Report No. CDOT-DTD-R-2001-15

Final Report

EVALUATION OF SELECTED DEICERS BASED ON A REVIEW OF THE LITERATURE

Marion Fischel

The SeaCrest Group

October 30, 2001

COLORADO DEPARTMENT OF TRANSPORTATION

RESEARCH BRANCH

Technical Report Documentation Page

1. Report No. CDOT-DTD-R-2001-15	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle

Evaluation of Selected Deicers Based on a Review of the Literature

5. Report Date
October 2001

6. Performing Organization Code

7. Author(s)
Marion Fischel

8. Performing Organization Report No.

9. Performing Organization Name and Address

The SeaCrest Group
1341 Cannon Street
Louisville, CO 80027

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
HA8-20-001/DV

12. Sponsoring Agency Name and Address
Colorado Department of Transportation
4201 East Arkansas Ave.
Denver, CO 80222

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

41.35

15. Supplementary Notes
Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration at the request of the Colorado Association of Ski Towns (CAST).

16. Abstract
A literature review was conducted on the following deicers used for snow and ice control: magnesium chloride (e.g., FreezGard Zero®, Ice-Stop™ CI, Caliber™ M1000, Ice Ban™ M50), calcium chloride (Liquidow*Armor*), sodium chloride (road salt and Ice Slicer®), Calcium Magnesium Acetate (CMA®), Potassium Acetate (CF7®), CMAK™ (mixture of CMA and Potassium Acetate), Sodium Acetate (NAAC®), and sanding materials. These deicers were evaluated for chemical contaminants, environmental effects, human health effects, corrosion, application rates, performance, cost, and advantages and disadvantages. For most of the deicers reviewed there were gaps in available information. Thus, additional studies would be necessary to further elucidate the potential impacts of the deicers. A summary of the water quality data collected by the U.S. Geological Survey (USGS) and the Roaring Fork Conservancy in the Roaring Fork watershed in Colorado is also provided.

A qualitative worker survey was also conducted. Questionnaires were sent to 126 employees of the Colorado Department of Transportation and Roaring Fork Transit Authority having daily contact with deicers. Of the 69 employees that responded to the survey, 26% reported minor symptoms including eye, skin, respiratory, and intestinal irritation. It was not possible, based on the qualitative nature of the survey, to determine whether the symptoms were related to deicer use.

Implementation
Based on a review of the literature, it is concluded that each of the deicers evaluated has both advantages and disadvantages, in terms of environmental effects, human health effects, cost, performance, and corrosion. Thus, the maintenance supervisor should evaluate the trade-offs in determining which deicer(s) to use in order to best meet the needs of the State, city, town, and the public.

17. Key Words
snow and ice control, deicer, magnesium chloride, sodium chloride, calcium chloride, CMA, NAAC, CMAK, Potassium Acetate, sand, environmental effects, human health effects, toxicity, water quality, costs, eutectic temperature, metals, corrosion.

18. Distribution Statement
No restriction. This document is available to the public through:
National Technical Information Service
5825 Port Royal Road
Springfield, VA

19. Security Classif. (of this report) None	**20. Security Classif. (of this page)** None	**21. No. of Pages** 273	**22. Price**

EVALUATION OF SELECTED DEICERS BASED ON A REVIEW OF THE LITERATURE

By

Marion Fischel

Report No. CDOT-DTD-R-2001-15

Prepared by
The SeaCrest Group
1341 Cannon Street
Louisville, CO 80027

Sponsored by the
Colorado Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

October 30, 2001

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
303-757-9506

ACKNOWLEDGMENTS

The author gratefully acknowledges the members of the Study Review Panel, who provided extensive comments on the draft report and valuable additional data for use in the final report. The members of the Review Panel include Mr. Richard Griffin, Research Coordination Engineer, CDOT; Ms. Lee Cassin, Director, City of Aspen Environmental Health Department; Ms. Kristine Crandall, Research Specialist, Roaring Fork Conservancy; Mr. Ed Fink, Staff Maintenance Superintendent, CDOT; Mr. Michael Silverstein, Planner, Air Pollution Control Division, CDPHE; Mr. Paul von Guerard, Subdistrict Chief, USGS; and Ms. Jacque Whitsitt, Director, Colorado Association of Ski Towns (CAST).

The author also gratefully acknowledges the assistance of several members of the Pacific Northwest Snowfighters (PNS) Association, especially Mr. Graham Gilfillan, Manager Material Damage Loss Prevention, ICBC; and Mr. Ronald Wright of the Idaho Department of Transportation; the CDOT Maintenance Supervisors Weldon Allen, Steve Carlson, Mike Hern, Randy Jensen, Chuch Loerwald, Bernard Lay, Wayne Lupton and the CDOT Librarian, Joan Pinamont.

The author also acknowledges the generous time and assistance of deicer manufacturers' personnel, including Keith Johnson, Cryotech, Inc.; Steve Bytnar, Minnesota Corn Processors, Inc.; Rusty Bastian, Redmond Minerals; Gerry Mathews, Dow Chemical Company; and deicer distributors E.G. "Greg" Leist, Envirotech Services, Inc. and Randy Parsons, GMCO Corporation. Ken Osier, Director of Roaring Fork Transit Authority, and the Maintenance Directors of the Colorado ski towns also provided invaluable information used in this report.

Acknowledgment is also given to the staff at The SeaCrest Group who assisted in reviewing the report, analyzing the worker survey results, and assisting with word processing.

EXECUTIVE SUMMARY

Sand and sodium chloride (the first deicer used) have been used for snow and ice control in the United States since the 1930s. These materials were cheap and abundant and enabled many roads to remain open during winter storms. By the 1950s some of the harmful effects of deicing salts had become widely known. However, the benefits of using deicers and sand for increasing safety of winter driving remained a major factor in the continuing use of these snow and ice control materials. Since the 1960s numerous studies have been conducted on the environmental and human health effects and corrosion from the use of deicers. A report prepared by Environment Canada (2000) proposed that road salts be considered “toxic” under the Canadian Environmental Protection Act of 1999. However, the report also stated that the use of deicing agents was an important component of the strategies to keep roads open and safe during the winter and minimize traffic accidents. It further concluded that human safety must never be compromised (Environment Canada 2000).

The deicers reviewed in this study are divided into the following three groups: chloride-based deicers, acetate-based deicers, and sanding materials. The chloride-based deicers include magnesium chloride (FreezGard Zero® with Shield LS®, Ice-Stop™ CI, Caliber™ M1000, Ice Ban™ M50), calcium chloride (Liquidow* Armor*), and sodium chloride (road salt and Ice Slicer®). The acetate-based deicers include Calcium Magnesium Acetate (CMA®), Potassium Acetate (CF7®), Sodium Acetate (NAAC®), and CMAK™ (a mixture of CMA and Potassium Acetate). For each of the deicers and sand, information is provided on chemical contaminants, environmental effects, human health effects, corrosion, application rate, performance at low temperatures, costs, advantages and disadvantages. Summary tables are also provided.

Chemical Contaminants

Chemical and corrosion specifications have been developed for deicers by Colorado, other states, and a consortium of northwestern states and British Columbia [Pacific Northwest Snowfighters (PNS) Association]. These specifications limit the amount of trace metals and other chemicals allowed in deicers and require that deicers containing corrosion inhibitors be at least 70% less corrosive to mild steel than salt (sodium chloride).

The concentrations of trace metals and other chemicals are provided for each of the deicers reviewed in this report. The trace metals that were analyzed include arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. Other chemicals and parameters that are provided include cyanide, total phosphorus, pH, sulfate, ammonia, nitrate, and Biochemical Oxygen Demand (BOD).

Environmental Effects

The environmental effects of the deicers are grouped into chloride-based deicers, acetate-based deicers and sand. The deicers are evaluated in terms of their effects on soil, surface water, groundwater (i.e., drinking water supplies), air, aquatic organisms, terrestrial vegetation, and terrestrial animals.

Chloride-based Deicers

The chloride ions in deicers increase the salinity of the soil near the roadways where they are applied. The magnesium and calcium ions increase the stability and permeability of the soil, whereas sodium ions decrease soil stability and permeability. Sodium chloride, magnesium chloride, and calcium chloride may contribute to the mobilization of trace metals from the soil to surface and groundwater, but field evidence of this effect is limited.

The chloride-based deicers have the potential to increase the salinity of the rivers, streams and lakes. Since the dilution of deicers from the roadways to nearby streams is estimated to range from 100 to 500-fold, salinity increases are only likely to occur in slow-flowing streams and small ponds. Increased salinity has been reported in groundwater at a distance of more than 300 feet from roadways.

The organic corrosion inhibitors present in some chloride deicers have the potential to cause oxygen depletion of streams near the roadways where the deicers are applied and can result in mortality of fish and other aquatic organisms. However, the 100 to 500-fold dilution estimated to occur from the roadways to the streams reduces the likelihood of these effects.

The chloride deicers have relatively low toxicity to fish and aquatic invertebrates. They reduce air pollution through a reduction in sand use. The solid chloride deicers, such as salt, may contribute to air pollution through particulates released into the air.

The chloride-based deicers have been shown to have adverse effects on terrestrial vegetation. Damage to vegetation from deicing salts has been reported to a distance of 100-650 feet. However, there is a wide range of tolerance of different species of plants to the effects of chlorides.

Sodium chloride crystals attract birds and mammals, which can contribute to road kills. Magnesium chloride and calcium chloride deicers, on the other hand, do not attract wildlife since the main chemical attractant is sodium. Acute toxicity tests show that there is slight oral toxicity of the chloride deicers to small animals.

Acetate-based Deicers

The acetate-based deicers are organic and have different kinds of effects on the environment than the chloride-based deicers. The acetate ions are broken down by soil microorganisms and may result in oxygen depletion of the soil, which can impact vegetation. The acetate deicers also have the potential to cause oxygen depletion in rivers, streams and lakes. Since the dilution of deicers from roadways to nearby streams is estimated to range from 100 to 500-fold, oxygen depletion is likely to occur only in slow flowing streams and small ponds. The aquatic toxicity of CMA to fish and invertebrates is low. The acetate deicers Potassium Acetate, Sodium Acetate (NAAC), and CMAK have higher toxicity to aquatic organisms.

The use of the acetate deicers results in the decrease of air pollution from the reduction in sand use. However, the solid acetate deicers CMA and NAAC may contribute fine particulates to the air and increase air pollution.

The acetate deicers CMA and Potassium Acetate are not harmful to terrestrial vegetation at the concentrations typically used on the roadways. However, NAAC may potentially have an adverse effect on vegetation because of the presence of the sodium ion, which decreases the stability and permeability of the soil. The depletion of oxygen in the soil from the breakdown of the acetate ion can have a negative effect on plant growth. However, field evidence of this effect is limited.

Slight acute oral toxicity to mammals has been reported for the acetate deicers. No studies have been conducted on whether the acetate deicers attract wildlife to roadways.

Sand

Sand is not a deicer, but has been used for snow and ice control since the early 20th Century. Sand has a negative effect on water quality as a result of the increased turbidity caused by the presence of sand particles in water. The increased water turbidity can result in mortality of fish and bottom-dwelling invertebrates that may be covered by the sand. The increased turbidity will also reduce or inhibit photosynthesis in aquatic plants. Sand used for snow and ice control increases air pollution and contributes approximately 45% of the small particulates present in air.

Water Quality Data Collected in the Roaring Fork Watershed

Water quality data has been collected by the U.S. Geological Survey (USGS) and the Roaring Fork Conservancy in the Roaring Fork watershed between Difficult Creek near Aspen, Colorado and the Roaring Fork River at Glenwood Springs, Colorado. The study was conducted to characterize the episodic occurrence of dissolved chloride resulting from the deicing of roadways. Mean daily stream flow, specific conductance, and dissolved chloride were measured and compared with historic data. The dissolved chloride concentrations were lowest at the upstream stations and highest at the downstream station at Glenwood Springs. The high levels of dissolved chloride found in the Roaring Fork River near Glenwood Springs may be the result of the interaction of the water with the sedimentary geology in the watershed.

The Roaring Fork Conservancy collected water samples from various locations in the Roaring Fork watershed and measured total chlorides and conductivity between September 2000 and September 2001. Samples were collected from the Roaring Fork River between Difficult Creek and Glenwood Springs, and the Crystal River, Frying Pan River, and several creeks that flow into the Roaring Fork River. The chloride levels were generally highest at the downstream stations near Glenwood Springs. A large geological feature and hot springs near Glenwood Springs was postulated to be the cause of higher chloride levels at that location. However, the chloride levels were still below the Colorado regulatory limit of 250 ppm for domestic water supplies.

Studies conducted by the Aspen Department of Environmental Health showed that chloride levels increased in the Roaring Fork River from above Aspen to downstream of Aspen when chloride-based deicers were used (L. Cassin, Aspen Environmental Health Department, personal communication).

Human Health Impacts

Potential human health effects of deicers may include irritation of the eyes, skin, respiratory tract and digestive tract, and possibly small increases in cancer rate from trace metals. Toxicity tests conducted on rats indicate that the deicers could have slight oral toxicity to humans. Elevated levels of sodium in drinking water have been linked to hypertension in humans. The deicers Ice Ban M50, inhibited calcium chloride, and CMAK have levels of nitrates above the Colorado drinking water standards. High blood levels of nitrates in infants and young children can interfere with oxygen uptake from the blood. Inhalation of sand over long periods of time could lead to diseases of the lungs, such as silicosis. Sand is also listed as a carcinogen.

Trace metals are naturally occurring elements that are present in some deicers in minute amounts. Vehicles and industrial activities also are sources of trace metals. Long-term exposure to trace metals may cause diseases of the lung, liver, kidneys, blood, nervous system, respiratory tract, kidneys, and skin. The trace metals arsenic, cadmium, and chromium (VI) have been identified as carcinogens. Lead and selenium (as selenium sulfide) may be carcinogens, but there is insufficient evidence that they can cause cancer in humans. Since the dilution of the deicers from the roadway to drinking water supplies is estimated to range from 100 to 500-fold, the small amounts of trace metals in deicers would probably not cause serious human health effects.

A study conducted by the Colorado Department of Public Health and the Environment (CDPHE) on the health effects of the deicers sodium chloride and magnesium chloride from exposure to air is summarized in this report. The results of the risk assessment indicated that arsenic, cadmium and chromium exceeded a cancer risk of 1 in 1,000,000 ($1x10^{-6}$) when exposure was 24 hours/day and 365 days/year. When exposure was based on eight hours of exposure/day and six months/year, arsenic and chromium still exceeded a cancer risk of 1 in 1,000,000 ($1x10^{-6}$). The report concluded that further study was necessary to determine a more precise assessment of risk from exposure to the metals in these deicers.

Other Factors

Other factors to consider in choosing the appropriate deicer include corrosion, application rates, performance at low temperatures, and cost of the deicer. The least corrosive deicers are the acetate-based deicers, whereas the most corrosive deicer is sodium chloride (road salt). Corrosion inhibitors are added to most of the chloride deicers and acetate deicers to reduce the potential of corrosion.

A study on the corrosion of sodium chloride and magnesium chloride was conducted by the Materials Laboratory at the University of Colorado at Boulder and is summarized in this report. The results showed that inhibited magnesium chloride was 2% more corrosive to stainless steel than sodium chloride. The results also showed that inhibited magnesium chloride was slightly more corrosive to aluminum than sodium chloride. However, other corrosion tests have shown that inhibited magnesium chloride is 70% less corrosive than sodium chloride to mild steel. Because of the inconsistencies in the test results, the data are being re-evaluated.

The application rates of deicers depend on a variety of factors including the deicer used, air and pavement temperature, amount of snow on the ground, and steepness of the roadway. For magnesium chloride, the application rate for "anti-icing" (i.e., applying deicer prior to a storm) ranges from 35-45 gal/lane-mile, while the application rate for "deicing" varies from 40-80 gal/lane-mile. The application rates for the solid deicers such as sodium chloride, CMA and NAAC average about 300 lbs/lane-mile. The application rate for sand varies from 200 lbs/lane-mile to 3000 lbs/lane-mile, depending on road conditions.

The performance of the deicers at low temperatures is determined by various factors, including the eutectic temperature (i.e., temperature at which a solution freezes) and effective temperature of the deicer. The deicers Caliber M1000, Ice Ban M50, Potassium Acetate, and calcium chloride have low eutectic and effective temperatures, whereas CMA, NAAC, and sodium chloride have higher eutectic and effective temperatures. Deicers with low eutectic and effective temperatures work well at low temperatures.

The lowest cost material for snow and ice control is sand at $0.6-16/ton. Among the deicers, sodium chloride (salt) has the lowest cost at $30/ton. The magnesium chloride deicers also are low in cost. The acetate deicers are the most costly deicers, with an average cost of $1000/ton.

The deicers have social and economic costs and benefits associated with them. The additional cost of sand is equipment and labor needed to remove the sand as well as the air and water quality impacts. The costs of the chloride-based deicers include corrosion of vehicles, highway bridges, and utilities; damage to vegetation; and decrease in soil and water quality. The costs associated with the organic acetate-based deicers include oxygen depletion of soil and water, eutrophication of lakes and streams, and high purchase price. The benefits of deicers and sand include a decrease in traffic accidents, reduced work absenteeism, and reduced delays in shipment of goods. Use of chemical deicers results in improvement in air quality from reduction in the use of sand.

Worker Surveys

A qualitative survey was conducted of maintenance workers (mechanics), bus drivers and washers, and deicing equipment operators to evaluate the potential health effects from magnesium chloride and the other deicers used in the State of Colorado. The questionnaire was sent to 126 workers at CDOT and Roaring Fork Transit Authority (RFTA) who come into contact with the deicers. A total of 26% of the respondents reported some symptoms, such as irritation of the eyes, skin, respiratory and intestinal tract. Some of the workers attributed the symptoms to colds and other causes. It was not possible, based on the qualitative nature of the survey, to determine whether the symptoms were related to deicer use.

Recommendations

Recommendations are made for additional studies needed to resolve some of the outstanding issues related to chemicals present in deicers, environmental effects, human health effects, corrosion, and other topics related to deicer use. A list of recommendations from the literature provides suggestions for reducing the impacts from deicer use.

Conclusions

Each of the snow and ice control methods (deicers and sand) described in this report has advantages and disadvantages. Some of the benefits and drawbacks are unique to a particular deicer. Thus, maintenance supervisors must evaluate the trade-offs in terms of environmental effects, human health effects, performance, cost, and corrosion, in choosing a deicer that will best meet the needs of the State, city, town, and the public.

GLOSSARY

Acetate-based deicers – Deicers that contain the organic compound acetate

Acute toxicity – Short-term lethal or other effect, usually defined as occurring within 4 days for fish and invertebrates and shorter times (2 days) for organisms with shorter life spans

Aerial Dispersion - Scattering through the air

Alga (Algae) – Aquatic plants that are single celled organisms to multicellular organisms

Anti-icer – A chemical applied to the road prior to a snow storm to prevent hazardous road conditions

Anti-icing – A snow and ice control strategy for prevention of a strong bond between frozen precipitation or frost and a pavement surface by application of a chemical freezing point depressant prior to a storm

Anaerobic - Absence of oxygen

Anoxic - Absence of oxygen

Biodegradation – Breaking down of organic and inorganic substances by biological action, a process usually involving bacteria and fungi

BOD – Biochemical Oxygen Demand is a test used to measure oxygen consumed by microorganisms in a sample of water during a specific period of time, generally 5 days

$CaCl_2$ – Calcium chloride

Caliber – Corn derivative used as corrosion inhibitor in Caliber M1000 deicer

Caliber M1000 – Deicer that is composed of 27% magnesium chloride solution plus 10% caliber inhibitor

Carcinogen – Capable of causing cancer

CAST – Colorado Association of Ski Towns

CDOT – Colorado Department of Transportation

CF7® – Brand name of deicer manufactured by Cryotech that is composed of potassium acetate

Chloride-based deicers – Deicers that contain chloride ions

Chronic Toxicity – Toxicity involving a stimulus that lingers or continues for a relatively long period of time. A chronic toxic effect can be measured in terms of reduced growth or reproduction, in addition to causing death of the organism.

CMA® – Deicer that is composed of calcium, magnesium, and acetate

CMAK™ - Deicer that is a blend of CMA and Potassium Acetate

COD – Chemical Oxygen Demand is a measure of organic carbon in a test sample and is defined as the amount of a specified oxidant that reacts with a sample

Conductance - A measure of a material's ability to conduct electrical charges

Conductivity – the measure of the ability of an aqueous solution to carry an electrical current

Corrosion – Destruction of metal or alloys by oxidation or chemical action

Corrosion inhibitor – A chemical that acts to inhibit corrosion of metals

Deicer – A chemical used during and after snow storms to reduce the snow and ice on roadways

Deicing – An operation where a treatment of a deicer is applied to the top of an accumulation of snow, ice, or frost that has already bonded to the pavement surface

Dose – The amount of toxicant to which a test animal is exposed

EC50 – Effective concentration; concentration that causes a sublethal effect to 50% of the test organisms at a specific exposure time, e.g., 96 hours

Effective temperature - An empirical value that describes the lowest temperature for practical use of a deicer and considers ice melting ability, anti-icing ability, type of precipitation and application rates

Eutectic temperature – Temperature at which solution will freeze based on chemical concentration. It is also defined as the freeze point of a solution based on the percent of the material in the solution

Eutrophication – The enrichment of water with nutrients, such as phosphorus resulting in the increase in numbers of aquatic algae in the water

FreezGard Zero® with Shield LS – Magnesium chloride deicer with corrosion inhibitor Shield LS

FY - Fiscal Year

Hazard Quotient (HQ) – A HQ is an indicator of the potential human health effects of a substance or chemical. A HQ less than or equal to one indicates that long-term exposure is unlikely to cause adverse health effects. A HQ greater than 1 may be a concern for potential health effects.

Heavy Metals – Also referred to as trace metals. Metals such as arsenic, mercury, cadmium, chromium, copper, lead and selenium

IC50 – Concentration of a chemical that causes inhibition of growth or reproduction in a test species. IC50 is a measure of chronic toxicity.

Ice Ban™ – Deicer that is a concentrated liquid residue of fermented corn byproducts

Ice Ban M50 – Deicer composed of 50 parts of 30% magnesium chloride to 50 parts of Ice Ban

Ice Slicer® – Deicer composed of mainly sodium chloride with small amounts of calcium chloride, potassium chloride, and magnesium chloride

Ice-Stop™CI – 30% magnesium chloride plus 4% organic amine corrosion inhibitor

Infantile methaemoglobinaemia – syndrome that may be observed in infants that have elevated levels of nitrates in the blood

Ion – An atom or group of atoms that has acquired a net electric charge by gaining or losing one or more electrons

Lane-mile – One travel lane 12 feet wide and one mile long

LC50 – Concentration of a chemical that causes mortality in 50% of the test species exposed to the chemical within 24-96 hours

LD50 – Dose of a chemical that causes mortality in 50% of test animals in a few days to weeks

Liquid Deicer – a chemical solution consisting of deicer product dissolved in water

Liquidow* Armor* – Deicer manufactured by Dow Chemical that is composed of 30% calcium chloride and a corrosion inhibitor

Maximum Contaminant Level or MCL - A standard establishing the maximum permissible level of a contaminant in water

Methylated - Replacement of a hydroxyl group (CH_3) with a metal

$MgCl_2$ – Magnesium chloride

MSDS – Material Safety Data Sheet

Mutagen – A chemical that can cause a change in the genetic material of an individual

NAAC® – Sodium acetate

NaCl – Sodium chloride; road salt

NOEC – No Observed Effects Concentration. Highest concentration of a chemical that does not cause toxic effects that are statistically significantly different from the control.

Nutrient – Specific substance required for growth of organisms

Optimum Eutectic Temperature - Lowest freeze point temperature achievable for a given product or solution

Osmotic pressure - The pressure exerted by the flow of water through a semi-permeable membrane separating two solutions with different concentrations of solute

Particulate Matter (PM) - A generic term applied to a broad class of chemically and physically diverse materials that exist as discrete particles

Percolate - To cause a liquid to pass through a porous substance such as sand

PM10 – Particulate matter that is less than 10 micrometers (µm) in dimensions

PPM - Parts per million also referred to as milligrams per liter or milligrams per kilogram

PNS – Pacific Northwest Snowfighters Association

Proprietary – Owned by a private individual or corporation under a trademark or patent.

RFTA – Roaring Fork Transit Authority

Rock Salt – Solid salt commonly used as a deicer. It is mined by conventional hard rock mining equipment and techniques.

Sand - A broad term that refers to different types of sanding materials used in snow and ice control. It includes silicon dioxide and crystalline quartz, chipped rock, volcanic cinders, and scoria.

Salt Brine – Solution of salt (generally 23%) used as a liquid deicer

Scoria - Porous cinder-like fragments of lava used as a sanding material

TOC – Total Organic Carbon is a test that measures the total organic compounds in a sample of water

Toxicity – The potential of a chemical or compound to cause adverse effects on living organisms

Trace metals - also referred to as heavy metals. Metals such as arsenic, mercury, cadmium, chromium, copper, lead and selenium

Uninhibited magnesium chloride - Magnesium chloride deicer that does not contain a corrosion inhibitor

U.S. EPA – United States Environmental Protection Agency

USGS – United States Geological Survey

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Salt (sodium chloride) and sand have been used for snow and ice control in the United States from the 1930s, since these materials were cheap and abundant and enabled many roads to remain open during winter storms. By the 1950s some of the harmful effects of deicing salts had become widely known. However, the benefits of using deicers for increasing safety of winter driving remained a major factor in the continued use of these snow and ice control materials. Since the 1960s numerous studies have been conducted on the environmental and human health effects, and corrosion from the use of deicers. One of the recent studies of the environmental effects of use of "road salts" as deicers was prepared by Environment Canada (2000). The Environment Canada report proposed that road salts be considered "toxic" under the Canadian Environmental Protection Act of 1999. However, the report also stated that the use of deicing agents was an important component of the strategies to keep roads open and safe during the winter and minimize traffic accidents and resulting injuries and fatalities. The Environment Canada report concluded that human safety must never be compromised. It proposed that selection of options for snow and ice control be based on optimization of winter road maintenance practices so as not to jeopardize road safety, while minimizing the potential for harm to the environment.

Deicers are used in the winter for several reasons, and include the following:

- To keep roads open in the winter by preventing ice and snow from bonding to the pavement
- To increase the safety of the driving public by reducing the likelihood of vehicular accidents
- To allow for higher traffic speed and traffic volume
- To minimize the need for sand thereby improving air quality
- To reduce the time and personnel needed for snow and ice removal
- To increase the level of service provided by the Department of Transportation, and
- To save on vehicle fuel consumption.

The liquid deicing agents can be used as anti-icers or deicers. Anti-icing refers to application of a liquid chemical to a road before a storm to prevent a hard bond of ice, reduce snow buildup and speed snow and ice breakup after a storm. Deicing refers to application of a chemical to remove a thin layer of snowpack or ice that is already on the road. It can be very effective for melting black ice and freezing rain (http://www2.state.id.us/itd/ida-road/WinterMaint-MgCl.htm).

This study, "Evaluation of Selected Deicers Based on a Review of the Literature" was conducted at the request of the Colorado Association of Ski Towns (CAST) to assess the impacts of the deicer magnesium chloride and to determine whether better alternatives exist. This study discusses the environmental and human health effects and corrosion from use of magnesium chloride and alternative deicers that are used or have been used in the State of Colorado. It also provides summaries of water quality studies conducted by the U.S. Geological Survey (USGS) and Roaring Fork Conservancy, human health studies conducted by the Colorado Department of Public Health and the Environment (CDPHE), and corrosion studies conducted for the Colorado Department of Transportation (CDOT) by the University of Colorado at Boulder.

This study provides information on the following topics related to deicer use and the potential impacts of selected deicers:

- Procedural Directives of the Colorado Department of Transportation (CDOT)
- Chemical Constituents
- Environmental Effects
- Human Health Effects
- Corrosion
- Application Rates
- Performance (Eutectic and Effective Temperatures)
- Costs/ Cost-Benefit
- Comparison of Alternative Deicers
- Worker Survey of Potential Health Effects of Deicers
- Recommendations for Further Study

The deicers reviewed in this study are divided into three groups:

- Chloride-containing deicers
- Acetate-containing deicers, and
- Sanding Materials.

The chloride-based deicers include:

- Magnesium Chloride [FreezGard-Zero®, Ice-Stop™CI, Caliber™M1000, Ice Ban™ M50]
- Calcium Chloride [Liquidow*Armor*)]
- Sodium Chloride [Sodium Chloride, Ice Slicer®]

The acetate-based deicers include:

- CMA®,
- CMAK™,
- NAAC®,
- Potassium Acetate (CF7®),

A variety of deicers are typically used for snow and ice control. The primary and secondary deicers and other snow and ice materials that are used in Colorado and other states are shown in Table 1.

Table 1. Primary and Secondary Deicers Used in Some States[1].

State	Deicing Chemicals
Alaska	Sodium chloride (p); Magnesium chloride (s).
Colorado	Magnesium chloride (p); sand/salt (s); some Caliber M1000 and Ice Slicer.
Connecticut	Sodium chloride (p); Calcium chloride (s).
Delaware	Sodium chloride (p); Ice Ban+sodium chloride for anti-icing; occasionally salt brine; CMA on some bridges.
Idaho	Magnesium chloride for anti-icing and prewetting of sand; sodium chloride and corrosion-inhibited sodium chloride with sand for deicing.
Illinois	Solid and liquid sodium chloride (p); solid and liquid calcium chloride (s).
Indiana	Calcium chloride and magnesium chloride; some salt brine.
Iowa	Sodium chloride (p); calcium chloride (s).
Maine	Sodium Chloride.
Maryland	Sodium chloride (p); salt brine (s); magnesium chloride in colder regions.
Massachusetts	Calcium chloride (p); occasionally sand/salt.
Michigan	Salt and sand (p); magnesium chloride (s)
Minnesota	Potassium acetate; CMA, calcium chloride; FreezGard Zero, Magnesium chloride; Ice Ban M50 and M80, Nu-salt.
Missouri	Sodium chloride (p); use salt brine or liquid calcium chloride for prewetting.
Montana	Magnesium chloride (FreezGardZero w/Shield LS and Ice-Stop CI 2000); prewet salt/sand with magnesium chloride.
New Jersey	Rock salt treated with liquid calcium chloride (p); magnesium chloride (s); also use sand/salt in some areas.
New York	Sodium chloride; Enhance the salt with MAGic (Ice Ban+MgCl2); magnesium chloride; calcium chloride; sodium chloride brine (in descending order).
Ohio	Rock salt (p); liquid calcium chloride (s).
Oregon	Magnesium chloride (p); CMA (s); Potassium Acetate when too cold for CMA.
Rhode Island	Sodium chloride (p); magnesium chloride on bridges.
South Dakota	Calcium chloride (p), magnesium chloride (s).
Utah	Deicing – Salt and salt/sand (p); Anti-icing – magnesium chloride and liquid brine.
Vermont	Calcium chloride (p); sand (s).
Washington	Magnesium chloride; Cal-Ban 70 (Calcium chloride/Ice Ban); CMA.
Wyoming	Sand/salt (p); sodium chloride; liquid magnesium chloride.

[1] – Personal communication with State maintenance supervisors

2. PROCEDURAL DIRECTIVES

The Colorado Department of Transportation (CDOT) has written procedural directives on snow and ice control. One of the directives is on "Priorities and Level of Service for Snow and Ice Control" (Number 1055.2), which became effective June 27, 1996. The other directive is "Road Closures, Adequate Snow Tires or Chains Required, and other Restrictive Measures" (Number 1055.1), which became effective November 28, 1988. The Colorado State Patrol has a policy on roadblocks and road closures, which is included in the CDOT directive on road closures.

The purpose of the procedural directive for snow and ice control is to guide state maintenance crews in the effort to provide reasonable protection, safety, and mobility for the traveling public by removing snow and ice from roadways as allotted resources allow. The procedure states that the CDOT regional maintenance forces will maintain all highways in as near normal winter driving conditions as resources and personnel can provide under given weather conditions. Roads will be closed when it is apparent to the Highway Maintenance Supervisor that the roadway will become impassable due to limited visibility, major accumulation of snow, drifting snow, avalanches, accidents, or stranded vehicles. The maintenance crews will make every effort to open all state highways to traffic as soon as safely possible. The application of abrasives, abrasives with melting agents, or the direct application of deicing or ant-icing agents may be applied to roadways in controlled quantities as may be mandated by CDOT maintenance supervisors to conform with local environmental laws, guidelines, or recommendations.

The priorities for snow and ice removal are listed below:

1. In rural areas, or when CDOT plows and snow removal personnel are the only apparent source of help, plow drivers or Highway Maintenance Supervisors should attempt to check all stranded vehicles and remove occupants, and, if necessary, to provide safety and shelter.

2. Open all blocked routes as soon as safely possible. Clear all school bus and mail routes as soon as practical.

3. Remove as much snow as feasible from the high side of super elevations or gore areas that may cause icy spots due to melting and re-freezing.

4. Widen snow ridges from roadways and shoulders where feasible to handle additional snow accumulation.

The level of service provided to roads is based on a classification system. Class A highways are all national highway systems, interstates, expressways, freeways and other highways over 2500 A.D.T (average two-way daily traffic volume). It represents the total annual traffic for the year divided by 365. Class B highways are those with 1000 to 2500 A.D.T. Class C highways are those with less than 1000 A.D.T. The first priority for service are Class A highways.

Appendix A contains the procedural directive for snow and ice control, and directives for road closures and other restrictive measures.

3. DEICER SPECIFICATIONS

In 1995, the representatives from the Department of Transportation from several of the western states met to discuss:

- The need for developing chemical specifications and testing protocols for the deicers
- Public concern about the use of chemicals for snow and ice control
- Environmental issues
- Inconsistent performance of the chemicals
- Proper storage of the deicers, and
- Corrosion of vehicles resulting from use of deicers.

The outcome of the meetings was to establish a program to develop standardized specifications, testing methods, and laboratories to use for testing the deicing chemicals (Dan Williams, Montana DOT, personal communication). The organization, which became known as the Pacific Northwest Snowfighters (PNS) Association, comprises the states of Idaho, Montana, Oregon, Washington, and the province of British Columbia. The chemical specifications that were developed were based on a model that incorporated the aquatic life limits established by the USEPA, NPDES limits for pollutants, drinking water standards, and hazardous waste limits. A factor of 100 was used as the expected dilution of the deicing products from the roadway to the waterways (R. Wright, Idaho DOT, personal communication). Based on the results of the model, specifications for specific metal constituents and other parameters were developed. The constituents for which there are PNS specifications include arsenic, barium, cadmium, chromium, copper, cyanide, lead, mercury, selenium, zinc, phosphorus, and pH. The specifications take into consideration human safety, the environment, protection from corrosion, cost-effectiveness, and performance.

The PNS has developed a pre-approved list of deicers based on the factors described above. The list of pre-approved deicers is shown in Table 2. Other states, including the State of Colorado, have also developed specifications that the vendors of deicers must comply with. These specifications may be slightly different than the PNS specifications for one or more of the chemicals.

Table 2. List of Deicers Pre-approved by the Pacific Northwest States Snowfighters (PNS) Association[1]

Chemical	Brand Name	Liquid/Solid	% Concentration
Magnesium Chloride + Corrosion Inhibitor	FreezGard Zero w. Shield LS	Liquid	30
Magnesium Chloride + Corrosion Inhibitor	FreezGard Zero w. TEA	Liquid	30
Magnesium chloride + corrosion inhibitor	Ice-Stop CI-2000	Liquid	28.5
Magnesium Chloride + Caliber	Caliber M1000	Liquid	27
Calcium Chloride + Corrosion Inhibitor	Liquidow Armor	Liquid	30
Calcium Magnesium Acetate	CMA	Liquid	25
Calcium Magnesium Acetate	CMA	Solid	96
Sodium Chloride + Corrosion Inhibitor	Ice Slicer	Solid	92-98
Sodium Chloride	Cargill Dry Salt	Solid	100

[1] - [http://www.wsdot.wa.gov/fossc/maint/pns/htm/qpl.htm]

Some of the reports that have been prepared on deicers for PNS were used in the preparation of this report and include Cheng and Guthrie (1998), Guthrie (1999), and Mussato and Guthrie (2000).

4. CHEMICAL CONSTITUENTS OF DEICERS

The trace metals and other chemicals found in the various deicers that are presently used or have been used in the State of Colorado are discussed below. The information on the deicers was obtained from Material Data Safety Sheets (MSDS), Product Specification Sheets, personal communication, and published literature. The MSDSs for the deicers discussed in this report are provided in Appendix B.

4.1. Chloride-based Deicers

4.1.1. Sodium Chloride Deicers

The two types of sodium chloride deicers used in Colorado are rock salt and Ice Slicer®. Both types of sodium chloride are solid materials. Sodium chloride is also used in a liquid form as a 23% brine solution. The brine solution of sodium chloride was analyzed for trace metals and other chemicals for PNS (Mussato and Guthrie 2000). The results showed that copper and cyanide were above the PNS specifications. Table 3 provides the results of the chemical analysis for trace metals and other parameters and the PNS specifications. The levels of phosphorus and nitrates are very low in the sodium chloride brine solution (Table 3). The Biochemical Oxygen Demand (BOD), which measures the ability of the deicer to cause oxygen depletion in lakes and streams, is also very low. A high BOD indicates that oxygen depletion is likely to occur. The topic of BOD will be discussed in greater detail in the section dealing with environmental effects of deicers.

Ice Slicer® is a solid deicer consisting mainly as sodium chloride, which is used in Colorado without a corrosion inhibitor. The manufacturer, Redmond Minerals, Inc., describes it as a mixture of Complex Chlorides™. In addition to sodium chloride, Ice Slicer contains small amounts of magnesium chloride, calcium chloride, and potassium chloride. The concentration of sodium chloride in Ice Slicer ranges from 92-98% (Envirotech Services 2000). Chemical analysis of the trace metals in Ice Slicer shows that they were below the PNS specifications (Table 3). The levels of phosphorus, nitrates and BOD are also very low in Ice Slicer.

Table 3. Trace Metals and Other Chemicals Measured in Deicers[1].

