a wider range of acceptable application rates.

## CONCLUSIONS

### Distribution of Salt Levels in Soil

- Chloride concentrations were not significantly different among samples collected from Zones A, B, and X. There was thus no statistically significant difference identified between application rates and observed chloride concentrations in soil. Therefore, it cannot be concluded that WSM activities are having a statistically significant influence on chloride concentrations in soil along ADOT roadways.
- Sodium concentrations in BMS 27 are significantly higher than all other samples and are considered a statistical outlier. As such, concentrations for BMS 27 were excluded from most analyses.
- There was a statistically significant difference in the sodium concentrations among A1, B1, and X samples. Soil closer to the roadway contained higher sodium levels than soil further from the roadway. As a result, we conclude that applications of road salt for WSM activities have a long-term impact on the sodium concentrations in soil along ADOT roadways.
- No significant difference in sodium or chloride levels was identified among the drainage-related samples (E, U, and D). Therefore, it cannot be concluded that the surface drainage characteristics have a clear and measureable impact on the distribution of salts within the BMS.
- Mean sodium concentrations were not significantly different between samples collected in the fall and samples collected in the spring.
- The total road salt applied to the roadway and the concentration of sodium in the A1 samples immediately after the application season did not indicate that winter application rates had a statistically significant impact on spring sodium levels in the soil.
- There was no indication that the soil sampled within the study area is reaching sodic levels, based on SAR values. A SAR of 13 or greater is considered sodic. The SAR values of the 347 samples tested were less than four, except for one sample that had a SAR value of 240. This high value is suspected to be a laboratory error.

### Vegetation Analysis and Results

- There was a statistically significant difference between the mean values of sodium concentrations in vegetation between V1 (within 50 ft from the edge of the pavement) and V2 (at least 100 ft from edge of the pavement) samples, indicating that proximity to the roadway has an impact on the sodium percentage in the vegetation. On average, trees closer to the roadway were found to have a higher concentration of sodium in their leaf tissue compared to trees a greater distance from the roadway.
- Sodium concentrations in A1 soil samples did not appear to have a statistically significant impact on the level of sodium in V1 vegetation samples. Therefore, it cannot be concluded that sodium concentrations in soil directly impact sodium concentrations in vegetation near the roadway.
- Winter road salt applications appear to correlate somewhat with sodium concentrations in V1 samples the following spring, but the correlation is rather weak. Therefore, a clear conclusion regarding the correlation between the two is not possible.

- While vegetation at two of the BMS examined as part of this study indicated potential impacts from roadway chemical applications, sodium levels in the vegetation were found to be well within an acceptable range of 0.01 percent to 0.2 percent (or 100 mg/kg to 2,000 mg/kg).

## RECOMMENDATIONS

### Road Salt Application Rates

Literature searches and field-based data analyses completed as part of this study did not indicate the need for ADOT to deviate from current application rate guidelines as outlined in ADOT's WSMOM (ADOT 2008b). However, the applications could be made more accurately and economically by implementing some program and procedural changes.

The following are recommended:

- Ensure that operators are trained to follow application rates provided in the guidelines, especially in environmentally sensitive areas as defined in the WSMOM.
- Using the AVL data, compile information on how much chemical is being applied per route per year, and correlate these amounts and routes with areas of stressed vegetation.
- To allow for a more thorough analysis of the appropriateness of application rates, consider recording information regarding temperature trends, precipitation type and intensity, and roadway surface conditions that correspond to the applications.
- Document local conditions that may impact WSM activities, such as sections of roadway with steep slopes, areas with significant shade, and areas that experience snow drifts. Document such conditions to justify higher or lower application rates within the ranges defined in the WSMOM.

### AVL System

The existing AVL system provides a basis for using real-time data collection to track winter storm chemical applications and their appropriateness. Increasing the type of data collected would provide for a more robust tracking system. Such a system would give decision makers tools to evaluate and document the best course of action, while continuing to ensure the safety of roadways during winter storms and minimizing impacts on the surrounding environment. The limitations encountered in this analysis as a result of faulty data (inaccurate temperature or geographic data) or missing parameters (such as real-time weather and roadway conditions) help identify potential improvements to ADOT recordkeeping, equipment maintenance, and personnel training regarding the AVL system.

Recommendations for future data collection and evaluation are as follows:

- Use available AVL data to assess the appropriateness of application rates by route, storm behavior, pavement temperature trends, and individual operator.
- Ensure properly functioning AVL systems by implementing a periodic equipment maintenance protocol that includes calibration of the pavement temperature sensors, spreader rate control, and GPS to ensure accurate readings.

**Ambient Monitoring Program**

Based on the recommendations that this report outlines regarding any future monitoring in ADOT districts where winter activities are prevalent, it may be reasonable to assign the monitoring to a consultant. It can be assumed that the consultant would perform the required sampling in a single round with laboratory costs equaling approximately $50 per sample per site (includes soil and vegetation analysis). Expenses can be based on assigning two people to perform the sampling at a sampling rate of four to six sites per day depending on travel distance between sites and assuming 10-hour days. The data analysis and reporting would entail further costs.

If additional monitoring is considered in the future, changes could be made to increase the quality of the data and efficiency of the program.

Recommended changes are as follows:

- Select BMS that represent a variety of vegetation types—forest, shrubland, grassland—and different levels of priority for WSM applications.
- When establishing BMS sites, include sites that indicate probable WSM impacts to vegetation.
- Reduce the sampling interval of vegetation and soil to once per year, preferably in the spring.
- Reduce the number of sampling locations and intervals at each BMS to two: one individual sample located between 25 and 50 ft from the edge of the pavement, to be tested annually, and one individual sample located more than 100 ft from the edge of the pavement, to be tested once every two years.
- Analyze soil and vegetation samples for sodium concentrations only
- Perform semiannual visual roadside surveys to identify areas showing indications of WSM impacts, and plot these areas on maps that show the total amount of chemical application. Collect samples of soil and vegetation from areas showing the highest degree of impact for comparison with BMS sampling results.
- Once baseline data have been established for trees showing no impact from WSM activities at a BMS that includes stressed vegetation, sample only vegetation showing signs of stress at that BMS.

