CDOT-CTI-95-5

Final Report

on

Environmentally Sensitive Sanding and Deicing Practices

submitted

to

Colorado Transportation Institute

and

Colorado Department of Transportation

by

ESSD Research Group
Department of Civil Engineering
University of Colorado at Denver

Nien-Yin Chang, Principal Investigator
Walter Pearson, Project Manager
James I. J. Chang, Project Engineer
Al Gross, Member
Mark Meyer, Member
Marva Jolly, Member
Barbara Vang, Member
Hellen Samour, Member

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16. Abstract

Growth in the Denver-metro area has led to an increased impact on the environment due to winter maintenance activities. According to the Regional Air Quality Council, the use of sand as a traction aid contributes up to 45% of the particulate air pollution (PM_{10}) in the Denver area. The Environmentally Sensitive Sanding and Deicing Practices at the University of Colorado at Denver investigated literature and current practices from a wide variety of sources to arrive at a document which summarizes the current state of knowledge about deicing practices and their effect on human health and the environment. Topics include, properties of snow and ice, roadway traction, anti-skid materials, air quality impacts of anti-skid materials, water quality impacts of deicing chemicals, deicing chemicals, equipment to apply deicers, snow and ice management practices, and current practices obtained from interviews and site visits. Topics for further research are also discussed.

Implementation:

This report recommends that the use of sand be reduced, that sand be swept up as soon as practical, that the use of alternative deicers be considered, that winter maintenance activities be timed for optimal efficiency, and that CDOT conduct technology transfer seminars around the State to increase awareness of environmental impacts.

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Prefixes Used With Units

Factor	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10^1	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ

Unit Conversions

Length

1 inch, in = 25.4 mm = .0254 m
1 foot, ft = .3048 m
1 mile = 5280 ft = 1.609 km
1 mil = 2.54×10^{-5} m = .0254 mm = 25.4 μm

Density

1 lb-mass/ft^3 = 16.018 kg/m^3
1 g/cm^3 = 10^3 kg/m^3 = 1 Mg/m^3 = 1 t/m^3
slug/ft^3 = 515.4 kg/m^3

Mass

1 pound mass, lbm = .4536 kg
1 metric ton, t = 10^3 kg = 10^6 g = 1 Mg
1 slug (1 lb-force/ft s^2) = 14.59 kg

Acceleration

ft/s^2 = .3048 m/s^2

Force

1 lb-force = 4.448 N
1 kip = 1000 lb-force = 4.448×10^3 N = 4.448 kN

Area

in^2 = 645.2 mm^2
ft^2 = .0929 m^2

Pressure

1 psi (lb-force/in^2) = 6.895×10^3 Pa
1 atm at STP = 1.013×10^5 Pa
1 kg-force/cm^2 = 9.807×10^4 Pa
1 bar = 1×10^5 Pa
1 lb-force/ft^2 = 47.88 Pa
Pa = N/m^2

Flowrate

cfs = .02832 m^3/s
m^3/s = 1,000 L/s

Volume

ft^3 = .02832 m^3
U.S. Gallon = .1337 ft^3 = 3.785 L

Viscosity

Absolute, μ = 1 lb s/ft^2 = 47.88 N s/m^2
Kinematic, ν = ft^2/s = .0929 m^2/s

Velocity

fps = .3048 m/s
mph = 1.609 km/h

Concentration

kg/m^3
ppm = parts per million

Temperature

°C = 5/9(oF - 32)
°F = 9/5(oC) + 32

Specific Weight

$lb/ft^3 = 157.1\ N/m^3$

Application Rate

1 gm/m^3 = 13 lb/lane mile
1 kg/km = 3.55 lb/lane mile
1 lb/lane mile = 2.764 N/km

Acknowledgment

During the course of this research, questionnaires and requests for literature and site visits were sent to various local and state agencies in the US, and other countries with significant winter sanding and deicing practices; their contribution to this research project is greatly appreciated. In particular, Colorado Department of Transportation (CDOT); Regional Air Quality Council (RAQC); Denver Regional Council of Governments; Colorado Air Quality Control Commission; Pikes Peak Area Council of Government; the Cities of Aspen, Boulder, Colorado Springs, Denver, and Lakewood, the States of Alaska, California, District of Columbia, Idaho, Kansas, Maine, Michigan, Minnesota, Montana, Nebraska, New Hampshire, New York, North Dakota, Ohio, Oregon, South Dakota, Texas, Utah, Vermont, Washington, Wisconsin, Wyoming; the Countries of Canada, England, Finland, Ireland, Italy, Norway Sweden and many more have contributed greatly to this project. The foresight of Mr. David S. Zelenok from the Colorado Springs Department of Transportation for requesting this research is hereby acknowledged. The sponsorship of this research project by the Colorado Transportation Institute (CTI) is also greatly appreciated. Finally, the tremendous vision of Dr. Ray Chamberlain, the former Executive Director of CDOT, for the creation of CTI and the leadership of Ralph Trapani, CTI President, and Richard Griffin, CTI Research Engineer, have placed CTI and the State of Colorado in a leadership role in transportation research. Their contribution to the advancement of transportation engineering and technology is, hereby, acknowledged. The excellent coordination and management effort of David Woodham of CDOT, and the constant input from Charles Cunningham of CDOT Region 6 are also greatly appreciated.

1. Introduction

Many people come to Colorado because of its beautiful scenery and clean environment. Now, after nearly a decade of economic downturn, the economy is beginning to turn around, and the state is starting to prosper. Riding this wave of prosperity, more and more businesses and people are moving into the state. However, the growth has led to a steady increase in traffic volume throughout the Denver-metro area and the entire region. This has made tasks such as maintaining air quality increasingly more difficult. Thus, unless action is taken to minimize the impact of the growth spurt, the economy will prosper but at the expense of the environment.

This threat has forced the state and city governments and local municipalities to examine new measures to protect the environment. A large part of this combined effort has focused on maintaining and improving air quality. Because the increase in traffic volume will inevitably impact the air quality negatively, agencies have been forced to reexamine their current practices. Much of this search has focused on reducing particulate emissions. This has resulted in a reevaluation of current snow abatement practices which, according to the Regional Air Quality Council, contribute up to 45% of the particulate pollution problem and has made winter highway/ street maintenance more challenging.

Enhancing highway safety is the major objective of winter road maintenance. Thus, "Traffic safety is Job 1" for the Department of Transportation. In the winter months, when roadway traction is greatly compromised by snow and ice, this mission becomes much more difficult. Currently, sands and/or deicing chemicals are used in the winter to enhance roadway traction and highway safety. An "If the snow ain't brown, the street ain't safe" attitude from the public has often resulted in the excessive use of sand on public roads and streets. In general, the use of sand and deicing chemicals has contributed to air and water pollution. Because current winter highway and traction enhancement practices appear to be on a direct collision course with the protection of both air and water quality, the search for an innovative and viable alternative has become more pressing.

Evidence indicates that the excessive application of sand has contributed to the deterioration of air quality, particularly in the metropolitan area. The grinding of sand and dry deicing chemicals by traffic produces particulates. Some of the particulates released contribute to what is known as PM_{10} which is defined as particulate matter with an aerodynamic diameter less than 10 μm. When dry, PM_{10} can easily become airborne and can be breathed into our lungs. Breathing in PM_{10} can result in a decrease in lung functioning while long term exposure can lead to lung damage and possibly even cause cancer and death. Thus, PM_{10} is a health concern and the need to reduce its levels is obvious. In Denver, the situation is particularly severe during winter temperature inversions when the pollution is trapped and lingers in the area.

The Environmental Protection Agency (EPA) has established the following PM_{10} related air quality standards in the Clean Air Act (CAA) as amended in 1990:

- ◊ The 24 hr PM_{10} average cannot exceed 150 $\mu g/m^3$. Three exceedances are allowed in a three year period.
- ◊ The annual arithmetic mean of PM_{10} cannot exceed 50 $\mu g/m^3$. No exceedances are allowed.
- ◊ A state implementation plan (SIP) must be developed for areas violating the PM_{10} standards.
- ◊ The SIP must demonstrate attainment of the PM_{10} standard by December 31,

1994 for areas designated moderate nonattainment.

◇ All states must complete the formulation of an SIP by the end of 1994.

Failure to comply with the standards places the state in "noncompliance status" and can result in the forfeiture of federal funding for transportation projects. Therefore, it is imperative for the state to formulate the SIP to demonstrate intent to comply with the air standard. Colorado submitted an SIP in June of 1993 which has been accepted by the EPA.

Complying with the PM_{10} standard while maintaining highway safety has proven to be an extremely challenging task. Excessive sand usage is a large contributor to the winter PM_{10} problems; therefore, it is imperative to formulate a best management plan that provides for sufficient winter roadway traction but does not compromise the protection of the environment.

A greater emphasis should also be placed on responsible driving. Even a well maintained road cannot guarantee absolute safety. On a snowy day, no matter how diligently the street or highway maintenance crews fulfill their duties of plowing, sanding, and deicing, highway traction is still often compromised. Thus, driving safety becomes as much the responsibility of the driver as the maintenance crews. The need for a public education program stressing the recognition of winter pavement traction limitations, and the need for safe and responsible winter driving cannot be overemphasized. The public's perception of "If the snow ain't brown, it ain't safe" simply "ain't true," and the only way to change this misperception is through education.

Finding a solution that best reconciles the need to maintain safe winter driving conditions with the need to protect the environment will be an ongoing effort. This can only be accomplished through the combined efforts of the state and local governments, agencies, the general public, and all concerned parties. The Environmentally Sensitive Sanding and Deicing Practices project was conceived in order to aid in this effort and was undertaken in order to provide more information about a complicated problem.

2. Method of Research

The Colorado Department of Transportation, through the Colorado Transportation Institute, has funded a project in the Civil Engineering Department at the University of Colorado Denver campus entitled "Environmentally Sensitive Sanding and Deicing Practices". Dr. N.Y. Chang, department chairman, is the Principal Investigator.

The project is in response to the environmental concerns associated with the snow abatement practice of sanding and/or salting roadways to improve traction and public safety. Many communities in Colorado, including the Denver Metro area, have been identified as having a real or potential PM_{10} problem by the Colorado Department of Health (CDH) and the EPA. Major defined contributors to the problem are the geological materials used in sanding of roadways.

Alternatives to the conventional practices for storm response are desired to both maintain public safety and be environmentally sensitive. Toward this end the ESSD project was initially funded in October of 1993 with Phase I, Data Synthesis, and is now at the conclusion of Phase I and the initial work of Phase II, Environmental Impact and Pavement Traction.

The Research Objectives of the ESSD proposal were stated as being:

- ◊ to formulate an environmentally sensitive sanding procedure, and;
- ◊ to formulate an environmentally sensitive deicing procedure;

for implementation in the State of Colorado to enhance winter driving safety. It consists of two phases as:

- ◊ review of the state of the art, practices and data synthesis;
- ◊ Environmental impact assessment and pavement traction with the following research tasks:
  laboratory testing;
  field testing;
  modeling, and;
  implementation of research findings.

Phase I focuses on "data synthesis", and has the three fold objectives of:

- ◊ comprehensive review of previous research and current practices on roadway sanding and deicing information;
- ◊ comprehensive review of current innovative practices by Colorado state and local agencies, other states, and other countries, and;
- ◊ the synthesis of the information obtained to define innovative ideas, to recommend future research needs and direction.

The proposal specified: reviewing previous research and current practices; summarizing the research findings and recommending practices appropriate for the Colorado environment and recommending further research appropriate for Colorado; identifying factors affecting the effectiveness of sanding and deicing; identifying sanding materials and deicing chemicals and their properties; identifying the sanding and deicing equipment and determining their effectiveness; and recommending future research needs and direction.

The objectives were pursued and met by a team of UCD students. The team has the following research tasks:

- comprehensive review of sanding and deicing practices in Colorado, the nation and other countries;

This was initiated with library searches for the basic areas of "Air Quality Standards to be Met"; "Water Quality Standards to be Met"; and "Physical Properties of Ice and Snow". The review continued with comprehensive computerized searches of commercial library data bases for articles, papers, books, etc. pertaining to the proposal. These references were then classified by subject and assigned by subject area to individual team members to obtain and review.

The reference search covered the time period from the mid 1970's to the present. References on the subject area were obtained from many foreign countries and numerous U.S. government agencies, states and private companies. The search also involved non- or not-for-profit agencies as the multiple county associations of a single metropolitan area (Denver Regional Council of Governments, etc). Over 300 references were pursued covering all phases of the proposal subject matter.

- send a letter of invitation for participation in and support of this research to municipalities, townships, metropolitan areas, highway departments of the states or Colorado counties, and other countries with similar winter concerns.

These letters went out in early December to over 140 recipients. A copy of the letter and materials sent is attached in Appendix I. The package includes the letter, the original proposal, and a Questionnaire. Responses have been received from over 45% of the recipients, including seven foreign countries. Additionally the team has made personal contact with several government agencies and regional agencies such as the Pikes Peak Area Council of Governments, the Regional Air Quality Council, the Colorado Department of Transportation, the Allergy Respiratory Institute of Colorado, etc.

- Identify currently available innovative approaches to sanding and deicing, and arrange information sharing and site visits during the winter sanding and deicing season.

This was pursued via the invitation letters and the associated follow up. Fifteen specific sites for visitation were targeted and visited. The fifteen sites visited were:

- Denver - downtown - Denver City and County
- Denver - interstate corridor - CDOT
- Colorado Springs - city area - city
- El Paso County - urban feeder roads
- Colorado Springs - interstate corridor - CDOT
- Loveland Area - local roads and feeder roads to interstate - city and Larimer County
- Loveland Pass/Eisenhower Tunnel - interstate - CDOT
- Aspen - city roads - winter resort area
- Limon - interstate - CDOT
- Lakewood - REALITE test area - Jefferson County & Lakewood
- Upper Bear Creek - paved and dirt feeder roads - Clear Creek County
- Telluride - winter resort area

◊ Garfield County - paved rural roads

◊ Boulder - innovative methods

♦ identify effective sanding materials and deicing chemicals currently being utilized and collect their material properties.

The reference search contributed greatly to this effort. However, the invitation letter questionnaire responses, the personal contacts with responsible agencies and the site visitations have furthered the comprehensive coverage of this task. Contacts have been made with chemical manufacturers and associations to obtain specific material properties for commercial products. This continues to be pursued.

♦ identify the application machinery and procedures and their cost effectiveness.

This too was a product of the reference search and the contacts being made through multiple means. The government agencies were the most reliable source for this information.

♦ summarize the research findings and recommend the practices deemed appropriate for the Colorado environment for implementation and/or further research for its appropriateness for use in Colorado.

This is the end product of Phase I and is presented in a comprehensive manner in the following sections. The results were presented in three quarterly reports as well as this final project report.

- through data synthesis, identify factors critical to the effectiveness of sanding and deicing, and the environmental protection, and the need and direction for future research aimed at producing environmentally-sensitive practices for improving traction on ice and snow.

This task is the final one for Phase I and is addressed in this final project report. The comprehensive review, as described above, has resulted in the accomplishment of this task.

Contacts made and the reference search have pointed to another function or task for ESSD, coordination with other agencies. A wealth of information and site specific data has been gathered along the Front Range of Colorado. Additionally there are ongoing efforts by many agencies and associations that need to be coordinated and utilized. This project is not commissioned to fill this function but the project must ensure that the project work is coordinated with these agencies and associations to derive the maximum benefit to the sponsors of the project. This was accomplished via continued personnel contacts and attending meetings of other agencies and associations. This effort needs to continue in Phase II.

3. Traction During Icy and Snowy Conditions

3.1 Introduction

Research on traction during Phase I focused on investigating properties of snow and ice, methods of measuring friction, types of anti-skid materials, and the engineering properties of these materials. This material was obtained through the CDOT library and many local, state, and international transportation departments. The purpose of this final report is to summarize all of this information, thereby supporting the Phase II or testing phase of this research effort.

3.2 Properties of Ice and Snow

3.2.1 Overview

This section discusses the deposition of snowfall and the metamorphic processes which determine the properties of snow. The frictional characteristics of snow and ice with regard to tire traction are also examined.

3.2.2 Snow Deposition

Ice particles that form in the atmosphere have a large variety of crystal habits and sizes. By the time they reach the ground, they have undergone a number of transformations resulting from growth, disintegration, or agglomeration. Typical densities of snowcover range from 10 kg/m^3 to 700 kg/m^3 and are shown in Table 3.1.

SNOW TYPE	DENSITY kg/m³
Wild Snow	10 to 30
Ordinary new snow immediately after falling in the still air	50 to 65
Settling Snow	70 to 90
Very slightly toughened by wind immediately after falling	63 to 80
Average wind-toughened snow	280
Hard wind slab	350
New firn* snow	400 to 550
Advanced firn* snow	550 to 600
Thawing firn* snow	600 to 700

*Snow Consolidated Partly Into Ice

Table 3.1 Snow Densities (After Seligman, 1962).

Snowcover is a residual product of snowfall and has characteristics quite different from those of the parent snowfall. The three primary factors affecting the characteristics of a snow deposit are the atmospheric conditions, the surface temperature, and the surface wind velocity.

◊ **Atmospheric Conditions**

The formation of snow in the atmosphere depends on many variables. The most important of which are that the ambient temperature must be less than 0°C, and that supercooled water must be present.

◊ **Temperature**

The surface temperature at the time of snowfall controls the dryness, hardness and crystalline form of the new snow. Consequently, the erodibility of a snowfall by the wind is directly related to the surface temperature.

◊ **Wind Velocity**

The flow of wind near the ground surface is normally turbulent and snowcover patterns reflect a resulting turbulent structure. Wind speed near the ground surface also determines how crystals arriving at the surface are packed. At high speeds, crystals are broken first in the extremely turbulent boundary layer in the lowest few meters above the surface, and then they are dragged across the surface (saltation). After being reduced in size and shaped more symmetrically, the crystals can be packed much more closely to produce a much denser surface layer than would occur in the absence of wind.

3.2.3 Metamorphism of Snowcover

After the snow is deposited the particle shapes are modified by a process known as metamorphism. Thus, smaller crystals decompose into fragments and larger fragments grow utilizing these smaller fragments. This process, known as sintering, continues until the fragments have been reduced to rounded grains of ice. Thermodynamically, the snow crystals are moving to a state of equilibrium, thus minimizing the ratio of surface area to volume. Consequently, the density of the snowpack is increased. This process also increases the strength of the snowpack.

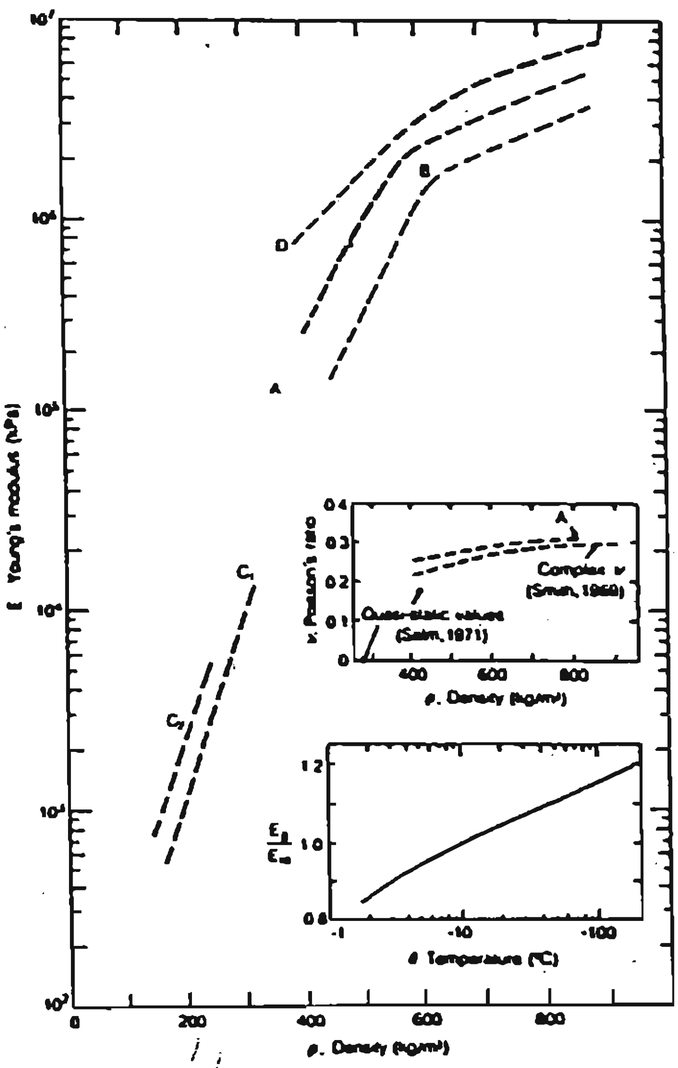
3.2.4 Properties of Dry Snow

The compilation of data in this section is selective and gives an indication of the range of variability of the bulk properties of snowcover. Most of this data results from measurements of snow on a macroscopic scale (tens of centimeters) and is not related to the crystalline nature of the snowfall. In recent years, mathematical models based on microscopic theory have been developed to describe the bulk properties of snow. However, they will not be discussed in this report.

◊ Mechanical Properties

Snow will deform elastically when subjected to a small load applied for a short period of time. Under these conditions the strains are small enough not to disrupt the grain structure and are recoverable once the stress is removed. Snow also deforms continuously and permanently if a sustained load is applied. This behavior is more commonly described as viscous or plastic flow. For snow however, the yield stress is so small that it cannot be measured. Thus, snow is commonly referred to as a visco-plastic material.

It should be noted that the Young's modules, E, of a snow pack varies with temperature. There is a factor of 10^5 between the smallest and the largest measured value of E. Less cohesive, more granular snow typically has a low E, however, E also increases with time during sintering as seen in Figure 3.1.



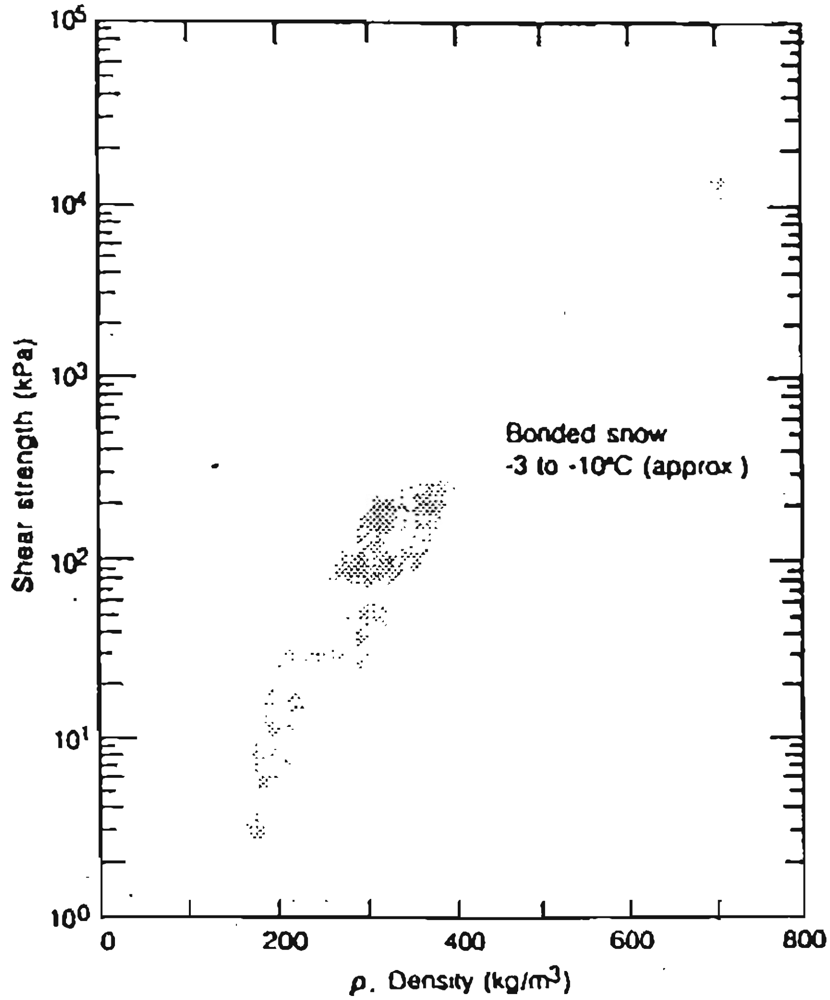
Young's modulus for sintered snow as a function of density (Mellor, 1975). A: pulse propagation or flexural vibration at high frequencies, -10 to -25°C (Bentley *et al.*, 1957; Nakaya, 1959a, b; Lee, 1961; Crary et al. 1962; Ramseier, 1963; Smith, 1965). B. Uniaxial compression, strain rate approximately 3×10^{-4} to 2×10^{-3} sec^{-1}, -25°C (Kovacs et al., 1969). C_1: Uniaxial compression and tension strain rate approximately 8×10^{-6} to 4×10^{-4} sec^{-1}, -12°C to -25°C. C_2: Static creep test, -6.5 to -19°C (Kojima, 1954). D: Complex modulus, 10^3 Hz, -14°C (N. Smith, 1969).

Figure 3.1

Under compression, the stress-strain rate of snow can vary by six or seven orders of magnitude since the strain history of a snow sample is in most cases unknown. Also, this variance may be caused by the effect of compression itself on the strain rate, and in practice is minimized by making measurements over small ranges of strain.

Because of this variance, the strain is resolved into two components by the theory of elasticity: deviatoric strain and volumetric strain. Deviatoric strain is pure shear strain, defined by the shear angle, Φ, measured under conditions of pure shear stress. Figure 3.2 shows stress-strain relationships interpolated for different densities of snowpack. Due to the visco-plastic nature of snow, the volumetric stress-strain relationship is extremely complicated and will not be discussed at this point.

The term "compactive viscosity" is defined as the ratio of overburden pressure to vertical strain when snow is subjected to uniaxial compression. The failure limits of a dry, uniform snow under compression are measured by the fracture or collapse of a test sample when subjected to tension or compression.



Failure limits of dry coherent snow under shear stress (Mellor, 1975). (Data from Haefeli, 1939; Butkovich, 1956; Ballard et al., 1965; Keeler and Weeks, 1967, and Keeler, 1969). Also avalanche release data from various sources summarized by Keeler, 1969. Some values from in situ shear vanes were rejected.

Figure 3.2

◊ **Frictional Properties**

The sliding or kinetic friction of snow is extremely low. Bowen (1955) showed that this is due to the presence of a liquid film as revealed by measurements of electric conductivity of the snow in contact with a runner. Near 0°C this film is probably produced by pressure at the points of contact between the snow grains and the runner, while at lower temperatures it is likely generated by frictional heating. This idea is supported by the fact that the coefficient of friction increases at lower temperatures.

Table 3.2 lists the lower and upper limits of the sliding friction coefficient for a number of common materials on snow. The lower values are for dry snow at 0°C. For wadable runner material, the friction rapidly increases as soon as the snow contains liquid water, and is probably due to work expended against surface tension forces as the contact menisci are dragged over the sliding surface.

Material	Lower Value (dry snow)	Upper Value
Poly tetraflorethelene	0.02	0.04
Poly ethylene	0.02	0.05
Poly vinyl chloride	0.03	0.08
Epoxy Resin	0.03	0.07
Glass	0.015	0.02
Aluminum	0.04	0.05
Iron	0.015	0.02
Wood	0.06	0.18
Beeswax	0.04	0.28

Table 3.2 Upper and Lower Limits for the Coefficients of Sliding Friction for Various Materials (Mellor).

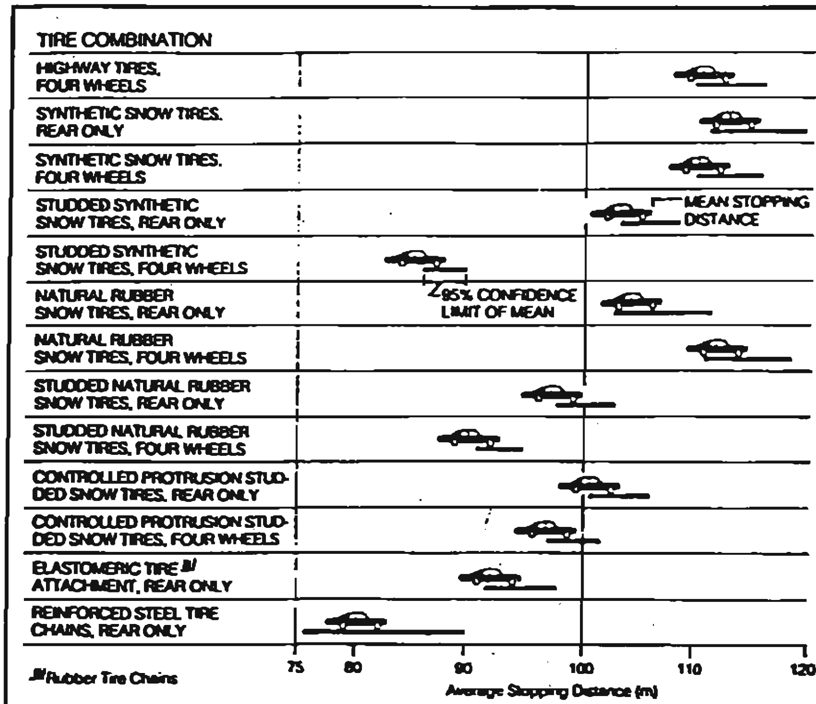
3.2.5 Properties of Wet Snow

Since wet snow cannot sustain temperature gradients in the same way as dry snow, it cannot conduct heat. Melting takes place at the upper surface because of absorbed solar radiation and heat transferred from the air. Warm rain can carry energy a short distance into the snow but the melting that occurs is very near the upper surface. The absorption of radiation can also cause melting within the snow (Langham, 1974) but again, this occurs near the surface.

As a result of daily nocturnal refreezing of a snowpack, a strong crust forms on the upper 10 cm of a snow layer. This process of melting and refreezing changes the microstructure of the snow and is known as melt-freeze metamorphism. During the melting process, the larger grains become rounded and the smaller grains disappear completely. Water is held between the grains and there is a general compaction of the snowpack. When the water refreezes the snow has an increased density. Furthermore, the snow's strength and hardness are increased due to a greater continuity of the ice matrix.

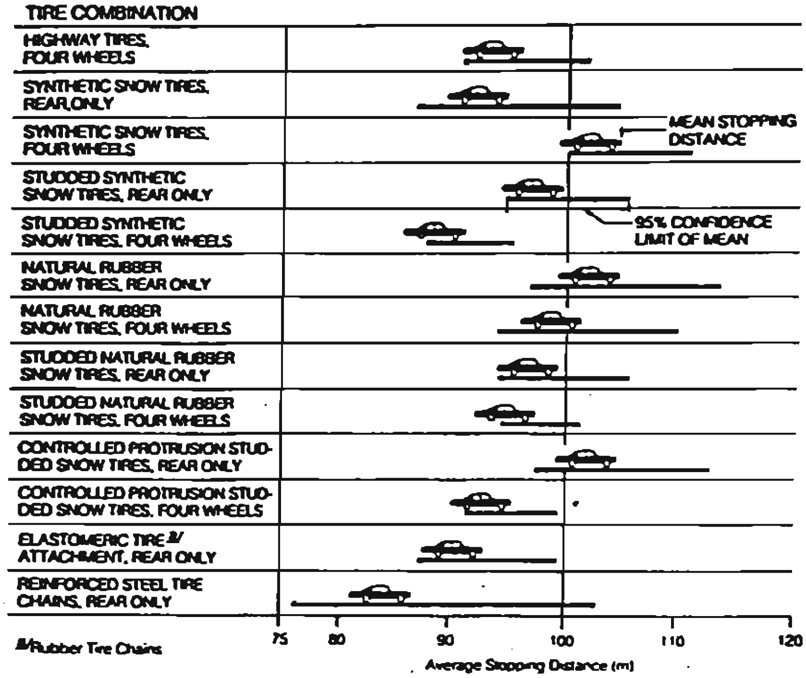
3.2.6 Frictional Properties of Ice

Results of a study of the stopping distances of cars on clear ice are shown in Figures 3.3 and 3.4. This study accounted for differing tire combinations and traction improving devices, such as studs and chains. The stopping distances were then averaged on clear ice at -1°C and -18°C. Generally, the stopping distances of all snow tires, with the exception of studded tires and tires fitted with chains, are significantly longer on clear ice at -1°C than at -18°C.



