South Dakota State University
Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

Theses and Dissertations

2016

Reuse of Aqueous Waste Streams For Transportation-Related Applications

Gregory L. Hansen
South Dakota State University

REUSE OF AQUEOUS WASTE STREAMS FOR TRANSPORTATION-RELATED APPLICATIONS

BY

GREGORY L HANSEN

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Civil Engineering

South Dakota State University

2016

REUSE OF AQUEOUS WASTE STREAMS FOR TRANSPORTATION-RELATED APPLICATIONS

This thesis is approved as a credible and independent investigation by a candidate for the Master of Science in Civil Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that conclusions reached by the candidate are necessarily the conclusions of the major department.

Guanghui Hua, Ph.D. Date
Thesis Advisor

Nadim Wehbe, Ph.D. Date
Head, Department of
Civil and Environmental Engineering Department

Kinchel C. Doerner, Ph.D. Date
Dean, Graduate School

ACKNOWLEDGEMENTS

This study was funded by the South Dakota Department of Transportation (SD DOT) and the Mountain Plains Consortium (MPC) with technical support from the City of Watertown, South Dakota; South Dakota Department of Environment and Natural Resources; Wisconsin Department of Natural Resources; South Dakota Local Technical Assistance Program; North Dakota Local Technical Assistance Program; and the Tennessee Department of Transportation.

Particular appreciation is owed to Dr. Guanghui Hua, who was my thesis advisor for this project. He provided valuable insight, knowledge and advice throughout the entire duration of the project. I would also like to thank Dr. Christopher Schmit, and Dr. Kyungnan Min for assisting with the project.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
BOD	Biochemical Oxygen Demand
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CCL	EPA's Contaminant Candidate List
CWA	Clean Water Act
DBP	Disinfection Byproduct
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DOT	Department of Transportation
DOR	Department of Roads
FHWA	Federal Highway Administration
MCL	EPA's Maximum Contaminant Level
MIEX®	Magnetic Ion Exchange Resin
NOM	Natural Organic Matter
NDDOH	North Dakota Department of Health
ODNR	Ohio Department of Natural Resources
RCRA	Resource Conservation and Recovery Act
RH	Relative Humidity

RO	Reverse Osmosis
RWIS	Road Weather Information System
SARA	Superfund Amendments and Reauthorization Act
SDDENR	South Dakota Department of Environment and Natural Resources
SDDOT	South Dakota Department of Transportation
SDSU	South Dakota State University
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WTMWTP	Watertown Municipal Water Treatment Plant

LIST OF FIGURES

LIST OF TABLES

ABSTACT

REUSE OF AQUEOUS WASTE STREAMS FOR TRANSPORTATION-RELATED APPLICATIONS

GREGORY L HANSEN

2016

Aqueous waste streams produced from commercial, industrial, and municipal processes may be potentially reused for transportation applications. The objectives of this project were to identify potential transportation-related applications for aqueous waste streams available in South Dakota, develop guidance for the beneficial reuse of aqueous waste streams, and evaluate the reuse of MIEX® brine generated by the Watertown Municipal Water Treatment Plant (WMWTP). This study identified many aqueous wastes from municipal water and wastewater treatment facilities, industrial and agricultural processes in South Dakota that can be potentially used for ice and dust control. Beneficial reuse of these waste streams requires a comprehensive evaluation for the effectiveness, safety, economics, environmental benefits and risks, and adherence to local, state, and federal regulations. The evaluation of MIEX® brine suggests that this brine can be used as a feed solution to produce final brine products at SDDOT facilities for winter road maintenance. Reusing the MIEX® brine in the Aberdeen region may reduce the cost of brine disposal for the City of Watertown and reduce the cost of winter road maintenance for SDDOT.

Chapter 1: Introduction

1.1 Background

Aqueous waste streams can be produced from many commercial, industrial, and municipal processes or activities. Proper management, treatment and disposal or reuse of these waste streams are necessary to conserve natural resources and reduce their environmental impacts. Some aqueous waste streams such as salt brine may be potentially used in transportation-related applications including pavement anti-icing and deicing, and dust control on unpaved roads. The use of these waste materials reduces costs of disposing and treating waste materials, saves maintenance costs for state and local highway departments and reduce the environmental impact of the waste streams. Beneficial reuse of waste streams in transportation applications requires a comprehensive evaluation of the effectiveness, safety, economics, environmental benefits and risks, and adherence to local, state, and federal regulations. Guidance should be developed to help state and local agencies determine how to evaluate waste streams for potential reuse in transportation applications and establish sound procedures to manage their reuse.

The WMWTP operates a magnetic ion exchange (MIEX®) system to treat its source water. The MIEX® system produces brine wastewater which is currently discharged to the sanitary sewer system after treatment. The MIEX® brine has moderate concentrations of salt. Therefore, the MIEX® brine may be used by transportation agencies in South Dakota for winter road maintenance. Beneficial reuse of the MIEX® brine could reduce costs of disposing brine waste and purchasing rock salts, and lead to more sustainable operations at state and local highway departments and municipal utilities.

1.2 Research Objectives

The primary objectives of this project were to evaluate aqueous waste streams for transportation-related application through:

- Identifying potential transportation applications for aqueous waste streams available in South Dakota
- Develop guidance for evaluating the suitability of aqueous waste streams for transportation applications
- Evaluate the reuse of MIEX® brine generated by the WMWTP.

Chapter 2: Literature Review

This chapter provides a comprehensive literature review on common dust and ice control procedures used by other states and agencies and their potential impact on the environment. Topics discussed in this chapter include:

- Typical ice control methods used by other states and agencies
- Typical dust control methods used by other states and agencies
- Environmental impacts of such treatments
- Alternative ice and dust control methods used by other states and agencies
- Summary of existing regulations & guidelines pertaining to ice and dust control applied to road surfaces
- Alternative transportation uses of aqueous waste streams

2.1 Winter Roadway Maintenance

Wintertime roadway maintenance is imperative for maintaining safe road surfaces. Winter storms can produce a combination of rain, snow, freezing rain and or sleet. Three major methods for winter roadway maintenance are mechanical removal, deicing, and anti-icing.

Mechanical removal consists of snow plowing using a blade attached to the front of a truck or for deeper snows, a snow thrower attachment may also be used. The primary goal through this measure is to physically remove snow, sleet or ice from the roadway.

Deicing is the process of “top down” melting of snow and ice. This method is utilized when snow and ice have already begun to stick to the road surfaces. Rock salt

(NaCl) is widely used for ice control. Pre-wetting of rock salts with a brine solution has been used to help the salt stick to the road.

Anti-icing is a pretreatment for road surfaces before a storm event. The process involves spraying a brine solution on the road surface and allowing the brine to dry which leaves a thin layer of evenly dispersed salt crystals on the road. These dried crystals are activated once the precipitation hits the road surface, thus inhibiting the ice from bonding with the pavement.

2.1.1 Conventional Snow and Ice Control Methods

Most state DOTs use ice and snow control technologies to maintain safe road conditions in the winter. Conventional ice control compounds include dry chloride based salts, organic salts and commercial products, abrasives, and salt brine solutions.

(1) Chloride Based Salts

Sodium chloride (NaCl) or rock salt is the most widely used deicing compound by many state DOTs due to its low cost and high effectiveness. Dry rock salts tend to bounce off the road surface which reduces their efficiency. One of the ways that DOTs have tried to remedy dry rock salt’s poor adhesion to the road surface is to pre-wet the rock salt with brine solutions before it is spread on the road surface. This pre-wetting process allows applications rates to be reduced by 20 to 30% since less of the salt is lost to the roadsides (Iowa DOT, 2015). NaCl generally performs best for ice control when the temperature is above 10 ^{o}F (Akin, 2013). At very cold temperatures (lower than 15 ^{o}F), calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$) have been used to supplement NaCl for ice control because they have lower freezing points.

Both $CaCl_2$ and $MgCl_2$ are effective deicing chemicals and perform well at temperatures below 15 ^oF (Minnesota DOT, 2012). $CaCl_2$ is known to be effective at temperatures as low as -20 ^oF due in part to its exothermic reaction with atmospheric water. $CaCl_2$ and $MgCl_2$ solutions have been used by many DOTs for anti-icing or to pre-wet rock salt. Field studies have shown that $CaCl_2$ and $MgCl_2$ are more efficient than NaCl due to their ability to absorb atmospheric moisture and attach to the roads. However, because of the same hygroscopic property, $CaCl_2$ and $MgCl_2$ residue on the road can attract more moisture than NaCl which may reduce roadway friction, resulting in dangerous, slippery conditions under certain circumstances (Minnesota DOT, 2012).

All chloride-based deicers contribute to corrosion of reinforcing steel in concrete roadway infrastructure. $CaCl_2$ and $MgCl_2$ can be more aggressive to the exposed metals than NaCl due to their hygroscopic property and the longer time of wetness. (Shi, 2009). In addition, $CaCl_2$ and $MgCl_2$ are typically more costly than NaCl for ice control.

(2) Acetate Products

Calcium magnesium acetate (CMA), potassium acetate (KAc) and sodium acetate (NaAc) are major acetate products used for anti-icing and deicing. These acetates are effective deicers and less corrosive than chloride salts to exposed concrete reinforcing bars, and they are also less environmentally harmful (Hedges, 2007).

The disadvantages of acetates are primarily related to their high biochemical oxygen demand (BOD) concentrations and potential impacts on receiving water bodies. In addition, acetate products are considerably more expensive when compared to an equivalent ice melting capacity of rock salt. The energy requirements for processing and creating CMA are on the order of 10 to 15 times higher than rock salt (Fitch et al., 2013).

(3) Abrasives

Abrasives are used to increase the traction on the road. Sand is the primary abrasive used on roadways. Abrasives do not melt any ice, but are used solely to add traction, especially in areas where the temperatures are expected to be low, or at critical areas such as intersections to increase safety for drivers. Abrasives can be mixed with solid deicers, or can be pre-wet by brine solutions of the deicers mentioned above. Sands and other abrasives may cause problems by clogging sewers and other drainage systems. In addition, abrasives may require cleanup after storm events which increases the costs of using abrasives (Minnesota DOT, 2012).

(4) Brine Solutions

Salt brines have been used by many state DOTs for anti-icing and deicing. Brine is a liquid mixture of water and a chloride salt at a specific concentration. Brine is typically most effective at anti-icing when its concentration is close to the eutectic point, which is the minimum freezing temperature of the solution. Figure 2.1 compares the phase diagrams of NaCl, $CaCl_2$ and $MgCl_2$. The brine concentrations that lead to the minimum freezing temperatures are 23.3%, 29.8%, and 21.6% for NaCl, $CaCl_2$ and $MgCl_2$, respectively (Jahan, 2012). When the concentration is increased or decreased beyond the eutectic point, the freezing point of the solution increases. Ideally, brine solutions should be made as close as possible to their eutectic concentrations to maximize

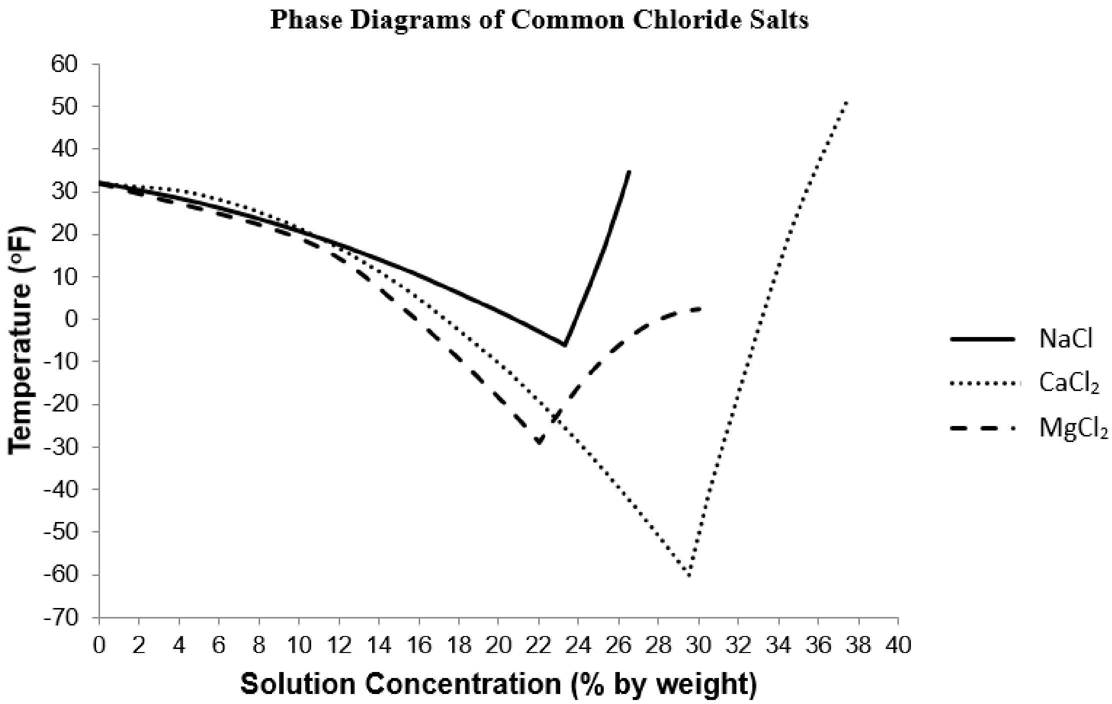

Figure 2.1 Phase diagrams for major chloride salts in brine solutions (Shi, 2009)

their efficiency.