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# APPENDIX A
# INDIVIDUAL BMS MAPS


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

N

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Site Maps
Winter Storm Management of
Arizona State Highways

| BMS 28 | MILEPOST | APPENDIX |
|---|---|---|
| Greer | 383.3 | A8 |

amec


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Site Maps
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| **BMS 24** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Alamo Wash | 378.5 | A9 |

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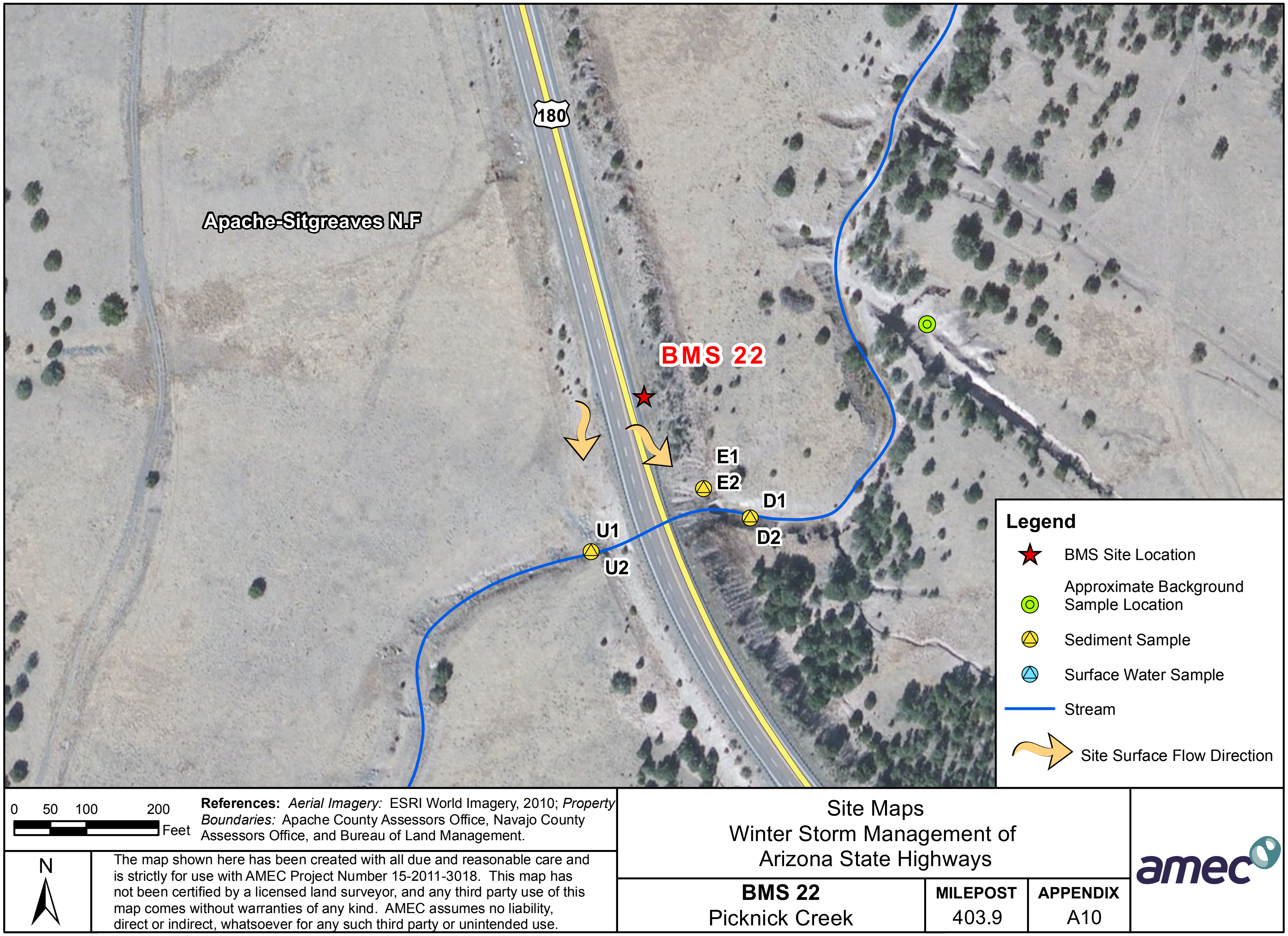


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Site Maps
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| BMS 22 Picknick Creek | MILEPOST | APPENDIX |
|---|---|---|
| | 403.9 | A10 |

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0 50 100 200 Feet

N

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Site Maps
Winter Storm Management of Arizona State Highways

| **BMS 21** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Nelson Reservoir | 408.7 | A11 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
Winter Storm Management of
Arizona State Highways

| **BMS 20** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Nutrioso | 416.9 | A12 |

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0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
Winter Storm Management of
Arizona State Highways

| **BMS 19** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Alpine | 423 | A13 |

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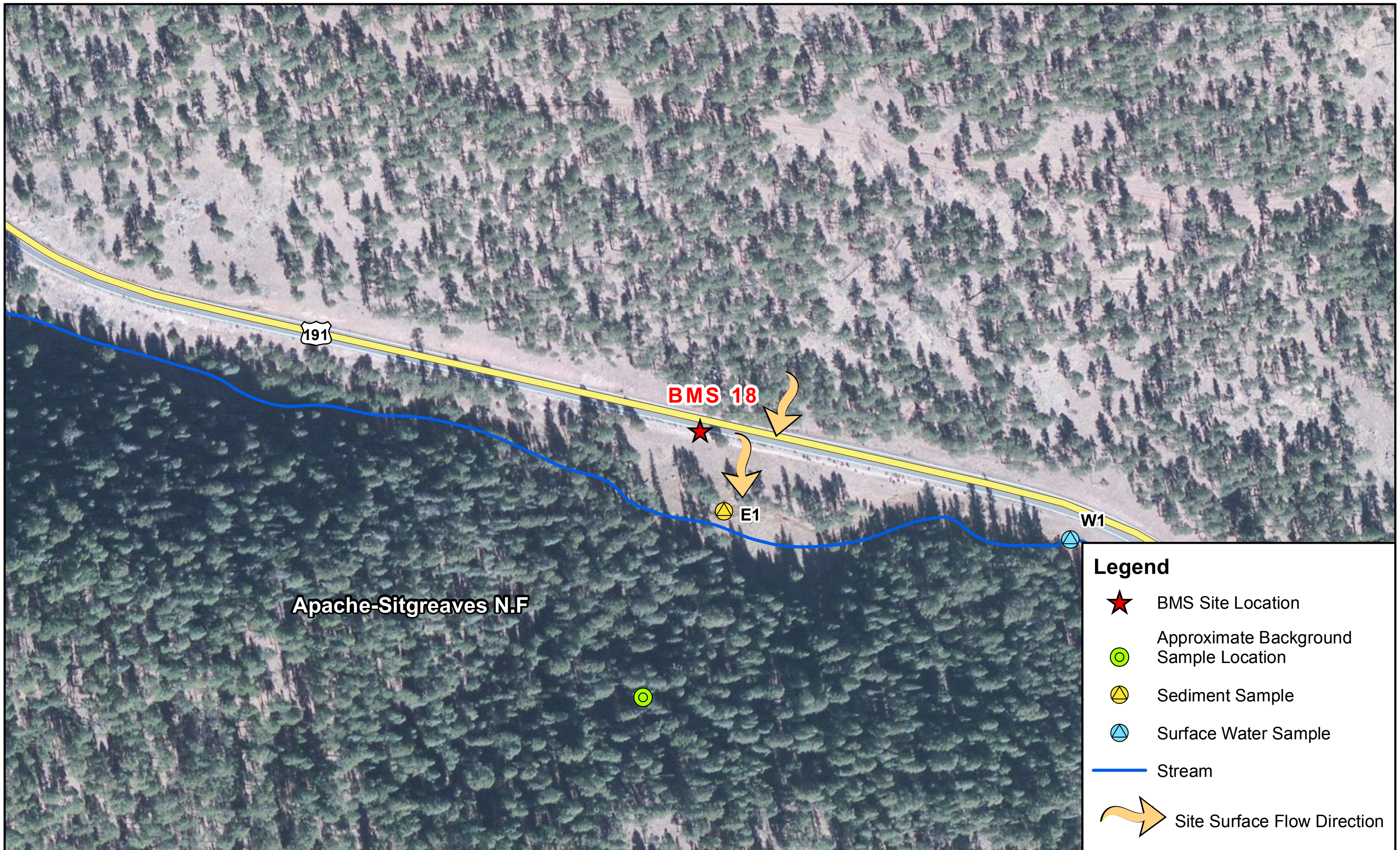