Stopping distances on clear ice at -1°C for different tire combinations. (Ontario Department of Transportation and Communications, 1971).

Figure 3.3



Stopping distances on clear ice at -18°C for different tire combinations. (Ontario Department of Transportation and Communications, 1971).

Figure 3.4

3.3 Interface Friction and Roadway Traction

3.3.1 Theory of Friction

When two surfaces are in contact, tangential interface friction forces will always develop if one attempts to move one surface with respect to the other. Friction between a tire and pavement surface can be explained using a simple block theory.

As shown in Figure 3.5, a block resting on a flat surface has weight and therefore an equal and opposite force must be exerted by the surface onto the block. This force is known as a normal force (N). Then another force P is applied and acts against the block in a horizontal direction. The friction force (F) can be defined to be the force sufficient to resist the force P and keep the block stationary. As the force P is increased and the block begins to move, the friction force is equal to the normal force (N) times a coefficient of kinetic friction (μ_k).

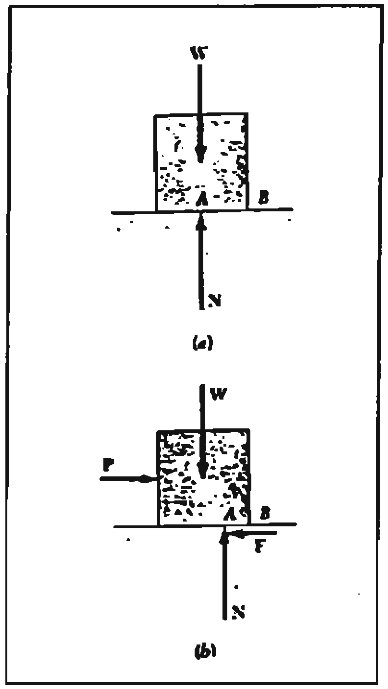


Figure 3.5 Friction Free Body Diagram (After Beers et al., 1988).

As a tire comes into contact with the road surface, the weight of the car is resisted by a normal force in the pavement. The friction force between the tire and road surface is affected by any materials between on the road surface. In icy and snowy conditions, the tires come into contact with a very slick surface and the coefficient of friction is low. On dry pavement, however, the coefficient of friction is very high. The addition of anti-skid materials to an icy or snowy road surface provides the vehicle tires with enhanced traction.

3.3.2 Measurement of Friction

In practice, road traction is measured in accordance with ASTM E 274. The measure of skid resistance is the skid number, or 100 times the measured coefficient of friction. The variation of skid number with speed is specified by the skid number gradient or the percentage normalized gradient. The skid number gradient is defined as the rate of decrease in skid number with increasing speed. The percent normalized gradient is defined as the percent of the rate of decrease in skid number with increasing speed (Mullen, 1974).

Skid number is a function of surface texture. Pavement texture is subdivided into macrotexture and microtexture. Macrotexture is a function of aggregate gradation, while microtexture is a function of aspirates and surface roughness of individual aggregate particles. A surface that has good microtexture ensures high skid resistance at low speeds. As speed increases, macrotexture becomes more important in determining the skid resistance of the road. The combined effects of macrotexture and microtexture interact to provide adequate skid resistance at high speeds as reported by Kummer and Meyer.

3.3.3 Field Measurements

Measurements of skid resistance and road friction can be made using a variety of devices.

- **Brake Force Trailer**

  Based on the ASTM standard E 274, the brake-force trailer is the most common technique used in North America to measure skid resistance of road surfaces. The test unit consists of a towing vehicle and a brake-force trailer. A commonly used unit is the Coralba Friction Tester. The test measures the steady friction force generated when the standard tire of the locked test wheel slides over pavement surface at a constant traveling speed. The measured friction force is described as the skid number (SN), which ranges from 0 to 100.

◊ **Mu-Meter**

The mu-meter is a continuously recording friction measuring trailer that measures the side-force friction generated between the text surface and two pneumatic tires. The tires are mounted on free running wheels set at a fixed toe out angle of 7.5° to the line of drag.

◊ **SCRIM**

The SCRIM device is also a continuous testing instrument used primarily in Great Britain. Similar to the mu-meter, it measures the coefficient of sideways force of the pavement surface. The test wheel is inclined at 20° to the line of travel and rolls free over pavement. The smooth test tire is inflated to a pressure of 345 kPa. The SCRIM has its own dead weight and suspension system. Consequently, there is a known static reaction between test tire and pavement. A signal from an electric load cell provides the sideways force input into the recording system. The recorded data is then processed by computer and a printout is produced that summarizes the coefficients of side for friction for each test section (Mullen, 1974).

3.3.4 Factors Affecting Road Traction

◊ **Mean Tire Contact Area With Road Surface**

The theoretical relationship between inflation pressure and average contact pressure is derived from the summation of forces to attain the following equilibrium equations (Van Vurren, 1974).

1) $Q = qA$

where :

$Q =$ normal reaction of ground on tire
$q =$ internal pressure of tire
$A =$ mean contact area of tire to road

2) $qf_1(B,L) + 2T_1\sin\theta_1 f_2(l) + 2T_2\sin\theta_2 f_3(b) = pf_4(b,L) + C$

where:

$f_1(B,L) = A$
$B =$ contact width
$L =$ contact length
$T_1 =$ tensile stress per unit length in the tire wall
$\theta_1 =$ angle between the horizontal and the force direction of T_1
$f_2(l) =$ projected length over which T is active
$l =$ imaginary length inside the tire over which p acts
$T_2 =$ tensile stress per unit length in the tire base
$f_3(b) =$ projected length over which T_2 is active
$b =$ imaginary pressure width
$f_4(b,l) =$ a, imaginary contact area inside the tire, which is a function of b and l
$C =$ component of load which is transmitted through the tire wall.

Empirical studies have shown that the mean contact pressure of a tire is a constant 76 percent of the inflation pressure over the entire practical range of wheel load and inflation pressure combinations.

◊ **Pavement Type**

The presence of ice inhibitors, such as $CaCl_2$ (Verglimit), in asphalt concrete mix has no effect on the skid resistance of the road surface (Ryell, 1979). Also generally, friction measurements on reinforced concrete pavement are lower than those on an asphalt concrete pavement (Cunningham, 1994).

◊ **Presence of Sand on Ice**

Borland and Blaisdell conducted a study of braking traction on sanded ice for the U.S. Army Corps of Engineers in 1992. They tested five distinct gradations of sand from a single host material shown in Figure 3.6. The experiment was conducted at full scale in the Frost Effects Research Facility at the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Results from this experiment are shown in Figure 3.7.

At surface temperatures of -10°C, their findings show that coarse sands perform well. They provide a friction number of about 15, which is an 83 percent increase over the bare ice friction of 8.2. The SAE and TC sands perform best under this condition.

At surface temperatures of -3°, fine sands gave the highest friction number, 18.4 which is a 64 percent improvement over the bare ice condition. This study also showed that sands with most of their grains about 1 to 2 mm in diameter performed well independent of ice temperature.

The concentration of a sand on ice strongly influences the degree of traction enhancement, as does the temperature of the sand when applied to the ice. Commonly, sand is used in conjunction with liquid disbonding agents, such as $CaCl_2$. The practice of prewetting sand has also been shown to assist in the placement and penetration of the sand to ice. As mentioned earlier, the temperature of the sand when applied to ice also affects traction. Heated sand has been tested by the State of Alaska and found to be effective at temperatures of 180°F, but these temperatures were difficult to achieve in field tests.

Sand Type	Sieve Number	Percent Finer by Weight
FAA	4	100
	8	97-100
	16	30-60
	50	0-10
TC	4	100
	8	30-50
	16	0-20
	50	0-2
SAE	6	100
	8	60-100
	25	0-20
	40	0-5
ASTM	4	100
	8	95-100
	16	40-75
	50	10-35
	100	2-15

Figure 3.6 Allowable Gradations for Several Specified Sands (After Transportation Research Record, No. 523, 1974).

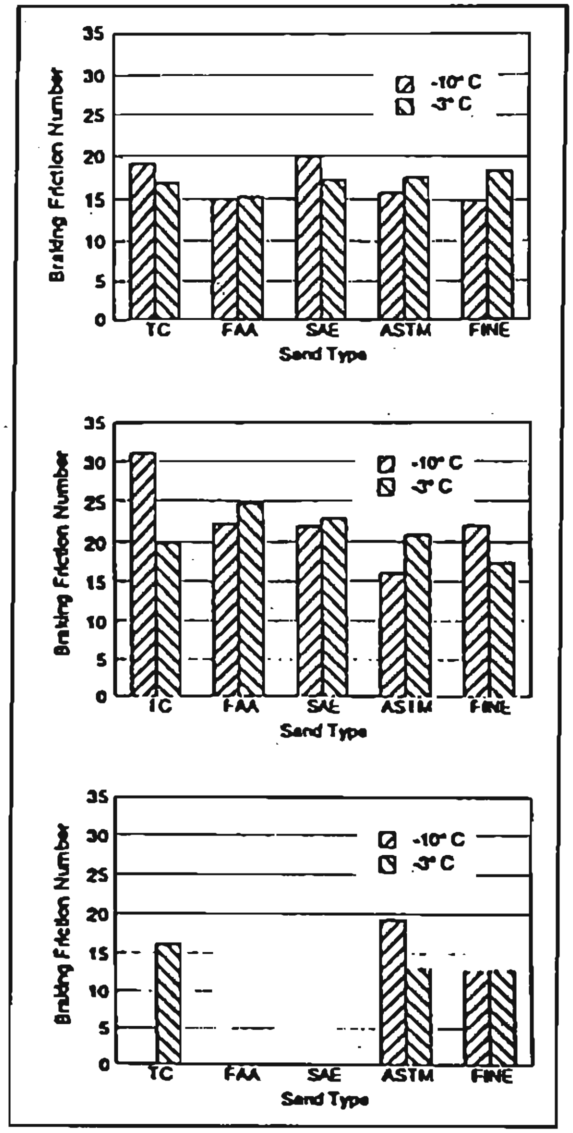


Figure 3.7 Braking Friction Performance at FAA-Recommended Sand Concentration (73g/m) (top), Twice the FAA-Recommended Sand Concentration (142 g/m^2) (middle), and half the FAA-Recommended Sand Concentration (34 g/m^2)(bottom).

3.4 Anti-skid Materials

3.4.1 Introduction

Anti-skid materials, most commonly sands, are used to increase traction between the vehicle tires and pavement surface. The sand is mixed with rock salt and/or coated with a chemical deicer, such as Calcium Magnesium Acetate (CMA), to increase the penetration into the ice and snow. After application, the sand grains 'dig' into snow and ice and provide a better friction surface between tire and pavement. Much of the information about anti-skid materials in this report was obtained from the questionnaires answered by state, local, and international departments of transportation.

3.4.2 Sand

River and crushed aggregate are the two main types of sand used to increase traction on the winter roads of Colorado. River sand is rounded and smooth while crushed aggregate is rough and angular. River sand is generally cleaner and has less contaminants than crushed aggregate. Crushed aggregate has been found to be particularly effective at increasing roadway traction, due to the angularity of the sand grains. The sand grains 'dig' into the snow and ice, thus keeping the sanding material on the road surface and providing traction for tires.

Application amounts of sand for the Denver metro area vary considerably. Amounts applied ranged from a minimum of 350 lbs per lane mile to a maximum of 2,900 lbs per lane mile. An average amount was found to be 800-1,200 lbs per lane mile. Amounts applied were dependent on the geographic location. Western areas of the Denver metro area generally used higher amounts of sand than the eastern locations. Sand was usually mixed with salt, and mixtures typically ranged from 3-20 % salt content

(Regional Air Quality Council-Street Sanding and Sweeping Survey, 1991).

◊ **Positive and Negatives of Sand Usage**

Initially after application, sand increases the coefficient of friction between the sand/snow mixture and tire. The coefficient of friction decreases somewhat as the sand is pushed below the ice surface and is moved to the edges of the lane. Sand is easily dispensed from sanding trucks and application amounts can easily be calibrated. The sand is usually mixed with rock salt and/or sprayed with a liquid chemical deicer to increase the effectiveness. Sand is very economical with prices ranging between $2 to $15 per ton. Many state localities excavate their own sand making it even more economical.

After a snow event the sand on the roads must be picked up by broom or vacuum sweepers. Street sweeping is costly and does not occur immediately after the snow melts, therefore, the sand is repeatedly crushed by automobile traffic. This crushing reduces the sand to fine particulate matter which is picked up into the atmosphere. The reentrained road dust contributes significantly to the PM_{10} problem the Denver metro area currently experiences. Refer to the section of this Report on Air Quality for further information on this topic.

Also, any leftover sand on the streets decreases the coefficient of friction which causes skidding and stopping distances to increase. This poses a threat to drivers and increases the probability for accidents. Sand leftover on streets can cause damage to windshields and autobody paint. Sand is also a factor in water pollution as discussed in the Water Quality Section of this report.

◊ **Trends In Sand Usage**

Highway departments across the metro area will be reducing their usage of sand applied to winter roads because of Regulation 16 which was enacted by the Regional Air Quality Council in August of 1991. This regulation requires all localities to reduce the amount of sand by at least 20% from their 1989 usage levels. The goal is to eventually reduce street sanding amounts to 500 lbs per lane mile. The RAQC also recommends that sanding be focused on priority areas such as:

- areas prone to accidents and areas requiring special safety concerns
- school zones and hospital zones and police and fire department zones
- bridges and overpasses
- curves and graded roads
- high volume traffic areas

3.4.3 Alternative Anti-Skid Materials

The initial survey of local and state departments of transportation defined a variety of anti-skid materials or abrasives currently being used. The most commonly used abrasive is sand; however, other materials are also used depending on availability and cost.

These materials are listed in Table 3.3.

PRODUCT	SIZE	EFFECTIVENESS
Realite Plus	1/8 in., 3/4 in.	Found too brittle, but more testing is required.
Sands (crushed aggregate and river)	1/4 in (avg.)	Very effective.
Bottom Ash	1/4 in. or smaller	Effective, not popular with local businesses.
Slag	1/4 in. or smaller	Used when locally available.
Volcanic Material	3/4 in. or smaller	Used when locally available.
Chat	1/4 in. or smaller	Used when locally available.
Heated Sand	3/8 in. or smaller	Effective only at 180°F temperatures

Table 3.3 Size and Effectiveness of Various Anti-Skid Materials.

◊ **Rea*lite*® Plus**

Produced by Western Aggregate, this material is a lightweight, kiln-fired, expanded shale aggregate considered both durable and porous. The porosity allows the absorption of chemical deicers. This material is undergoing in-situ tests to determine its durability, PM_{10} potential, and effect on traction. The city of Aspen, Colorado will be testing this material as a chip seal. Because of its porous nature, Rea*lite*® Plus can be injected with deicers, which are then released during a winter storm event. If this process performs as expected, snow and ice will be prevented from bonding to the pavement surface.

The City of Lakewood, Colorado in cooperation with the Regional Air Quality Council (RAQC), tested Rea*lite*® Plus as an anti-skid material alternative to sand. The main objective of the test was to determine the PM_{10} potential of Rea*lite*® as compared to sands. However, the results only showed reduced PM_{10} levels on the first day; subsequent days did not produce any significant difference in PM_{10} levels. Further testing was suggested.

◊ **Bottom Ash**

Bottom ash is a by-product of coal fired power plants. This material is utilized when locally available, but local businesses dislike the residue which is frequently tracked into stores.

◊ **Slag**

Slag is a ceramic aggregate waste product produced by the burning of coal in boilers and can be used when industry provides a source. Slag has been found to have a higher density and be more angular than sands. These qualities allow it to remain on the pavement longer and provide better traction. However, the particles are sharp and can cause damage to tires and road surfaces. The state of Kansas uses a variety of anti-skid materials including slag, chat, rock, and sands (State of Kansas, Specifications for Aggregate Ice Control, 1982).

◊ **Volcanic Materials**

Materials such as volcanic aggregate and volcanic cinders have been found very effective due to size and durability. These materials are not used widely, but offer a feasible alternative when locally available. Although these materials provide good traction on the road surface, volcanic materials have a high angularity and can cause damage to tires.

◊ **Chat**

Chat consists of mine tailings or by-products of lead or zinc milling operations. Again, the availability of this material for traction enhancement depends on the location and geography of an area. The state of Kansas lists this material as a type of aggregate for control of ice.

◊ **Heated Sand**

Application of heated sand to the road surface was studied and field tested in a study done in Alaska in 1987. The tests concluded that heating the sand to 180°F produced the best results, allowing the sand to more quickly penetrate the ice and snow. The equipment had difficulty achieving this temperature, and vapor clouds during application created traffic hazards.

3.4.4 Characteristics of Abrasives

Abrasives can be compared using various methods and criteria. The qualities of an abrasive which make it more effective at enhancing friction include: durability, grain size, hardness, angularity, and PM_{10} potential.

◊ **Durability**

Durability of an abrasive refers to the strength and rate of breakdown of the abrasive by repeated grinding from traffic. In Colorado, many local transportation departments follow Regulation 16 specifications for durability standards of the sands used. Regulation 16 specifies that sands must be either:

- < 2% fines and < 45% durability index or
- < 4% fines and < 33% durability index and have a high angularity.

Regulation 16 defines the term durability index to be the percent loss of weight as determined using ASTM "Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine." Preliminary testing of Realite® Plus as an aggregate by the Colorado Department of Transportation determined it to be too brittle for use as an anti-skid material. (Cunningham, 1994).

◊ **Grain Size**

The effectiveness of anti-skid materials increases with average grain size. Larger particles "grip" into the snow and ice and provide a greater contact area on the tire, therefore increasing traction. Aggregates are tested using the ASTM Sieve Analysis to determine the range of grain sizes in a sample.

As shown on Table 3.3 the average grain size for most materials is 1/4 inch in diameter. However, the volcanic materials have grains as large as 3/4 inch in diameter, which are very durable and easy to see on the road surface.

◊ **Hardness**

Hardness refers to the resistance of a substance to abrasion, (Fagan, 1965). Geologists use a Moh's scale of minerals in order of increasing hardness to judge other substances against. Substances are given a number to rate hardness from 1-10. During the literature review, little was discovered as to hardness testing of the various anti-skid materials. Future research could include testing of the various materials. Below is the Moh's scale in order from talc being the softest to diamond being the hardest:

1. talc	6. orthoclase
2. gypsum	7. quartz
3. calcite	8. topaz
4. florite	9. corundum
5. apatite	10. diamond

◊ **Angularity**

The angularity of an individual grain refers to the number of intersecting planar faces on the surface of the particle. Generally, the angular particles possess better traction enhancing properties, such as higher shear strength, (McCarthy, 1993). For example, crushed aggregate is more angular and also exhibits a greater durability than natural sands.

◊ **PM_{10} Potential**

Studies have not been conducted to determine the PM_{10} potentials of many of the various anti-skid materials. Sands are the primary anti-skid materials used and are reported to contribute approximately 45% of the PM_{10} according to the SIP (ESSD First Quarterly Report, 1994).

3.4.5 Tire Characteristics

The tires on a vehicle directly interact with pavement conditions. Tire manufactures make a variety of tires suited to different vehicles and weather conditions. For winter driving, snow or studded tires are often used to increase traction on the icy and snowy roads.

Tire tread design is one alternative to increase road traction. At the Nevada Automotive Test Center in Carson City, tires were tested in varying snow conditions comparing braking traction, slip velocity, and lateral traction. Results showed that tread design is critical in skid resistance and if it is not sufficient then mechanical means such as studded tires must be used. In Figures 3.8 and 3.9 the traction resistance is shown over a variety of winter environments.

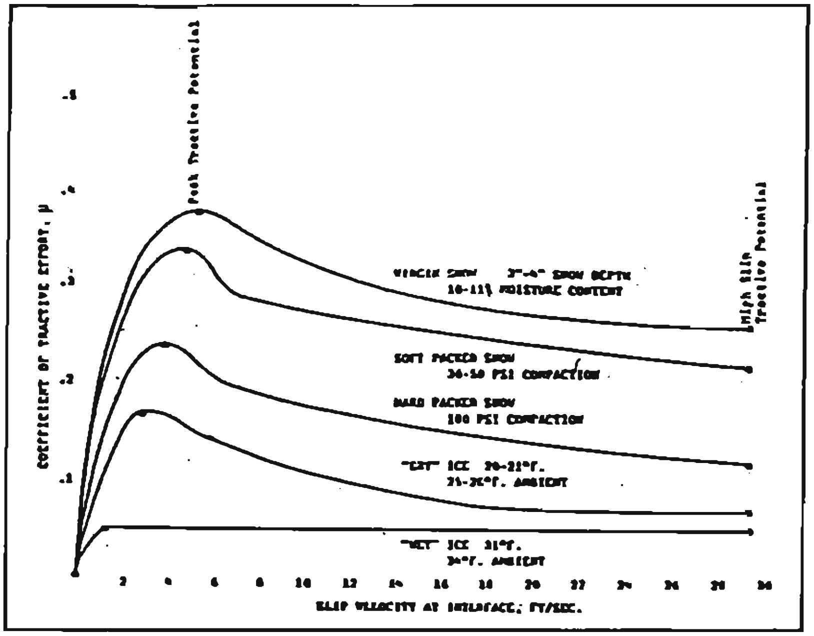


Figure 3.8 Characteristic Winter Tire Acceleration (After Hodges, 1973).

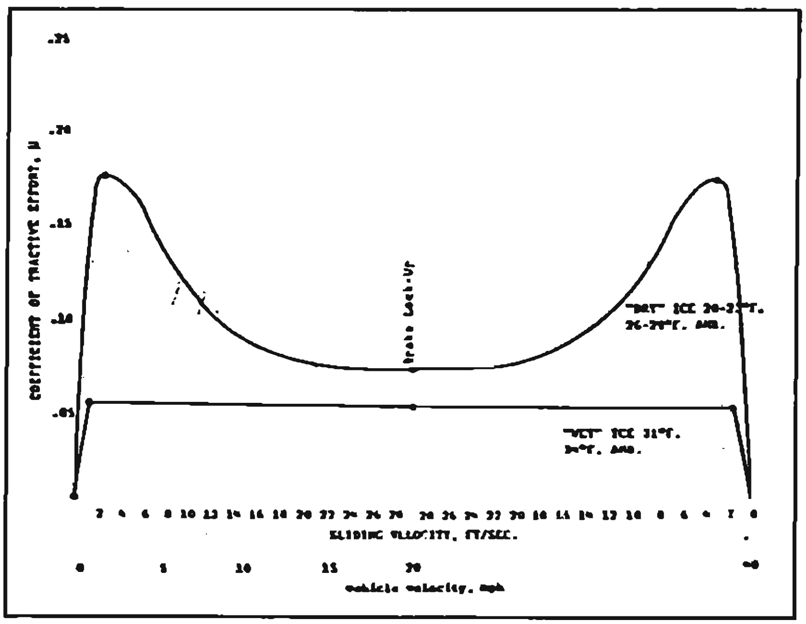


Figure 3.9 Characteristic Winter Tire Braking (After Hodges, 1973).

In a study by the Washington State Highway Commission in 1973, several types of tires were tested and evaluated on both wet and dry pavements. The two test vehicles used were a Department of Highway's Plymouth Fury III (DOH) and a Washington State Patrol Plymouth pursuit vehicle (WSP). The types of belted tires tested include:

- Highway tread tires, 6 ply tread.
- Snow tires, 4 ply tread.
- Tungsten studded snow tires, 4 ply tread.
- Norfin studded snow tires, 4 ply tread.
- Highway studded (Pathfinder), 4 ply tread.
- Garnet snow tires (recapped tires).

In summary, the tests revealed that, overall, the highway tread tire performed better than the other tire treads in the majority of the tests. Figures 3.10 and 3.11 show the comparison of traction tests of the various tires on wet and dry pavements. Figures 3.12 and 3.13 show the results of locked wheel stopping tests performed by both test vehicles. The test results also revealed that there was little difference in traction characteristics between the types of tires tested.

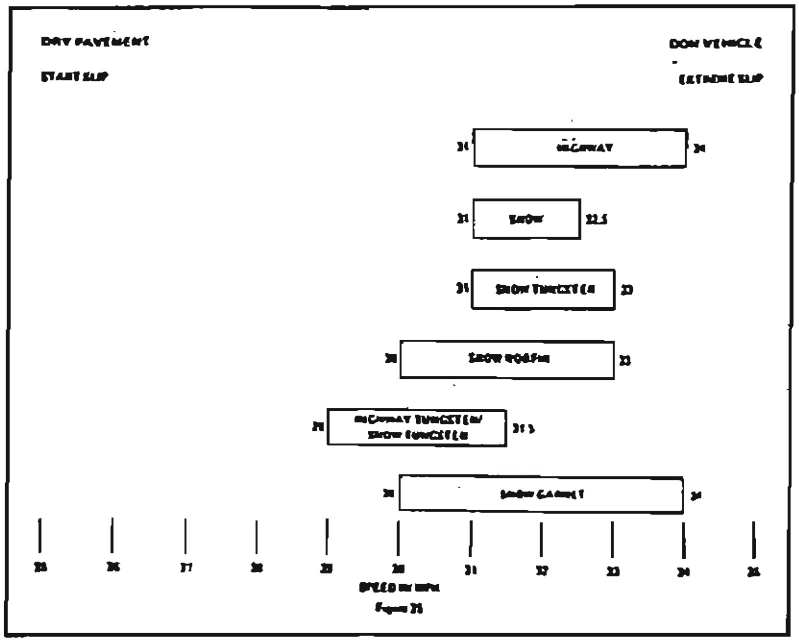


Figure 3.10 Tire Traction Testing Maneuvering on Dry Pavement (After Toney, 1973).

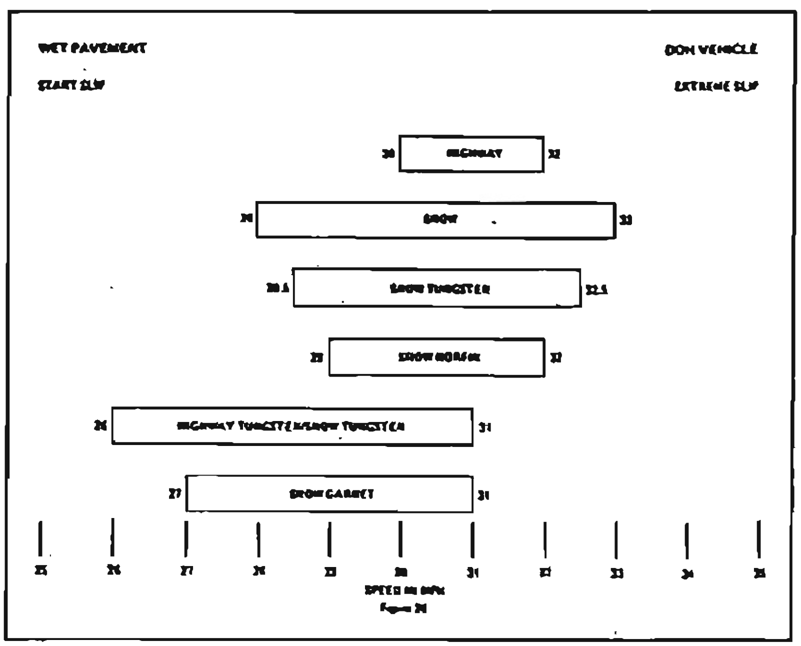


Figure 3.11 Tire Traction Testing Maneuvering Wet Pavement (After Toney, 1973).

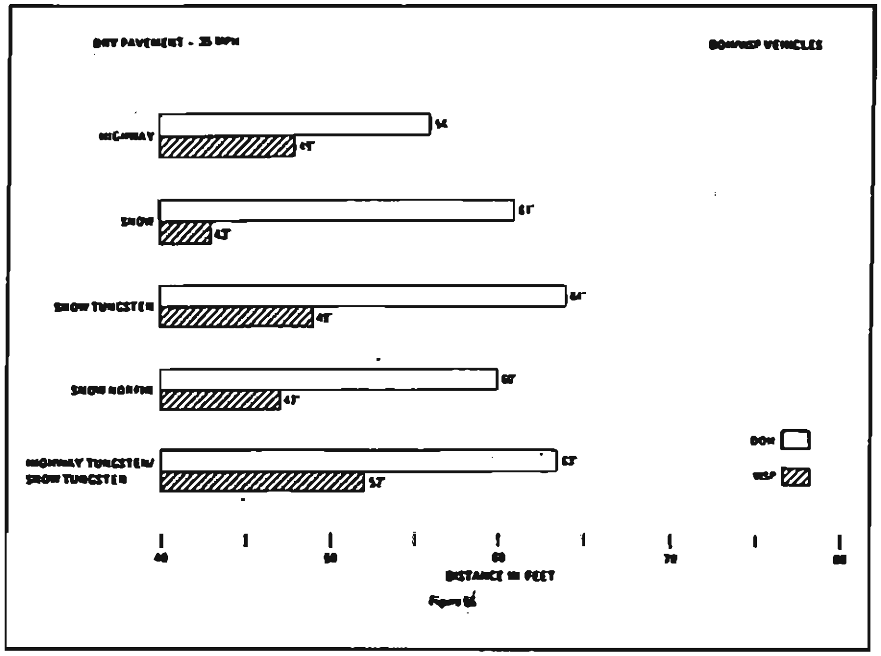


Figure 3.12 Tire Traction Testing Locked Wheel Stop on Dry Pavement (After Toney, 1973).

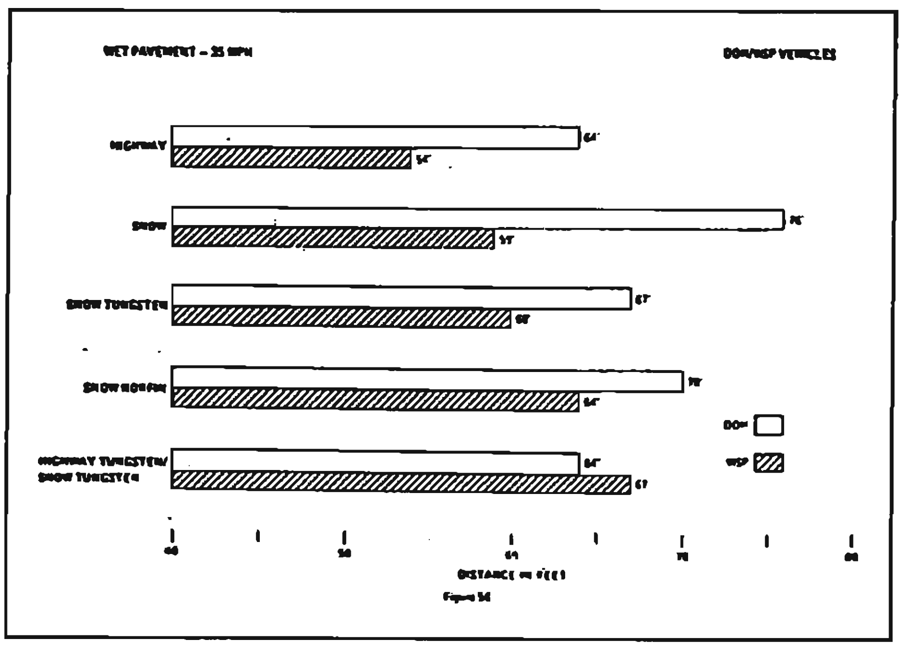


Figure 3.13 Tire Traction Testing Locked Wheel Stop on Wet Pavement (After Toney, 1973).

3.5 Pavement Traction

3.5.1 Pavement Additives

The addition of abrasives and chemicals into asphalt is an attempt to increase traction and improve winter driving conditions. These deicing chemicals are released during winter storm events as the pavement is worn down by traffic. In effect, during its service life the roadway is expected to be free from ice build-up, as the released chemical prevents bonding of the ice and snow to the road surface. This theory was put to the test in New Jersey using a deicing material called Verglimit. Verglimit consists of calcium chloride flakes coated with polymerized linseed oil. Skid resistance was tested monthly and results were the same as in other areas. The study concluded that Verglimit should be used to supplement the main source of ice control in areas particularly dangerous to traffic (Rainero, 1988).