Brine solutions are made by mixing a single chloride salt or a combination of $NaCl$, $CaCl_2$, or $MgCl_2$ in water. Brine can be used to pre-wet solid salts or sand for deicing application. The solution can be either sprayed on top of the road by using an overhead sprayer system to equally distribute the solution, or it can be applied to the materials just before they leave the truck by using a spray nozzle (Figure 2.2). These trucks are often solid rock salt application trucks converted or retrofitted to disperse brine to the salts.

Pre-wetting using salt brines has been shown to increase the performance of salts and abrasives, as well as their longevity on the roadway surface, thereby reducing the amount of materials required (Levelton, 2007; Minnesota DOT, 2012). According to

Figure 2.2 A typical truck with a brine pre-wetting unit (left) and a truck with an auger used to break up any salt clumps that may form (right) (Iowa DOT).

the Iowa DOT, pre-wetting has resulted in a reduction of 20 to 30% of rock salts for winter road maintenance. In addition to the reduced consumption of salts, pre-wetting can increase the deicing performance because melting of snow and ice can commence immediately since the salt slurry is already in the liquid state.

Brines can also be used for anti-icing which is the pre-storm application of the brine solution directly to the road surface. The brine solution typically dries after application and a thin layer of evenly dispersed salts are left on the road surface. Anti-icing using brines can reduce the chances of ice formation on the road surface and increase the efficiency of snow plowing operations. This practice can reduce overall salt consumption compared to using dry salts alone.

Brines can easily be made by DOTs with minimal investment. Often the use of brines can reduce the purchase of virgin materials enough to offset the expense of the equipment needed to make the brine. For trucks dispersing brine directly to the road surface, many options of size are available. Figure 2.3 shows three different brine spreading trucks with different capacities. Different types of nozzles including fan nozzles, streamer nozzles, and concentrated nozzles are available for brine spreading. Examples of these nozzles are shown in Figure 2.4.

Figure 2.3 Brine speading trucks, 250 gallons (left), 1,800 gallons (middle) and a 5,000 gallons (right) (Iowa DOT)

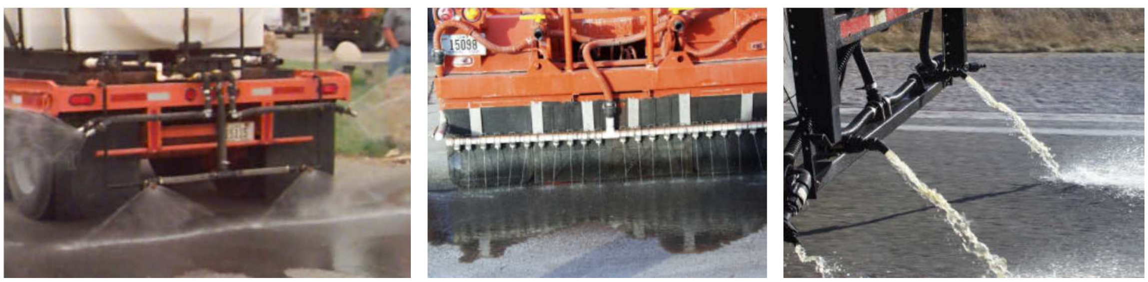

Figure 2.4 Brine spreading nozzles, fan style (left), streamer nozzle (middle) and concentrated method (right) (Iowa DOT)

2.1.2 Industrial and Agricultural Byproducts

Many state DOTs have used or evaluated industrial and agricultural byproducts as alternative anti-icing and deicing methods. These byproducts include oil field brines, cheese brines, beet juice, potato juices and others. The use of these byproducts can increase the performance of anti-icing and deicing, and reduce the consumption of rock salts.

2.1.2.1 Oil Field Brines

Oil field brine use is permitted by Michigan New York, North Dakota, Ohio, Pennsylvania, and other states for snow and ice control. Oil field brine functions very similar to the brines made from salts. These oil field brines can be applied using the same equipment used for dispersing conventional salt brines. The use of oil field brine for pre-wetting the road surface has been proven to be an effective anti-icing method for winter storms (Ohio DNR, 2004). The use of oil field brine by state DOTs not only reduces rock salt usage but also substantially reduces the costs associated with brine treatment and disposal.

The effectiveness of oil field brine for anti-icing and deicing depends on the brine salinity, which can vary significantly at different locations. Brines with salinity ranging from 30,000 to 225,000 mg/L chloride have been used in Ohio (Ohio DNR, 2004). Many oil field brines also contain high concentrations of calcium and magnesium. The presence of calcium and magnesium salts can increase the performance of the oil field brine for ice control. The North Dakota Department of Health (NDDOH) has developed a guideline for the use of oil field salt brines for dust and ice control. According to the guideline, oil field brines used for dust and ice control should have calcium plus magnesium concentrations greater than 10,000 mg/L, and chloride concentrations greater than 75,000 mg/L.

Many oil wells in South Dakota have low salinity based on the data provided by the USGS. The effectiveness of the oil field brine for ice control can be limited if the salinity is low. Therefore, the salts concentrations of oil field brine should be carefully evaluated before it can be used for anti-icing or deicing.

Many state environmental protection agencies have developed regulations or guidelines to manage the spread of oil field brines on road surfaces. The experiences of these states suggest that oil field brine can be used as an effective ice control method with minimum environmental impacts.

The Ohio Department of Natural Resources (ODNR) has developed a guidance for local authorities regarding spreading oil field brine for dust and ice control. According to the guidance, brine spreading shall be approved by a resolution adopted by the Board of County Commissioners, Board of Township Trustees or legislative authority that owns the right to control the roadway. Brine shall not be applied to a water saturated surface or within 12 feet of structures crossing bodies of water. The maximum uniform application rate of brine shall be 3,000 gallon per mile on a 12-foot-wide road or 3 gallons per 60 square feet on unpaved roads.

2.1.2.2 Cheese Making Byproducts and Other Food Processing Wastes

Cheese brine produced during the cheese making process has been used for road ice control. Brining cheese is the process of soaking a cheese in salt water for a period of time to flavor and preserve the cheese. Eventually the brine can no longer be used and must be discharged from the system. These brines can have varying concentrations of salts (primarily NaCl) ranging from 6% for cheddar cheeses to about 20% for mozzarella cheese.

Wisconsin DOT has been using cheese brines for deicing since 2008. The mozzarella cheese brine is currently used in Wisconsin due to its high salt concentrations (Norby, 2010). Cheese brines produced from two cheese plants in Polk County, F & A Dairy Products in Dresser, and Burnett Dairy Cooperative in Grantsburg, are currently permitted by Wisconsin Department of Natural Resources (DNR) for ice control. Pre-treatment of waste cheese brines by ultrafiltration is needed to reclaim fats and proteins before it can be used for ice control (Johnson, 2011).

Cheese brine is currently used only as a pre-wet solution for salts and sands. Pre-wetting of rock salts using cheese brine has been shown to improve the deicing performance by reducing rock salt bouncing off the road surface and expediting ice and snow melting. This practice has resulted in 30 to 40% cost savings in purchased rock salts for Polk County DOT (Norby, 2010). Using cheese brine for ice control also saves F & A dairy as much as $10,000 per year on cheese waste disposal (Johnson, 2011).

Because of the successful application of cheese brine for winter roadway maintenance in Wisconsin, the state DOT is evaluating the use of other waste streams from food processing for ice control. These waste streams include a waste salt brine generated in the coolant system from a meat processing manufacturer, Jennie – O Turkey Store in Barron, WI and a brine solution produced from a soy sauce manufacturer, Kikkoman Foods in Walworth, WI. The coolant system is used to cool down processed turkeys and consists of municipal drinking water and salt in a self-contained system. The waste brine from this meat manufacturer has approximately 23% NaCl concentration, thus making it an ideal candidate for deicing and anti-icing applications. The other industry participating in the study is Kikkoman Foods, which is a soy sauce manufacturer. This manufacturer produces a waste brine solution during the soy sauce production, which can be used to pre-wet rock salts for deicing and anti-icing applications. The soy sauce brine can potentially create a “light brown tinge” on the road surfaces. However, it is expected that it should wash off over time and not cause any permanent stains. Using these food based wastes falls under the Wisconsin DNR’s jurisdiction for approval, and more specifically, requires a “low-hazard” waste exemption to re-use any salt brines for transportation applications (Walworth County Today, 2014).

The other cheese making byproduct that has the potential of being used for ice control is cheese whey. Janke and Johnson (1997) proposed a patented method for using these whey products for a low corrosive deicing chemical. More investigation should be done to evaluate the effectiveness and practicality of using cheese whey for winter roadway maintenance. In addition to deicing applications, cheese whey can also be used as a raw material to synthesize CMA (Janke and Johnson, 1998).

2.1.2.3 Beet, Potato, and Tomato Juices

Beet juice is a byproduct of the sugar beet processing industry and has been used in pre-wetting salt and sand for deicing and anti-icing in Idaho, Minnesota, Nebraska, Pennsylvania and Tennessee. The beet juice is water soluble and contains high concentrations of carbohydrates. Addition of beet juice to a brine solution can enhance its performance by decreasing the freezing point, reducing the brine corrosivity, and reducing the rock salts bouncing off of road surfaces (Nixon, 2007). Tennessee has also experimented with potato juice for winter road maintenance. Beet and potato juice both contain carbohydrates that allow better adhesion properties of the rock salts (Jahan, 2012). Potato juice is a byproduct of the distillation process used to make vodka which has a very low freezing point (Cassidy, 2015). In addition to beet and potato juice, there have been ongoing investigations on using tomato juice for deicing and anti-icing applications (Prentice, 2014).

2.1.3 Commercial Products

Many commercial deicers are available for state DOTs for winter road maintenance. Many of the deicing chemicals are formulated with waste products recycled from agricultural and industrial processes such as corn, wheat, and rice. These waste materials include corn steepwater and other corn milling byproducts, vintners' condensed solubles from the wine industry, beet juice, beer brewer products, and others. However, most of these products are patented, so information on their exact formulations is not known. Some of these deicers are produced by reducing longer chain starches and polysaccharides into smaller chain sugars, which are more effective at reducing the freezing point of brine solutions. Examples of these commercial deicers are Geomelt®, Magic Minus Zero® and Magic Salt®, Icenator Liquid Deicer, Bare Ground Solutions™ and Caliber M1000. Many commercial deicers utilize the performance enhancing characteristics of carbohydrates, such as high-fructose corn syrup, to reduce the freezing points, reduce corrosion, and increase salts adhesion onto road surfaces (Jahan, 2012; Iowa DOT, 2015). Commercial products can have varying availability based on demand, production capacity and initial waste generation amounts.

2.2 Dust Control on Unpaved Roads

Transportation agencies use dust suppressants to control erosion and reduce maintenance costs on unpaved roads. Materials used as dust suppressants include water, salts, asphalt emulsion, vegetable oils, molasses, synthetic polymers, mulches and lignin products (USEPA, 2002). Many of the dust suppressants are formulated with waste products recycled from other industries. Approximately 75 to 80% of all dust suppressants used by transportation agencies are chloride salts and salt brine products (Travnik, 1991). These salt products stabilize the soil surface by absorbing moisture from the atmosphere. Oil field brines have also been used as a cost effective dust suppressant and road stabilizer, and its efficiency for dust control has been well recognized (Pennsylvania DEP, 2015).

2.2.1 Conventional Methods for Dust Control

The most common dust suppressants are chloride salts including $CaCl_2$ and $MgCl_2$ (Piechota et al., 2002). These hygroscopic chemicals can absorb atmospheric moisture and keep the road surface damp. This helps form a crust and hold the fine soil particles on the road surface. $CaCl_2$ can also prevent soil moisture from evaporating and tighten the compacted soil thereby leading to a stronger road. The effectiveness of $CaCl_2$ can range from 6 to 12 months depending on traffic volume and climate (Wisconsin Transportation Bulletin, 2007). Generally, $MgCl_2$ is more sensitive to temperature, and it is not as effective as $CaCl_2$ when temperatures are below 77^{o}F and the relative humidity is below 32% (Han, 1992). Either dry chloride salts or salt brines can be used for dust control on unpaved roads. Sodium chloride is seldom used for dust control on unpaved roads. NaCl starts to absorb water from air at 76% relative humidity and above 77^{o}F. This property limits its effective application range. However, a mixture of sodium chloride and $CaCl_2$ can be used to effectively stabilize the soil and control the dust, while considerably reducing the material costs.

Water is an environmentally friendly option for short-term dust control. The use of water as a dust suppressant may be favorable in humid climates with close access to a plentiful fresh water source. The extensive labor and transportation costs associated with applying water may limit its use for long-term application in areas with hot and dry climates (Piechota et al., 2002).

Other materials used for dust control include ligninsulfonate which is a byproduct of the paper milling industry (Piechota et al., 2002). Vegetable oils can also be used as dust suppressants but these oils are prone to being flushed from the soil under heavy precipitation events (Han, 1992). Petroleum products, such as asphalt emulsions and tars can be effective at dust control since they are not water-soluble and do not readily evaporate (Piechota et al., 2002). Fiber mixtures which include wood fibers (mulch) or other binding agents such as plaster of paris, work at controlling dust emissions by producing a physical barrier to restrain the dust from leaving the surface (Piechota et al., 2002).