Chemicals (ppm)	Magnesium Chloride (FreezGard Zero w/Shield LS)	Magnesium Chloride (Ice Stop CI)[4]	Magnesium Chloride/Caliber (Caliber M1000)[1]	Magnesium Chloride/Ice Ban (50:50)(Ice Ban M50)	Sodium Chloride (Ice Slicer)[3]	Sodium Chloride Brine (23%)[1]
Arsenic	0.001	<0.5	<1	<1	ND	<0.2
Barium	0.0013	<0.07	0.23	0.11	<4.0	<0.2
Cadmium	0.00001	<0.05	<0.02	<0.02	ND	<0.2
Chromium	0.0003	0.13	<0.1	0.4	ND	<0.5
Copper	0.0047	<0.09	<0.1	1.1	0.29	0.78
Lead	0.0009	<0.3	0.57	0.3	<0.2	<0.1
Mercury	<0.0004	<0.01	<0.01	<0.01	ND	<0.01
Selenium	<0.0008	<0.5	<1	<0.1	ND	<0.1
Zinc	0.007	0.34	0.71	16.1	10	2
Total Cyanide	<0.0003	<0.05	0.09	<0.05	<0.2	0.25
Total Phosphorus, ppm (1% solution)	1.02	<10.0	0.76	21.6	<4.0	<0.02
pH (1:4 Solution)	NA	NA	7.78	2.94	NA	7.68
Sulfate (% by wt)	NA	0.3-0.8	0.19	2.7	0.3-0.7	0.09
Ammonia-nitrogen	0.505	NA	15	59.4	NA	NA
Nitrate-nitrogen	0.0681	NA	0.13	14.7	NA	NA
Biochemical Oxygen Demand (BOD)	<200	<200	34000	83,000	NA	<5
Corrosion Inhibitor	1-2% (organic)	4% amine	10% Caliber	50% Ice Ban	None	None

Table 3 (continued). Trace Metals and Other Chemicals Measured in Deicers[1].

Chemicals (ppm)	CMA (25%)[1]	Potassium Acetate (50%)[1]	CMAK (50% CMA: 50%KA)[1]	NAAC (solid)[2]	Calcium Chloride (LIQUIDOW ARMOR)[1]	Sand[5]	PNS Specifications (ppm)
Arsenic	<0.2	<0.2	<0.2	<10	<2	<0.5	5
Barium	2	<0.2	0.49	NA	1.27	NA	10
Cadmium	<0.2	<0.2	<0.2	NA	<0.1	<0.1	0.2
Chromium	<0.5	<0.5	<0.5	<1	<0.5	<0.5	0.5
Copper	<0.1	<0.1	<0.1	NA	<0.1	<0.5	0.2
Lead	<0.1	<0.1	<0.1	<5	<0.5	<0.5	1
Mercury	<0.01	<0.01	<0.01	NA	<0.01	NA	0.05
Selenium	<0.1	<0.1	<0.1	NA	<1	NA	5
Zinc	<0.5	<0.5	<0.5	NA	0.8	NA	10
Total Cyanide	0.2	0.33	0.25	NA	0.12	NA	0.2
Total Phosphorus (1%solution)	0.24	0.86	1.2	7.5	0.53	NA	25
pH (1:4 Solution)	9.58	9.38	8.04	8-10.5 (10% sol)	7.84	NA	6 - 9
Sulfate (% by wt)	0.03	<0.02	0.06	0.02	0.3	NA	2
Ammonia -N	NA	0.1	10.7	NA	17.1	NA	
Nitrate-N /Nitrite-N	NA	<2	12.1	NA	112	NA	
Biochemical Oxygen Demand (BOD)	114,000	148,000	132,000	580,000 (BOD_{20})	16,000	NA	
Corrosion Inhibitor	None	<1%	<1%	<1%	6.5-8.5% (organic)	None	

NA=Not Available
[1]From Mussato and Guthrie(200) and Product Information Sheets
[2]Metals analysis by ICAP by Midwest Laboratories, Inc.; other data on chemical constituents from K Johnson, Cryotech
[3]Data provided by Greg Leist, Envirotech
[4]Metals analysis by Western Analysis, Inc.; other analytical data from Reilly Wendover product information sheet s
[5]Missoula City-County Health Dept., 1996

4.1.2. Magnesium Chloride Deicers

4.1.2.1. Magnesium Chloride

There are several brands of magnesium chloride deicers that are presently used or have been used in Colorado. The magnesium chloride deicers generally consist of approximately 30% magnesium chloride in water and a corrosion inhibitor to reduce the likelihood of metal corrosion. The corrosion inhibitors in the magnesium chloride deicers vary depending on the brand of deicer used. FreezGard-Zero® contains approximately 1-2% Shield LS as a corrosion inhibitor. This corrosion inhibitor is a proprietary organic substance. Ice-Stop™CI contains approximately 4% organic amine as a corrosion inhibitor. FreezGard Zero/TEA uses triethanolamine (TEA) as a corrosion inhibitor. Caliber M1000 contains 10% carbohydrate manufactured from corn, which serves as a corrosion inhibitor. Ice Ban™ M50 contains 50% Ice Ban, which is derived from corn byproducts and serves as a corrosion inhibitor. Freezgard-Zero with Shield LS, Ice-Stop CI, and Caliber M1000 are on the PNS approved product list. The Ice Ban products are not on the list of approved deicers (see Table 2).

Magnesium chloride has been used as both a deicer in the winter and a chemical that reduces road dust in the summer. It can be applied as either a liquid or solid. The magnesium chloride deicer is generally used in the liquid form. Chemical analysis tests were conducted by Lewis (2000) on the magnesium chloride deicer used in Colorado in the winter of 1996-97. The results indicated high concentrations of the copper, lead, zinc, arsenic, cadmium and phosphorus (Lewis 1997). The magnesium chloride deicers used today by CDOT are required to meet the Colorado specifications. Table 3 shows the concentrations of trace metals and other key chemicals in the different brands of magnesium chloride deicers. The metal concentrations in FreezGard Zero and Ice-Stop CI are below the PNS specifications. The levels of phosphorus, nitrates, and BOD are low in these magnesium chloride deicers.

4.1.2.2. Caliber™M1000

The substance “Caliber” in the deicer Caliber M1000 is manufactured from corn by the Minnesota Corn Processors, Inc. Caliber is combined with magnesium chloride to enable the deicer to function effectively at deicing the roadway at lower temperatures than would be possible with magnesium chloride alone. Caliber deicers also inhibit corrosion and suppress crystal formation (Product Specification Sheet). Caliber M1000 was first used on some highways in Colorado by CDOT in the winter 2000-2001 during periods of cold weather.

A study on Caliber M1000 was recently conducted for CDOT by Lewis (2000). Lewis (2000) reported that the samples of Caliber M1000 he analyzed had high concentrations of phosphorus, ammonia, and organic matter. The total amount of phosphorus in Caliber M1000 was reported to be 25,000-30,000 times higher than in the other magnesium chloride deicers. The concentration of ammonia-nitrogen in Caliber M1000 was reported to be 1,000 times higher than in the other magnesium chloride deicers (Lewis 2000). The organic matter in Caliber M1000, measured as Total Organic Carbon, is 16,000 times higher than the other magnesium chloride deicers (Lewis 2000). When Lewis (2000) tested for BOD levels by mixing the deicer with water from Colorado streams for 24 hours he found that the BOD was very low. However, the typical BOD test is usually conducted for 5 days. The 5-day standard BOD test results indicated moderate BOD levels in Caliber M1000 (34,000 ppm) (Mussato and Guthrie 2000).

4.1.2.3. Ice Ban™ M50

Ice Ban™, manufactured by ICE BAN America, Inc., is a concentrated liquid substance that is the residue of fermented and distilled agricultural byproducts. It consists of various base stocks of raw material, such as cane or beet sugar syrup, corn, barley, other carbohydrates, and milk (HITEC 1998). Ice Ban can be used alone or mixed with a solution of 30% magnesium chloride. Two Ice Ban/magnesium chloride products that have been used as deicers in Colorado are Ice Ban M50 (50:50 mixture of Ice Ban and magnesium chloride) and Ice Ban M80 (20:80 mixture of Ice Ban and magnesium chloride) (G. Leist, Envirotech, personal communication).

Chemical analysis of Ice Ban M50 revealed that the concentrations of copper, zinc, and sulfate are above the PNS specifications (Table 3). The pH of Ice Ban M50 is less than 4.0 (MSDS), which does not meet the PNS specifications of pH 6-10. Levels of nitrates in Ice Ban M50 are above the drinking water limit of 10 ppm. Although phosphorus levels are below the PNS specifications, they are higher than the other chloride-based deicers. The BOD levels in Ice Ban M50 are also high (83,000 ppm).

4.1.2.4. Calcium Chloride

Calcium chloride is used as a deicer in several states (see Table 1). A corrosion-inhibited brand of liquid calcium chloride deicer that is used is LIQUIDOW* ARMOR*, manufactured by Dow Chemical Company (*=Trademark of The Dow Chemical Company). The deicer is used at a concentration of 30% calcium chloride and contains a proprietary organic corrosion inhibitor at a concentration of 4%.

Inhibited calcium chloride was analyzed for trace metals and other chemicals by Mussato and Guthrie 2000 and was reported to be below the PNS specifications for metals (Table 3). The phosphorus and sulfate concentrations are within PNS specifications and BOD levels are relatively low. However, the nitrate levels are above the Colorado drinking water limit of 10 ppm.

4.2. Acetate-based Deicers

4.2.1. CMA®

Anhydrous Calcium Magnesium Acetate is a solid deicer manufactured by Cryotech, Inc. under the name of CMA®. It is also manufactured as CMA25®, which is a 25% aqueous solution of CMA by weight. CMA is produced from a corn fermentation process to derive acetic acid, which is combined with dolomitic lime to produce CMA. Chevron Chemical Company produces CMA from natural gas (Wegner and Yaggi 2001). Chemical analysis was conducted on CMA for trace metals and other constituents (Mussato and Guthrie 2000). The results of the tests indicated that the deicer was within PNS specifications for all the metals analyzed (Table 3). The phosphorus and sulfate levels are below PNS specifications. The nitrate levels were not reported in the literature on CMA. The BOD levels are above 100,000 ppm, which is considered to be high by Mussato and Guthrie (2000) and other authors.

4.2.2. Potassium Acetate

Potassium Acetate is a liquid deicer manufactured by Cryotech as CF7®. It is a 50% aqueous solution of Potassium Acetate by weight, and contains a proprietary corrosion inhibitor at a concentration of less than 1% (Cryotech MSDS). Potassium Acetate is a relatively new deicer and was approved for use in the United States in 1992. Potassium Acetate is now used at most of the U.S. Air Force airports (Nolan Davis 1994).

The results of analysis of Potassium Acetate for trace metals and other chemicals are shown in Table 3. The potassium acetate deicer is above the PNS specifications for cyanide and above the maximum allowable concentration in drinking water (0.2 ppm). The phosphorus, nitrate, and sulfate concentrations are below the PNS specifications, whereas the BOD level is high (over 100,000 ppm).

4.2.3. CMAK™

CMAK™ is a 50%:50% blend of CMA25 and Potassium Acetate manufactured by Cryotech. The deicer met all of the PNS specifications except for total cyanide, which was slightly above the specifications (Table 3). The phosphorus and sulfate levels are low. However, the nitrate levels are above the drinking water limit for nitrates, and the BOD is high at a level greater than 100,000 ppm.

4.2.4. NAAC®

Anhydrous Sodium Acetate (NAAC®) is a relatively new solid deicer, manufactured by Cryotech. It is primarily used on airport runways, but is also used in Colorado by the towns of Aspen and Snowmass. It is certified to U.S. Federal Aviation Administration approved specifications for use by airports and military units. NAAC contains a proprietary corrosion inhibitor at a concentration of less than 1%. Chemical analysis of NAAC was conducted for Cryotech by Midwest Laboratories, Inc. The analytical results are shown in Table 3. Arsenic, chromium, and lead were below the detection level using the ICAP (Inductively Coupled Argon Plasma) Method. The deicer was not analyzed for cadmium, copper, mercury, selenium, zinc or cyanide.

The level of phosphorus in a 1% solution of NAAC was measured to be 7.5 ppm (K. Johnson, Cryotech personal communication), which is below PNS specifications. The pH of a 10% solution of NAAC is slightly over the upper limit of the PNS specifications. The level of nitrates in NAAC was not analyzed. The BOD level is over 500,000 ppm (MSDS), which is higher than all the other acetate deicers.

4.3. Sand

River sand and crushed aggregate are the two main types of sanding materials used to increase road traction in Colorado in the winter (Chang et al 1994). River sand is rounded and smooth while crushed aggregate is rough and angular. Crushed aggregate has been found to be particularly effective at increasing roadway traction, due to the angularity of the sand grains.

The sand used for ice and snow control is composed of silicon dioxide and crystalline quartz (Holliday Sand and Gravel MSDS). Sand was analyzed for arsenic, cadmium, chromium, copper, and lead (Missoula 1996). The concentrations of these chemicals in sand are shown in Table 3. With the exception of copper, the concentrations of the chemicals tested are within the PNS specifications. Since there are numerous sources of sanding material, the analytical results will vary depending on the source of the sand.

5. ENVIRONMENTAL EFFECTS

5.1. Introduction

In this section, the deicers are grouped into chloride-based deicers, acetate-based deicers, and sand. The environmental effects of each group will be discussed separately. The environmental effects of the deicers on soil, air, surface and groundwater, aquatic organisms, terrestrial plants, and terrestrial animals are presented below. The alternate pathways of the deicers into the environment are shown in Figure 1.

5.2. Chloride-based Deicers

Sodium chloride (road salt) was the first of the chloride-containing deicers utilized and has been used for snow and ice control since the early part of the 20th century. The amount of chloride deicers in the United States was estimated to range from 8-12 million tons/year (NRC 1991). Salts applied to roadways enter the environment from direct runoff or snowmelt, release from surface soils, and/or from wind-borne spray. These salts accumulate and persist in watersheds and pose risks to aquatic organisms and water quality (Wegner and Yaggi 2001). Approximately 55% of the chloride ions are transported in surface runoff and the remaining 45% infiltrate through soils and into groundwater aquifers (Church and Friesz 1993).

One of the recent reports on the environmental effects of chloride deicers was prepared by Environment Canada (2000). The environmental effects of "road salts" were reviewed by Environment Canada as part of the requirements of the Canadian Environmental Protection Act of 1999. The Act required that a Priority Substances List be prepared to identify substances that might be harmful to the environment or constitute a danger to human health. The Environment Canada report focuses on the environmental effects of sodium chloride, but also discusses calcium chloride and magnesium chloride. The report does not discuss human health effects, but

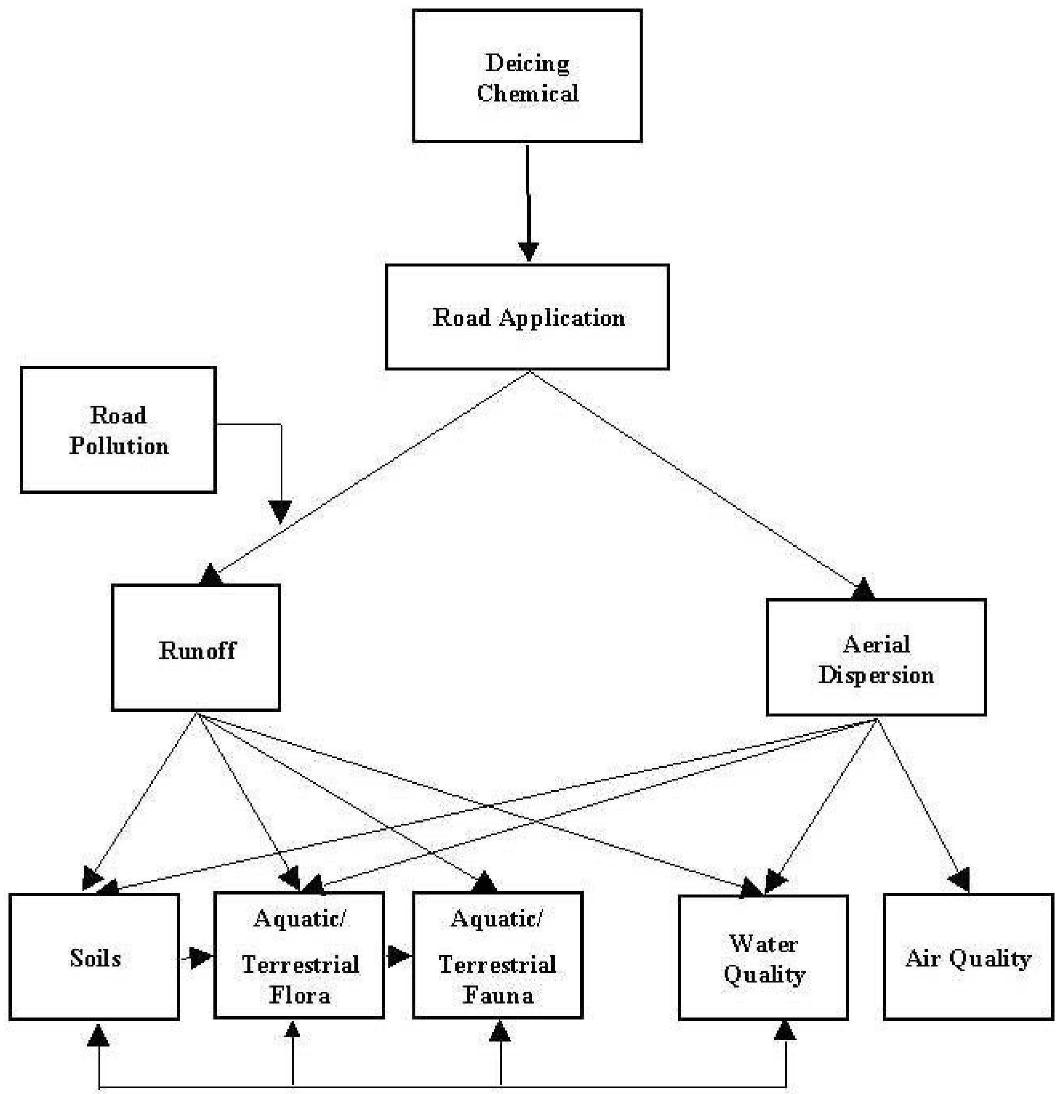


Figure 1. Pathways of Deicers into the Environment (from RCI 1992, in Cheng and Guthrie 1998).

states that humans are exposed to road salt principally through contamination of water wells and that these elements (e.g., sodium and chloride ions, magnesium and calcium) are not considered toxic to humans (Environment Canada 2000).

Based on a review of available literature by Environment Canada (2000), it was determined that "road salts are entering the environment in a quantity or concentration or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity, and that constitute or may constitute a danger to the environment on which life depends." Therefore, the report proposes that road salts be considered "toxic" under Section 64 of the Canadian Environmental Protection Act.

Although the Environment Canada report recommends that road salts be considered toxic, it states that use of deicing agents is an important component of the strategies to keep roadways open and safe during the winter and minimize traffic accidents, injuries and fatalities under icy and snowy conditions. It further specifies that any measures established as a result of its assessment of road salts "must never compromise human safety" (Environment Canada 2000). A summary of the Environment Canada report from the Environment Canada web site (http://www.ec.gc.ca/cceb1/eng/public/road_salts.html) is provided in Appendix C.

The environmental effects of the chloride-containing deicers that are discussed below include sodium chloride, calcium chloride, and deicers that contain magnesium chloride, including FreezGard Zero with Shield LS, FreezGard Zero with TEA, Ice-Stop CI, Caliber M1000, and Ice Ban M50.

5.2.1. Soil

5.2.1.1. Chloride Ions

The infiltration of chloride ions into soil depends on a variety of site-specific factors, including slope of the roadside, direction of drainage, type of highway drainage system, soil type, vegetative cover, and presence of snow and ice (Sorenson et al 1996). Soil types such as gravel, sand, and other coarse-textured soils will result in rapid infiltration of chlorides, whereas clay and other fine-textured soils slow the infiltration rate (Jones et al 1986). The runoff of chloride deicers from non-compacted soils was reported to be 35%, whereas the runoff from compact soil was 75% (Satterfield 1997).

The distance of salt migration depends on the slope of the roadside, direction of drainage, type of highway drainage system, soil type, vegetative cover, presence of snow and ice, and precipitation (Colwill et al 1992). The levels of chlorides in the soil resulting from use of deicers on the highways have been shown to decrease rapidly from levels found at the edge of the roadways. The highest concentrations of chlorides in the soil are found within 2-3 m (6.5-10 feet) from the edge of the roadway. Concentrations of chloride above background levels have been reported at a distance of 10 m (33 feet) from the road (Hofstra and Smith 1984). Chloride concentrations in the soil have been reported to be elevated up to a depth of 1 m (3.3 feet) in the soil (Cheng and Guthrie 1998; Prior and Berthouex 1967; Hutchinson and Olson 1967; Gidley 1989).

The effects of chlorides on the soil include soil swelling, reduced soil stability (loss of structure), decreased permeability, increased salinity, and increased potential for erosion (Chang et al 1994; Cheng and Guthrie 1998; Environment Canada 2000). The presence of chlorides in the soil also causes a decrease in the availability of water to plants; a decrease in essential nutrients required by plants; an increase in soil pH, which results in inhibition of uptake of chemicals by plants; a decrease in root growth; leaching of organic materials from the soil; and compaction of the soil (Chang et al 1994). Chloride ions in the soil may also cause an increase the movement of trace metals to the groundwater (Satterfield 1997; Amrhein and Strong 1990).

Soil microorganisms have been shown to be quite sensitive to the presence of salt. Sensitive soil bacteria are moderately inhibited by sodium chloride at concentrations of 60 ppm sodium and 90 ppm chloride (Environment Canada 2000). Concentrations of sodium chloride above those levels in the soil have been reported to occur 30 m (100 feet) from the edge of roadways (Environment Canada 2000). Soil microorganisms are important in maintaining soil structure, and when they die erosion will occur (Wegner and Yaggi 2001).

5.2.1.2. Sodium, Magnesium, and Calcium Ions

The sodium ions in deicers have been known to cause adverse effects to the soil. It has been reported that sodium ions are more detrimental to the soil than chloride ions (Cheng and Guthrie 1998; Sorenson et al 1996). High levels of sodium in clay soils will cause displacement of calcium and magnesium ions from the soil. Sodium ions also cause the existing soil structure to deteriorate resulting in a decrease in water movement through the soil, a reduction in water infiltration, and increased soil runoff (Warrington 1993). Sodium ions may also increase the movement of trace metals into the groundwater (Satterfield 1997; Amrhein and Strong 1990).

Magnesium and calcium ions have beneficial effects on the soil structure (Lewis 1997; Cheng and Guthrie 1998). The calcium ion causes fine clay particles to clump together to form aggregates, which improves water drainage and soil aeration (Bohn 1985). However, high levels of magnesium and calcium ions can cause movement of metals from the soil to groundwater (Satterfield 1997).

5.2.1.3. Organic Corrosion Inhibitors

Some of the chloride-based deicers contain organic corrosion inhibitors that reduce the corrosive effects of the deicing salts, whereas others, such as sodium chloride, do not contain corrosion inhibitors. FreezGard Zero with Shield LS contains 1-2% organic corrosion inhibitor (Product Data Sheet), FreezGard Zero with TEA contains 5% corrosion inhibitor (Mussato and Guthrie 2000), Ice-Stop CI contains 0.2% organic corrosion inhibitor (Product Specification Sheet), Caliber M1000 contains 10% organic corrosion inhibitor (Product Specification Sheet), and Ice Ban M50 contains 50% Ice Ban (Product Specification Sheet), which acts as a corrosion inhibitor.

The organic materials in corrosion inhibitors, such as Caliber and Ice Ban, are broken down by soil microorganisms and can temporarily create anoxic (anaerobic) conditions in the soil, which could result in mortality to vegetation. At cold temperatures decomposition of the organic material in soil is reduced, which increases the potential of transport of these substances into groundwater (Cheng and Guthrie 1998). Lewis (2000), however, reported that significant breakdown of organic materials in Caliber did not occur. Another factor to consider in deicers is pH, and Ice Ban has a pH less than 4, which could result in acidification of the soil and leaching of metals from the soil into groundwater (Mussato and Guthrie 2000).

5.2.2. Water Quality

5.2.2.1. Chlorides

Chlorides in surface and groundwater can come from various sources, including oil formation brines, mining and industrial wastes, vehicle exhaust emissions, septic tanks, landfills, waste lagoons, deicers, and other urban activities (Sorenson et al 1996). Chlorides in deicers can reach surface water from aerial dispersion, highway runoff, storm sewers, and land drainage channels. These ions can reach groundwater aquifers by percolation through the soil into groundwater (Seawell and Agbenowosi 1998; Cheng and Guthrie 1998).

Several factors have been reported to determine the ability of chloride ions to leach from soil to groundwater (Sorensen et al 1996; Cheng and Guthrie 1998). They include:

- Type of surface rock, soil or sediment;
- The ion-exchange or buffering capacity of the soil;
- Permeability of the aquifer material;
- Amount of runoff that occurs before the soil thaws;
- Direction and velocity of the groundwater;
- Distance from the highway to local water wells;
- Evaporative conditions in the soil pores;
- Amount of rainfall; and
- Texture and drainage characteristics of the roadside.

As a result of their high solubility in water, chloride deicers can have significant negative effects on surface water and groundwater quality (Cheng and Guthrie 1998). Dissolved salt may alter the physical properties of surface water by increasing its density, which may result in the accumulation of the salt in the deeper layers of water and prevent the water in lakes and ponds from mixing (Environment Canada 2000). The denser salt-rich water on the bottom of a lake or stream can lead to the isolation of the bottom layer, which impairs the distribution and cycling of oxygen and nutrients and can result in mortality of bottom-dwelling fishes and invertebrates (Lewis 1997; Wegner and Yaggi 2001).

Chlorides also cause acidification of groundwater down-gradient from highways where the deicers are used (Chang and Guthrie 1998; Granato et al 1995). Lakes and wetlands with only seasonal outflow of water are most vulnerable to deicing salts (Sorenson et al 1996), and slow-flowing streams near roadways are also of concern (Jones et al 1992).

Chloride levels in surface water have been reported to increase 66 times in small streams at a distance up to 100 meters (330 feet) downstream from a highway which had been treated with chloride-based deicers. These levels have been reported to persist for six months following the termination of deicer application (Demers and Sage 1990). Lewis (2000) reported increases in chloride concentrations in Colorado streams. However, such increases in chloride levels have not been observed in larger water bodies because of the rapid dilution of the deicer (Cheng and Guthrie 1998). The estimated dilution of chloride deicers from roadways where the deicers are used to the stream or lake is 500-fold (Lewis 2000).

Concentrations of trace metals were reported to be higher in groundwater down-gradient from highways where chloride deicers had been used (Pilon and Howard 1987; Granato et al 1995; Cheng and Guthrie 1998). However, at other locations concentrations of trace metals in groundwater beneath roadside soils were similar to those in locations not exposed to chloride deicers (Pilon and Howard 1987). Elevated levels of chlorides in groundwater have been reported in water wells 30 meters (100 feet) down-gradient of the roadway in the direction of groundwater movement (Cheng and Guthrie 1998).

5.2.2.2. Sodium, Magnesium, and Calcium

Increased concentrations of sodium cause a depression of calcium and magnesium levels in water, thereby reducing the water hardness (Chang et al 1994). Conversely, high concentrations of calcium and magnesium in water increase the hardness of water (Cheng and Guthrie 1998). An increase in water hardness decreases the toxicity of the metals dissolved in water (Lewis 1997), since toxicity of many heavy metals is inversely related to water hardness. This means that metals dissolved in hard water will have lower toxicity than in soft water.

5.2.2.3. Organic Corrosion Inhibitors

The organic corrosion inhibitors in the chloride deicers discussed in this report include Caliber (10%), Ice Ban (50%), and proprietary organic substances in small amounts (1-5%). Lewis (2000) reported that the deicer Caliber contains high levels of phosphorus, ammonia, and organic matter. He utilized mathematical models to estimate the concentrations of these substances that could be found in Colorado streams when Caliber M1000 was used as a deicer. Background concentrations of phosphorus in streams in Summit County, Colorado ranged from 0.005-0.010 ppm.

The organic material in Caliber M1000 can result in eutrophication of the surface water, which occurs when the water contains high concentrations of organic nutrients. Eutrophication of water results in the proliferation of aquatic plants, especially blue-green algae, which can deplete the oxygen in the water and cause the mortality of fish and invertebrates in the lake or stream. The phosphorus in Caliber M1000 will also stimulate the growth of aquatic plants, resulting in eutrophication of the lake or stream. Lewis (2000) reported that typical application concentrations of Caliber M1000 could result in mean annual increases in phosphorus concentrations of 25-105%.

Lewis (2000) stated that ammonia levels in Caliber M1000 could cause toxic effects to trout and other aquatic organisms at concentrations as low as 0.02 ppm. The concentration of ammonia in streams and rivers in Colorado is regulated by the Colorado Water Quality Control Commission, which specifies a limit of 0.02 ppm of ammonia for chronic exposure of cold water aquatic life. He also stated that water at the edge of roadways containing Caliber M1000 is likely to exceed the ammonia stream standard for protection of aquatic life.

Lewis (2000) estimated that Caliber M1000 has a total organic carbon level of 33,000 ppm. He conducted an experiment in which Caliber M1000 was added to water collected from three Colorado streams to determine whether high concentrations of organic matter would result in oxygen depletion of the water body. The results of the 24-hour BOD tests showed that the addition of Caliber M1000 to the water did not result in oxygen depletion. Lewis had expected that the relatively high concentration of organic matter in Caliber M1000 would cause the depletion of oxygen in the stream water. Since that did not occur, he postulated that the organic matter in the Caliber deicer might be not be readily useable by most microorganisms. The test duration of 24 hours is shorter than the 5-day BOD tests that are typically conducted to determine the ability of a substance to cause oxygen depletion. It is possible that the shorter duration of the test may have affected the test results. Lewis (2000) concluded that Caliber M1000 could cause oxygen depletion if it were allowed to remain in ponds, wetlands, or lakes over a period of time. Aquatic organisms in cold water environments, such as Colorado, are especially sensitive to oxygen depletion (Lewis 2000).

Ice Ban, the organic corrosion inhibitor in Ice Ban M50, also contains high concentrations of phosphorus, sulfates, ammonia, and nitrates and organic materials, which can have adverse effects on water quality. The presence of these substances can result in the growth of undesirable aquatic vegetation, result in oxygen depletion, and cause mortality to aquatic organisms (Mussato and Guthrie 2000). High concentrations of nitrates in Ice Ban can result in contamination of the groundwater.

5.2.3. Aquatic Organisms

5.2.3.1. Chlorides

The background concentrations of chlorides in inland streams in Colorado may be as low as 2-3 ppm. However, most aquatic animals can tolerate exposures exceeding that amount by 10-100 times or more without any harmful effects (Lewis 1997). Rainbow trout can tolerate concentrations of chlorides of 20,000 ppm. The fathead minnow can also tolerate high concentrations of chlorides. However, some fish species are affected by concentrations of chlorides below 1,000 ppm (Lewis 1997). The EPA limit for chlorides in surface water is 860 ppm for acute effects to aquatic organisms and 230 ppm for chronic effects.

It has been estimated that there is a 500-fold dilution of chlorides from the roadways where the deicers are used to rivers and streams (Lewis 2000). The chloride levels are rapidly diluted once they enter the surface water. Even streams at the headwaters of rivers where deicing is a common practice typically show concentrations of chlorides below the EPA limits (Lewis 1997).

Increase in chloride levels and salinity has been reported to adversely affect freshwater organisms. The number of species of aquatic animals decreases as the salinity increases to concentrations of 1,000-3,000 ppm (Wetzel 1983).

Since water containing chlorides is denser than water that does not contain chlorides, it can cause the formation of a lens of salt-rich water on the bottom of a lake, resulting in the isolation of the bottom layer, oxygen depletion, and the mortality of bottom-dwelling invertebrates and fishes (Lewis 1997).

5.2.3.2. Organic Corrosion Inhibitors

Aquatic organisms require a certain amount of oxygen to survive. The chlorides in deicers do not reduce the oxygen level in the water. However, many of the chloride deicers contain organic corrosion inhibitors in various amounts. The organic materials are broken down by microorganisms in the soil and water, a process which uses oxygen. If the oxygen level in water is reduced substantially, then fish and invertebrates will be unable to survive.

The chloride deicers, such as sodium chloride (e.g., rock salt and Ice Slicer) have no corrosion inhibitors and have very low BOD levels. Magnesium chloride deicers (FreezGard Zero and Ice Stop-CI) also have low BOD levels. Inhibited calcium chloride (Liquidow Armor) has a somewhat higher BOD. The magnesium chloride deicer Caliber M1000, which contains 10% corn derivitive as a corrosion inhibitor, has higher BOD levels and could potentially cause oxygen depletion in small ponds or slow-flowing streams (Lewis 2000). The deicer Ice Ban M50, which contains 50% Ice Ban as a corrosion inhibitor, has the highest BOD levels of the chloride-based deicers. High BOD levels are an indication that the deicer can cause significant depletion of oxygen levels in the water.

The organic materials in Caliber and Ice Ban can cause eutrophication of water, which will result in the proliferation of noxious aquatic plants, especially blue-green algae. The increase in algae reduces the oxygen level in the water and often causes the mortality of fish and invertebrates in the lake or stream. Phosphorus and ammonium ion in Caliber and Ice Ban can stimulate growth of aquatic plants. Ammonia is toxic to fish and aquatic invertebrates at low concentrations (Lewis 2000). The ammonia standard for the protection of aquatic life is 0.02 ppm for chronic exposure to cold water aquatic life (Lewis 2000).

5.2.3.3. Air Quality

The use of liquid chloride deicers, such as magnesium chloride, improves air quality by reducing the levels of PM10 (particulates less than 10 μm in diameter) in the atmosphere. The increase in the use of liquid magnesium chloride deicer in Colorado resulted in the decrease in sand use by almost 86,000 tons between FY 1995 and 2000 (E. Fink, CDOT, personal communication). However, the use of solid chloride deicers, such as rock salt (sodium chloride) can contribute to the deterioration of local air quality by generating airborne fine particulates (Cheng and Guthrie 1998).

The chloride deicers contain low levels of trace metals, such as arsenic, cadmium, copper, chromium and zinc. These metals may become airborne through dispersion during the deicing operations. The presence of trace metals was reported on air monitoring filters placed in three cities in Colorado (CDPHE 2000). However, the sample size was too small to determine whether the metals came from the magnesium chloride deicer or other sources of metals (L. Cassin, Aspen Environmental Health Department, personal communication)

5.2.4. Terrestrial Vegetation

5.2.4.1. Chlorides

The adverse effects of chloride-based deicers on terrestrial vegetation were first reported in the literature in the 1950s. Numerous studies on the effects of sodium chloride on vegetation have been conducted since that time, including French 1959; Prior and Berthouex 1967; Roberts 1967; Westing 1969; Bernstein et al 1972; Sorenson 1996; Hanes et al 1970; Chang et al 1994; Lewis

1997; Satterfield 1997; Chang and Guthrie 1998; Mussato and Guthrie 2000; and Environment Canada 2000; among others.

The impacts of chloride deicers to vegetation depend on several factors, such as soil type, salinity of the soil, the age of plant, and tolerance of the plant species to changing soil conditions (Bernstein et al 1972; Cheng and Guthrie 1998; Hanes et al 1970; Chang et al 1994.

The majority of the impacts of chloride deicers on vegetation occur near roadsides receiving heavy treatment of deicers (D'Itri 1992). Sodium chloride has been reported to be responsible for the damage or death of approximately 5-10% of roadside trees within 100 feet from the roadway (NRC 1991; Lewis 1997). However, other factors associated with automobile traffic also stress vegetation and contribute to mortality of trees adjacent to roadways (Lewis 1997). Environment Canada (2000) reported that damage to vegetation can occur up to 200 m (650 feet) from the roadway treated with deicing salts.

The specific effects of elevated levels of chlorides in plants reported by Gidley 1989; Prior and Berthouex; Chang et al 1994; Environment Canada 2000, and others include:

- Inhibition of water and nutrient absorption;
- Osmotic stress;
- Reduced flowering and seed germination;
- Reduced shoot and root growth;
- Browning of leaves and premature leaf drop;
- Nutritional imbalances for some species resulting from disruption of uptake of nutrients;
- Thinning of tree crowns;
- Increased vulnerability to other stresses and disease; and
- Death of the plant.

Damage to vegetation from deicing salts can amplify the impacts of deicers on drinking water quality. Impacts to water quality can be particularly acute when heavily used roads are adjacent to drinking water reservoirs that are only insulated by narrow buffer areas (Wegner and Yaggi 2001).

Plants vary in their sensitivity to the chlorides in deicers. In general, grasses are more resistant to deicing salts than trees (Sorenson 1996). Most annual crops and short-lived perennials are also relatively tolerant to chlorides. On the other hand, vines and woody ornamental plants, and some trees are quite sensitive to the effects of chloride ions (California Fertilizer Association 1985).

The vegetation that is most sensitive to the effects of chlorides includes native grass species; wetland species, such as sphagnum moss and sedges; and maple, pine, Douglas fir, dogwood, peach, and plum trees (Environment Canada 2000). Conifers, in general, are more sensitive to salt injury than deciduous trees (Hanes et al 1970). When the sensitive species die, they are replaced by more salt-tolerant plant species, such as narrow-leafed cattail, common reed-grass, and weedy species such as sow-thistle, common ragweed, and wild carrot (Environment Canada 2000).

The Western Fertilizer Handbook (1975) provides information on safe levels of chlorides in plants. Chloride concentrations less than 70 ppm are safe for all plants; concentrations between 70–140 ppm will result in some damage to sensitive vegetation; concentrations between 140-350 ppm will result in some damage to moderately tolerant plants; and concentrations greater than 350 ppm can cause severe vegetation damage. Environment Canada (2000) reported that exposure to sodium chloride as low as 100 ppm in soil inhibits seed germination and root growth in grasses and wildflowers.

5.2.4.2. Sodium, Calcium and Magnesium Ions

Sodium, calcium and magnesium ions have varying effects on terrestrial vegetation. Sodium is accumulated in twigs (Prior and Berthouex 1967) and may be toxic at levels above 0.3% dry weight in leaves (Westing 1969). Calcium and magnesium, on the other hand, are important plant nutrients. Calcium is a major structural component of plant cell walls, and most plants have between 1 to 2% dry weight of calcium in their leaves (Cheng and Guthrie 1998). Calcium ions also appear to reduce the uptake of chloride ions by the plants (Cheng and Guthrie 1998). Magnesium is an important component of the chlorophyll molecule and is not considered toxic even at high concentrations (Bohn 1985; Lewis 1997; Cheng and Guthrie 1998).