The addition of Realite® Plus injected with deicing chemicals is proposed to be tested in chip seal in Aspen, Colorado. Rea*lite*® Plus has a high porosity and is capable of absorbing large amounts of deicing chemicals and release them during storm events. The tests will also determine whether the addition of Rea*lite*® Plus in chip seal also enhances pavement traction.

3.5.2 Deicers

Deicers are often applied to pavement during winter storm events and it is important to understand the effects on traction. One study conducted by the Strategic Highway Research Program (SHRP) in 1992, tested liquid and solid chemical deicers including:

- NaCl, solid , two separate application rates
- NaCl/$CaCl_2$, solid/solid
- NaCl/$CaCl_2$, solid/liquid
- $MgCl_2$, liquid/27% ,
- CMA, liquid/25% ,two separate application rates
- Potassium Acetate, liquid/50% , two separate application rates
- Urea , solid
- CMA, solid, two separate application rates

A Saab Friction Tester was used to measure the friction coefficient during each test. The test concluded that the liquid chemical deicers proved to be more effective at anti-icing. Figures 3.14 through 3.17 show the recorded friction coefficients as a function of time. For a more comprehensive list of deicing chemicals and their characteristics, refer to Section 7 on Deicers.

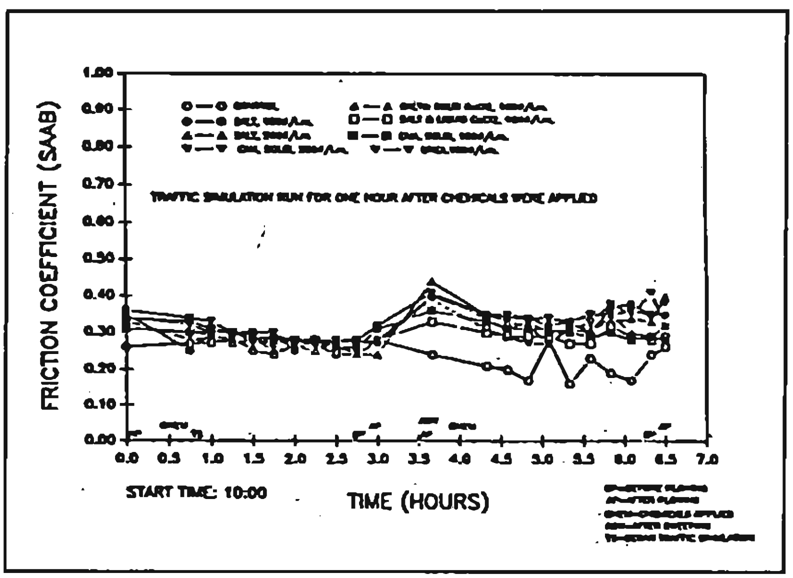


Figure 3.14 Friction Values - Solids (After Alger et al, 1994).

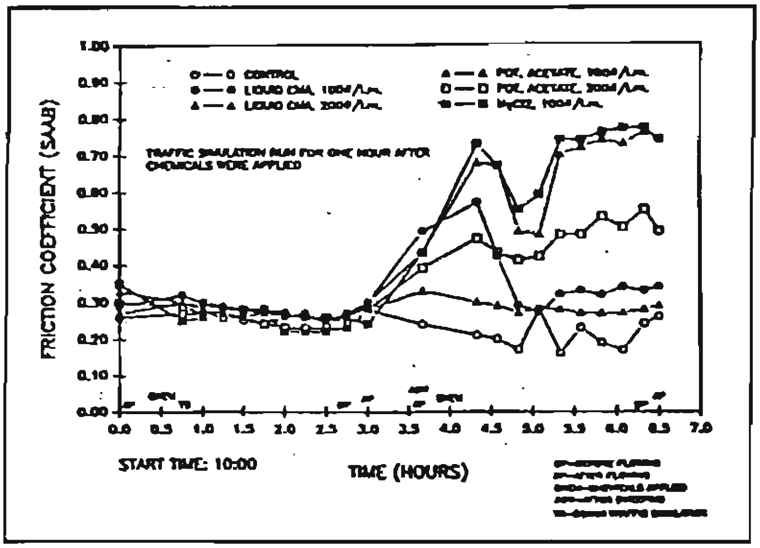


Figure 3.15 Friction Values - Liquids (After Alger et al., 1994).

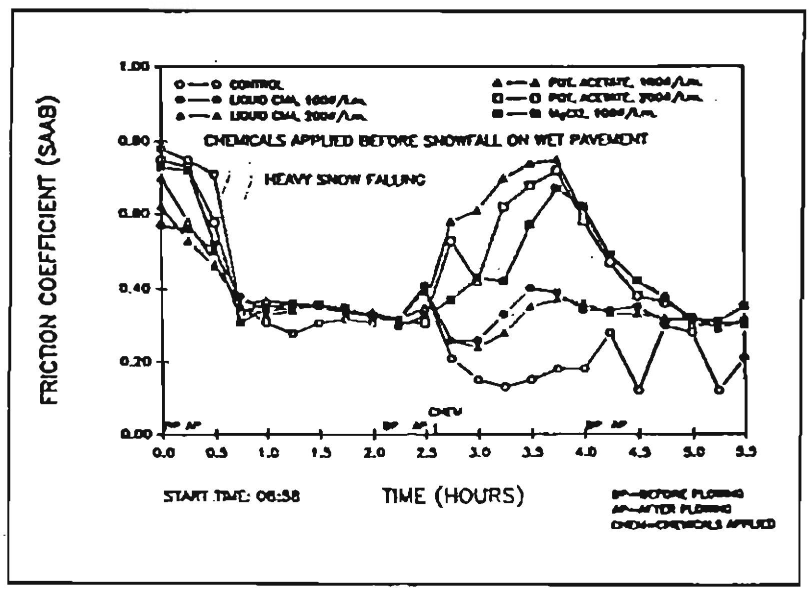


Figure 3.16 Friction Values of Solid Deicers (After Alger et al, 1994).

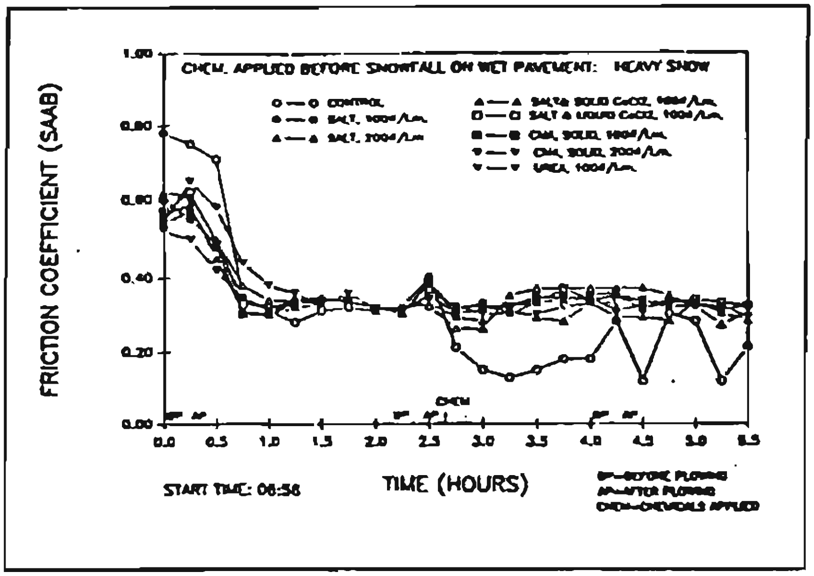


Figure 3.17 Friction Values of Liquid Deicers (After Alger et al, 1994).

3.5.3 Effects of Weather and Road Conditions on Traction

Road traction is affected by the conditions of the pavement. Dry pavement has a high coefficient of friction, while icy conditions cause the pavement surface to have a low coefficient of friction. The Colorado Department of Transportation monitors friction measurements throughout the city of Denver using a Coralba Friction Tester. The meter measures the friction force between the road surface and tires. To operate the meter, the truck is driven at a steady speed in the range of 40-45 mph. The driver then shifts the truck into neutral and applies a steady force on the brake for a second or two. Table 3.4 shows some typical coefficients as recorded by the Coralba Friction Meter.

These friction readings are used to determine the roadway areas needing applications of anti-skid materials during winter storm events. This device allows the Department of Transportation to monitor the road conditions and better maintain traction throughout the city.

ROAD CONDITIONS	FRICTION READING
Glare Ice	0.13
Icy	0.18
Slushy	0.38
Wet	0.56
Dry	>0.65

Table 3.4 Typical Friction Meter Readings On Various Road Surface Conditions.

3.6 Summary

This report represents a comprehensive summary of the first three reports and therefore concludes the Phase I research of the ESSD project. This portion of the research focused on gathering traction information from the CDOT library, survey questionnaires, site visits, and correspondence. Literature on snow and ice formation, stopping distances, alternative anti-skid materials, and friction has been reviewed and collected in the database.

Review of the current literature and practices of transportation departments reveals a widespread desire towards more environmentally sound sanding and deicing procedures. Many localities, such as Aspen, Colorado, have either reduced or replaced the sand use with deicers and/or aggressive snow removal methods in the hopes of reducing PM_{10} levels.

Public awareness and support of such measures is an area of support often overlooked. However, this is not the case in Boulder, Colorado. These residents are informed of related issues in television spots and in their utility bills. Maintaining a close link to the public has provided positive support for alternative sanding and deicing methods in this community.

The use of Rea*lite*® Plus as an alternative anti-skid material is currently being tested. This lightweight, porous material when used as a chip seal could potentially increase traction and reduce accidents in hazardous road areas. Further reports on these field tests will soon be available for review.

A proposal for future research has been prepared and will be submitted to the Colorado Technology Institute for approval. The proposed Phase II research will involve some literature review, but the main focus will be on laboratory and field testing. The traction enhancing properties of several alternative anti-skid materials will be investigated. In addition, testing will encompass the effects of the abrasives and chemical deicers on road traction during varying weather conditions.

4. Environmental Impact of Sanding and Deicing

A major goal of the Environmentally Sensitive Sanding and Deicing Practices Project was to investigate the impact of sanding and deicing on the environment. The scope of the project ranged from examining effects of sanding and deicing on soil, vegetation, air quality, water quality, and human health. Literature reviewed and materials found in each area are presented in separate sections. All material pertaining to air and water quality are presented in the air and water quality sections.

4.1 Impact of Deicing Chemicals on Soil and Roadside Vegetation

Deicing chemicals that are applied on the roads can impact soil and roadside vegetation. Salt, $CaCl_2$, $MgCl_2$, and other deicers applied to roads eventually run off into the surrounding soil where they can change the properties of the soil. The changes that occur vary with the site-specific conditions such as soil type. Indeed, the Zone of Influence (ZI)[1] is affected by both the soil type and slope (Eppard et al., 1993). In general, the sodium in salt makes the soil less permeable, reduces its aeration, and increases alkalinity and pH. Because of its positive charge, it is not highly mobile. Instead, the soil structure changes, and the soil becomes less permeable as the sodium is adsorbed by clay or organic matter. Additionally, sodium replaces the clay's calcium in the anion exchange process. As the salt accumulates and the salinity of the soil increases, the alkalinity and pH of the soil also increase. Calcium and magnesium, on the other hand, occur naturally in the soil. No studies of their effect on soil structure were found.

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1 Zone of Influence is defined as the distance from the end of pavement (EOP) to the furthest salt-affected tree.

Chloride ions from the deicers are negatively charged. Because of this, they are highly mobile and don't directly impact the soil structure. The chloride doesn't readily enter into biochemical oxidation-reduction reactions and does not easily form salt reaction complexes; consequently, the ions can pass unhindered through the soil.

CMA also impacts soil properties. Unlike salt which tends to decrease the permeablilty of the soil, CMA increases soil permeability (Horner, 1988). CMA has also been shown to mobilize trace elements found in the soil. These elements can then impact the groundwater.

Chemical deicers that are used also affect the vegetation that borders the road. Roadside vegetation can be damaged when deicer solution is sprayed on its foliage (spray-salt) or when the deicer laden water becomes concentrated in the root zone (soil-salt). Contact with spray can lead to vegetation burn and to die-back. Deicing components such as sodium and chloride can also accumulate in plant tissue and can lead to metabolic problems. Additionally, increasing deicing chemical concentrations can lead to increased osmotic stress which makes it harder for the plant to absorb water. Damage to the plants also depends on the tolerance of the species to the changing soil conditions such as pH and permeability. Soil salt damage can lead to (Sucoff, 1975):

- ◊ Interference with cell membranes. The stability of the cell membrane and some processes would be affected.
- ◊ Bleaching of chlorophyll and interference with photosynthesis.
- ◊ Leaf death.

Soil salt buildup would affect the soil properties and might include or lead to:

- ◊ Decrease in the availability of water to plants as water uptake ability of the plant changes.
- ◊ Decrease in availability of other ions such as calcium to the roots.
- ◊ Increase in soil pH above desirable levels leading to inhibition of both ion uptake and root growth.
- ◊ Leaching out of organic material.
- ◊ Prevention of soil aggregation leading to the compaction of the soil.

Sucoff also developed some general guidelines to identify soil-salt or spray-salt damage in both the deciduous and coniferous trees examined. Visual observations as shown in Tables 4.1 - 4.3 were made. Leaf sodium and leaf chloride tests were used to confirm damage. Additionally, the conductivity of saturation paste was measured to determine the electrolyte level in soil water, and exchangeable sodium tests were conducted to measure the total cation exchange capacity occupied by sodium.

Sucoff observed that salt damage was not a major cause of death in mature plants; rather, the damage led to reduced growth, disfigurement, and overall poor plant performance. New plantings exhibited the greatest sensitivity to salt damage, and salt damage played an important part in their mortality. Salt damage, though not fatal to mature plants, still led to increased maintenance costs such as the need for increased weeding and increased pruning to maintain the health of salt-damaged plants.

SOIL-SALT TOXICITY SYMPTOMS IN DECIDUOUS TREES
Reduced Growth.
Browning of the leaves. A distinct boundary occurs between the browning portion and the healthy green portion of the leaf with a yellow band in between. Browning commonly occurs only on the side facing the road.
Premature fall coloration followed be premature lead drop.
Tree is thin and has a sick-looking leaf and branch system resulting from having fewer leaves. Leaves present appear small and yellowing.
Thinning crown resulting from twig and branch dieback.
Tree death.

Table 4.1 Soil-salt toxicity symptoms in deciduous trees (Modified after Sucoff, 1975).

SPRAY-SALT TOXICITY SYMPTOMS IN DECIDUOUS TREES
Dieback of previous years growth beginning at the twig tip. Dieback usually occurs during winter.
Death of terminal buds results in formation of brooms formed from lateral buds.
Tree crowns are narrow.
Full leafing out in spring is delayed by as much as three weeks.

Table 4.2 Spray-salt toxicity symptoms for deciduous trees (Modified after Sucoff, 1975).

SALT TOXICITY SYMPTOMS IN PINE AND OTHER CONIFERS
Tips of 1 year old needles bleach and then turn bronze when weather warms. Before browning, needles become flecked with bleach spots that later disappear.
Entire tree looks rusty brown cover as 2-3 year old needles that continue to brown. Needles that are more than 1/2 brown tend to fall off.
Thinning crown, reduced height, reduced diameter growth. This results from loss of needles and needle area.
Soil-salt damage is likely when needles sheltered from spray exhibit as much damage as those exposed to salt spray. Soil-salt damage is also possible when needles exhibit browning right after emerging from the bud.

Table 4.3 Salt toxicity symptoms in Pine and other conifers (Modified after Sucoff, 1975).

From the literature reviewed, salt damage to plants would seem to be inevitable. However, the impact can be reduced through the following:

- ◊ Refrain from using species intolerant of salt accumulation (Button, 1976).
- ◊ Plant species that are more salt-tolerant. Forbs and grasses should be considered whenever revegetation is required. Foliage from the forbs and grasses would be replaced annually and allow the vegetation to get rid of salt-filled leaves (Eppard, et al., 1993).
- ◊ Use weather systems, better equipment coupled with better training, and alternative deicers (Eppard et al., 1993).
- ◊ Research to develop more efficient ways of applying deicing materials (Button et al., 1976).
- ◊ Alter expectations of plantings in salt-damage susceptible areas (Sucoff, 1975).

4.2 Deicing Chemical Toxicity

As deicers affect soil, vegetation, and water quality, both terrestrial and aquatic life are also affected. The deicer can cause oral toxicity, eye irritation, and dermal sensitization; however, the exposure effects and the extent of the symptoms differ with interspecies and instraspecies variation. In general, small animals such as rabbits are more sensitive to salt; however, snow, amount of deicer applied, and availability also factor into the level of sensitivity (Trainer, 1960). Terrestrial life requires a certain amount of salt to survive. Thus, some animals such as deer are attracted to the salts that are applied. This can pose a hazard to the animals if they come into close proximity to a heavily travelled area.

Deicing chemicals can affect health via three routes, ingestion, inhalation, or through dermal contact. Ingestion of deicing chemicals can be potentially harmful to human health. For example, eating large amounts of salt can lead to hypertension; however, results are inconclusive (Jones et al., 1986). Additionally, factors such as the concentration of the chemical, the exposure duration, the exposure frequency, and individual variability can also determine which health problems arise.

G.F.S. Hiatt et al., 1988 investigated the toxicity of salt, calcium chloride, and CMA. Hiatt conducted tests to measure acute oral toxicity, acute inhalation toxicity, eye irritation, skin irritation, and also subchronic oral toxicity. Acute tests were conducted to investigate the potential health problems that might result from a single or occasional human overexposure. On the other hand, subchronic tests were conducted to measure toxicity after intermittent or moderate duration exposures. The results of the toxicity tests can be summarized below and are presented in Table 4.4.

- ◊ Subchronic Oral Toxicity and Acute Oral Toxicity. CMA and sodium chloride were found to be slightly toxic.
- ◊ Acute Inhalation Toxicity[2]. Salt was observed to produce minor lung irritation while CMA produced some respiratory difficulties.
- ◊ Eye Irritation. CMA was found to be a mild to moderate eye irritant. However, part of the irritation was caused not by the chemical properties of CMA but by its granular nature.

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2 The effects of particulate matter on human health are discussed more in depth in the air quality section.

◊ Acute Dermal. CMA was found to produce irritation to exposed skin. Salt was not tested because there was no evidence that exposure to salt led to skin irritation.

The laboratory tests conducted on laboratory animals under controled conditions indicated that the deicing agents were, at worst, only slightly toxic. However, actual exposure effects on humans remain to be studied.

TOXICITY COMPARISON BETWEEN SALT, CMA, AND CALCIUM CHLORIDE					
TEST		SALT	CMA	CaCl2	DESCRIPTION
ACUTE ORAL TOXICITY	LD50*	3,150 mg/kg Slightly Toxic	3,750 mg/kg Slightly Toxic	1000-2000 mg/kg Slightly Toxic	Test relevant to occasional human overexposure.
SUBCHRONIC ORAL TOXICITY	LD50	2,690 mg/kg/day	Similar to salt	N/A	Test to determine if toxicity can develop from repeated exposures.
ACUTE INHALATION TOXICITY	LC50	N/A	>5,000 mg/m3	N/A	Toxicity test with exposure from breathing.
EYE IRRITATION		13/110** Mild to Moderate Irritant	11/110 Moderate Irritant	N/A	Measures irritation or damage from direct eye contact.
SKIN IRRITATION		Nonirritating	Mildly Irritating	N/A	Tests ability to irritate or damage skin on contact.
ACUTE DERMAL TOXICITY	LD50	N/A	>5,000 mg/kg	N/A	Tests whether absorption of enough compound across the skin can lead to systemic toxicity.
DERMAL SENSITIZATION		None Found In Literature	No Reaction	N/A	Predicts ability to elicit allergic skin reactions.

** LD50 = Lethal Dose at which 50% of animals die.*
*** Mean irritation score of 13 out of a possible 110.*

Table 4.4 Toxicity Comparison Between Salt, CMA, and Calcium Chloride (After Hiatt et al, 1988).

5. Air Quality

The impact of sanding and deicing on air quality has been a major focus during Phase I. This section presents some of the findings of this investigation. Sanding and deicing practiecs can contribute to particulate matter pollution. This section traces the development of the air quality regulations for particulate pollution, discusses sources of PM_{10} pollution, presents the potential negative health effects of particulate pollution, and introduces studies that have been conducted and their limitations.

5.1 Air Quality Standards

The Federal Air Quality Act of 1967 commonly referred to as the Clean Air Act (CAA) was originally passed in 1955. Its purpose was to regulate emissions from both moving and nonmoving sources, to regulate air quality, and to protect human health and welfare. In setting air quality standards, the EPA used the most recent scientific information about the relationship between type of pollutant, concentration of the pollutant, and pollutant effects on human health and welfare. With the available information, the EPA promulgated National Ambient Air Quality Standards (NAAQS) for particulate matter, sulfur oxides (SO_x), carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_x), and lead.

The CAA continued to evolve as a result of several amendments in 1970, 1974, 1977, and 1990. The CAA amendments of 1977 allowed states to classify areas as either I, II, or III. Air quality was not allowed to change in Class I areas such as state parks, while Class II and Class III allowed moderate and intensive industrial growth, respectively. The CAA amendments of 1990 aided greatly in efforts to improve ambient air quality. The amendments addressed areas from enforcement of the act to the phasing out of ozone depleting chemicals and was an example of the EPA's desire to regulate more than conventional air pollutants. The amendments also allowed the EPA to address attainment of the ambient air quality standards. Title I allowed the EPA to establish geographic boundaries and to assign a grade to nonattainment areas. Furthermore, the EPA could then penalize states and cities in noncompliance by imposing sanctions such as withholding highway and construction funds and emission offset requirements for new sources.

5.2 Development of PM_{10} Standards

One of the pollutants regulated under the National Ambient Air Quality Standards (NAAQS) of the Clean Air Act is particulate matter. The ambient air quality standard for particulate matter was first established in 1971. The EPA promulgated primary and secondary NAAQS. Primary standards were adopted based on the administrator's judgement as necessary to protect human health. Secondary standards were promulgated to ensure public welfare.

Total suspended particulates (TSP) or particles less than 40 microns in diameter were originally used as the indicator pollutant. TSP standards were set using both a geometric mean and a 24-hour period. Annual TSP concentrations were never to exceed a geometric annual mean of 75 $\mu g/m^3$, and daily 24-hour TSP concentrations were not to exceed 260 $\mu g/m^3$ more than once a year. However, in 1987, because of compelling medical evidence, the EPA promulgated particulate matter ambient air quality standards using particulate matter less than 10 microns (PM_{10}) as the indicator pollutant. The switch was made because medical evidence indicated that particles greater than 10 microns in diameter were filtered out by the hair and mucous found in the upper respiratory tract (conducting portion) while particles smaller than 10 microns were respirable and could be inhaled deeply into the lungs. The EPA set annual and 24-

hour standards for particulate matter using PM_{10} as the indicator pollutant as shown in Table 5.1.

PRIMARY AMBIENT AIR QUALITY STANDARDS FOR PM_{10} *		
Averaging Time	Concentration	Allowable Exceedances
Annual Arithmetic Mean	50 $\mu g/m^3$	None
24-hours	150 $\mu g/m^3$	3 times over 3 yr period

* Primary and Secondary standards for PM_{10} are the same.

Table 5.1 Primary Ambient Air Quality Standards For PM_{10}

Particulate matter can be further divided into fine particles and coarse particles. Fine particles have aerodynamic diameters less than 2.5 microns, typically have a acidic pH, and include soot and acid condensates from vehicle emissions and other human activities. On the other hand, coarse particles have diameters greater than 2.5 microns, typically have a basic pH, and originate from uncontrolled combustion and mechanical breakup of soil (Ware 1993).

5.3 Makeup and Sources of PM_{10}

PM_{10} is made up of primary particles and secondary particles. Primary particles are emitted directly into the atmosphere from the source. Dust is an example of primary particles. Secondary particles are nitrogen and sulfur oxide emissions from the combustion of fossil fuels that, once released into the atmosphere, react with ammonia to form particulate matter.

Sources of PM_{10} include those that produce primary particles and also those that produce nitrogen and sulfur emissions. Sources of PM_{10} include sanding/cleaning operations, wood burning, stationary sources, and mobile sources. Stationary sources include power plants or manufacturing facilities that either produce primary particles or release nitrogen and/or sulfur oxide emissions. Mobile sources include passenger vehicles, trucks, and commercial vehicles.

The Denver metro area is classified as a moderate nonattainment area. According to the SIP: Denver Element prepared by the Regional Air Quality Council (RAQC), the Colorado Department of Health (CDH), and the Air Pollution Control Division (APCD), several sources of particulates contribute to the Denver PM_{10} problem. Sources of Denver particulate matter include wood burning, industrial sources, vehicle exhaust, street sand, and others. The PM_{10} breakdown is shown in Figure 5.1.

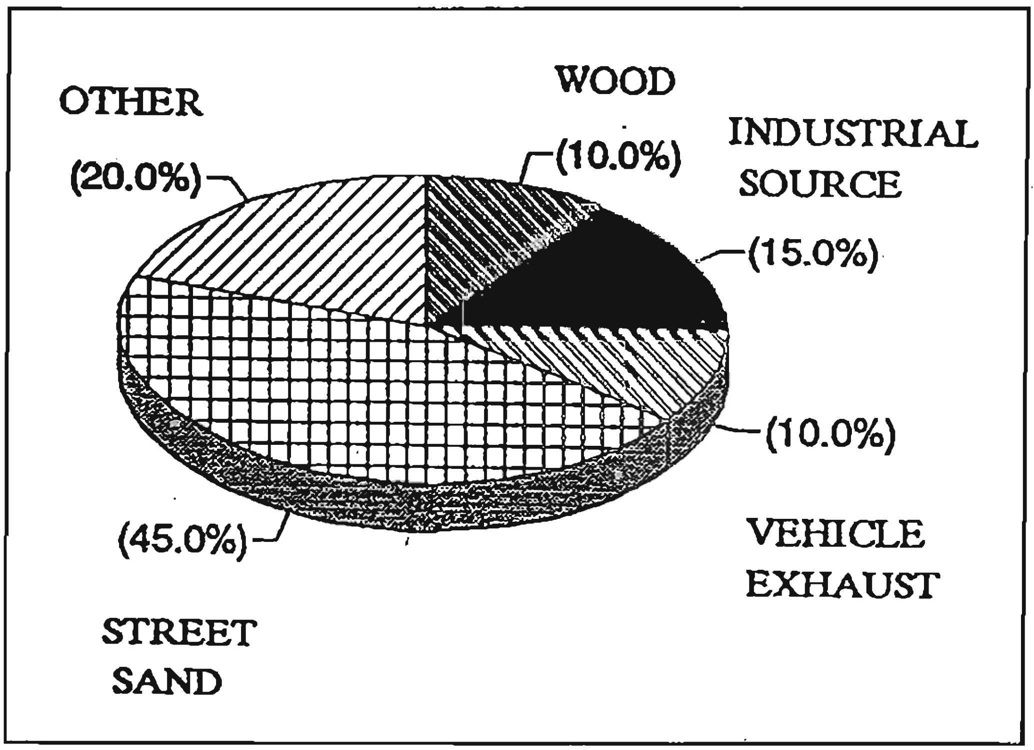

Figure 5.1 Breakdown of PM_{10} Sources (After SIP, 1993).

Contributions to PM_{10} levels and species can vary as a result of meteorological conditions, geologic formations, and traffic patterns. In a 1990 study conducted as part of the Southern

California Air Quality Study (SCAQS), particulate levels were found to vary with time of day and with prevailing weather conditions.

For example, at Claremont, daytime levels of PM_{10} were greater than nighttime levels. Part of this was attributed to winds and street activities that stirred up crustal material and street dust (Wolff et al., 1990).

5.4 Effects of Particulate Matter on Human Health

Particulate matter originates from many different sources. Some particulate matter results from human activities (i.e. combustion products, dust from sanding operations, etc..) while some occur naturally (i.e. crustal material). Both types of particulates can affect human health once inhaled.

Particulate matter size is a major factor. Particulate matter less than 10 microns in aerodynamic diameter (PM_{10}) is regulated because of its potential health effects. Particle size determines how deeply the particulate matter can penetrate into the respiratory system. Material larger than PM_{10} becomes trapped in the nose, sinuses, trachea, and bronchial tubes (conducting portion of the lungs, Figure 5.2). While PM_{10} can penetrate deeply into the lungs and reach the alveoli, sites of gas exchange (Fennelly, 1994).

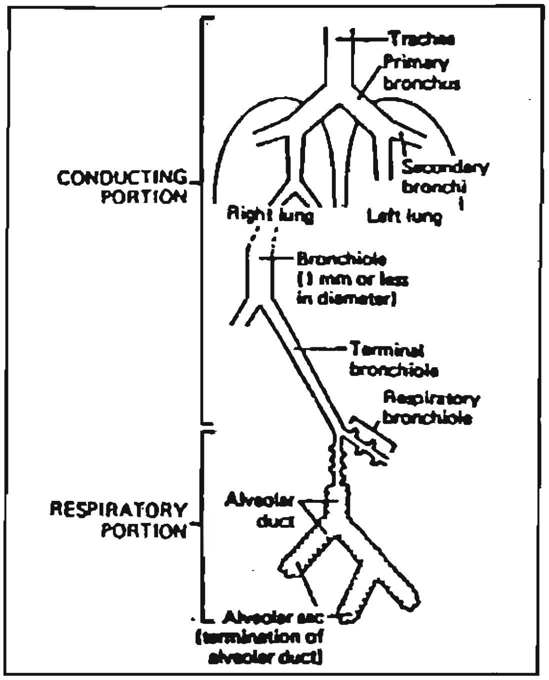

Figure 5.2 The Main Divisions of the Respiratory Tract (After Junqueira et al., 1989).

Some of the coarser particulates are trapped in the conducting portion by the hair and the mucous lining. Particulates can then be swept up by cilia , little hair-like projections that are found in cells that line the conducting portion of the respiratory system. In nonsmokers, poorly soluble particulates are cleared more rapidly from ciliated airways than from alveoli (Mauderly, 1994). Most of the particulates that are phagocytized by macrophages are carried to the mucociliary apparatus for clearance. Others move into the interstitium and the lymphatic system. The mechanism of acute and chronic injury is not fully understood, but, according to Mauderly, particulate contact with epithelial cells and macrophages can initiate events such as release of growth factors and proteases that can lead to tumor formation, fibrosis, and cell damage. Additionally, the macrophages can recruit inflammatory cells.

Moreover, the toxicity of the particle depends on the deposition of the particle in the respiratory tract and on the physicochemical nature. Some particle characteristics that can affect toxicity include size, shape, solubility, and composition (e.g. acidity, crystallinicity, antigenicity, organics, and metals).

5.5 Types of Studies

Health studies involving particulate matter usually involve epidemiological, clinical, and inhalation toxicology studies. Epidemiological studies investigate the frequency and distribution of health effects in populations and are useful in examining chronic health effects. In general, epidemiological studies consider mortality rates, hospital admissions, symptoms, and changes in lung function. Four study designs are used (Samet, 1994):

- ◊ Ecologic. In ecologic design, the unit of analysis is a group that is usually defined by geography and exposure is assumed for individuals based on the characteristics of the group.
- ◊ Cross sectional. In the cross-sectional design, observations concerning exposure and outcome are made at one point in time.
- ◊ Cohort (longitudinal or follow-up). In the cohort studies, the subjects are enrolled and then followed longitudinally for exposure and outcome.
- ◊ Case-control. In the case-control study, exposures of cases with the disease of interest are compared with those of control subjects without the disease.

In some studies, cross sectional data is often used to compare different communities. For example, mortality rates and particulate matter concentrations have been studied and compared among various communities (Fennelly, 1994). A cohort study where two similar communities, one exposed and the other not exposed, are followed over time can also be used. A prospective cohort study is also commonly used and is the most rigorous epidemiological study, and consists of individuals in a well characterized population that are followed over time. Barriers do exist in interpreting epidemiological studies. The first barrier is bias; either selection bias where the manner of subject selection distorts the exposure-disease relationship, or information bias where error exists in classifying exposure and disease. Increasingly more complex models are now being used to analyze data and to compensate for the numerous variables; however, these models may not appropriately represent the outcome interest and the predictor variables (Samet, 1994). Moreover, Samet states that fitting the models according to statistical criteria alone may be inappropriate. Furthermore, another point of difficulty is inferring causality from association. Combining epidemiological studies with other kinds of studies will allow researchers to draw upon more information to help reduce the barriers to data interpretation.