There are two main methods for the application of dust suppressants to a road surface. First, dust suppressants can be directly applied on a properly prepared surface. This method typically requires multiple applications over time to maintain the effectiveness (Addo et al., 2004). The second method is an in-depth application. This method physically mixes the dust suppressant with the road surface which can strengthen the road surface and allow for fewer applications (Addo et al., 2004).

2.2.2 Oil Field Brines for Dust Control

Oil field brines can be used for dust control because they typically contain large amounts of calcium and magnesium, which are the key components for dust control (Guerra et al., 2011). Brines made from NaCl are typically not very effective for dust control. However, a brine mixture of NaCl and $CaCl_2$ can be effective at dust control. This is due to the ability of NaCl to stabilize the soil particles and the hygroscopic properties of CaCl2 (Han, 1992). The oil field brine should have relatively high concentrations of calcium and magnesium in order to be used as an effective dust suppressant.

Oil field brines used for dust control can be applied in a similar manner to salt brines. The spread of oil field brine on unpaved roads is typically regulated by state environmental protection agencies. For example, Michigan has set regulations on spreading rates, spreading equipment and frequency of spreading oil field brine (Piechota et al., 2002). In addition, Michigan also requires that operators who use the brine maintain a detailed record on the application of oil field brine (Michigan DEQ, 2015).

2.2.3 Other Dust Control Options

Soybean soapstock, a waste product from soybean processing, has been used for dust control. Soybean soapstock can penetrate a gravel surface and provides bonding action between soil particles which reduces dust emissions (Skorseth and Selim, 2000). Soybean soapstock can be effective in many different soil types. However, under dry conditions the oils can break up and lose their effectiveness (Han, 1992). Another byproduct of soybean processing is crude glycerin. Concentrated crude glycerin has also been used for dust control and was found to be effective. A study of the effectiveness of concentrated crude glycerin was conducted on a dirt road servicing a sand and gravel facility. The product was 80%, 10-11%, 7%, and 1-2% by weight glycerin, water, NaCl, and fatty acids with methyl esters, respectively. A maintenance dose of 20% by weight crude glycerin in water was applied four weeks later. It was reported that the customer was satisfied with the level of dust suppression the concentrated glycerin provided. (Yan, 2011).

Lignin products generated during the paper milling process can also be used for dust control. These products provide cohesion to bind the soil particles together and limit dust emissions (Skorseth and Selim, 2000). However, lignosulfonates are water soluble and can be washed away during rainfall events (Alaska Department of Environmental Conservation, 2006).

2.3 Other Transportation Applications of Aqueous Waste Streams

In addition to the industries mentioned above, municipal water and wastewater treatment facilities also produce aqueous waste streams that can be potentially used for transportation-related applications. Drinking water treatment plants in South Dakota generate lime and coagulation sludge through lime softening and coagulation processes. Municipal wastewater treatment facilities produce treated effluents that are typically discharged to surface waters. The treated effluents can be potentially used for dust control and concrete mixing on construction sites. The use of treated wastewater can reduce the consumption of potable water which helps conserve natural water resources.

2.3.1 Lime Sludge

Lime sludge is produced by the lime softening treatment process where lime is added to water to reduce the hardness. Disposal of lime sludge remains a major challenge to many municipalities in the Midwest. Lime sludge may be potentially used on gravel roads to reduce dust generation and it may be used as an aggregate in cement production (Iowa DOT, 2004).

Lime sludge consists mainly of calcium carbonate and therefore it can replace limestone in cement production. To be used for cement production, lime sludge needs to be dried at the water treatment plants and transported to the cement manufacturer. The costs associated with drying and transportation may limit this sludge reuse option. Lime sludge can also be used as a filling material for road construction (Van Leeuwen et al., 2011). Further testing of the durability of lime sludge is needed to determine its long term performance.

Chapter 3: Significant Public and Private Aqueous Waste Streams Produced in South Dakota

This chapter provides a summary of the major public and private producers of aqueous waste streams in the State of South Dakota. Topics discussed in this chapter include:

- Municipal drinking water treatment aqueous waste streams
- Municipal waste water treatment aqueous waste streams
- Industrial aqueous waste streams
- Agricultural waste streams

3.1 Municipal Drinking Water Treatment Plant Aqueous Waste Streams

Municipal drinking water treatment facilities provide safe drinking water to the public to support population and economic growth. Raw water for drinking water plants in South Dakota includes surface and groundwater sources. The source waters generally require treatment to meet the USEPA's drinking water standards before it can be delivered to the public. Conventional treatment processes used by drinking water plants in South Dakota include coagulation, lime softening, sedimentation, filtration and disinfection. These treatment technologies are used to remove particles, hardness, natural organic matter and microorganisms from the raw water. In addition to the conventional treatment processes, new water treatment technologies such as magnetic ion exchange and membrane filtration are also used in several water treatment facilities in South Dakota. Drinking water sludge is the major aqueous waste byproduct generated during the conventional water treatment processes. The quality and quantity of the drinking water sludge depend on the source water type (surface and groundwater) and treatment chemicals and processes. Waste brine is another aqueous waste byproduct generated when ion exchange is used for drinking water treatment.

3.1.1 Drinking Water Treatment Sludge

Most groundwater supplies in South Dakota contain high concentrations of calcium and magnesium that need to be removed to reduce the hardness of the water. Lime softening is the most popular treatment technology used in drinking water plants to reduce the water hardness. In this process, lime ($Ca(OH)_2$) is added to the raw water to precipitate calcium and magnesium as calcium carbonate and magnesium hydroxide, respectively. The produced lime sludge is then removed from the water treatment process for further treatment and disposal.

Coagulation is a common process used by surface water plants in South Dakota to remove particles and NOM in the raw water supplies such as the Missouri River and the Big Sioux River. Alum and ferric chloride are the two primary coagulants used in the coagulation process. The added coagulant can precipitate particles and organic matter. Similar to drinking water lime sludge, coagulation sludge produced during water treatment also needs further treatment and disposal.

Water treatment plants in South Dakota typically use dewatering processes to reduce the water content of the produced sludge. The dried sludge can then be disposed of through landfilling. Because of its high pH and similarity to soil, drinking water sludge has been used by producers in South Dakota as a soil conditioner to improve the soil quality and productivity. Drinking water sludge has also been proposed to be used as a filling material for construction activities, a raw material for brick and cement production, and an adsorption medium for water quality control. Nearly all drinking water treatment facilities in South Dakota produce sludge through different treatment processes. These drinking water sludges are widely available in the state for potential beneficial reuse.

3.1.2 Drinking Water Treatment Waste Brine

The WMWTP operates a (MIEX®) system to treat its source water. The MIEX® system is an advanced ion exchange treatment process developed by Orica Inc. to remove dissolved organic matter in the source water. A schematic of the process is shown in Figure 6.1. Raw water is pumped into the reactor vessel and slowly mixed with the MIEX® resin. Since the resin is magnetic, it acts to build larger particles that will settle quickly, even at high hydraulic load. At the top of the reactor, a series of plates work to separate the resin from the treated water.

A fraction of the MIEX® resin must be removed from the reactor and regenerated to maintain the treatment capacity. The resin that is removed from the tank is pumped to a regeneration vessel. In this vessel, a brine solution (typically 12% NaCl) is added to the resin and is allowed to flow through the resin. After the resin is regenerated, the brine is reused until its conductivity reaches a certain threshold. At that point, the brine is discarded as a waste brine (Orica, Inc., 2012). In addition to sodium chloride, the waste brine may also contain some of the organic and inorganic components from the raw water supply such as NOM, sulfate, and metals.

Currently, Watertown is the only city in South Dakota that uses this relatively new technology. The MIEX® system of the WMWTP generates 1,500 gallons per day of salt brine solution through the MIEX® regeneration process during summer months. A total of 150,000 gallons of waste brine is produced each summer season. The MIEX® waste brine solution is currently discharged to the sewer system.

3.2 Municipal Wastewater Treatment Aqueous Waste Streams

Municipal wastewater treatment facilities are typically responsible for the collection and treatment of wastewater generated by residential, commercial, and industrial dischargers. The two main municipal wastewater treatment systems used in South Dakota are stabilization ponds, and activated sludge systems. Many small wastewater systems in South Dakota use stabilization ponds which generally require large land space. Treated wastewater from stabilization ponds systems is typically disposed of through seasonal surface discharges. Activated sludge systems are generally used by large municipalities for wastewater treatment. Major treatment processes of a plant with an activated sludge system include preliminary treatment, primary clarification, aeration, secondary clarification, filtration, and disinfection. Aeration basins are used to remove organic compounds in the wastewater by activated sludge, and secondary clarifiers are used to separate the sludge and the treated effluent.

Waste sludge and treated wastewater are the two main aqueous streams generated during wastewater treatment using activated sludge systems. Waste sludge is typically stabilized by a digestion process and disposed of through land application. Treated wastewater is typically discharged to surface waters. It can also be used for irrigation and other reuse applications.

3.3 Industrial Aqueous Waste Streams

Industrial waste streams are produced from many different manufacturing processes. Major aqueous waste streams from industrial processes in South Dakota were identified based on the information provided by SDDENR, SDDOT and various industries. Particular emphasis is placed on aqueous wastes that may be potentially used for transportation-related applications.

3.3.1 Oil and Gas Production Aqueous Waste Streams

Oil field brine, or produced water, is a major aqueous waste stream produced from oil and gas production. It is a saline byproduct generated during oil and gas drilling, completion, and production operations. The characteristics of oil field brine vary considerably due to the various geologic formations at different locations. The major constituents in oil field brine from conventional sources include salts of sodium, potassium, magnesium and calcium, oil and grease, chemical compounds added to the drilling fluids, and natural radioactive materials (Clark and Veil, 2009). Major cation species in the oil field brine found in South Dakota include sodium (75%), calcium (21%) and magnesium (4%) (USGS, 2015). It is important to note that the variance for these cation species was quite high, suggesting that different wells could produce significantly different results. Figure 3.1 presents the chloride concentrations in brine solutions from different oil wells in South Dakota. Sodium salts are the primary salts in the oil field

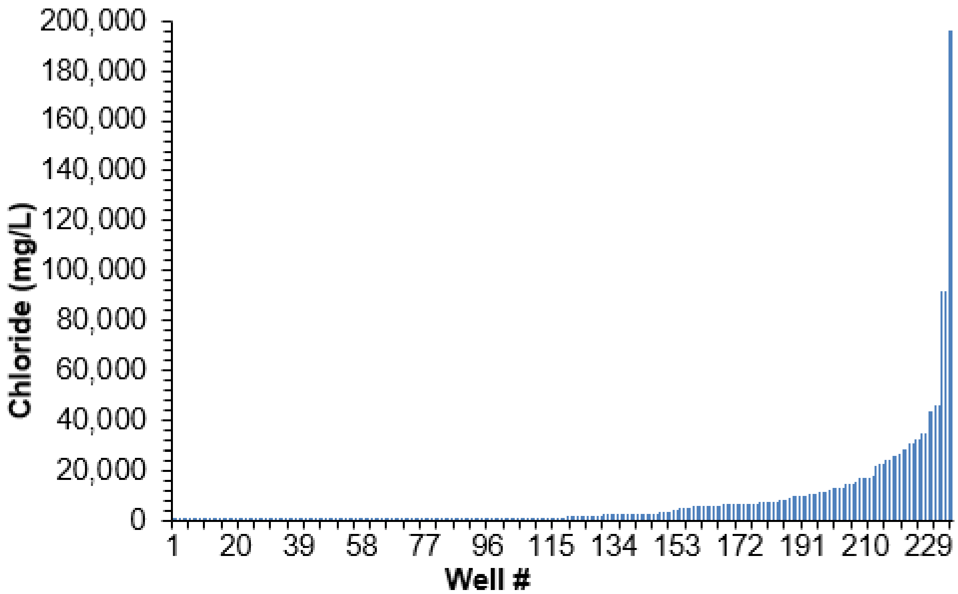

Figure 3.1 Chloride Concentrations in Selected Oil Wells in South Dakota (USGS)

brine in South Dakota, and the chloride concentrations in these brine solutions are typically below 40,000 mg/L.

Approximately 98% of South Dakota's oil field wastes are generated in Harding County. The other two counties with any drilling are Falls River County and Custer County. The average value of total dissolved solids (TDS) in oil field brine from Harding County was around 25,000 mg/L. This TDS level is almost an order of magnitude lower than the average TDS level of 225,000 mg/L found in North Dakota's oil fields. The SDDENR (Minerals and Mining Program – Oil and Gas Section) oversees the produced water generated in South Dakota. It is estimated that 1.8 million barrels of oil and 7.7 million barrels of produced water are generated annually in South Dakota. Only about 4% of the produced water produced nationally is discharged above ground, including livestock water and irrigation (Clark and Veil, 2009).

3.3.2 Mining Aqueous Wastes

According to the SDDENR, South Dakota has several gold mines that use RO technology, which produces brine wastes. However, these brines would likely be very high in heavy metals and would likely not be suitable for beneficial reuse.