5.2.4.3. Organic Corrosion Inhibitors

The decomposition of the organic material in Caliber and Ice Ban by soil microorganisms can temporarily deplete oxygen in the soil, which can result in death of plants. Caliber and Ice Ban also contain phosphorus, which is a plant nutrient and stimulates plant growth in small quantities. However, higher concentrations of phosphorus can cause toxic effects (Lewis 2000). Ice Ban also contains high levels of ammonia-nitrogen, which serves as a plant nutrient and stimulates plant growth in minute amounts. However, at concentrations as low as 0.02 ppm, ammonia is toxic to vegetation (Lewis 2000).

5.2.5. Terrestrial Animals

Birds and mammals often do not receive enough salt in their diet, so when salt is available they seek it out (Environment Canada 2000). Bird kills by vehicles as a result of birds eating salt on roads are common in many parts of the U.S. and Canada (Environment Canada 2000). Birds have been reported to ingest salt crystals as grit to aid in grinding food, and suffer from acute salt toxicity that can result in death of the bird (Gionfriddo and Best 1995). The lethal dose of salt in sparrows was reported to be 3000 mg/kg (Wegner and Yaggi 2001). Small mammals and birds are generally more susceptible to the toxic effects of salt (Jones et al 1992).

Large mammals, such as moose, mule deer, white-tailed deer, elk, and bighorn sheep, are attracted to road salt (sodium chloride), which may be a factor in roadkills of these animals (Environment Canada 2000). The deicers containing magnesium chloride are unlikely to attract wildlife, based on research conducted by Newhouse and Kinley (2001). The authors suggest the use of magnesium chloride deicers as a non-attracting alternative to sodium chloride (Newhouse and Kinley 2001). According to N. Kinley (Sylvan Consulting, personal communication), the literature indicates that it is the sodium component in sodium chloride that attracts animals.

Tolerance of large mammals to salt is usually quite high, provided that adequate drinking water is available (Cheng and Guthrie 1998). Domestic animals (e.g., sheep) have been reported to adapt to water containing 1.3% chloride without adverse effects on body weight and wool production (Jones et al 1992). Cassin (1999) reported sores on livestock pastured near roads treated with magnesium chloride.

Deicing salt may also affect wildlife through its impact on wildlife habitat, by destroying food resources, habitat corridors, shelter and breeding or nesting sites (Wegner and Yaggi 2001).

The acute oral toxicity of deicing salts in rats, used as a surrogate for other animals, varies from a LD50 of 3750 mg/kg for sodium chloride to 8100 mg/kg for magnesium chloride (Cheng and Guthrie 1998) (Table 4). Acute toxicity values (LD50) above 5000 mg/kg are considered to be practically non-toxic (Hiatt et al 1989). A higher LD50 means lower toxicity to the chemical.

Table 4. Acute Oral Toxicity Values of Selected Deicers (from Cheng and Guthrie 1998).

Deicer	**LD50[1] (mg/kg)**
Magnesium Chloride	8100
CMA	5000
Calcium Chloride	4000
Sodium Chloride	3750
Potassium Acetate	3250

[1] = Dose that is lethal to 50% of the test organisms. A higher LD50 value means lower toxicity of the chemical

5.3. Acetate-based Deicers

The first acetate-based deicer developed was Calcium Magnesium Acetate, which is known as CMA®. Several other deicers that contain acetate ions were developed in the 1990s and include:

- Potassium Acetate, manufactured by Cryotech as CF7®,
- CMAK™, which is a mixture of CMA and Potassium Acetate, and
- Sodium Acetate, commonly referred to as NAAC®.

Since the majority of the published information available about the acetate-based deicers is on CMA, the discussion on acetate deicers will focus on CMA. Data that are available on the other acetate-based deicers will also be presented.

5.3.1. Soil

Horner (1988) reported that CMA increased the permeability of soils by up to 20 times over controls, but the author did not believe that the increase would have an adverse effect. The calcium and magnesium ions in CMA are strongly adsorbed to the soil and have beneficial effects on soil properties (Bohn 1985). A high concentration of calcium causes fine clay particles to clump together to form aggregates. The presence of these aggregates results in improved water drainage and aeration (Bohn 1985). However, an excess of calcium in the soil from the use of CMA could create a nutrient imbalance and reduce the availability of potassium and magnesium to soil microorganisms and plants (Cheng and Guthrie 1998).

Laboratory and field tests on CMA have indicated a potential for this deicer to mobilize and release trace metals from soils (Horner 1988; Winters et al 1985; Cheng and Guthrie 1998). Wegner and Yaggi (2001) reported that CMA can extract iron, aluminum, sodium and potassium from roadside soils. Horner (1988) reported that the tendency of CMA to release trace metals from soil was greater than that of sodium chloride. McFarland and O'Reilly (1992), on the other hand, stated that CMA did not mobilize pre-existing trace metals from roadside soils.

Modeling studies predicted that typical CMA concentrations in runoff from highways would be in the order of magnitude of 10 to 100 ppm, with 5000 ppm being the maximum concentration expected from normal use. These concentrations would be rapidly diluted in rivers and streams (Horner 1988).

The acetate ion in CMA is an organic material and serves as a nutrient that can be readily utilized by soil microorganisms. Decomposition of acetate ions by microorganisms can lead to oxygen deficient conditions in roadside soils and leaching of acetate to the groundwater. At temperatures above 10^{o}C (50°F), acetate decomposition was achieved in two weeks (Horner 1988). At temperatures below 2ºC (36°F) acetate decomposition in soil is greatly reduced (Horner 1988), which increases the potential for leaching of acetate ions to the groundwater (Cheng and Guthrie 1998). The soil conditions resulting from acetate decomposition by microorganisms can increase the movement of trace metals from the soil (Cheng and Guthrie 1998).

A significant proportion of acetate in CMA is adsorbed to the soil surface and not transported in runoff. Although the acetate ion is potentially mobile and transported through the soil, less than 10% of acetate applied to test field plots appeared in surface water or groundwater (Horner 1988). Sodium (in NAAC) and Potassium (in Potassium Acetate) are not strongly adsorbed to the soil, so there is a potential for the leaching of these ions into groundwater (Cheng and Guthrie 1998).

5.3.2. Water Quality

The acetate ion in CMA and the other acetate deicers can reduce the oxygen level in water as a result of its breakdown by microorganisms. Oxygen depletion from CMA has been demonstrated in both laboratory and experimental field tests. Concentrations of 100 ppm completely depleted the oxygen in the water within two days. Concentrations as low as 10 ppm of CMA to the water temporarily reduced saturated dissolved oxygen levels in field ponds by about 50%. At higher water temperatures there is greater potential for oxygen depletion from CMA (Cheng and Guthrie 1998). The ability of relatively low concentrations of CMA to reduce dissolved oxygen in water is the major potential environmental impact from the use of CMA (Horner 1988).

A study on the deicer Potassium Acetate reported that it did not penetrate groundwater aquifers and did not impact water chemistry (Davis et al 1994).

Laboratory tests to determine the Biochemical Oxygen Demand (BOD) of CMA, CMAK, Potassium Acetate, and NAAC have shown an oxygen demand greater than 100,000 ppm for these acetate-based deicers. BOD levels greater that 100,000 ppm are considered to be high and likely to cause oxygen depletion of surface water (Mussato and Guthrie 2000).

McFarland and O'Reilly (1992), however, reported that use of CMA is unlikely to have significant negative impacts on dissolved oxygen levels in receiving water for most application scenarios. They also reported that the deicer did not result in an increase in aquatic algae in surface water (McFarland and O'Reilly 1992).

CMA and the other acetate-based deicers contain phosphorus. Phosphorus can serve as a nutrient to microorganisms and algae in the water and can result in eutrophication, especially in small ponds and lakes (Horner 1988). CMAK is reported to have high nitrogen levels, in the form of ammonia and nitrates, which can result in growth of algae and undesirable aquatic plants (Mussato and Guthrie 2000). The levels of nitrates were low in Potassium Acetate. No data were found in the literature reviewed on the concentration of nitrates in CMA and NAAC.

5.3.3. Air Quality

CMA and NAAC are solid deicers, which can generate dust during preparation of the liquid form and contribute to deterioration of local air quality (Cheng and Guthrie 1998). Airborne particulates may also cause deterioration in visibility. The liquid form of CMA, and liquid Potassium Acetate and CMAK decrease air pollution through reduction in the use of sanding materials for snow and ice control.

5.3.4. Aquatic Organisms

The high Biochemical Oxygen Demand (BOD) levels reported for CMA, CMAK, Potassium Acetate, and NAAC can stimulate the growth of blue-green algae and cause oxygen deficiency in the water. The resulting oxygen deficiency can have adverse effects on fish and invertebrates. Horner (1988) reported that the presence of relatively low concentrations of CMA does not have a harmful effect on aquatic invertebrates. At higher concentrations of CMA, invertebrates were adversely affected by low oxygen levels in the water (Horner 1988). In laboratory toxicity tests, some species of fish appeared to be relatively resistant to osmotic stress from oxygen depletion. When the laboratory test containers were aerated, fish survival was high. At concentrations of CMA above 1,000 ppm, the oxygen in the water became depleted and fish survival was low. When field experiments were conducted in ponds, no negative impacts from CMA were observed in bluegills and fathead minnows. However, the ponds did not contain rainbow trout, which are sensitive to the effects of oxygen depletion (Horner 1988).

5.3.5. Terrestrial Vegetation

Studies have been conducted to evaluate the effects of CMA on terrestrial vegetation by Winters et al 1985; Horner 1988; McFarland and O'Reilly 1992, and others. The results of a study conducted by Winters et al (1985) indicated that CMA was less harmful to plants than sodium chloride. Of a total of 18 tree species exposed to CMA, only one species, the Russian olive, was damaged more by CMA than by sodium chloride.

A study conducted by Horner (1988) revealed that applications of CMA to vegetation at concentrations up to 3,000 ppm through spraying and flooding did not affect the yield, cover, vigor or rooting of various herbaceous and woody plants, including Douglas fir and alder saplings. This concentration is higher than that expected from routine applications of CMA to roadways. However, concentrations of CMA above 5,000 ppm did reduce plant yield and resulted in mortality of seedlings as a result of osmotic stress (Horner 1988).

Several species of woody plants (Douglas fir, red alder saplings, pine, balsam fir, red maple seedlings, and salt tolerant shrubs) were sprayed with CMA at concentrations that would be expected to occur along roadsides from deicing operations. Upon observation the following spring all the plants were healthy. No vegetation damage was noted in any case. Horner (1988) concluded that, in general, CMA does not harm terrestrial vegetation, except when concentrations in the root zone are high enough to cause osmotic stress (Horner 1988). McFarland and O'Reilly (1992) also reported that CMA at concentrations used for deicing roads would have little to no toxic effects on roadside vegetation. The presence of CMA in the soil may, in fact, stimulate plant growth by improving soil structure and permeability (Cheng and Guthrie 1998).

Field tests were conducted on Potassium Acetate by Transport Canada (Nolan Davis 1994) to evaluate the effects of this deicer on vegetation. These studies showed that there was little or no inhibition of surface vegetative growth when Potassium Acetate was used at concentrations below 500 mg solids/liter, which is equivalent to the concentrations encountered during normal deicing operations (Cheng and Guthrie 1998). However, at concentrations of 1,000 mg solids/l, plant growth was inhibited by almost 50% (Cheng and Guthrie 1998).

5.3.6. Terrestrial Animals

Preliminary laboratory tests and review of the literature by Cheng and Guthrie (1998) indicate that CMA is harmless to animals. Acute oral toxicity tests on rats indicate low toxicity of the acetate deicers to mammals (see Table 4). It is not expected that CMA, CMAK or Potassium Acetate would attract wildlife. However, it is possible that NAAC (Sodium Acetate) may attract wildlife and contribute to roadkills of animals, because of the presence of sodium in this deicer. Several reports have indicated that the sodium component in salt attracts animals (Newhouse and Kinley 2001).

5.4. Sand

Sand has probably been used for snow and ice control since the first quarter of the 20^{th} century and is frequently used in combination with sodium chloride. Two types of sand are commonly used in snow and ice control: river sand and crushed aggregate. River sand is cleaner and contains less contaminants. Crushed aggregate sand is more effective in increasing roadway traction (Chang et al 1994). In some towns in Colorado, sand is the only method of snow and ice control used.

5.4.1. Soil

The sand used for snow and ice control can affect the composition of the soil adjacent to roadways. Sand also contains small amounts of trace metals which results in an increase the concentration of these chemicals in the soils. A sufficiently high concentration of metals in the soil may inhibit growth of soil microorganisms.

5.4.2. Water Quality

The sand applied to roads in winter enters the drainage system and is emptied into streams and rivers (Chang et al 1994). Sand has negative impacts on water quality by increasing suspended solid levels and turbidity, and increasing sediment loading in streams (Oberle 1999). Trace metals in the sand, such as cadmium, chromium and copper may leach from the soil and affect surface and groundwater quality.

5.4.3. Aquatic Organisms

Sand used for snow and ice control can increase the turbidity of the water (Oberle 1999). The increase in turbidity reduces the light that penetrates the water and inhibits photosynthesis in aquatic vegetation. Sand particles may clog the gills of fish and reduce their ability to exchange gases. Fish obtain oxygen and other gases and eliminate carbon dioxide and other waste gases by taking in water through the mouth and ejecting it through the gills (Audesirk and Audesirk 1993). If large amounts of sand cover the bottom of streams adjacent to roadsides, it can prevent egg development and displace stream insects (Oberle 1999). The smothering effect of the sand can also result in the mortality of benthic organisms.

5.4.4. Air Quality

The use of sand for snow and ice control has played a major role in the deterioration of the air quality in many areas of the U.S. Airborne particulates resulting from the use of sand may also cause deterioration in visibility (Cheng and Guthrie 1998). The high levels of particulates in the air from the use of sand during winter months has affected the air quality in the Denver metropolitan area and resulted in classification of Denver as a moderate non-attainment area (Chang et al 1994). In 1991 the Colorado Regional Air Quality Council enacted Regulation 16. Its goal was to reduce the amount of sand used on roads for snow and ice control to 500 pounds/lane-mile (Chang et al 1994).

Sand has been reported to contribute approximately 45% of particulate matter less than 10 μm in diameter, referred to as PM10 (Chang et al 1994; Oberle 1999). The percent of total PM10 emissions from road dust increases from between 50% to 90% during the 24-hour period following road sanding (Cowherd 1998). The EPA air quality standard for PM10 is 50 $\mu g/m^3$ (annually), 150 $\mu g/m^3$ (in a 24-hour period), with three allowable exceedences over a three-year period (Oberle 1999).

5.4.5. Vegetation

The use of sand for snow and ice control can impact vegetation by stressing and smothering of roadside vegetation (Oberle 1999). The sand particles can adhere to the stomates, which regulate the rate of exchange of oxygen, carbon dioxide and water vapor between the atmosphere and the leaf interior. If the opening of the stomates is blocked because of sand particles, then photosynthesis will be reduced or inhibited (Audesirk and Audesirk 1993). Blockage of the stomates will prevent the plant from absorbing nutrients and water from the soil (Audesirk and Audesirk 1993).

5.4.6. Terrestrial Organisms

Sand may have adverse effects on small burrowing mammals if the sand blocks the opening of the burrows. It is not expected that sand would have impacts on larger mammals.

5.5. Toxicity of Deicers to Aquatic Organisms

Aquatic toxicity tests are a useful means of evaluating the potential toxic effects of various chemicals to aquatic organisms. Different species of aquatic organisms are not equally susceptible to the same toxic substances, nor are the same species of organisms equally susceptible to a chemical at different times in their life cycle (Standard Methods 1998).

Toxicity tests are classified as short-term, intermediate, and long-term tests. Short-term tests (i.e., acute toxicity tests) are usually conducted for 24 to 96 hours. Acute toxicity tests measure the ability of a chemical to cause mortality in test organisms. The concentration that is lethal (acutely toxic) to 50% of the test organisms is referred to as the LC50 and is used as an indicator of the toxicity of a chemical (Standard Methods 1998). The higher the LC50, the lower is the toxicity of the chemical to the test organism.

Intermediate-term toxicity tests may be conducted for 10 to 90 days, while long-term toxicity tests (i.e., chronic toxicity tests) may continue throughout the complete life cycle of the test organism which may range from a few weeks to several months. Chronic toxicity tests measure growth (i.e., increase in weight), reproduction (i.e., number of offspring) or mortality over the long term. The concentration of a chemical that causes inhibition of reproduction or growth by 50%, when compared to the control population, is referred to as an IC50 (Standard Methods 1998). Short-term chronic tests, in which test organisms are exposed to chemicals for seven days are frequently conducted.

Aquatic invertebrate species that are often used as test species for toxicity tests in fresh water are water fleas, such as *Daphnia magna* or *Ceriodaphnia dubia*. Fish species that are frequently used for freshwater toxicity tests are fathead minnows (*Pimephales promelas*) and rainbow trout (*Oncorhynchus mykiss*). An aquatic plant that is frequently used to evaluate the effects of chemicals on aquatic vegetation is the green microalga *Selenastrum capricornutum*.

Aquatic toxicity tests were conducted on sodium chloride and chloride ions for 24 hours, 72 hours, and 7 days (Environment Canada 2000). The results of toxicity tests are shown in Table 5. Rainbow trout were the most tolerant of the presence of sodium chloride. The water flea (*Ceriodaphnia dubia)* and fathead minnows (*Pimephales promelas*) were the most sensitive to the presence of the salt. In short-term chronic tests, fathead minnows and their embryos were most sensitive to the effects of sodium chloride and chloride ions. The test results showed that

Table 5. Toxicity of Fish and Invertebrates Exposed to Sodium Chloride for One to Seven Days (modified from Environment Canada 2000).

Species	Common Name	NaCl (ppm)	Chloride ion (ppm)	Response	Exposure	Reference
Lepomis macrochirus	Bluegill (fish)	14,000	8550	LC50[1]	24 hr	Doudoroff and Katz 1953
Daphnia magna	Water flea	7754	4704	LC50	24 hr	Cowgill et al 1990
Daphnia pulex	Water flea	2724	1652	LC50	24 hr	Cowgill et al 1990
Ceriodaphnia dubia	Water flea	2724	1652	LC50	24 hr	Cowgill et al 1990
Ceriodaphnia dubia	Water flea	2308	1400	LC50	72 hr	Cowgill et al 1990
Daphnia magna	Water flea	3054	1853	LC50	72 hr	Anderson 1948
Chironomus attenatus	Chironomid (midge)	6637	4026	LC50	72 hr	Thorton and Sauer 1972
Pimephales promelas	Fathead minnow	7650	4640	LC50	72 hr	Adelman et al 1976
Lepomis macrochirus	Bluegill (fish)	9627	5840	LC50	72 hr	Birge et al 1985
Oncorhynchus mykiss	Rainbow trout	11,112	6743	LC50	72 hr	Spehar 1987
Pimephales promelas	Fathead minnow embryos, survival	1440	874	LC50	7-day	Beak 1999
Ceriodaphnia dubia	Water flea, mean brood size	1761	1068	EC50	7-day	Cowgill and Milazzo 1990
Oncorhynchus mykiss	Rainbow trout egg embryo, survival	2400	1456	LC50	7-day	Beak 1999
Daphnia magna	Water flea, mean brood size	4040	2451	LC50	7-day	Cowgill and Milazzo 1990
Pimephales promelas	Fathead minnow larvae, growth	4990	3029	EC50	7-day	Beak 1999

[1] = Concentration that is lethal to 50% of the test organisms. A higher LC50 value means lower toxicity of the chemical.

chloride ions alone were more toxic to fish and invertebrates than sodium chloride (Environment Canada 2000). Aquatic toxicity tests conducted on the acetate-based deicer CMA by McFarland and O'Reilly (1992) showed low toxicity to fish, but higher toxicity to the water flea (Table 6).

Toxicity tests have also been conducted on the actual deicer formulations, including the corrosion inhibitors, for those deicers that are used with corrosion inhibitors. Acute and chronic toxicity tests were conducted on the chloride-based deicers and acetate-based deicers by the Levelton Laboratories and reported in Mussato and Guthrie (2000). The results of these tests are provided in Table 7.

Table 6. Aquatic Toxicity of CMA to Fish and Invertebrates (from McFarland and O'Reilly 1992).

Test Species	**Test Method**	**LC50[1] (ppm)**	**Reference**
Rainbow trout (*Oncorhynchus mykiss*)	Acute Static 96-hour	17,500	Horner 1990
Rainbow trout	Acute Static 96-hour	18,700	Winters et al 1985
Rainbow trout	Chronic Larval static Renewal-45 days	NOEC[2] = 1000	Horner 1990, Winters et al 1985
Fathead minnow (*Pimephales promelas*)	Acute Static 96 hour	12,500	Horner 1990
Fathead minnow	Acute Static 96 hour	21,000	Winters et al 1985
Daphnia magna	48-hour Acute	>1000	NW Aquatic Lab 1990
Daphnia magna	96-hour Acute	2000	Horner 1990
Amphipod (*Hyalella azteca*)	Flow-through 14 days	2000	Horner 1990

[1] = A higher the LC50 value means lower toxicity to test animals
[2] = No Observed Effects Concentration (NOEC)

Among the chloride-based deicers tested by Levelton Laboratories, sodium chloride brine showed the lowest acute and chronic toxicity to rainbow trout and water fleas. The magnesium chloride deicers were more toxic to fish and invertebrates than either sodium chloride or calcium chloride (Mussato and Guthrie 2000). The Environment Canada (2000) literature review also reported that magnesium chloride salts were generally more toxic to aquatic organisms than sodium chloride. Growth inhibition (toxicity) tests on the green alga *Selenastrum* indicated lower toxicity to sodium chloride than magnesium chloride or calcium chloride.

CMA was the least toxic of the acetate deicers to fish and invertebrates (Table 7). It was more toxic to fish than sodium chloride, but less toxic than magnesium chloride (Mussato and Guthrie 2000). The concentrations of CMA that were toxic to fish were higher than the concentrations expected in highway runoff (Horner 1988), which suggests that CMA is unlikely to cause toxic effects to fish. Horner (1988), however, reported relatively high toxicity of CMA to the invertebrate *Daphnia*. Mussato and Guthrie (2000) also reported higher toxicity of CMA to invertebrates than sodium chloride, magnesium chloride and calcium chloride. Horner (1988) reported that growth was significantly inhibited in the green alga *Selenastrum* when exposed to as little as of 1 ppm of CMA.

The results of aquatic toxicity testing reported by Mussato and Guthrie (2000) are used here to rank the deicers. The test results from Mussato and Guthrie (2000) are used to compare the deicers because the data compare the toxicity of the majority of the deicers being evaluated in this report. Toxicity tests on different deicers conducted by the same laboratory and using the same test organisms are expected to be comparable. Toxicity tests conducted by multiple laboratories may not be comparable, since different concentrations of deicers, test methods, and test organisms may have been used.

The results of the ranking of the deicers in terms of are shown below, with No. 1 being the least toxic and No. 9 being the most toxic to fish, invertebrates and algae.

<u>Ranking of Acute Aquatic Toxicity of Selected Deicers to Rainbow Trout</u>:

1. Sodium Chloride Brine (23%)
2. CMA (25%)
3. Calcium Chloride (Liquidow Armor)
4. CMAK
5. Magnesium Chloride + Caliber (Caliber M1000)
6. Magnesium Chloride (FreezGard Zero w/TEA)
7. NAAC
8. Potassium Acetate
9. Ice Ban + Magnesium Chloride (50:50) (Ice Ban M50)

Table 7. Acute/Chronic Aquatic Toxicity Test Results for Various Deicers[1].

Chemical	Brand/ Alternate Name	LC50 Rainbow Trout[2] (ppm) (acute)	LC50 *Ceriodaphnia*[3] (ppm) (acute)	IC50 *Ceriodaphnia*[3] (ppm) (chronic)	IC50 *Selenastrum*[4] (ppm) (growth inhibition)
Chloride -based deicers					
Inhibited Magnesium Chloride ($MgCl_2$)	FreezGard Zero/TEA	3160	3668	1781	6254
Inhibited $MgCl_2$	Ice-Stop CI	NA	NA	NA	NA
$MgCl_2$ + Caliber Inhibitor[1]	Caliber M1000	6621	4950	2150	631
$MgCl_2$ + Ice Ban	Ice Ban M50	620	585	164	1090
Sodium Chloride (23% Brine)	Salt	68454	6583	2919	9186
Sodium Chloride	Ice Slicer	NA	NA	NA	NA
Inhibited $CaCl_2$	Liquidow Armor	23452	3828	2722	2422
Acetate-based deicers					
Liquid CMA (25%)	CMA	35000	4670	1039	706
Liquid Potassium Acetate (51%)	CF7	2280	660	240	318
CMA + Potassium Acetate (liquid)	CMAK	14091	1918	466	330
Sodium Acetate[5]	NAAC	2750mg/l (Fathead minnow) (24-hr)	2400 mg/l (*Daphia magna)* (48-hr)	NA	NA
Sand	Volcanic cinders, chipped rock, scoria	NA	NA	NA	NA

[1]=Mussato and Guthrie (2000)
[2]=Rainbow trout 96-hour acute static bioassay (LC50)
[3]=7-day survival (LC50) and reproduction (IC50) bioassay using *Ceriodaphnia dubia*
[4]=Growth inhibition (IC50) bioassay with the alga *Selenastrum capricornutum*
[5]=Cryotech MSDS and Product Information Sheets (www.cryotech.com).
NA = Not Available.
Note: A higher LC50 value means lower toxicity of the chemical tested.

<u>Ranking of Acute Aquatic Toxicity of Selected Deicers to Water Fleas (Invertebrates):</u>

1. Sodium Chloride Brine (23%)
2. Magnesium Chloride + Caliber (Caliber M1000)
3. CMA (25%)
4. Calcium Chloride (Liquidow Armor)
5. Magnesium Chloride (FreezGard Zero w/TEA)
6. NAAC
7. CMAK
8. Potassium Acetate
9. Ice Ban + Magnesium Chloride (50:50) (Ice Ban M50)

<u>Ranking of Chronic Aquatic Toxicity of Selected Deicers to Water Fleas:</u>

1. Sodium Chloride Brine (25%)
2. Calcium Chloride (Liquidow Armor)
3. Magnesium Chloride + Caliber (Caliber M1000)
4. Magnesium Chloride (FreezGard Zero w/ TEA)
5. CMA (25%)
6. CMAK
7. Potassium Acetate
8. Ice Ban + Magnesium Chloride (50:50) (Ice Ban M50)

<u>Ranking of Growth Inhibition Tests of Selected Deicers to Aquatic Plants (*Selenastrum*):</u>

1. Sodium Chloride Brine (25%)
2. Magnesium Chloride (FreezGard Zero w/TEA)
3. Calcium Chloride (Liquidow Armor)
4. Ice Ban + Magnesium Chloride (50:50) (Ice Ban M50)
5. CMA (25%)
6. Magnesium Chloride + Caliber (Caliber M1000)
7. CMAK
8. Potassium Acetate

Based on the toxicity test results, the deicer Ice Ban M50 was the most toxic to fish and aquatic invertebrates. The acetate-based deicers Potassium Acetate, CMAK and NAAC were also more toxic to fish and water fleas than the other deicers. The chloride-based deicer that had the lowest acute and chronic toxicity to fish and aquatic invertebrates was sodium chloride brine. Magnesium chloride salts were generally more toxic to aquatic organisms than sodium chloride. The acetate-based deicer that showed the lowest toxicity to fish and invertebrates was CMA. The sodium chloride brine showed the lowest toxicity to aquatic plants, whereas Potassium Acetate was the most toxic.

5.6. Trace Metal Toxicity

The deicers reviewed in this report contain trace metals at varying concentrations (see Table 3). High concentrations of deicers in surface water can lead to the release of metals from aquatic sediments and suspended particulate material. Deicers can also result in the release of trace metals from the soil, which can then enter the surface water or groundwater. Some of the trace metals cause acute toxicity in aquatic organisms at very low concentrations. Mercury, one of the metals found in some deicers, accumulates in fish tissue when it is present in its methylated form (Environment Canada 2000). Table 8 shows the concentrations at which selected metals cause acute toxicity to aquatic organisms. The acute surface water standards for cold water aquatic life developed by the State of Colorado are also shown in Table 8.

Table 8. Acute Toxicity Test Results (LC50) for Rainbow Trout and *Daphnia magna* Exposed to Trace Metals.

Metal	Rainbow Trout (*Oncorhynchus mykiss*) (ppm)[1]	Water Flea (*Daphnia magna*) (ppm)[2]	Surface Water Standards (ppm) (Aquatic Life – Acute)[5]
Arsenic[3]	0.17-15.6	3.3-4.3	0.34
Barium[3]	-	320-530	-
Cadmium[3]	0.001-0.014	0.14-0.155	0.002
Chromium (total)[3]	100	0.022	0.323 (Cr III)
Copper[3]	0.02-0.25	0.021-0.113	0.007
Cyanide[3]	0.12-0.18 (Bluegill)	-	0.005
Lead[3]	1.2-542	3.6-5.3	0.03
Mercury[4]	0.02	0.002	0.0014
Selenium[3]	11.5-12.5	0.3-0.3	0.018
Zinc[3]	0.24-7.2	0.068-1.59	0.065

[1] = 96-hour test (acute) [3] = www.epa/gov/ecotox/ [5] = CDPHE Regulation No. 31
[2] = 48-hour test (acute) [4] = CCME (1991)

The State of Colorado has also promulgated more stringent surface water standards for cold water aquatic life for "chronic" exposure to metals, cyanide, chloride, nitrates, and sulfates

(Colorado Regulation No. 31). These standards are provided in Table 9. The Colorado primary drinking water standards developed for some of these metals and other chemicals are also shown in Table 9. Since the dilution of deicers is estimated to be 500-fold from the roadway, where they are applied, to nearby rivers and streams (Lewis 2000), the concentration of trace metals from the deicers would probably not reach levels that could cause acute or chronic toxic effects to aquatic life.

Table 9. Colorado Surface Water Standards for Aquatic Life and Drinking Water Standards[1,2].

Parameter	CO Primary Drinking Water Standards (ppm)[3]	CO Surface Water Standards (ppm)[4]	Reference for Surface Water Standards
Metals			
Arsenic	0.05	0.15 (chronic)	CO Water Control Commission (1986)
Barium	2.0	0.490 (30-day) (drinking water supply)	CO Regulation No. 31
Cadmium	0.005	0.0013 (chronic)/ mean hardness 50 ppm	CO Regulation No. 31
Chromium (total)	0.1	-	CO Regulation No. 31
Chromium III	-	0.042 (chronic) @ hardness=50 ppm	CO Regulation No. 31
Chromium VI	-	0.011 (chronic)	CO Regulation No. 31
Copper	-	0.005 (chronic) @ hardness=50 ppm	CO Regulation No. 31
Lead	-	0.0012 (chronic) @ hardness=50 ppm	CO Regulation No. 31
Mercury	0.002	0.00077	CO Regulation No. 31
Selenium	0.05	0.0046	CO Regulation No. 31
Zinc	-	0.066 (chronic) @ hardness=50 ppm	CO Regulation No. 31
Other			
Ammonia (as Nitrogen)	-	0.02 (chronic)	State of Colorado (1986)
Chloride	-	250 (30-day)	EPA 1997
Cyanide	0.2	0.005 (1 day)	AFS 1978
Dissolved Oxygen	-	6.0	EPA 1975
Nitrate	10	10 (1-day) domestic water supply	State of Colorado (1986)
PH	-	6.5-9.0	EPA 1976
Sulfate	-	250 (30-day)	EPA 1977

[1] – Class I Cold Water Biota
[2] – See Table 3 for concentrations of metals that were measured in deicers.
[3] – Colorado Primary Drinking Water Regulations (November 18, 1998).
[4] – Colorado Department of Public Health and Environment, Water Quality Control Commission, Regulation No. 31, Basic Standards and Methodologies for Surface Water.

5.7. Comparison of Environmental Effects

Each of the deicers discussed in this report has potential impacts on the environment. The effects of the chloride-based deicers, acetate-based deicers, and sand to water quality, soils, aquatic organisms, air, terrestrial vegetation and terrestrial animals are compared below. The environmental effects of the various deicers are summarized in Table 10.

Sodium chloride, magnesium chloride, and calcium chloride deicers have adverse effects on soil because the presence of the chloride ions increases the salinity of the soil, decreases the soil stability, and enables the movement of metals from soil to water. The chloride ion can have a negative effect on water quality through increased salinity, especially in small streams. In larger water bodies, where there is rapid dilution of the deicer, impacts are unlikely. Chlorides will also affect aquatic organisms due to the increased salinity of the water. However, aquatic toxicity tests have shown relatively low toxicity of the chloride deicers to fish and invertebrates.

Probably the most noticeable effect of the chloride-based deicers is damage and death of roadside vegetation resulting from the use of these deicers. However, there is a wide range of tolerance of different species of plants to the deicing salts. The toxicity of the chloride deicers to terrestrial animals is low, based on oral toxicity tests. Terrestrial animals are known to have a high tolerance to elevated chloride levels in drinking water. However, sodium chloride deicers on the roadways attract birds and mammals, because of insufficient salt in their diet, and may be the cause of roadkills. In addition, solid sodium chloride ingested as grit by birds can cause acute toxicity and death. Magnesium chloride and calcium chloride have not been shown to attract wildlife.

The solid forms of chloride-based deicers, such as sodium chloride and Ice Slicer, may increase air pollution from the small particulates and dust generated from their use. Use of liquid deicers, such as magnesium chloride, salt brine, and liquid calcium chloride, decrease air pollution as a result of the reduction in the use of sanding materials for snow and ice control.

Table 10. Potential Environmental Impacts of Deicers.

Deicer	Brand or Alternate Name	Soil	Water Quality	Aquatic Organisms	Air Quality	Terrestrial Vegetation	Terrestrial Animals
Chloride - based deicers							
Inhibited Magnesium Chloride	FreezGard Zero w Shield LS; FreezGard w TEA; Ice-Stop CI;	Increases soil salinity; improves soil structure and permeability.	Potential increase in water salinity; slight increase in metals.	Low toxicity to fish and invertebrates.	Decrease in air pollution from reduction in sand use.	Inhibits water and nutrient uptake; vegetation damage and mortality.	Slight oral toxicity.
Magnesium Chloride + Caliber	Caliber M1000	Increases soil salinity; improves soil structure and permeability; potential oxygen depletion from breakdown of organics.	Potential increase in water salinity; slight increase in metals; oxygen depletion; eutrophication[1].	Low toxicity to fish and invertebrates; potential mortality from oxygen depletion; toxic effects to aquatic algae.	Decrease in air pollution from reduction in sand use.	Inhibits water and nutrient uptake; vegetation damage and mortality.	Slight oral toxicity.
Magnesium Chloride + Ice Ban	Ice Ban M50	Increases soil salinity; improves soil structure and permeability; potential oxygen depletion from breakdown of organics.	Potential increase in water salinity; slight increase in metals; oxygen depletion; eutrophication.	Moderately toxic to fish and invertebrates; potential mortality from oxygen depletion; toxic effects to aquatic algae.	Decrease in air pollution from reduction in sand use.	Inhibits water and nutrient uptake; vegetation damage and mortality.	Slight oral toxicity.
Sodium Chloride	Salt/ Ice Slicer	Increases soil salinity; decreases soil stability and permeability.	Potential increase in water salinity; slight increase in metals.	Low toxicity to fish and invertebrates.	Decrease in air pollution from reduction in sand use	Inhibits water and nutrient uptake; vegetation damage and mortality.	Sodium ion attracts wildlife contributing to road kills; slight oral toxicity.
Inhibited Calcium Chloride	Liquidow Armor	Increases soil salinity; improves soil structure.	Potential increase in water salinity; slight increase in metals.	Low toxicity to fish and invertebrates.	Decrease in air pollution from reduction in sand use.	Inhibits water and nutrient uptake; vegetation damage and mortality.	Slight oral toxicity.

Table 10 (continued). Potential Environmental Impacts of Deicers.

Deicer	Brand or Alternate Name	Soil	Water Quality	Aquatic Organisms	Air Quality	Terrestrial Vegetation	Terrestrial Animals
Acetate-based deicers							
Calcium Magnesium Acetate	CMA	Improves soil structure and permeability; potential oxygen depletion from breakdown of acetate.	Potential oxygen depletion; eutrophication[1].	Low toxicity to fish and invertebrates; potential mortality from oxygen depletion; toxic effects to aquatic algae.	Decrease in air pollution from reduction in sand use.	Not harmful at concentrations typically used; potential mortality from oxygen depletion in soil.	Slight oral toxicity.
Potassium Acetate	Cryotech CF7	No known effect on soil stability; potential oxygen depletion from breakdown of acetate.	Potential oxygen depletion; eutrophication.	Moderately toxic to fish and invertebrates; potential mortality from oxygen depletion; toxic effects to aquatic algae.	Decrease in air pollution from reduction in sand use.	Not harmful at concentrations typically used; potential mortality from oxygen depletion in soil.	Slight oral toxicity.
CMA and Potassium Acetate	CMAK	Improves soil structure and permeability; potential oxygen depletion from breakdown of acetate.	Potential oxygen depletion; eutrophication.	Moderately toxic to fish and invertebrates; potential mortality from oxygen depletion; toxic effects to aquatic algae.	Decrease in air pollution from reduction in sand use.	Not harmful at concentrations typically used; potential mortality from oxygen depletion in soil.	Slight oral toxicity.
Sodium Acetate	NAAC	Decreases soil stability and permeability; potential oxygen depletion from breakdown of acetate.	Slight increase in metals; Potential oxygen depletion; eutrophication.	Moderately toxic to fish and invertebrates; potential mortality from oxygen depletion.	Decrease in air pollution from reduction in sand use.	Decreases soil stability and permeability; potential mortality from oxygen depletion in soil.	Sodium ion attracts wildlife and may contribute to roadkills; slight oral toxicity.
Sand	Volcanic cinders, chipped rock, scoria	Little effect on soil expected.	Increases turbidity.	Increased turbidity may cause mortality in fish and benthic organisms; inhibits photosynthesis in aquatic plants.	Fine particulate material (PM10) increases air pollution	Can smother roadside vegetation causing mortality.	No harmful effect expected.

[1] = eutrophication – a process by which pollutants cause a water body to become overly rich in organic and mineral nutrients, so that algae grow rapidly and deplete the oxygen supply.