Besides epidemiological studies, clinical studies are also used. Unlike epidemiological studies, clinical studies focus on individual responses to particulate matter. After exposing individuals to known amounts of air pollutants, a clinical study may then observe effects through the use of, lung function tests, biomarkers, etc. in order to evaluate the significance of exposure. Because clinical studies involve exposing individuals to known amounts of pollutants, variables can be controlled and measured. Also, the uncertainty involved in applying results from animal testing to humans can be avoided. Clinical tests however, do have disadvantages. It is often difficult to study susceptible populations, and the studies are limited to acute tests on a small sample group (Fennelly, 1994).

Inhalation toxicology studies are the third type of study often used to investigate the effects of particulate pollution on human health. An inhalation toxicology study involves exposing laboratory animals to known pollutants. Like the clinical studies on human patients, variables can be controlled and measured. An additional advantage is that tests can be run on a large sample group. The ability to test very toxic particulates is also an added bonus. Though conducting tests on laboratory animals does have advantages, uncertainties are also present. Perhaps the biggest uncertainty would involve the generalization of results from laboratory animals to the human population (Fennelly, 1994).

5.6 Mortality Studies

As mentioned earlier, epidemiological studies have been conducted to investigate whether an association exists between particulate matter pollution and mortality rates. Ware 1993 states that current studies indicate that mortality increases 0.6 to 1.6% for each 10 $\mu g/m^3$ increase in PM_{10} concentration. However, doubts have been raised about the particulate matter-mortality association,because it has been suggested that some other pollutants such as sulfur oxide and ozone may be responsible for the mortality association, not particulate matter. Furthermore, it has been suggested that the particulate matter-mortality association is affected by confounding factors. However, there appears to be evidence that both claims can be discounted. Available statistical data shows that the association between particulate matter and mortality is much stronger than that between sulfur dioxide and mortality. Indeed, ozone level appears to have no influence. Ozone corrections applied to particulate matter-mortality studies conducted in both high and low ozone environments did not affect particulate matter-mortality association.

The effect of confounding factors has also been addressed. A confounding factor is a third factor or group of factors that affects both mortality and PM_{10} concentrations. However, confounding factors must vary with time in order to influence particulate matter-mortality association. Thus, variables such as diet, smoking, or genetic predisposition that don't vary with time do not act as confounding factors. Furthermore, a multitude of studies using different procedural methods and statistical methods have found a relationship between particulate matter and mortality.

Evidence also exists that may link particulate matter pollution to an increase in both hospital admissions and ER visits. In a study conducted by Pope, hospital admissions and ER visits were found to increase with particulate matter pollution. Admissions and visits in three counties with similar demographics and housing characteristics in Utah (Utah County, Cache, and Salt Lake) were compared to one another. The study focused on the steel mill located in Utah county; mill emissions were trapped by inversions. As a result, the particulate matter pollution was greater in Utah county. A comparison of the three counties showed that the rate of hospitalization of children for respiratory illnesses was two times greater for Utah county than for either of the other two counties. A dramatic turn around occurred when a strike closed the mill for three months. The rate of hospitalization decreased to the point where it was virtually identical to the rates of both Cache and Salt Lake.

5.7 Mount St. Helens Studies

The Mount St. Helens eruption also provided researchers with a unique opportunity to study the effects of particulate matter pollution on human health. The eruption on May 18, 1980 scattered ash of varying size and composition in Washington and neighboring states. From samples collected throughout eastern Washington, Fruchter characterized both ash composition and characteristics. The ash was found to be about 80% glass composed of coarse silica, with particle size distribution varying with distance from the eruption (See Table 5.2). Between 94 to 99 percent of the particles were less than 10 μm. Thus, ash particles from the eruption could penetrate deeply into the respiratory system. Though the ash could pose a threat to human health, pulmonary toxicity tests conducted on samples of the ash collected from the Moses Lake region of Washington state found that the toxicity of the ash samples was about equivalent to the toxicity of Al_2O_3 dust which is considered inert. Beck also found that the toxicity response induced by α-quartz[3] was much greater than both ash or Al_2O_3 (Beck et al., 1981). A monitoring study in Montana during the eruption also seems to confirm that short term exposure to the volcanic ash did not lead to a decline in lung function.

The study, called the Montana Air Pollution Study (MAPS), was carried out with the goal of monitoring the pulmonary functions along with air quality in Missoula, Montana and other communities from 1977-1980 (Johnson et al, 1982). The study included testing the pulmonary function of 120 fourth and fifth graders during the 1979 - 1980 school year. Because of the eruption, both schools and businesses were shut down for 4 days in May. Total Suspended Particles (TSP) concentrations during the closure period ranged from 11,054 $\mu g/m^3$ to 948 $\mu g/m^3$ (See Table 5.3).

After the four days, the children were tested to observe possible effect of exposure to the volcanic ash using the PFT (Pulmonary function test). The forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and maximal mid expiratory flow rate ($FEF_{25-75\%}$) were recorded by the PFT. Before each child was tested, each child was questioned about his/her

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[3] "α-quartz is a highly toxic mineral dust that can cause severe fibrosis and eventual death over extended periods of time. Acute exposure can result in acute silicosis and death within 1-3 years." (Beck et al, 1981)

activities during the school closure and was asked whether protective clothing was worn when outside. The responses were highly variable; however, most children stated that some sort of protective clothing had been worn and that outside activities had been restricted.

SIZE DISTRIBUTION OF MOUNT ST HELENS ASH AT MISSOULA*

Observed Particle Diameter		
Maximum		53.0 μm
Minimum		0.16 μm
Calculated Median Diameter		
By count		1.47 μm
By Volume		35.0 μm
Size Distribution		
By count:	⟨ 10 μm	96%
	⟨ 2 μm	58%
By Volume:	⟨ 10 μm	9.3%
	⟨ 2 μm	0.1%

* From Fruchter, et al. (1)

VOLCANIC ASH PARTICLE SIZES BASED ON DICHOTOMOUS PARTICULATE SAMPLERS AT MISSOULA

Date	Fine ($\mu g/m^3$) submicrons to 2.5 microns	Course ($\mu g/m^3$) 25 to 15 microns
5/19/80	112	3704
5/20/80	91	5124

Table 5.2 Size Distribution; Particle Sizes Based on Dichotomous Samplers from Missoula, Montana (After Johnson et al, 1982).

COMPARISON OF CHILDREN'S AVERAGE ADJUSTED PULMONARY FUNCTION TESTS BEFORE AND AFTER EXPOSURE TO MOUNT ST. HELENS VOLCANIC ASH*

Pulmonary Function	Sex	5 Test 1 Average	Following Ash
FVC	Male	2473	2458 (.099)
	Female	2197	2218 (.051)
FEV	Male	2036	2011 (.095)
	Female	1872	1892 (.185)
$FEV_{25\text{-}75}$	male	2199	2199 (.065)
	Female	2252	2262 (.818)

* Numbers represent averages (in milliliters) of all individuals adjusted for test room temperature, individual differences, and height. Numbers in parentheses represent covariance analsis probability levels.
1 The 5 tests conducted on low TSP days prior to the vocanic eruption.

Table 5.3 Adjusted Pulmonary Tests Results (After Johnson et al, 1982).

The tests failed to show any decrease in pulmonary function after exposure to ash. The children had previously been tested on a day of non-ash TSP (440 $\mu g/m_3$) and were found to have a significant decrease in pulmonary functions. Thus, from the test results, it would seem that the urban particulate matter affected the children more than the short term exposure to the coarse volcanic ash.

5.8 Survey of Studies on Particulate Matter Health Effects

From recent epidemiological studies, relationships between health effects and particulate concentrations below the standards set in the National Ambient Air Quality Standards (NAAQS) were observed. The following have been associated with particulate pollution (Fennelly, 1994):

◊ Increased death rates

◊ Increased Hospital Admissions for respiratory conditions

◊ Increased emergency room admissions for asthma

◊ Increased Respiratory symptoms

◊ Decreases in lung function

◊ Increased medication use among asthmatics

Studies also seem to indicate that fine particulate matter (< 2.5 μm), possibly derived from the combustion of fossil fuels, is more toxic than coarse particulate matter (>2.5 μm). However, much uncertainty still exists. The mechanisms which contribute to increased mortality are still unknown and are being investigated. Because of the numerous species of particulate matter, uncertainty also exists as to which species is responsible for the health effects.

5.9 Future Studies

Research into the health effects of particulate matter and human health is ongoing. The Environmentally Sensitive Sanding and Deicing Practices group will continue its efforts as Phase I of the project comes to a close. While the focus of Phase I was on literature review, Phase II will emphasize experimentation including both laboratory and field testing. Research has been proposed to investigate the effects of using different deicers on PM_{10} emissions. This research is important to the Denver Metropolitan area and will include, but is not limited to, the following: the effects of meteorology on air pollution, sampling methods, sampling apparatuses, and sample analysis techniques. To comply with national air pollution laws, a reduction in sand usage and a subsequent switch to deicing chemicals becomes more likely. Thus, research investigating whether a switch to deicing chemicals will reduce or increase PM_{10} emissions becomes more and more necessary.

6. Water Quality

6.1 Introduction

The goal of Phase I of the Environmentally Sensitive Sanding and Deicing Practices Research was to investigate and document the current practices on sanding and deicing roadways and current innovative practices utilized by the municipalities within the state of Colorado. With this final report of Phase I, many different areas impacted by the use of sanding and deicing are being proposed as part of Phase II research. One important area not yet well investigated is the effect of storm water runoff on water quality. The second phase of the research will not only involve sampling and testing snow melt runoff, but also implementing modeling techniques to define quantitative impact.

6.2 Water Quality Standards

6.2.1 Background and History

Through the passage of the Clean Water Act (1963-1983) as amended and the Safe Drinking Water Act (1974-1986) as amended, the U.S. Congress has established national goals for water quality which are intended to protect the general public and regulate the amount of pollutants discharged into the water environment.

6.2.2 Specific Water Quality Standards

Various water quality standards have been set by the Environmental Protection Agency (EPA) which include standards for drinking water, ambient water quality standards for aquatic life, standards for irrigation and agriculture, and standards for industry. Some of these are enforceable and some are merely recommendations. The EPA has established Primary and Secondary Drinking Water Standards. The Primary standards specify maximum contaminant levels (MCL) and are legally enforceable. The Secondary standards specify the secondary maximum contaminant levels (SMCL) which primarily affect the esthetic qualities of water such as color, odor and taste. These standards are only meant to be guidelines for the states and are not enforceable. In addition, the EPA may issue health advisories which are intended as a guide and do not affect the majority of the population's health for short periods of time. The standards are shown in Tables 6.1 and 6.2.

CONSTITUENT	SMCL	CONSTITUENT	SMCL
Chloride	250	Manganese	0.05
Color	15	Odor-threshold No.	3
Copper	1	pH	6.5-8.2
Corrosivity	noncorrosive	Sulfate	250
Fluoride	2.0	Total	500
Surfactants	0.5	Zinc	5.0
Iron	0.3		

Source: Environmental Protection Agency

Table 6.1 National Secondary Drinking Water Standards

CONSTITUENT	MCL	CONSTITUENT	MCL
Inorganics		Lindane	0.004
Arsenic	0.05	Methoxychlor	0.1
Barium	1.0	Toxaphene	0.005
Cadmium	0.01	Trihalomethanes	0.10
Chromium	0.05	Volatile Organic Chemicals	
Fluoride	4.0	Benzene	0.005
Lead	0.05	Carbon	0.005
Mercury	0.002	1,2-Dichloroethane	0.005
Nitrate	10.0	1,1-Dichloroethane	0.007
Selenium	0.001	1,1-1-Trichloroethane	0.02
Silver	0.05	para-Dichlorobenzene	0.075
Microbiological		Trichloroethylene	0.005
Coliforms	1/100 ml	Vinyl-chloride	0.002
Physical Characteristics			
Turbidity-NTU	1-5		
Organics			
2,4-D	0.1		
2,4,5-TP Silvex	0.01		
Endrin	0.0002		

Source: Environmental Protection Agency

* All concentrations shown are in mg/L except where noted.

Table 6.2 National Primary Water Standards

6.2.3 Water Quality Impact by use of Sanding and Deicing Practices In Colorado

Many different chemicals and substances are presently used in sanding and deicing in the state of Colorado. These include inorganic salts such as sodium chloride, potassium chloride, magnesium chloride, calcium chloride and organic substances such as Calcium Magnesium Acetate (CMA), urea (fertilizer) and sodium formate. Primarily across the Denver metro area, a sand and salt mixture is used for deicing and traction. Mixtures of salt to sand in the 3-20% range are frequently used. CMA has also been used for the past several years on the new viaducts in the Denver metro area, as it is noncorrosive.

The sand and deicing chemicals, when applied to the winter roads, make snow and ice removal easier and result in safer driving. In order to work, the deicing chemicals go into solution and become part of the snow melt runoff. The runoff enters the storm water drainage stem and is emptied into the streams and rivers. The chemicals found in the road sand (either naturally or by contamination from the automobile's grease and various fluids) leach out into the snow melt runoff. These chemicals find their way into the rivers and streams of the state by the processes described above. Table 6.3 shows some of the heavy metals found in street sweepings (amounts and urban runoff concentrations).

HEAVY METAL	STREET SWEEPING mg/Kg	URBAN RUNOFF ug/L
Cadmium	3.4	18
Chromium	211	33
Copper	104	45
Iron	22000	
Lead	1810	235
Manganese	418	
Nickel	35	24
Zinc	370	

*It should be noted that many of these chemicals are naturally occurring in the environment and some have very high concentrations.

Source: Environmental Protection Agency

Table 6.3 Average Concentrations of Heavy Metals in Street Sweepings and Urban Runoff.

Deicers eventually infiltrate the groundwater or reach surface water via runoff. However, their impact largely depends on the type of water body encountered, as some water bodies have a decreased contact time and can more readily dilute the chemicals. Thus, standing water is more heavily impacted than flowing water, and smaller water bodies are more heavily impacted than larger water bodies. Deicing chemicals can eventually impact water quality. As concentrations of sodium, chlorine, calcium, and magnesium increase, the taste, hardness, and water quality are impacted.

For example, chlorine concentrations exceeding 250 mg/L would exceed the upper threshold set to protect taste. Chlorine could also pose a severe problem because it is very persistent and can't be removed from aquatic environments by chemical, physical, or biological processes (Hochstein and Sills, 1989). If rock salt were used, the increasing levels of sodium would then depress calcium and magnesium levels in the water, thereby reducing the hardness of the water. The changing concentrations of ions would also lead to increasing osmotic stress and would place additional stress on aquatic life.

CMA can also affect water quality. CMA depletes the oxygen by exerting oxygen demand as it is degraded. Biochemical Oxygen Demand (BOD) was measured to be 75% of the CMA concentration (Horner, 1988). CMA can also lead to changes in osmotic stress that would be potentially harmful to aquatic organisms.

Polluted waters interfere with the water body's ability to distribute nutrients by affecting the density gradient. Lake waters are usually mixed when additional water is added. This serves to distribute oxygen and nutrients to the aquatic life that exists at different strata within the lake. If the incoming water contains salt or other pollutants that affect the density of the water, the distribution of nutrients can be impeded. For example, as dense saline water enters a standing body of water, it travels to the bottom of the lake. If the water stays dense, the mixing of the layers of water is inhibited. Thus, the oxygen and the nutrients needed by the aquatic organisms would be trapped in a different layer. Once deprived of a food source, the organisms would die off.

6.3 Storm Event Runoff Projects

The state of Colorado had conducted urban runoff studies in the late 1970's in the Denver metro area. Littleton, Lakewood and the city of Denver were included in the study. It was concluded that urban runoff may be a significant contributor to the total ammonia nitrogen, total nonfilterable residue, total copper, total iron, total lead and total zinc of local receiving waters. During the winter months snow melt runoff may be a significant contributor of sodium chloride to local receiving waters (Ellis and Alley, 1979).

The EPA in the early 1980's had a study conducted entitled the National Urban Runoff Program (NURP) which included Denver, Colorado, as one of its test sites. The NURP study was initiated to evaluate the presence, concentrations and potential water quality impacts of priority pollutants in urban stormwater runoff. From 1980 to 1983, 121 runoff samples were collected from 61 residential and commercial sites from 20 cities across the country. The samples were analyzed for 127 priority pollutants. Seventy-seven were detected, which included 14 inorganic and 63 organic pollutants.

Stormwater runoff does not generally go through sewage and wastewater treatment facilities and usually enters the stormwater drainage system. From there it enters the rivers, streams and lakes. The EPA determined that risk to aquatic life from priority metals was a concern. Levels of Cadmium, Copper, Lead, and Zinc in undiluted runoff exceeded the EPA 1980 acute criteria for protection of aquatic life by factors of 2 to 8. As a result, the EPA concluded these trace metal pollutants could cause harm to aquatic life. The extent of damage depends on factors such as receiving stream dilution, storm duration, and whether the metal is in toxic soluble form. Table 6.4 shows the toxic metals found in Denver test samples (EPA-NURP study).

CHEMICAL	FREQUENCY OF DETECTION %	RANGE OF CONCENTRATION
Arsenic	52	1-50.5
Copper	58	1-100
Cyanides	23	2-300
Lead	94	6-460
Zinc	94	10-2400

*specific concentrations for the particular cities were not provided in this report, only ranges and frequencies for the 20 cities.

Table 6.4 Toxic Metals Found in Denver Water Samples From EPA NURP Study.

These studies indicate that urban runoff in Colorado contains trace metals which could violate EPA ambient water quality standards for aquatic life. These standards contain levels allowed for 30 day average maximum concentrations, and 24 and 96 hour maximum concentrations. Whether specific levels for Denver were violated was not stated in the report. How much snow melt runoff contributes to the stormwater runoff remains is not known. It is a possible area for investigation.

It was determined that sodium chloride from road salt could be a contributor to the increases in sodium and chloride ions in local receiving waters of streams and rivers. However, it is felt that due to the large flows during runoff that these ion concentrations would be sufficiently diluted and would not pose a threat to the aquatic life in rivers and streams of Colorado. It should be noted that the NURP study did not test for chlorine. In a follow-up study that tested for non-priority metals, sodium was tested for, and the frequency of detection was minimal.

6.4 Snow Melt Runoff

Typically, a snow pack will contain a significant amount of water which is then released when the snow melts. Initially, the snowpack has a tempature less than 0 degrees Celsius with an average snow density of 50% or less. Before any snow melt can occur, sufficient thermal energy must be absorbed by the snowpack from the surrounding air in order to meet the liquid water deficiency and cold content . The cold content of snow melt is referred to as the amount of thermal energy required to bring the snow pack tempature to 0 degrees Celsius. The liquid water deficiency must be zero, or the liquid water content of a snowpack must be at a maximum before any melting will occur.

Once the liquid water content and cold content are satisfied, snow melt will occur first with surface melting. As the liquid water from the melt percolates into the snow pack, thermal energy is transferred further. At this state, the snow pack is considered ripe which causes melting to occur from the bottom. Thus, snow melt may result through a process of convection of heat from the surrounding air into the snow pack. At this stage, condensation will occur from the snow pack surface or advection will result from rainfall on snow.

6.4.1 Snow Melt Runoff Quantity and Quality

Many researchers have defined various sequences in which snow melt runoff occurs in urban areas. Mr. Gray L. Oberts of the Metropolitan Council in St. Paul, Minnesota represents the snow melt sequence as shown in Figure 6.1. He describes the process with the first stage being that of pavement melt. The melting occurs with the application of chemical deicers and/or the transfer of heat from solar energy onto paved areas covered with snow. The second stage as described by Mr. Oberts refers to roadside melt. This stage represents the melting of the snow pack alongside the road. In the last stage of the melting sequence, the snow pack in pervious areas begin to contribute to the runoff.

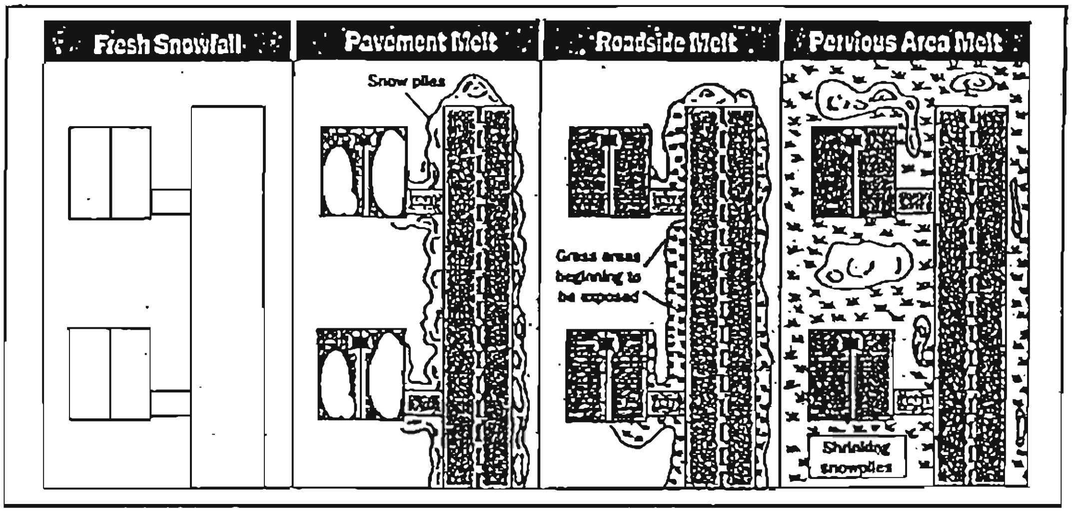

Figure 6.1 Snowmelt Sequence (After Oberts et al., 1994).

The runoff contribution from roadside melt and pervious melt contributes the greatest quantity of runoff volume.(Oberts, 1994) In northern climates such as in Minnesota, the melting process may continue on for weeks. With rainfall, the runoff volume may be magnified.

The characteristics of snow melt runoff water quality may be potentially impacted by the use of chemical deicers. The confounding effects can only be determined through sampling and testing.

6.5 Modeling

The load concentration trends measure the level of contaminant in the runoff flow and when the loads peak, or are at their lowest. The contaminants measured differ from project to project based on the drainage basin studied and project focus. Some of the commonly monitored contaminants include:

- ◊ Total copper
- ◊ Total lead
- ◊ Total zinc
- ◊ Total chromium
- ◊ Total ammonia-nitrogen
- ◊ Total suspended solids
- ◊ Specific conductance
- ◊ Total iron
- ◊ Total magnesium
- ◊ Total cadmium
- ◊ Total phosphorous
- ◊ Total nonfilterable residue
- ◊ Chemical oxygen demand

Rainfall and snow melt runoff quantity measurements measure the actual runoff flow, that is, the bulk amount of fluid that is being produced by the study area. The quantity measurements are crucial in identifying the contamination level as well as providing the flow information for modeling programs. Load source tracking identifies the source of the contaminant(s) being measured. Traditionally, the load source is categorized by land use types (commercial, farming, multifamily housing, single family housing, shopping centers, industrial ...etc.). Certain contaminants are common to different types of land use and there are strong relationships between runoff formation, pollutant loading, and land use characteristics.

Most of the studies listed in Table 6.1 utilized a computer modeling program to predict the loading levels for various runoff events. In addition to predicting contaminant levels, some of the studies tested the computer programs to ascertain their strengths and weaknesses.

One goal set aside for the second phase of the project is to be able to simulate real storm events with meteorological data to characterize and predict the impact of the use of chemical deicers in terms of quantitative and qualitative values. Although many hydrologic modeling programs exist, currently, the Storm Water Management Model Version 4.3 (SWMM) is being analyzed for its compatibility with the scope of the project. Figure 6.2 represents an overview of the links of SWMM.

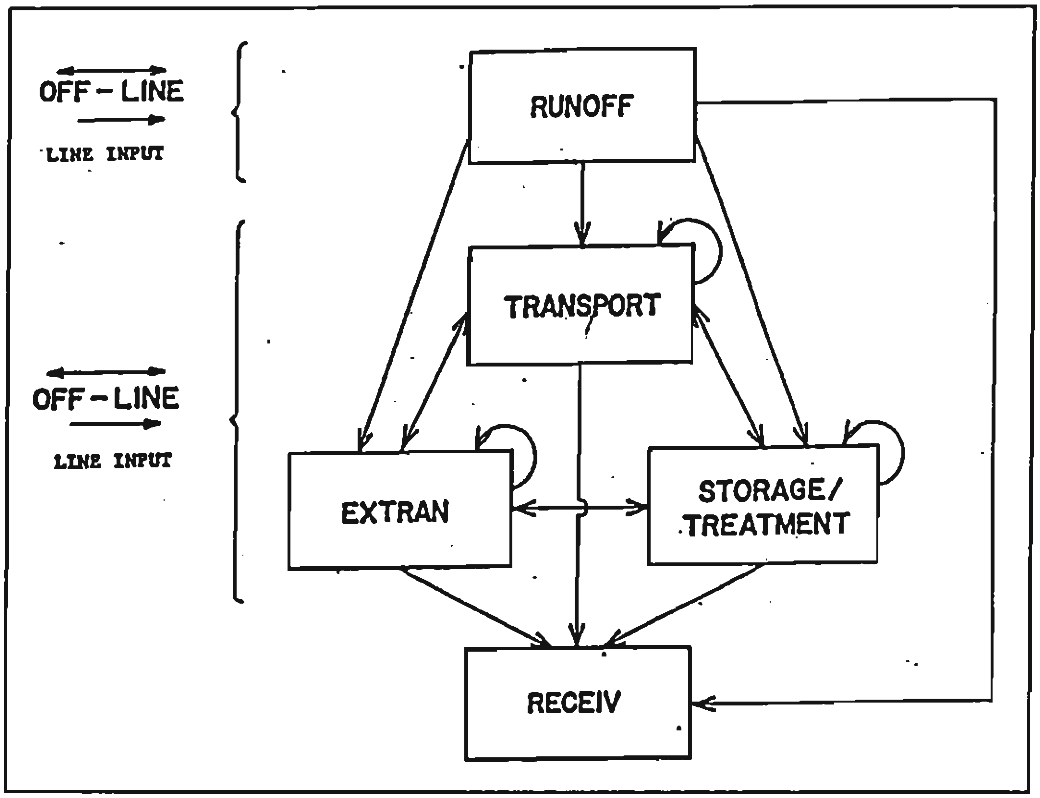

Figure 6.2 Overview of the Links of SWMM (After Huber, 1992).

6.6 Conclusion

The Environmentally Sensitive Sanding and Deicing Practices Research team initially investigated and documented the current practices used by local governments to maintain safety on roadways during the winter months. With Phase I ending, many areas have been recognized as being potential pollution problems due to the use of sanding and chemical deicers. A proposal is underway to study specifically the impact of snow melt runoff on water quality. With this phase, sampling and testing will take place to quantify the constituent loadings. Finally, the

Storm Water Management Model will be utilized to simulate and predict outcomes in terms of quantity and quality values.

The Project is designed to monitor snow melt runoff for contamination levels provided by three predominantly used deicing chemicals and/or aggregates. The monitoring will be at three sites with one chemical being monitored per site. The project is expected to take three winters; 1995-96, 1996-97, and 1997-98. The goal of the project is to assess the effects of deicing chemicals on pollutant concentrations and on water quality and determine maximum application rates. The results are projected to be published in a brochure format for use by road maintenance departments, environmental agencies, and others involved in winter storm response.

7. Deicers

7.1 Introduction

The main points of the different topics from the previous reports will be reviewed and summarized. This section on deicers will summarize the topics of anti-icing and deicing, corrosion and inhibition, deicer performance, salt enhancement, and finally, a complete listing of the alternative deicers presented in previous quarterly reports. An additional topic will be covered on application amounts for deicing and anti-icing methods. A summary deicer rating table will be provided listing all the deicers covered to this point.

Through the reference search it was determined that the deicing chemicals predominantly used for winter road maintenance are:

- ◊ Sodium Chloride, $NaCl$
- ◊ Calcium Chloride, $CaCl_2$
- ◊ Magnesium Chloride, $MgCl_2$
- ◊ Potassium Chloride, KCl
- ◊ Urea, a nitrate, $CH_4\text{-}N_2O$
- ◊ CMA, calcium magnesium acetate, $Ca_xMg_y(C_2H_3O_2)_{2(x+y)}$, $x = 3$ to 4, $y = 7$ to 6
- ◊ Sodium Formate, $CHNaO_2$

7.2 Anti-icing and Deicing

Deicing refers to the putting down of a deicing chemical after the snow or ice has accumulated or formed. It is often referred to as a curative rather than a preventative approach.

It requires that a large volume of chemical be used to melt through a 1-3" layer of ice and snow. The process is begun after the fact and the chemical must penetrate through the accumulation down to the ice/snow-pavement bond. Once this bond is broken, the street may be plowed. The deicing process is not very efficient because large amounts of chemicals are often used and there is a real possibility that the melted snow/ice may refreeze and create an even more dangerous situation. Deicing is often used in conjunction with abrasives.

Anti-icing consists of using dilute concentrations of liquid deicing chemicals which are applied prior to or early in the winter storm event. This allows the deicing chemical to be stored on the pavement surface and prevents the snow from bonding with the pavement. The snow does not form a hard pack layer and makes plowing and subsequent snow removal easier and more efficient.

The Scandinavian countries have done considerable research and testing with the use of brines (liquid deicing chemicals) over the last few years and these methods are now being tried in the U.S.

The Strategic Highway Research Program has recently published their preliminary report on Anti-icing methods. This study provides some of the results of two previous studies by SHRP and the FHWA which were conducted across the U.S. in 24 states beginning in 1991. The report 'A Preliminary Guide to Anti-Icing Practices', is a guide for the highway maintenance manager and provides valuable information about anti-icing and prewetting techniques. The report explains the different techniques and the equipment required to implement them.

Some of the limitations to the use of anti-icing methods are:

- ◊ Anti-icing techniques are only effective down to approximately 21° F.
- ◊ They are not effective with snow fall rates greater than 1 inch per hour.
- ◊ With higher snow fall rates, prewetting and traditional deicing techniques may be more effective.
- ◊ When using anti-icing methods at lower temperatures and greater snow depths, care must be taken, as melting and subsequent refreezing may occur.

7.3 Corrosion

Corrosion is a natural process occurring when bare metal is exposed to the environment. The key ingredients which must be present for corrosion to occur are: metal, water and oxygen. The chloride deicing salts can accelerate the corrosion process by acting as a 'catalyst' in the electrochemical reaction. The chloride deicing chemicals are very corrosive and can cause deep pitting on metal surfaces. This can affect the structural integrity of highway structures, including bridge decks.

Automobile manufacturer's have made significant advancements concerning paint finishes and undercoatings. These have greatly reduced corrosion effects. In addition, coated rebar in reinforced concrete and geomembranes on bridge deckings have greatly increased the long term life of bridges.

Corrosion is a series of electrochemical reactions. The reactions which occur on the metal surface are:

Anodic Reaction: (chemical oxidation)	$Fe_{(s)}$ « $Fe^{++} + 2e$ $2Fe(OH)_2 + 1/2O_2 + H_2O$ « $2Fe(OH)_3$
Cathodic Reaction (chemical reduction)	$1/2\ O_2 + H_2O + 2e$ « $2OH^-$ (neutral or alkaline)
	$2H^+ + 2e$ « H_2 $1/2\ O_2 + 2H^+ + 2e$ « $2H_2O$ (acidic)

The overall reaction is:

$4Fe^{2+}_{(aq)} + O_{2(g)} + (4+2n)H_2O_{(l)}$ « $2Fe_2O_3 \cdot nH_2O_{(s)}$ [rust] $+ 8H^+_{(aq)}$ (Zumdahl, 1989)

A diagram of the electrical reactions occurring on the surface of the metal is shown in Figure 7.1 below.