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**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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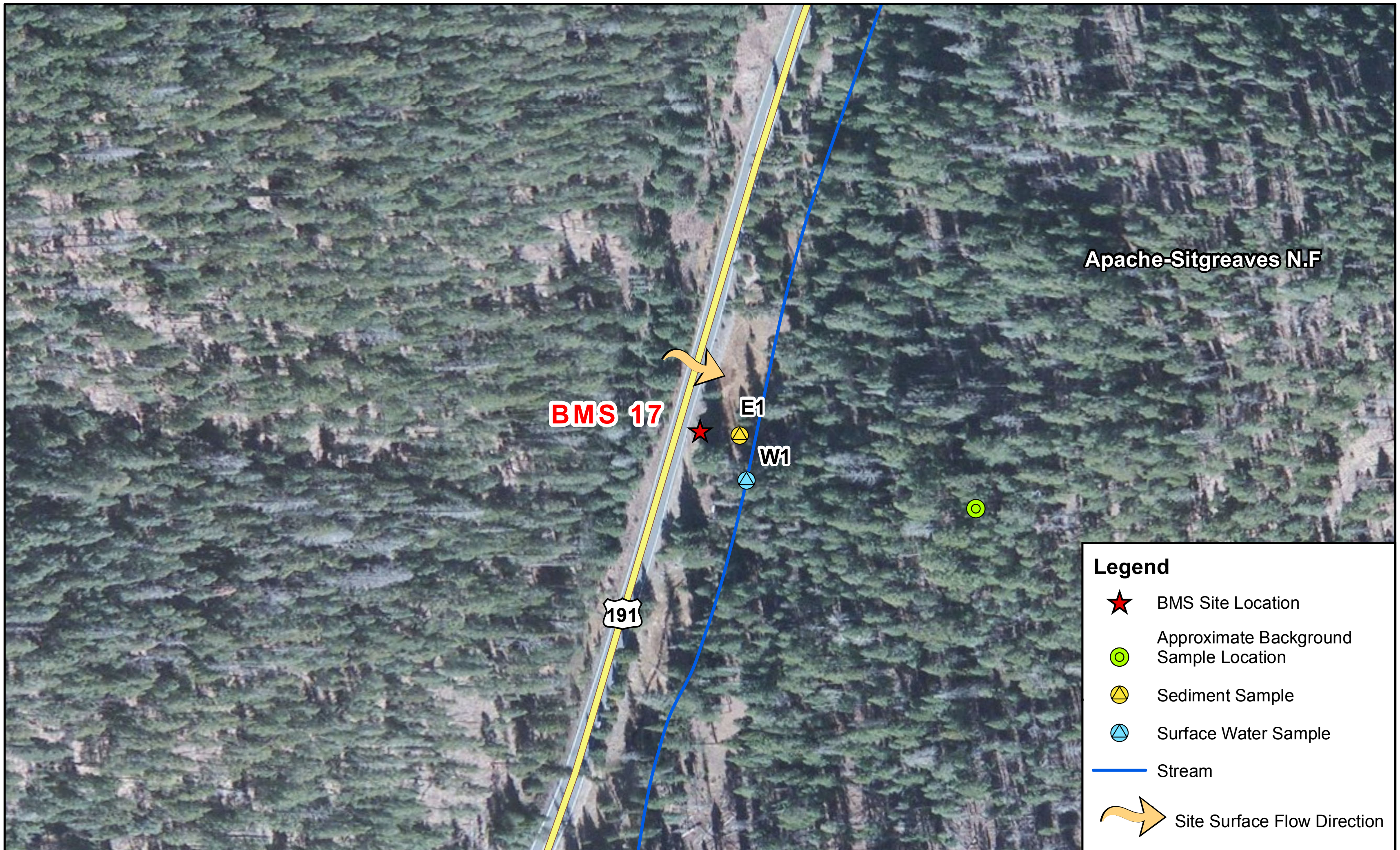
| **BMS 18** | **MILEPOST** | **APPENDIX** |
| --- | --- | --- |
| Campbell Blue Ridge | 243.8 | A14 |

amec




0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
Winter Storm Management of
Arizona State Highways

| BMS 17 | MILEPOST | APPENDIX |
|---|---|---|
| Hannigan Creek | 235.7 | A15 |

amec


0 50 100 200 Feet

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**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| BMS 16 | MILEPOST | APPENDIX |
|---|---|---|
| KP Cienega | 226.1 | A16 |

amec


**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| **BMS 31** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Phoenix Park Wash | 314.5 | A1 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| **BMS 30** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Rogers Lane | 323.3 | A2 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| **BMS 29** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Fornsworth Ranch | 330.5 | A3 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| **BMS 25** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Mogollon Rim Trail | 336.9 | A4 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