3.3.3 Cheese Making Wastes

A significant number of different cheeses are available in the market and their manufacturing procedures can differ but generally all cheeses begin as whole pasteurized milk. The milk is added to large vats and heated to a specific temperature and a starter bacterium is added. The starter bacterium generates lactic acid from the milk. The pH of the mix begins to decrease by the influx of lactic acid to the mix. When the pH of the mix reaches the desired limit, the enzyme rennet is added to form curds (solid) and whey (liquid) with whey making up about 90% of the batch. Sometimes the curds are salted which makes the whey salty as well. Some types of cheeses are matured in a brine solution. The waste from this process is known as cheese brine.

Typically, the whey is condensed and sold because there is a market for whey products. The whey can be condensed by heating or filtering out the large protein molecules with ultra-filtration (UF) or RO. According to the SDDENR, cheese whey is the major liquid waste produced by these cheese manufacturers in South Dakota. The cheese whey can be sold or land applied for disposal. Cheese whey and brine wastes typically contain high concentrations of salt, protein, and carbohydrates.

3.3.4 Meat Processing Wastes

There are a large number of meat processors in South Dakota that produce a wide variety of different meat products. Brine solution is used in certain meat processing. The waste brine from meat processing typically contains high concentrations of salt, fat, oil, and grease.

3.3.5 Beer Brewing Wastes

Figure 3.2 presents a schematic for typical beer making process. Major steps in this process include milling, mashing, boiling and wort clarification, cooling and aerating, primary fermentation, maturation, clarification, and sterilization. The primary wastes that are generated from beer breweries are spent grains, kieselguhr sludge, and yeast surplus which is recovered from the bottom of the fermentation tanks.

The main components in the spent grains consist of the used malt and trub components (barley, hops, and or corn, rice, or wheat) with their chemical compositions comprising about 17% cellulose, 28% non-cellulosic polysaccharides, about 28% lignin and the rest being comprised of plant fibers (Mussatto et al., 2006). The Kieselguhr sludge is primarily composed of diatomaceous earth sludge, water, and organic compounds. It is typically spread on agricultural land, composted, regenerated, or sent to a landfill. The yeast surplus byproducts can be sold to industries to produce animal and livestock feed.

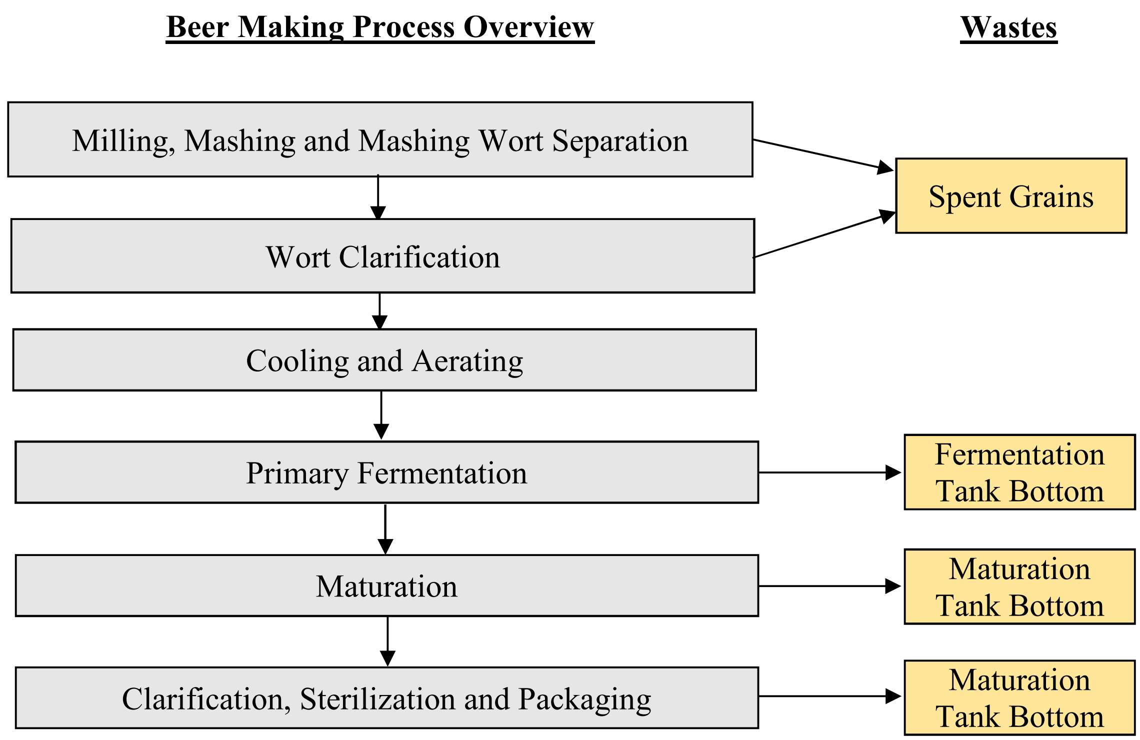

Figure 3.2 Typical Beer Waste Process Schematic

Breweries also have wastewater effluents that primarily consist of sugars, soluble starches, ethanol and volatile fatty acids. The pH levels in the wastewater stream depend on the cleaning method. Common cleaning chemicals include caustic soda, phosphoric acid, and nitric acid. Phosphorus levels may be high in the waste stream.

3.3.6 Wine Making Wastes

During the wine making process, grapes are washed and separated from the stems and the juice is pressed out through mechanical processes. Red wines are fermented with their skins. The lees or vintners' condensed solubles and pomace (the grape skins, seeds, and other unneeded parts from the grapes) are removed from the process. After this process, the wines are then fermented and aged. Further lees come from the fermentation and ageing processes. The final steps are clarification, stabilization and bottling. The waste products from wine making are high in organic matter.

3.4 Agricultural Aqueous Wastes Streams

Agricultural wastes are generated during the processing of agricultural products such as soybeans for oil and corn for ethanol production. Through communication with the SDDENR and industries that produce soybean products and ethanol, aqueous waste streams from soybean and corn processing were identified.

3.4.1 Soybean Plant Wastes

Soybeans are typically processed to produce soybean oil, protein, soybean meal for livestock, and plant sterols. Soapstock is the primary waste stream produced from the caustic refining process of the degummed oil (Skorseth and Selim, 2000). Figure 3.3 shows an overview of typical soybean processing highlighting the stages that wastes are produced.

3.4.2 Corn-Milling Byproducts (Ethanol Production)

Two primary corn processing methods are used for ethanol production: corn-wet milling and corn-dry milling. Corn-wet milling is the process that is primarily used for extracting a wide variety of products from corn in addition to ethanol such as corn oil, corn gluten, and corn meal. Corn-dry milling focuses mainly on ethanol production, so the production of other commodities is limited (Bothast, 2004). Figure 3.4 represents an overview of the corn-milling process for ethanol production. The primary waste produced from corn-wet milling is corn steep water. For corn-dry milling the primary byproducts

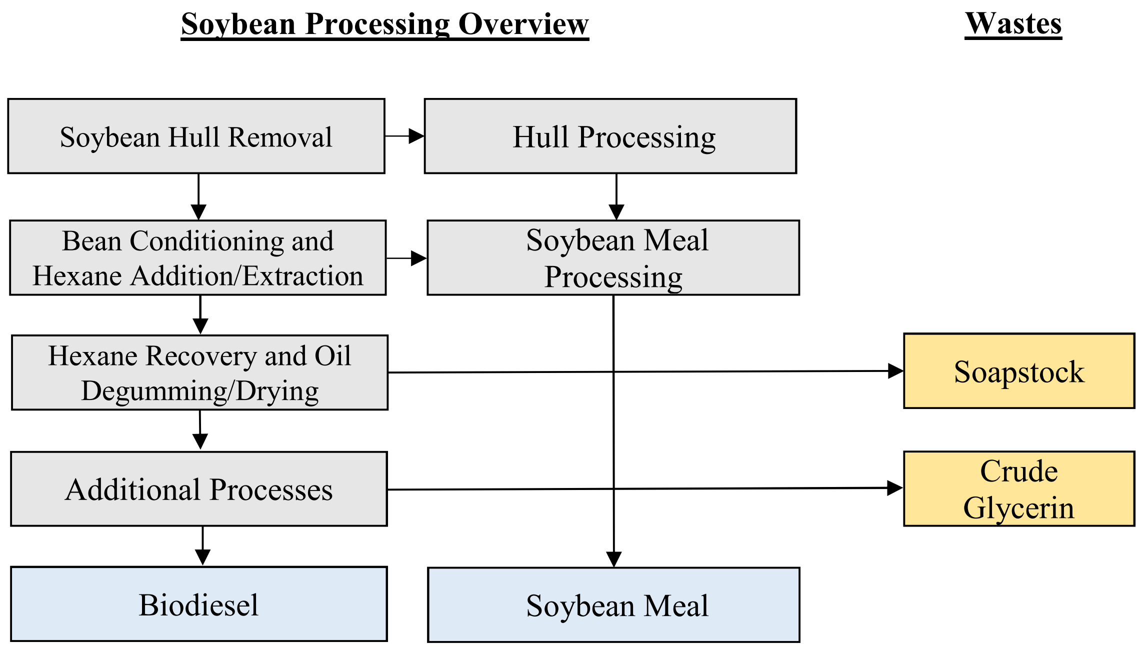

Figure 3.3 Overview of a typical soybean processing plant operation waste product generation

are thin and thick stillage. The thin stillage is what is left in the stills after the fermentation process is complete.The additional removal of moisture from the thin stillage produces thick stillage. The other byproducts from the ethanol dry-milling process are dry distillers grains (DDG) and dry distillers grains with solubles (DDGs) which are generally sold for livestock feed (Kharshan et al., 2012).

The corn steep water is high in soluble proteins, amino acids, and carbohydrates. Typically, it is recombined with corn gluten feed and used as feeds for livestock (USDA, 2010). Corn-dry milling products have similar compositions of proteins, carbohydrates and amino acids to corn steep water. These byproducts are also often combined and sold as livestock feed. Other wastes from ethanol plants include reject water from the cooling tower RO treatment process. In addition, there is also reject water from the water softener blowdown process.

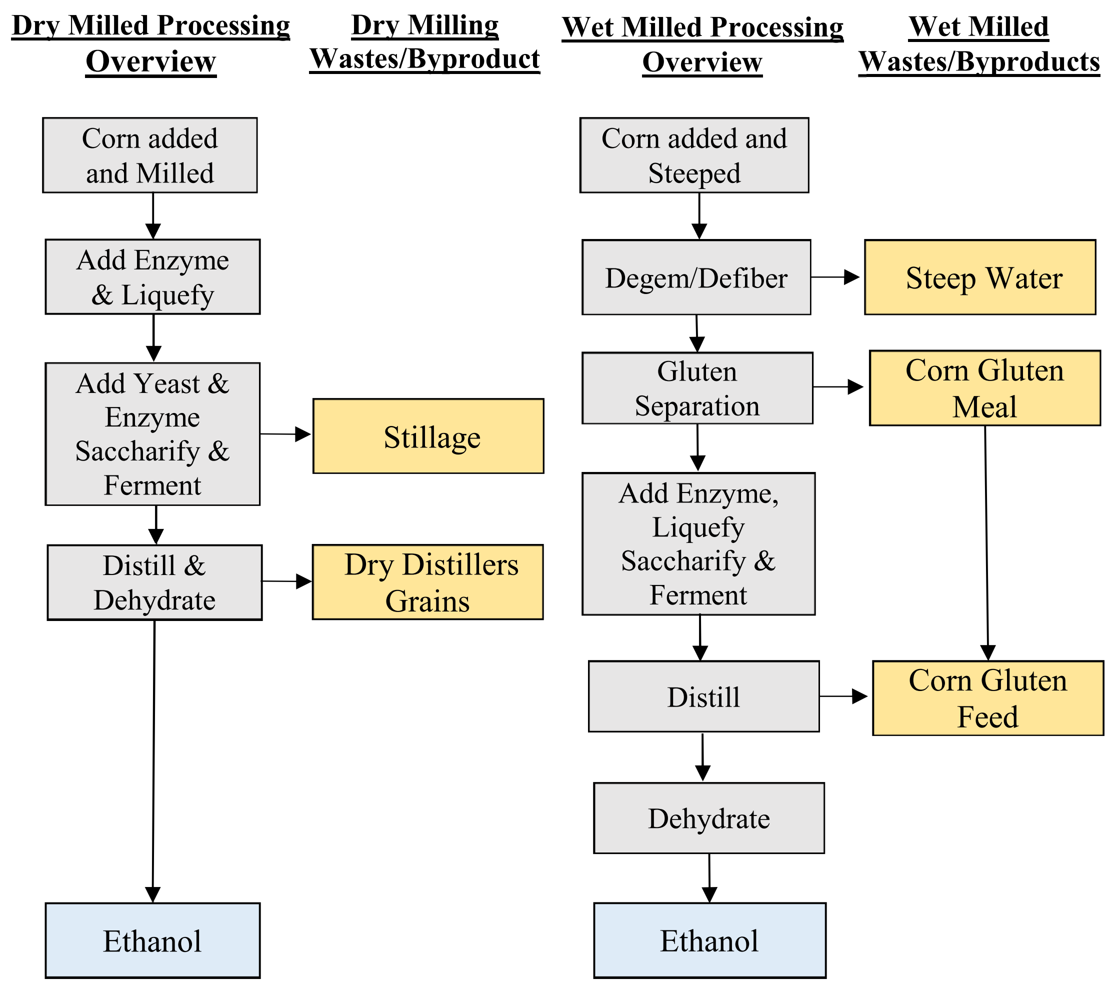

Figure 3.4 Overview of the corn-milling process for ethanol production

3.5 Summary of Aqueous Wastes Produced in South Dakota

Table 3.1 presents a summary of the aqueous waste streams generated by major industrial, agricultural, and municipal processes in South Dakota.