Most of the chloride-based deicers that are used in Colorado contain small amounts (1-10%) of organic corrosion inhibitors. The deicer Ice Ban, when mixed with magnesium chloride at concentrations of 30% and 50%, also serves as a corrosion inhibitor. The organic corrosion inhibitors can affect the water quality as a result of oxygen depletion caused by high BOD levels. The presence of high levels of phosphorus, ammonia, and nitrates in some organic corrosion inhibitors can result in eutrophication of the surface water, which will also deplete the oxygen levels.

The acetate-based deicers also have impacts on the environment. The organic acetate ion serves as a nutrient for soil microorganisms. Large numbers of soil microorganisms will deplete the oxygen. Soil lacking oxygen in the root zone of plants can kill the vegetation. The breakdown of acetate by soil microorganisms can result in mobilization of trace metals to groundwater. The particulates and dust from the solid form of the acetate-based deicers, such as CMA and NAAC, can contribute to air pollution.

The major potential impact of acetate deicers in surface water is oxygen depletion due to the high BOD levels of these deicers. The presence of phosphorus and nitrates in the acetate-based deicers can also deplete the oxygen supply in the water. Water containing low levels of oxygen can result in the mortality of fish and invertebrates. Toxicity tests indicate that acetate deicers cause higher "chronic" toxicity to water fleas than the chloride deicers. Acetate deicers are also substantially more toxic to aquatic algae than the chloride deicers.

One of the benefits of the use of acetate deicers is that they are not harmful to terrestrial vegetation at the concentrations of the deicer applied to the roadways. However, at high concentrations the acetate deicers will inhibit plant growth.

CMA, CMAK, and Potassium Acetate are not expected to attract terrestrial wildlife, although no studies have apparently been conducted on these deicers. However, NAAC, which consists of sodium acetate, may attract wildlife and contribute to roadkills. The sodium ion has been reported to be the element that attracts wildlife to road salt (Newhouse and Kinley 2001).

The deicers containing calcium and magnesium (e.g., magnesium chloride, calcium chloride, CMA and CMAK) have beneficial effects on the soil, including improved water drainage and aeration of the soil. Calcium and magnesium ions also increase the hardness of the water, which reduces the toxicity of metals. The deicers containing sodium, such as sodium chloride and NAAC, can have negative effects on soil because they cause displacement of calcium and magnesium ions from the soil and deterioration of the soil structure.

Sanding materials used for snow and ice control can have harmful effects on the environment. Although sand is not likely to have adverse effects on soil, it can have negative effects on water quality as a result of increased turbidity of the water. The increased turbidity will have impacts on fish, benthic organisms, and aquatic plants. Bottom-dwelling invertebrates may be suffocated by a layer of sand covering them. High turbidity of the water will reduce the sunlight reaching aquatic plants and result in a decrease in photosynthesis. Sanding materials have adverse effects on air quality as a result of the small particulates in sand that cause air pollution. Sand may also impact vegetation by blocking the openings of the stomates in the leaves, which are necessary for transporting water and nutrients from the roots to the leaves and releasing oxygen, carbon dioxide, and water into the atmosphere.

6. WATER QUALITY DATA USGS/ROARING FORK CONSERVANCY

6.1. USGS Water Quality Data

The following summary of water quality data collected on the Roaring Fork River is based on information provided by Paul von Guerard (USGS). The locations of the USGS sample collections are shown in Figure 2. Magnesium chloride solution is used for deicing roads during the winter months and as a dust suppressant during summer and fall. During Water Year 2000, the U.S. Geological Survey, in cooperation with the City of Aspen and the Colorado Association of Ski Towns, collected water quality data to characterize the episodic occurrence of dissolved chloride resulting from the deicing of roadways. The results of this characterization may be applicable to other areas in Colorado where magnesium chloride is used for the deicing and dust suppression on roadways. Figures 1-D through 11-D in Appendix D illustrate different aspects of streamflow and water quality in the Roaring Fork River. These data were collected at the Roaring Fork River above Difficult Creek (USGS station number 09073300), Roaring Fork River near Basalt (USGS station number 392110107011300), Roaring Fork River near Emma, CO (USGS station number 09081000), and the Roaring Fork River at Glenwood Springs (USGS station number 09085000).

Data presented were collected during Water Year 2000. In addition, historic streamflow and water quality data are presented for the Roaring Fork River near Emma, CO and the Roaring Fork River at Glenwood Springs. All data presented are available in Water Resources Data for Colorado Volume 2 for various Water Years. Streamflow data and water quality data collected at a USGS streamgauging station (eight digit downstream order number) are available on the Internet at http://water.usgs.gov/nwis. Of particular note are two samples for dissolved chloride collected January 13, 2000 at the Roaring Fork River near Basalt. The samples were collected at 0830 and 1330 (1:30pm). The sample collected at 0830 represents conditions when no runoff was occurring. Between 0830 and 1330 air temperatures rose above freezing and snowmelt adjacent to roads and elsewhere entered the stream. Between 0830 and 1330 streamflow at the Roaring Fork River near Basalt was estimated to have increased by 28 cubic feet per second. Dissolved chloride concentrations decreased from 5.5 milligrams per liter at 0830 to 4.7 milligrams per liter at 1330.

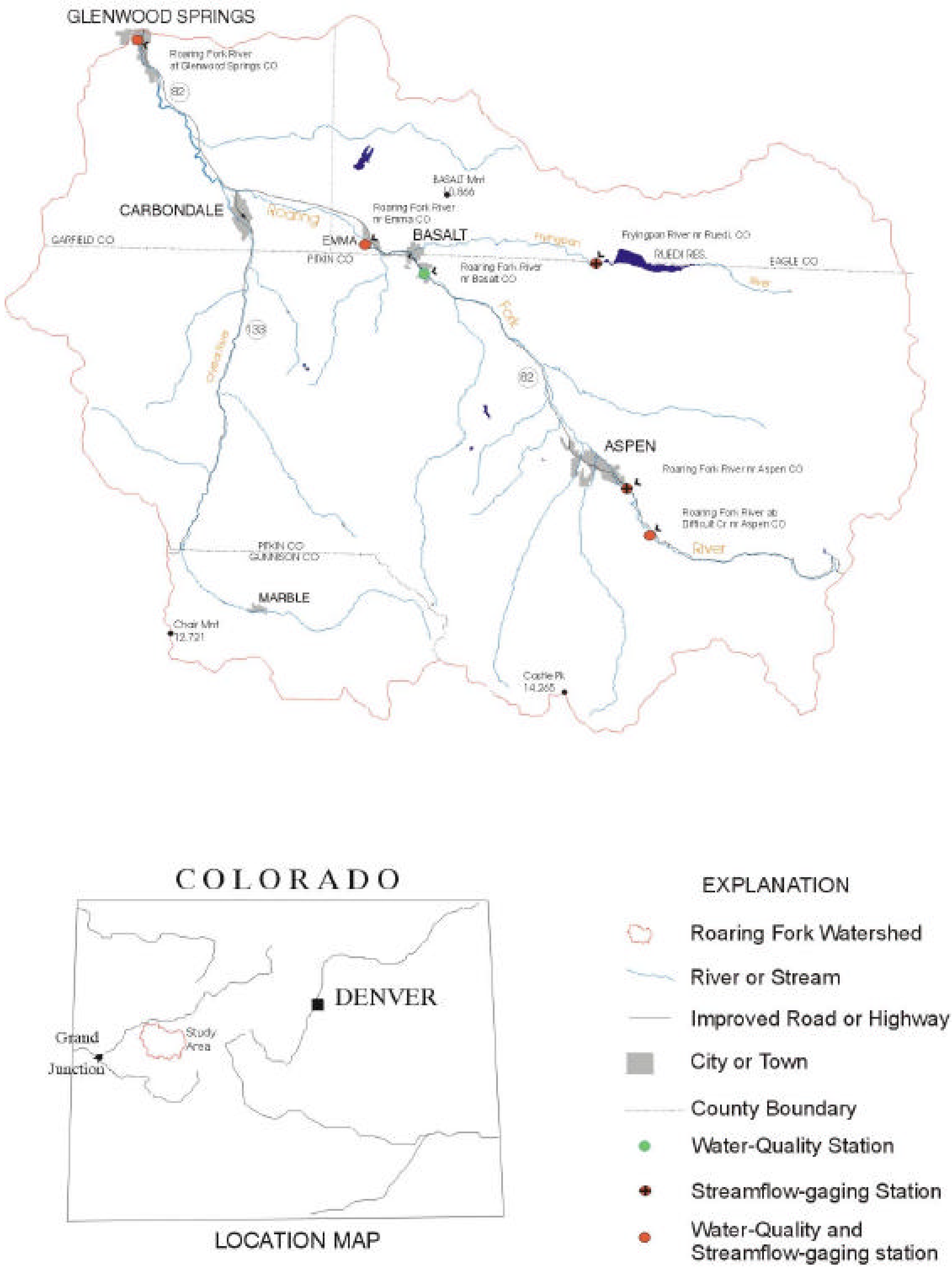


Figure 2. Location of USGS Water Sample Collections.

Daily mean specific conductance and daily mean streamflow for the Roaring Fork River above Difficult Creek and calculated streamflows for the Roaring Fork River near Basalt are presented in Figure 1-D (Appendix D). The calculated flows for the Roaring Fork River near Basalt were computed by subtracting the flows for the Fryingpan River near Reudi (USGS station number 09080400) from the flows for Roaring Fork River near Emma. This calculation does not account for inflows that occur downstream from the Fryingpan River near Reudi and between the Roaring Fork River near Basalt and the Roaring Fork River near Emma. Specific conductance is inversely related to streamflow. As streamflow rises specific conductance decreases (Figure 1-D, Appendix D). Specific conductance is an indirect measurement of dissolved solids in water.

Dissolved chloride-specific conductance relations are illustrated in Figures 2-D through 5-D for selected sites on the Roaring Fork River. For the Roaring Fork River above Difficult Creek, only two samples had concentrations above the minimum reporting level (0.29 milligrams per liter). Other laboratory results for dissolved chloride at this site are reported as less than (censored) values or were estimated by the laboratory below the minimum reporting level (Figure 2-D, Appendix D). Because of the small range in concentrations and because of censored values, a relation between dissolved chloride and specific conductance is difficult to define. Plots of dissolved chloride-specific conductance relation for the Roaring Fork River near Basalt, Roaring Fork River near Emma, and the Roaring Fork River at Glenwood Springs indicate there is a good (nonlinear) relation between dissolved chloride concentrations and specific conductance (Figures 3-D – 5-D, Appendix D). Figure 3-D represents the relation that can be used at the Roaring Fork River near Basalt to synthesize dissolved chloride concentrations using continuous record of specific conductance. Preliminary results of this data synthesis indicate, that for the period represented by the continuous record of specific conductance, dissolved chloride was not predicted to occur above 5.5 milligrams per liter. Downstream from the Roaring Fork above Difficult Creek, the surface geology in the basin transitions from primarily igneous rocks to sedimentary rocks. The likely source of dissolved chloride found in the Roaring Fork River near Basalt is from water interacting with the sedimentary geology in the watershed. The specific conductance-dissolved chloride relation for Roaring Fork River at Glenwood Springs (Figure 5-D, Appendix D) compares the relation for data representing 1950-1984 and 1996 to 2000. The comparison indicates that there does not appear to have been a shift in the relation between the periods.

Dissolved chloride versus streamflow for selected sites on the Roaring Fork River is shown in Figures 6-D through 9-D (Appendix D). Because of the small range in concentrations and because of values below the minimum reporting limit, a relation between dissolved chloride and streamflow for the Roaring Fork River above Difficult Creek is difficult to define. Plots of dissolved chloride versus streamflow for the Roaring Fork River near Basalt, Roaring Fork River near Emma, and the Roaring Fork River at Glenwood Springs show a good inverse relation between dissolved chloride concentrations and streamflow. For the Roaring Fork River at Glenwood Springs, there have been dissolved chloride data available since the early 1950s. Figure 9-D (Appendix D) illustrates the relation between dissolved-chloride data collected between 1950 and 1984 and dissolved-chloride data collected during 1996 to 2000. Similar to the specific conductance-dissolved-chloride relation for Roaring Fork River at Glenwood Springs (Figure 5-D, Appendix D), the comparison of data representing 1950-1984 and 1996 to 2000 indicates that there does not appear to have been a shift in the relation between the periods.

A plot of dissolved chloride loads (concentration multiplied by streamflow) for the Roaring Fork River near Basalt during Water Year 2000 is presented in Figure 10-D (Appendix D). These data provide an indication of the seasonal variation in dissolved chloride loads.

Figure 11-D is a plot of dissolved chloride concentrations at selected sites for comparable times of the year representing similar rates of streamflow. The plot illustrates the effects of inflow from various portions of the basin on dissolved chloride concentrations in the Roaring Fork River basin. Upstream from Difficult Creek, dissolved chloride concentrations are at or near the detection limit. Dissolved chloride concentrations increase in the stream reach between Aspen and Basalt. Dilution from the Fryingpan River is indicated by a decrease in concentrations at the Roaring Fork River near Emma, CO. The large increase in dissolved chloride concentrations at the Roaring Fork River at Glenwood Springs is most likely attributed to the inflow of thermal springs in the lower portion of the basin (Kirkham et al 1999).

6.2. Roaring Fork Conservancy Water Quality Data

The Roaring Fork Conservancy has been collecting water samples for water quality analysis in the Roaring Fork River from the headwaters at Difficult Creek to Glenwood Springs, Colorado since September 2000. Samples have also been collected from the Crystal River, Frying Pan River, and several creeks, all of which flow into the Roaring Fork River (see Figure 2). The water was analyzed for conductivity and total chlorides. Conductivity is a measure of the ability of water to carry an electric current and is directly related to the presence of various ions, such as calcium, magnesium, sodium, potassium, carbonates, sulfates, and chlorides in the water. The Conservancy also analyzed the water for total chlorides using the silver nitrate titration method. This analysis differs from the dissolved chlorides measured in the USGS study. Thus, the results of the two types of analysis (i.e., total chloride and dissolved chloride) are not comparable (P. von Guerard, USGS, personal communication).

Samples have been collected at monthly intervals since September 2000. Sampling will continue through September 2001. The data collected between September 2000 and June 2001 were provided by Paul Hempel of the Roaring Fork Conservancy and are presented in Table 11.

The Conservancy data provides a baseline indication of spatial and temporal variations in chloride and conductivity levels in the rivers of the Roaring Fork Valley. The data for these parameters reflect background levels, and future data will be utilized to track changes in chloride and conductivity levels, such as those potentially caused by factors such as runoff of deicing compounds.

The conductivity and total chloride results were reviewed to evaluate the differences that existed at different locations and times of the year. The conductivity values from the Roaring Fork River were higher in September, and January through April than in October through December and May through June. The total chloride results were lower in September, December, and April through June and higher in October and November, and January through March. Although there is generally a positive relationship between chloride and conductivity values (i.e., as the conductivity levels increase the chloride levels will also increase), there are two data points

Table 11. Conductivity and Chloride Data Collected from September 2000 to June 2001 by Roaring Fork Conservancy.

Sites Sept-Dec 2000	September		October		November		December	
	Conductivity (uS/cm)[1]	Chlorides (mg/l)[2]	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)
Difficult	45	1	17.7	6	18	2	20.6	4
Mill St Br	65	2	22.7	5	27	2	26.3	4
Slaughterhouse	176	2	62.8	13			82.6	6
Brush Cr	225	9	88	13	93	12	93.1	13
Gerbaz Br	232	4	93.2	9	99	8	99.6	7
Capitol Cr	274	4			160	4	159.4	11
Snowmass Cr	303	4			122	5	120	7
Below RF Club	249	6	100.5	8	106	6	120.8	11
7-11 Br	253	6	101.5	9			106.2	7
Meredith	20	2	27.8	4	33	3	34.2	3
Baetis Br	100	3	41.6	4	47	3	44	3
Below 7 Castles	104	2	47.4	4	50	2	49.1	3
Upper Basalt Bridge	105	2	51.1	5			51.4	4
Midland	148	2	70.7	7	78	4	78.4	5
Sopris Cr	256	5	100.3	9	105	7	105.2	8
Emma	187	4	87.6	6	96	9		
Ranch @ RF	210	4	93.8	8	98	8	93.5	8
Genter Mine Br	118	2	68.2	4	92	2	102.8	7
Redstone	205	2			104	5	108.6	5
Coal Cr/Rec	474	11	174	15	233	18	210	16
Coryell Ranch	301	7	129.8	10	142	8	140.1	11
Sanders Ranch	254	5	115.1	9	50	7	114.8	10
Park East	306	33	143.1	48	53	36		
7th St Br	323	41	149.4	55	150	43		

Table 11 (continued). Conductivity and Chloride Data Collected from September 2000 to June 2001 by Roaring Fork Conservancy.

Sites Jan-June 2001	January		February		March		April		May		June	
	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/cm)	Chlorides (mg/l)	Conductivity (uS/l)	Chlorides (mg/l)
Difficult	56.3	4	77.1	3	37.3	1	35	2	15	2	20.5	1
Mill St Br	85.1	5	133.6	11	51.2	3	29	2			22.4	2
Slaughterhouse	103.3	6	140.1	7			179	4	54.6	3		
Brush Cr	368.6	17	185.7	24	187.6	23	216	11	72	3		
Gerbaz Br	275.8	9	176.7	9	155.9	7	212	5	61.1	3	89.1	2
Capitol Cr	463	12	289.9	10	335.9	22	197	5	202.8	7	275.1	7
Snowmass Cr	340.7	12	212.9	7	265.4	8	151	5	71.1	3	108.2	3
7-11 Br	145.8	10	185.6	9	157.8	7	128	7				
Meredith			140.2	4					25.7	3		
Baetis Br	155.1	4	103.6	3	106.5	2	85	2	71.6	2	81.1	2
Upper Basalt	85	4	152.5	3	98.7	2	89	3				
Sopris Cr			231.6	15	451.1	7	145	6	95.1	3	106	3
Emma	458.1	10	331.1	8	170.4	6	111	4	88	3	105.6	3
Ranch @ RF	260.3	9	165.6	8	158.2	7	122	5	82.8	3	102.4	4
Genter Mine Br	282.8	4	214.1	3	178.8	3	111	2	49.2	2	62.4	3
Redstone	353	5	212.1	5	460.1	4	114	4				
Coal Cr/Rec			367.5	16					89.6	4		
Crystal	423.7	11	333.7	14	251.2	10	161	8	74.5	3	74.5	2
Coryell Ranch	426.3	12	261	13	246.2	11	175	8	137.3	3	81.3	4
Sanders Ranch	337.7	8	203	9	195.9	8	131	7	69	3	99.6	4
4 Mile Cr			244	14	237.4	14	122	9	236.3	11	13	217.6
Park East	388.5	28	233.2	27	223.7	24	142	14	74.9	7		
7th St Br	409.9	38	257.3	42	253.1	35	148	22	110.9	13		

[1] - uS/cm means microSiemens/centimeters and is the unit of measure for reporting conductivity.

[2] - mg/l is the same as parts per million (ppm)

where this relationship differs from the norm. In October and November, the conductivity results were low whereas the total chloride levels were high. From January to March, both conductivity and chloride levels were relatively high.

The conductivity values from the Frying Pan River and Crystal River were lower in October through December and higher from January through March, which is similar to the conductivity results from the Roaring Fork River. The chloride values from the Crystal River were almost twice as high as the chloride values from the Frying Pan River, although the chloride values from these two rivers were lower than the chloride values from the Roaring Fork River.

The conductivity and chloride levels at the Coal Creek sampling station were generally higher than at the other sampling locations. The Mancos Shale deposit at that location adds more minerals to the water, and therefore would result in higher conductivity values (P. Hempel, Roaring Fork Conservancy, personal communication). A large geological feature and the presence of hot springs near Glenwood Springs were postulated to be the cause of higher chloride levels in that area (P. Hempel, RFC, personal communication). However, the chloride levels were still below the Colorado regulatory limit of 250 ppm for chlorides (Regulation No. 31).

In order to further explain the differences in the conductivity and total chloride data reported at the different times of year and locations on the Roaring Fork River and its tributaries, the following additional information will be assessed:

- Specific sampling locations (latitude-longitude) so that the data could be compared with the results obtained by the USGS
- Geology of the area (e.g., type of rocks, presence of thermal springs, etc.)
- Drainage of the area, aspect, and elevation
- Land use (i.e., miles of roads in a basin and other possible sources of chlorides and other ions), and
- Stream flow values to assist in determining the relative importance of chloride contributions from a basin.

A detailed report of the completed data collected by the Roaring Fork Conservancy, in which the factors mentioned above will be evaluated, will be available from the Conservancy in Fall 2001.

7. HUMAN HEALTH EFFECTS OF DEICERS

The three main routes through which deicing chemicals can affect human health are by ingestion, inhalation, and dermal contact. The degree of potentially harmful effects is influenced by concentration (dose), duration of exposure, frequency of exposure, and individual variability (Chang et al 1994). The effects of deicers on human health can be estimated on the basis of toxicity tests conducted on mammals (e.g., rats, mice, rabbits) or from human epidemiology studies. The types of toxicity tests conducted to determine potential human health effects include acute oral toxicity, acute inhalation toxicity, acute dermal toxicity, eye irritation, skin irritation, sub-chronic oral toxicity tests (Cheng and Guthrie 1998), and long-term studies of cancer and other illnesses. The acute toxicity value of the deicer tested is expressed as a LD50, which is the dose that causes mortality to 50% of the test animals. Oral toxicity (LD50) values for rats in the range of 500-5,000 mg/kg are considered to be slightly toxic, while toxicity values between 5,000 and 15,000 mg/kg are considered to be practically non-toxic (Hiatt et al 1989).

The human health effects of the deicers and other snow and ice control materials will be separated into chloride-based and acetate-based deicers and sand. The effects of the trace metals present in the deicers will be discussed separately in Section 7.4.

7.1. Chloride-based Deicers

7.1.1. Sodium Chloride

Sodium chloride is often used in combination with sand for snow and ice control. Toxicity tests have been conducted on small mammals to determine the acute and sub-chronic oral toxicity from sodium chloride. The results of the toxicity tests are shown in Table 12. The oral toxicity test results in rats exposed to sodium chloride suggest that this deicer is slightly toxic to humans (Chang et al 1994).

Exposure to small amounts of sodium chloride has been reported to cause mild irritation to the nose and throat, mild skin irritation, gastrointestinal effects from ingestion, and irritation and inflammation of the eyes (MSDS).

Elevated sodium levels in drinking water have been linked to hypertension in humans (Cheng and Guthrie 1998). However, there is no statistically significant link between road salting activity and deaths due to hypertension. The concentration of salt deicer in some of the communities that were studied was less than 5% of the level thought to pose a significant health risk (Vitaliano 1992). The American Medical Association has established a limit of 22 ppm sodium for low-salt or salt-free diets (Moran et al 1992). Sodium chloride is not listed as a carcinogen by the EPA or other government health agencies.

7.1.2. Magnesium Chloride

The magnesium chloride deicers that are used in Colorado contain various types of corrosion inhibitors, depending on the brand of magnesium chloride used as a deicer. The magnesium chloride deicers also contain trace metals (See Table 3). The available information on the corrosion inhibitors in the different magnesium chloride products is presented later in this section.

The magnesium chloride deicers that are used or have recently been used in Colorado include FreezGard Zero® with Shield LS, Ice-Stop™CI, Caliber M1000, and Ice Ban M50. Oral toxicity tests on rats indicate that magnesium chloride is practically non-toxic to rats (Cheng and Guthrie 1998) (Table 12). Magnesium chloride deicers can result in skin and eye irritation, and minor digestive tract symptoms. Acute exposure to magnesium dust can irritate the mucus membranes of the upper respiratory tract (CDPHE 2000). The CDPHE study reported that there was no evidence that magnesium chloride was a carcinogen. It is also not listed as a carcinogen in the MSDS. A more detailed summary of the potential human health effects of magnesium chloride discussed in the CDPHE (2000) report is presented in Section 7.5.

The chloride limits for drinking water, established by the US Public Health Service, are a maximum of 250 ppm, with 25 ppm being a recommended level. There is no evidence of adverse health effects attributed to elevated levels of the magnesium ion in drinking water (Health Canada 1996).

7.1.3. Corrosion Inhibitors

Shield LS®

One of the corrosion inhibitors used in the magnesium chloride deicer is Shield LS®. This corrosion inhibitor is a proprietary organic material that is added to the magnesium chloride deicer FreezGard Zero at a concentration of approximately 1.9%. The Shield LS corrosion inhibitor may cause mild irritation to the respiratory tract, skin and eyes. No gastrointestinal effects have been reported, if less than 1.2 liters is ingested (Paradigm Chemicals LLC, Product Data Sheet). The MSDS states that there are no hazardous materials in Shield LS.

Triethanolamine (TEA)

Triethanolamine (TEA) is an organic substance that is used as a corrosion inhibitor in some magnesium chloride deicers. Based on oral toxicity test results in rats, it is considered to be slightly toxic (MSDS). TEA is listed as a human health hazard in the MSDS and can cause skin irritation, severe eye irritation, and irritation to the digestive tract (Table 12). It is not listed as a carcinogen (MSDS).

Caliber™

Caliber is an organic material derived from corn. It is not listed as a health hazard in the MSDS. The MSDS further states that no personal protective equipment is needed for protecting respiratory tract, eyes, face, or skin and that ingestion of this product does not require any first aid procedures. Mammalian toxicity data are not available for Caliber. Caliber is not listed as a carcinogen (MSDS). The nitrate level in Caliber M1000 is below the Colorado drinking water limit (See Table 3).

Ice Ban™

Ice Ban is a concentrated liquid residue of the fermentation and processing of agricultural products, such as cane or beet sugar, corn, barley, other crops and milk. Since Ice Ban is an acidic substance, it would be expected to cause some skin and eye irritation. Ice Ban is not listed as a hazardous substance and not indicated as a carcinogen (MSDS). Ice Ban M50 contains relatively high levels of phosphorus. No limit has been established for phosphorus in drinking water (Mussato and Guthrie 2000).

The level of nitrates in Ice Ban is above the Colorado drinking water limit of 10 ppm. Elevated levels of nitrates could potentially lead to infantile methaemoglobinaemia (blue-baby syndrome), which can develop in very young children when high blood nitrate levels interfere with oxygen uptake from the blood (Mussato and Guthrie 2000).

7.1.4. Inhibited Calcium Chloride (Liquidow Armor*)*

Calcium chloride is described as a skin and eye irritant. Prolonged exposure of calcium chloride to the skin may cause irritation and burns. Incidental ingestion of calcium chloride during normal handling is not likely to cause any symptoms. Inhalation of mists containing calcium chloride may cause irritation to the upper respiratory tract (MSDS). Oral toxicity tests on rats revealed that calcium chloride is slightly toxic (Cheng and Guthrie 1998) (Table 12). Calcium chloride is not listed as a carcinogen (MSDS).

There is no evidence of adverse health effects resulting from elevated levels of the calcium ion in drinking water (Cheng and Guthrie 1998). The level of nitrates in inhibited calcium chloride is above the Colorado drinking water limit, which is probably due to the proprietary organic corrosion inhibitor in this deicer.

7.2. Acetate-based Deicers

7.2.1. CMA®

Studies have been conducted on the potential toxic effects of Calcium Magnesium Acetate (CMA) using rats, rabbits, and guinea pigs (Table 13).

CMA is considered to be slightly toxic to rats when tested for oral toxicity (Cheng and Guthrie 1998). McFarland and O'Reilly (1992) reported that CMA is slightly irritating to the eyes and may cause mild irritation to the nose, throat, and intestinal tract.

The concentration of nitrates in CMA has not been reported. However, it is possible that CMA has levels of nitrates above the Colorado drinking water standard (10 ppm), since CMAK, which consists of CMA and Potassium Acetate (KA), has nitrate levels above the standard, whereas Potassium Acetate does not (See Table 3).

Table 12. Health Effects of Selected Deicers[1].

Common name	Mammalian Toxicity	Potential Minor Health Effects	Potential Serious Health Effects	Carcinogen
Chloride Deicers				
Magnesium Chloride	LD50 (acute oral) 8100 mg/kg.[2]	Skin, eye, respiratory, GI tract irritation	No	No
Sodium Chloride	LD50 (oral-rats) 3750 mg/kg[2]; subchronic (oral-rats) 2690 mg/kg/day.[3]	Skin, eye, respiratory, GI tract irritation	Hypertension	No
Calcium Chloride	LD50(skin) >5000 ppm; LD50 (oral-rats) 4000 mg/kg.[2]	Skin, eye, respiratory, GI tract irritation	No	No
Acetate Deicers				
CMA	LD50 >5000 mg/kg (skin-rabbit)[4]; LC50 (4-hr inhalation-rats) >4.6 mg/l[5]; LD50-5000 mg/kg (oral-rats).[2]	Eye, skin, respiratory and GI tract irritation	No	No
CMAK	LD50 >5000 mg/kg (expected)	Eye, skin, GI tract irritation	No	No
NAAC	LD50 (oral-rat) 3530 mg/kg[5]; LD50 (SCU-mouse) 8000 mg/kg[5]; LD50 (IV-mouse 335 mg/kg.[5]	Eye, skin, respiratory and GI tract irritation	No	No
Potassium Acetate	LD50 >5000 mg/kg (rabbits); acute oral-rats 3250 mg/kg.[2]	Eye, skin, respiratory and GI tract irritation	No	No
Sand	NA	Eye, respiratory tract irritation	Silicosis	Yes
Corrosion Inhibitors				
Caliber	NA	No	No	No
Ice Ban	NA	No	No	No
Triethanol-amine	LD50 (oral-rat) 8000 mg/kg; skin rabbit 560 mg/kg (24hr); Eye rabbit 5.62 mg/kg.	Skin, eye, digestive tract irritation	No	No
Shield LS[6]	NA	No	No	No

[1] – Based in information in MSDS and other sources
[2] – From Cheng and Guthrie (1998)
[3] – From Chang et al (1994)
[4] – From McFarland and O'Reilly (1992)
[5] – From Cryotech Product Information Sheets
[6] - From Paradigm Chemicals LLC (Envirotech)
NA = Data not available; > = Greater than; < = Less than.
Note: Higher LD50 means lower toxic effects.

Table 13. Mammalian and Human Toxicity Testing Results for Calcium Magnesium Acetate (CMA) (from McFarland and O'Reilly 1992).

Toxicity Test	Test Animals	Test Results[1]	Comments
Acute Inhalation	Rats	LC50 >5000 mg/m3	--
Acute Oral	Rats	LD50 >5000 mg/kg	Practically non-toxic
Subchronic Oral Toxicity	Rats	No Effect or Low Effect at 1000 mg/kg for 28 days	--
Eye Irritation	Rabbits	Slightly irritating	--
Acute Dermal	Rabbits	LD50 >5000 mg/kg	Not a hazard
Skin Irritation	Humans	Minimal irritation	--
Skin Sensitizer	Guinea Pigs	Not a skin sensitizer	--

[1] – Higher LC50 or LD50 means lower toxicity.
[2] - > means greater than.

Calcium and magnesium ions in CMA are essential elements for human nutrition. Thus, there is no evidence of adverse health effects attributed to elevated levels of calcium and magnesium in drinking water (Health Canada 1996).

7.2.2. Potassium Acetate (CF7®)

Potassium Acetate (Cryotech CF7) has been reported to show slight oral toxicity in rats (Cheng and Guthrie (1998) (see Table 12). Inhalation of Potassium Acetate may cause irritation of the nose, throat, and respiratory tract. It may also cause mild irritation to skin, eyes, and digestive tract. The levels of nitrates in Potassium Acetate are below the Colorado drinking water limit.

The effects of Potassium Acetate in young children or adults with kidney or heart disease include irritation and inflammation of the stomach lining, muscular weakness, burning, tingling and numbness sensations of hands and feet, slower heart beat, reduced blood pressure, and irregular heart beat (MSDS). The effects are probably due to the potassium.

7.2.3. CMAK™

Liquid CMAK, manufactured by Cryotech, is a blend of CMA and Potassium Acetate. For chemical analysis and toxicity testing a mixture of 50% CMA and 50% Potassium Acetate was used (Mussato and Guthrie 2000). Potential minor health effects of CMAK include irritation of the eyes, skin, and digestive tract (Table 12).

Chemical analysis of CMAK revealed that it contains levels of nitrates that exceed the Colorado drinking water limit (See Table 3). Elevated levels of nitrates may potentially lead to infantile methaemoglobinaemia (blue-baby syndrome), which can develop in very young children when high blood nitrate levels interfere with oxygen uptake from the blood (Mussato and Guthrie 2000).

7.2.4. NAAC™

Sodium acetate (NAAC) is a solid deicer, which was developed as a replacement for urea deicers (Cryotech Product Information Sheet). The oral toxicity results on rats and mice indicate that it is slightly toxic (MSDS) (Table 12). NAAC dust, at high concentrations, may cause irritation of eyes, nose and throat, skin, and digestive tract. NAAC is not listed as a human carcinogen (MSDS). The level of nitrates in NAAC has not been reported.

7.3. Sand

The use of sand for snow and ice control results in large amounts of particulate material in the air. Sand is reported to be the source of approximately 45% of the PM10 (particulates less than 10 µm in diameter) in the air (Chang et al 1994; Cowherd 1998) and up to 83% in Aspen (L. Cassin, Aspen Environmental Health Department, personal communication). In 1987 regulations were promulgated by EPA to establish limits to the amount of PM10 permitted in the air. These regulations were passed because medical evidence indicated that particulate matter less than 10 µm could be inhaled deeply into the lungs and reach the alveoli, the sites of gas exchange (Chang et al 1994). The ambient air quality standards for PM10 established by EPA are 50 $\mu g/m^3$ (annual arithmetic mean) and 150 $\mu g/m^3$ (24-hour limit).

The health effects of PM10 include eye, nose and throat irritation, difficulty in breathing, chest pains, cough, inflammation of the alveolar cells of the lungs, tumor formation, and fibrosis (Table 12). Sand containing high levels of silica could also result in silicosis, a disabling, progressive and sometimes fatal fibrosis of the lung tissue. Symptoms of silicosis often may not develop until years of exposure to particulate matter (Chang et al 1994; MSDS). The silicon dioxide in sand is classified as a carcinogen (MSDS). Studies have shown increased hospital admission, illness, and death rates associated with increased PM10 levels (L. Cassin, personal communication). Individuals at high risk from PM10 exposure include children, individuals with respiratory or cardiovascular diseases, and the elderly (CDPHE 2000). Studies conducted on children in areas of high PM10 levels have shown significant decrease in pulmonary function (Chang et al 1994).

7.4. Potential Health Effects of Trace Metals in Deicers

The trace metals that are present in magnesium chloride and the other deicers used in Colorado may include arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. The concentrations of these metals in the deicers are shown in Table 14. However, some of the deicers discussed in this report were not analyzed for all the chemicals mentioned above. In addition, the analytical method and detection limits used to determine the presence of trace metals in different deicers varied substantially. Thus, specific information on the concentration of metals in certain deicers (e.g., NAAC) is not available. In general, the deicers that are "mined" (e.g., sodium chloride and magnesium chloride) are more likely to contain trace metals than the manufactured deicers (e.g., CMA) (L. Cassin, Aspen Environmental Health Department, personal communication). The element cyanide, which is not classified as a metal, is present in some deicers and radioactive cesium has been reported to be present in magnesium chloride (L. Cassin, Aspen Environmental Health Department, personal communication).

The trace metals arsenic, cadmium and chromium (VI) are known carcinogens. The trace metals can cause harmful effects on the lungs, liver, kidneys, central nervous system and other organs. The potential health effects associated with each of the metals are shown in Table 15. The EPA drinking water limit and OSHA exposure limit for an 8-hour day and 40-hour work week are also provided in Table 15. A more detailed discussion of the health effects of the trace metals is presented in Appendix E.

The concentrations of trace metals in deicers used on roadways must meet specifications established by Colorado, other states or the PNS. Deicers containing metals above the specifications are not considered to be acceptable for use on public roads and highways.

Table 14. Trace Metal Concentrations (ppm) in Selected Deicers[1,2].

Deicers	Arsenic	Barium	Cadmium	Chromium	Copper	Cyanide	Lead	Mercury	Selenium	Zinc
Magnesium Chloride										
FreezGard Zero w/ Shield LS	0.001	0.0013	0.00001	0.0003	0.0047	<0.0003	0.0009	<0.0004	<0.0008	0.007
Ice-Stop CI	<0.5	<0.07	<0.05	0.13	<0.09	<0.05	<0.3	<0.01	<0.5	0.34
Caliber M1000	<1	0.23	<0.02	<0.1	<0.1	0.09	0.57	<0.01	<1	0.71
Ice Ban M50	<1	0.11	<0.02	0.4	1.1	<0.05	0.3	<0.01	<0.1	16.1
Sodium/Calcium Chloride										
Sodium Chloride Brine (25%)	<0.2	<0.2	<0.2	<0.5	0.78	0.25	<0.1	<0.01	<0.1	2
Ice Slicer	ND	<4.0	ND	ND	0.29	<0.2	<0.2	ND	ND	10
Inhibited Calcium Chloride	<2	1.27	<0.1	<0.5	<0.1	0.12	<0.5	<0.01	<1	0.8
Acetate-based Deicers										
CMA (25%)	<0.2	2	<0.2	<0.5	<0.1	0.2	<0.1	<0.01	<0.1	<0.5
Potassium Acetate (50%)	<0.2	<0.2	<0.2	<0.5	<0.1	0.33	<0.1	<0.01	<0.1	<0.5
CMAK (50:50)	<0.2	0.49	<0.2	<0.5	<0.1	0.25	<0.1	<0.01	<0.1	<0.5
NAAC	<10	NA	NA	<1	NA	NA	<5	NA	NA	NA
Other										
Sand	<0.5	NA	<0.1	<0.5	<0.5	NA	<0.5	NA	NA	NA
Colorado Drinking Water Standards (ppm)	0.05	2.0	0.005	0.1	NA	0.2	NA	0.002	0.05	NA
PNS Specifications (ppm)	5.0	10.0	0.2	0.5	0.2	0.2	1.0	0.05	5.0	10.0

[1] = The results of the analytical tests are dependent on the specific test conducted. Different test methods were used for many of the deicers tested. A more sensitive test will have a lower detection limit. Therefore, a concentration of 0.001 ppm may not be less than <0.05 ppm.

< = below the detection limit of analytical test. The detection limit varies with the sensitivity of the analytical test

[2] = Note that the expected dilution of deicers from roadway application to nearby streams is 500-fold (Lewis 2000).