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Site Maps
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| BMS 26 | MILEPOST | APPENDIX |
|---|---|---|
| Show Low | 344.1 | A5 |

amec


0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

N

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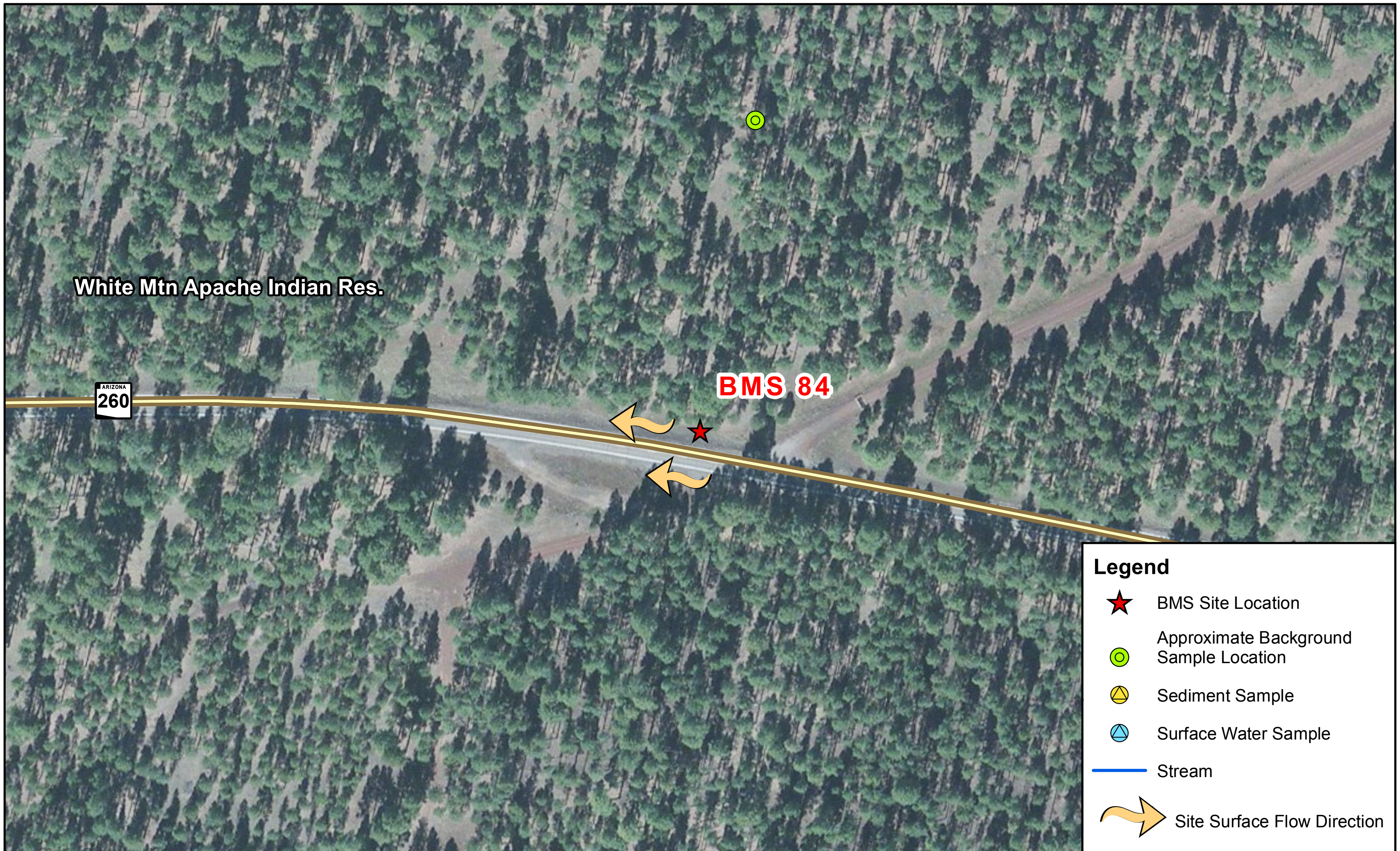
Site Maps
Winter Storm Management of
Arizona State Highways

| **BMS 27** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| Latigo Wall | 355 | A6 |

amec




0 50 100 200 Feet

**References:** *Aerial Imagery:* ESRI World Imagery, 2010; *Property Boundaries:* Apache County Assessors Office, Navajo County Assessors Office, and Bureau of Land Management.

N

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Site Maps
Winter Storm Management of
Arizona State Highways

| **BMS 84** | **MILEPOST** | **APPENDIX** |
|---|---|---|
| McNary | 364 | A7 |

amec

yp

# APPENDIX B
# BMS DESCRIPTIONS AND NOTES

**BMS #16** **MP 226.1**
**KP Cienega** **US 191**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. At the site, road slopes to the east; general road grade in vicinity is south to north. BMS is located in a low spot along the road; north of the BMS road grade is to the north and south of the BMS road grade is to the south.
Open (no) shade at the site, does receive some moderate to heavy shade from tall trees in immediate vicinity.

Surface flow:
Immediate area surface flow is to the east..

Waterbodies/Presence of water:
None.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Slopes towards the BMS. |
| Grade | Moderate toward the south |
| Lanes | 2 |

Features of Interest:

Vegetation:
Vegetation at the site is dominated by mixed conifer trees (blue spruce [*Picea pungens*], Douglas-fir [*Pseudotsuga menziesii*]) with some aspen; little to no shrub layer. Trees within ~15 ft of roadway. BMS sampled along edge of forest vegetation. Evidence of wildfire (Wallow Fire) by blackened tree trunks and browning pine needles.

Elevation:
~9,240 ft amsl

Misc. notes:

F11: BMS sign is black with no BMS #.
Definite WSM activities – salt residue on road.
4-6 inches of snow, lower layers of snow fluffy so melting into soil so far is unlikely.

S12: Turkey seen en route and on way out. X samples taken at proposed GPS point. Heavily burned area. Snow present on side of road N of BMS16 (small patches). En route to BMS 18-16, heavy fire damage and looks like a lot of clearing of dead wood along roadsides. Impact to sediment load of streams? Deer (5) seen on way back to motel.

F12: A1 and A2 samples moved North due to tree clearing/felling activity and torn up ground. No B samples due to felled trees/inaccessibility of site. No fuzzy nails founds- relocated A samples northward (clearer area). Observed strawberry (*Fragaria* sp.) blooming – is this normal?