Table 3.1 Summary of major aqueous waste streams in South Dakota

Category	Process	Major Aqueous Waste Stream	Location	Characteristics
Municipal Water Treatment	Lime softening	Lime sludge	Nearly all groundwater plants and some surface water plants	High in $CaCO_3$ and $MgCO_3$
	Coagulation	Coagulation sludge	Nearly all surface water plants	Similar to soil content
	MIEX® process	MIEX® Brine	Watertown	Moderately high in NaCl
Municipal Wastewater Treatment	Activated Sludge Process	Treated wastewater	Major cities in South Dakota	Treated effluents that meet SDDNER discharge permit
Industrial Processes	Oil and Gas Production	Oil field brine	98% in Harding County	Variable Na, Ca, Mg and Cl concentrations
	Mining	RO reject water	Butte County, Custer County, Fall River County, Lawrence County, Meade County, Pennington County	Potentially high in heavy metals and radiological contaminants
	Cheese Making	Cheese brine, Cheese whey	Big Stone City, Brookings, Dimock, Lake Norden, Milbank, Pollock	High in NaCl, High in protein and carbohydrates
	Meat Processing	Meat brine, Meat processing wastewater	Aberdeen, Alpena, Huron, Rapid City, Sioux Falls, Yankton	High in NaCl, High in fats, oils, grease and solids
	Beer Brewing	Beer brewing wastes	Brookings, Custer, Hill City, Lead, Rapid City, Sioux Falls, Spearfish, Yankton, Watertown	High in carbohydrates
	Wine Making	Vintners' condensed solubles	Beresford, Brandon, Custer, Deadwood, Dell Rapids, Hill City, Pierre, Rapid City, Renner, Toronto, Volga	High in carbohydrates
Agricultural Processes	Soybean processing	Soapstock	Voga and St Lawrence	High in soybean oils
	Ethanol production	Steepwater solubles	16 plants in eastern SD	High in carbohydrates

Chapter 4: Best Practices for Evaluating the Use of Waste Streams for Transportation Applications

This chapter provides an overview of the best practices for evaluating and regulating the use of waste streams in transportation applications. Topics discussed in this chapter include:

- Existing regulations
- Effectiveness
- Safety
- Economics
- Environmental benefits and risks

4.1 Regulations on Using Aqueous Wastes for Transportation Applications

Most of the research on dust suppressants and deicing materials has focused on the effectiveness and cost. Currently, there are no federal regulations controlling the application of aqueous waste products for dust and ice control and road stabilization. However, several states have developed guidelines for the use of anti-icing and deicing materials and dust suppressants for transportation applications. Oil field brine has been used for ice and dust control in Michigan, New York, North Dakota, Ohio, Pennsylvania, and other areas for decades. The environmental protection agencies of these states have developed regulations and guidelines on spreading oil field brine on roadway surfaces. These regulations have been used to manage the beneficial reuse of the oil field brine for ice and dust control.

The oil field brine spreading regulations from Michigan, North Dakota, Ohio, and Pennsylvania are summarized to determine the key elements of these regulations. In addition to oil field brine, the Wisconsin DNR has developed a regulation on beneficial reuse of cheese brine for ice control. These state regulations provide important information that can help the state of South Dakota develop similar guidelines to manage the beneficial reuse of aqueous waste streams for transportation-related applications.

4.1.1 Cheese Brine Regulations

Wisconsin DNR regulates the use of cheese brine as a roadway deicing additive in the state of Wisconsin. The Wisconsin DNR requires submitting a request for approval for the application of cheese brine. The information that should be submitted to the Wisconsin DNR includes cheese plant information, filtration processes, volume of brine generated per week, proposed application rate and analytical information. The analytical information includes salt content, total kjeldahl nitrogen (TKN), pH, and BOD_5. The BOD_5 of cheese brine should not exceed 20,000 mg/L for ice control.

4.1.2 Oil Field Brine Regulations

(1) Michigan Department of Environmental Quality

Michigan Department of Environmental Quality (DEQ) is in charge of issuing permits to allow the use of oil field brines for ice and dust control in the state of Michigan. An annual permit fee is required by the Michigan DEQ for the approval. No specific test parameters are listed in the regulation. A summary of the key elements of the regulation is presented in Table 4.1

Table 4.1 Michigan Department of Environmental Quality Regulations

Approval Procedure	No brine may be used without a certificate of approval from the Michigan DEQ, end user must request a permit to use the oil field brine.
	Brine must meet standards noted in Michigan's administrative code R 324.705 (3) of Part 615.
	An annual permit fee must be paid to the Michigan DEQ under section 324.3122 of the Michigan Act.
Operating Requirements	Brine applications measurement methods must be used to ensure that the brine application rates are within limits set by the Michigan DEQ.
	Brine should only be applied at a rate and frequency necessary to control dust and ice in order to protect the public health, safety and welfare, and up to the maximum allowed by the general permit.
	Brines shall not be applied at a location determined to be a site for environmental contamination for chlorides under Part 201, Environmental Remediation of Act 451.
Dust Control	Brine may be applied to the surfaces of roads, parking lots, and other land up to 3 or 4 applications each year depending on the county locations.
	Brine must be spread with a spreader bar over a distance of at least 8 ft evenly.
	Brine may be applied at a maximum rate of 1,500 gallons per lane mile or 1,250 gallons per acre, provided that runoff does not occur.
Ice Control	Brine shall only be applied to paved roads or parking lots.
	500 gallons per lane mile and 400 gallons per acre are the maximum application rates for ice control.
	Brine must be applied only when the air temperature is above 20^{o}F, unless used for pre-wetting solid salt.
	Brine for ice control should be spread in a manner to direct the brine toward the crown of the roadway to limit waste runoff.
Reporting Requirements	Records shall be kept of the use of brine and should contain driver's name, location, loading date, source of brine, date of brine spreading, county or township the brine was applied, and gallons applied.
	Records should be kept for a minimum of 3 years by the discharger from the date they were generated and shall be available for inspection by the Department or a peace officer.
	The records from the previous two weeks should be maintained in the truck spreading the brine and shall be available for inspection by the Department or a peace officer.
	Documentation of supervisor of wells approval for use.

(2) North Dakota Department of Health

The NDDOH is the authority in regulating the use of oil field brines in the state. The NDDOH developed a guideline for using oil field brines for dust and ice control. The guideline is divided into 4 main components: definitions, criteria for the choice of a brine, end user responsibilities, and brine spreading guidelines. The key elements of the guideline are summarized in Table 4.2.

Table 4.2 North Dakota Department of Health Regulations

Approval Procedure	All end users who hope to use the brine for ice or dust control must submit a plan in writing to the NDDOH.
	These pre-approval plans should include the following information:
	The name, address and telephone numbers of those responsible for the spreading of the brine;
	A legible map of the areas showing where the brine will be stored;
	The proposed rate and frequency of application;
	The name of the brine producer and loading locations (township, range, section, and the quarter section);
	The geological formation that the brine came from.
	Chemical analyses conducted anytime within the previous 36 months for following parameters: pH, specific conductivity; major ions (including iron, manganese, sodium, potassium, phosphorous, SO42-, HCO3-, CO32-, and OH-), TDS, total alkalinity, oil and grease, and the trace elements and compounds of aluminum, ammonia, arsenic, barium, boron, copper, chromium, lead, nickel, selenium, and zinc must be submitted.
	Brine shall not have hydrogen sulfide concentrations which constitute a hazard.
	Calcium and magnesium concentrations should be greater than 10,000 mg/L and chloride concentrations should be greater than 75,000 mg/L.
	Only brines from production waters may be used. No drilling fluids, exploration fluids or work-over liquids shall be used.
	Brine should be mostly free of oils and sludge and leave no visible sheen on any surface water.
Operating Requirements	Any change in the brine must be reported to the NDDOH. In addition, any change to equipment, spreading area, or brine supplier must be communicated to the NDDOH.
	Any brine spreading vehicle used should be clearly marked with a legible sign identifying it as a brine spreader.
	Brine application must be performed in a way that minimizes impact to the environment. Brine may only be applied at a rate and frequency necessary to control dust and ice. This rate must be controlled to limit the brine infiltrating the ground water or running off the road surface into roadside ditches, streams, creeks, lakes or any other body of water.
	No brine may be spread without a report submitted to the NDDOH and the NDDOH's approval.
	An annual report is due to the NDDOH for the brine used. Records of brine used must also be kept for 3 consecutive years.
Dust Control	Brine for dust control shall be applied by use of a spreader bar, with shut-off controls accessible from the cab of the truck.
	The initial application of brine shall be spread at a rate of ½ gallon per square yard and subsequent applications shall not exceed 1/3 gallon per square yard per month, unless weather or traffic condition require more frequent applications.
Ice Control	Brine application rates and frequency shall be similar to those used by the North Dakota DOT.
	For spreading liquid brine, the truck shall employ a spreader bar, with shut-off controls accessible from the cab of the truck.
Reporting Requirements	A log of all spreading, including dates, rates, volumes, locations and brine source shall be kept in the spreader vehicle and owner's office. The office copy should be updated at least once a week and kept on file for at least 3 years. These logs should be made available to state inspectors from law enforcement, oil and gas, and or the state or local NDDOH.
	An annual report of the ice and or dust control programs should be prepared and maintained by the owner and be available for review upon request. This report should include the locations, sources, rates and volumes of brine spread. For ice control, the report should be completed by June 1st, and for dust control by January 1st. These reports should be maintained for 3 years.
	Significant revisions to the spreading plan shall be communicated by letter to the department before implementing the revision.

(3) Ohio Department of Natural Resources

The ODNR regulates the use of oil field brines use for transportation-related applications in the state of Ohio. Similar to the other states, Ohio requires that the end user submit a brine application plan to the ODNR. The ODNR is responsible for approving the plan, and no brine should be spread before ODNR's approval. Some of the main regulations are summarized in Table 4.3.

Table 4.3 Ohio Department of Natural Resources Regulations

Approval Procedure	The ODNR has the authority to approve oil field brine for use in transportation-related applications. Before approval, the end user must submit a pre-use plan that shall identify the sources of the brine, identify the name, address, and registration certificate, if applicable, of any transporters of the brine, state the places that the brine will be applied, and specify and describe the method, rate, and frequency of application.
Operating Requirements	Brine should not be applied to a water-saturated surface, directly to vegetation, within 12 feet of structures crossing bodies of water, drainage ditches and or between sundown and sunrise except for ice control.
	Brine application should automatically stop when the application vehicle stops.
	The application vehicle should be moving at least 5 miles per hour while the brine is being applied.
	The maximum spreading rate is 3,000 gallons per 12 ft wide lane mile, or 3 gallons per 60 square feet for unpaved lots.
	The angle of discharge of the spreader bar should not be greater than 60 degrees from the perpendicular to the road surface.
Dust Control	
Ice Control	Brine application rates and frequency shall be similar to those used by the North Dakota Department of Transportation.
	For spreading liquid brine, the truck shall employ a spreader bar, with shut-off controls accessible from the cab of the truck.
Reporting Requirements	Annual reporting is required to provide information on brine spreading during the last calendar year.

(4) Pennsylvania Department of Environmental Protection

Pennsylvania Department of Environmental Protection (DEP) oversees the approval and use of oil field brines for ice and dust control in the state. According to the PDEP, the brine generator, the transporter, the applicator and the roadway administrator share the responsibility to assure the proper use of oil field brine. A summary of Pennsylvania's regulations is presented in Table 4.4.