ND = Not detected

NA = Not available.

Table 15. Effects of Metals on Human Health[1].

Metal	Target Organs	Carcinogen	EPA Limit in Drinking Water (ppm)	OSHA[2] Exposure Limit (8-hr day/40-hr week)
Arsenic	Lung, skin, liver, kidneys, lymphatic system	Yes (lung, lymphatic cancer)	0.05	0.010 mg/m^3
Barium	Liver, kidneys, heart, spleen, stomach	No	2.0	0.5 mg/m^3
Cadmium	Kidneys, lungs, prostate, blood	Yes (lung, prostate)	0.005	0.200 mg/ m^3
Copper	Eyes, kidneys, liver, respiratory system; increased risk with Wilson's disease.	No	1.3	0.1 mg/m^3
Chromium (metal)	Eyes, skin, respiratory system	No	-	1mg/m^3
Chromium VI	Kidneys, liver	Yes	0.1	0.52mg/m^3
Cyanide	Brain, heart, blood, thyroid	No	0.2	5 mg/m^3
Lead	Eyes, GI tract, CNS, kidneys, blood, gums.	Insufficient evidence for humans	0.015	0.0015 mg/m^3 averaged over 3 mo (EPA)
Mercury	Eyes, skin, nervous system, kidneys.	Possible carcinogen	0.002	0.05 mg/m^3 (metallic mercury vapor)
Selenium	Spleen, eyes, skin, respiratory system, liver, kidneys, blood.	Selenium sulfide is possible carcinogen	0.05	0.2 mg/m^3
Zinc	Eyes, skin, respiratory system.	No	5	1 mg/m^3 (zinc chloride)

[1] – ATSDR Toxicological Fact Sheets (ToxFAQs™); NIOSH Pocket Guide to Chemical Hazards (1994).
[2] – OSHA = Occupational Safety and Health Administration

The Colorado Department of Public Health and Environment (CDPHE 2000) recently conducted a quantitative risk assessment using standard EPA methodology (EPA 1989) to determine the potential health risks from air exposure to the heavy metals found in the deicers. Although the deicing chemicals become airborne through the movement of vehicles on the roads, the levels of metals in the air had not previously been studied. Estimates of exposure were based on data obtained from air monitoring filters placed on building roofs at various locations in Aspen, Denver, and Pagosa Springs. When the risk assessment assumed that human exposure was 24 hours/day and 365 days/year, the results indicated that the concentrations of barium and manganese were high enough to potentially cause serious health effects to the liver, kidneys and other organs. It also indicated that the concentration of airborne arsenic, cadmium, and chromium exceeded a cancer risk of 1 in 1,000,000 (i.e., $1x10^{-6}$) for most sites. When the risk assessment used an exposure assumption of 8 hours/day and 6 months/year, the results indicated that the systemic effects from barium and manganese were unlikely. However, the metals chromium and arsenic still exceeded the cancer risk of $1x10^{-6}$.

The concentrations of metals found on the air monitoring filters could not be attributed to a specific source (M. Silverstein, CDPHE, personal communication). Possible sources of metals in the air include tire materials (tread and burning), burning of household trash, cigarette smoking (source of cadmium, nickel and zinc), power plant and combustion sources (source of mercury), and occupational exposures. The native soil in Aspen has been shown to be a source of arsenic and cadmium (L. Cassin, Aspen Environmental Health Department, personal communication).

The CDPHE (2000) report recommended that more precise quantitative analyses, based on additional data, were necessary to provide a better assessment of the potential effects of the trace metals on human health. A more detailed summary of the CDPHE (2000) report is provided in Section 7.5 below.

7.5. Review of CDPHE Report on Health Effects of Deicers

The Colorado Department of Public Health and Environment (CDPHE 2000) conducted a study of the potential health effects of magnesium chloride and sodium chloride deicers, corrosion inhibitors, and particulate matter through a review of the current toxicology literature. The CDPHE report also evaluated the potential risk of exposure to the deicers by conducting a quantitative risk assessment using standard EPA methodology (EPA 1989). Below is a summary of the CDPHE report.

7.5.1. Potential Health Effects of Deicers

7.5.1.1. Magnesium Chloride

The studies reviewed by CDPHE (2000) evaluated the effects of magnesium chloride on respiratory tract, reproduction, ingestion, and carcinogenicity. Inhalation studies in rabbits exposed to magnesium chloride showed no harmful effects at concentrations of 1.1 mg/m^3 or 3.9 mg/m^3 after 4-6 weeks. Acute exposure to magnesium dust, however, was reported to irritate the mucous membranes of respiratory tract.

A thirteen-week oral toxicity study of magnesium chloride in mice by Tanaka et al (1994) was reviewed by CDPHE (2000). Various doses of magnesium chloride were administered to the mice. The authors concluded that the minimal dose of magnesium chloride that would cause toxic effects in mice was at a concentration above 2.5% (Tanaka et al 1994).

A review of reproductive studies by CDPHE showed conflicting results. Magnesium chloride was injected into pregnant mice in one study and showed accelerated development and learning in the offspring. Another study reported adverse reproductive effects from magnesium chloride. However, the results of the latter study were not statistically significant. Data from REPROTEXT databases indicated that magnesium chloride was "not known to affect animal reproduction."

Another study reviewed by CDPHE (2000) evaluated the potential of carcinogenicity of magnesium chloride by conducting a long-term feeding study in mice (Kurata et al 1989). Groups of male and female mice were given magnesium chloride at various dose levels for 96 weeks. Although there was a decrease of body weight in females in the highest dose group, there was no difference in survival between treatment and control groups in either males or females. There were also no differences in tumor incidence between the treated animals and the controls. The results showed a lack of carcinogenic effects from exposing mice to a diet with magnesium chloride (Kurata et al 1989).

The CDPHE report concluded that there was no evidence that magnesium chloride was carcinogenic.

7.5.1.2. Sodium Chloride

The CDPHE report also evaluated the human health effects of the sodium chloride deicer. CDPHE (2000) reported that acute exposure to sodium chloride could cause eye and skin irritation. Ingestion of large quantities of sodium chloride can irritate the stomach, and high dietary intake in humans was reported to cause a greater incidence of hypertension and cardiovascular disease. However, the report concluded that there was no evidence that sodium chloride was carcinogenic. The MSDS for sodium chloride also did not indicate that sodium chloride was a carcinogen. In laboratory experiments with rats and mice, sodium chloride was reported to cause birth defects and toxic effects to the embryo and fetus. High doses injected into mice resulted in toxicity to the embryo and skeletal defects. No studies were found that reported similar effects in humans (CDPHE 2000).

The CDPHE report described the effects of three corrosion inhibitors used in the magnesium chloride deicers, a proprietary inhibitor, zinc sulfate, and sodium metahexaphosphate. The distributors of magnesium chloride deicers in Colorado stated that zinc sulfate and sodium metahexaphosphate are no longer used as corrosion inhibitors in magnesium chloride deicers (Randy Parsons, GMCO; Greg Leist, Envirotech).

7.5.1.3. Particulate Matter

Particulate matter (PM) is a generic term applied to a broad class of chemically and physically diverse substances that exist as discrete particles. Sources of particulate matter include natural sources, such as pollen and fire, and human sources such as agricultural practices, combustion, transportation, and industry. Some of the particulate matter can reach the lung tissue and cause serious health effects. The fraction identified as PM10, which refers to particulate matter less than 10 micrometers (µm) in size, has been shown to cause serious illnesses of the respiratory tract. Individuals most at risk from PM10 exposure include children, persons with respiratory disease or heart disease, and the elderly.

7.5.1.4. Quantitative Risk Assessment

A quantitative risk assessment was conducted, using standard EPA methodology (EPA 1989) to determine the potential health risks from exposure to the deicing salts. A risk assessment evaluates the potential of systemic effects of deicers to humans by calculating a Hazard Quotient. A Hazard Quotient (HQ) assumes that there is a safe level of exposure below which it is unlikely for even sensitive populations to experience adverse health effects (EPA 1989). A Hazard Quotient that is less than or equal to 1 indicates that long-term exposure is unlikely to produce adverse human health effects. If the HQ is greater than 1, there may be a concern for potential health effects. The probability of developing cancer over a lifetime as a result of exposure to a carcinogenic chemical is also evaluated. A risk factor of $1x10^{-6}$ means that there is a probability of 1 in 1,000,000 of an individual developing cancer (CDPHE 2000).

Estimates of exposure to the deicers were based on information obtained from air monitoring filters placed on building roofs at various locations in Aspen, Denver, and Pagosa Springs. It was not possible to determine the specific sources of the trace metals found on the air monitoring filters (M. Silverstein, CDPHE, personal communication). Potential sources of metals in the air include, auto/truck exhaust, brake wear, pavement degradation, tire materials (tread and tire burning), building materials, soil, burning of household trash, cigarette smoking (cadmium, nickel, and zinc), and power plant and other combustion sources (mercury) (M. Silverstein and M. McMillan, CDPHE, personal communication).

When the risk assessment conducted by CDPHE (2000) assumed human exposure to the metals of 24 hours/day and 365 days/year, the results indicated that the metals barium and manganese exceeded a Hazard Quotient of 1 and that arsenic, cadmium, and chromium exceeded a cancer risk of 10^{-6} for most sites sampled. When exposure to the deicers was re-evaluated by CDPHE using more refined exposure assumptions of 8 hours/day for 6 months/year, the results indicated that chromium and arsenic still exceeded the cancer risk of 10^{-6}, but that the Hazard Quotients for manganese and barium were below 1 and, therefore, unlikely to cause systemic effects. The CDPHE report noted that neither barium or manganese was detected in the magnesium chloride and sodium chloride solutions analyzed for these metals.

The Aspen Department of Environmental Health critiqued the CDPHE report and concluded that human health risk to the population of Aspen had been underestimated because 1) the samples were collected on the top of a 3-story building rather than at ground level and 2) exposure was assumed to be 8 hours/day and 6 months/year, rather than 24 hours/day and 365 days/year (L. Cassin, Aspen Environmental Health Department, personal communication).

7.6. Comparison of Health Effects

In evaluating the potential human health effects of deicers, it is important to note that the deicers are diluted rapidly from their application on roadways to surface water and drinking water supplies. The dilution of deicing products entering most the water is expected to be a factor of at least 100 (R. Wright, Idaho DOT, personal communication). Lewis (2000) estimated that the dilution of deicers was 500 fold. This factor should be taken into consideration when evaluating human health effects of the deicers.

Small mammals, such as rats, mice and rabbits, have been used as surrogates to determine the potential toxicological effects of deicers to humans. Some tests have been conducted using commercial deicer formulations. In other tests the pure form of the deicing chemical has been used in toxicity tests conducted for estimating potential human health effects (Cheng and Guthrie 1998). Thus, the test results for different deicers are not necessarily comparable.

The oral LD50 values for rats indicated that all of the deicer products tested are either practically non-toxic or slightly toxic. Based on the data reported in Cheng and Guthrie (1998), magnesium chloride had a lower potential for acute oral toxicity to rats than CMA, calcium chloride, sodium chloride and potassium acetate. Based on the MSDSs and other literature, most of the deicers have the potential to cause minor irritation to the eyes, skin, and respiratory tract. Incidental ingestion of most of the deicers could potentially cause minor gastrointestinal (GI) symptoms.

The chloride ions in sodium chloride, magnesium chloride and calcium chloride can potentially contaminate drinking water and groundwater (Cheng and Guthrie 1998). Both sodium and chloride levels are regulated in drinking water by the State of Colorado. Sodium chloride in drinking water has been linked to hypertension in humans.

The acetate-based deicers, CMA, potassium acetate, NAAC, CMAK, are biodegradable, so potential contamination of acetates in drinking water is likely to be transient. The presence of the organic materials Caliber and Ice Ban in the magnesium chloride deicers would also likely be transient.

CMAK, Ice Ban and Liquidow Armor ($CaCl_2$) contain levels of nitrates that exceed the drinking water limit. Elevated levels of nitrates may result in infantile methaemoglobinaemia (blue-baby syndrome). This condition can develop in very young children when high nitrate levels in the blood interfere with oxygen uptake from the blood (Mussato and Guthrie 2000).

Long-term exposure to the sand used for snow and ice control may cause harmful effects to humans, since the PM10 particulates in sand can penetrate the lungs and cause or exacerbate a variety of respiratory symptoms, including cough, asthma, and cardiovascular disease. It can also result in tumor formation and fibrosis and silicosis, a potentially fatal lung disease (Chang et al 1994).

Some of the trace metals in deicers are carcinogens and have the potential to cause cancer in humans. However, the metals in most of the deicers are below the PNS specifications, which were established based on drinking water standards, aquatic life standards, and hazardous waste limits. A human health risk assessment was conducted on the trace metals in magnesium chloride and sodium chloride. Based on the assumption of continuous human exposure, the levels of arsenic, cadmium, and chromium exceeded the cancer risk of 1 in 1,000,000 (CDPHE 2000). However, the CDPHE report concluded that a more precise quantitative risk assessment, requiring further analysis and based on higher quality and quantity of data, was needed to better evaluate the potential effects of exposure to deicing products.

8. OTHER FACTORS TO CONSIDER

In addition to potential environmental and human health effects of deicers, there are several other factors to consider before deciding which deicer is the best to use in a particular location or under specific circumstances. These other factors include corrosion, application rates, performance (considering eutectic and effective temperatures), costs, and benefits of deicer use. These topics are discussed below.

8.1. Corrosion

Although deicing and anti-icing chemicals have been important in making roads safe for travel in ice and snow conditions, the use of deicers has resulted in corrosion of vehicles, bridges, pipelines and utilities. Trucking companies have reported an increase in wear on their equipment since CDOT began using magnesium chloride as a deicer (Xi and Olsgard 2000). The trucking companies have reported damage to chrome, tractor or trailer bodies, aluminum parts, wheels, hoses and connectors and electrical parts. The types of damage identified most often by truckers included corrosion, pitting, staining/tarnishing, discoloration, drying/cracking (hoses), and accelerated rusting (Xi and Olsgard 2000).

There are several factors that influence corrosion of metals, including humidity, dissolved oxygen level, debris, wheel speed, location, and type of metal (Jones and Jeffreys 1992). The processes involved in structural corrosion of concrete-reinforcing steel bars used in highway structures include scaling, osmotic pressure changes, freeze/thaw cycles, reduced pH, micro- and macro-cells, deliquescence, lowered corrosion threshold, and crystal growth (Jones and Jeffreys 1992).

Test methods to measure corrosion potential of deicing chemicals have been developed by various organizations and include American Society of Testing Materials (ASTM), National Association of Corrosion Engineers (NACE), Society of Automotive Engineers (SAE) and the State of Washington Department of Transportation (WSDOT), among others. The PNS has also developed test protocols for evaluating corrosion rates of the different deicers. The PNS requires that tests for corrosion rates in deicers be conducted using the NACE Standard TM-01-69 (1976 Revision), as modified by PNS. Information on the specific test methods for corrosion is included on the PNS web site (http://www.wsdot.wa.gov/fossc/maint/pns/99deicerspecs.htm). In order for a deicer to be approved by PNS, a corrosion inhibited chemical deicer, is required to be 70% less corrosive to mild steel than sodium chloride.

In the studies reviewed in this report for evaluation of corrosion of the different deicers, various test methods and metals were used, including flat steel, rolled steel, mild steel, aluminum, and concrete. Corrosion test results have been shown to be highly dependent upon the test method used and the metal tested (E. Fink, CDOT, personal communication). Thus, the results of the tests in the studies described below are not necessarily comparable.

Jones et al (1992) reported that sodium chloride causes the greatest corrosion on steel. The magnesium chloride deicer FreezGard® with the corrosion inhibitor (PCI) was shown to cause less corrosion than distilled water alone (McCrum 1992). A ranking of corrosion effects of several deicers to bridge steel, based on laboratory tests, showed the least corrosion in FreezGard+PCI and the greatest corrosion in sodium chloride (McCrum 1992) (Table 16). In field testing on bridge steel, the least corrosive deicer was CMA®. FreezGard+PCI caused moderate corrosion, while the most corrosive deicer was sodium chloride (McCrum 1992).

Another study that evaluated corrosion in various deicers including magnesium chloride, FreezGard, and Ice Slicer® (sodium chloride) showed that corrosion was lowest in magnesium chloride, somewhat higher in FreezGard and highest in Ice Slicer (Addo 1995). A study conducted by Vancouver (1998) rated CMA as having a low corrosion potential, magnesium chloride as moderate corrosion potential, and calcium chloride and sodium chloride as causing severe corrosion (Table 16).

A study conducted by the Highway Innovative Technology Evaluation Center (HITEC 1998) compared the corrosion rate of Ice Ban with other deicers (Table 17). The results of corrosion tests using the WSDOT Test Method on flat steel showed that sodium chloride was the most corrosive and Ice Ban the least corrosive. In some tests Ice Ban was found to be less corrosive than distilled water.

Table 16. Corrosion Test Results from Various Studies.

Ranking	HITEC (1998) (flat steel)	McCrum (1992) (bridge steel – laboratory testing)	McCrum (1992) (bridge steel – field testing)	Addo (1995) (mild steel)	Vancouver City Council (1998) (unprotected steel)
Least Corrosive	70% Ice Ban + 30% $MgCl_2$	Inhibited $MgCl_2$ (FreezGard+ PCI)	CMA	$MgCl_2$	CMA
Low Corrosion	Inhibited $MgCl_2$	CMA			
Moderate Corrosion			Inhibited $MgCl_2$	$MgCl_2$ (FreezGard)	$MgCl_2$
Most Corrosive	NaCl	NaCl	NaCl	NaCl (Ice Slicer)	NaCl and $CaCl_2$

Table 17. Corrosion Rate of Selected Deicers Using the Washington State Department of Transportation Method (from HITEC 1998).

Sample	Metal	Millimeters/ Year MPY)
Sodium Chloride (3% total solids)	Flat Steel	52.94
30% Magnesium Chloride (0.9% total solids)	Flat Steel	17.44
Corrosion Inhibited 30% Magnesium Chloride (0.9% total solids)	Flat Steel	11.08
Type II Distilled Water	Flat Steel	3.82
Ice Ban (15% total solids)	Flat Steel	3.71

The PNS evaluated the corrosion rate of various deicers using its modified NACE test method and compared the corrosion with sodium chloride. The interim test results available from PNS are shown in Table 18. These data were provided by Ron Wright, Idaho Department of Transportation.

Table 18. Corrosion Rate of Selected Deicers [from PNS 2001 (Draft)]

Product	**Manufacturer of Product Tested**	**Deicer Concentration (%)**	**Corrosion Rate % Effectiveness[1]**
Corrosion Inhibited Magnesium Chloride			
FreezGard Zero with Shield LS	IMC Kalium	30	21
FreezGard Zero with TEA	IMC Kalium	30	19.7
Ice Stop CI-2000	Reilly Wendover	28.5	20.3
Caliber M1000	Envirotech Services	27	22.3
Corrosion Inhibited Calcium Chloride			
Liquidow Armor	Dow Chemical	30	26
Non-Corrosion Inhibited CMA			
Liquid CMA	Cryotech	25	-11
Corrosion Inhibited Sodium Chloride			
Ice Slicer	Envirotech Services	NA[2]	30
Calcium Magnesium Acetate (solid)			
CMA	Cryotech	96	-7
Non Corrosion Inhibited Sodium Chloride			
Cargill Dry Salt	Cargill	NA[2]	NA[2]

[1] - Corrosion rate compared to non-inhibited sodium chloride (100%)
[2] NA = not applicable

A study to compare corrosion in magnesium chloride with that of sodium chloride was recently conducted for CDOT by the Materials Laboratory at the University of Colorado at Boulder (Xi and Olsgard 2000). Since the final report is not yet available, the results presented here are based on the draft report. The University of Colorado Materials Laboratory conducted corrosion testing on the sodium chloride and magnesium chloride deicers using the ASTM and SAE methods. Corrosion tests were conducted on stainless steel and aluminum alloys (Xi and Olsgard 2000). The results, using the SAE test, showed that inhibited magnesium chloride was more corrosive to stainless steel than either non-inhibited magnesium chloride or sodium chloride (Table 19). Inhibited magnesium chloride caused 1.3 millimeters per year (MPY) more corrosion to stainless steel than sodium chloride, a difference of 2%. Tests conducted on aluminum also showed that inhibited magnesium chloride was slightly more corrosive than sodium chloride, but less corrosive than uninhibited magnesium chloride. The inhibited magnesium chloride was 2.5 times less corrosive than uninhibited magnesium chloride. Because of inconsistencies in the corrosion tests conducted by the Materials Laboratory at University of Colorado/Boulder, the data are presently being re-evaluated (E. Fink, CDOT, personal communication).

Table 19. Corrosion Test Results on Magnesium Chloride and Sodium Chloride (Xi and Olsgard 2000) (Draft).

Metal	Test Method	Sodium Chloride (MPY[1])	Magnesium Chloride Reagent (MPY)	Inhibited Magnesium Chloride (MPY)	Difference between Sodium Chloride and Inhibited $MgCl_2$ (MPY and %)
Mild Steel	NACE	45	-	13	Inhibited $MgCl_2$ is 32 MPY less corrosive than NaCl (70% less corrosive)
Stainless Steel	SAE	0.0820	0.4326	1.3819	Inhibited $MgCl_2$ is 1.3 MPY more corrosive than NaCl (2% more corrosive)
Aluminum	SAE	0.0613	0.1987	0.078	Inhibited $MgCl_2$ is 0.017 MPY more corrosive than NaCl

[1] – millimeters per year

When mild steel is tested using the NACE method, the results show that sodium chloride causes 45 MPY corrosion in mild steel, whereas corrosion from inhibited magnesium chloride is only 13 MPY (E. Fink, CDOT Maintenance Superintendent, personal communication). Thus, inhibited magnesium chloride is 70% less corrosive than sodium chloride to mild steel. The increase in corrosion to stainless steel from inhibited magnesium chloride is less than 2%. The 70% reduction in corrosion in mild steel when inhibited magnesium chloride is used far outweighs the slight increase in corrosion in stainless steel and aluminum (E. Fink, CDOT, personal communication). Mr. Fink believes that the metal at greatest risk of corrosion from deicers is mild steel. He also believes that the PNS modified NACE test is more appropriate for analyzing deicing materials than the SAE test, which appears to overpower the corrosion inhibitors in the deicers. The NACE test demonstrates that the magnesium chloride deicer used by CDOT is far less corrosive than sodium chloride (E. Fink, CDOT, personal communication).

According to Mr. Fink, the current challenge for CDOT is to find a test method that most adequately reflects the way that the deicers function from a corrosion standpoint under the conditions found on the highways for the specific metals most likely to be encountered on vehicles and bridges. For stainless steel and aluminum, the test will most likely be a modified NACE test of longer duration, similar to the test developed by PNS. When CDOT has developed a satisfactory corrosion test, the deicer specifications will include language stating that magnesium chloride will be no more corrosive to the four specific aluminum and stainless steel alloys than sodium chloride. CDOT may require the use of different corrosion inhibitors or higher concentrations of the current ones to satisfy future corrosion specifications. However, the Colorado specifications will continue to require that magnesium chloride be 70% less corrosive than sodium chloride to mild steel (E. Fink, CDOT, personal communication).

8.2. Deicer Application Rates

Deicer application rates are dependent on a variety of factors, including the type of deicer, air temperature, pavement temperature, amount of snow on the ground, and steepness of the road. The application rates of the deicers and sand used by CDOT were provided by the maintenance supervisors and are shown in Table 20.

The deicer most commonly used by CDOT is magnesium chloride. The application rate for magnesium chloride for anti-icing ranges from 35-45 gal/lane-mile. When magnesium chloride is used for deicing, the application rate varies from 40-60 gal/lane-mile. If heavy snowpack is present an application rate of more than 60 gal/lane-mile is used. The application rate for Glenwood Canyon, where use of sand is prohibited, may be up to 80 gal/lane-mile (W. Allen, CDOT, personal communication).

The application rates of sand for the Denver metro area may vary considerably, ranging from a minimum of 350 lbs/lane-mile to a maximum of 2,900 lbs/lane-mile (Chang at al 1994). The average ranges from 800-1,200 lbs/lane-mile. The sand is usually mixed with salt (sodium chloride) at a concentration of 3-20% salt (Chang et al 1994).

Table 20. Deicers Used by CDOT in Colorado - Application Rates, Advantages, and Disadvantages[1].

Maintenance Section	Contact	Location	Deicers and Other Materials Used	Application Rates	Advantages	Disadvantages	Comments
MS 1	Mike Hern	Greeley	FreezGard Zero w/inhibitor; Caliber M1000; Ice Slicer; sand/salt.	40 GPLM [2] (anti-icing); 40-60 GPLM (deicing); Ice Slicer (100-125 lb/lane-mile; Caliber M1000 20-50 GPLM; 200-400 lb/lane-mile	Liquid deicers enables us to sustain ice-free travel lanes for a longer period of time than with sand/salt. Advantage of Caliber M1000 is that it can be applied at lower temperatures.	Public not yet knowledgeable and comfortable with use of liquid deicers.	The success with using the liquid deicers has been very good. Reducing the use of sand/salt enables us to meet clean air standards.
MS 2	Weldon Allen	Grand Junction	$MgCl_2$ w/ inhibitor; sand/ salt (5-10%); Ice Slicer; Limited use of Caliber M1000.	40 GPLM (anti-icing); up to 80 GPLM in Glenwood Canyon where cannot use sand; sand application rate 300-2000 lb/lane-mile.	Deicer use before snowpack forms will return roadway to bare condition much quicker; less time that road is icy or snow packed; allows more efficient use of staff.	Sand must be picked up. Costs and environmental impacts of sand are much greater than liquid deicers.	Deicer use has dramatically affected our ability to move people and goods on state highways; results in increased level of service to our customers.
MS 3	Wayne Lupton	Durango	Sand/salt (5-10%); $MgCl_2$ (27%); Ice Slicer; Sand/ Ice Slicer (6%); Caliber M1000.	MgCl2 =35-40 GPLM (anti-icing); Ice Slicer=200 lb/lane-mile; Sand=500 lb/lane-mile	Allows the snowpack not to bond to the road reducing the time for cleanup; anti-icing keeps road wet longer during heavy storm events; anti-icing reduces plow miles by at least 20%. Use of sand is the only way to have temporary traction on the roadway.		Use of deicers has increased our level of service and made the highways safer.
MS 4	Jerry Lutz/ Tom Berry	Trinidad/ Walsenburg Areas	FreezGard Zero w/inhibitor; sand/salt (20%)	30-40 GPLM; 60 GPLM on heavy snowpack.	$MgCl_2$ works well to melt black ice; effective in removing snowpack; minimizes need for sand, thereby improving air quality; sand enhances traction.		$MgCl_2$ works very well as anti-icer for on- and off-ramps on I-25 corridor.
MS4	Phil Breesawitz	Colorado Springs	FreezGard Zero w/inhibitor; sand/ salt (20%)	40-45 GPLM	Sand/ salt assists $MgCl_2$ in the melting of pack snow		Ice Ban was the best product we used. Would like to see it used again.

Table 20 (continued). Deicers Used by CDOT in Colorado - Application Rates, Advantages, and Disadvantages[1].

Maintenance Section	Contact	Location	Deicers and Other Materials Used	Application Rates	Advantages	Disadvantages	Comments
MS 5	Chuck Loerwald	Aurora	$MgCl_2$ w/inhibitor and Caliber M1000; Sand	Start at 40 GPLM, higher as needed.	The deicers remove the snowpack and ice off the road, so do not have to use as much sand.	Sand has to be picked up.	MgCl2 works well in spring and fall before it gets too cold. Caliber M1000 works well when it is cold. Caliber M1000 works better than MgCl2.
MS 6	Bernard Lay	Craig	FreezGard Zero, Caliber M1000, Ice Slicer, Sand	40 GPLM	Get roads back to a non-icy safer condition much quicker.	Sand very costly to clean up.	Use sand/salt everywhere except Steamboat Springs and Rabbit Ears Pass, where use sand/salt impregnated with Freezgard.
MS 7	Frank Holman	Alamoso	$MgCl_2$ and Caliber M1000	80 GPLM (pretreatment); 40-80 GPLM depending on conditions.	Less sand use; less snow pack; fewer inconveniences for motorists.	Problems with electricals systems on our trucks; cost, complaints from motorists.	Do not use liquid deicers in combination with sand.
MS 8	Randy Jensen	Denver	MgCl2 (30%), sand/salt, Ice Slicer, Caliber M1000	40 GPLM	Helped reduce salt and sand usage as required by Regulation 16, air pollution regulation.		Maintenance staff likes Ice Slicer, but it is more costly ($58/ton).
MS 9	Michael Solomon	Eisenhower/ Johnson Memorial Tunnels	Sand/salt around the tunnels				Section 9 does not have direct responsibility for any of the roadways. Section 5 is responsible for treating I-70 through the tunnel.

[1] – Personal communication with CDOT Maintenance Supervisors [2] - GPLM = gallons/lane-mile

8.3. Performance

The performance of a deicer is determined by its ability to melt, penetrate, undercut, and disbond the ice and snow (Chang et al 1994). Two of the factors that determine the ability of a deicer to perform these functions are based on the eutectic and effective temperatures of the deicer. A deicer does not perform efficiently if the ambient temperature is below the eutectic or effective temperature. The eutectic and effective temperatures of the deicers discussed in this report are presented below. Additional information on deicer performance can be found in Chang et al (1994).

8.3.1. Eutectic Temperature

The term "eutectic temperature" applies to both solids and liquids and is used and defined in many ways (Ice and Snow Technologies 2000). The eutectic temperature, as defined in Ice and Snow Technologies (2000), is the temperature at which a solution will freeze based on the chemical concentration (i.e., percent of material in solution). The "optimum eutectic temperature" is the lowest freeze point temperature achievable for a given product or solution. Low eutectic temperatures are associated with high miscibility or solubility in water (Chappelow 1990). A larger difference between ambient temperature and eutectic temperature results in a higher rate of melting of snow and ice (OECD 1989). The ideal deicer has a eutectic temperature well below the expected ambient temperature range, dissolves rapidly in water and brine solutions, and lowers the freezing point of water at a high proportion relative to its concentration (Chappelow 1990; Woodham 1994).

The eutectic temperatures for the various deicers are shown in Table 21. Sodium chloride and Ice Slicer have the highest eutectic temperatures at -6^{o}F, which means that they do not work well at low temperatures. The deicers with the lowest eutectic temperatures, Caliber M1000, Ice Ban M50, Liquidow Armor (calcium chloride), and Potassium Acetate (CF7), work well at low temperatures.

Table 21. Eutectic Temperatures of Selected Deicers.

Deicer	**Concentration**	**Eutectic Temperature (ºF)**	**Reference**
Caliber™ M1000	27% magnesium chloride	-85	Product Specification Sheet
CMA® (anhydrous)	32.6% calcium magnesium acetate	-18	K. Johnson, Cryotech, personal communication
CMA25® (25% aqueous solution)	100% calcium magnesium acetate	+1	K. Johnson, Cryotech, personal communication
CMAK™ (50:50 blend of CMA25 and CF7)	100% CMAK	-25	K. Johnson, Cryotech, personal communication
FreezGard-Zero® with Shield LS®	22% magnesium chloride	-27	Envirotech Product Information Sheet
Ice Ban M50™	30% magnesium chloride + Ice Ban (ratio 1:1)	-78	M. Duran, Envirotech, personal communication
Ice Slicer®	92-98% sodium chloride	-6	G. Liest, Envirotech, pers. communication
Ice-Stop™CI	21.6% magnesium chloride	-28	Product Specification Sheet
Liquidow* Armor*	30% calcium chloride	-59	Product Information Sheet
NAAC® (anhydrous)	27% sodium acetate	-7	K. Johnson, Cryotech pers. communication
Potassium Acetate (CF7®) (50% aqueous solution)	100% potassium acetate	-76	K. Johnson, Cryotech, personal communication
Sodium Chloride	23% sodium chloride	-6	Dow Chemical Product Information Document[1]

[1] – Dow Chemical Company – Manual of Good Practice for Snow and Ice Control with Dow Calcium Chloride Products (no date).

8.3.2. Effective Temperature

Another term that is used to describe the efficiency of a deicer at melting snow and ice is its effective temperature. The effective temperature is an empirical value that attempts to describe the lowest temperature for practical use, considering ice melting, anti-icing ability, type of precipitation and application rates (K. Johnson, Cryotech, personal communication). The effective temperatures of selected deicers are provided in Table 22.

Chang et al (1994) compared the effectiveness of calcium chloride to sodium chloride. The authors reported that calcium chloride worked more than twice as fast as sodium chloride in melting ice, and was more effective in ice penetration tests than sodium chloride. Cheng and Guthrie (1998) reported that calcium chloride tends to adhere to road surfaces better, dissolve more rapidly, and melt ice at lower ambient temperatures.

Table 22. Effective Temperatures of Selected Deicers.

Chemical	Brand Name	Effective Temperature (°F)	Reference
30% Magnesium Chloride + 10% carbohydrates	Caliber™ M1000	-10°F	G. Leist, Envirotech, pers. Communication
30% Magnesium Chloride	FreezGard® with Shield LS	+5°F	G. Leist, Envirotech, pers. Communication
Magnesium Chloride	Ice Stop™CI	+5° F	Product Specification Sheet
Sodium Chloride	Ice Slicer®	0 to +5°F	Product Specification Sheet
Sodium Chloride	Rock Salt	+15°F	Chang et al 1994
Calcium Chloride	Liquidow* Armor*	-25°F	Dow Chemical Product Information Document[1]
Calcium Magnesium Acetate	CMA®	+20°F	K. Johnson, Cryotech, pers. communication
CMA25	CMA25®	+20°F	K. Johnson, Cryotech, pers. communication
CMA + Potassium Acetate	CMAK™	0°F	K. Johnson, Cryotech, pers. communication
Potassium Acetate	CF7®	-15°F	K. Johnson, Cryotech, pers. communication
Sodium Acetate	NAAC®	+5°F	K. Johnson, Cryotech, pers. communication

1 – Dow Chemical Company Manual of Good Practice for Snow and Ice control with Dow Calcium Chloride Products (no date).
NA – Not available

The deicer CMA was also evaluated by Chang et al (1994). They reported that CMA did not produce any significant melt volumes at temperatures below 15°F and had poor ice penetration. In order to obtain dry pavement conditions, approximately 2.6 times as much CMA was required as sodium chloride (Chang et al 1994). According to K. Johnson (Cryotech, personal communication), acetate deicers interfere with the ability of snow particles to stick together or to the pavement surface, making mechanical removal easier.

The effectiveness of Ice Ban was compared to that of magnesium chloride deicers. Ice Ban was reported to melt snow and ice faster and at lower temperatures than magnesium chloride solutions. It also provided a more consistent, longer lasting residual effect (i.e., ability to reactivate between storms) than magnesium chloride (HITEC/CERF 1999).

8.4. Costs and Benefits

Cost is an important factor to consider in determining which deicer to use. Cost is especially critical to small towns that have limited budgets to allocate for snow and ice control. The cost of the various deicers ranges from less than $10/ton for sand to $3000/ton for calcium magnesium acetate (CMA), based on information from maintenance supervisors, distributors, and manufacturers. The range of costs is shown in Table 23. The costs for a particular deicer are variable because they include distance charges for transporting a deicer to the particular location (R. Parsons, GMCO). The amount of deicer used and costs of deicers reported by some ski towns, cities and CDOT are shown in Table 24.

The most economical material used in snow and ice control is sand. The price of sand ranges from approximately $6–16 per ton. The price of cinders, which one of the towns in Colorado uses, is somewhat more expensive at $20 per ton. According to Chang et al (1994) many regions excavate their own sand, making it even more economical. However, the sand on the roads must be removed and street sweeping is costly. Sand left on roads decreases the coefficient of friction, which causes skidding and increases the stopping distances of vehicles, increasing the probability for accidents. Sand can also cause damage to windshields and auto body paint (Chang et al 1994).

The costs of the liquid deicers range from $0.25/gal for magnesium chloride (Ice-Stop CI) to $3.30/gal for Potassium Acetate. The costs of the solid deicers range from $30/ton for sodium chloride to more than $1000/ton for CMA. The costs of the acetate-based deicers, such as CMA, NAAC, CMAK, and Potassium Acetate are substantially higher than the chloride-based deicers. The CDOT maintenance costs per year for snow and ice control and use of sand/salt and liquid deicers are shown in Table 25.

The costs, plow miles and labor days are directly related to the annual snowfall. The use of sand/salt has decreased each year since 1995, while the use of liquid deicers has increased. The numbers for FY 2001 are not yet available, but the costs are expected to be significantly higher, because of increased fuel costs and the fact that 2001 was the most severe winter in seven years (E. Fink, CDOT, personal communication).

Table 23. Range of Costs of Selected Deicers and Sand[1].

Chemical	Deicer Name	Costs
Calcium Chloride + Corrosion Inhibitor (liquid)	Liquidow* Armor*	$0.50/gal = $91/ton
Magnesium Chloride + Caliber (liquid)	Caliber™ M1000	$0.55/gal = $100/ton
Magnesium Chloride + Corrosion Inhibitor (liquid)	Ice-Stop™CI	$0.25/gal = $46/ton)
Magnesium Choride + Corrosion Inhibitor (liquid)	Freezgard-Zero® w/ Shield LS®	$0.34/gal = $62/ton
Magnesium Chloride + Ice Ban (liquid)	Ice Ban M50™	$0.78/gal = $142/ton
Road Salt (solid)	Sodium Chloride	$30/ton
Sodium Chloride (solid)	Ice Slicer®	$58/ton
Calcium Magnesium Acetate (solid)	CMA®	$1000/ton
CMA + Potassium Acetate (liquid)	CMAK™	$1000/ton
Sodium Acetate (solid)	NAAC®	$1000/ton
Potassium Acetate (liquid)	CF7®	$3.30/gal = $601/ton
Silicon dioxide, etc.	Sand	$6-16/ton

[1] – Personal communication from CDOT maintenance supervisors, manufacturers, and distributors.