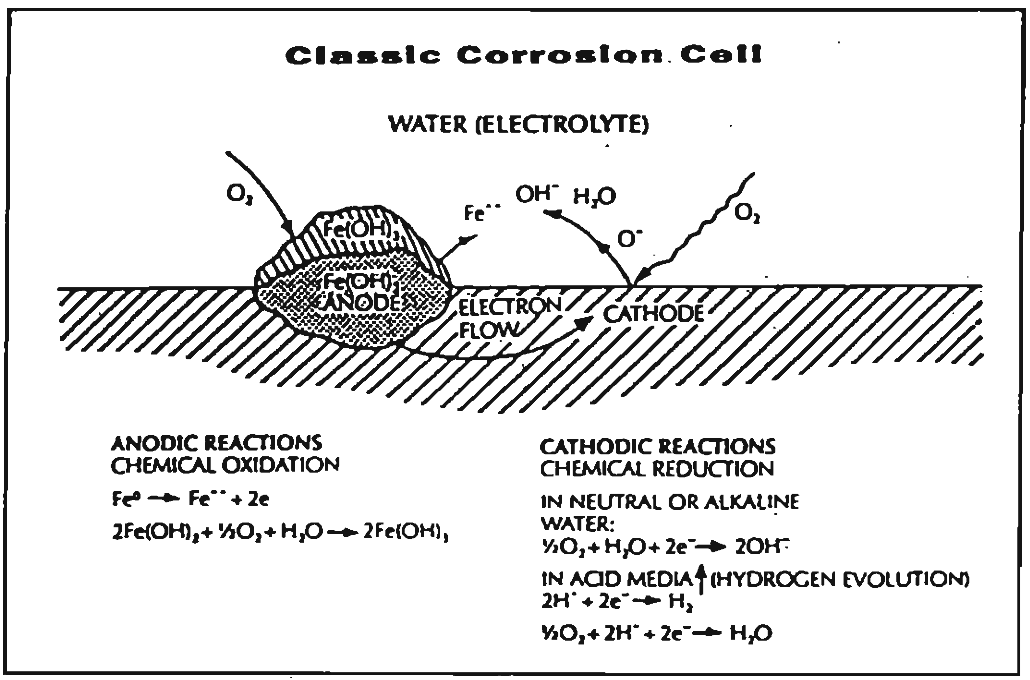

Figure 7.1 Corrosion Cell (After Cargill Inc., 1993).

Chemicals which reduce corrosion in deicing salts are now being used with success. These are referred to as corrosion inhibitors. Most of the commercial deicing chemicals that incorporate chloride salts have added corrosion inhibitors. These are mixed in small amounts, usually 1-5%.

Washington State DOT performed a comprehensive corrosion study of commercial deicers. For a deicer to meet their corrosion requirements, it had to offer at least 70% corrosion protection (deionized water offered 100% protection while straight salt-sodium chloride, offered 0%). Several of the deicers with added inhibitors offered 70% corrosion protection or better and one offered 110% corrosion protection.

Examples of corrosion inhibitors which are being used by the deicer manufacturer's are Zinc Sulfate, Zinc Chloride, Magnesium Sulfate, Sodium hexametaphosphate, PCI (Calcium Lignon Sulfonate) and CMA. CMA has been used as a deicing chemical and as a corrosion inhibitor. In several studies CMA, when mixed with Sodium Chloride, has been shown to be much less corrosive than Sodium Chloride alone.

In testing performed by SHRP, Zinc Sulfate and Zinc Chloride with Sodium Tri-polyphospate corrosion inhibitors were the most effective for reducing corrosion on mild steel and aluminum test samples. At low concentrations, CMA demonstrated a low corrosion rate (70%) but showed only a (30%) corrosion rate reduction when used at a 10% concentration. These results are contradictory and may require additional study.

Organic deicers have also been developed which are not as corrosive as the chloride deicing salts. These chemicals are naturally non-corrosive and do not require corrosion inhibitors.

The chemicals include Calcium Magnesium Acetate, Formates (Sodium Formate), and South Dakota Deicer No. 1 and 2 (a blend of Sodium Acetate and Sodium Formate, patented by South Dakota DOT). CMA has been extensively tested in both the lab and field. The Formates and So. Dakota Deicer's No. 1 & 2 are presently undergoing testing with results forthcoming. Preliminary testing looks promising.

7.4 Spalling

Spalling in concrete is a process whereby the concrete surface flakes or chips off in small pieces. It occurs as a result of freeze-thaw cycles or exposure to deicing chemicals. Spalling can also be influenced by other factors such as: concrete cure time, concrete grade, concrete to water ratio and % air entrainment. Results of the spalling test by SHRP indicate: Magnesium chloride, CMA and deionized water showed the least degree of spalling in concrete test samples while Sodium Chloride and Calcium Chloride demonstrated the highest degree of spalling.

◊ The ranking of the Chloride deicers and CMA in order of highest to lowest rate of spalling is:

$$NaCl > CaCl_2 > MgCl_2 > CMA$$

7.5 Performance

The performance properties of deicers includes: Melting, Penetration, Undercutting and Disbonding. SHRP investigated these fundamental characteristics in the report H-647, 'Evaluation Procedures For Deicing Chemicals and Improved Sodium Chloride'.

7.5.1 Melting

Melting is a measure of a deicer's ability to produce a volume of liquid in a prescribed time and at a given temperature. In lab testing, application rates are much greater then would ordinarily be used in the field. This is to insure measurable melt volumes are produced. Results from SHRP melting studies indicate that when working with deicers at or near the eutectic temperature there is a great deal of uncertainty and results are not consistent. However, results from this and other studies can be drawn. Figure 7.2 illustrates how the concentration of a deicer can vary the temperature at which a deicer will freeze.

Calcium Chloride worked twice as fast as Sodium Chloride at shorter time intervals (15-20 minutes) and at lower temperatures (below 15 F). Sodium Chloride did produce the same melt volumes at longer time intervals (45-60 minutes) and at temperatures greater than 15 F. CMA, urea and Potassium Chloride did not produce any significant melt volumes at temperatures below 15-20 F and required 20-30 minutes longer than Sodium Chloride to produce them.

The Formates and Acetates were similar to Sodium Chloride in respect to melting from the preliminary testing. Magnesium Chloride was not tested in any of the literature articles reviewed and represents a major gap as it is so widely used. However, it has been tested by the major deicing manufacturer's - Cargill and Great Salt Lakes Minerals Corp.

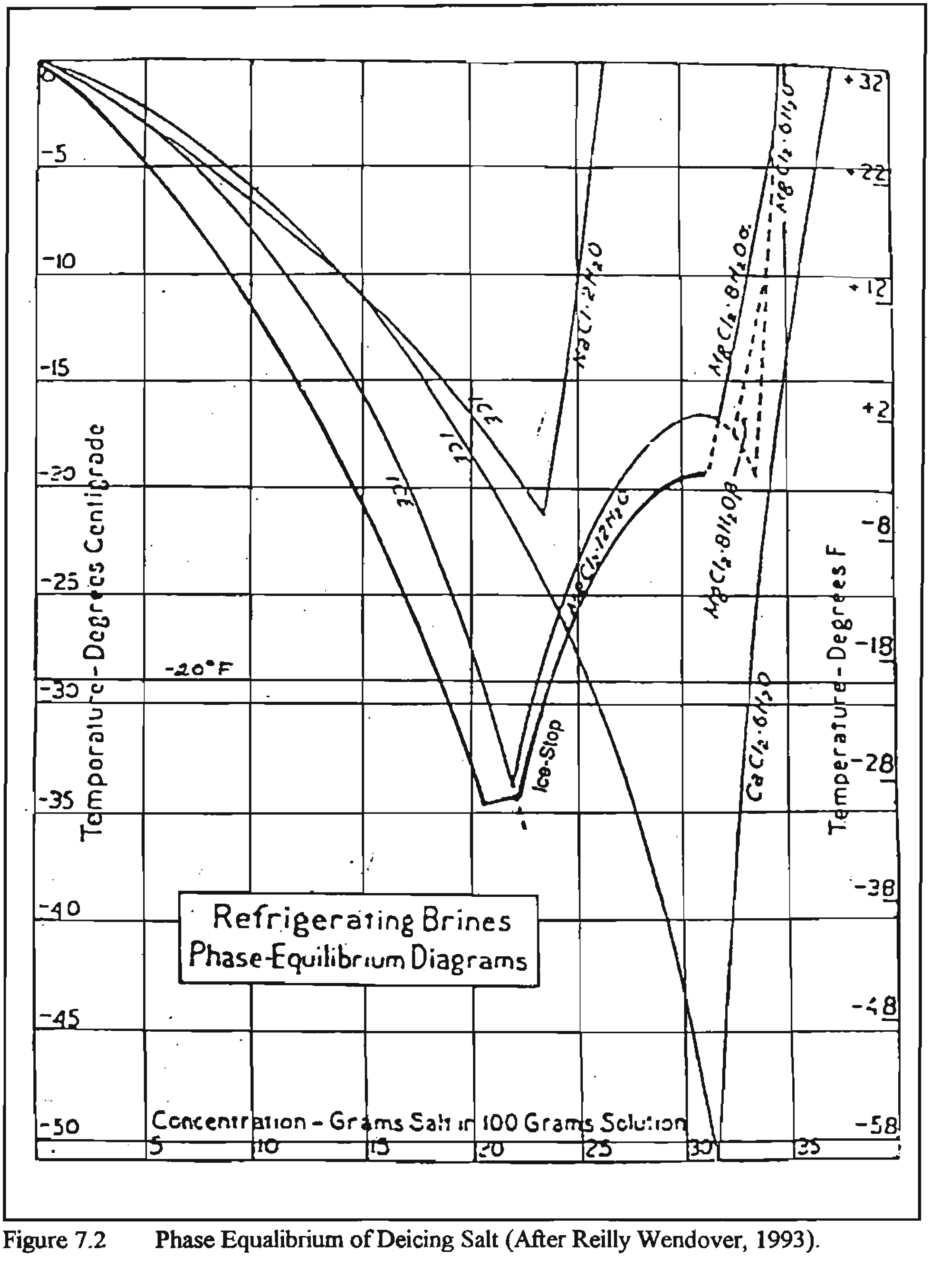

Figure 7.2 Phase Equalibrium of Deicing Salt (After Reilly Wendover, 1993).

7.5.2 Penetration

Penetration tests measure the time required for a deicer to move a vertical distance through an ice substrate. It is an artificial test in that the deicer is placed in narrow channels and allowed to penetrate vertically downward.

In the field Sodium Chloride tends to migrate horizontally through ice layers while Calcium Chloride moves predominantly vertically. It is not known how Magnesium Chloride penetrates through an ice layer.

Penetration is the first step in the 'Deicing" process and once it occurs, undercutting and disbonding can proceed. Penetration properties of deicers are reflective of melting characteristics since melting is an integral part of the penetration process. As a result, deicing chemicals which are effective at melting are also effective at penetrating. Calcium Chloride was more effective in penetration tests than Sodium Chloride. This was especially true for shorter time intervals and lower temperatures. CMA, Urea and Potassium Chloride penetrated minimal distances for all time intervals and temperatures.

7.5.3 Undercutting and Disbonding

These tests provide the most direct measure of a deicer's effectiveness. The key to a deicer's effectiveness is to first penetrate the ice/snow pack and then move out horizontally and begin the disbonding process. Once the ice/pavement bond is broken, plowing and subsequent snow removal can be achieved. The result is bare pavement and a higher coefficient of friction between the tire and pavement surface.

In testing, deicers are applied to the pavement and allowed to dry and be stored on the pavement surface. An ice substrate is then bonded to the pavement. The disbonding force (the mechanical shear force required to remove the ice) is then measured. This force can be determined for the different deicers versus application amounts and temperatures. Disbonding is more reflective of a deicer's effectiveness in an Anti-icing capacity.

The results of several studies indicate the organic deicers are more effective in disbonding than the chloride deicing salts. The researchers felt that the organic deicers (CMA and South Dakota Deicer No. 1) interacted with the pavement (was stored in the pores of the pavement) and could even produce a residual effect which could last for several days. This has been noticed in field studies with CMA.

Undercutting is the ability of a deicer to move out horizontally beneath the ice layer and interact with the ice/pavement bond.

In typical undercutting tests, the deicer must first penetrate a small distance (several millimeters) and then move horizontally beneath the ice layer. Undercut areas are measured at discrete time intervals and at varying temperatures. The amount of deicer is usually not varied for these tests. Results indicate that the Chloride deicing salts are more effective than the organic deicers. Calcium Chloride produced larger undercut areas than Sodium Chloride, again at shorter time intervals and at lower temperatures. Magnesium Chloride was not tested in any of the undercutting or disbonding studies reviewed. SHRP tested deicers with regards to undercutting and disbonding as part of the H-647 project. The results of the study were:

- ◊ Using solid deicers was more effective when distributing uniformly on the pavementand using as small a size particle as practical.
- ◊ Applying liquid deicers prior to or early in the winter storm event was the best and most efficient practice.
- ◊ Ice formed over a pretreated pavement surface will be bonded weaker and more prone to undercutting and disbonding.
- ◊ liquid deicers are not as effective at undercutting and disbonding if applied directly to ice and snowsurfaces. They do not possess the melting and penetration capabilities of solid deicers.

7.6 Salt Enhancement

SHRP has investigated ways to enhance the deicing capabilities of Sodium Chloride - commonly called rock salt. The effectiveness of Sodium Chloride decreases considerably when the temperature falls below approximately 15 °F. SHRP wanted to improve the deicing performance down to temperatures in the range of 0°F. Since Sodium Chloride is considered highly corrosive to metallic surfaces, SHRP felt that by combining Sodium Chloride with a corrosion inhibitor system it could make it less corrosive. Corrosion and low temperature performance were the main areas of concern in the SHRP study of salt enhancement. The results of the study concluded:

- ◊ When solid NaCl reacts with an ice substrate the controlling factor regarding melting is the rate at which the particle dissolves.
- ◊ The dissolution period may be shortened substantially by wetting the solid particles.
- ◊ Using a salt brine solution will allow the melting to proceed spontaneously.

- ◊ Sodium Chloride one hour melting was enhanced approximately 2.36 times by adding Calcium Chloride and Ethylene Glycol in a 1:1 ratio.
- ◊ Small particle size was also shown to be more effective in starting melting action.
- ◊ Prewetting with Calcium Chloride solution (or any other more effective deicer, such as Magnesium Chloride) would greatly enhance the rate and temperature at which Sodium Chloride would work. Previous studies in the literature substantiate these findings (SHRP report H-647, 1993).

7.7 Alternative Deicers

The following deicers were reviewed in previous quarterly reports. The characteristics summarized were: composition, inhibitors, working or effective temperature, corrosion, spalling, cost and environmental effects. Costs were determined relative to the cost of Sodium Chloride. The information is from manufacturer's product literature, site visits and literature published from independent sources. **The ESSD group provides the values for comparative and informational purposes and does not endorse or recommend any of the commercial products listed.**

Sodium Chloride Akzo Inc. Solid

Composition: Sodium Chloride with 1-4% impurities
Effective Temp.: 15-20 F
Corrosion Protection: None
Spalling Protection: None
Environment: Cl^- ion
Costs: 1x
Uses: deicing, mixed with abrasives

Calcium Chloride — General Chemical Corp — Solid/Flake

Composition: Calcium chloride
Effective Temp.: below O F
Corrosion Protection: None
Spalling Protection: None
Environment: Cl^- ion
Costs 6-7x
Uses: deicing, mixed with NaCl, prewetting NaCl, abrasives

Magnesium Chloride — Great Salt Lakes Mineral — Liquid/Flake

Composition: Magnesium chloride
Effective Temp.: down to +5 F
Corrosion Protection: less corrosive than NaCl
Spalling Protection: minimal effects
Environment: Cl^- ion
Costs 6-7x
Uses: liquid applications, prewetting NaCl and abrasives

Potassium Chloride — Various Manufacturer's — Solid

Composition: Potassium chloride
Effective Temp.: 25 F
Corrosion Protection: None
Spalling Protection: None
Environment: Cl^- ion
Costs 4x
Uses: deicing, mixed with more effective deicing chemicals

CG-90™ — Cargill

◊ Original Deicer — Solid

Composition: 93.5% NaCl, 4.5% Corr. Inhibitor
Effective Temp.: 14.9 F
Corrosion Protection: 90-100%
Spalling Protection: n.a.
Environment: Cl^- ion
Costs 4x
Uses: deicing, mixed with abrasives

◊ Surface Saver Liquid

Composition: 73% NaCl, 25.5% $MgCl_2$, 2%MgSo4.
0.3% Corr. Inhibitor
Effective Temp.: 10.9 F
Corrosion Protection: 90-100%
Spalling Protection: 90%
Environment: Cl^- ion
Costs:2x
Uses: anti-icing, prewetting NaCl, abrasives

◊ Surface Saver Solid

Composition:75% NaCl, 21.9 $MgCl_2$, 3.1% Corr.Inhib
Effective Temp.: +1 F
Corrosion Protection: 90-100%
Spalling Protection: 90%
Environment: Cl^- ion
Costs:6x
Uses: deicing, mix with abrasives

Freezgard[R] Great Salt Lakes Minerals Liquid/flake

Composition: Magnesium Chloride with Corr. Inhib.
Effective Temp.: +10-15 F
Corrosion Protection: very good
Spalling Protection: good
Environment: Cl^- ion
Costs: 2x
Uses: anti-icing, deicing, prewetting of abrasives

Ice-Slicer™ Redmond Clay and Salt Co. Solid

Composition: 93.5% NaCl with complex chlorides and
trace elements
Effective Temp.: 15-20 F
Corrosion Protection: more than NaCl
Spalling Protection: more than NaCl
Environment: Cl^- ion
Costs: 2x
Uses: Deicing, mixing with abrasives

Ice-Stop™ | Reilly Wendover | Liquid

Composition: 25% solution of Magnesium Chloride
Effective Temp.:10-15 F
Corrosion Protection: 110%
Spalling Protection: very good
Environment: Cl^- ion
Costs: 2x
Uses:anti-icing, prewetting abrasives

Meltdown 20 | Redmond Clay and Salt Co./Envirotech Services

Composition: 80% Redmond Salt and 20% $MgCl_2$
Effective Temp.: 10-15 F
Corrosion Protection: added Corr.Inhib. very good
Spalling Protection: good
Environment: Cl^- ion
Costs : 6x
Uses: Deicing, mixing with abrasives

C-92™ | Cryotech Deicing Tech. | Liquid

Composition: 50% solution Potassium Acetate
Effective Temp.: well below 0 F
Corrosion Protection: 110%
Spalling Protection: average
Environment: acetate ion, increased BOD
Costs: 10x
Uses: aircraft deicer, prewet abrasives

CMS-B | RDE Inc. | Liquid/Solid

Composition: 27% solids, 10% Potassium Chloride
Effective Temp.: below 0 F
Corrosion Protection: No inhibitor, testing
Spalling Protection: testing
Environment: Cl^- ion
Costs: 2x
Uses: Deicing, anti-icing

LoCorr Brand Deicer | Akzo Inc. | Solid

Composition: 98.5% NaCl with Corrosion Inhibitor
Effective Temp.: 15-20 F
Corrosion Protection: 50-70%
Spalling Protection: none
Environment: Cl^- ion
Costs: 3-4x (estimate)
Uses: deicing and mixing with abrasives

LowTherm Deicer | ChemMark Corp. | Liquid

Composition: Liquid $MgCl_2$ with corrosion inhibitor
Effective Temp.: 10-15 F
Corrosion Protection: very good 90-100%
Spalling Protection: good
Environment: Cl^- ion
Costs: 2x
Uses: anti-icing, prewetting abrasives

South Dakota Deicer No. 2 | South Dakota DOT | Solid

Composition: Sodium Acetate/ Sodium Formate blend
Effective Temp.: 15-20 F
Corrosion Protection: good-testing
Spalling Protection: good-testing
Environment: formate, acetate ion, increased BOD
Costs: 10-15x, estimate
Uses: Deicing and anti-icing

CMA | Cryotech Deicing Technology | Solid

Composition: Calcium Magnesium Acetate
Effective Temp.: 20-25 F
Corrosion Protection: very good
Spalling Protection: very good
Environment: Acetate ion, increased BOD
Costs: 15x
Uses: Anti-icing, mixed with abrasives

Glycols-Ethylene	Various Manufacturers	Liquid

Composition: 50% solution
Effective Temp.: below 0 F
Corrosion Protection: excellent
Spalling Protection: very good
Environment: increased BOD, toxic to humans
Costs: 25x
Uses: Aircraft and runway deicer

Methanol	Various Manufacturers	Liquid

Composition: Wood Alcohol
Effective Temp.: well below 0 F
Corrosion Protection: excellent
Spalling Protection: very good
Environment: increased BOD, toxic to humans
Costs: 6x
Uses: Deicing, evaporates quickly

Urea	Various Manufacturers	Solid

Composition: $CO(NH_2)_2$
Effective Temp.: +25 F
Corrosion Protection: very good
Spalling Protection: very good
Environment: increased NOD
Costs: 6-7x
Uses: Deicing and anti-icing

Oil and Gas Brines	West Virginia DOT	Liquid

Composition: variable but Complex Chlorides with trace elements, oil and grease
Effective Temp.: 10-15 F
Corrosion Protection: similar to NaCl
Spalling Protection: similar to NaCl
Environment: Cl^- ion and trace elements, Sulfates, Lead, oil and grease
Costs: 2x (estimate)

Verglimit | Verglimit Co. | Asphalt Overlay

Composition: Calcium Chloride flakes mixed with asphalt
Effective Temp.: Variable 15-20 F
Corrosion Protection: n.a.
Spalling Protection: n.a.
Environment: dilute concentrations of Cl^- ion
Costs: 3-4x conventional overlays
Uses: high freeze-up areas

7.8 Deicing Application Rates

Several tables illustrating application rates for deicing and anti-icing have been included. Two, from Norway and Finland, show anti-icing application rates for varying road and weather conditions. A third table gives application rates for CMA from various state agencies across the U.S. The fourth gives application rates for Cryotech CF7, liquid Potassium Acetate, for varying application techniques over different road and weather conditions. The last provides application rates for liquid Magnesium Chloride for both deicing and anti-icing methods.

Weather and Road Condition	Brine Quantity gal/ln mi
Preventive action against ice	
Dry road, humidity < 85%	13.25 - 20
Dry road, humidity > 85%	20 - 26.5
Wet road	20 - 26.5
Preventative action against snow	53
On hoarfrost and thin ice	20 - 26.5
On snow and during snowfall	53 - 79.5

Table 7.1 Norwegian recommendations for brine quantities to apply for various road and weather conditions (from Stotterude and Reitan, 1993).

Pavement temp. deg. F	Black Ice lb/ln mi	Preventive Salting gal/ln mi	Snow and Sleet lb/ln-mi	Cold weather slickness lb/ln-mi
28-35	65-260	65-195		
26-35			260-530	
5-35				130

Table 7.2 Finnish recommendations for application of liquid salt (from SHRP-preliminary recommendations for anti-icing practices, 1994).

CMA Usage Rates				
Transportation Agency	Mix	Average Daily Traffic	Application Rate lbs/Ln Mile	Usage Comparison CMA/Salt
Denver	CMA/Sand	24,000 – 30,000	167–333	1/1
Massachusetts DPW District 7	CMA	12,000	280	0.87/1
Massachusetts DPW District 6	CMA	2,000	300	0.44/1
Michigan DOT	CMA	31,000	300	1/1
Nebraska DOH	CMA/Sand	29,000	400–500	1/1
West Virginia DOH	CMA	13,000	325	1.3/1
Caltrans	CMA	1,350 – 12,000	350–400	NA
Ontario MOT	CMA	32,000	266	NA

Table 7.3 CMA Usage Rates (After Cryotech Deicing Technology, 1993).

METHOD	APPLICATION RATE
Deicing Conditions:	
< 32 F / thin ice	52.8 gal / lane mile
< 10 F / 1 inch ice	158.4 gal / lane mile
Anti-icing	26.4 gal / lane mile
Prewetting	1.25 gal / 1000 lb sand

Table 7.4 Application Rates for Cryotech CF7 - liquid potassium acetate - 50% concentration solution, (Cryotech Deicing Technology, 1993).

A. DEICING
Packed Snow and Ice
Gallons per lane mile

	TEMPERATURE		
DEPTH	20 to 32 F	10 to 20 F	10 F and below
2 to 3 inches	234 gal / ln mi	281 gal / ln mi	577 gal / ln mi
1 to 2 inches	144 gal / ln mi	171 gal/ ln mi	380 gal / ln mi
1/2 to 1 inch	76 gal / ln mi	114 gal / ln mi	191 gal / ln mi
Less than 1/2 inch	57 gal / ln mi	76 gal / ln mi	114 gal / ln mi
Glare Ice	57 gal / ln mi	76 gal / ln mi	114 gal / ln mi

Note: It is not recommended that liquid deicers be used, without abrasives, at higher snow and ice depths

B. ANTI-ICING

Expected freezing conditions :	21 to 32 gallon per lane mile

Figure 7.5 Application Rates for Liquid Magnesium Chloride (Charles Cunningham-CDOT, 1994)

7.9 Summary Deicing Table

A summary of the alternative deicers with characteristics are provided in Table 7.6 and 7.7. The deicers are listed along the left while the characteristics are listed across the top. The deicers are ranked for each category according to the method described in the commentary on the following page. The Performance, Cost and Environmental characteristics are weighted by a factor of two. A value is then calculated for each characteristic. The individual values are totalled for each deicer and a cumulative value is determined. This value corresponds to a rating i.e. Average, Good, Excellent. This rating system is subjective as infinite weighting possibilities exist. It was determined to weight the three most important characteristics - Performance, Environment and Cost by a factor of two.

7.10 Conclusion

The deicer field has progressed rapidly over the past two years. In response to the PM_{10} problem, many state and local agencies have begun decreasing the use of abrasives while increasing the use of deicing chemicals. As a result, new deicer products, which provide increased performance (melting, penetration and undercutting) while significantly reducing corrosivity, have been developed.

In addition, new techniques from the Scandinavian countries have been researched and tested, and results are making their way to the U.S. In order to be used successfully, these methods require new techniques and equipment.

In response to this new information, SHRP has recently completed their own study on anti-icing. This report provides valuable practical information on anti-icing procedures for the highway maintenance manager.

DEICING CHEMICAL	Form	Eutectic temp.	Concentration	Working temp.	Specificity	Performance	Corrosivity	Spalling	Environment	Cost	Rating
		Degree F	@ eutectic %	Degree F	Anti-Icing/deicing	Melt./Penet./Disbond					
Potassium Chloride	Solid	+13	19.5	+25	Deicing	Average 5*2=(10)	High (3)	High (3)	Moderate 6*2 =(12)	4x / 7*2=(14)	42 / Average
Sodium Chloride	Solid	-5.8	23.8	+15 -20	Deicing	Good 7*2=(14)	High (3)	High (3)	Moderate 6*2 =(12)	1x / 10*2=(20)	52 / Good
NaCl	Solid w/ Cl	n.a.	n.a.	+15 -20	Deicing	Good 7*2=(14)	Moderate (6)	High (3)	Moderate 6*2 =(12)	3-4X / 8*2=(16)	51 / Good
Calcium Chloride	Solid	-60	32.5	Below -10	Deicing	Excellent 10*2=(20)	High (3)	High (3)	High 3*2 =(6)	7x / 6*2=(12)	44 / Average
CaCl2	Liquid	-60	32.5	Below 0	Prewetting	Excellent 9*2=(18)	Moderate (6)	Moderate (6)	Moderate 6*2 =(12)	3-4X / 8*2=(16)	58 / Very Good
	Liquid w/ Cl	n.a.	n.a.	Below 0	Anti-Icing	Excellent 9*2=(18)	Low (8)	Moderate (6)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	58 / Very Good
Magnesium Chloride	Solid	-28	21.6	+ 5	Deicing	Excellent 9*2=(18)	Moderate (6)	Moderate (7)	High 3*2 =(6)	7x / 6*2=(12)	49 / Good
MgCl2	Liquid	-28	21.6	+5	Anti-Icing	Very good 8*2=(16)	Low (8)	Low (8)	Moderate 6*2 =(12)	3-4x / 8*2=(16)	60 / Very Good
	Liquid w/ Cl	n.a.	n.a.	+5	Anti-Icing	Very good 8*2=(16)	Very Low (9)	Low (8)	Moderate 6*2 =(12)	3-4x / 8*2=(16)	61 / Excellent
Combinations											
Sodium/Magnesium Chloride	Solid	n.a.	n.a.	+10	Deicing	Good 8*2=(16)	Moderate (5)	Moderate (5)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	52 / Good
NaCl/MgCl2 - 80/20 mix	Solid w/ Cl	n.a.	n.a.	+10	Deicing	Good 8*2=(16)	Low (8)	Moderate (5)	Moderate 7*2 =(14)	4-5x / 7*2 = (14)	57 / Very Good
	Liq. w/ Cl	n.a.	n.a.	+10	Anti-Icing	Good 8*2=(16)	Very Low (9)	Low (8)	Moderate 7*2 =(14)	3-4X / 8*2=(16)	63 / Excellent
Sodium/Calcium Chloride	Solid	n.a.	n.a.	Below 5	Deicing	Very good 8*2=(16)	High (3)	High (3)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	48 / Good
NaCl/CaCl2 - 80/20 mix	Solid w/ Cl	n.a.	n.a.	Below 5	Deicing	Very good 8*2=(16)	Moderate (6)	High (3)	Moderate 6*2 =(12)	4-5x / 6.5*2 = (13)	50 / Good
CMA	Solid	-12 (variable)	34	+20-25	Anti-Icing	Average 6*2=(12)	Low (9)	Low (9)	Low 9*2=(18)	15x / 2*2=(4)	52 / Good
CaMgAc					Deicing						
Potassium Acetate	Liquid	-58	50	Below 0	Deicing	Excellent 9*2=(18)	Very low (10)	High (3)	High 3*2 =(6)	10-15x / 2*2=(4)	41 / Average
KAc					Anti-Icing						
Sodium Formate/Acetate	Solid	-6	N.A.	+15	Deicing	Good 7*2=(14)	Low (8)	Moderate (6)	Moderate 6*2 =(12)	10-15x / 3*2=(6)	46 / Average
Na-F/Na-Ac											
Urea	Solid	+11	32.6	+25	Anti-Icing	Average 6*2=(12)	Low (9)	Low (9)	High 3*2 =(6)	7x / 6*2=(12)	48 / Good
CO(NH2)2					Deicing						
Sodium Formate	Liquid	+7	20	Approx. +15	Deicing	Good 7*2 =(14)	Low (9)	Moderate (6)	Moderate 6*2 =(12)	10-15x / 3*2=(6)	47 / Good
Na-F											
Methanol*	Liquid	-144	100	Below 0	Deicing	Excellent 10*2=(20)	Very low (10)	Low (9)	High 1*2 =(2)	7-8x / 5*2=(10)	51 / Good
CH3OH											
Glycols - Ethylene	Liquid	-59.8	60	Below 0	Deicing	Excellent 9*2=(18)	Very low (10)	Low (9)	Moderate 6*2 =(12)	20x / 2*2=(4)	53 / Good
C2H6O2											

*The ESSD group does not recommend Methanol because it is highly toxic to humans

Table 7.6 Deicer Rating Table

DEICING CHEMICAL	Form	Performance	Corrosivity	Spalling	Environment	Cost	Rating
		Melt./Penet./Disbond.					
Potassium Chloride	Solid	Average 5*2=(10)	High (3)	High (3)	Moderate 6*2 =(12)	4x / 7*2=(14)	42 / Average
KCl							
Sodium Chloride	Solid	Good 7*2=(14)	High (3)	High (3)	Moderate 6*2 =(12)	1x / 10*2=(20)	52 / Good
NaCl	Solid w/ Cl	Good 7*2=(14)	Moderate (6)	High (3)	Moderate 6*2 =(12)	3-4X / 8*2=(16)	51 / Good
Calcium Chloride	Solid	Excellent 10*2=(20)	High (3)	High (3)	High 3*2 =(6)	7x / 6*2=(12)	44 / Average
CaCl2	Liquid	Excellent 9*2=(18)	Moderate (6)	Moderate (6)	Moderate 6*2 =(12)	3-4X / 8*2=(16)	58 / Very Good
	Liquid w/ Cl	Excellent 9*2=(18)	Low (8)	Moderate (6)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	58 / Very Good
Magnesium Chloride	Solid	Excellent 9*2=(18)	Moderate (6)	Moderate (7)	High 3*2 =(6)	7x / 6*2=(12)	49 / Good
MgCl2	Liquid	Very good 8*2=(16)	Low (8)	Low (8)	Moderate 6*2 =(12)	3-4x / 8*2=(16)	60 / Very Good
	Liquid w/ Cl	Very good 8*2=(16)	Very Low (9)	Low (8)	Moderate 6*2 =(12)	3-4x / 8*2=(16)	61 / Excellent
Combinations							
Sodium/Magnesium Chloride	Solid	Good 8*2=(16)	Moderate (5)	Moderate (5)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	52 / Good
NaCl/MgCl2 - 80/20 mix	Solid w/ Cl	Good 8*2=(16)	Low (8)	Moderate (5)	Moderate 7*2 =(14)	4-5x / 7*2 = (14)	57 / Very Good
	Liq. w/ Cl	Good 8*2=(16)	Very Low (9)	Low (8)	Moderate 7*2 =(14)	3-4X / 8*2=(16)	63 / Excellent
Sodium/Calcium Chloride	Solid	Very good 8*2=(16)	High (3)	High (3)	Moderate 6*2 =(12)	4-5x / 7*2 = (14)	48 / Good
NaCl/CaCl2 - 80/20 mix	Solid w/ Cl	Very good 8*2=(16)	Moderate (6)	High (3)	Moderate 6*2 =(12)	4-5x / 6.5*2 = (13)	50 / Good
CMA	Solid	Average 6*2=(12)	Low (9)	Low (9)	Low 9*2=(18)	15x / 2*2=(4)	52 / Good
CaMgAc							
Potassium Acetate	Liquid	Excellent 9*2=(18)	Very low (10)	High (3)	High 3*2 =(6)	10-15x / 2*2=(4)	41 / Average
KAc							
Sodium Formate/Acetate	Solid	Good 7*2=(14)	Low (8)	Moderate (6)	Moderate 6*2 =(12)	10-15x / 3*2=(6)	46 / Average
Na-F/Na-Ac							
Urea	Solid	Average 6*2=(12)	Low (9)	Low (9)	High 3*2 =(6)	7x / 6*2=(12)	48 / Good
CO(NH2)2							
Sodium Formate	Liquid	Good 7*2 =(14)	Low (9)	Moderate (6)	Moderate 6*2 =(12)	10-15x / 3*2=(6)	47 / Good
Na-F							
Methanol*	Liquid	Excellent 10*2=(20)	Very low (10)	Low (9)	High 1*2 =(2)	7-8x / 5*2=(10)	51 / Good
CH3OH							
Glycols - Ethylene	Liquid	Excellent 9*2=(18)	Very low (10)	Low (9)	Moderate 6*2 =(12)	20x / 2*2=(4)	53 / Good
C2H6O2							

*The ESSD group does not recommend Methanol because it is highly toxic to humans

Table 7.7 Deicer Rating Table

Commentary on Deicer Rating Table:

The deicers were rated according to basic parameters. These included: performance (melting, penetration, and disbonding), corrosion, spalling, environment and cost. The performance criteria was ranked by the following method:

Poor (5)
Average (6)
Good (7)
Very Good (8)
Excellent (9 - 10)

The poor ranking (5) has a smaller values associated with it, than the excellent (9-10) ranking. The 'better' the deicer performs the higher the ranking.