S13: Nothing new to note.

**BMS #17** **MP 235.7**
**Hannagan Creek** **US 191**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. Overall slope is south to north. No shoulder on west side of road. Terrain slopes steeply up to the west; flatter terrain from road east to creek.
Moderate to heavy shade at the site.

Surface flow:
Site surface flow is to east. Hannagan Creek flows south to north.

Waterbodies/Presence of water:
Hannagan Creek to east of BMS, parallel to road.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly. |
| Grade | Slight toward the north. |
| Lanes | 2 |

Features of Interest:
Site appears to be within the floodplain/terrace of Hannagan Creek. Evidence of previous large flow events on terrace (4-ft high flood debris caught in trees on flood terrace)

Vegetation:
Grassy in immediately vicinity of site; mixed conifer trees (blue spruce [*Picea pungens*], Douglas-fir [*Pseudotsuga menziesii*]) with some aspen in forested areas east and west of sign. Potential vegetation impacts observed on herbaceous and pine foliage.

Elevation:
~ 8,240 ft amsl

Misc. notes:
F11: BMS sign labeled “80”. Salt residue on roadway.

S12: Photos of moss (?) on bank above stream. No B.3 samples. Re-mark with fuzzy nails:

| **Sample** | **Distance to Pavement** | **Distance from Reference Point** |
|---|---|---|
| A1.1 | 22 | 12 |
| A1.2 | 25 | 53 |
| A1.3 | 27 | 81 |
| B1.1 | 56 | 12 |
| B1.2 | 56 | 53 |

No BX.3 samples taken.

F12: BMS sign down/mangled, needs replacement. A portion of the site is heavily altered with felled trees and rocks from forest fire clearing activities. Lots of mullein also observed. A samples moved North, only 2 A samples taken and only 2 B samples taken. B.3 site not found. B.1 was found and used as B.2, Took B.1 sample in new location further N.

S13: Nothing new to note.

**BMS #18** **MP 243.8**
**Campbell Blue Ridge** **US 191**

Location/orientation of BMS:
Adjacent to southbound lane (arbitrarily assigned as west side of road).
Geographically on south side of road. North side of road is steeply sloped upward, south side is flatter leading towards creek.
Open (no) shade at the A and B sample locations. E sample is located in moderate shade.

Surface flow:
Site surface flow is south. Creek flows west to east.

Waterbodies/Presence of water:
Campbell Blue Creek to the south of the site, roughly parallel to roadway.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly. |
| Grade | Slight toward the south. |
| Lanes | 2 |

Features of Interest:

Vegetation:
Ponderosa pine trees on steep embankment north side of road. Site is located in a grassy area that extends downslope to creek with few scattered young pine trees. Larger pine trees (ponderosa) located across the creek. No deciduous trees noticed. Evidence of fire damage to trees (blackened trunks).

Elevation:
~7,640 ft amsl

Misc. notes:
F11: BMS sign labeled “78”.
Snow in shaded areas.

S12: X samples taken at proposed GPS point.

F12: BMS sign is flattened, needs replacing. The few trees along the road at BMS have been cut down, even saplings. Some saplings remain in the A zone. B1.2 is in a somewhat moist area that conveys runoff to stream from the site.
- B1.2 and B1.3 samples are 30 ft from A samples (60 ft from pavement).
- B1.1 is approx. 26ft from A1.1 (56 ft from pavement).

S13: V1.0 sample collected near BMS sign. V1.1 sample collected south of BMS but at equivalent distance as B samples from roadway; collected away from BMS due to fire damage – few trees remain at site post-fire. All vegetation samples collected are and have been ponderosa pine.

**BMS #19** **MP 423**
**Alpine** **US 180**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. West side of road is steeply sloped upward, east side slopes down towards stream.
Open (no) shade at the A sample locations, moderately shaded as you move away from the road.

Surface flow:
Site surface flow is parallel to road and east toward creek. Creek flows north to south.

Waterbodies/Presence of water:
Unnamed creek on east side of road. Small drainage area appears to convey runoff from road east towards creek (no defined bed/bank) and includes a marshy/wet pocket in open grassy area.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly. |
| Grade | Mderate toward the south. |
| Lanes | 2 |

Features of Interest:
Culvert beneath highway located north of site. Small rills around site appear to indicate relatively concentrated runoff from the road flowing across/through site towards creek.
Surface flows that do not enter the creek immediately appear to flow into creekbed downstream of site that includes a small marshy area. This marshy area may have been filled-in in the past or otherwise altered.

Vegetation:
Site is open grassy area with some ponderosa pine trees. Opposite side of road is open ponderosa forest (with occasional other conifers), as is the area east of the site and creek. No deciduous trees noted. Trees at site show signs of browning.

Elevation:
~8,350 ft amsl

Misc. notes:
F11: Salt residue on road.

S12: X samples taken at proposed GPS point.

F12: Photos taken of evidence of high (summer?) flow events – lots of sediment washed through, well above current stream channel. Channel is more braided now than used to be (check past photos for reference/to confirm).

S13: V1.0 sample was collected a bit upstream of BMS; V1.1 was collected near BMS sign.

**BMS #20** **MP 416.9**
**Nutrioso** **US 180**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. West side of road is open (pasture?) field. Relatively flat terrain. Open (no) shade at site.

Surface flow:
Surface flow is east towards site, continuing north towards Nutrioso Creek. Nutrioso Creek flows east to west, perpendicular to roadway.

Waterbodies/Presence of water:
Nutrioso Creek north of site.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Towards the BMS – road is banked for the curve. |
| Grade | Flat |
| Lanes | 2 |

Features of Interest:
Private land (homes & horse lots) in immediate vicinity of site.

Vegetation:
Open grassy/mixed weeds and herbaceous, no trees. Most land is altered by human use (pasture/grazing/farmland).

Elevation:
~7,660 ft amsl

Misc. notes:
F11: n/a

S12: X samples taken at proposed GPS point.

F12: No B1 samples, ROW too narrow. See sediment layer in ipad- placeholder gps point taken at culvert under road to convey water from E to W. Not sure if we had noticed this before. Photos also taken.

S13: Nothing new to note.

**BMS #21** **MP 408.7**
**Nelson Reservoir** **US 180**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. Relatively flat terrain.
Open (no) shade at site.

Surface flow:
Surface flow at site is south and eastward; surface flow on west side of road is to the south. General surface flow in area is to the north.