The use of deicers for snow and ice control also have social and economic costs associated with them. The costs associated with using chloride-based deicers include damage to utilities, corrosion of vehicles and highway bridges, damage to vegetation and water supplies, and the cost of deicer purchase and application. Other potential costs include increased salinity of rivers from use of chloride-based deicers, effects on aquatic life, corrosion, potential increased incidence of

Table 24. Deicers and Sanding Materials Used by Colorado Ski Towns, Cities[1] and Colorado Department of Transportation (CDOT)[2]

Location	Deicer/Sanding Material Used	Amount Used/ Year	Application Rate	Cost	Comments
Aspen	CMAK; 50:50 NAAC mixed with 3/8" chipped rock	15,000 gal/ season	50 gal/lane-mile	\$3.85/lb CMAK; \$1,078/bag NAAC (1 bag=2205lb); \$6.25/ton Sand.	Environmentally friendly
Avon	CMA; volcanic cinders (3/4-1")	30 tons CMA; 1000 tons cinders.	Vary depending on whether anti-icing or deicing; cinders ~3yd/lane-mile	CMA=\$2000-\$3000/ton; cinders \$20/ton.	Previously used $MgCl_2$, but too corrosive on their equipment; sweep often and year round.
Basalt	3/8" chipped rock	150 tons/ season	--	\$11/ ton	MgCl2 is a good deicer, but environmental concerns for heavy metals and chlorides in the river outweighed its benefits for snow management.
Breckenridge	$MgCl_2$ (Ice-Stop); 2%salt /sand mixture	30,000 gal $MgCl_2$;	13 gal/lane-mi	$MgCl_2$=\$0.13/gal; Sand=\$16.50/ton	Use $MgCl_2$ only in Spring and Fall; winter use salt/sand mixture.
Durango	Ice-Stop CI; sand+$CaCl_2$ pellets	8000-25000 gal	--	--	Inorganic corrosion inhibitor less environmental impact
Glenwood Springs	$MgCl_2$; chipped rock (3/8")	--	--	--	Use $MgCl_2$ because most effective material. Use on main thoroughfares and steep streets. Also electrically heat steeper roads with heating element embedded in concrete.
Grand Lake	Ice Slicer/Sand mixture	100-125 tons	Do not have specific application rate	\$15/ton mixture; \$10/ton sand; \$50/ton Ice Slicer.	Liquid deicer too expensive. Primarily use on hills and street corners.
Gunnison	8% mined rock salt +3/8" rock chip (this year); changed from $MgCl_2$	500-750 tons	Application varies depending on condition	\$17/ton	Used $MgCl_2$ past 4 years. Concern is corrosion of vehicles, concrete, water quality
Minturn	Sand/salt mixture	8-10 tons	Same as CDOT	Same as CDOT	Only sand at street corners. No longer push salt/sand mixture into river; pick up and haul away
Mt. Crested Butte	Sand treated with 5% $MgCl_2$	150 tons sand; 1350 gal $MgCl_2$	Application varies depending on condition	Sand=\$12.85/ton; $MgCl_2$=\$0.54/gal	Close to non-attainment, but no violations since 1997 .

Location	Deicer/Sanding Material Used	Amount Used/ Year	Application Rate	Cost	Comments
Pitkin County	Salt/Sand mixture (7-9% NaCl)	2500 tons	Varies depending on conditions, traffic volumes, topography, etc.	Mixture=$12-$14/ton	Used typically on hills, intersections, curves. Salt is corrosive and can be harmful to plants, but at reduced rate of application have not experienced any problems.
Snowmass	NAAC; 3/8" rock chips.	33 tons	50 rock: 50 NAAC	$15/ton for rock; $1500/metric ton for NAAC	Switched from $MgCl_2$ because of corrosion effects on cement. NAAC is very expensive and not as effective as $MgCl_2$. May stop using NAAC because of budgetary constraints.
Steamboat Springs	$MgCl_2$; Scoria (volcanic pumice).	2000 gal	0.1 gal/cu. yd	$MgCl_2$=$0.36/gal;	$MgCl_2$ used as pre-wetting agent for scoria; limited use of $MgCl_2$ so probably no impacts.
Telluride	Ice-Stop CI Plus; washed pea sanding material after snowpack forms	12,000 gal	50 gal/lane-mile	$0.33/gal	Recommended by governmental agency. Have not had any complaints from the public about magnesium chloride.
CDOT[2]	NaCl	700 tons		$42.05/ton	
	5-30% Salt/Sand Mixture	366,837 tons		$13.57/ton	
	$CaCl_2$	1444 sacks		$9.16/ sack	
	$MgCl_2$	6,014,829 gal		$0.36/gal	
	Ice Slicer	12,342 ton		$59.23/ton	

[1]= Personal communication from maintenance supervisors from Colorado Ski Towns and Cities
[2]= CDOT, 2000.

Table 25. CDOT Maintenance Costs and Other Information Related to Snow and Ice Control[1].

Data	FY1995	FY1998	FY1999	FY2000
MPA[2] Totals	$26,200,000	$29,400,000	$25,100,000	$27,500,000
Increase in Cost Over FY 95	-	12.0%	-4.3%	5.0%
Increase in Cost Over Previous Year	-	-9.2%	-14.5%	9.7%
Snow Plow/Sanding/Deicing (Total COFRS[3] Loaded Costs)	$22,500,000	$26,200,000	$22,700,000	$24,100,000
No. Miles Plowed	5,800,000	5,900,000	4,700,000	4,400,000
Labor Days	49,600	51,000	42,100	40,700
MMS[4] Costs/plow mi.	$3.86	$4.48	$4.81	$5.48
Sand/Salt Used (tons)	452,500	537,000	395,000	366,800
Liquid Deicer Used (gal)	715,500	4,900,000	3,700,000	6,000,000

[1] – E. Fink (2001). Maintenance Snow & Ice Costs, Staff Branches Update. Presentation to the Transportation Commission.
[2] - MPA = Maintenance Program Area
[3] - COFRS = Colorado Financial Reporting System
[4] - MMS = Maintenance Management System

cancer from the presence of metals from deicers in the air (L. Cassin, Aspen Environmental Health Department). In 1991 the U.S. Congressional Office of Technology Assessment reported that 23% of the 575,000 bridges in the United States were deficient because of deteriorated structural components. D'Itri (1992) reported that it would cost more than $67 billion to repair or replace the deficient bridges in the federal highway system alone.

The social and economic costs of the acetate-based deicers include potential oxygen depletion in the aquatic environment resulting in potential reduction in fishing opportunities due to the decreased number of fish in lakes or streams affected by eutrophication. The acetate deicers are also substantially more expensive than the chloride-based deicers, which has prevented some cities and towns from using them. Since the acetate deicers have only been used in the last several years, there may be other potential costs that are, as yet, unknown.

When sand is used, equipment and labor for sand removal must be considered (McCrum 1992). The air quality and water quality impacts of sand use also result in substantial social and economic costs.

The use of deicers also have social and economic benefits associated with them. Some of these benefits were reported by McCrum (1992) and include:

- **Social Benefits**
    - Lives saved in reduced traffic accidents
    - Lives saved in reduced response time to medical emergencies

- **Economic benefits**
    - Energy savings in fuel costs
    - Reduced wage loss from work absenteeism
    - Reduced production losses
    - Reduced delays in shipment of goods.

Epps and Coulson (1997) estimated that the total annual cost savings from snow and ice control by state agencies was $1.67 billion with an annual motorist accident cost savings of $1.35 billion. In the city of Kamloops, British Columbia the use of liquid deicers reduced vehicle collisions by 73% (Cheng and Guthrie 1998).

The benefits of deicer use were also identified by the CDOT maintenance supervisors (See Table 20) and include the following:

- Sustains ice-free roads for a longer period of time than with use of sand
- Returns roads to bare conditions rapidly
- Reduces time and personnel needed for removal of snow and ice
- Keeps roads wet longer during heavy storm events
- Effective in melting black ice
- Minimizes the need for sand, thereby improving air quality
- Greatly increases ease of traffic movement on the highways
- Increases the level of service that CDOT can provide
- Makes the highways safer for motorists.

9. COMPARISON OF DEICERS

The deicers that are reviewed in this study are sodium chloride, magnesium chloride, calcium chloride, calcium magnesium acetate (CMA), potassium acetate, CMAK (mixture of CMA and potassium acetate), and sodium acetate (NAAC). The impacts of sand are also discussed. A matrix comparing cost/lane-mile, application rates, corrosion rates, eutectic temperature, trace metal and other chemical contamination, environmental and human health effects, and advantages and disadvantages of use of the deicers discussed in this report is shown in Table 26. A summary table describing the environmental and human health effects, corrosion, cost and performance of the deicers is also provided (Table 27).

9.1. Environmental

Each of the deicers discussed in this report has potential impacts on the environment. The potential effects of the chloride-based deicers, acetate-based deicers, and sand on water quality, soil, aquatic organisms, air, terrestrial vegetation and terrestrial animals were compared.

The chloride ions in the chloride-based deicers increase the salinity of the soil, decrease soil stability, and may mobilize the movement of trace metals from soil to water. The chloride ion can have a negative effect on water quality through increased salinity, especially in small streams. In larger water bodies, where there is rapid dilution of the deicer in the water, impacts are unlikely. Chlorides may also affect aquatic organisms due to the increased salinity of the water. However, aquatic toxicity tests have shown relatively low toxicity of the chloride deicers to fish, invertebrates, and aquatic algae.

Probably the most noticeable impact of the chloride-based deicers is damage to roadside vegetation resulting from the use of these deicers. However, there is a wide range of tolerance of different species of plants to the deicing salts. The toxicity of the chloride deicers to terrestrial animals is low, based on oral toxicity tests. Terrestrial animals have a high tolerance to elevated chloride levels in drinking water. However, sodium chloride deicers on the roadways attract in

Table 26. Matrix for Comparison of Deicers[1].

Deicer	Brand Name/ Manufacturer	Liquid/ Solid	Cost/ Lane-Mile ($)	Application Rates	Corrosion Rate[2]	Eutectic Temperature (degrees F)	Metals above PNS Specs[3]/ Other Chemicals of Concern[4]	Potential Human Health Effects
Chlorides								
Inhibited Magnesium chloride	FreezGard Zero/ IMC Ogden Corp.	Liquid	$14-27	40 gal/lane-mile (anti-icing; 40-80 gal/lane-mile (deicing)	21%	-27 (@22% $MgCl_2$)	None/ None	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity.
	Ice Stop-CI/ Reilly Wendover	Liquid	$8-18	30 gal/lane-mile (anti-icing; 30-70 gal/lane-mile (deicing)	20.30%	-28 (@21.6% MgCl2)	None/ None	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity.
	Caliber M1000/ Minnesota Corn Processors	Liquid	$11-28	20-50 gal/lane-mile	22.30%	-85 (@27% MgCl2)	None/ Phosphorus, Ammonia	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity.
	Ice Ban M50/ ICE BAN AMERICA	Liquid	$23-27	30-35 gal/lane-mile	NA[5]	-78	Copper, zinc/ sulfate, phosphorus, pH, ammonia, nitrate	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity.
Sodium Chloride	Road Salt/ Cargill Salt	Solid/ Brine	$5	300 lb/lane-mile	100%	-6	Copper, cyanide/ None	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity; potential for hypertension.
	Uninhibited Ice Slicer/ Redmond Minerals	Solid	$3-6	100-200 lb/lane-mile	80%[6]	-6	Copper/ None	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity; potential for hypertension.
Inhibited Calcium Chloride	Liqidow Armor/ Dow Chemical	Liquid	$10-25	20-50 gal/lane-mile	26%	-59 (@30% CaCl2)	None/ Nitrate, ammonia	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity; potential for increased nitrates in drinking water.

Table 26. Matrix for Comparison of Deicers[1].

Deicer	Potential Environmental Effects	Advantages	Disadvantages
Chlorides			
Inhibited Magnesium Chloride (FreezGard Zero)	Damage to vegetation; low toxicity to aquatic organisms; increases salinity of soil and water.	Low cost; minimal air pollution; reduced corrosion potential; does not attract wildlife.	Less effective in cold temperatures; damages roadside vegetation; adds chlorides to water.
Inhibited Magnesium Chloride (Ice Stop-CI)	Damage to vegetation; low toxicity to aquatic organisms; increases salinity of soil and water.	Low cost; minimal air pollution; reduced corrosion potential; does not attract wildlife.	Less effective in cold temperatures; damages roadside vegetation; adds chlorides to water.
Inhibited Magnesium Chloride (Caliber M1000)	Potential damage to vegetation; relatively low toxicity to aquatic organisms; increases salinity of soil and water; potential for oxygen depletion in soil and water.	Relatively low cost; minimal air pollution; does not attract wildlife; reduced corrosion potential; effective at low temperature.	Damages roadside vegetation; adds chlorides to water; potential oxygen depletion in soil and water.
Inhibited Magnesium Chloride (Ice Ban M50)	Potential damage to vegetation; moderate toxicity to aquatic organisms; increases salinity of soil and water; potential for oxygen depletion in soil and water.	Relatively low cost; minimal air pollution; does not attract wildlife; reduced corrosion potential; effective at low temperature.	Reduced potential for corrosion; damages roadside vegetation; adds chlorides to water; potential oxygen depletion in soil and water.
Sodium Chloride (Road Salt)	Damage to vegetation; low toxicity to aquatic organisms; decreases soil stability; increases salinity of soil and water; attracts wildlife contributing to road kills.	Very low cost; low air pollution.	Corrosive to metals; not effective at low temperatures; damages roadside vegetation; adds chlorides to soil and water.
Sodium Chloride (Ice Slicer)	Damage to vegetation; low toxicity to aquatic organisms; decreases soil stability; increases salinity of soil and water; attracts wildlife contributing to road kills.	Low cost; low air pollution.	Corrosive to metals; not effective at low temperatures; damages roadside vegetation; adds chlorides to soil and water.
Inhibited Calcium Chloride (Liqidow* Armor*)	Damage to vegetation; low toxicity to aquatic organisms; increases salinity of soil and water.	Relatively low cost; minimal air pollution; does not attract wildlife; reduced corrosion potential; effective at low temperature.	Damages roadside vegetation; adds chlorides to soil and water; nitrates may affect drinking water quality.

Table 26. Matrix for Comparison of Deicers[1].

Deicer	Brand Name/ Manufacturer	Liquid/ Solid	Cost/ Lane-Mile ($)	Application Rates	Corrosion Rate[2]	Eutectic Temperature (degrees F)	Metals above PNS Specs[3]/ Other Chemicals of Concern[4]	Potential Human Health Effects
Acetates								
Calcium Magnesium Acetate	CMA/ Cryotech	Solid/ Liquid	$150-200	300-400 lb/lane-mile	-7% (solid); -11% (liquid)	1 (@25% CMA)	None/ pH, data on nitrates not available	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity.
Potassium Acetate	CF7/ Cryotech	Liquid	$198-264	25-60 gal/lane-mile (anti-icing; 60-180 gal/lane-mile (deicing)	Non-corrosive	-76	Cyanide/ pH	Potential for minor eye, skin, respiratory, GI effects ; low acute oral toxicity.
CMA + Potassium Acetate	CMAK/ Cryotech	Liquid	$330-440	25-60 gal/lane-mile (anti-icing; 60-180 gal/lane-mile (deicing)	Non-corrosive	-25	Cyanide/ nitrate, ammonia	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity; potential for increased nitrates in drinking water.
Sodium Acetate	NAAC/ Cryotech	Solid	$150	300 lb/lane-mile	Non-corrosive	-7(@27% NAAC)	Data on most chemicals not available/ pH	Potential for minor eye, skin, respiratory, GI effects; low acute oral toxicity; potential for increased nitrates in drinking water.
Sand[7]	Sand	Solid	$0.6-16	200-2000 lb/lane-mile	Does not cause corrosion	NA	Copper/ None	Potential for respiratory effects and lung cancer.

Table 26. Matrix for Comparison of Deicers[1].

Deicer	Potential Environmental Effects	Advantages	Disadvantages
Acetates			
CMA	Minimal damage to vegetation; low toxicity to aquatic organisms; potential for oxygen depletion in soil and water.	Non-corrosive; minimal damage to roadside vegetation; does not attract wildlife.	High cost; not effective at low temperatures; potential oxygen depletion in soil and water; eutrophication.
Potassium Acetate (CF7)	Minimal damage to vegetation; moderate toxicity to aquatic organisms; potential for oxygen depletion in soil and water.	Non-corrosive; minimal damage to roadside vegetation; effective at low temperature; does not attract wildlife.	High cost; potential oxygen depletion of soil and water; eutrophication.
CMAK	Minimal damage to vegetation; moderate toxicity to aquatic organisms; potential for oxygen depletion in soil and water.	Non-corrosive; damage to roadside vegetation not expected; effective at low temperature; does not attract wildlife.	High cost; potential oxygen depletion in soil and water; eutrophication; nitrates may affect drinking water quality.
NAAC	Decreases soil stability; vegetation effects not documented; low toxicity to aquatic organisms; potential for oxygen depletion in soil and water.	Non-corrosive; damage to roadside vegetation not expected; effective at low temperature; does not attract wildlife.	High cost; potential oxygen depletion in soil and water; eutrophication; sodium may attract wildlife.
Sand[7]	Increased air pollution; increased turbidity of water; smothering of vegetation.	Very low cost; provides traction for vehicles.	Air pollution (PM10 particulates); water pollution (turbidity); human health effects (carcinogen).

1- Information from manufacturers, distributors, PNS, maintenance supervisors, and published literature.

2 - Based on information from PNS draft (2001) [corrosion rates of deicers are compared with sodium chloride (100%)], where available.

3 - Only metals above PNS Specifications are listed. Trace metal concentrations are shown in Table 3, Table 14.

4 - Based on information from Mussato and Guthrie (2000), Colorado Regulation 31, and Lewis (2000). See Table 3, Table 14 for details.

5 - Lower corrosion rate than magnesium chloride, since corrosion rate of Ice Ban is less than distilled water

6 - G. Leist, Envirotech, personal communication.

7 - Sanding materials include 3/8" chipped rock; 3/4" volcanic cinders, washed pea sanding material, scoria, sand.

Table 27. Summary Table Comparing Potential Environmental Effects, Human Health Effects, Corrosion, Cost and Performance of Selected Deicers.

Deicer/ Para-meter	Inhibited Magnesium Chloride (Liquid)	Caliber + Magnesium Chloride (Liquid)	Ice Ban + Magnesium Chloride (Liquid)	Sodium Chloride/ Ice Slicer (Solid)	Inhibited Calcium Chloride (Liquid)	CMA (Solid/ Liquid)	CMAK (Liquid)	Potas-sium Acetate (Liquid)	NAAC (Solid)	Sand
Chemicals	Trace metals[1]	Trace metals[1], phosphorus, ammonia	Trace metals[1], phosphorus, ammonia, nitrates	Trace metals[1]	Trace metals[1], ammonia, nitrates.	Trace metals[1]	Trace metals[1], ammonia, nitrates.	Trace metals[1]	Trace metals[1], phosphorus	Trace metals[1]
Soil	Improves structure, increases salinity	Improves structure, increases salinity, oxygen depletion	Improves structure, increases salinity, oxygen depletion	Increases salinity; decreases stability	Improves structure, increases salinity	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Improves structure; oxygen depletion	Decreases stability; oxygen depletion	Minimal effects
Water Quality	Increases salinity	Increases salinity; oxygen depletion	Increases salinity; oxygen depletion	Increases salinity	Increases salinity	Oxygen depletion	Oxygen depletion	Oxygen depletion	Oxygen depletion	Increases turbidity.
Air Quality	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Minimal air pollution	Some air pollution	High air pollution potential.
Aquatic Organisms	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Relatively low toxicity	Relatively low toxicity	Relatively low toxicity	Moderate toxicity	Moderate toxicity	Relatively low toxicity	Can cover benthic organisms and cause mortality
Terrestrial Vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Chlorides damage vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Minimal damage to vegetation	Effect to vegetation not determined	Can cover vegetation and cause mortality
Terrestrial Animals	Does not attract wildlife	Does not attract wildlife	Does not attract wildlife	Attracts wildlife contributing to road kills	Does not attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	Not expected to attract wildlife	May attract wildlife contributing to roadkills	May cover burrows of small animals and cause mortality

Table 27 (continued). Summary Table Comparing Potential Environmental Effects, Human Health Effects, Corrosion, Cost and Performance of Selected Deicers.

Deicer/ Para-meter	Inhibited Magnesium Chloride (Liquid)	Caliber + Magnesium Chloride (Liquid)	Ice Ban + Magnesium Chloride (Liquid)	Sodium Chloride/ Ice Slicer (Solid)	Inhibited Calcium Chloride (Liquid)	CMA (Solid/ Liquid)	CMAK (Liquid)	Potas-sium Acetate (Liquid)	NAAC (Solid)	Sand
Human Health	Potential skin, eye, GI, respiratory tract irritation	Potential skin, eye, GI, respiratory tract irritation	Potential skin, eye, GI, respiratory tract irritation; potential to cause blue-baby syndrome	Potential skin, eye, GI, respiratory tract irritation; potential to cause hypertension	Potential skin, eye, respiratory, GI tract, irritation, potential to cause blue-baby syndrome	Potential skin, eye, respiratory, GI tract irritation	Potential skin, eye, respiratory, GI tract irritation; potential to cause blue-baby syndrome	Potential skin, eye, respiratory, GI tract irritation	Potential skin, eye, respiratory, GI tract irritation	Potential eye. respiratory irritation; potential to cause silicosis and lung cancer
Corrosion	Low corrosion	Low corrosion	Low corrosion	Corrosive	Low corrosion	Non-corrosive	Non-corrosive	Non-corrosive	Non-corrosive	Non-corrosive
Perform-ance	Moderately effective at low temperature	Effective at low temperature	Effective at low temperature	Not effective at low temperature	Effective at low temperature	Not effective at low temperature	Effective at low temperature	Effective at low temperature	Moderately effective at low temperature	Effective at low temperature
Cost	Low cost	Relatively low cost	Relatively low cost	Low cost	Relatively low cost	High cost	High cost	High cost	High cost	Low cost

[1] – Trace metals that may be present include arsenic, barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc. See Table 3 for further detail.

.

birds and mammals because of insufficient salt in their diet, and may contribute to roadkills. Solid sodium chloride ingested as grit by birds can cause acute toxicity and death. The magnesium chloride deicers do not attract wildlife.

Use of liquid chloride deicers, such as magnesium chloride, salt brine, and liquid calcium chloride, decrease air pollution as a result of the reduction in the use of sanding materials for snow and ice control. The solid forms of chloride-based deicers, such as sodium chloride and Ice Slicer, may increase air pollution through small particulates and dust generated from their use.

Most of the chloride-based deicers used in Colorado contain small amounts (1-10%) of organic corrosion inhibitors. The organic deicer Ice Ban, when mixed with magnesium chloride at concentrations of 30% and 50%, also serves as a corrosion inhibitor. The organic corrosion inhibitors can affect water quality as a result of oxygen depletion caused by high BOD levels. The presence of high levels of phosphorus, ammonia, and nitrates in some organic corrosion inhibitors can result in eutrophication of the surface water, which can deplete the oxygen levels and impact aquatic organisms.

The organic acetate-based deicers also have impacts on the environment. The organic acetate ion serves as a nutrient for soil microorganisms and will increase the number of soil microorganisms. Large numbers of microorganisms in the soil can deplete the oxygen in the soil. Soil lacking oxygen in the root zone of plants can kill vegetation. The breakdown of acetate by soil microorganisms can also result in mobilization of trace metals to groundwater. The particulates and dust from the solid form of the acetate-based deicers, such as CMA and NAAC, can contribute to air pollution.

The major potential impact of acetate deicers is oxygen depletion in soil and surface water. The presence of high levels of phosphorus and ammonia in some of the acetate-based deicers can result in eutrophication of the water. Water containing low levels of oxygen can cause mortality of fish and invertebrates. Toxicity tests indicate that acetate deicers are more likely to cause "chronic" toxic effects to aquatic invertebrates than the chloride deicers. Acetate deicers are also more toxic to aquatic algae than the chloride deicers.

One of the main benefits of the acetate-based deicers is that they are not harmful to terrestrial vegetation at the concentrations of the deicer applied to the roadways. However, at high concentrations the acetate deicers can inhibit plant growth.

Sanding materials used for snow and ice control have harmful effects on the environment. Sand can have negative effects on water quality by increasing the turbidity of surface water. The increased turbidity will impact fish, bottom-dwelling organisms, and aquatic plants. High turbidity of the water will prevent sunlight from reaching aquatic plants and result in a decrease in photosynthesis. Sanding materials have adverse effects on air quality due to the small particulates (PM10) in the sand. Sand may also impact vegetation by blocking the openings of the stomates in the leaves, which are necessary for gaseous exchange in plants.

9.2. Human Health

Tests on small mammals, used as surrogates to determine the potential effects of deicers to humans, indicate that the deicers tested are either practically non-toxic or slightly toxic. Most of the deicers have the potential to cause minor irritation to the eyes, skin, and respiratory tract. Incidental ingestion of deicers could potentially cause minor gastrointestinal symptoms.

Sodium chloride in drinking water has been linked to hypertension in humans. The levels of sodium and chloride in drinking water are regulated by Colorado and the Federal government. The chloride ions in the chloride-based deicers can potentially contaminate drinking water. The organic components in the acetate-based deicers are biodegradable, so potential contamination of acetates in drinking water is likely to be transient. The effects of Caliber and Ice Ban in drinking water are also likely to be transient.

CMAK, Ice Ban and Liquidow Armor (inhibited calcium chloride) contain levels of nitrates that exceed the drinking water limit. Elevated levels of nitrates in the blood of infants and young children have the potential to interfere with oxygen uptake by the blood (Mussato and Guthrie 2000).

Long-term exposure to sanding materials used in snow and ice control may cause adverse effects to humans, since the PM10 particulates in the sand can penetrate the lungs and cause respiratory symptoms, tumor formation, and silicosis, a potentially fatal lung disease (Chang et al 1994). Sand is also classified as a carcinogen.

The trace metals arsenic, cadmium, and chromium are present in minute quantities in some deicers and have been identified as carcinogens. However, the expected dilution of deicers from roadways is 500-fold before reaching most waterways (Lewis 2000). A risk assessment conducted by CDPHE (2000) on trace metals on air filters in Aspen, Pagosa Springs and Denver, estimated that continuous exposure to arsenic, cadmium, and chromium would exceed the cancer risk of 10^{-6}. The concentrations of metals found on the air filters did not correlate with the contaminants found in the deicing product samples.

9.3. Corrosion

The chloride-based deicers cause corrosion of vehicles, highway bridges and utilities. Sodium chloride causes the most extensive corrosion. Most of the magnesium chloride and calcium chloride deicers presently used contain corrosion inhibitors, which reduce the corrosion potential. Some tests have shown slightly higher levels of corrosion from magnesium chloride to stainless steel and aluminum than sodium chloride (Xi and Olsgard 2000), but these tests are being re-evaluated because of inconsistencies in the results. One of the major benefits of acetate-based deicers is that they are not corrosive.

9.4. Performance

The magnesium chloride deicers Caliber M1000 and Ice Ban M50, and calcium chloride and Potassium Acetate deicers are most effective at low temperatures. The other magnesium chloride deicers, CMAK, and NAAC are moderately effective at low temperatures. The sodium chloride deicers do not work well in cold temperatures. The least effective deicer at low temperatures is CMA.

9.5. Cost

Sand is the lowest cost material for snow and ice control. Among the deicers, sodium chloride is the least costly. The costs of the magnesium chloride deicers are also low, whereas the acetate deicers are expensive.

10. WORKER SURVEYS

A survey was conducted of maintenance workers (mechanics), bus drivers and bus washers, and deicing equipment operators to evaluate the possible health effects of magnesium chloride and other deicers used in the State of Colorado. The focus of the survey was on magnesium chloride, but other deicers were also reported to be used by the survey respondants and included Ice Slicer, Caliber M1000, sand, and salt.

The survey questionnaire was sent to 126 workers at CDOT and the Roaring Fork Transit Authority (RFTA) who come into contact with deicers. A total of 69 (~55%) of the questionnaires were returned. The highest percent of respondents reporting symptoms were bus washers and maintenance workers. Symptoms reported by the respondents were fairly evenly distributed among eyes, skin, and respiratory tract. Intestinal symptoms were reported less frequently. The percent of contact with deicers for all workers was fairly evenly distributed except for bus washers who reported 76-100% contact for 100% of respondents. Most workers were exposed equally to magnesium chloride and sand and only slightly less so to salt.

Sixty-one percent of all symptoms were reported by workers from the Roaring Fork Transit Authority. This compared to 28% in CDOT Maintenance District 2 and slightly more than 5% in Districts 1 and 3. No symptoms were reported by workers in Districts 5 and 6. A total of 89% of the maintenance workers and 67% of the bus washers in the RFTA reported symptoms. Only 20% of the RFTA drivers reported symptoms. By comparison, in District 2 with the next highest group reporting symptoms, only 25% of the maintenance workers and 24% of the equipment operators reported symptoms. Skin, respiratory, and eye symptoms were equally reported. Greater than 50% of the workers in District 2 and the RFTA reported exposure to deicers greater than 50% of the time. Less than 50% of the workers in the other districts reported exposure to deicers greater than 50% of the time.

In order to interpret the results of the survey several factors need to be considered. The survey lacked a strict scientific basis, so caution is necessary when interpreting the results. The survey results seemed to indicate some correlation between deicer exposure, the area where people worked, and the type of job held by the worker. However, the amount of time of exposure to the deicers was based on each worker's perception, so that it is difficult to accurately quantify amount of exposure. For example, an equipment operator may be on a road every day where deicers are used and report a 100% exposure, but the actual level of exposure may be quite different from that of a maintenance worker (mechanic) who also reports a 100% exposure.

In reporting the results, no attempts were made to attribute causes to the symptoms. In several instances, workers reported their symptoms as being related to "colds" or other causes. All responses in the questionnaires were given equal weight. Thus, at this level of the survey, it is difficult to definitively attribute any of the reported symptoms to a specific cause. A sample questionnaire, a more detailed report of the survey results, and a spreadsheet of the results of the survey is provided in Appendix F.

11. RECOMMENDATIONS

11.1. Recommendations for Additional Studies

Recommendations for additional studies were made by the author and members of the study review panel. They include the following suggestions:

- Conduct chemical analysis on all deicers using the same analytical methods that have detection limits below the PNS and Colorado specifications so that the user can be certain that the deicer meets the specifications.

- Conduct acute aquatic toxicity tests of the deicer formulations presently used on roadways on fish and invertebrates to determine the toxicity of the deicers to aquatic organisms.

- Conduct tests to further evaluate the effects of the deicers used in Colorado on vegetation along the roadways.

- Conduct a more definitive quantitative study on the human health effects of the deicing chemicals using a larger data set than was used in the CDPHE (2000) study.

- Conduct studies on the environmental and human health effects of the newer deicers, such as NAAC, CMAK, and Potassium Acetate, since little information is available on these chemicals.

- Conduct additional studies on corrosion of the deicers used using the modified NACE method or other appropriate method.

- Conduct a study to measure the concentrations of specific deicers in the soil at varying distances from the roadway where the chemicals are used and the closest stream or river.

- Conduct studies to evaluate the effects of dust-suppression chemicals (e.g., magnesium chloride) on vegetation and local wildlife, since these chemicals remain in the environment long after application.

- Conduct quantitative worker surveys to determine whether the symptoms reported by some of the CDOT and RFTA employees could be attributed to exposure to the deicers.

11.2. Recommendations for Reducing the Impact from Deicers

Recommendations have been made in published reports on reducing the impacts from deicers and educating the public about deicers (Sorenson et al 1996; Hanes et al 1976; O'Daugherty 1992; Eppard 1992; Chang et al 1994; Vancouver 1998; Cassin 1999). These recommendations include the following:

- Reduce traffic speeds during winter months
- Increase driver education
- Identify areas that are vulnerable to effects of deicing chemicals (e.g., aquifers, salt sensitive vegetation, lakes, wetlands, rivers, streams)
- Use weather information to determine which deicer/abrasive combination would be the most effective
- Develop a simple decision support system based on weather conditions
- Train operators to determine optimal application rates and provide assistance in selecting deicing materials
- Use minimum amounts of deicers needed for effective ice and snow removal
- Collect runoff in special lagoons lined with impervious membranes. Pump out regularly and transport to appropriate treatment facilities.
- Use pavement condition sensors to obtain surface temperature and moisture, to allow accurate predictions of the presence of frost or ice
- Plant salt-tolerant local species and persistent turf species adjacent to areas exposed to deicing chemicals

- Use small amounts of sand, but aggressively remove sand to minimize potential of air quality violations.
- Use more aggressive snow plowing, while using less sand and deicers
- Use anti-icing strategies which reduce the total amount of chemical applied
- Develop a community awareness and public education program, so that the public is better informed about existing snow and ice control practices and their limitations. This would minimize unrealistic expectations by the public about the snow and ice control program.

12. CONCLUSIONS

Each of the snow and ice control methods (deicers and sand) described in this report has advantages and disadvantages. The advantages and disadvantages of each deicer are different, so the user must consider the trade-offs of the various deicers before choosing a deicer that will best meet the needs of the State, city, town, and the public.

12.1. General

- Deicers reduce the number of accidents from winter driving.
- Deicers reduce air pollution when compared with sand.
- Human health effects of deicers may include skin, eye, respiratory and intestinal irritation, and, possibly, increases in cancer rates from trace metals.
- The estimated dilution of deicers from roadway to surface water is 100 to 500-fold, which reduces the potential of environmental and human health effects.
- Chemical analysis methods with lower detection levels should be used for determining the concentrations of trace metals and other chemicals in deicers.
- Most deicers contain minute amounts of some trace metals.
- Additional research is needed to determine whether the small amounts of trace metals present in deicers pose a human health concern.
- Some deicers are more effective in cold temperatures than other deicers.
- Aquatic toxicity tests should be conducted on all deicers under the same test conditions to characterize the relative toxicity of each deicer.

12.2. Chloride-based Deicers

- Chlorides can increase the salinity of soil, surface water, and groundwater.
- Acute toxicity of chloride-based deicers to aquatic life is generally low.
- Sodium chloride attracts wildlife, thereby contributing to roadkills; magnesium chloride and calcium chloride do not attract wildlife.

- Chloride-based deicers are corrosive to vehicles, highway bridges and utilities; addition of corrosion inhibitors to deicers generally reduces the corrosion potential.
- Some corrosion inhibitors in the chloride-based deicers are organic compounds with high levels of phosphorus, ammonia, and nitrates, which can potentially cause oxygen depletion of surface water.
- Additional studies are needed to resolve inconsistencies in corrosion test results.
- Chloride-based deicers are low in cost.

12.3. Acetate-based Deicers

- CMA and Potassium Acetate are not harmful to roadside vegetation at the concentrations used. Studies on vegetation effects of the other acetate deicers have not been conducted.
- Acetate deicers are moderately toxic to aquatic algae.
- Acetate deicers are not corrosive to metals in vehicles, bridges, and utilities.
- Acetate deicers can cause depletion of oxygen in soil and water.
- The cost of purchasing acetate deicers is high.
- Additional research is needed on potential environmental and human health effects of acetate-based deicers, since few studies have been conducted.

12.4. Sand

- Sand causes air and water pollution.
- Sand may potentially cause serious lung disease and is listed as a carcinogen.
- Although the cost of purchasing sand is low, the removal costs need to be considered.

13. REFERENCES

Addo, J. 1995. Report on Laboratory Corrosion Test. Prepared for Envirotech Services, Inc., Colorado. March 16, 1995.

American Fisheries Society. 1978. A review of the EPA Red Book Quality Criteria for Water (Preliminary Edition). June 1978.

Amrhein, C. and J.E. Strong. 1990. The Effect of Deicing Salts on Trace Mobility in Roadside Soils. Journal of Environmental Quality 19(4): p. 765-762.

Audesirk, G. and T. Audesirk. 1993. Biology, Life on Earth. Macmillan Publishing Co., New York.

Bernstein, L., L.E. Francois, and R.A. Clark. 1972. Salt Tolerance of Ornamental Shrubs and Ground Covers. Journal of American Society of Horticultural Science 97: 550-556.

Bohn, J., B.L. McNeal and G.A. O'Connor. 1985. Soil Chemistry. Wiley-Interscience. New York.

California Fertilizer Association. 1985. Western Fertilizer Handbook. The Interstate Printers and Publishers, Inc. Dansville, Illinois.

Cassin, L. 1999. Summary of Existing Information on $MgCl_2$. Memo from Lee Cassin, Aspen Environmental Health Director (received from RFC).

CDOT. 2000. Liquid Magnesium Chloride Specifications. State of Colorado Department of Transportation. (www.gssa.state.co.us).

CDPHE. 2000. Health Effects of Deicing Applications in Colorado. Colorado Department of Public Health and Environment.

CDPHE. 2001. Regulation No. 31. The Basic Standards and Metholologies for Surface Water (5 CCR 1002-31). Colorado Department of Public Health and Environment Water Quality Control Commission. Adopted May 22 1979. Last Effective Date May 14, 2001.

Chang, N., W. Pearson, J.I.J. Chang, A. Gross, M. Meyer, M. Jolly, B. Vang, and H. Samour. 1994. Environmentally Sensitive Sanding and Deicing Practices, Final Report. Prepared for the Colorado Transportation Institute and the Colorado Department of Transportation by the ESSD Research Group of the Department of Civil Engineering of the University of Colorado at Denver, November. CDOT-CTI-95-5.

Chappelow, C. 1990. Evaluation Procedures for Deicing Chemicals, Interim Report. Midwest Research Institute. Prepared for Strategic Highway Research Program.

Chappelow, C.C., A.D. McElroy, R.R. Blackburn, D. Darwin, F.G. de Noyelles and C.E. Locke. 1993. Handbook of Test Methods for Evaluating Chemical Deicers. Prepared by Midwest Research Institute and the University of Kansas Centre for Research Inc. for the National Research Council Strategic Highway Research Program.

Cheng, K. and T. Guthrie. 1998. Liquid Road Deicing Environment Impact. Prepared for Insurance Corporation of British Columbia.

Church, P. and P. Friesz. 1993. Effectiveness of Highway Drainage Systems in Preventing Road-Salt Contamination of Groundwater: Preliminary Findings. Transportation Research Board. Transportation Research Record 1420.

Colwill, D.M.. J.R. Thompson and A.J. Rutter. 1992. An Assessment of the Condition of Shrubs along Motorways. Report 1061, U.K. Transport & Road Research Laboratory, Crowthorne, Berkeshire, England.

Cowherd, C. 1998. Particulate Matter from Roadways, Final Report. Midwest Research Institute, Report No. CDOT-DTD-98-8.

Davis, G., S. Krannitz and M. Goldstein. 1992. A Reconnaissance Study of Roadside Tree Injury and Decline at 17 Sites in Interior B.C. Roadside Tree Injury Committee, Victoria. B.C. 37 pp.