4.1.3 Other Aqueous Waste Streams

Currently, there are no federal or state regulations controlling the use of other aqueous wastes for dust and ice control. These aqueous wastes include lignin derivatives and soybean soapstock for dust control, and beet and potato juices for pre-wetting solid salts. However, the application of waste materials on roadway surfaces generally falls under several generic regulations set by the EPA which include Clean Water Act

Table 4.4 Pennsylvania Department of Environmental Protection Regulations

<table>
<tr><th rowspan="7">Approval Procedure</th><td>Any person who spreads brine from oil and gas wells for dust suppression must submit a plan to the PADEP on a yearly basis. The plan must show how pollution potential is minimized and approval from PADEP must be received before brine spreading can begin. The plan must include the following information:</td></tr>
<tr><td>The name, address and telephone numbers of those responsible for the spreading of the brine. The license plate number of the brine spreader trucks also needs to be submitted.</td></tr>
<tr><td>An original, signed and dated statement from the municipality or other person authorizing the use of brine on their roads and that they will supervise the frequency of spreading.</td></tr>
<tr><td>A legible map of the area identifying the roads that will receive the brine.</td></tr>
<tr><td>A description of how the brine will be applied and the proposed rate and frequency of spreading.</td></tr>
<tr><td>The identification of the geologic formation from which the brine is produced.</td></tr>
<tr><td>A representative chemical analysis of the brine for the following parameters: calcium, sodium, chloride, magnesium, and TDS.</td></tr>
<tr><th rowspan="8">Operating Requirements</th><td>The application of brine must be performed in accordance with the approved plan.</td></tr>
<tr><td>Recommended spreading rates: ½ gallon per square yard and subsequent rates of 1/3 gallon per square yard per month.</td></tr>
<tr><td>Only produced water from conventional wells may be used. Brine must be free of oil before spreading.</td></tr>
<tr><td>Brine must not be applied within 150 feet of a body of water. Brine must not be placed on roads with grades exceeding 10%. Brine must not be spread on wet roads and during rain.</td></tr>
<tr><td>Brine must be spread by use of a spreader bar with shut-off controls in the cab of the truck.</td></tr>
<tr><td>Brine spreading vehicles shall have a clearly legible sign identifying the applicator on both sides of the vehicle.</td></tr>
<tr><td>The company spreading the brine must notify the appropriate region PADEP the business day before spreading the brine.</td></tr>
<tr><td>Any changes made to the plan must be submitted to the PADEP for approval before they can be implemented.</td></tr>
<tr><th>Dust Control</th><td></td></tr>
<tr><th>Ice Control</th><td></td></tr>
<tr><th>Reporting Requirements</th><td>Monthly reports must be submitted to the PADEP indicating the location and amount of brine spread during the month. Transporters of brine must keep a daily operations record and file an annual operational report with PADEP by March.</td></tr>
</table>

(CWA), and Resource Conservation Recovery Act (RCRA). These acts generally hold the applicator responsible for not introducing any harmful chemical into the environment (Piechota, 2002).

4.2 Effectiveness and Pre-Treatment Requirements

The effectiveness and pre-treatment requirements of aqueous waste streams for transportation-related applications are highly site-specific. The waste materials for ice and dust control can be generally classified into two major categories: brine based materials and organic based materials.

4.2.1 Brine Based Materials

The effectiveness of waste brine for ice and dust control is primarily determined by its salt concentrations. For anti-icing and deicing applications, the optimum brine salinity is 23% (NaCl) which has the lowest freezing point. Oil field brine typically has high concentrations of sodium chloride, which makes it an effective deicer. NDDOH regulates that chloride concentrations of oil field brine for ice control should be greater than 75,000 mg/L. The presence of calcium and magnesium in oil field brine can enhance its deicing performance due to their lower freezing points. The experiences of many state DOTs suggest that oil field brines are highly effective at ice control during winter seasons. According to the North Dakota LTAP, counties that relied on oil field brines for deicing and anti-icing did not need to purchase any traditional rock salts due to the high effectiveness of the oil field brines. For dust control, the brine wastes should contain high concentrations of calcium and magnesium because sodium chloride is generally not an effective dust suppressant. NDDOH regulates that calcium and magnesium concentrations of oil field brine for dust control should be greater than 10,000 mg/L. Oil field brine generally does not require future treatment or enrichment for dust and ice control. The oil and sludge in the oil field brine are typically removed by the generator before the delivery to the application locations.

Cheese brine is another brine waste material that has been successfully used for ice control. Wisconsin DOT has used cheese brine for pre-wetting solid salt and sand since 2008. The cheese brine generated from mozzarella cheese production has sodium chloride concentrations about 17 to 23%. The salinity of this cheese brine makes it a suitable option for deicing without any further enrichment or dilution. The only pre-treatment performed on this cheese brine is using ultrafiltration to reclaim proteins. This pre-treatment is accomplished by the cheese factory. According to the Wisconsin DOT, the cheese brine was an effective choice in keeping roads clearer and helped to melt the ice faster.

Based on the application of oil field brine and cheese brine for ice control, the brine waste materials should be pre-treated to remove oil and grease and other large particles. To achieve the best performance for ice control, the brine waste should contain a NaCl concentration close to 23% for direct applications. For dust control, the waste brine solution should have relatively high concentrations of calcium and magnesium.

4.2.2 Organic Based Materials

Organic waste materials used for anti-icing and deicing applications typically contain high concentrations of carbohydrates such as starches, polysaccharides and sugars. These waste materials include beet juice, potato juice and other agricultural processing wastes. These organic waste materials can reduce the freezing points when mixing with rock salts and brine solutions. They also have better adherence to the road surface compared to traditional brines which further increase their deicing performance. The effectiveness of organic waste materials for ice control depends on the magnitude of the reduction in freezing point, which can be best determined by field applications. Several organizations also provide testing guidelines to determine ice melting performance, skid resistance effects, and others. These organizations include:

- Pacific Northwest Snowfighters (Snow and Ice Control Chemical Products Specification and Test Protocols)
- American Society for Testing and Materials (ASTM)
- American Association of State Highway and Transportation Officials (AASHTO)

Soybean soapstock, which is a byproduct from soybean processing, has been used for dust control on unpaved roads. The oil content in this waste material can help bind soil particles to reduce dust emission. According to the South Dakota LTAP, soybean soapstock can be effective at dust control when it is properly applied to the road surface. Similar to ice control, the effectiveness of this waste material for dust control is best observed through field applications. One of the advantages of using soybean soapstock for dust control is that it is less corrosive compared to salt based materials. The disadvantage is that soybean soapstock costs much more than calcium and magnesium salts. This can limit the wide use of soybean soapstock for dust control.

4.3 Safety

The waste brines for ice and dust control generally have similar properties to the traditional brines made from rock salt. The handling of these waste brines does not pose a serious threat to human health. Personal protective equipment such as goggles and gloves should be used while working with the brine as the high salinity of the water may be irritating to skin and eyes. The chance of fire or explosion is not possible because the brine solution is not combustible. Storage and piping equipment should be evaluated as salt brines can be corrosive to most metals.

Organic waste materials for ice control are mostly byproducts from food or industrial processes using agricultural products. The chemical compositions of these organic wastes can vary significantly, but they all contain similar compounds such as starch, carbohydrates and sugars. These materials are typically not considered harmful to human health unless ingested. Personal protective equipment such as gloves and goggles are not required, but recommended. These organic wastes are not combustible due to high water content. Their base ingredients, carbohydrates and sugars, can be combustible when they are dried.

Soybean soapstock is also not harmful to human health unless ingested. Personal protective equipment should also be used when handing this oil. It can be treated similar to other fuel oils, such as diesel fuel. Soybean soapstock is somewhat combustible, but not flammable like gasoline or other hydrocarbons.

4.4 Economics

Beneficial reuse of aqueous waste streams in transportation-related applications can result in significant economic benefits for both transportation agencies and the waste generators. The use of waste brine solutions will reduce the costs associated with purchasing new salts for ice and dust control. For example, when oil field brine was used by North Dakota DOT, they did not need to purchase any rock salts for anti-icing applications because the oil field brine was very effective. The use of cheese brine in Polk County, Wisconsin results in 30 to 40% salt reduction because the enhanced deicing efficiency by pre-wetting solid salts with the brine. Similarly, using beet juice as an additive can also result in less salt usage for ice control. In addition to using less salt, the pre-wetting of rock salts allows the operator to spread salts at a faster application rate, thus reducing labor costs. Reduced labor costs can also be realized when using oil field brine for anti-icing because pre-wetting of the road surface can be performed during regular working hours before storm events.

The use of waste materials for dust and ice control can substantially lower the costs associated with waste management, treatment, and disposal for the generators. Using oil field brine for transportation applications reduces the financial burden of brine storage and disposal for oil and gas companies. Before cheese brine was reused for ice control, F & A Dairy had to pay the cost for transport and disposal of the brine at the Duluth Wastewater Treatment Plant (Johnson, 2011).

The cost analysis of beneficial reuse of aqueous waste streams should consider equipment cost, transportation cost, labor cost, waste management and disposal savings, and materials savings to determine the economic benefits for both DOTs and waste generators. For example, the Barron County Highway Department in Wisconsin has evaluated waste brine from one of the cheese plants in Barron County which produces cheddar cheese. The salinity of this cheese brine was 6%, which is not sufficient to work as a deicer. The highway department would need to purchase commercial salt brine and mix it with the cheddar cheese brine to raise the salinity. New mixing equipment is also needed. After the evaluation, the highway department determined that it is cost prohibitive to use the cheddar cheese brine for ice control. Therefore, detailed cost analysis is required when evaluating a new waste solution for transportation-related applications.

Some waste products, such as soybean soapstock and cheese whey solids are commodities that have a market. These products are more environmentally friendly than traditional salt products but they are also more expensive. The use of these products may be justified by the environmental benefits.

4.5 Environmental Benefits and Risks

4.5.1 Environmental Benefits

The environmental benefits of using aqueous waste streams for transportation applications include the reduced consumption of raw salt materials, and the reduction in overall salt loading to the environment due to increased efficiency. The reduced salt usage can lead to the conservation of natural resources, and energy savings in mining salts and transportation of the material. The reduction in overall salt loadings can reduce the impact of salt contamination on surface water and groundwater. The potential impact of salts on vegetation can also be reduced.

4.5.2 Environmental Risks

The primary environmental risk associated with spreading waste brines on road surfaces is the damage to nearby vegetation and increases in salt loading to waterways. This environmental risk is similar to the use of traditional rock salts. The impacts of deicing salts on vegetation and natural waters have been extensively evaluated. The results of these evaluations suggest that the impact of deicing salts on the environment can be controlled to acceptable levels through best management practice. Many state environmental protection agencies have developed guidelines on the application of waste brines for ice and dust control in an effort to minimize their environmental impact.

Another problem posed by chloride brines are their corrosive tendencies. The corrosive effects of salt brines on vehicles and infrastructure are well known. However, less commonly, there have been reports of damage to railroad signals and electrical power equipment as well from the salt spray that occurs near roads where salt is regularly used to control ice. (Hedges, 2007).

In addition to chloride salts, waste brines may also contain many other chemicals such as trace organics, heavy metals, and total dissolved solids. NDDOH requires the analyses of certain organic and inorganic parameters for oil field brines used for ice and dust control. Organic based waste materials from food processing may pose environmental risks due to high BOD, nitrogen or phosphorous content. Wisconsin DNR sets restrictions on the maximum BOD concentration and maximum application rate of cheese brine for pre-wetting solid salts. BOD is a measurement of how much potential oxygen depletion may occur from the introduction of a waste. Oxygen depletion can be problematic since aquatic life depend on it for their existence. A waste introduced into waterways with a high BOD may deplete the dissolved oxygen enough to have detrimental effects on aquatic life and the health of that body of water. Nitrogen and phosphorous provide nutrients to algae and other plant life which can become invasive in the water body and after the plant dies, it then can deplete the dissolved oxygen in the water which causes the same problems as BOD does. These waste parameters should be limited for waste products that are to be used for beneficial reuse. Through proper planning and evaluation of a waste, the environmental impact of aqueous wastes can be successfully minimized.

4.6 Typical Regulatory Requirements

4.6.1 Introduction

Aqueous waste streams produced from municipal and industrial processes have been used for ice and dust control and soil stabilization. These guidelines were developed to minimize the environmental impact resulting from the use of aqueous wastes on road maintenance. The beneficial use of aqueous wastes for ice and dust control must follow these guidelines. The owner, the generator, the transporter, and the applicator share the responsibility to assure that all activities are conducted in accordance with the guidelines. This guideline was developed for SDDENR to produce a formal guideline for regulating beneficial reuse of aqueous waste streams in South Dakota.

4.6.2 Definitions

- Owner: The person, government or business that owns or has legal control over roads or parking lots where aqueous wastes will be applied for ice or dust control.
- Generator: The company or organization who produces the aqueous wastes for the purpose for ice or dust control
- Transporter: The person or company who transports the aqueous wastes from the generator to the owner.
- Applicator: The driver of the vehicle that applies aqueous waste to roads or parking lots for ice or dust control.
- Aqueous wastes: The aqueous wastes produced for beneficial reuse for transportation-related applications.

4.6.3 Approval Procedure

Any person or organization that uses aqueous wastes on roads for dust or ice control must submit a plan to the SDDENR for approval. The plan must be approved by SDDENR before the application of aqueous wastes can begin. The plan must contain the following information:

1. Use of aqueous waste stream
2. The contact information of the person submitting the plan, and the organization spreading the aqueous waste.
3. A signed and dated statement from the aqueous waste stream source and road owner stating:

a. Acceptance of use

b. Roads to be used on

c. SDDENR may require detailed chemical analysis of aqueous waste

4. A legible map showing the road(s) that will receive the aqueous wastes.

5. A description of the equipment and method for the waste application.

6. The proposed frequency and rate of application.

7. A description of the environmental impact of use

8. Primary components in the stream

9. How aqueous waste stream will be tracked if required

The SDDENR will review the plan after a complete plan is received. SDDENR will determine whether an approval will be granted based on the information provided and if tracking is required. Figure 4.1 shows the decision-making tree for the reuse of aqueous wastes for transportation-related applications. From this case study, the MIEX® brine was shown to have no significant environmental impact. Following the flow chart, the waste would be reused for ice control, and it was shown to not have an environmental impact. According to the flow chart, no further action would be required.