The corrosion, spalling and environmental criteria were ranked according to the following method:

Low (8 - 10)
Moderate (5 - 7)
High (2 - 4)

The cost parameter was determined based on its cost relative to the cost of salt. As an example, the cost of salt is approximately $30 per ton. A hypothetical deicer 'Z' cost $100 per ton. Relatively, deicer Z's cost is 3 times that of salt. The 'x' is the symbol for multiplication or 'times'. The method for ranking is shown below:

(1 - 4)x	Low	(8 - 10)
(5 - 8)x	Moderate	(5 - 7)
(9 - 15)x	High	(2 - 4)

The performance, environmental and cost factors were weighted by a factor of two. These parameters were considered more important and weighted accordingly. The rating was calculated according to the formula:

Rating = 2 * Performance + Corrosion + Spalling + 2 * Environment + 2 * Cost

The deicer rankings were multiplied by the weights and then totalled to give a numerical value for the rating. The numerical values correspond to a classification system as follows:

Average	(40 - 46)
Good	(47 - 53)
Very good	(54 - 60)
Excellent	(61 - 69)

As an example, Magnesium Chloride (solid), had the the following rankings:

Performance :	9 * 2 = 18
Corrosion:	6 * 1 = 6
Spalling:	7 * 1 = 7
Environment:	3 * 2 = 6
Cost:	6 * 2 = 12
Total	49

The total ranking value is 49 which corresponds to a good rating.

The two main concepts the ESSD group has learned from the literature search and the site visits conducted across the state are:

- ◊ Each situation is unique. The solutions to winter road maintenance problems are site specific and 'no one size fits all'. What works for John Sewell in Boulder and Jack Reid in Aspen may not be appropriate for Charles Cunningham of the CDOT in Denver and,

- ◊ The drivers make the solution to winter road maintenance problems possible. Computers and improved technology provide valuable resources but the drivers dedication and good judgement make it work.

8. Equipment

8.1 Introduction

Driving conditions rapidly and severely deteriorate in the presence of snow and ice. Wheeled vehicles normally cannot travel when the snow depth exceeds the vehicle's wheel radius. These adverse driving conditions dictate that we have equipment capable of quickly and effectively clearing roadways and applying traction and deicing material. Much of the following equipment information was extracted from *Handbook of Snow, Principles, Processes, Management & Use.*, Gray 1981.

8.2 Plows

The most common method of snow removal is through the use of plows. Most plows can be classified into one of three categories: displacement plows, rotary plows (snow blowers) and specialized plows. Figure 8.1 categorizes the various types of plows used in snow and ice removal.

Displacement plows, sometimes referred to as blade plows, are commonly classified according to where they are located on the carrying vehicle (ie. front-mounted, side-mounted, underbody and trailing). Displacement plows are also frequently classified by shape and/or functional characteristic such as V-blade or one-way fixed.

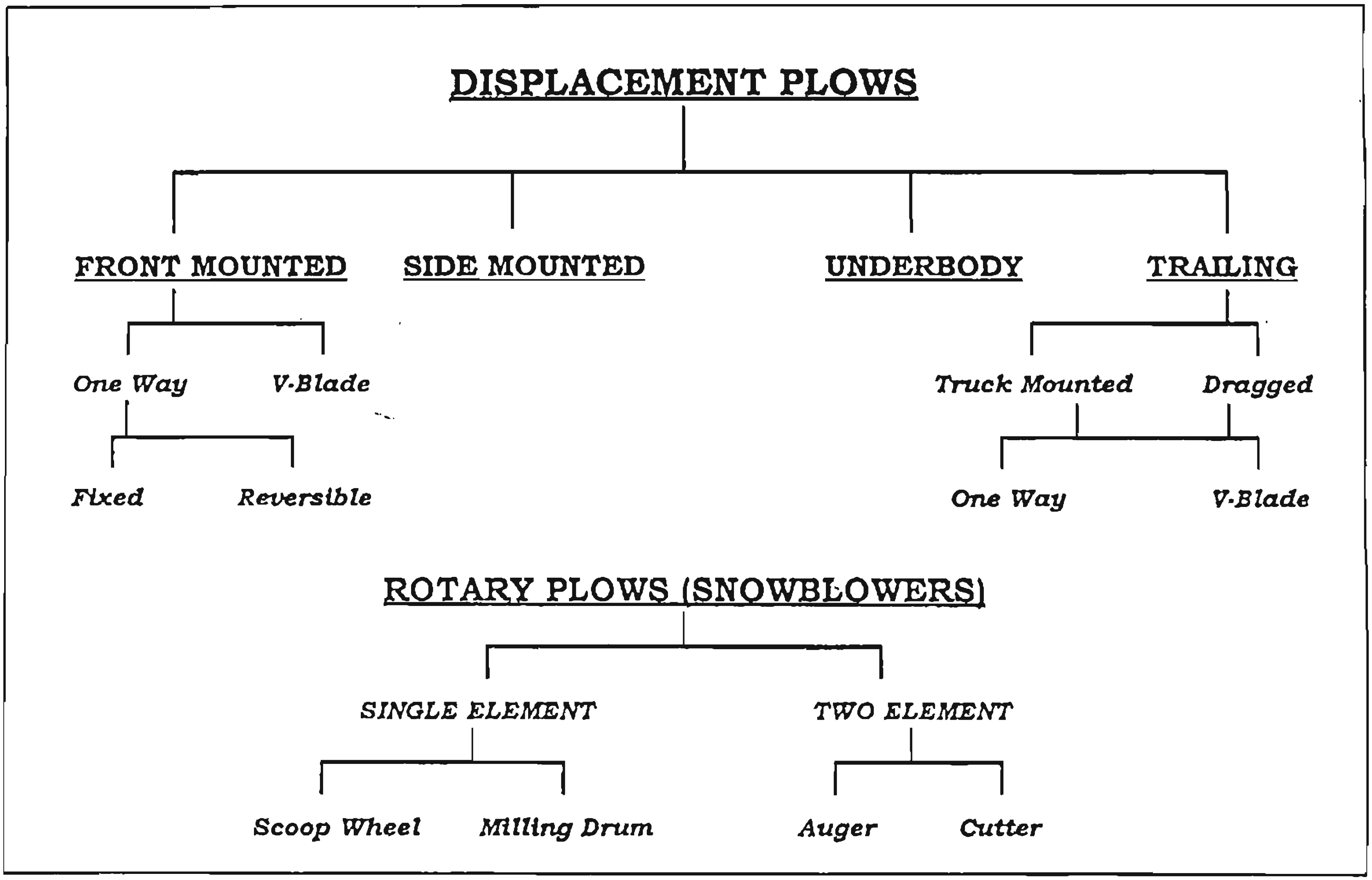

Figure 8.1 Plows

◊ **Front-mounted**

A Front-mounted displacement plow is the most common type of snow removal equipment. This plow generally displaces the snow in a direction perpendicular to the direction of the vehicle movement.

◊ **One-way**

The one-way blade plow is a continuous linear blade angled towards the direction of desired displacement (ie. the face of the blade opens to the desired side). A one-way plow can be either fixed or reversible.

◊ **One-way Fixed**

The one way fixed plow is pre-set to case snow either to the right or the left of the vehicle. The direction of snow displacement cannot be changed.

◊ **One-way Reversible**

Reversible blades adjust to cast snow to either side via a rollover or a swivel mechanism. The rollover blade changes direction by rotating 180° about a horizontal axis parallel to the pavement and through the vertical center of the blade. The swivel blade performs the transformation by pivoting the blade though an axis normal to the road surface. See Figure 8.2.

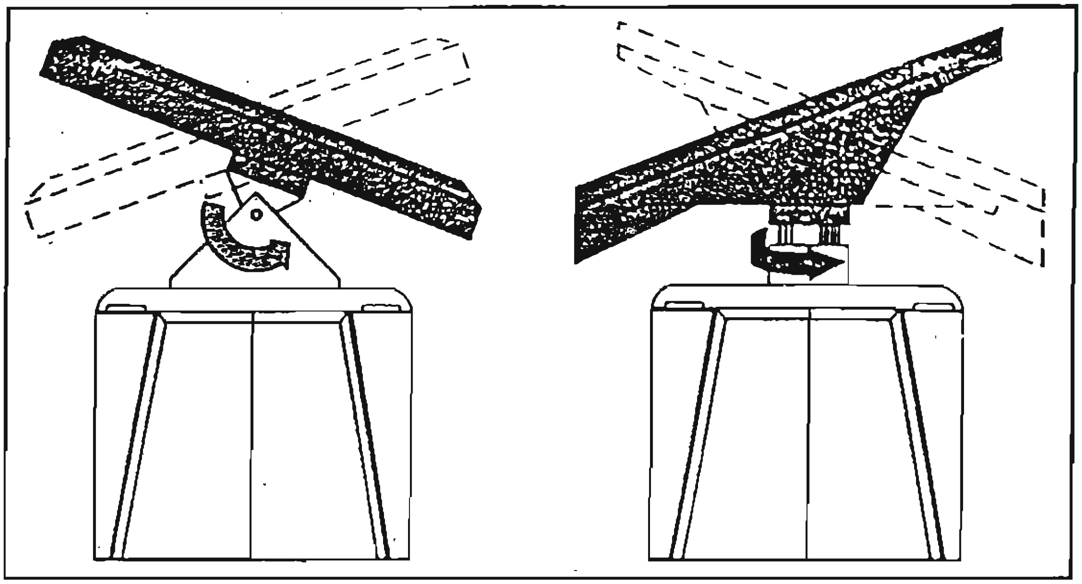

Figure 8.2 Rollover and Swivel Blades (After Gray, 1982).

◊ **V-blade**

The V-blade plow displaces snow to both sides of the vehicle simultaneously. The blade is shaped like a "V" and is attached to the vehicle with the point of the "V" in front.

◊ **Side Mounted (Wings)**

Side mounted plows are one-way blades mounted on the side of a vehicle and angled to cast snow away from the vehicle. These blades are usually used to extend the width of cut or to slope high banks of snow. When used in the latter sense, the plows are mounted so that the bottom edge (cutting edge) is raised off the pavement and angled to the degree necessary to perform the desired task. This is also referred to as "high winging".

◊ **Underbody Plow**

Underbody plows are one-way or V-blade plows mounted under the vehicle. The primary advantage to underbody plows is the additional weight that can be applied to the cutting edge of the plow thereby rendering the blade more effective in removing compact snow and ice. Underbody plows also improve the operators vision which can be impaired by front mounted plows. Graders are an example of an underbody plow.

◊ **Trailing Plow**

Trailing or tailgate plows are one-way or V-blade plows mounted on the rear of the vehicle. These blades can be either truck mounted or dragging. Like the underbody blades, the trailing plows provide a better range of vision over the front mounted blades.

In many cases, the portion of a blade plow that comes in contact with the surface of the road is made of a hard rubber or plastic to prevent excessive damage to the road surface. It is also common to mount this "soft edge" on a spring hinge to allow the edge to contract when it encounters a solid object or protrusion such as a manhole cover. These type of spring loaded blade edges are called trip edges.

Rotary plows or snowblowers are another commonly used type of snow removal equipment. Their main advantage over blade plows is that they can displace deep or very hard snow further and more effectively by cutting the snow into pieces of varying size and casting it through a directional chute. This is done using one or a series of rotating cutting and displacing devices.

Rotary plows can be classified as single-element or two-element which describes the mechanical method used to perform the before mentioned process. The subcategories of these two types of rotary plows are outlined in Figure 8.1.

◊ **Single-element**

Single element rotary plows (Figure 8.3) use the same rotating device to disaggregate and displace the snow. This is done through the use of a scoop wheel or milling drum.

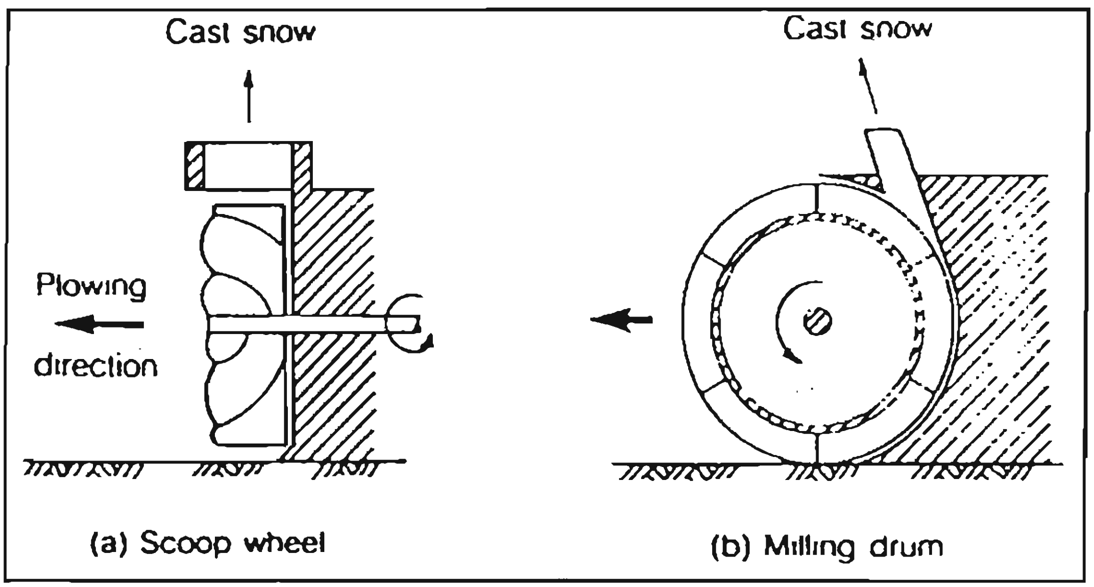

Figure 8.3 Single Element Rotary Plow (After Gray, 1982).

◊ **Scoop Wheel**

The scoop wheel disaggregates and casts the snow using a scoop rotating on an axis parallel to the direction of the vehicle movement, much like an auger.

- **Milling Drum**

  The milling drum is a cylindrical unit with fins which rotates on an axis normal to the plane formed by the road surface. The snow is disaggregated in the front and discarded out the side.

- **Two-element**

  Two element plows have separate mechanical components: one to disaggregate the snow and one to cast it aside. The disaggregating device is referred to as an impeller and consist of a series of blades attached to a web or a disk. The web or disk rotates on an axis normal to the plane formed by the road surface and directs the chopped snow towards the casting device. The casting device is traditionally similar to the scoop wheel.

- **Auger**

  An auger is a two-element rotary plow which utilizes two or more impellers to disaggregate the snow.

- **Cutter**

  Cutters, often referred to as ribbon or helical cutters, are two-element rotary plow which uses a single impeller to disaggregate the snow.

There are many machines on the market that incorporate a combination of the various types of plowing devices. For example, a hybrid machine may consist of a blade which displaces snow into a casting element or a combination of blades to perform a specific task. For the most part, these types of equipment are not used in every day snow removal activities.

8.3 Power Brooms

Sweeping devices or power brooms are also used for snow removal. The brooms usually consist of a long horizontal rod with steel or synthetic fibers protruding radially out of the rod. The rod is attached to a motor causing it to rotate about it's horizontal axis producing the sweeping effect. Little directional control is possible for these sweeping devices, therefore, their usage is limited. Usually, the snow is cast up into the direction of prevailing winds.

8.4 Sand/Salt Spreaders

There are many different types of equipment designed to disperse sand and solid deicing aggregate. The two most common designs are V-bed (or hopper bottom) and tailgate sanders. Both types can be fitted on most vehicles from a standard pick-up to a heavy duty tandem axil truck.

The V-bed spreader, seen in Figure 8.4, is composed of a hopper container of varying slope with a conveyor at the bottom to feed aggregate to the dispersion device. The hopper can hold one to ten plus cubic yards of aggregate and may weigh over 5,000 pounds depending on the size of the unit.

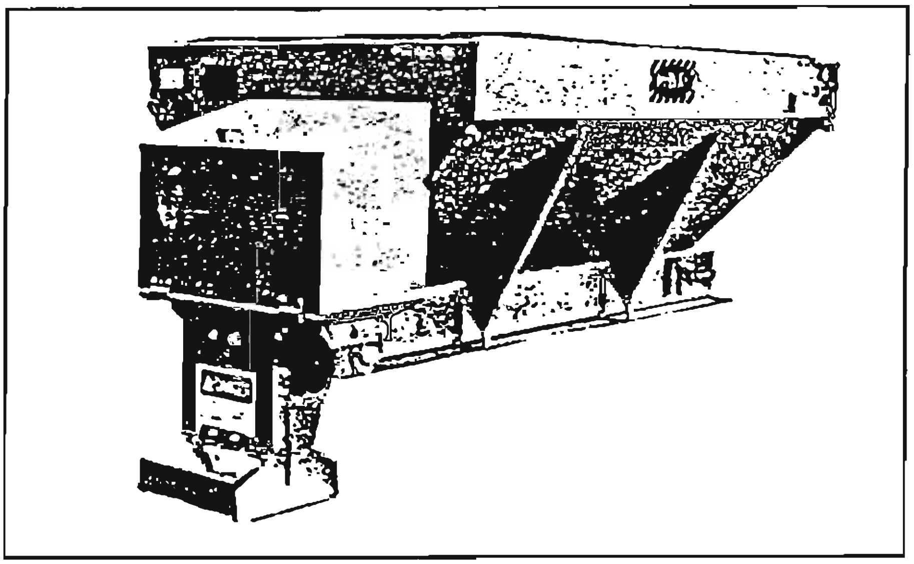

Figure 8.4 V-bed Spreader with Dispersion Device.

The dispersion device at the end of the conveyor is almost always a "spinner" assembly. The spinner is a flat disk of approximately 18 to 24 inches diameter with fins attached (usually six) in an evenly spaced, radial pattern resembling a fan. The spinner is connected to a motor causing it to rotate about an axis normal to the plane formed by the road surface. When aggregate is poured on to the top of the spinning disk, the fins catch it and fling it radially outward on to the road.

Tailgate spreaders attach to or completely replace the tailgate of a hoist style dump truck. The dump body is filled with aggregate and tilted enough to allow the material to flow towards the tailgate spreader. These types of spreaders fall into two categories; conveyor (or auger) systems and "direct dumping" systems.

In a conveyor system the aggregate flows out of the dump body into a troth with a conveyor or auger at the bottom. The conveyor or auger directs the aggregate to a discharge shoot with a spreading device (usually a spinner) at the end. The spinner assembly and sometimes the entire tailgate assemble pivots to remain level with the road when the dump body is tilted.

The direct dumping type of tailgate spreader, Figure 8.5, is composed of a series of spill plates which are spring mounted gates that open intermittently to release the aggregate. The spill plates rest against a long drum with short intermittently spaced ribs on it's surface (much like the drum in a music box). When the drum rotates, the ribs cause the spill plates to open slightly thereby releasing aggregate. When the rib is not present, the spill plate stays closed.

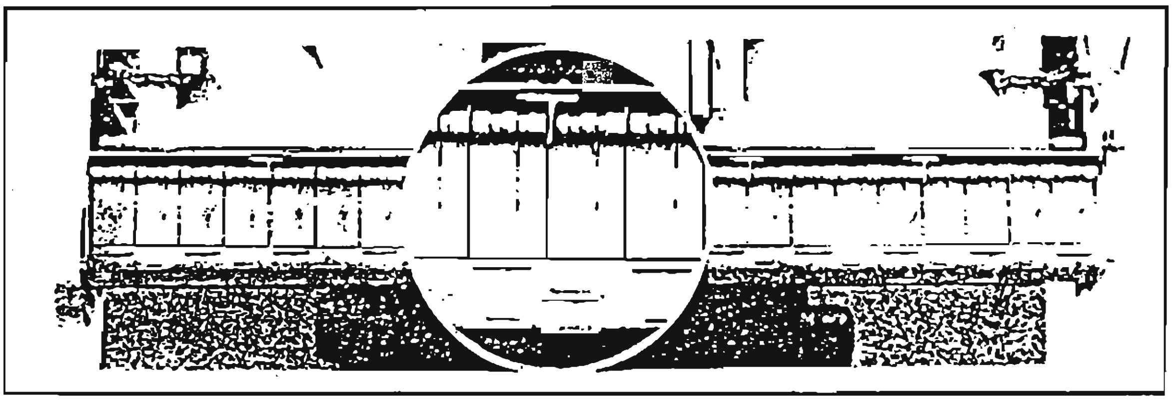

Figure 8.5 Direct Dumping Tailgate Spreader.

8.5 Sweepers

When the snow has cleared and the streets are dry, the aggregate remaining on the pavement must be removed. This is the critical stage for reducing PM_{10}. The road sweepers that remove this aggregate are either mechanical sweepers or vacuum sweepers.

Mechanical sweepers are commonly comprised of gutter brooms and elevator or main brooms. The gutter broom(s) sweep debris from the side of the vehicle towards the elevator broom located under the vehicle. The elevator broom sweeps the debris up into the catch basin of the sweeper. Here the debris will be stored until dumped.

Vacuum sweepers have a similar broom setup except the gutter and central brooms sweep the aggregate towards the vacuum mouth(s). The debris is then vacuumed up into the catch basin where it is stored. Vacuum sweepers have the option of dumping or vacuuming out the catch basin to dispose of the debris. Many vacuum sweepers have both options.

Several street sweepers spray water on the waste just before it is swept thereby reducing dust and flyaway's. The water spraying system is composed of a storage tank, pump, and series of spray nozzles. The nozzles are usually located immediately in front of the gutter brooms and main brooms.

Additional features of the water systems may include a fire hydrant refill hose, vehicle wash down hose and catch basin flush.

8.6 Liquid Deicing Equipment

In many cases, Liquid deicing chemicals are used to help clear roadways and stop the formation of ice. These chemicals can be sprayed directly on the road or applied to aggregate before spreading.

Liquid can be sprayed on aggregate using several types of systems. The most common application is spraying the liquid on top of a dump bed or hopper full of aggregate. This type of system is comprised of a storage tank, pump and spraying apparatus. Here, the drivers simply position the truck full of aggregate under the sprayer and apply the appropriate amount of deicer. It is a good idea to enclose this type of application setup inside a shed or some type of structure to keep wind from blowing the liquid chemical about when it is being sprayed.

The liquid deicer can also be sprayed on the aggregate as it is being applied to the streets. This usually entails mounting liquid tanks on the vehicles along side the aggregate container. The liquid application nozzles are positioned to spray the aggregate just before it hits the spinner.

When the deicer is to be applied directly to the pavement, a tank truck or tank system that is retrofitted on a vehicle is used. Again, this would involve a storage tank, pump, and spraying apparatus. The flow rate of the sprayer can be preset or adjusted from within the cab of the vehicle as it is moving.

8.7 Vehicles

Street maintenance departments use powerful trucks to push the plows and haul the sand. These vehicles can be built in their intended form or designed so that dump bodies or sanding units can be easily retrofitted on the vehicle. The trucks vary from standard pickups to heavy duty single and tandem axle trucks.

It has become more common to install equipment on the vehicles that allow the drivers to control the application rate from inside the cab. This will not only provide better control over amounts of material used but will increase the effectiveness of the deicing operation and provide safer driving conditions for the motoring public. This is possible because the maintenance driver can automatically increase the application amount on approach to major intersections and on particularly bad stretches of road, and decrease application amounts where it is not as needed.

8.8 Signage

A precautionary measure taken by most road maintenance departments is posting signs which warn the driving public of potential hazardous driving conditions. These signs are permanently placed in habitual trouble areas such as bridges, hills, low areas and troublesome turns. Some examples are: "Watch For Fog, Ice, Blowing Snow, Ice On Bridge, Sharp Curve", ...etc.

Changeable message signs are another way of providing the driving public with up to the minute information on road conditions. These signs may be programmed to display whatever message is appropriate at that time. Changeable message signs can be powered by generators, solar power or can be hard wired into the city utility system.

8.9 Weather Services

In order for maintenance crews to effectively battle winter storms, they need to be alerted to the storm and its surrounding conditions several hours before it hits. There are several forecasting services and weather information systems available to assist them in this task.

Forecasting services such as the National Weather Service traditionally provide information regarding air temperature, surface temperature, moisture levels, wind speeds and directions, and cloud formations. This information is transmitted to street maintenance department computers by modem. The computers produce satellite imagery and 24 hour to 30 day forecasts of weather patterns in the area. The data can be received on a 286 processor with monochrome monitor but a speedy processor with super VGA graphics capability is preferred due to the detailed nature of the satellite imagery.

Road Weather Information Systems (RWIS's) are another method of predicting the severity of driving conditions during a winter storm. These systems access information directly from the source, that is, the road surface. Sensors are placed approximately 20 in. below the pavement (subsurface sensors) and on the surface to measure pavement temperature and if heat is flowing toward or away from the surface. The sensors, in conjunction with weather radar information, validate pavement temperature, determine whether ice formation or bonding will occur, and in turn tell the user whether plowing and/or salting is necessary.

Again, the information is received through a phone modem into a computer. The data is primarily in text form and includes wind speed and direction, presence of precipitation, type of precipitation, humidity, air temperature, % of chemicals present, and pavement temperatures and trends. Since the information is primarily text, a high tech VGA system is not necessary (but usually preferred).

The agency using RWIS specifies where the sensors are to be placed and what type of information they wish to receive. The RWIS company (Surface Systems, Inc. in the United States) provides and installs all the sensors and hardware, including the receiving computers if necessary, and charges accordingly. Information from RWIS is updated several times a day.

RWIS also track meteorological information to compare with the pavement information. This data is put in a database which allows them to better interpret current readings based on historic accuracy.

Other weather systems range from local weather forecasting experts to weather predicting models based on historic patterns or geographic location. There are also aviation oriented weather services available to street maintenance departments.

9. Management

The ESSD project developed and mailed questionnaires to Road Maintenance Departments world wide. The questionnaires were designed to gather information regarding how each respondents department was managed. Questionnaire subjects included budget, types of aggregates used, problem seasons, regulations, personnel, etc. Researchers also visited many road maintenance departments to observe first hand the management techniques being utilized. The research was an effort to determine ways of reducing the impact of road sanding and deicing on our environment, using the most economical methods.

Quick removal of snow and ice during a winter storm is imperative to the proper functioning of urban and rural areas. The process is considered an emergency operation utilizing all available resources and requiring the most effective and practical management strategies, methods, equipment and materials. It is necessary to have a predetermined course of action for every conceivable situation, whether it is abandoned vehicles, road closures or ice storms.

The best winter road management practices for Street Maintenance Supervisor are not necessarily the same for every location. Each manager must custom design a management system to fit his or her situation based on geographic location and weather patterns.

While there are no absolute answers when it comes to winter street maintenance, there are many similarities between methods. Most all Road Maintenance Supervisors prioritize the routes, usually based on average daily traffic (ADT). A predetermined Level of Service (LOS) is common and equipment choices are usually similar in similar climates. Personnel training and very low turnover rates are also comparable from department to department. The low turnover of maintenance vehicle drivers is universally reported to stem from the strong driver dedication to the job.

Other management practices include the use of state of the art weather systems and advanced aggregate application devices (ie. computer controlled application rates). Using weather condition response charts and actively testing new deicing and anti-skid materials are also common practices. Other less-utilized management practices are interdepartmental cooperation, personnel sharing, equipment sharing and community education programs.

9.1 Priorities

The first task in developing an effective winter maintenance program is identifying the high, medium and low priority roads. The priority system can be based on average daily traffic flow (ADT or AADT for annual average daily traffic) and/or road usage.

Generally, the ADT is the annual two way traffic volume per year divided by 365 days. Some organizations may consider ADT per lane as a suitable classification method. High priority roads (also called class "A", super commuter, primary collectors... etc.) are frequently interstates, freeways and highways with over 2,500 ADT. Small collectors and connecting roads with between 800 and 2,500 ADT are classified as medium priority. Residential roads commonly carry less than 800 ADT and are classified as low priority.

Road classification is also frequently based on what each road is used for as well as how much it is used. For example, school bus and mail routes, even though with under 800 ADT, traditionally receive a higher priority because of their importance to the community. This also holds true for Fire Department and Police Department access roads.

Troublesome or hazardous areas may also receive a priority rating higher than their ADT merits. For example, it is common practice to remove snow from the high side of super elevations or gorge areas that cause icy spots due to melting and freezing. Of course, there is always that stretch of road on a steep hill that never receives direct sunlight and when left unchecked, turns into a solid sheet of ice. The Street Maintenance Department must be aware of these idiosyncrasies and handle them accordingly.

It is common practice for the Street Maintenance Department to have a map of their service area with each street color coded according to its priority level.

9.2 Level of Service

Each route classification has its own recommended level of service which stipulates the degree to which the street will be cleared. In some cases, the level of service guidelines are specified by the state; otherwise they are determined by the Maintenance Department.