Demers, C.L. and R.W. Sage. 1990. Effects of Road Deicing Salt on Chloride Levels in Four Adirondack Streams. Water, Air and Soil Pollution 49: (3-4) pp. 369-373.

D'Itri, F. (ed). 1992. Chemical Deicers and the Environment. Lewis Publishers, Inc., Michigan.

Dow Chemical Company. no date. Manual of Good Practice for Snow and Ice Control with Dow Calcium Chloride Products.

Environment Canada. 1984. Calcium Chloride: Environmental and Technical Information for Problem Spills. Protection Programs Directorate, Technical Services Branch.

Environment Canada. 2000. Canadian Environmental Protection Act, 1999 Priority Substance List Assessment Report – Road Salts. Draft for Public Comments. Environment Canada, Health Canada. August 2000.

Envirotech. 2000. Ice Slicer and Ice Slicer-RS Chemical Analysis. Envirotech Services, Inc.

EPA. 1976. Quality Criteria for Water. July 1976. U.S. Environmental Protection Agency, U.S. Government Printing Office: 1977 0-222-904, Washington, D.C. 256 pp.

EPA. 1977. March 1977. Proposed National Secondary Drinking Water Regulation, Federal Register, vol. 42, No. 62, pp. 17143-17147. U.S. Environmental Protection Agency.

EPA. 1989. Risk Assessment Guidance for Superfund (RAGS). Volume I. U.S. Environmental Protection Agency.

Eppard, R. et. al. 1992. Effects of Deicing Salt on Overstory Vegetation in the Lake Tahoe Basin. Transportation Research Record No. 1352.

Epps, J.A. and M. Ardila-Coulson 1997. Summary of SHRP Research and Economic Benefits of Snow and Ice Control. Report No. FHWA-SA-98-015. RoadSavers. December 1997.

Evans, M. and C. Frick. 2000. The Effects of Road Salts in Stream, Lake and Wetland Ecosystems. Draft. National Waters Research Institute, Saskatoon, Saskatchewan.

Fink, E. 2001. Maintenance Snow & Ice Costs, Staff Branches Update. Presentation to the Transportation Commission. April 19, 2001.

French, D.W. 1959. Boulevard Trees are Damaged by Salt Applied to Streets. Minnesota Farm & Home Science 16(2).

Gidley, J. 1989. Survey of Soil and Plant Tissue Samples for Salt Impacts Due to Highway Deicing Operations. California Department of Transportation.

Gionfriddo, J.P. and L.B. Best. 1995. Grit Use by House Sparrows: Effects of Diet and Grit Size. The Condor 97: 57 – 67.

Granato, G., P.E. Church, and V.J. Stone. 1995. Mobilization of Major and Trace Constituents of Highway Runoff in Groundwater Caused by Deicing Chemical Migration. Transportation Research Record, No. 1483.

Guthrie, T.F. 1999. Freezgard Zero Chemical and Toxicity Testing. Report submitted to Insurance Corporation of British Columbia, March 31, 1999.

Hanes, R.E., L.W. Zelanzy, and R.E. Blaser. 1970. Effects of Deicing Salts on Water Quality and Biota, Literature Review and Recommended Research. National Cooperative Highway Research Program Report 91.

Hanes, R.E., L.W. Zelanzy, K.G. Verghese, R.P. Bosshart, E.W. Carson, Jr., R.E. Blaser and D.D. Wolf. 1976. Effects of Deicing Salts on Plant Biota and Soil, Experimental Phase. Transportation Research Board. National Cooperative Highway Research Program Report No. 170.

Health Canada. 1996. Guidelines for Canadian Drinking Water Quality, 6th Edition. Ministry of Supply & Services Canada, Ottawa, Ontario, 90 pp.

Hiatt, G.F.S., George, N.A., Cushman, J.R., Griffis, L.C. and Rausina, G.A. 1989. Calcium Magnesium Acetate: Comparative Toxicity Tests and an Industrial Hygiene Site Investigation, Transportation Research Record 1157.

HITEC. 1998. Preliminary Evaluation Findings for Ice Ban™. Technical Evaluation Report. Highway Innovative Technology Evaluation Center/ Civil Engineering Research Foundation (CERF). CERF Report #40340.

HITEC. 1999. Summary of Evaluation Findings for the Testing of Ice Ban®. Technical Evaluation Report. Prepared by Highway Innovative Technology Evaluation Center (HITEC)/ Civil Engineering Research Foundation (CERF). CERF Report #40410. September 1999.

Hofstra, G. and D.W. Smith. 1984. The Effects of Road Deicing Salt on the Levels of Ions in Roadside Soils in Southern Ontario. Journal of Environmental Management 19: 261-271.

Horner, R.R. 1988. Environmental Monitoring and Evaluation of Calcium Magnesium Acetate. Transportation Research Board, National Research Council, Washington, D.C.

Horner, R.R. 1990. Environmental Effects of Calcium Magnesium Acetate: Emphasizing Aquatic Ecosystem Effects. In: The Environmental Impact of Highway Deicing. Institute of Ecology Publication No. 33, September 1990, Proceedings of Conference October 13, 1989, Davis, University of California.

Hutchinson, F.E. and B.E. Olson. 1967. The Relationship of Road Salt Applications to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways. In Highway Research Record 193, HRB, National Research Council, Washington, D.C.

Jones, P.H., J.A. Jeffrey, P.K. Watler, and H. Hutchon. 1986. Environmental Impact of Road Salting-State of the Art. Ontario Ministry of Transportation Technical Report RR 237.

Jones, P., B. Jeffrey, P. Watler and H. Hutchon. 1992. Environmental Impact of Road Salting. In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc., Michigan.

Keep, D. and D. Parker. 2000. Proactive Guide to Snow and Ice Control: A Guide for Highway Winter Maintenance Personnel. Prepared by Ice and Snow Technologies, LLC., Washington.

Kirkham, R., Zook, J, and Sares, M. 1999. Reconnaissance Field Investigation of Surface-water Specific Conductance in the Snowmass to Glenwood Springs Area, West-Central Colorado. Colorado Geological Survey Information Series 49. 21 pp.

Kurata, Y. et. al. 1989. Lack of Carcinogenicity to Magnesium Chloride in a Long-term Feeding Study in B6C3F Mice. Food Chemistry & Toxicology, Vol. 27 (9):559-563.

Lewis, Jr., W. 1997. Magnesium Chloride Deicer: A Literature Review with Emphasis on the State of Colorado. CDOT-CTI-95-5.

Lewis, Jr. W. 2000. Preliminary Environmental Evaluation of Caliber M1000 for Use in Colorado, Final Report. Prepared for Colorado Department of Transportation.

McCrum, R.L. 1992. Corrosion and Alternate Deicers. In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc., Michigan.

McFarland, B. and K. O'Reilly. 1992. Environmental Impacts and Toxicological Characteristics of Calcium Magnesium Acetate (CMA). In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc.

Midwest Laboratories. 2000. Chemical Analysis Results for Sodium Acetate (NAAC). Report Number 00-346-2171. December 13, 2000.

Missoula. 1996. Evaluation of the Water Quality Impacts of Chemical Deicer Usage in Missoula, Montana, Volume 1. Prepared by Missoula City-County Health Department/ Missoula Valley Water Quality District.. September 1996.

Moran, V., L. Abron and L. Weinberger. 1992. A Comparison of Conventional and Alternate Deicers: An Environmental Impact Perspective. In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc.

Mussato, B. and T. Guthrie. 2000. Anti-Icers – Chemical Analysis and Toxicity Test Results. Prepared for: Insurance Corporation of British Columbia.

Newhouse, N. and T. Kinley. 2001. Preliminary Assessments of Cayenne Pepper as a Deterrent to Road Salt Licking by Sheep and Magnesium Chloride as a Non-attracting Alternative to Road Salt. Prepared by Sylvan Consulting Ltd. Prepared for Insurance Corporation of British Columbia, Kamloops, BC.

Nolan, Davis. 1994. A Comparison of the Effects of Urea, Potassium Acetate, Calcium Magnesium Acetate and Sodium Formate Runway Deicers On The Environment. Transport Canada Report TP12285E, Ottawa, Ontario.

NRC. 1991. Highway Deicing: Comparing Salt and Calcium Magnesium Acetate. Transportation Research Board, Washington. D.C.

Oberle, L. 1999. Study of Magnesium Chloride as an Alternative Deicer. Colorado Department of Public Health and Environment.

O'Doherty, J. 1992. Winter Highway Maintenance in Michigan. In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc., Michigan.

OECD. 1989. Curtailing Usage of De-icing Agents in Winter Maintenance. OECD Scientific Group. OECD, Paris, France.

Pilon, P.E., K.W.F. Howard. 1987. Contamination of Subsurface Waters by Road Deicing Chemicals. Water Pollution Research Jounal of Canada 22: (1) pp. 157-172.

Prior, G.A. and P.M. Berthouex. 1967. A Study of Salt Pollution of Soil by Highway Salting. In Highway Research Record 193, HRB, National Research Council, Washington, D.C., pp.8-21.

Roberts, E.C. and E.L. Zybura. 1967. Effect of Sodium Chloride on Grasses for Roadside Use. Highway Research Record Number 193. Highway Research Board.

Satterfield, C. 1997. Magnesium Chloride Environmental Consequences. Draft. Prepared for Great Salt Lake Minerals and Riley Windover. March 3, 1997.

Schraufnagel, F.H. 1967. Pollution Aspects Associated with Chemical Deicing. Highway Research Record 193:22-33.

Seasell, C. and N. Agbenowski. 1998. Effects of Road Deicing Salts on Groundwater Systems. Unk. Web site, 6/7/98.

Sorensen, D., V. Mortenson and R. Zollinger. 1996. A Review and Synthesis of the Impacts of Road Salting on Water Quality. Utah DOT.

State of Colorado. 1986. Proposed Nitrogenous Water Quality Standards for the State of Colorado. Prepared by the Nitrogen Cycle Committee of the Basic Standards Review Task Force. March 12, 1986. Final Draft.

Tanaka, H. et. al. 1994. Thirteen Week Oral Toxicity Study of Magnesium Chloride in B6C3F Mice. Toxicology Letters Vol 73, p. 25-32.

Vancouver City Council. 1998. Use of Road Salt for Deicing. Administrative Report, Vancouver City Council, Mar. 9, 1998.

Vitaliano, D. 1992. Environmental Costs of Road Salting. In: Chemical Deicers and the Environment, D'Itri (ed), Lewis Publishers, Inc.

Warrington, G.E. 1993. Roadside Vegetation Problems in Summit County Colorado. The Resulfs of Preliminary Soil Sampling and Testing. A Repot to D.V. Norman, White River National Forest Dillon Ranger District, Silverthorn, CO.

Wegner, W. And M. Yaggi. 2001. Environmental Impacts of Road Salt and Alternatives in the New York City Watershed. Stormwater. July/August 2001.

Westing, A. 1969. Plants and Salt in the Roadside Environment. Phytopathology 59: 1174-1181.

Wetzel, R.G. 1983. Limnology. Saunders College Publishing. Toronto, Ontario. Canada.

Winters, G.R., J. Gidley and H.Hunt. 1985. Environmental Evaluation of Calcium Magnesium Acetate (CMA). Report FHWA-RD-84-094. California Department of Transportation, June

1985.

Woodham, D. 1994. Alternative Deicing Chemicals Research. Prepared in Cooperation with the U.S. Department of Transportation, federal Highway Administration. Final Report, January 1994.

Xi, Y. and Olsgard. 2000. Effects of De-Icing Agents (Magnesium Chloride and Sodium Chloride) on Corrosion of Truck Components. University of Colorado/Boulder. Western Highway Institute. November 2000. Prepared for Colorado Department of Transportation Research Branch.

APPENDIX B

MATERIAL SAFETY DATA SHEETS (MSDS)

LIST OF MATERIAL SAFETY DATA SHEETS

DEICERS

Caliber M1000 (Magnesium Chloride + Caliber)

CF7 (Potassium Acetate)

CMA (Calcium Magnesium Acetate)

CMAK (mixture CMA and Potassium Acetate)

FreezGard Zero with Shield LS (magnesium chloride)

Ice Ban M50 (Magnesium Chloride + Ice Ban)

Ice-Stop CI (Magnesium Chloride)

Ice Slicer (Sodium Chloride)

Liquidow Armor (Calcium Chloride)

NAAC (Sodium Acetate)

Sodium Chloride (road salt)

Sand

CORROSION INHIBITORS

Caliber

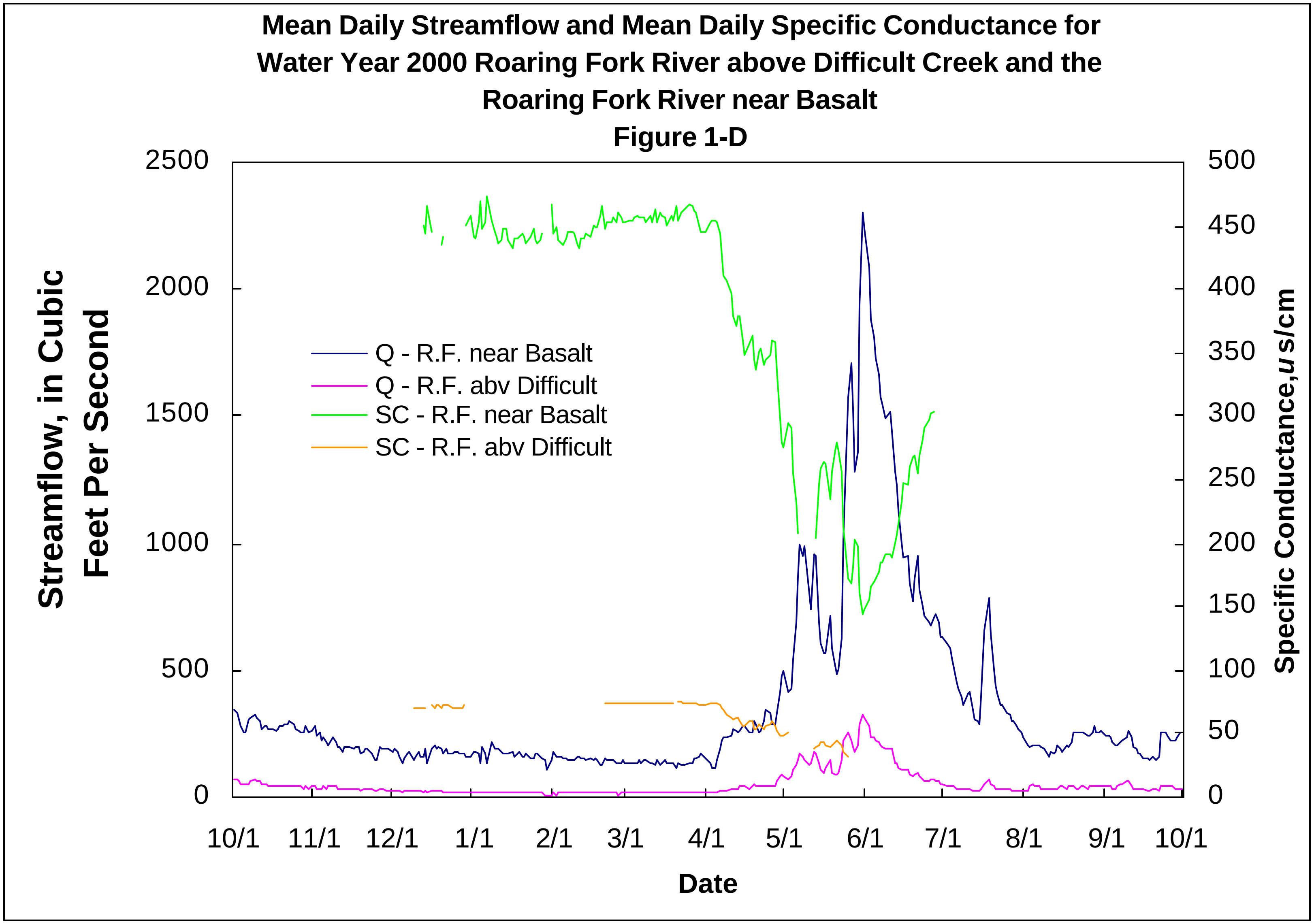
Ice Ban

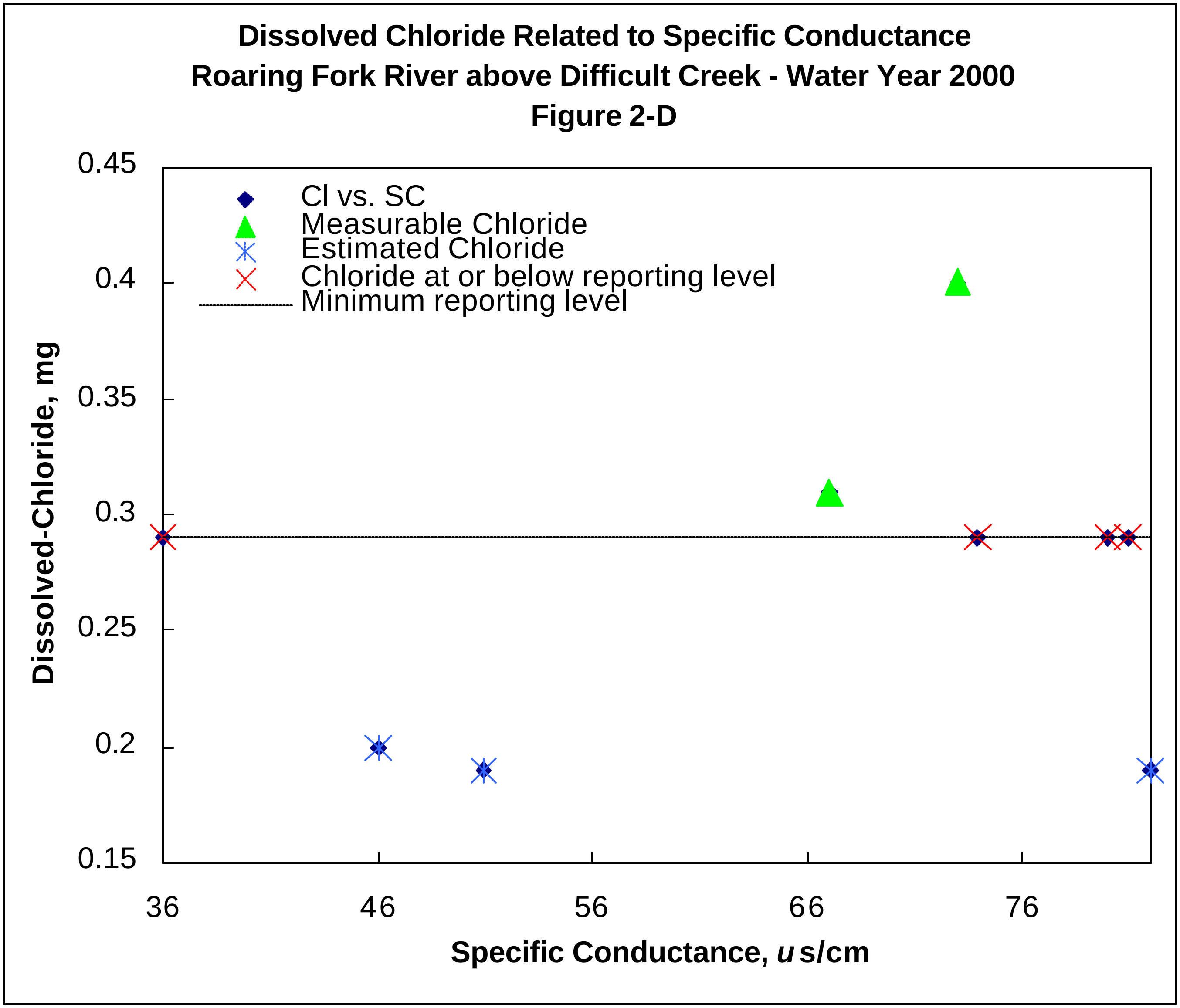
Shield LS

Triethanolamine

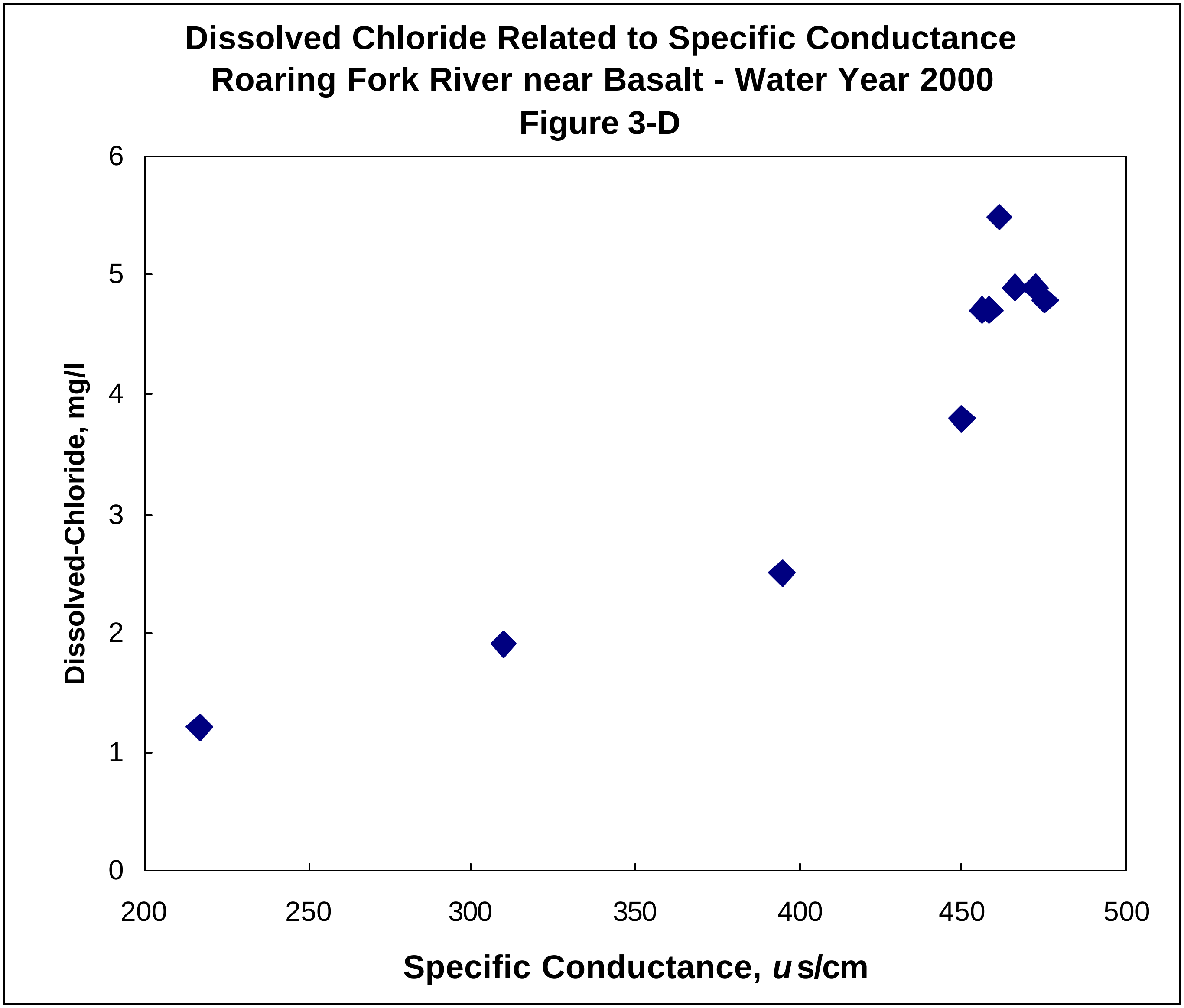
APPENDIX D

USGS FIGURES ON CHLORIDE LEVELS IN THE ROARING FORK RIVER, COLORADO

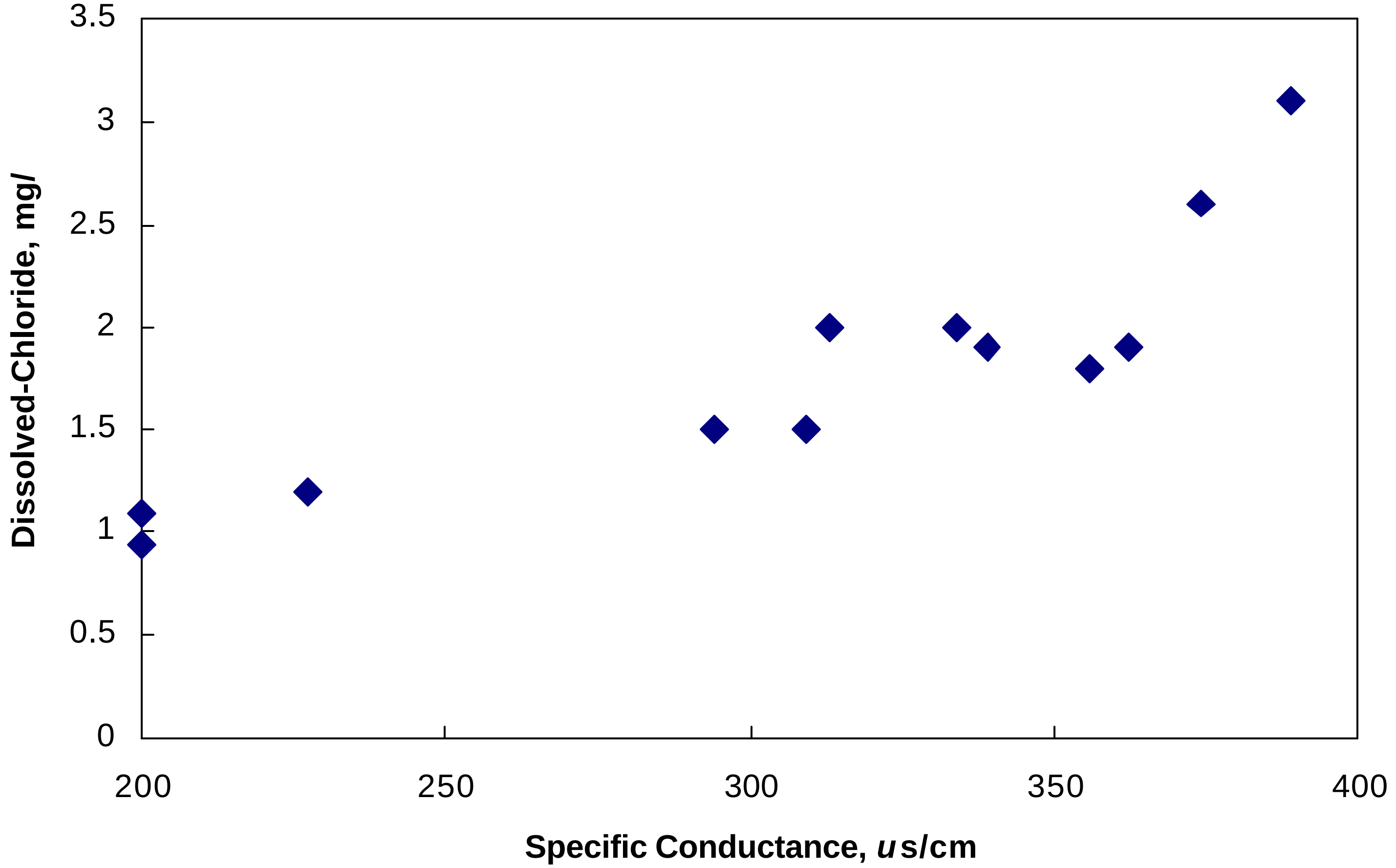

Mean Daily Streamflow and Mean Daily Specific Conductance for
Water Year 2000 Roaring Fork River above Difficult Creek and the
Roaring Fork River near Basalt
Figure 1-D
Streamflow, in Cubic Feet Per Second
Specific Conductance,u s/cm
Q - R.F. near Basalt
Q - R.F. abv Difficult
SC - R.F. near Basalt
SC - R.F. abv Difficult
2500
2000
1500
1000
500
0
500
450
400
350
300
250
200
150
100
50
0
10/1
11/1
12/1
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
Date



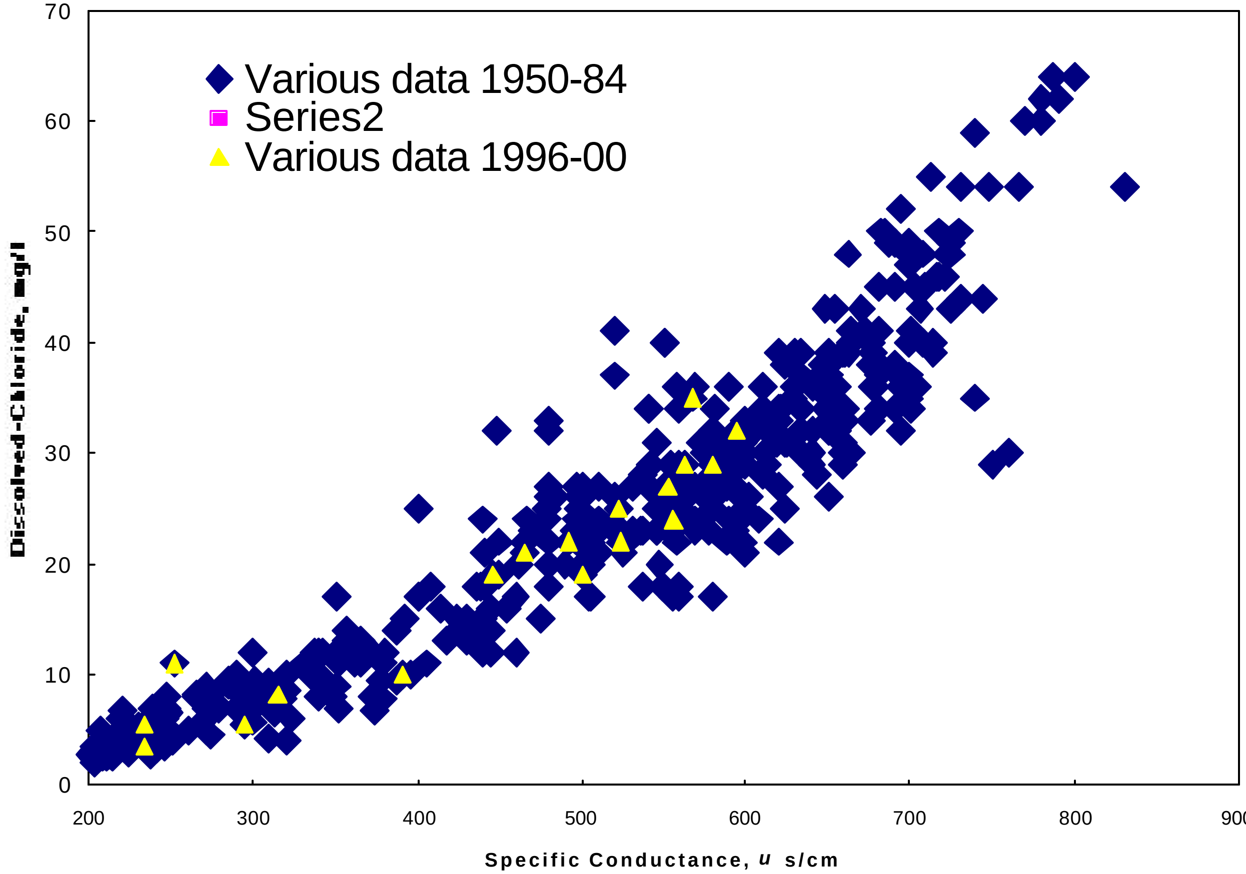
Dissolved Chloride Related to Specific Conductance
Roaring Fork River above Difficult Creek - Water Year 2000
Figure 2-D
Cl vs. SC
Measurable Chloride
Estimated Chloride
Chloride at or below reporting level
Minimum reporting level
Dissolved-Chloride, mg
0.45
0.4
0.35
0.3
0.25
0.2
0.15
36
46
56
66
76
Specific Conductance, u s/cm

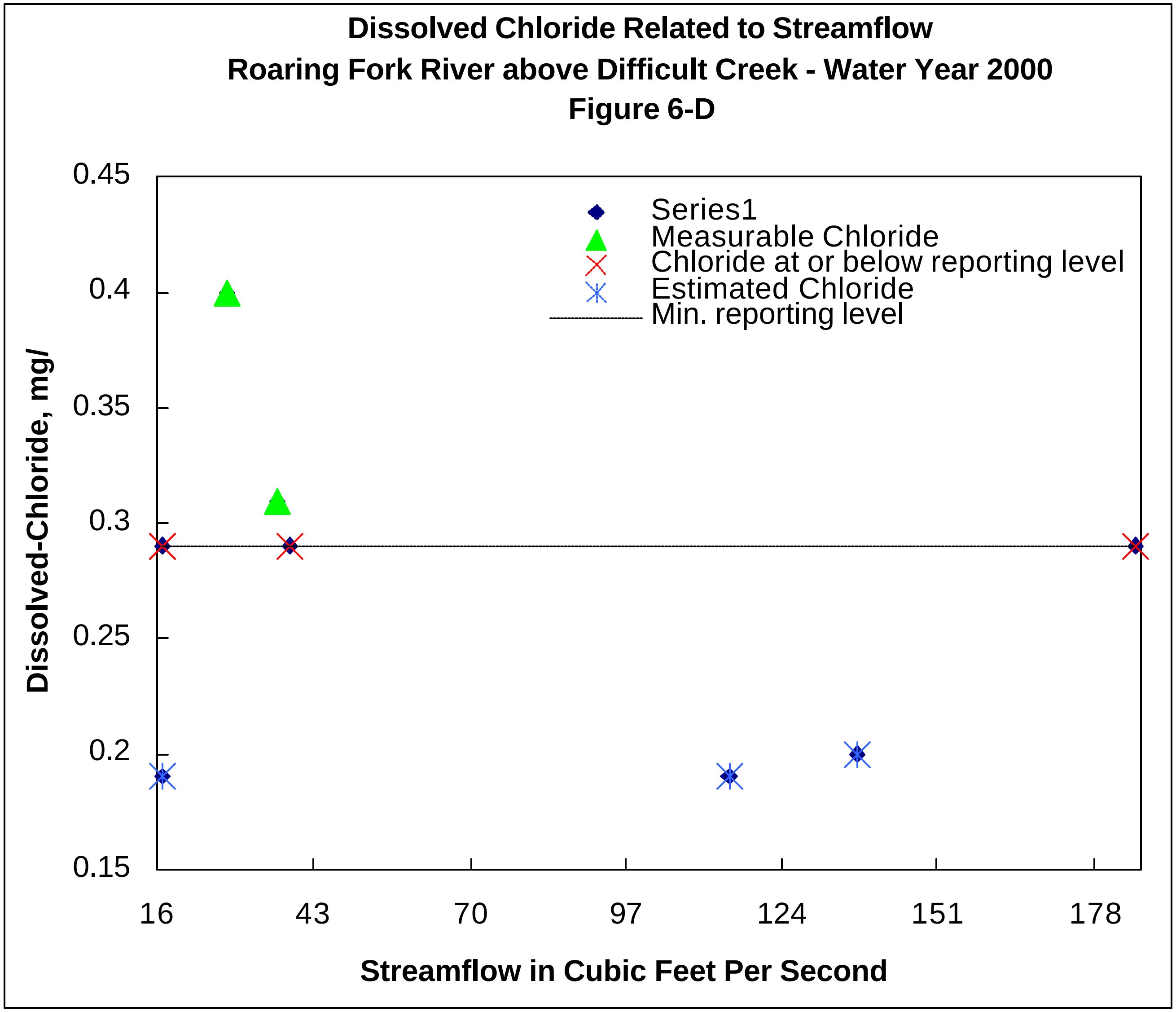

Dissolved Chloride Related to Specific Conductance
Roaring Fork River near Basalt - Water Year 2000
Figure 3-D
Dissolved-Chloride, mg/l
0
1
2
3
4
5
6
200
250
300
350
400
450
500
Specific Conductance, u s/cm

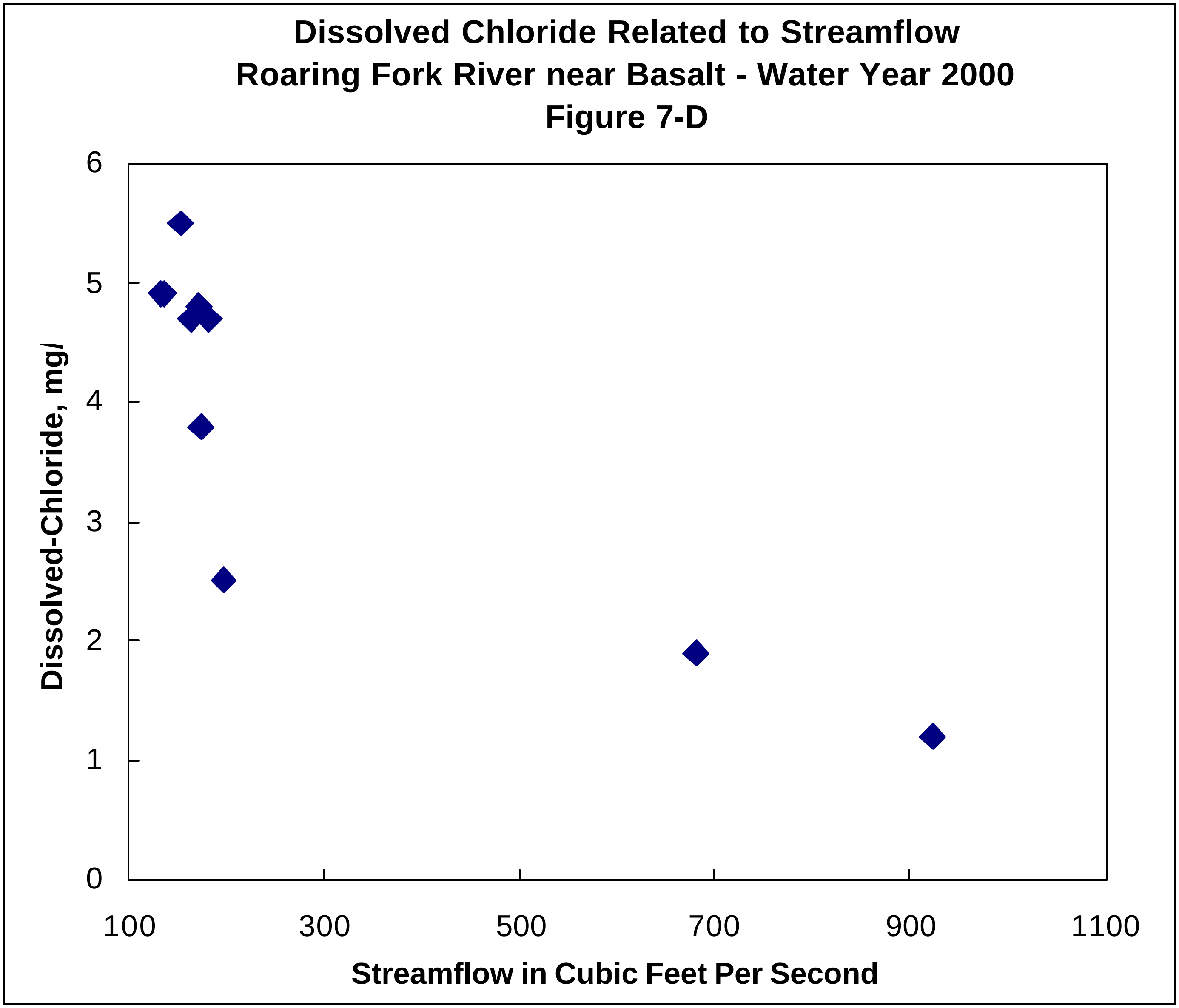
Dissolved Chloride Related to Specific Conductance
Roaring Fork River near Emma - Water Years 1998-2000
Figure 4-D