Waterbodies/Presence of water:
Nutrioso Creek, water present.

Roadway Characteristics:

| | |
|---|---|
| Pitch | North of the guardrail at BMS, road is pitched towards the BMS. North of this the road is flat or slightly crowned. |
| Grade | Flat |
| Lanes | 2 |

Features of Interest:
Topography and evident surface flow of area makes it difficult to identify discrete discharge point of surface water into creek, including correct upstream and downstream reaches. No section of creek appears “upstream” from BMS location or upstream of adjacent WSM activities.

Vegetation:
Grassy with some brush; scattered trees or junipers located approx. 50 feet to the west and 200feet east of the site as well as south of the creek (on opposite bank).

Elevation:
~7,360 ft amsl

Misc. notes:
F11: n/a

S12: No vegetation samples - sparse shrubs relatively far from roadside. X samples taken at proposed GPS point.

F12: Water in channel - U and D samples were taken from top of bank; banks steep and well-defined. B samples were 56 ft from road.

S13: Nothing new to note.

**BMS #22** **MP 403.9**
**Picknick Creek** **US 180**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. On east side of road is a steep dropoff approximately 50 feet from roadway.
Open (no) shade at site.

Surface flow:
Surface flow at site is south parallel to roadway to a point just north of the creek, at which point surface flow is east into creek. Creek flows west to east in vicinity of site, general flow is to the north.

Waterbodies/Presence of water:
Picknick Creek; wash was dry during Fall 2011 sampling.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned along yellow stripe (middle of road) from north of the BMS until the guardrail at BMS. From that point south, road is pitched toward the BMS (east) side of road – banked for the curve. |
| Grade | Slight toward the south. |
| Lanes | 3; 1 northbound, 2 southbound |

Features of Interest:

Vegetation:
Grasslands to west and east; scattered shrubs (*Purshia stansburiana,Gutierrezia*, juniper, *Chrysothamnus*) on east side of road and along creek.

Elevation:
~7,260 ft amsl
Steep dropoff on east side of road approx. 50 feet from road.

Misc. notes:

F11: No BMS marker at site; placed a wooden stake and fuzzy nail at approximately MP403.9. USFS land to west, unknown to east.

S12: X samples taken 49 meters shy of proposed GPS point (in line with direct path between BMS and GPS points). X site taken before crossing stream, slight rise, then dip, between site and BMS sign.

F12: A2 samples are shallow (rocky/difficult soil). No B1 samples collected due to terrain – B samples would be down on the hillslope (sketch in field notes).

S13: Nothing new to note.

**BMS #24** **MP 378.5**
**Alamo Wash** **US 180**

Location/orientation of BMS:
Adjacent to northbound lane (arbitrarily assigned as east side of road).
Geographically on east side of road. Very flat terrain at site.
Open (no) shade at the site.

Surface flow:
South from site towards Chimney Wash. General surface flow (incl. Chimney Wash) is west to east.

Waterbodies/Presence of water:
Chimney Wash

Roadway Characteristics:

| | |
|---|---|
| Pitch | Slightly crowned. |
| Grade | Flat |
| Lanes | 2 |

Features of Interest:

Vegetation:
Brushy grassland (*Chrysothamnus, Gutierrezia*, bunchgrasses) on both sides of road. Larger bushes (maybe a juniper or two, *Lycium*) along wash.

Elevation:
~5,940 ft amsl

Misc. notes:
F11: Private land adjacent (barbed wire).

S12: Evidence of recent use by cattle. X samples taken at proposed GPS point.

F12: B1 is 60 ft from road. *Pulled off into BMS. Took off bottom of bumper/air dam guard. Watch out for this next time. Lots of broken glass in the area as well.

S13: Nothing new to note.

**BMS #25** **MP 336.9**
**Mogollon Rim Trail** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on east side of road. Land slopes upward on east side of road.
Moderately shaded site.

Surface flow:
Site flow east of BMS marker is to the west; from BMS flow is north towards culvert. General surface flow is to the west. Culvert located north (downgradient) of the site.

Waterbodies/Presence of water:
None at site.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Moderate to slight toward the west. |
| Lanes | 2 |

Features of Interest:

Vegetation:
Pinyon-Juniper; trees within 15 feet of either side of road.

Elevation:
~6,250 ft amsl

Misc. notes:
F11: No BMS marker; placed a stake at site.
Samples taken along the drainage area parallel to road leading to culvert.

S12: New sign placed slightly offset from correct place. Samples taken from wooden stake location. X samples taken 23 meters SSW of proposed GPS point.

F12: All B1 samples slightly up-gradient from A samples.

S13: ADOT BMS 25 metal sign is ~330 feet east of sampling location. Samples have been taken from near the wooden BMS stake since Fall 2011.

**BMS #26** **MP 344.1**
**Show Low** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on east side of road.
Open (no) shade at site. One line of trees occurs at the site from the BMS sign westwards.

Surface flow:
Site flow is north and east towards wash. A drainage feature is located perpendicular to the road that conveys flows northeast to unnamed wash.

Waterbodies/Presence of water:
Unnamed wash is located east of site, roughly parallel to road.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Flat to very slight toward the west. |
| Lanes | 4 plus 1 paved median lane. |

Features of Interest:
Drainage feature was sampled for upstream/downstream/exit ROW sediment samples.

Vegetation:
Pine forest (predominantly Ponderosa pine) with some juniper and deciduous shrubs/trees in the area along road. Grassy along roadside and drainage embankment.

Elevation:
~6,420 ft amsl

Misc. notes:
F11: High traffic area; private landowners adjacent.

S12: X samples taken from top of bank of ravine furthest from Road. V1 samples taken near fenceline of R/W. V2 samples taken from Reference point due to terrain.

F12: No B1.1 sample- upgradient from A sample. B1.2 and B1.3 were collected. Natural gas pipeline near/along B sample line.

S13: Vegetation samples: V1.0 = ponderosa pine, V1.1 = juniper, V2.0 = juniper, V2.1 = ponderosa pine.

**BMS #27** **MP 355**
**Latigo Wall** **SR 260**

Location/orientation of BMS:
Adjacent to eastbound lane (arbitrarily assigned as south side of road).
Geographically on the west side of the road. Relatively level terrain.
BMS sign located on North side of road, samples collected from South side of road.
Shaded site from tall trees over a narrow grassy roadside.

Surface flow:
Site flow is to the north, parallel to road. Localized drainage along east side of road (adjacent to westbound lane).