Many agencies have a "dry road" policy which requires the maintenance crews to work until the pavement is clean and dry. The other side of the level of service spectrum is no service at all. This is common in residential areas.

Each level of service has a corresponding suggested coverage time. This dictates how much time will be spent clearing each route and in some cases start and stop times. For example, an agency may decide a certain street will only have a 14 hour coverage time from 5 a.m. to 7p.m.

9.3 Preparedness

In order to insure a successful operation, the drivers, vehicles, materials and equipment must be ready to go at a moments notice. Local and county governments typically publish preparedness guidelines for effective snow removal. Typical guidelines are:

- ◊ The names, addresses and telephone numbers of all employees qualified to perform winter duties should be compiled and posted in each work area.
- ◊ All staff must have a thorough understanding of their duties, plowing speeds and methods, and be familiar with the plowing, sanding, and salting routes in their area.
- ◊ Equipment should be allocated, inspected and overhauled. Stocks of replacement parts and small tools must be checked and replacements ordered. Communications equipment should also be inspected and all employees instructed in their use.
- ◊ Sand and salt should be stockpiled in sufficient quantities, and snow fences be installed to control abnormal snow drifting. Thus, by the time the first snow falls, all staff in supervisory positions would by ready to manage maintenance operations. (Gray, 1982).

9.4 Weather Condition Response Charts

Weather condition response charts indicate the appropriate application rates for various chemicals and aggregates based on the temperature, pavement condition (wet, icy, snow packed,...) and precipitation type (snow, sleet/freezing rain, ...). Since the temperature, pavement condition and precipitation type are easily identifiable, the appropriate application amount can be readily determined by the driver of a sanding or chemical application vehicle.

These charts list all the weather conditions of their area and the appropriate response and application rates. They can be simple or complex depending on the type of weather information systems available to the agency and the types of plowing and application equipment being used. An example of one such chart had been supplied by the Kansas DOT and is shown in Figure 9.1.

9.5 Materials

The decision of what materials to use is based on many factors, but usually boils down to two: cost and effectiveness. The maintenance department needs to sort through all the sand, salt, aggregate, ash and chemical deicer information and sales literature to find those materials which are the most effective at the lowest cost. With all these considerations to balance, it is common for maintenance departments to test new products on small sections of road before committing to full scale use.

The maintenance department must also consider the types of equipment needed to apply the material, any corrosive or undesired properties the material might posses, government regulations controlling the use of or side effects of the material, weight, size, shape, and more.

TEMP. DEGREES F.	PAVEMENT CONDITION	PRECIPITATION	3:1 SAND/SALT MIXTURE BY VOLUME		SALT		COMMENTS
			APPLICATION RATE Pounds per 2 lane mile	MILES/CY (2 LANE) @ 2,978 #/cy	APPLICATION RATE Pounds per 2 lane mile	MILES/CY (2 LANE) @ 2,000 #/cy	
30° & Rising	WET	Snow	1,200	2.48	300	6.67	Wait at least 0.5 hour before plowing
		Sleet or Freezing Rain	800	3.72	200	10.00	Reapply as necessary (3-4 hours)
25°- 30°	ICE/ PACK. SNOW		800 - 1000	3.72 - 2.98	200 - 250	10.00- 8.00	Reapply as necessary
	WET	Snow or Sleet	800 - 1600	3.72 - 1.86	200 - 400	10.00- 5.00	Wait at least 0.5 hour before plowing
		Freezing Rain	800 - 1200	3.72 - 2.48	200 - 300	10.00- 6.67	Reapply as necessary (3 - 4 hours)
20°- 25°	ICE/ PACK. SNOW		800 - 1000	3.72 - 2.98	200 - 500	10.00- 4.00	Reapply as necessary
	WET	Snow or Sleet	1000 - 2000	2.98 - 1.49	250 - 500	8.00- 4.00	Wait at least 0.75 hour before plowing - Repeat application and plowing
		Freezing Rain	1200 - 1600	2.48 - 1.86	300 - 400	6.67- 5.00	Reapply as necessary (3 - 4 hours)
15°- 20°	ICE/ PACK. SNOW		1000 - 1600	2.98 - 1.86	250 - 1000	8.00- 2.00	Reapply as necessary
	DRY	Dry Snow	PLOW		PLOW		Treat hazardous areas with abrasives only. (1500 Lbs/mile)
	WET	Wet Snow or Sleet	2000	1.49	500	4.00	Wait at least 1.0 hour before plowing; Continue plowing until storm ends. Then repeat application
10°- 25°	ICE/ PACK. SNOW	Light or None			200 - 1500	10.00- 1.33	Treat salt with 10 gallon of "Liquid calcium or Magnesium chloride" per ton of salt (Salt must be wet when applied if the road is not wet.) Wait 1 hour or more before plowing.
Below 15°	ICE/ PACK. SNOW						Treat with abrasives only.
	Dry	Dry Snow	PLOW		PLOW		Treat hazardous areas with abrasives only. (1500 Lbs./2 lane mile)

Figure 9.1 Kansas Department of Transportation Application Guidelines (After Kansas Department of Transportation).

9.6 Personnel

Street maintenance personnel are the heart of all winter maintenance operations. They must be highly dedicated and properly trained in equipment operation, preventative maintenance, safety and agency policy.

Training of new and existing employees is an ongoing process, the bulk of which is usually performed during the late summer and early fall. The training includes safety, equipment maintenance, department policy, "dry runs" on their respective routes and tips on how to interact with the driving public when plowing and sanding. New employees traditionally are not the primary plow/sanding route drivers during their first season on the job. Instead, new hires are utilized as backup or second shift drivers and are assigned a route after their experience level has increased and positions become available. Turnover for these positions is very low.

The key to any winter maintenance operation are the drivers. Without their support and commitment, effective snow removal is virtually impossible. The drivers are put on alert (usually on call with a beeper) as soon as the manager is alerted to the possibility of a winter storm. If a storm seems inevitable, the drivers are called in and the vehicles are fueled and readied for action. Once the snow has reached a predetermined depth or the storm has reached a certain intensity, the drivers start clearing their assigned routes.

In the event of an exceptionally intense winter storm, the maintenance crews may be required to operate continuously for 24 hours or more. In these situations, the crews work 8 to 12 hour shifts, with the most experienced drivers handling the first shifts and/or most troublesome time periods (rush hour). In these intense storm situations it may be necessary to maintain only priority one roads until conditions change.

In many cases contract help is utilized by street maintenance departments during winter storms. Most maintenance departments have a list of available contract services (with rates) that they can call if additional assistance is needed. In some instances, contract trucks and drivers are used every time the roads need clearing. These are usually areas where it is not financially feasible for the maintenance department to allocate one of their own trucks and driver.

9.7 Damage Precautions

There are several methods of protecting structures and pavement from the damaging effects of sand and deicing salts and chemicals. Some of these methods include epoxy coated rebar, deck overlays, deck underlays, cathodic protection and sealants. The maintenance department may also implement sanding and deicing policies designed to further reduce potential damage. These policies may include using inhibitors for exceptionally corrosive deicers or "No Salt" policies for bridges.

9.8 Cleanup

The timing of the cleanup (sweeping) process is integral to controlling PM-10. The longer deicing sand and aggregate remain on the pavement and are subject to crushing and re-entrainment, the higher the potential PM-10 concentration.

How long an agency waits to sweep the streets depends in part on the climate of that region. Areas whose winters are characterized by continuous sub freezing temperatures, high humidity and frequent precipitation are more likely to have snow and ice on the roads for long periods of time and therefore cannot immediately sweep the streets. On the other hand, many regions that experience winter snow and ice can be normally very arid with average winter temperatures above freezing. The snow in these areas melts and/or evaporates quickly thus leaving clean, dry streets just two or three days after even the worst winter storms. For this and other reasons, sweeping policy ranges widely from not sweeping at all to sweeping in the Spring to sweeping all roads within days of each and every winter storm.

9.9 Interdepartmental and Community Cooperation

Another excellent method of reducing costs and increasing operational efficiency is cooperation and resource pooling between departments and even between adjoining cities and counties. One example of this is in Loveland, Colorado. In Loveland, the Parks and Recreation Department lends vehicles and manpower to the Street Maintenance Department during winter storms. They also cooperate with adjoining counties by pooling resources and purchasing sand and salt in bulk. In this system, the sand and salt is stored at a central site and each county takes a turn managing the storage facility for a winter. The amount of inventory used by each county was recorded by an honor system. One may also find situations where the Street Maintenance Department and the Waste Water Department worked together on the aggregate cleanup efforts. Any situation where another department has down time during winter storms or vehicles and personnel available is an opportunity to coordinate efforts and save money.

The information network and cooperation between the Street Maintenance Department, Police Department, Highway Patrol, news media and driving public is an important aspect of winter storm management. Information on storm events and road conditions needs to be relayed to all of the above as soon as possible. For example, the Police or Highway Patrol can inform the Street Department of an extremely hazardous stretch of road. The Street Department can send vehicles and inform the media who can then warn the motoring public. Any combination of cooperation and information exchange can significantly reduce the potential problems involved in a winter storm.

9.10 Community Awareness/Public Education

Community education programs are another potentially productive management technique. Most maintenance departments have plow route information or brochures available to the public. Some operations offer winter drivers education programs or information packet mailings concerning safe driving precautions and technics. These types of community awareness and education programs can reduce the amount of friction that can occur between the driving public and maintenance vehicles. These programs may also help to improve winter driving safety.

Open information sharing and cooperation with other departments and the public, use of state of the art weather systems and equipment and actively testing the latest deicing or anti-skid material on the market are all methods of providing maximum winter driving safety at the most economical price.

10. Public Education

The ESSD Team has met with numerous snow abatement professionals and discussed the dominant issues to the project. These discussions have brought about the realization of the need for Public Education on at least four fronts for any Snow/Ice event;

- ◊ Driving safety;
- ◊ Timing of storm and its abatement;
- ◊ Abatement options, and;
- ◊ Cost of abatement.

Through contact with these professionals, we have determined that the public;

- ◊ has misconceptions with respect to safety and current storm abatement procedures;
- ◊ demands a high level of driving safety, often for unrealistic speeds for the weather conditions;
- ◊ is comfortable with status quo;
- ◊ is reluctant to change or test new ideas;
- ◊ has a limited understanding of storm abatement costs;
- ◊ has very little understanding of storm and storm abatement timing;
- ◊ needs a better grasp of safe driving practices in storm events;
- ◊ does not appreciate the dedication of storm abatement personnel.

Professionals contacted expressed both a desire to see such a public education program and an interest in contributing to such a project. Concern was expressed about acceptance of presented information by the public and the potential for misrepresentation by the radio and TV media "slicks". There was support for a university, as UCD, to take the lead in developing such a program as an independent third party with no underlying agenda. It was felt this approach would be better received by the public and the media.

ESSD research has uncovered several successful programs in Sweden, New York State, and East Coast communities. The public's knowing participation in "level of service" tests resulted in the acceptance of reduced salt usage for storm event abatement or reduced overall level of service in response to lower budgets. Sweden has experimented with unsalted roads since 1980 and have published three papers which document the inclusion of the public prior and subsequent to the testing. They informed the public of the testing and basis for the testing before the tests were conducted. They collected registration numbers of cars on the test roads during testing and sent questionnaires to the owners, 1000 after the salted tests and 1000 after the unsalted tests. The response rate was high at 90%. There was an increase in the negative attitude toward salting and an increased acceptance of more driver responsibility.

Brighton, New York, conducted public involved testing in the winter of 1979-1980. Two test areas were selected. The first was Home Acres where a 70% reduction in salt was tested. The second was the Struckmar area, where there was no change in response from past practices. The public was involved prior to, during, and subsequent to the testing. The result was a decision to expand the areas of reduced response.

Though small in number, these references do indicate that where the public is involved and better informed, environmentally sensitive storm event abatement practices have met with acceptance and success. Public attitudes and concerns are best addressed with a balanced presentation of realistic information before practices are revised.

The public does have opinions and concerns on the subject. However, too often these are a product of unbalanced media coverage, personal perceptions, unfounded securities, and past negative experiences. Additionally, the desire for an ever improved standard of living, or driving, has made these individual positions self centered and unrealistic.

ESSD will propose, as a part of Phase II, a comprehensive public education program to increase the level of the public's knowledge of contemporary and alternative storm event abatement practices and driving safety issues. The scope will cover the four fronts defined previously and be accomplished by;

I. Ascertaining the public's current position via statistically sound surveying techniques.

II. Obtaining constructive input from the line and management professionals in storm abatement.

III. Determining the current position of the public, setting goals for where the program needs to go, and defining what resources are needed.

IV. Obtaining the cooperation of the people resources desired/needed and other required resources.

V. Developing the comprehensive program to achieve the goals for the four areas defined above.

VI. Produce products (flyers, radio and TV spots, etc.) that meet the goals and are acceptable for general public distribution.

The storm abatement technological advances are only as valuable as the public's acceptance allows. Storm abatement is the domain of the government (local, state, and federal) and, especially in this realm, the public's voice to elected government officials is heard and heeded. Often the level of response is a direct function of the volume of calls to locally elected representatives. The more informed the public, hopefully, the more informed the input to the elected representatives.

11. Questionnaire Summation

The ESSD project developed and mailed questionnaires to Road Maintenance Departments world wide. The questionnaires are designed to gather information regarding how each respondents department is managed. Questionnaire subjects include budget, types of aggregates used, problem seasons, regulations, personnel, etc.

A database was developed using Microsoft ACCESS in order to manage the information resulting from the questionnaires. The database table may be imported from ACCESS directly into most DBase programs and many spreadsheet programs such as LOTUS 123 and EXCEL. It is also possible to write the data out to a text or ASCII file and then import into another format.

Responses were received from 24 States and 7 Countries. The States ranged from Texas to Alaska and Maine to California. Responding Countries included Ireland, Finland, Sweden, England, Italy and Canada. The following summarizes the results.

RESULTS RELATING TO SANDING/DEICING AGGREGATE

Percent responding to questionnaire: 44.68%

Breakdown of road type:

Primary Roads	19.79%
Residential Roads	61.83%
Secondary Roads	0.86%

Material used:

Sand	80.95%
Sodium Salt	69.84%
Calcium Salt	23.81%
Magnesium Salt	25.40%
CMA	17.46%
CG90	7.94%
PGI	4.76%
Ash	3.17%
Other	20.63%

Budget as percent of total:

Sand	9.18%
Salt	12.97%
Deicing Chemicals	0.24%
Materials	4.32%
Equipment	9.01%
Labor	19.36%
Contracts	0.05%
Winter Sweeping	28.90%
All Sweeping	4.36%
Miscellaneous	11.61%

23.81% report an increase in salt usage
22.22% report a decrease
12.70% report no change

9.52% report an increase in sand usage
20.63% report a decrease
4.76% report no change

26.98% report an increase in chemical usage
7.94% report a decrease
4.76% report no change

42.86% are testing alternatives to sand or salt. Of those:
- 3.17% testing Realite
- 9.52% testing liquid magnesium chloride
- 6.35% testing liquid deicers
- 9.52% testing pre-wetting solution
- 9.52% testing CG90

RESULTS RELATING TO AIR AND WATER QUALITY

41.27% have real or potential PM-10 problem

28.57% have a State Implementation Plan of other measure to address the PM-10 problem

20.63% have a policy for reducing salt in environmentally sensitive areas

15.87% have a problem with road salt contaminating the ground water. Of those:
- 4.76% report road application as source of contamination
- 4.76% report contamination from storage facilities

25.40% monitor the effect of road salt on water quality

All respondents prioritize their sanding routes.

25.40% Have a drivers education program specifically to improve winter driving

RESULTS RELATING TO OVERALL POLICY

42.86% of respondents base salt/chemical application rates on agency policy.

19.05% have application rates controlled by government agencies

RESULTS RELATING TO ACCIDENT RATES AND LEVEL OF SERVICE POLICY

The following are identified as problem months by over 20% of respondents:

October	22.20%
November	47.62%
December	57.14%
January	58.73%
February	58.73%
March	49.21%
April	31.75%

3.17% report no increase in accident rates due to problem weather

55.56% report an increase in accident rates due to problem weather

51.17% is the reported mean increase in accident rates due to problem weather

The following driving condition policies are reported:

17.46% No policy
20.63% Clean and dry road policy
38.10% Provide "reasonably safe driving conditions"
20.63% Provide clean wheel tracks
3.17% Report other policies

OTHER RESULTS

Structural protection measures:

14.29% None
22.22% Epoxy coated rebar
3.17% Air entrained concrete
11.11% Deck overlays
12.70% Deck membranes
1.59% Inhibitors
3.17% "No salt" policy
22.22% Other

15.87% have conducted prior studies on snow and ice removal

69.84% Sweep the sanding and deicing aggregate off the road. Of those:

40.91% sweep ASAP
6.82% sweep "when the snow melts"
4.55% report an ongoing sweeping operation
38.64% sweep in the spring

The majority of the questions are designed to solicit a "yes" or "no" response from the participant. The percentages sighted are derived by dividing the number of positive responses per question by the total number of respondents. The only group of percentages that are designed to add to 100% are the materials used and the budget percentages. The remaining figures are raw percent responded per question and are not intended to be a portion of another total.

The most common materials used are sand and sodium chloride salt. These two items comprised 22.15% of the budget. 42.86% of respondents are actively testing alternatives to sand and salt and the usage trend for both sand and salt is down whereas the trend for chemical usage is up. 42.86% of application rates are based on local agency policy and 19.05% of application rates are based on government policy.

41.27% reported a PM-10 (Air quality) problem and 28.57% have a policy in place to address that problem. 69.84% of respondents sweep the aggregate off the road; 40.91% sweep ASAP and 38.64% sweep in the spring. 15.87% report a problem with road salt contaminating ground water. 4.76% indicate contamination resulting from storage facilities and 4.76% resulting from applying the salt to the road. 20.63% have policies in place specifically for reducing salt usage in environmentally sensitive areas.

October through April is the indicated problem season (ie. winter). 55.56% report an increase in accidents due to winter weather. The mean reported increase is 51.71%. 38.10% of responding agencies describe their target level of service as "reasonably safe driving conditions" and 20.63% report a "clean and dry road" policy. All respondents prioritized their sanding routes and 25.40% have a drivers education program specifically to improve winter driving.

Other results sight Epoxy Coated Rebar and Deck Membranes as the two most popular structural protection measures (22.22% and 12.70% respectively). 15.87% of agencies responding indicate that they have done a prior study on snow and ice removal.

Parties interested in participating in this research may obtain a questionnaire form by writing or calling:

University of Colorado, Denver
Department of Civil Engineering
Campus Box 113
PO Box 173364
Denver, Colorado 80217-3364
(303) 556-2363 or (303) 556-2871

12. Site Visit

An objective of the project's Phase I was to, "Identify currently available innovative approaches to sanding and deicing, and arrange information sharing and site visits during the winter sanding and deicing season." This has been pursued through the questionnaire and with visits to specific identified sites as defined in the First Quarterly Report. There were originally eleven sites identified for visitation. However, additional sites were identified and visited.

These visits have been most valuable and have provided direction to the reference search in many instances. They were designed to both provide a base of conventional practices and of current innovative practices being implemented or tested. They have also afforded insight to the real problems associated with winter road maintenance, especially time management during storm events and operational cost considerations. The direction of Phase II must consider these practical implications if the results are to be of practical value.

Additionally, the contacts made during these site visits become a significant part of the network of the project for future phases. This network is important to future phases from both a data input and a "sounding board" perspective. The individual results of the site visits follow with the site visit summaries of the project team members.

The project team members have also attended meetings and seminars held by various agencies. The following is a list of the meetings; summaries are not provided;

- ◊ Air Quality Technical Committee Meeting held at the PPACG on November 17, 1993.
- ◊ Colorado Air Quality Control Commission hearing in November, 1993
- ◊ Regional Air Quality Council in December, 1993.
- ◊ Workshop for "Development of Additional PM_{10} Control Measures for the Denver Nonattainment Area" sponsored by the Colorado Department of Health and held on January 19, 1994.
- ◊ Workshop for "Alternative Deicing Methods" sponsored by Envirotech Services, Inc. held on August 18, 1994.
- ◊ Seminar on Construction Quality Assurance/Construction Quality Control (CQA/CQC) for Waste Containment Facilities and Hydrologic Evaluation of Landfill Performance (HELP) Model sponsored by the Environmental Protection Agency on August 10-11, 1994.
- ◊ 67th Annual Transportation Conference held on October 18-19, 1994.
- ◊ Summit County Workshop held in Breckenridge on October 18, 1994.
- ◊ "Particulate Air Pollution: Environmental and Occupational Health Effects" sponsored by the American College of Occupational and Environmental Medicine held on October 24, 1994.

Site Visit:	CDOT LIMON, COLORADO
Met With:	Jerry Cordell
Attendants:	Al Gross, Walt Pearson
When:	January 11, 1994

Al Gross and Walt Pearson met with Jerry Cordell at CDOT Limon, Colorado on January 11, 1994 from 9:00 to 11:30 a.m.

Jerry, along with John and Lou, showed us around the facilities which included: two large buildings where the trucks were kept, a large yard where the loaders and graders were parked, and a sand stock pile. The men were very helpful and cordial. They willingly answered all of our questions. Bob Churchwell, the MMS coordinator for CDOT, was also very helpful over the phone and provided all the information regarding materials used along with amounts and costs.

Limon CDOT is responsible for mostly paved roads which total approximately 2,117 miles. A total of 3,140 tons of sand/salt mixture (16 to 1) was applied to the roads. This calculated to be 6.7 tons per mile. The average cost resulted in $3.21 per mile. The salt/sand mixture cost $7.94 per ton.

The breakdown of the sand/salt mixture applied on the different roads serviced was:

Highway 24:	73 tons
Route 71C:	297 tons
Route 71D:	679 tons
Interstate 70:	2003 tons
Highway 40:	88 tons

Equipment at the site included two loaders, seven trucks, one grader and two small pickup trucks. The large trucks were used for plowing and sanding and were equipped with V boxes and square boxes. The square boxes had tail gate dispensing systems (rollers) while the v boxes had spinner distribution mechanisms for dispensing sand.

The trucks maintained 30-35 mph while putting down the sand/salt mixture. The drivers try to apply 500 lbs per lane mile, but since Limon does not have a PM-10 problem this amount is not absolute. Safety for the driving public is the number one concern. The trucks were loaded by hoppers and front end loaders which were located near the sand stock piles. The salt was not stored on a pad.

Sweeping is done 2-3 times per month with sweepers being rotated through the CDOT region when necessary. The sand is reused for fill purposes.

The interstate roads have a bare road policy and are plowed and sanded from beginning to end. Roads are maintained till the winter event is over. Drivers have a 15 hour limit for being on the shift.

Driver judgement determines the amount of sand put down at a particular location. This depends on the current weather and road conditions.

Limon recently acquired a SSI Weather Scan System within the last year. It includes 7 weather stations which are equipped with road sensors. Weather training is part of a 14 week orientation program module which all new personnel are required to complete.

Limon encounters many unique problems because of severe winter weather and long stretches of uninhabited areas along the highways.

High winds are very prevalent in the area and contribute to snow drifting and poor visibility. High winds can be a problem for tractor trailer trucks and other high profile vehicles.

Fog can also be a problem in the low lying areas. Bridges and over passes ice up frequently.

The I-70 stretch between Limon and the Kansas border has been closed several times in recent years and receives a lot of media attention. Jerry has the responsibility for making that decision. The decision is based on factors such as: 1) safety of the driving public and 2) the number of hotel rooms available in the town. After the road has been closed, the State Patrol must fly out and search the highway to make sure there aren't any stranded motorists.

A variety of factors (drifting snow, high winds, long uninhabited miles of highways), make Limon unique and made for a very interesting site visit. We learned a lot from Jerry, John and Lou with their many years of winter maintenance experience.

Site Visit: EL PASO COUNTY
Met With: Chuck Whyte, Manager, Transportation Division
Attendants: Jan Chang, Al Gross
When: January 13, 1994

El Paso County is a mostly rural area around 2000 square miles surrounding Colorado Springs. The terrain presents some interesting challenges because it ranges from plains to rolling hills to mountains. Thus, snow removal operations present some interesting challenges in areas such as management and coordination of resources, including people and equipment.

El Paso County has a 14-21 million dollar yearly budget. Of this, 1.5 million is earmarked for snow and ice removal, with 70,000 set aside for ice control. The county is responsible for around 1900 miles of roads (550 paved 1350 unpaved) which includes main arterial, schools, and residential areas not yet incorporated. For areas bordering other municipalities, the county and municipalities coordinate their efforts. For example, the county may cover certain areas for the cities of Fountain and Colorado Springs and vice versa.

The county uses both sand and salt. Around 5311 tons of sand is used annually. Salt use totals around 670 tons annually. Use of both is determined by the road conditions and by how much is needed to maintain safe driving conditions for the public. Generally, the amount of salt applied is determined visually. A sand/salt mixture, containing a sand/salt ratio of 6.6% salt by volume, is also used. This has been reduced from the previous ratio of 15% by volume. Anti-skid material is also used by the county. Anti-skid material is just larger aggregate that meets the health department standards regarding fines and durability. The anti-skid material is not mixed with salt and is stored outside in a 15-20 ton pile. However, the salt and sand are mixed under cover on a concrete pad and stored in a covered structure. The material to be spread is then loaded using both hoppers and front end loaders.

The county has at its disposal 30 graders, 39 trucks, and 3 broom sweepers. Vacuum sweepers are not used because the larger aggregate used tends to foul up the fans and the shrouds. To operate the equipment, operators undergo an initial 72 hour training program when they first start. Later on, if any difficulties arise, field operation foremen, who constantly monitor the work being done, can always help out when needed. The crews are deployed in two shifts. The regular shifts are usually limited to 8-9 hour shifts, but can be extended if the need arises.

Once called out, each driver is responsible for a specific area. This allows the drivers to become more familiar with their routes. Thus, once they become familiar with their routes, they can better identify trouble areas and can better sense what needs to be done in order to protect public safety. The county does not have a bare pavement policy. Rather, it tries to provide the best possible level of service. For larger storms, this may mean opening up the road one way. For residential areas, only the middle half of the roads is plowed. This allows residents to gain access to other streets without pushing the snow on the sidewalks or trapping their cars. Additional problems can be reported via the police and the general public.

The county also has an unique advantage in that it also keeps in close contact with area businesses and often gets first hand reports on street conditions. Road supervisors also drive the roads to make sure conditions are safe. Spot plowing is usually carried out as needed. Sweeping is then started as soon as possible after a storm. Usually, this means that sweeping operations start around two days after a major storm because this allows snow to melt and also allows the roads to dry up a little more.

Site Visit: LOVELAND
Met With: Mick Mercer, Street Super.
Attendants: Mark Meyer, Jan Chang
When: January 13, 1994

The city of Eubanks's street maintenance facility pulls sand and salt out of a storage area in the city of Loveland. Two other agencies along with the City of Loveland pull out of this facility. The other agencies are billed by the City of Loveland for the aggregate they use. Records concerning who used how much are kept by the honor system which seems to be working fine. Approximately 25,000 tons of sand and 2,500 tons of salt are stored at the site. Loveland currently uses a mixture of 8% salt 92% sand. All mixing is done on site with the dozer used to load the trucks. The dozer is supplied by one of the agencies (they take turns) and is kept on site throughout the winter season.

The city and county of Loveland have been divided into four sections for the purpose of sanding and deicing. Each section is assigned two or three vehicles depending on the total lane miles required to cover each area. The City has assigned specific drivers for each section and very little turnover has been experienced from year to year. If the situation requires more than one shift, there exists a second shift of trained (but less qualified) drivers. Each shift runs 12 hours long. There are not enough employees to run two full shifts.

The Water Utilities Department handles the sweeping operation. Mr. Dean Bach, at (303) 962-3722, is our contact at the Water Utilities Department.

Mr. Mick Mercer will be testing experimental equipment, hopefully this winter. The equipment is a combined liquid and solid deicer spreader. The amount of liquid and aggregate being discharged can be controlled from the cab of the truck and can range from 100% liquid to

100% solid. The designer of the equipment is currently manufacturing solid aggregate spreading equipment.

The liquid deicer used in the experimental equipment is Freeze Guard which is manufactured in Greeley Colorado by Envirotec. We can contact Mr. Roger Knoph @ (303) 352-8845 at Envirotec.

Site Visit: CITY OF LAKEWOOD
Met With: Chris Jacobsen, Maintenance Operations Manager
Attendants: Walt Pearson, Mark Meyer
When: January 26, 1994

The Lakewood Street Maintenance Department maintains 450 centerline miles of road (659 lane miles) classified as 71 miles of collectors, 18 miles arterial and 361 miles residential. There is an additional 709 lane miles of residential streets that is plowed only when more than six inches of snow falls. The City has a dry road policy for the non-residential streets meaning the plows/sanders keep going until the snow is gone. Residential streets are not sanded. All streets are swept ASAP even if snow is still in the gutters. The crews are divided into two twelve hour shifts.

Lakewood spreads an 85% sand 15% salt (sodium chloride) mixture on the roads. They also spray a 3%-4% (by weight) non-inhibited liquid magnesium chloride solution on the aggregate before spreading. They have reduced the amount of sand mixture being used by 35% over the previous year. All aggregate is pulled from piles in the maintenance yard. The main storage area is off site and the aggregate is trucked to the maintenance yard to reload after each storm.

Lakewood is currently testing Realite on 30 miles of road. The Realite is saturated with calcium chloride and mixed with 5% sodium chloride. The sodium chloride is a brand called Red Salt. We received a brochure for the Red Salt from Chris. Chris has agreed to provide us with the results of the Realite testing. Realite is manufactured by Western Aggregate, (303) 499-1010; Mr. Mike DeCew is our contact at Western Aggregate.

The Lakewood Street Department has access to 43 plows (25 owned) and 8 graders (2 owned). All the plows have steel trip edge blades to reduce damage to the pavement. Lakewood uses contract plows for every storm. The sanding units are currently tailgate sanders mounted on dump bodies. These units are calibrated once per year. The City will be purchasing 5 new sanding units with V-bed sanders and computer calibrated ground speed control spinners invented by John Deere Company. Currently, the amount of sand being applied is tracked by the drivers weighing in and out each trip. The liquid magnesium chloride is calibrated to spray a certain amount for each truck. Lakewood owns 5 sweepers and contracts 3. All sweepers are broom (mechanical) sweepers. Lakewood buys their equipment from MacDonald Equipment in Denver.

The City of Lakewood uses a private forecasting service and is installing the Scan Weather System this spring.

Site Visit:	CDOT,DENVER AREA
Met With:	Charles Cunningham
Attendants:	Tia Raamot, Jan Chang
When:	January 28, 1994

We met with Mr. Cunningham to see the Region Six facilities. The meeting began with an introduction of the weather forecasting system used by Region 6. For an in-depth summary of this, please see Jan Chang's summary of this site visit.

After our orientation to the weather system, Mr. Cunningham took us to a one domed storage facility where prewetted sand is kept. He pointed out a conveyor and loading door on top of the dome facility which makes delivery of the sand much more efficient. He stated that not all of the domed facilities have this arrangement. We also visited a dome without a conveyor, this facility was used to store CG-90. There are a total of six domed storage facilities in this district. All of which are used by more than one patrol. All other storage facilities in this district are open-air facilities.

During this visit, we also visited a new maintenance shop. We learned a little bit about the fire protection and ventilation requirements of such a facility. We also learned about the required maintenance and up-keep of snow removal equipment. For instance, an average of two plow blades are used per plow in a heavy snow event.

In the maintenance yards, we saw the tanker used to prewet the sand stockpiles and deice bridges. We also saw a variety of spreaders used by the CDOT. Mr. Cunningham pointed out adaptations which have been made to the equipment over time to improve performance. For instance, the tanker had a new distribution system.

Mr. Cunningham also explained to us that some of the sanding equipment had a "black box" which regulated the amount of sand placed on the highways. This box, however, could be over-ridden by the driver as he deemed it necessary.

We also discussed the friction meter truck used by Region 6 to determine the effectiveness of their snow removal efforts. Mr. Cunningham gave us copies of the output as recorded on the Coralba Friction Meter Test form at predetermined locations for several past snow events and agreed to furnish us with similar output in future snow events.