4.6.4 Reporting Requirements

To assure the environmental impact of the reuse of aqueous waste streams is minimized, the SDDENR must be notified of all waste streams used for transportation-related applications. The SDDENR will determine if the waste can be used or if there are additional reporting requirements.

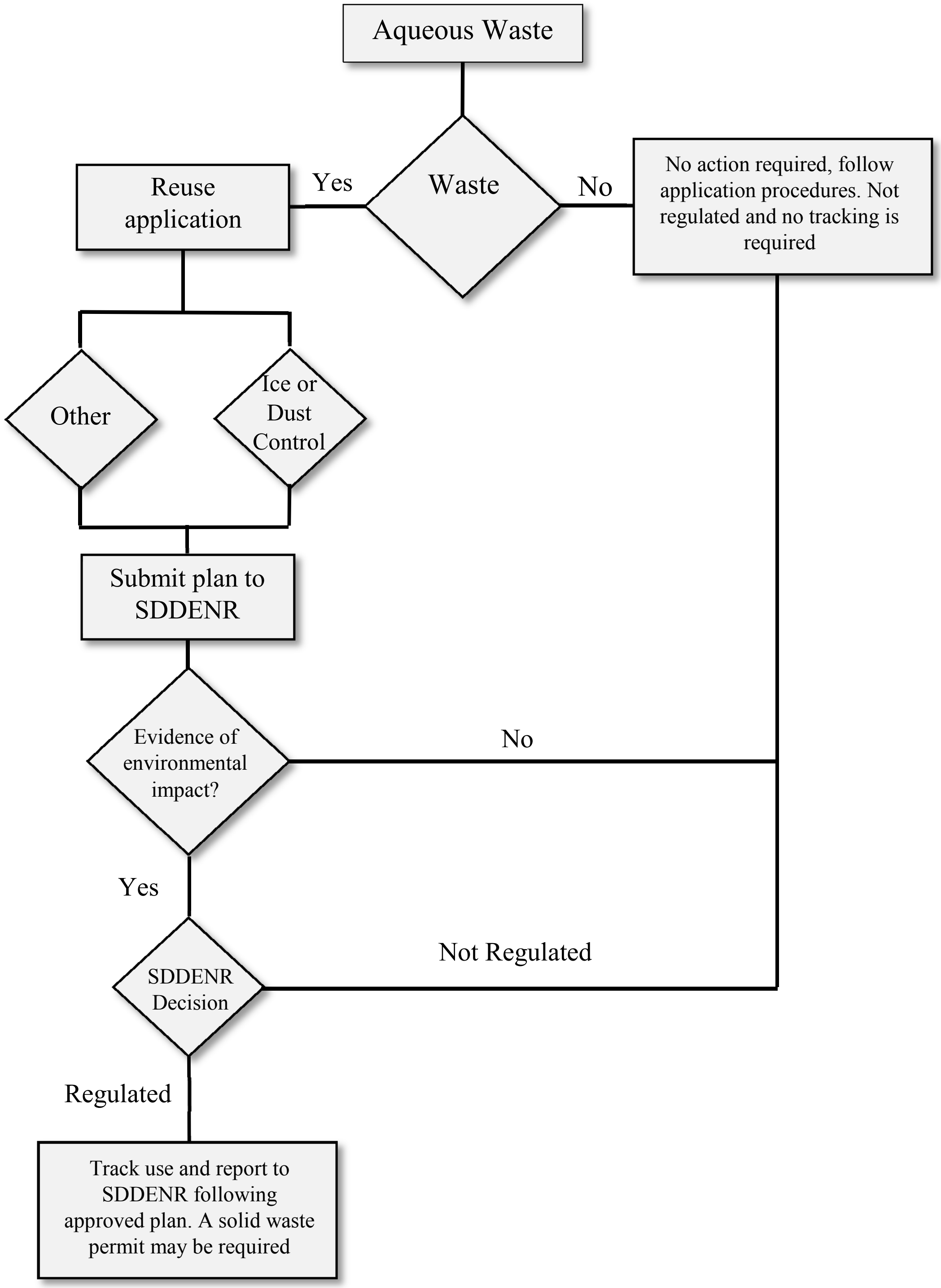

Figure 4.1 shows the decision-making tree for the reuse of aqueous wastes for transportation-related applications

Chapter 5: Beneficial Reuse of MIEX® Brine for Transportation Applications

This chapter provides an overview of the WMWTP's MIEX® system and the cost analysis for its reuse. Topics discussed in this chapter include:

- An overview of Watertown's MIEX® process
- Water quality of Watertown's MIEX® brine
- Potential transportation applications for the MIEX® brine
- Environmental benefits and risks
- Economic Analysis

5.1 Watertown Municipal Water Treatment Plant's MIEX® System

The WMWTP located in Watertown, South Dakota uses a MIEX® process to remove NOM from several drinking water wells to reduce formation of disinfection byproducts (DBPs). These wells are typically only used during the summer season when the water demand is high.

5.1.1 Overview of the MIEX® Process

Chorine is the most widely used chemical disinfectant in drinking water treatment in the United States. It has been identified since 1970s that chlorine can react with NOM in the source water to form harmful DBPs including trihalomethanes (THMs) and haloacetic acids (HAAs). Some of the DBPs are suspected human carcinogens. The USEPA currently regulates four THMs and five HAAs in drinking water to reduce the health risks associated with DBPs. Since the adoption of the EPA's DBP rules, drinking water utilities have been working to improve treatment processes to limit the DBP formation. One strategy for DBP control is to remove the NOM precursor using advanced technologies, thereby reducing the DBP formation during chlorination.

The MIEX® system was developed in Australia by the Orica Watercare Corporation to specifically address the removal of NOM from drinking water. The MIEX® resin consists of ion exchange materials that are capable of removing organic matter from the water. In addition, the resin has a macroporous structure formed by the cross-linked acrylic skeleton which allows the resin to remain stable and effective. The resin is also very small, with an average diameter of 180 μm. The small sizes increase the rate of NOM removal by the MIEX® resin. The MIEX® resin also contains a magnetic compound imbedded in the structure of the resin which allows it to act as a magnet and create large particles which can settle even under high hydraulic loadings, thus reducing overall footprint of the contactors.

Figure 5.1 provides an overview of a typical MIEX® process in municipal water treatment. The overall process of the MIEX® system includes three main components: resin contacting, resin separation, and resin regeneration. The contacting and separation occur in the process line of the water treatment plant, while the regeneration process happens in a separate section. The recycle line from the settler returns some of the settled resin to a separate holding tank, while the rest is diverted to the contactors again with regenerated resin. The resin in the separate holding tank is regenerated in a batch mode. In this tank, a brine solution (typically 12% NaCl) is added to the resin and is allowed to flow through the resin. After the resin is regenerated, the brine is reused until its

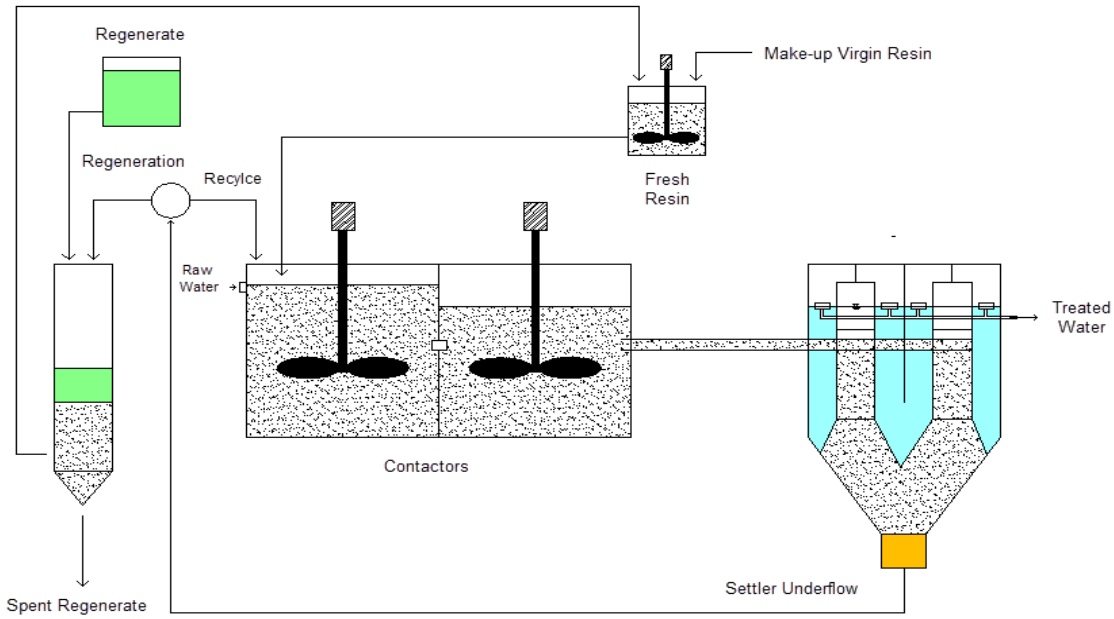

Figure 5.1 An overview of the MIEX® process (Reproduced from Orica Watercare, Inc)

conductivity reaches a certain threshold approximately 30 mS/cm. At that point, the brine is discarded as waste brine. Figure 5.2 shows the MIEX® storage and regeneration tanks at the WMWTP.

5.1.2 Quantity of MIEX® Brine in Watertown

The MIEX® system in Watertown's water treatment plant was specifically installed to reduce the NOM content of water from several of the wells to reduce the DBP formation. The water use of Watertown increases during the summer months, particularly during the warm and dry months of July, August and September. The WMWTP operates the MIEX® system during the summer season to reduce the concentration of NOM in the raw water to control the formation of DBPs. According to the WMWTP, the MIEX® process produces approximately 1,500 gallons of waste brine per day, and averages around 150,000 gallons per summer season.

MIEX® Storage Tanks MIEX® Regeneration

Figure 5.2 The WMWTP MIEX® storage and regeneration tanks

5.2 Water Quality of the MIEX® Brine

According to the aqueous wastes reuse guideline developed in this study, it is important to understand the quality of the MIEX® brine to evaluate its potential for transportation-related applications. Once the chemical composition of the brine is known, it can be compared to other ice control compounds that are known to be effective. The MIEX® brine was originally tested by US Water Services for the sample taken by WMWTP employees on December 20, 2012. As part of this project, two MIEX® brine samples were collected on October 16, 2015 and the samples were analyzed by US Water Services and the Water Environmental Engineering Research Center (WEERC) at South Dakota State University. The analytical results of the MIEX® brine samples collected at both dates were used to determine its reuse potential.

5.2.1 Salt Concentration

The beneficial reuse of waste brine for transportation applications depends on its salt concentration. Table 5.1 presents the MIEX® brine salt concentrations for the 2012 and 2015 samples. The results of the 2015 samples are the average values of the two samples analyzed by the two labs. It can be seen from Table 5.1 that the two samples showed substantially different salt concentrations. The 2012 MIEX® brine sample had a chloride concentration of 43,289 mg/L, which was more than eight times of the 2015 brine sample (5,083 mg/L). The two samples are designated as high and low salt brine samples, respectively, to facilitate the discussion. According to the WMWTP operating staff, the MIEX® system did not operate during the summer of 2015. The system was started on October 16 for the project team to take the MIEX® brine samples. The low salt concentrations may have been caused by the system startup and the brine sample may have been diluted by low salt water. The WMWTP operating staff have indicated that the salt concentration of the 2012 MIEX® brine is likely the typical level under normal operating conditions. The calculated equivalent NaCl percentages were 6.55% and 0.83% for the high and low salt samples, which lead to annual salt production of 43.9 and 5.24 tons, respectively. The percent by weight salt calculations are shown below. The total material calculations were based on the estimated annual MIEX® brine production of 150,000 gallons.

$$2012\ \%\ by\ Weight\ NaCl = \left(\frac{70.137\ g}{1000\frac{g}{L} + 70.137}\right) x\ 100\% = 6.55\%$$

$$2015\ \%\ by\ Weight\ NaCl = \left(\frac{8.379\ g}{1000\frac{g}{L} + 8.379}\right) x\ 100\% = 0.83\%$$

$$2016\ \%\ by\ Weight\ NaCl = \left(\frac{42.38\ g}{1000\frac{g}{L} + 42.38}\right) x\ 100\% = 4.07\%$$

Table 5.1 MIEX® Brine Salt Concentrations and Productions

MIEX® Brine Salt Content	**2012 Sample (High Salt)**	**2015 Sample (Low Salt)**	**2016 Sample (Low Salt)**
Sample Date	12/20/2012	10/16/2015	6/16/16
Cl Concentration (mg/L)	43,289	5,083	25,771
Equivalent NaCl Concentration (mg/L)	70,137	8,379	42,380
Equivalent NaCl (%)	6.55%	0.83%	4.07%
Total MIEX® Brine Production (gallons/year)	150,000	150,000	150,000
Total MIEX® Brine Salt (NaCl) Production (lbs/year)	87,798	10,489	53,052
Total MIEX® Brine Salt (NaCl) Production (US tons/year)	43.9	5.24	26.5

5.2.2 MIEX® Water Quality Analysis

Table 9.2 shows the MIEX® brine water quality results of the 2012 sample analyzed by US water services and the 2015 samples analyzed by US water service and WEERC. The SDDENR Groundwater Standards are also included in the table as a reference.