Waterbodies/Presence of water:
None.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Flat |
| Lanes | 4 with median and left turn lane (eastern portion of site) |

Features of Interest:

Vegetation:
Pine forest (predominantly ponderosa) with some deciduous shrubs/trees in the area along road.

Elevation:
~7,140 ft amsl

Misc. notes:

F11: Subdivision to the north of site with walking paths (asphalt) and localized drainage. Unsure of ADOT ROW location on east side of road (adjacent to westbound lane).
Snow in shaded areas on side of road.
Marker missing; placed a stake at site.

S12: X samples taken at proposed GPS point. No photos taken at X site. V2 samples taken from front yard of property owner w/in HOA. ADOT installed BMS sign on N side of 260. We pulled BMS wooden stake from S side of 260. Samples taken from S side.

F12: No B1 samples – R/W to narrow. BMS sign on N side of road, samples collected from S side of road. Tar spray observed along roadside/roadside veg, puddling and running off of roadside. Presumably to hold down loose pebbles/debris along shoulder?

S13: Given the size/age of ponderosa trees, V1.0 & V1.1 each are taken from 2 trees growing next to each other in order to obtain sufficient sample volume.

**BMS #28** **MP 383.3**
**Greer** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically located on west side of road. Land rises steeply to the east.
Site is moderately shaded.

Surface flow:
Site flow is to the north/northeast parallel to the road. On the aast side of the road, site runoff flows west (downslope) towards road and then flows north/northeast parallel to road.

Waterbodies/Presence of water:
None.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Road is banked along the curve. Pitch is away from the site at the BMS, and towards the site west of the BMS. |
| Grade | Moderate to steep toward east. |
| Lanes | 2 |

Features of Interest:

Vegetation:
Ponderosa pine forest; grassy in immediately vicinity of site/roadside.

Elevation:
~8,820 ft amsl

Misc. notes:
F11: Snow on ground. WSM activities assumed. 13°F temperature during sampling.
BMS sign labeled “77”.

S12: No A2 samples. BMS sign still reads "77". X samples at proposed GPS point.

F12: No B1.3 sample collected, too rocky.

S13: All vegetation samples were of ponderosa pine.

**BMS #29** **MP 330.5**
**Fornsorth Ranch** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on north side of road. Land rises to the north and slopes down to the south side of road.
Moderately shaded at A and B sample locations.

Surface flow:
Site flow is toward the site from the north side of road. Culvert conveys flow from north side of road to south side. Wash/drainage feature along south side of road conveys flow northwest, roughly parallel to road.

Waterbodies/Presence of water:
Dry wash/drainage. Culvert located approximately 300 feet west of site. No sediment samples were collected.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Flat |
| Lanes | 2 |

Features of Interest:

Vegetation:
Juniper/pine woodland with few mixed deciduous shrubs/trees including oak (*Quercus*) and grasses.

Elevation:
~6,520 ft amsl

Misc. notes:
F11: Adjacent landowners unknown.

S12: X samples taken at proposed GPS point.

F12: B samples 54-ft from road. No Bx.3 sample because that is uphill from Ax.3 sample. Bx.1 and Bx.2 are still downgradient (topography sketch in field notes).

S13: 2 photos of “fluffy soil” between A and B sample locations. Soil cracks at B sample location.

**BMS #30** **MP 323.3**
**Rogers Lane** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on north side of road. Relatively level terrain.
Open (no) shade at site.

Surface flow:
Site flow is parallel to road towards the west. General surface flow is to the north.

Waterbodies/Presence of water:
Drainage swale along south side of road. Larger drainage approximately 500 feet west of site conveys flows to the north. Drainage structure/culvert located approximately 100 feet east of the site on private land.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Moderate to slight toward the west |
| Lanes | 2 |

Features of Interest:

Vegetation:
Mixed shrub grassland: widely scattered shrub (Junipers) in grassland on north side of road. South side of road from site has slightly higher shrub/tree density (Juniper, pine trees, deciduous tree) in drainage area surrounded by open grassland.

Elevation:
~6,340 ft amsl

Misc. notes:
F11: Drainage structure (culvert or similar) located approximately 100 feet to the east of site located on private land.
Private land on both sides of road.

S12: Cattle present. X sample taken 26 meters ESE of proposed GPS point.

F12: B samples taken from bottom of hill. B samples 54 ft. from road.

S13: Fluffy soils at B locations.

**BMS #31** **MP 311.5**
**Phoenix Park Wash** **SR 260**

<u>Location/orientation of BMS:</u>
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on the north side of road. Relatively level terrain.
Open (no) shade at site.

<u>Surface flow:</u>
Site flow is to the northwest, parallel to road on both sides of roadway. General surface flow is to the north.

<u>Waterbodies/Presence of water:</u>
Phoenix Park Wash located approximately 300 feet west of site. Water?

<u>Roadway Characteristics:</u>

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Slopes toward the west |
| Lanes | 2 |

<u>Features of Interest:</u>

<u>Vegetation:</u>
Open mixed shrub grassland: widely scattered shrub (Junipers) and trees (Pine) in grassland.

<u>Elevation:</u>
~6,540 ft amsl

<u>Misc. notes:</u>
F11: n/a

S12: No A2 samples. Too rocky to get depth. X samples taken at proposed GPS point.

F12: Water present in downstream portion of Phoenix Park Wash. B samples taken from bottom of hill. BMS is at MP 311.5, has a BMS sign. There is also a BMS sign at MP 314.5 (we had originally thought that BMS should be located at MP314.5).

S13: 1 photo of B1 area soils (“fluffy soils”?). Loose soil- airy. B1 is also in a drainage type area. 1 photo taken of this drainage area.

**BMS #84** **MP 364**
**McNary** **SR 260**

Location/orientation of BMS:
Adjacent to westbound lane (arbitrarily assigned as north side of road).
Geographically on north side of road. Relatively level terrain.
BMS sign installed on South side of road, samples collected from North side of road.
Site is half open, half moderately shaded by mature ponderosa pines.

Surface flow:
Site flow is west along road on both sides of roadway. North side of road appears to convey more drainage (more visible) than on south side. General surface flow in area is to the northwest.

Waterbodies/Presence of water:
None.

Roadway Characteristics:

| | |
|---|---|
| Pitch | Crowned slightly |
| Grade | Flat |
| Lanes | 2 |

Features of Interest:

Vegetation:
Pine (predominantly ponderosa) forest.

Elevation:
~7,584 ft amsl

Misc. notes:
F11: BMS sign missing; placed a wooden stake at site. Snow on ground.