The meeting concluded with a viewing of the training video used for drivers of snow removal equipment. This video clearly indicated the significant difficulty of maintaining adequate road visibility from the cab of the plowing truck. It was also clear from the video that drivers around the plowing trucks often do not make an effort to stay out of the plow's plume.

Overall, this was a very informative meeting. For further information, please see the ESSD correspondence file.

Site Visit: CDOT, DENVER AREA
Met With: Charles Cunningham
Attendants: Tia Raamot, Walter Pearson, Mark Meyer
When: January , 1994

We sat down with Mr. Cunningham to discuss the snow removal operations along the interstate corridor of I-25 through Denver.

The annual winter maintenance budget for this District is $2,300,000. A total of 436,988 miles of highway are maintained for the 1992/1993 snow season. In this district, approximately 3,379 lane miles are maintained.

The district itself is divided into twenty maintenance sites and 30 Patrols, each composed of about 8 people. A total of 230 people and 90 trucks and one tanker are employed in the snow removal effort. Snow removal along the interstate is continuous. Typically, maintenance crews are put on alert at the first warning of a snow event, and they work until the end of it rotating in 8 hour shifts to keep overtime at a minimum. Each patrol has it's own "shed" location where a master list is kept with the names and home phone numbers of each of the patrol members.

Five products are currently being put on the roads along the interstate corridor through Denver. They are sand with 18% salt (75978 tons annually), Freezgard® (3003 gallons annually), Calcium Chloride (650 gallons annually), and Magnesium Chloride (952 gallons annually). CG-90 was not used in the 1992/1993 period, but in the 1993/1994 period approximately 500 tons were used. Approximately 5¾ ton per lane mile of sand and/or 67 gallons per lane mile of liquid deicers are placed on the highway during a snow season. During a single snow event, approximately 221 lbs. of sand is used. However, these amounts may vary at the discression of the driver. The department has a dry pavement policy.

Mr. Cunningham expressed a general satisfaction with the performance of all the products being used. However, he stated that there were some problems with the dust produced by CG-90, an enhanced salt that they are placing on the highway. He also commented that he could see the beneficial effects of residual magnesium chloride left on the road from one storm event to another.

All sweeping after a storm event is done at night to avoid traffic conflicts.

A future site visit will be scheduled to visit the patrol sites and see the equipment and operations.

Site Visit: CDOT, DENVER AREA
Met With: Charles Cunningham
Attendants: Tia Raamot, Jan Chang
When: January 28, 1994

Bill Hibbard from the CDOT office briefly described three types of weather systems now being used at CDOT to predict weather and pavement conditions: the SSI system, the WSI system, and the Wells system. Summaries of each weather system are presented below. Because the summaries are not complete, it is suggested that Charles Cunningham be contacted if further information is desired.

SSI

- Had a screen with different street locations. There was a color indicator that corresponds to the working status of the sensing pucks (RPU's).
- Information on pavement conditions is measured by a puck sensing unit. The puck measures voltage and can tell when ice is about to form. The voltage across the puck is measured when the circuit is completed by deicing chemicals. Sensor information is then relayed to a centralized location.
- Sensors are located in different areas around town. Not all the pucks are owned by Denver. Some are owned by Denver while others are owned by Boulder County.

WSI

- Information is provided by the National Weather Service.
- A map of the area of interest is provided via a modem. Information transmitted includes forecast, air temp, surface temp, and dew point (amount of moisture air can hold without having precipitation).

- A partial image is included.

Wels

- The Wels system is a weather prediction model that is currently being "Beta" tested. This means that the location is a test site.
- Information such as geographical information and location are entered in.
- The Wels system predicts:
    - Start and stop time of precipitation, amount of precipitation, and also type of precipitation.
    - Wind speed and direction
    - Pavement conditions
- See "Evaluation of Wels Weather Prediction Model" packet

(Available in the ESSD files).

Site Visit: THE CITY AND COUNTY OF DENVER
Met With: Steve Eubanks
Attendants: Dr. Chang and entire team
When: February 10, 1994

The entire ESSD Team met with Steve Embanks at his office to discuss Denver's operational procedures for storm events. Steve informed the team that Denver uses 18% rock salt mixed sand. This prevents sand freezing and has beneficial snow/ice melting characteristics. He referred to the sand as "crushed aggregate" or "squeegee". Steve indicated that the sanding policy was a function of both public safety and perception. He also indicated that public perception was changing with time and the environmental picture of Metro Denver, ie. PM_{10}.

Denver began a serious reduction effort in the 1992-1993 winter season for sand/salt mixture. During this season the sand/salt volumes were reduced 35%, which exceeded the targeted 30% reduction by the RAQC.

Steve indicated that Denver considered using $CaCl_2$ in the 1988-1989 season but met with public resistance and the effort was terminated. He would like the opportunity to test commercial deicers for specific situations and hopes to do so in the near future. These would be corrosion inhibited deicers such as the $MgCl_2$ blends currently used by the CDOT and Aspen.

Steve indicated that the downtown Denver area could be an excellent candidate for deicers because of logistics of snow removal vs. melting and the lack of sun light in the area during winter. Also the public drives slower and stops more often in this area. The frequent stops results in a high accident potential if ice is present. The deicers could improve public safety.

Steve is hesitant to mix areas of deicers and sand/salt service, as this could create differential driving conditions for the public to deal with. He feels the public must be made aware of any policy changes for storm events so they are prepared when driving.

If deicers were tested Steve suggested using 25 gal./lane mile for anti-icing and 75 gal./lane mile for deicing situations.

Denver uses the National Weather Service and a private meteorologist to predict storm events. They respond to 15-20 events per year.

Sweeping has become a primary PM_{10} abatement effort for Denver. They sweep ASAP after a storm event with broom sweepers and later with vacuum sweepers to get all fines. They do not recycle the sand. It is landfilled at Lowery where it is used as cover material.

Sand is also collected in the storm sewers, the rivers, and in retention/infiltration basins. The sand collected was tested in 1989 at a commercial lab and found to be twice as impure as fill dirt but still not in a harmful range. A 1994 retest was conducted but was not available yet.

Steve indicated Denver spent $400,000 per year on materials for storm events. The total Denver budget is $14 million per year. This is spent at the rate of $3,000 per hour during storm events. Weekend storms cost more due to labor costs.

Denver does use some CMA in a 35% CMA and 65% sand ratio.

Steve then provided the team with a tour of the equipment yard and the shop areas. Here he pointed out the features of the equipment utilized for storm events.

Site Visit: CITY OF COLORADO SPRINGS
Met With: Bob Allen, Operations Manager, Street Division
Attendants: Jan Chang
When: February 11, 1994

The city of Colorado Springs is responsible for 1200 paved miles of roads with 371 priority centerline miles. The city sets priorities for roads within its jurisdiction. Examples of priority roads might include hospitals, schools, main arterial, and hilly areas. For the roads it maintains, the city has a safe driving conditions policy which emphasizes spot sanding. Supervisors check road conditions to ensure the roads are safe. Besides visual inspections, they can also use information from the National Weather Service and the puck sensors at the airport to decide what has to be done. In addition to the supervisors, problem areas can be reported by the police or by the general public who can call and leave a message. The city can deploy 45 personnel on a full call-out. In addition to the regular personnel, "big storm" contractors are also available if the need arises. Sweeping operations are then started as soon as possible after the storm and is usually done around 4 A.M. because traffic volume is smaller.

In the previous winter, the city used aggregate slag from the CFI plant. They are currently using a crushed granite. The city also uses a 5% salt/sand mixture. All stocks are stored in two covered facilities and are initially premixed before storage. The salt, sand, or the premixed material can then be transferred to the trucks using front end loaders as needed.

Colorado Springs uses tow-behind sanders, spinner sanders, and tailgate spreaders. The tow-behind sanders are quite useful because they can be removed rapidly so that the truck can be used for other purposes. Before each winter season starts, equipment operators take dry runs in August which includes hooking up the equipment and driving the route. This helps the driver refamiliarize himself with the equipment and with the route.

Site Visit:	ASPEN
Met With:	Jack Reid & Jim Mickey
Attendants:	Dr. Chang & Walt Pearson
When:	March 31, 1994

Jack indicated he has gone to depending mainly on the deicer ICESTOP CI for most of the streets in Aspen to stay in compliance with the PM_{10} requirements. He does still use sand with deicer on streets with special needs or higher slopes. He also indicated he will test using Realite Plus in chip seal on streets sheltered from the sun. These streets will be anti-iced with deicer for storm events. He hopes the deicer will permeate the Realite and prevent bonding for an extended time period. He does not plan to use Realite Plus as a sand alternative.

He indicated that the following volumes were used in the past:

Year	Sand Tons	Deicer Gals.
90-91	1000	0
91-91	750	3,000
92-93	194	14,000
93-94	68.4	15,437

Aspen recorded the highest PM_{10} reading on Washington's Birthday 1991 of 230. This reading later proved to be inaccurate but set the stage for Aspen's change in storm event response. Since that date the PM_{10} readings have never exceeded 150. Most of the high readings are below 100.

Aspen's readings are taken by the Colorado Department of Health. Lee Cassin collects the samples in Aspen and sends them to Mike Silverstein in Denver. The results are most often delayed for several months. This causes a timing problem for Jack and Aspen.

Jack feels his results with ICESTOP CI have been a success and that Denver should consider using a similar program to meet the standards. Jack uses 4 gallons to the ton for sand which is mixed on the fly as the sand is spread. The deicer is spread at 20 gallons to the lane mile or more depending on the specifics of the situation. Jim indicated that spreading requires a dedicated driver who knows his area well to be effective. Driver training and continuity is most important.

The deicer turns the snow to an oatmeal like consistency which results in good traction prior to plowing. The snow/ice does not bond to the street and is easily plowed and removed. The deicer is most effective on the more level and sun covered streets. The sand is used only on the higher sloped streets or shaded streets. For Aspen this is only a small percentage that requires sand. The deicer is especially effective on the concrete "S" curves on Main Street and for streets with bus traffic.

The procedure for Aspen is to plow from 4 PM to midnight. Main Street is plowed to the center and the snow windowed. It is later picked up by a snow blower and trucked to a dump site. Jim does most of the deicer placement. Sweeping is required on all streets due mostly to fine material carried into Aspen by cars from other areas as dirt roads or sanded county/state roads. This is a real problem for Aspen as the area has many dirt roads and parking lots. Jack tries to flush and sweep as it is more effective. This is temperature dependent.

Jack stated that North-South streets are better for deicers because of sun cover. The East-West streets are still good candidates if rather level to shallow slopes. On the steep non-sunny streets he has experienced some slick street problems and so he uses sand. The deicer is spread on 50% of the road and traffic completes the cover to 100%. This also works well to cover intersections as cars turn the corners. Deicer is applied with first snow flurries.

Jack showed the equipment Aspen uses, including the Bearcat Deicer spreader and the sand trucks. The sweepers they use are vacuum types with and without water. The Teravac is a dry sweeper that has proven effective for Aspen. Aspen is in the process of building a modern shop facility which will be ready for the next snow season.

Jack then provided a tour of Aspen streets and pointed out where deicer and sand were used. The streets were very clean on April 1 and little sand was seen anywhere except for junctions with dirt alleys or dirt parking lots. The deicer appears to be very effective for Aspen.

Site Visit: GARFIELD COUNTY
Met With: King Lloyd
Attendants: Dr. Chang & Walt Pearson
When: April 1, 1994

King submitted his Questionnaire response and it was reviewed. His area is mainly rural county roads which are best suited to sanding as opposed to deicers. PM_{10} is not a problem for his area. The sand is treated with ICEMELT to prevent freezing.

King stressed public education as a most beneficial approach for improving storm event response. The public needs to understand the timing of storm responses and the cost of response levels. Also there are safety problems with the public's driving in the presence of response equipment. He feels that if the public is made aware of the real timing situation they would be more understanding and better prepared for safe driving.

His county has many gravel roads and high slope paved roads to service. Also dead end roads used daily for commuters must be plowed. These are all special need situations and are time consuming to service. They must also service unincorporated areas as Battlement Mesa that are subdivisions with high elderly populations.

King is not as interested in deicers for his area, as the conditions and topography are not as suitable for deicers as, say, Aspen. Sand treated with deicers is a more effective solution and more cost effective.

The area requires trained and dedicated drivers to ensure proper response and safe driving conditions. The drivers' experiences range from 50 years to a few years. Most are in the 50 to 15 year range. They use mostly single and tandem axle trucks with removable spreading devices.

They are calibrated for sanding control but the sand is spotted based on experience and not continuously spread. Experience with the special situations of specific roads is the key to effective response and safe driving conditions.

The sand used is either crushed aggregate or scoria, depending on the bidding process. King prefers the scoria but has confidence in either material. The crushed aggregate is very coarse, sieve size 5-10, and washed to remove fines.

Much of the discussion was based around the practical matters of response to events at different times of day. As with other areas, limited man power and budget impact response but have not impacted public safety. King indicated that for every $1,000 of county revenue only $12 goes to road maintenance. This can be spent for any one taxpayer before the plow reaches their driveway.

King encourages research into alternatives to sanding but reminded us that sanding is still the most cost effective and provides the greatest public safety in many situations. He feels sanding cannot be eliminated for all situations and should not be. The situation dictates the best response measure to implement.

King provided a tour of his facilities and equipment. He also provided other contacts for ESSD to pursue and suggested conferences to attend.

Site Visit: Allergy Respiratory Institute of Colorado
Met With: Dr. P. Brock Williams
Attendants: Jan, Marva, Mark, Hellen
When: June 3, 1994

The purpose of the site visit was to talk to Dr. P. Brock Williams who is currently monitoring PM_{10}. From his monitoring, he has found black particles on the filters. Upon further analysis, most turned out to be tire fragments which contained native latex proteins, a common component of tires. To do his monitoring, Dr. Williams employs an impaction sampler which spins and becomes impacted with tire fragments, pollen grains, and crustal debris. To prove that the material collected was actually rubber, gas chromatography and mass spectroscopy was used. Immunoassay tests confirmed that the particulate matter on the filter contained protein derived from natural latex. Although most of the particulates trapped were less than PM_{10}, the collector used was also most inefficient below 10 microns. Indeed, the mode of the particles gathered occurred at around 6.6 microns. Because of the limitations of the collection device, an uncertainty exists as to how much particulate matter smaller than 10 microns was actually present. Dr. Williams has also encountered difficulty in separating particles from one another, which makes the collected matter difficult to analyze. This makes it difficult to determine what was collected and in what quantities. To remedy these problems, Dr. Williams is currently testing different filters.

Besides just monitoring PM_{10} emitted near existing streets, a study is proposed to study particulate matter released when crum rubber is mixed in asphalt. A mandate put forth by the Federal government requires that rubber be put in asphalt. This technique usually works better in the South where the rubber wears better. The current plan is to add varying percentages of rubber (10%. 20%, and 30%) in 1/2 mile stretches of C-470 where asphalt will be laid. Dr. Williams will then monitor the levels of particulate matter produced. He predicts that larger amounts of rubber will be collected in the Fall and in the Spring when the weather is cooler and the rubber is more brittle and probably condenses more readily.

Dr. Williams also discussed other studies involving particulate matter. According to a study conducted in the 70's, gravel on the road would enhance production of tire fragments. In the study, tires were spun on a stainless steel surface. When abrasives such as cornstarch were applied, the tires produced smaller particulate matter. Furthermore, a Swedish study found that using abrasives produced a greater number of smaller tire fragments. According to Dr. Williams, pollution could stress plants. In Japan, pollution enhancing sensitization was found. Diesel fuel pollution was found to influence Japanese Cedar Pollen Sensitivity. It was theorized that interaction with pollutants could change pollen antigenicity. Thus, as the plant became more stressed, it would make more plant pathogenicity related proteins which are allergenic. A German study also concluded that pollen from plants were impacted by PM_{10}. Thus, they produced more allergens especially in the city where pollution was greater.

Latex protein also poses a potential threat to human health. Latex sensitization causes swelling and inflammation, can lead to asthma like symptoms. Overall, Asthma symptoms have steadily increased 2-3%/year in US urban areas. Studies conducted by Pope and Schwartz have linked asthma to increased mortality. Children seem to be the very susceptible to latex protein and PM_{10}. Recent surveys have shown that asthma medicine is now the most commonly prescribed drug in schools. A recent analysis showed that 6.5% of normal adult samples had latex antibodies while 17.5% of samples from children had antibodies.

To get a better understanding, studies have been conducted on mice; however, these have encountered difficulties. First, mice have a different metabolism than humans. Besides having small airways, they also clear out things so quickly that they are difficult to test.

Dr. Williams is also currently investigating biomarkers of latex exposure. The presence of a biomarker would indicate that the person had been exposed to latex protein. Biomarkers can include rubber tire metabolites or other substances associated with tire fragments.

Site Visit: National Jewish Center For Immunology and Respiratory Medicine
Met With: Dr. Kevin Fennelly, M.D., M.P.H.
Attendants: Jan, and Hellen
When: June 27, 1994

Dr. Fennelly indicated that PM_{10} refers to fine particulate matter. Particulates less than 2.5 microns are usually combustion products while matter between 2.5 and 10 microns is often made up of geologic and crustal material. He mentioned that surface area may be an important factor. Because smaller particles have more surface area, the contact area is greater. Dr. Fennelly also mentioned several sources of information that are or will be available:

- ◊ Inhalation Toxicology Colloquium - Took place in Irvine, CA Jan 24-25, 1994. The information will be available by 4/95 in Inhalation Toxicology

- ◊ The Perils of Particulates - American Lung Association (MMWR)

- ◊ Annual Review of Public Health, Vol. 15, 1994 (Dockery and Pope)

Site Visit: Eisenhower Tunnel
Met With: Cathy
Attendants: Walt, Mark, Al, Jan, Marva, Hellen
When: July 1, 1994

We met at the Eisenhower Tunnel at 9:30 A.M. on the morning of July 1, 1994. Our contact person was Cathy. In 1973 two lanes (East and West bound) were opened to the travelling public. In 1979, two additional lanes were opened and remain so today. The tunnel is 1.7 miles long and has a speed limit of 50 mph. The tunnel has several large exhaust fans which clean 540,000 cubic feet per minute. The fans, which can be seen on the roof as one drives toward the tunnel, cost approximately $70,000 per month to operate.

The control room, which is located some floors up, contains television monitors with 24 views of the East and West bound lanes. The room also has control panels which monitor CO gas in the tunnel. This is accomplished by three analyzers. The level is maintained normally at 100 ppm and 30 ppm when workers are in the tunnel. The control panels for power, which operate the lighting and ventilation systems, are also found in the control room. The tunnel has height detectors so that vehicles over 13' 7" cannot enter the tunnel. The tunnel currently has 22 electrical signs, 11 in each tunnel. The electrical signs hang over one lane in each tunnel. However, the electrical signs are going to be replaced with message boards similar to the ones found in the Glenwood Tunnel. The message boards will hang over both lanes in each tunnel.

The Eisenhower Tunnel, although powered by both Dillon and Georgetown, has an emergency generator in case of a full power failure. The power is also tied together so that if it fails on one side, the other side will power the whole tunnel.

The tunnel hosts approximately 400 cars per hour and has an average of 15 accidents per year. These are mainly vehicles which break down due to vapor lock and must be towed. Emergency staff and equipment are on hand for these types of situations. The equipment, which is used for both inside and outside the tunnel, consist of a fire truck, an emergency vehicle, an ambulance, and a tow truck. If the tunnel has to be evacuated, there are three cross cut walk ways which the public can use. The tunnel also has a 20,000 gallon holding tank for fuel spills.

The tunnel is in charge of its own winter maintenance. The tunnel uses a sand/salt mixture on the East bound approach to the tunnel and at the exit on the West bound side. Sodium Salt is used inside the tunnel. During the 93-94 winter season, the tunnel used the deicers Ice-Be-Gone and Ice Melt. However, the deicers were not very effective. The staff have thought about anti-icing but have not tried it yet. During the winter season, the tunnel is swept twice a week. When too much snow is tracked into the tunnel, the tunnel is shut down so that it can be plowed. The tunnel recently acquired a spreader which is mounted onto a pick-up truck. The spreader is used strictly for salt. The tunnel uses an estimated 60 tons of salt per year. The tunnel does not recycle salt since there is no place to stock pile or to store it. However, the tunnel is currently trying to work something out. The tunnel gets washed out twice a year, once in late spring and once in early fall.

The tunnel operates a waste water plant in the lower level for drainage. The water undergoes a sedimentation and a filtration process. It is then released into Clear Creek.

Site Visit: Straight Creek
Met With:
Attendants: Al and Mark
When: July 1, 1994

Al and Mark visited Straight Creek after the Eisenhower Tunnel Visit. The approach was located on the West side of the tunnel going East bound. A steep, dirt/gravel service road was taken down approximately a fourth of a mile. At this point the road stops. A sedimentation pond which was not operating blocked the road. A pipe carried the water from the area above. This formed the headwaters of Straight Creek. Runoff was also occurring on the South side and emptied into the sedimentation pond. The land around was very damp and wet. A large variety of vegetation was growing over the entire area.

We walked down the service road for about a quarter of a mile. The creek was observed at various points. At this stage it is very narrow and goes through a large elevation change. Sand and gravel deposits were seen along the banks and wherever the velocity decreased enough to let it settle out. The flow was estimated to be between 15-25 cfs.
Fine sediment was also observed in the water.

We did not proceed any further since the road was closed at this point. The excavation occurring further down the creek was not observed. It did not appear the crews were using the service road we had come in on. When walking back, it was noticed that on the North side there was a steep sand/gravel bank which could be where the erosion was occurring. We returned to Denver at this point.

Site Visit: City of Boulder, Colorado
Met With: John Sewell, Street Maintenance Supervisor
Attendants: Dr.Chang, Al, Jan, Marva, Hellen
When: September 26, 1994

In 1993 the City of Boulder changed its snow abatement practices by switching from Sanding to Deicing and Anti-Icing. According to John Sewell, the Street Maintenance Supervisor, using Deicers and Anti-icers are better for the environment, decreases overall maintenance costs, and is more effective than sodium chloride.

In 1993, the City of Boulder was a recipient of the "Clean Air Colorado Campaign." Throughout last year's winter season, the City of Boulder's PM_{10} readings did not exceed 150 $\mu g/m^3$. John Sewell stated that the decrease in PM_{10} levels was due to the decrease in sanding and an increase in training.

According to Sewell, snow and ice control activities are only performed on 10% of the city's roads. However, sanding, usually spot sanding, only occurs in trouble spots. For example on hills, the deicers run down and are not very effective. Spot sanding is also used on curves and stops. Boulder has stopped the use of salt, and all sanding material is prewetted with $MgCl_2$.

Street Maintenance has 32 workers, 22 of which are full time workers. Street Maintenance provides extensive training of employees to reduce excessive sanding. Additionally, each driver usually drives the same route year after year so that each one knows where the trouble spots are located, how much sand to put down, and how often.

Sweeping also decreases the PM_{10} levels. Sewell mentioned that Street Maintenance tries to sweep the sand up as soon as the snow melts. The sooner you pick it up, the less pollution. Wind is also a contributing factor.

During the last winter season, the City of Boulder used approximately 20,000 gallons of Freezgard (liquid $MgCl_2$). Freezgard costs $.32 a gallon, has a 28% concentration, and is used with PCI rust inhibitor (a wood pulp product -- liquid sulfate). Because PCI has a brown color it can cause tracking problems. Hence, Street Maintenance plans to use a new clear inhibitor for this upcoming winter season - it will be phased in halfway through the year.

Boulder has had a few problems with de-icer freezing up. According to Sewell, on a few occasions after spreading the de-icer, it froze, and then re-melted. However, the temperature and the humidity may have been factors.

In the past, Street Maintenance had to sand and sweep 250 lane miles. Sewell mentioned that sweeping the sand takes 3-4 times longer than it does to put it down. Street Maintenance uses an average of 47 gallons of deicers per lane mile. However, this amount varies for each snow event. Street Maintenance uses deicers on all major arterials. The Park Department also uses deicers on the bike paths. This has eliminated the problem of sand lingering on the road after a storm.

The City of Boulder has three stream monitors to monitor the water quality at Boulder Creek. The Water Quality Department is responsible for watching the monitors. The State of Colorado monitors the air quality, and the Irrigation Ditch Co. monitors any sand that may migrate into creeks or streams.

Although the City of Boulder does both, deicing and anti-icing, Sewell believes that anti-icing is more effective. Street Maintenance tries to anti-ice 2 hours before a snow event. However, Street Maintenance has found that deicers do not work well on hard pack snow. Thus, they have to plow prior to deicing. Boulder has 15 plows that are used to implement a "bare pavement" policy. This means that the drivers try to get as close to the pavement as possible, without ruining the plows or the manhole covers. The manhole covers are also checked to make sure they do not extend beyond the pavement area. Before the winter season begins, the drivers drive their routes and learn where all of the manhole covers are located.

Boulder has 5 sweepers which sweep 24 hours a day, weather permitting, and 15 trucks for snow duty. Of the 15 trucks, 5 are used for chemicals, while the other 10 are used for sanding. The City of Boulder uses two types of chemical tanks, a Steel and a Poly. The Steel tank holds 2200 gallons, while the Poly tank holds 1800-1900 gallons. Typically the chemicals are only applied twice during a 12 hour shift which allows to perform other snow related duties. All trucks for sand and liquid deicers can be switched in 15 minutes.

With help from radio stations, public service and the school districts, the City of Boulder tries to keep the public involved and informed about the snow abatement practices. Along with their water bill, the public receives information on any changes that the City of Boulder might make during the winter season. The School Districts also try to educate children about the dangers of snow, playing or walking on the streets, and getting too close to traffic. John Sewell suggests that the best thing anyone can do during a snow event is to have snow tires, reduce trips, reduce the use of cars (take a bus or carpool), and use better judgment while driving.

13. Recommendations for Implementation

To combat the PM_{10} problems in Colorado, the following tasks are recommended for implementation:

- ◊ Perform all environmental impact studies for winter roadway traction and highway safety enhancement strategies to assure maximum safety at minimum cost to the environment.

- ◊ Significantly reduce the use of sands as a traction enhancement materials.

- ◊ Sweep up sands on streets and roadway immediately after snow melt. This will reduce the potential for PM_{10} production due to further grinding of sands by vehicles.

- ◊ Develop a new vacuum sweeper for an effective sweeping of PM_{10}.

- ◊ Find or develop a new air quality monitor capable of obtaining all size particles of PM_{10}.

◊ Increase the use of anti-icing/deicing chemicals as a partial replacement for sand as a traction enhancement materials.[4]

◊ Optimally combine the use of anti/deicing chemicals, sands, snow plowing, and street sweeping to maintain good winter roadway traction and safety, while minimizing the environmental impact of traction enhancement strategy. The ESSD Research Team believes that it is impractical to completely eliminate the use of sands as a traction enhancement material and sands will still be required at some strategic locations, such as places of steep grade.

◊ Street maintenance crews are very dedicated to their jobs and deserve much respect.

◊ Maximize the utility of the information learned from this Phase I research by implementing an effective technology transfer program, such as one-day presentation by the ESSD Research Team at all Regions of CDOT, and cities and counties with winter roadway maintenance related problems.

◊ Recommend major tire manufacturers to research into manufacturing new tires with much less potential for producing fine latex protein.

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[4]This recommendation is made pending laboratory and field test that will determine whether the use of deicing chemicals will negatively impact water quality and particulate pollution.

◊ In the Phase II ESSD Research, continue research to establish an environmentally sensitive winter roadway traction enhancement practice(s) and to assist the state in implementing the State Implementation Plan (SIP).

14. Recommendation for Phase II Research on Environmentally Sensitive Sanding and Deicing Practices

The ESSD research team has completed the Phase I research on Environmentally Sensitive Sanding and Deicing Practices and is ready to begin Phase II research. It is proposed to include the following areas in Phase II:

- ◊ Effective Winter Highway Safety and Traction Enhancement Strategy (EWHSATES).
- ◊ PM_{10} Reduction Strategy and Air Quality Impact of EWHSATES.
- ◊ Water Quality Impact of EWHSATES.
- ◊ Evaluation and Ranking of the Effectiveness of Deicing Chemicals.
- ◊ Public Education for Acceptance of EWHSATES and Responsible Winter Driving.

The above proposed research will include literature study, laboratory testing, and field testing. Final proposal will be submitted to CTI and CDOT for evaluation and further research funding.

Additionally, the ESSD Team also recommends the comprehensive literature research on the effects of deicing chemicals on plant health, soil properties, the human respiratory system, and aquatic lives. The ESSD Team also recommends prospective manufacturers to develope a more effective vacuum sweepers and new tires with less latex protein potential.

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Appendix A

Invitation Letter and Complete Questionnaire

April 11, 1995

Gentlemen:

The Civil Engineering Department of the University of Colorado at Denver has received funding for a three phase project entitled "Environmentally Sensitive Sanding and Deicing Practices". The initial phase of this project was initiated on October 1, 1993. The details of the project and the project goals are delineated in the attached materials.

It is felt that this is a most timely effort which will be of interest to many organizations both public and private. We are contacting you to request your cooperation in the data collection of the initial phase and any suggestions for research directions. The project is funded through Phase I by the Colorado Transportation Institute, however, we are seeking additional support to ensure the project prudently covers all possibilities encountered in Phase I.

We would appreciate your reviewing and considering our materials and any assistance you can provide to our information gathering efforts of this initial phase. The goal of this phase is to document as complete a base of data as possible in as usable a format as possible. This will be the foundation of the second phase which is planned to follow the initial phase immediately.

Specifically we are soliciting written documents of materials, procedures and experience. We may desire to visit sites to gain experience and knowledge of materials and/or equipment. We are sure that there is a lot of data already accumulated which could be of great assistance to our efforts and we ask that such data be made available to us.

Please give the above some thought and contact us so we may determine how our joint interests can best be served. Any results of our project will be shared with the public and especially those that have participated. We look forward to hearing from you in the near future.

Yours truly,

Dr. N.Y. Chang
Chairman and Professor

Walter Pearson
Project Manager

QUESTIONNAIRE

1. Does your agency use;

	Yes/No	Annual tonnage	Amount per lane mile
a. Sand?			
b. Sodium salt?			
c. Calcium salt?			
d. Magnesium salt?			
e. CMA?			
f. Other deicers?			

2. What is your agency's annual budget for snow and ice removal?
How is it allocated between sand, salts, deicer chemicals, other?

3. Are sand and salt/chemical application rates based on a prescribed agency policy?
If so can we obtain a copy of that policy for our project?

4. What salts and chemicals does your agency use for snow and ice removal?
Under what circumstances are they used or not used?

5. Is your agency testing alternatives to sand or salt? What are they? Do you have results you can share?

6. Does your immediate area have a real or potential PM10 problem?
If yes, how does it affect your agency's efforts/practices?

Is there a SIP Plan or other measures in effect to address the PM10 problem?

7. Does your agency have a policy for reducing salt usage in environmentally sensitive areas?
If yes, what is the policy?

8. Does your area have a problem with road salts contaminating regional waters or the natural environment?

9. Is there monitoring in your area for effects of road salt runoff on the water quality and the eco-system?

10. What is the annual trend in road salt/chemical usage in your area for snow and ice removal?

11. What structure (as bridge) protection measures for corrosion from salts/chemicals are utilized in your area?

12. Does your government agency regulate the use of salts/chemicals for snow and ice removal? If yes, can we obtain a summary of the regulations for our project?

13. Does your agency use sand or crushed aggregate? If yes, what are the standards set for the material and by whom?

14. Do you sweep up the sand/crushed aggregate? How soon after to weather event? What is the annual cost?

15. What is the normal problem season in your area?

16. Can you attribute an increase in accident rates to this problem weather season? If yes, about what percentage increase?

17. Has your agency conducted prior studies on snow and ice removal that you could make available to our project?

18. What is your agency's policy with respect to providing driving conditions to the public during snow/ice events? (ie. as good as dry or some reduction in quality)

19. What types of equipment does your agency utilize in the snow and ice removal effort?

20. How do you establish the priority for sanding of specific sites?

21. Is there a drivers education program in your area to improve winter driving skills?