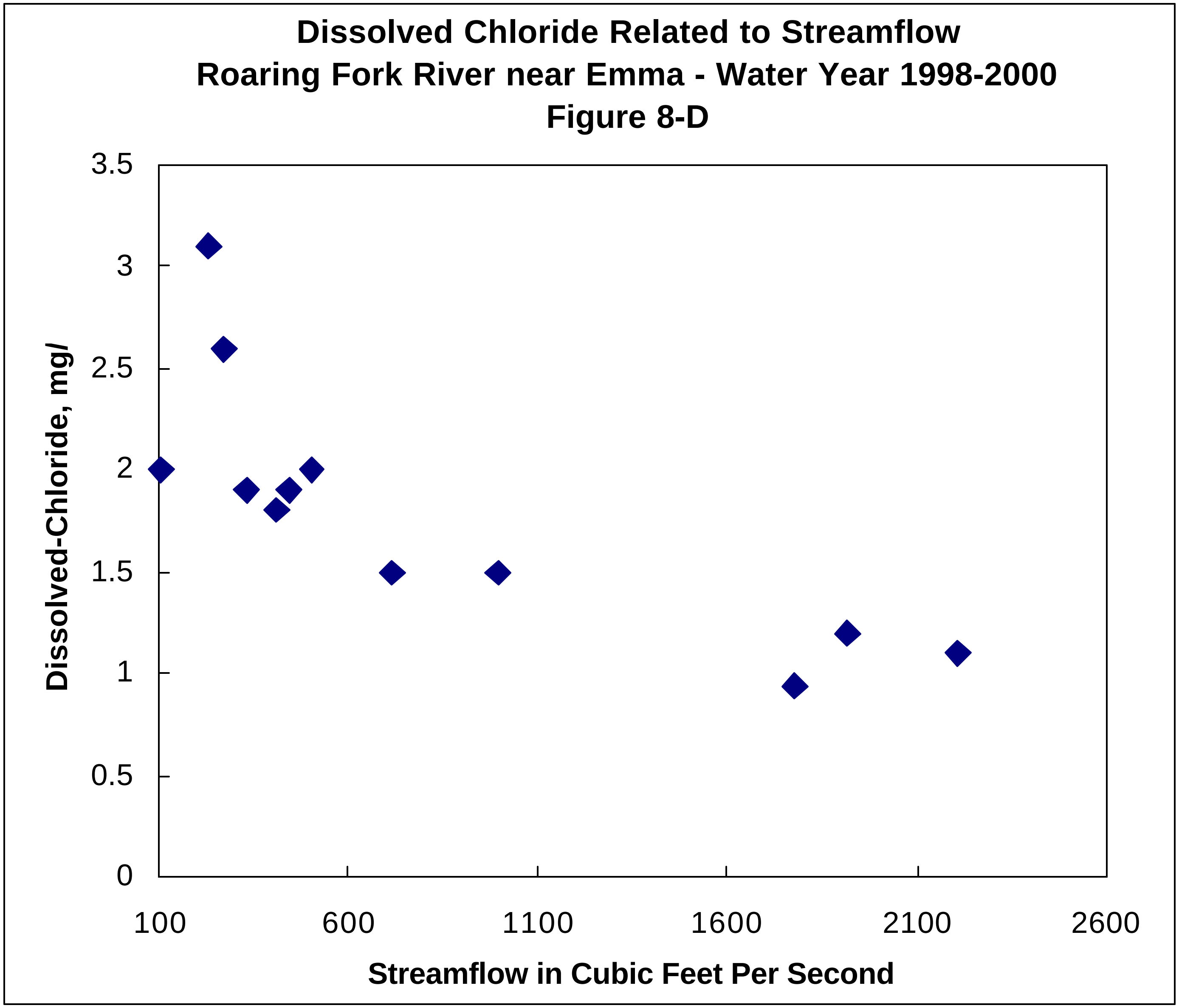


Dissolved Chloride Related to Specific Conductance
Roaring Fork River at Glenwood Springs - Selected Water Years 1950-2000
Figure 5-D

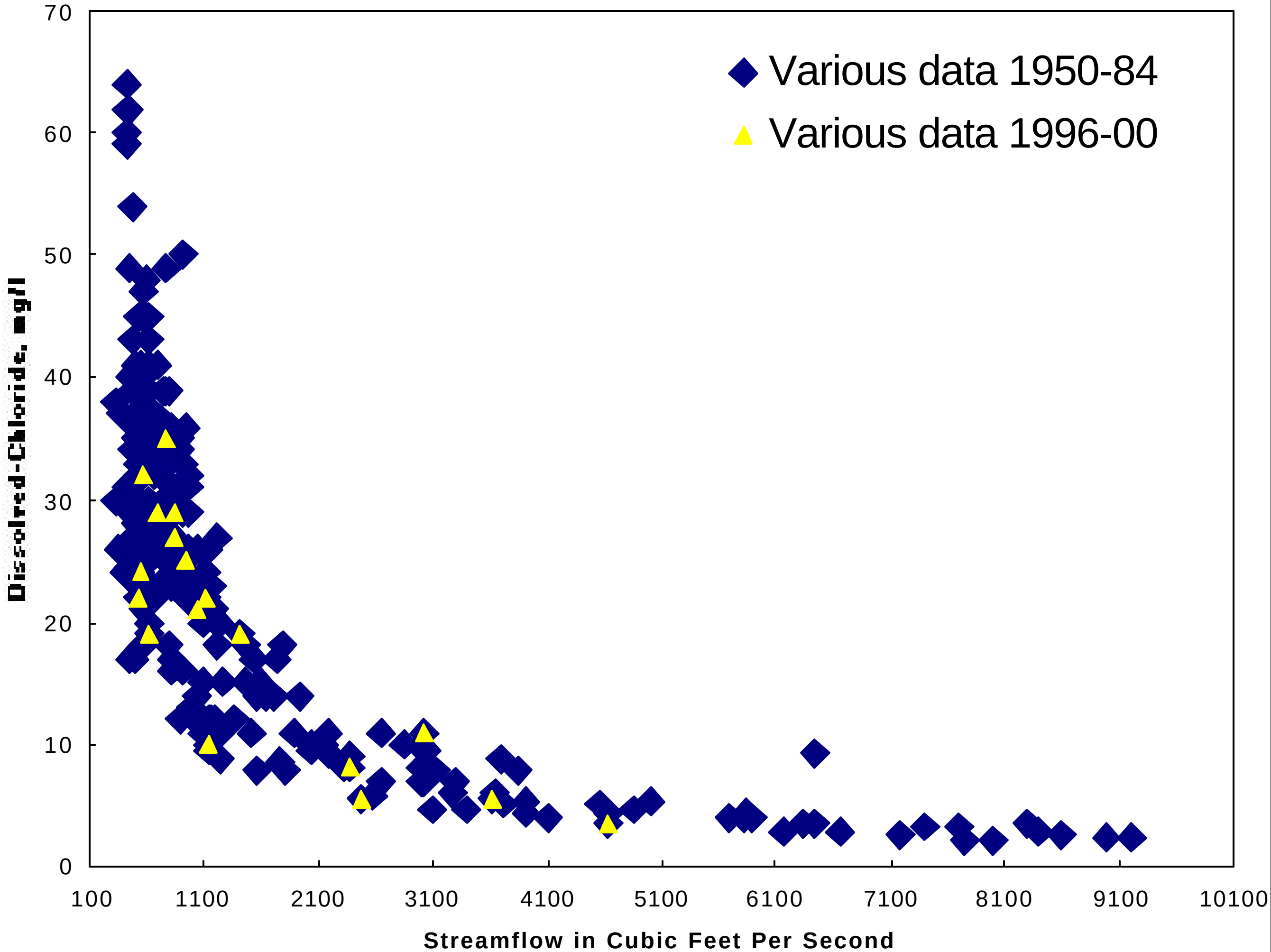


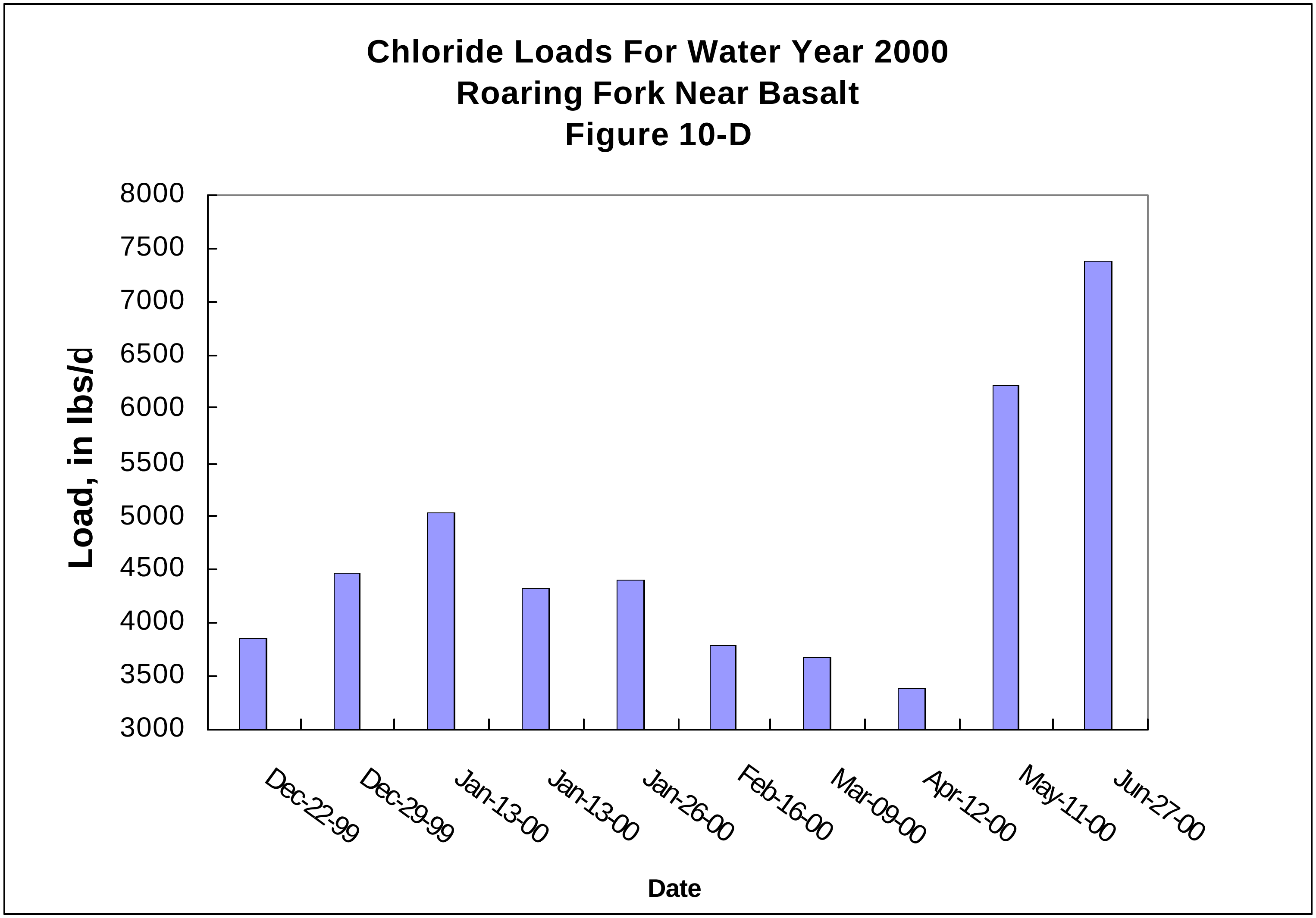

Dissolved Chloride Related to Streamflow
Roaring Fork River above Difficult Creek - Water Year 2000
Figure 6-D
Dissolved-Chloride, mg/
0.45
0.4
0.35
0.3
0.25
0.2
0.15
16
43
70
97
124
151
178
Streamflow in Cubic Feet Per Second
Series1
Measurable Chloride
Chloride at or below reporting level
Estimated Chloride
Min. reporting level


Dissolved Chloride Related to Streamflow
Roaring Fork River near Basalt - Water Year 2000
Figure 7-D
Dissolved-Chloride, mg/l
0
1
2
3
4
5
6
100
300
500
700
900
1100
Streamflow in Cubic Feet Per Second

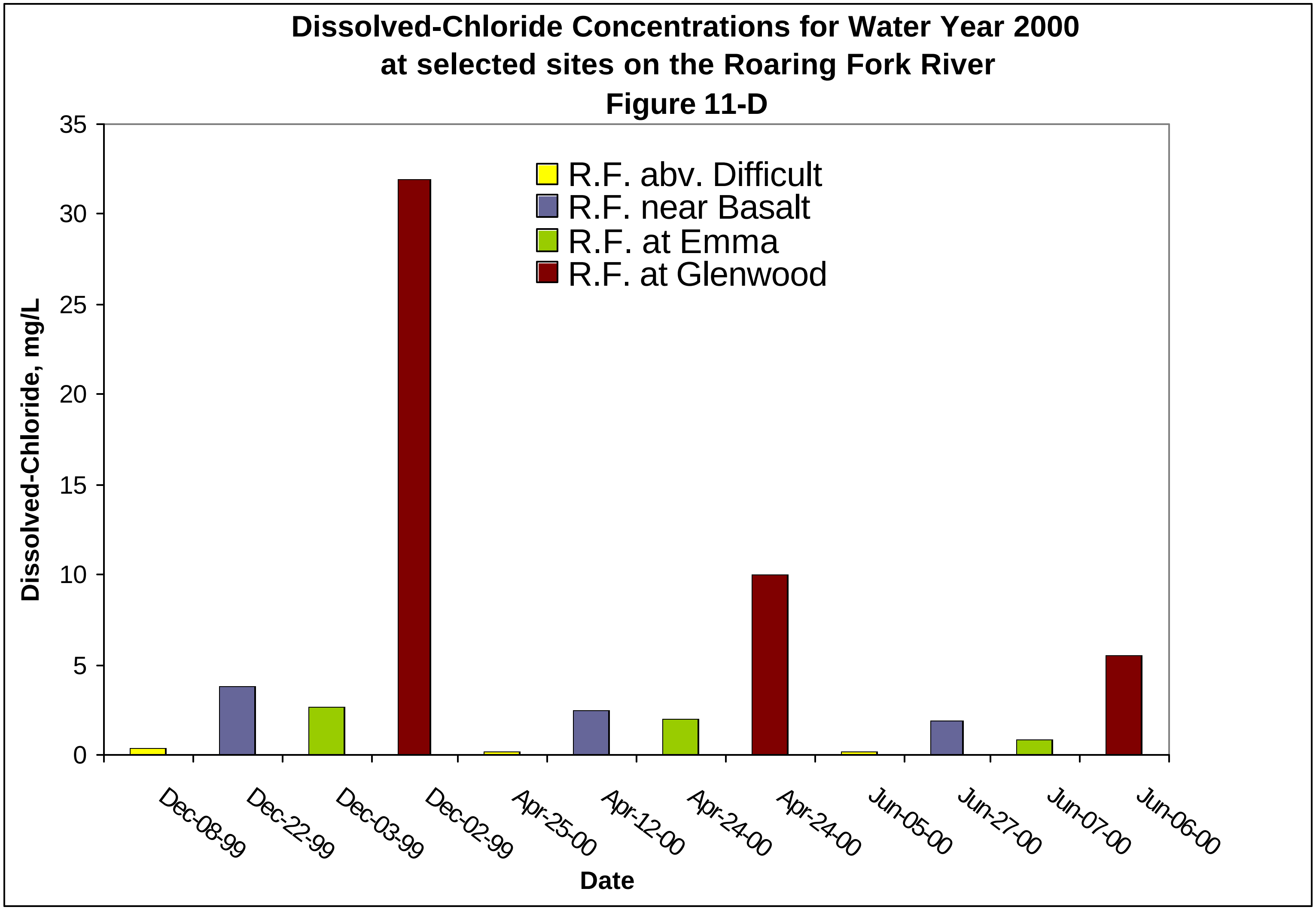

Dissolved Chloride Related to Streamflow
Roaring Fork River near Emma - Water Year 1998-2000
Figure 8-D
Dissolved-Chloride, mg/
3.5
3
2.5
2
1.5
1
0.5
0
100
600
1100
1600
2100
2600
Streamflow in Cubic Feet Per Second

Dissolved Chloride Related to Streamflow
Roaring Fork River at Glenwood - Various Water Year 1950-00
Figure 9-D





Chloride Loads For Water Year 2000
Roaring Fork Near Basalt
Figure 10-D
Load, in lbs/d
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
Dec-22-99
Dec-29-99
Jan-13-00
Jan-13-00
Jan-26-00
Feb-16-00
Mar-09-00
Apr-12-00
May-11-00
Jun-27-00
Date


Dissolved-Chloride Concentrations for Water Year 2000
at selected sites on the Roaring Fork River
Figure 11-D
Dissolved-Chloride, mg/L
35
30
25
20
15
10
5
0
R.F. abv. Difficult
R.F. near Basalt
R.F. at Emma
R.F. at Glenwood
Dec-08-99
Dec-22-99
Dec-03-99
Dec-02-99
Apr-25-00
Apr-12-00
Apr-24-00
Apr-24-00
Jun-05-00
Jun-27-00
Jun-07-00
Jun-06-00
Date

APPENDIX E

HUMAN HEALTH EFFECTS OF TRACE METALS

HUMAN HEALTH EFFECTS OF TRACE METALS

The trace metals that may be present in deicing chemicals can have toxic effects to humans. They include arsenic, barium, cadmium, chromium, copper, lead, magnesium, mercury, selenium, and zinc. Another chemical present in some deicers that may cause human health effects is cyanide.

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Agency for Toxic Substances and Disease Registry (ATSDR) was required to develop toxicological profiles for trace metals and other chemicals that could cause acute, sub-acute and chronic health effects. The toxicological profiles prepared by ATSDR for trace metals are summarized below.

ARSENIC

Arsenic is a naturally occurring element widely distributed in the earth's crust. Breathing high levels of inorganic arsenic can cause irritation of the respiratory tract and lungs. Ingesting high levels of inorganic arsenic can result in death. Lower levels of arsenic can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, and damage to blood vessels. Ingesting or breathing low levels of arsenic may cause darkening of the skin. Skin contact with arsenic may cause redness and swelling. Birth defects have been observed in animals exposed to inorganic arsenic.

Several studies have shown that arsenic can increase the risk of cancer of the lungs, skin, bladder, liver, kidney and prostate. The Department of Health and Human Services and the U.S. EPA have determined that inorganic arsenic is a human carcinogen. The EPA has set a limit of 0.05 ppm for arsenic in drinking water. The Occupational Safety and Health Administration (OSHA) has set limits of 10 $\mu g/m^3$ for 8-hour shifts and 40-hour work weeks.

BARIUM

Barium is a silvery-white metal found in nature. Ingesting high levels of barium compounds that dissolve in water over the short term can result in the following health effects:

- Difficulty in breathing
- Increased blood pressure
- Changes in heart rhythm
- Stomach irritation
- Brain swelling
- Muscle weakness
- Damage to the liver, kidney, heart, and spleen.

Barium is not classified as a human carcinogen by the EPA or the Department of Health and Human Services. The limits of barium in drinking water are 2 ppm. The Occupational Safety and Health Administration has set an occupational exposure limit of 0.5 mg/m^3 of soluble barium for an 8-hour workday and 40-hour work week.

CADMIUM

Cadmium is a natural element in the earth's crust. Breathing high levels of cadmium severely damages the lungs and can cause death. Eating food or drinking water with very high levels of cadmium causes severe irritation of the stomach, leading to vomiting and diarrhea. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease. Other long-term effects are lung damage and fragile bones. Skin contact with cadmium is not known to cause health effects in humans or animals. The Department of Health and Human Services has determined that cadmium may reasonably be anticipated to be a carcinogen.

The EPA has set a limit of 0.005 ppm of cadmium in drinking water. The Occupational Safety and Health Administration limits cadmium in workplace air to 200 $\mu g/m^3$.

CHROMIUM

Chromium is a naturally occurring element and is an essential nutrient. It is present in several forms, the most common being chromium (III) and chromium (VI). Chromium VI is generally produced by industrial processes. Breathing high levels of chromium VI can cause irritation to the nose. Ingesting large amounts of chromium VI can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and death. Skin contact with certain chromium VI compounds can cause skin ulcers. Allergic reactions consisting of severe redness and swelling of the skin have been reported. Several studies have shown that chromium VI compounds can increase the risk of cancer.

The EPA has set a limit of 0.1 ppm drinking water for chromium III and chromium VI. The Occupational Safety and Health Administration has set limits of 500 µg/m^3 for chromium III compounds and 52 µg/m3 for insoluble chromium VI for 8-hour work shifts and 40-hour work weeks.

COPPER

Copper is a naturally occurring element that is essential nutrient for plants, animals and humans. However, large doses can be harmful. Long-term exposure to copper in the air can irritate the nose, mouth, and eyes and cause dizziness, headaches, and diarrhea. Eating or drinking high amounts of copper can cause liver and kidney damage and adverse effects on the blood. Skin contact with copper can cause skin irritation or a rash. Copper has not been shown to cause cancer in humans or animals.

The EPA has set an action level of 1.3 ppm of copper in water. The Occupational Safety and Health Administration has set occupational exposure limits of 1 mg/m^3 of copper as dust or mist for an 8-hour work day and 40-hour work week.

CYANIDE

Cyanide occurs naturally in cassava roots which are potato-like plants that grow in tropical countries. Cyanide is a highly toxic chemical. Exposure to high levels of cyanide in air for a short time can damage the brain and heart and may lead to coma and death. Exposure to lower levels of cyanide for long periods of time may result in breathing difficulties, heart pains, vomiting, blood changes, headaches and enlargement of the thyroid gland. Ingestion of large amounts of cyanide may cause shortness of breath, convulsions, loss of consciousness and death. High levels of cyanide in the blood may result in weakness of fingers and toes, difficulty in walking, dimness of vision, deafness, and decreased thryoid gland function.

The EPA has determined that cyanide is not a human carcinogen. The maximum level of cyanide allowed in drinking water is 0.2 ppm. The Occupational Safety and Health Administration has set the permissible exposure limit of cyanide at 5 mg/m^3 for an 8-hour work day and 40-hour work week.

LEAD

Lead is a naturally occurring metal found in small amounts in the earth's crust. Much of the lead in the environment comes from human activities including burning fossil fuels, mining, and manufacturing. The toxic effects of lead can result from breathing and ingestion. Lead can affect almost every organ and organ system in humans. The most sensitive system is the central nervous system, particularly in children. Lead also damages kidneys and the reproductive system. At high levels lead may decrease reaction time, cause weakness in fingers, wrists, or ankles, and possibly affect memory. Lead may cause anemia and can also damage the male reproductive system.

Small children are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead may develop blood anemia, severe stomach ache, muscle weakness and brain damage. Exposure to lead by the developing fetus may cause premature births, smaller babies, decreased mental ability, learning difficulties, and reduced growth.

The Department of Health and Human Services has determined that lead acetate and lead phosphate may be carcinogens, based on animal studies. However, there is insufficient evidence to clearly determine whether lead causes cancer in humans. The EPA limits the allowable lead in air to 1.5 µg/m3 averaged over three months. The EPA drinking water limit is 0.015 ppm.

MERCURY

Mercury is a naturally occurring metal, which can be found in a solid, liquid or gaseous form. Methyl mercury and metallic mercury vapors are more harmful than other forms because more of the mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. The effects on nervous system may include irritability, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause lung damage, nausea, vomiting, diarrhea, increase in blood pressure or heart rate, skin rashes, and eye irritation. The effects of mercury exposure to the developing fetus include brain damage, mental retardation, lack of coordination, blindness, seizures, and inability to speak. Children exposed to high levels of mercury may develop problems of the nervous and digestive systems, and kidney damage.

The EPA has determined that mercuric chloride and methyl mercury are possible human carcinogens. The EPA has established a limit of 0.002 ppm in drinking water. The Food and Drug Administration (FDA) has set a maximum permissible level in seafood of 1 ppm. The Occupational Safety and Health Administration has set limits of 0.05 mg/m^3 of metallic mercury vapor for 8-hour work days and 40-hour work weeks.

SELENIUM

Selenium is an essential element that helps prevent damage caused by oxygen. Most diets provide selenium at or above the daily requirement. Humans exposed to high levels of selenium have reported dizziness, fatigue, irritation, collection of fluid in the lungs and severe bronchitis. Skin contact with selenium may cause rashes, swelling and pain. Very high amounts of selenium have resulted in adverse reproductive effects in rats and monkeys. It is not known whether human exposure causes similar effects. Exposure to high levels of selenium in birds has caused malformations, but there is no evidence that birth defects are caused by high levels of selenium in mammals or humans.

The Department of Health and Human Services had determined that selenium sulfide is reasonably anticipated to be a carcinogen. However selenium sulfide has not caused cancer in animals when placed on the skin. The EPA believes that other selenium compounds are not carcinogens. Some studies, in fact, have shown that selenium has anti-cancer effects.

The EPA limit for selenium in drinking water is 0.05 ppm. The Occupational Safety and Health Administration exposure limit for selenium compounds in the workplace air is 0.2 mg/m^3 for an 8-hour work day over a 40-hour work week.

ZINC

Zinc is one of the most common elements in the earth's crust and is considered an essential element in human diets. Insufficient zinc in the diet can result in loss of appetite, decreased taste and smell, slow wound healing, skin sores, and impaired immune system. Insufficient zinc may also cause growth retardation in the developing fetus. Ingestion of excessive zinc in the diet may cause stomach cramps, nausea, and vomiting. Longer exposure can cause anemia, damage to the pancreas, and lower levels of high density lipoprotein (HDL) cholesterol. Inhalation of large amounts of zinc fume can cause a short-term disease called metal fume fever. Zinc has not been shown to cause cancer in humans.

The EPA limit for zinc in water is 5 ppm, because of taste. The Occupational Safety and Health Administration has established a maximum concentration limit for zinc chloride fumes in the workplace to 1mg/m^3 for an 8-hour work day over a 40-hour work week and 5 mg/m^3 for zinc oxide fumes.

APPENDIX F

SUMMARY OF RESULTS OF WORKER SURVEY/ SURVEY QUESTIONNAIRE

A SUMMARY OF RESULTS FOR A SURVEY CONDUCTED ON THE POTENTIAL HEALTH EFFECTS OF MAGNESIUM CHLORIDE AND OTHER DEICERS

Conducted by:

The SeaCrest Group

1341 Cannon Street

Louisville, Colorado 80027

April 30, 2001

INTRODUCTION

The SeaCrest Group was contracted by the Colorado Department of Transportation to evaluate the possible effects of Magnesium Chloride deicers on the environment as well as humans exposed to the chemicals. The main objective was to review existing literature to evaluate the known effects of deicers in the environment, describe their use and characteristics with regards to beneficial uses and negative impacts, and evaluate how they were being used in Colorado. As part of the overall study, a survey of workers who are subject to potentially high levels of magnesium chloride was conducted. The purpose of the survey was to serve as an indicator to determine the potential need for further human health research as it pertains to magnesium chloride exposure. The survey results are summarized in this report.

MATERIALS AND METHODS

A survey questionnaire was prepared and submitted to the study panel, which includes Richard Griffin, CDOT, Lee Cassin, City of Aspen, Kristine Crandall, Roaring Fork Conservancy, Ed Fink, CDOT Staff Maintenance, Mike Silverstein, CDPHE, Paul von Guerard, USGS, and Jacque Whitsitt, Colorado Association of Ski Towns. A copy of the approved questionnaire is included as an attachment to this report (Attachment 1).

The questionnaire was sent to a total of 126 workers. These workers were located in CDOT Districts 1, 2, 3, 5, and 6. Additional surveys were sent to workers in the Roaring Fork Transit Authority. Table 1 shows the location and number of questionnaires sent to each district.

Table 1-F. Location and return rate of responses by district.

DISTRICT	LOCATION	NO. OF QUESTIONNAIRES SENT/ NO. RESPONSES
1	Boulder, Longmont, Estes Park	21/18
2	Vail, Glenwood Springs, Aspen, Grand Junction, Montrose	30/21
3	Telluride, Durango	14/7
5	I-70, Vail to Eisenhower Tunnel	28/5
6	Craig, Steamboat Springs	5/1
Roaring Fork Transit	Glenwood Springs to Aspen	28/17

Data were compiled on a Microsoft Excel spreadsheet and analyzed for responses by job and by area. Reported jobs included equipment operator, bus driver, bus washer (hostler), and mechanic. Respondents who listed their job as both equipment operator and maintenance workers were analyzed as maintenance workers. This was based on a worst case scenario that maintenance were assumed to have more direct contact to deicers than equipment operators.

RESULTS

Of the 126 questionnaires sent out, a total of 69 (54.7%) were returned. This is considered to be a good response rate. A summary of the results is provided on the attached spreadsheet (Table 2).

Except for Road Districts 5 and 6, the rate of return exceeded 50% in each district. The areas with high rates of return included road districts that are expected to have high levels of use of deicers during the winter. The largest number of returns came from equipment operators while maintenance workers, bus drivers and bus washers responded less frequently. The highest percent of respondents reporting symptoms were bus washers and maintenance workers. It should be noted that this report is taking no position in regard to the causal relationship between reported symptoms and exposure to deicers.

Symptoms were fairly evenly distributed between eyes, skin and respiratory. Intestinal symptoms were reported less frequently. The percent of contact with deicers for all workers was fairly evenly distributed except for bus washers who reported 76-100% contact for 100% of respondents. Most workers were exposed equally to magnesium chloride and sand and only slightly less so to salt.

Sixty-one percent of all symptoms were reported by workers from the Roaring Fork Transit Authority. This compared to 28% in District 2 and slightly more than 5% in Districts 1 and 3. No symptoms were reported by workers in Districts 5 and 6. A total of 89% of the maintenance workers in the RFTA reported symptoms; this compared to 67% of the bus washers. Only 20% of the RFTA drivers reported symptoms. By comparison, in District 2 with the next highest area incidence of symptoms, only 25% of the maintenance workers and 24% of the equipment operators reported symptoms. Skin, respiratory, and eye symptoms were equally reported. Greater than 50% of the workers in District 2 and the RFTA reported exposure to deicers greater than 50% of the time. Less than 50% of the workers in the other districts reported an exposure to deicers greater than 50% of the time.

DISCUSSION

The survey provided an acceptable return of questionnaires. With minor exceptions, the rate of return for each area was acceptable. The survey lacked a strict scientific basis, so caution must be used when interpreting the results. The survey results seemed to indicate some correlation between exposures, the area where people work, and the type of job. This is based on each worker's perception of the amount of time each is exposed to the deicers. One could argue that it is difficult to accurately quantify amounts of exposure based on the present survey and this is admittedly a shortcoming of these results. For instance, an equipment operator may be on a road every day where deicers are used and report a 100% exposure but the actual level of exposure may be quite different from that of a maintenance worker who also reports a 100% exposure. An additional qualifier is that no attempts were made to attribute causes to the symptoms. In several instances, workers reported their symptoms as being related to "colds" or other types of factors. In reporting results, no distinction was made for such comments. Rather all responses were assumed to have equal weight. At this level of the survey, it is difficult to definitively attribute any of the reported symptoms to a specific cause.

Table 2-F. Survey Results Summarized by Job Type and Areas[1]

	Number of Responses by Job Type					**Number of Responses by Area and Job**					
						Colorado Department of Transportation Section					
	Maintenance	**Drivers**	**Eqpmnt. Operator**	**Bus Washer**	**TOTAL**	**1**	**2**	**3**	**5**	**6**	**RFTA**
Number Responses	16	5	45	3	69	18-e	17-e, 4-m	6-e, 1-m	4-e, 1-m	1-m	9-m, 5-d, 3-h
Number Reporting Symptoms	9	1	6	2	18	1-e	4-e, 1-m	1-e	0	0	8-m, 1-d, 2-h
% Symptoms	56%	20%	13%	67%	26%	5.6% -e	23.5%-e, 25%-m	16.7%-e	0	0	89%-m, 20%-d, 67%-h
Total % symptons by area						5.60%	23.81%	14.30%	0%	0%	64.71%
Total % all symptons						5.60%	27.78%	5.26%	0%	0%	61.11%
Types of Symptoms											
Skin	7	0	5	1	13	1-e	3-e	1-e	0	0	7-m, 1-h
Respiratory	7	1	2	1	11	0	1-e	1-e	0	0	7-m, 1-d, 1-h
Intestinal	1	1	1	1	4	0	1-e	0	0	0	1-d, 1-h, 1-m
Eye	7	1	3	1	12	0	1-m, 2-e	1-e	0	0	6-m, 1-d, 1-h
Amount of Contact											
0-25%	3	2	13	0	18	10-e	1-m, 3-e	1-m	1-m	0	2-d
25-50%	4	1	10	0	15	3-e	2-e	3-e	2-e	1-m	3-m, 1-d
51-75%	4	0	14	0	18	3-e	1-m, 9-e		1-e	0	3-m, 1-e
76-100%	4	2	9	3	18	2-e	2-m, 3-e	3-e	1-e	0	2-d, 3-h, 2-m
Type of Deicer											
Magnesium chloride	13	5	41	3	62	15-e	4-m, 17-e	1-m, 6-e	1-m, 3-e	1-m	6-m, 5-d, 3-h
Sand	13	3	43	1	60	18-e	15-e, 4-m	1-m, 6-e	1-m, 4-e	1-m	6-m, 3-d, 1-h
Salt	9	1	30	0	40	15-e	2-m, 10-e	1-m, 1-e	1-m, 4-e	1-m	5-m, 1-d
Other	1	0	7	0	8	3-e	1-m, 3-e	0	1-e	0	0

[1] e=equipment operator, m=maintenance, d=driver, h=hostler

ATTACHMENT 1

SURVEY QUESTIONNAIRE - SNOW AND ICE CONTROL OPERATIONS

BACKGROUND

The Colorado Association of Ski Towns (CAST) has requested that a survey be conducted of individuals that may come into contact with materials used for snow and ice control, such as road anti-icers, deicers, sand, and other materials. The term **"contact"** refers to 1) working directly with the materials, 2) incidental contact through working in an area where these materials are used, and/or 3) working on vehicles to which these materials may adhere.

Our goal in conducting this survey is to learn about your work activities, the chemicals that you may come into contact with at work and any health issues that may be associated with your work environment.

PLEASE READ CAREFULLY AND ANSWER THE FOLLOWING QUESTIONS.

1. What job title best describes the work you do **[Circle all that apply]**
   a. deicer equipment operator
   b. sand and salt equipment operator
   c. bus driver
   d. bus washer (hostler)
   e. mechanic (vehicle maintenance)
   f. other (describe) ____

2. Briefly describe the tasks you do during your work day.
   ____
   ____
   ____
   ____

3. How many winter seasons (years) have you been doing this type of work? ____

4. Do you come into contact with snow and ice control materials. **Circle "yes" or "no."**. If your answer is "**Yes,"** circle all materials listed below that you work with.
   a. Sand
   b. Salt (Sodium Chloride)
   c. Magnesium Chloride (Freezgard, Ice-Stop, Caliber M1000)
   d. Other chemical deicers (name) ____________________
   e. Don't know which deicers

Answer questions 5 to 8 only if you answered "Yes" to question #4. Otherwise skip to question # 14.

5. During an average work week in the winter season, how much of the time do you generally come into contact with snow and ice control materials **[Circle only one]**
   a. 0-25%
   b. 26-50%
   c. 51-75%
   d. 76-100%

6. Which of the following describes the type of direct contact you have with snow and ice control materials **[Circle all that apply]**
   a. skin contact
   b. inhalation (respiratory)
   c. eye
   d. ingestion
   e. other
      (describe)____

7. What Personal Protective Equipment do you use while you work with snow and ice control materials **[Circle all that apply]**
   a. gloves
   b. dust mask
   c. coveralls
   d. goggles
   e. other
      (describe) ____
   f. none of the above

8. Have you experienced any health effects during or after working with snow and ice control materials? **[Answer yes or no]**
   ____.

Answer questions 9-13 if you answered yes to question #8. Otherwise skip to question #14.

9. Do you think the symptoms you have are related to your work environment and/or the work you are doing? **[Answer yes or no]** ______________________________________

10. What symptoms do you have **[Circle all that apply]**
   a. respiratory (nose and throat dryness, cough)
   b. eye irritation
   c. skin rash
   d. intestinal (upset stomach, diarrhea)
   e. other
      (descibe) ____

11. Are these symptoms of short duration (hours) or long-term (days or weeks)? ____.

12. Are these symptoms severe enough that you have to take time off from work **[Answer yes or no]** If your answer is **"yes,"** approximately how many work days have you had to take off for sick time because of these symptoms? ____.

13. Have you noticed whether other people that are doing the same kind of work have similar symptoms? **[Answer yes or no]**

    ____

14. Any other comments about your work environment and your contact with snow and ice control materials?

    ____
    ____
    ____
    ____
    ____
    __________________________.

Thank you for participating in this survey.

Marion Fischel
Senior Scientist
The SeaCrest Group
303-661-9324
e-mail – marion@seacrestgroup.com