S12: X samples taken 28 meters S of proposed GPS point. No wooden BMS stake, BMS sign installed on S side of 260.

F12: B1 samples still in same low area as A samples, but *slightly* upgradient from A1. BMS sign on S side of road.

S13: All vegetation samples were ponderosa pine.

| # | BMS | Roadway | | | | | | | Vegetation | | BMS (A samples) | | | Surface Water | | | Elevation (feet) | Drainage Structures | Setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Route | MP | No. of lanes | Draining to BMS | Crowned | Slope | Degree of slope | Type(s) | Shade | Side of Road* | Distance from pavement | Elevation below road | Description | Type | Flow Direction | | | |
| 1 | 31 | 260 | 311.5 | 2 | 1 | Yes | West | Moderate | Open Pinyon-Juniper/ mixed shrub grassland | None | North | 25ft | 5ft | Phoenix Wash approximately 200ft west | Intermittent Wash | South to North | 6540 | Culvert | Unpopulated |
| 2 | 30 | 260 | 323.3 | 2 | 1 | Yes | West | Moderate to low | Pinyon-Juniper/mixed shrub grassland. | None | North | 22ft | 10ft | Drainage feature 500ft west | Drainage feature | South to North | 6340 | Culvert approx. 500ft west | Unpopulated |
| 3 | 29 | 260 | 330.5 | 2 | 1 | Yes | Flat | Flat | Pinyon-Juniper grassland intergrade with Ponderosa pine forest | Morning shade | North | 37ft | 10ft | Slightly defined channel 20ft downgradient of BMS | Drainage feature | Southeast to Northwest | 6520 | None | Unpopulated |
| 4 | 25 | 260 | 336.9 | 2 | 1 | Yes | West | Moderate to low | Ponderosa pine forest | Heavy morning shade. Some afternoon shade. | North | 18ft | <5ft | None | None | None | 6250 | Culvert approx. 500ft west | Residential/ Commercial |
| 5 | 26 | 260 | 344.1 | 4 | 2 | Yes | West | Flat to low | Ponderosa pine forest, grassy roadside and drainage embankment | Heavy early morning and late afternoon | North | 20ft | 0ft | Parallel to roadway | Intermittent | South to North | 6420 | Culvert under roadway approx. 100ft north | Residential/ Commercial |

| # | BMS | Roadway | | | | | | | Vegetation | | BMS (A samples) | | | Surface Water | | | Elevation (feet) | Drainage Structures | Setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Route | MP | No. of lanes | Draining to BMS | Crowned | Slope | Degree of slope | Type(s) | Shade | Side of Road* | Distance from pavement | Elevation below road | Description | Type | Flow Direction | | | |
| 6 | 27 | 260 | 355 | 4 | 2 | Yes | Flat | Flat | Ponderosa pine forest with mixed deciduous tree/shrubs along road | Heavy morning and afternoon | South | 15ft | 0ft | None | None | None | 7140 | None | Residential/ Commercial |
| 7 | 84 | 260 | 364 | 2 | 1 | Yes | Flat | Flat | Ponderosa pine forest | Heavy | North | 22ft | 5ft | None | None | None | 7584 | None | Unpopulated/ Reservation |
| 8 | 28 | 260 | 383.3 | 2 | 1 | Pitched towards BMS upgradient; Pitched away from BMS downgradient | East | Moderate to high | Ponderosa pine forest, grassy roadside | Heavy | North | 30ft | <5ft | None | None | None | 8820 | None | Unpopulated/ Reservation |
| 9 | 24 | 180 | 378.5 | 2 | 1 | Yes | Flat | Flat | Open mixed shrub/ Pinyon-Juniper grassland | None | East | 25ft | 0ft | Wash 100ft south of site | Intermittent | West to East | 5940 | Box culvert under roadway | Unpopulated |
| 10 | 22 | 180 | 403.9 | 2 | 2 | Crowned upgradient and at BMS; pitched towards BMS at BMS and downgradient | North | Slight | Mixed shrub/ Pinyon-Juniper grassland | None | East | 18ft | <5ft | Wash 300ft south of BMS | Intermittent | Southwest to Northeast | 7260 | Culvert under roadway | Unpopulated |

| # | BMS | Roadway | | | | | | | Vegetation | | BMS (A samples) | | | Surface Water | | | Elevation (feet) | Drainage Structures | Setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Route | MP | No. of lanes | Draining to BMS | Crowned | Slope | Degree of slope | Type(s) | Shade | Side of Road* | Distance from pavement | Elevation below road | Description | Type | Flow Direction | | | |
| 11 | 21 | 180 | 408.7 | 2 | 2 | Pitched towards BMS; crowned in vicinity | Flat | Flat | Open Pinyon-Juniper mixed shrub grassland | None | East | 18ft | 10ft | Stream 300ft south of BMS | Perennial | Southwest to Northeast | 7360 | Box culvert at bridge | Unpopulated |
| 12 | 20 | 180 | 416.9 | 2 | 2 | Pitched towards BMS | Flat | Flat | Grasses, pasture adjacent | None | East | 31ft | <5ft | Nutrioso Creek 300ft north of BMS | Perennial | East to West | 7660 | Box culvert at bridge | Populated, rural |
| 13 | 19 | 180 | 423 | 2 | 1 | Yes | South | Moderate | Open ponderosa pine forest (grassy understory) | Heavy | East | 39ft | 5ft | Surface Water parallels site to the east | Perennial | North to South | 8350 | Culvert under road discharges drainage from west side of road to just north of BMS. | Populated, rural |
| 14 | 18 | 191 | 243.8 | 2 | 1 | Yes | South | Slight | Ponderosa pine forest, grassy understory | Light | West | 30ft | 15ft | Stream to the south of the BMS | Perennial | Northwest to southeast | 7640 | Cculvert down gradient of the BMS, discharges drainage from north to south of roadway | Unpopulated |
| 15 | 17 | 191 | 235.7 | 2 | 1 | Yes | North | Slight | Mixed conifer forest (spruce, fir), grassy understory | Moderate | East | 27ft | <5ft | Stream parallel to the east | Perennial | South to North | 8240 | None | Unpopulated |
| 16 | 16 | 191 | 226.1 | 2 | 2 | Pitched towards BMS | South | Moderate | Mixed conifer forest (spruce, fir) with some aspen in vicinity | Heavy (open post-burn) | East | 12ft | <5ft | None | None | None | 9240 | None | Unpopulated |