The pH values of the MIEX® brine samples fell within the typical range in natural waters. High concentrations of total organic carbon of the brine samples are expected as the MIEX® resin is effective at removing the organic matter from the source water. The properties of the organic matter in the MIEX® brine are expected to be similar to the NOM in natural water bodies. The ammonia, nitrate, nitrite, and phosphate concentrations of the MIEX® brine were generally low. This indicates that the MIEX® brine would not contribute large amounts of nutrient to the natural environment during reuse.

Relatively high concentrations of sulfate were found in the MIEX® brine. The USEPA sets a limit of 250 mg/L for sulfate in the secondary drinking water standards.

The secondary standards are non-mandatory water quality standards that are established as guidelines to assist public water systems in managing their drinking water for aesthetic consideration. Currently, no federal water quality criteria exist for the protection of freshwater aquatic life for sulfate. Illinois, Iowa and Minnesota are a few states that set guidelines for surface water sulfate concentrations, ranging from 10 to 2000 mg/L for different protections of certain sensitive water bodies with different water quality criteria. (Iowa DNR, 2009; Ministry of Environment of British Columbia, 2013). In general, sulfate is considered less toxic to aquatic animals than chloride and bicarbonate (Ministry of Environment of British Columbia, 2013).

Increased sulfate concentrations may impact groundwater quality. Sulfate can be reduced to hydrogen sulfide under anaerobic conditions by sulfur-reducing bacteria. Hydrogen sulfide is a very common problem for water treatment plants using a groundwater supply. Conventional drinking water treatment processes are effective for hydrogen sulfide removal. The sulfate reduction process has some beneficial effects on the environment. For example, the sulfate reduction process can lead to metal sulfide precipitation which may reduce the concentrations of heavy metals such as arsenic in natural water bodies (Church et al., 2007). Sulfate reduction bacteria can degrade hydrocarbons in groundwater (USEPA, 2002). Some negative impacts may be caused by the sulfate reduction process in the sediment. Increasing sulfate concentrations has the potential to increase phosphate release from the sediment. High sulfate concentrations may result in high rates of mercury methylation (Ministry of Environment of British Columbia, 2013).

Table 6.2 MIEX® brine water quality

Water Quality	2012 Sample	2015 Samples	2015 Samples	SDDENR Groundwater Standards	Unit
	US Water Services	US Water Services	SDSU WEERC		
pH	7.44	7.84	7.74	6.5 - 8.5	
Total Organic Carbon	545	902	820	NA	mg/L
Alkalinity	1,080	1,110	1,035	NA	mg/L
Bromide	< 5.00	< 0.5	NA	NA	mg/L
Chloride	43,289	4,232	5,314	250	mg/L
Fluoride	< 4.0	< 0.4	NA	4	mg/L
Nitrate	119	1.21	NA	10 mg/L as N	mg/L
Nitrite	< 5.0	< 0.5	NA	1 mg/L as N	mg/L
Sulfate	14,945	20,076	24,986	500	mg/L
Total Phosphate	1.80	< 0.8	NA	NA	mg/L
Ortho-Phosphate	1.70	0.32	NA	NA	mg/L
Total Dissolved Solids	85,468	37,036	38,155	1,000	mg/L
TSS	186	55	29.5	NA	mg/L
Ammonia, Nitrogen	1.19	< 1.00	1.02	NA	mg/L
Total Hardness	2,234	6,037	5,013	NA	mg/L
Calcium	1,609	4,200	NA	NA	mg/L
Magnesium	625	1,837	218	NA	mg/L
Arsenic	< 0.05	< 0.1	0.83	0.01	mg/L
Barium	0.20	0.482	0.114	2	mg/L
Beryllium	< 0.05	NA	NA	0.004	mg/L
Boron	0.206	0.563	< 0.1	NA	mg/L
Cadmium	< 0.05	NA	<0.05	0.005	mg/L
Chromium	< 0.05	NA	0.009	0.1	mg/L
Cobalt	< 0.05	NA	0.015	NA	mg/L
Copper	0.050	< 0.1	0.027	1.0	mg/L
Iron	1.43	2.28	2.93	NA	mg/L
Lead	< 0.05	NA	NA	0.015	mg/L
Manganese	3.71	10.65	5.93	NA	mg/L
Molybdenum	0.473	0.312	0.707	NA	mg/L
Nickel	0.17	NA	0.099	NA	mg/L
Potassium	96.40	57.45	77.8	NA	mg/L
Selenium	0.178	0.448	NA	0.05	mg/L
Silica	23.20	46.5	15.45	NA	mg/L
Sodium	27,590	9,571	9,215	NA	mg/L
Strontium	2.77	5.74	1.54	NA	mg/L
Thallium	< 0.25	NA	NA	0.002	mg/L
Tin	< 0.10	< 0.2	0.012	NA	mg/L

* NA: not available.

Certain heavy metals are expected in the MIEX® brine because naturally occurring metals in groundwater can be removed by the MIEX® resin and occur in the waste brine during regeneration. As shown in Table 9.2, most of the metals were below detection limits or low in concentrations. Molybdenum, selenium, and strontium were the heavy metals that showed relatively high concentrations for both samples.

The molybdenum concentration in the MIEX® brine is slightly elevated when compared to typical ground water sources. According to the World Health Organization, typical molybdenum concentrations in ground water range from undetectable to 0.270 mg/L, while surface waters can naturally range from 0.002 to 1.5 mg/L. Currently, the EPA does not have regulations on molybdenum for drinking water, but it is currently on the EPA's Contaminant Candidate List (CCL). Similar to molybdenum, strontium is not regulated by the EPA but currently on the CCL.

Selenium exceeds the USEPA primary drinking water standard and the groundwater standard of 0.05 mg/L. Transportation agencies typically use salt brine to pre-wet the road surface or rock salts during winter maintenance. It is unlikely that these application methods will cause significant risks from selenium during MIEX® brine reuse.

6.3 Potential Transportation Reuses for MIEX® Brine

Brines made from rock salt, and calcium and magnesium salts have been increasingly used for dust control and ice control. In recent years, waste brine generated from industrial processes (e.g. cheese making, oil and gas production) have been successfully used for anti-icing and deicing. The MIEX® brine produced from WMWTP was evaluated for these transportation-related applications based on its quality and quantity.

6.3.1 Direct Applications – Ice Control

The MIEX® brine can be potentially used for deicing and anti-icing applications. Pre-wetting using salt brines has been shown to increase the performance of salts and abrasives, as well as their longevity on the roadway surface, thereby reducing the amount of materials required.

Brines can also be used for anti-icing, which is the pre-storm application of the brine solution directly to the road surface. Anti-icing using brines can reduce the chances of ice formation on the road surface and increase the efficiency of snow plowing operations. Brine salt strength is a critical factor that decides the applicability and efficiency of the deicing and anti-icing applications. Ideally, brine solutions should be made as close as possible to the eutectic concentration. When the concentration is increased or decreased beyond the eutectic point, the freezing point of the solution increases. For sodium chloride brine, the concentrations that lead to the minimum freezing temperatures is approximately 23%.

The salt concentrations of the MIEX® brine was 6.55% for the sample collected in 2012. However, the salt concentration was well below the optimum 23% (-6^{o}F freezing point) for ice control. The freezing temperatures of the MIEX® brine are expected to be around 25^{o}F. Direct application of the MIEX® brine for pre-storm application or pre-wetting of salts and abrasives may lead to the formation of ice or dissolution of the rock salt. Therefore, direct application of the MIEX® brine for ice control is not recommended due to its low salt strength.

6.3.2 Dust Control

The waste MIEX® brine could also be used for dust control. Calcium chloride and magnesium chloride are the most commonly used dust suppressants in transportation applications. Sodium chloride is seldom used for dust control on unpaved roads because it starts to absorb water from air at limited ranges of humidity and temperatures. The calcium concentration of the MIEX® brine is relatively low, and therefore it would not be effective for dust control by direct applications.

There is some evidence that a mixture of sodium chloride and calcium chloride can be used to effectively stabilize the soil and control the dust, while reducing the material costs. The MIEX® brine could be potentially used to mix with calcium chloride or magnesium chloride to make dust control brine solutions. This practice needs to be tested in the laboratory and the field to determine its efficiency. However, such investigations exceed the scope of this project. Due to the uncertainty in the efficiency and cost savings of this practice, reusing MIEX® brine for dust control is not recommended.

6.3.3 Use MIEX® Brine as a Base for Full Strength Brining

The SDDOT currently has multiple brine making facilities in its Aberdeen and Mitchell regions. These facilities use commercial rock salts to produce brine solutions and store them on-site for pre-wetting the rock salts during winter road maintenance. Through discussions with the SDDOT, the most feasible reuse option for the MIEX®

brine is to use it as a base solution to make the brine solution. The MIEX® brine can be processed through the SDDOT's existing brine making equipment to the final 23% salt concentration. The final product can be used in a way similar to the conventional rock salt brine. This MIEX® brine reuse practice will reduce the consumption of water and rock salts for brine making for SDDOT. A detailed cost analysis was performed for this reuse option and recommendations were made based on the results of the economic analysis in the following sections.

6.4 Environmental Benefits and Risks

The environmental benefits of using MIEX® brine as a feed solution to make final brine products include the reduced consumption of raw salt materials and water, reduced MIEX® brine waste disposal and management, and reduction in overall salt loading to the environment due to increased efficiency. The salt content of the MIEX® brine can reduce the required raw rock salts for brine production at the SDDOT. The reduced salt use can lead to the conservation of natural resources, and energy savings in mining salts and transportation of the material. The use of MIEX® brine also reduces the consumption of water for brine making, which helps conserve the natural water resources. The SDDOT uses salt brine for pre-wetting rock salts before their application to the road surface. This allows the salt to better adhere to the road, and reduces the bouncing tendency of the dry salt, thus allowing for faster application rates and less overall rock salt used. The reduction in overall salt loadings can reduce the impact of salt contamination on surface water and groundwater. The potential impact of salts on vegetation can also be reduced.

The WMWTP currently discharges the MIEX® brine into the sanitary sewer system. This waste brine is treated at the Watertown wastewater treatment plant and is ultimately discharged to the environment. Beneficial reuse of the MIEX® brine will reduce the cost associated with the management and disposal of this waste brine for the WMWTP, and the impact of the brine on wastewater treatment.

The primary environmental risk associated with spreading waste brines on road surfaces is the damage to nearby vegetation and increases in salt loading to waterways. This environmental risk is similar to the use of traditional rock salts. The impacts of deicing salts on vegetation and natural waters have been extensively evaluated, and the results of these evaluations suggest that the impact of deicing salts on the environment can be controlled to acceptable levels through best management practice.

In addition to chloride salts, the MIEX® brine also contains certain heavy metals derived from the groundwater. The water quality analysis showed that most of the metals in the brine were below detection limits or low in concentrations. Elevated metal concentrations were observed for molybdenum, selenium, and strontium. The MIEX® brine also contain high concentrations of sulfate. However, the MIEX® brine will be used as a feed solution for brine making and then to pre-wet the rock salts. This practice is expected to result in low environmental risks associated with these heavy metals and sulfate. The nutrient levels of the MIEX® brine are generally low and will not contribute substantially to the eutrophication of the surface waters during reuse. All of the constituents except for the salts in the MIEX® brine are originated from natural groundwater and produced as waste products during drinking water production. Overall, the source, generation, quality, and recommended reuse method of the MIEX® brine will likely result in low environmental risks during reuse at the SDDOT.

6.5 Economic Analysis

The use of the MIEX® brine must be economically feasible in order to justify its beneficial reuse. Due to the low salt content of the MIEX® brine, the most viable reuse option is to use the MIEX® brine as a base solution for the SDDOT's brine making operations. To determine the economic feasibility of reusing the waste brine, we evaluated the existing brine making facilities, required new equipment, costs and savings for City of Watertown and SDDOT for the proposed MIEX® reuse option.

6.5.1 Existing Conditions of Brine Making

The SDDOT currently uses brine for pre-wetting road salt before applying it to the roadway. From correspondence with the SDDOT, the Aberdeen region uses an average of 298,900 gallons of brine per season for pre-wetting salt for roadway deicing operations. Many of the SDDOT maintenance locations in the Aberdeen region and the Mitchell region use the VeriTech SB600 salt brine maker. The brine maker can produce salt brine at a rate of 3,600 gallons per hour and is shown in Figure 6.3.

Figure 6.3 Typical brine maker used at the SDDOT maintenance shops (©2010 VeriTech Industries)

Currently, most of the maintenance shops in the Aberdeen region have brine making equipment, so their supply of brine is generated and stored on site. However, the majority of the maintenance shops in the Mitchell region do not have a brine maker, and they only have brine storage tanks on site. For those maintenance shops without brine making capability, salt brine is generated at the closest maintenance shop and then shipped to that location. Figure 6.4 shows a map of the SDDOT maintenance locations in the Aberdeen and Mitchell regions. Table 6.3 presents a summary of the brine making capability and storage volume of each maintenance location. The brine storage capacity of these locations varied from 3,000 to 39,500 gallons. The distance from the WMWTP and Watertown DOT shop to each maintenance location in these two regions is also provided in Table 6.3.

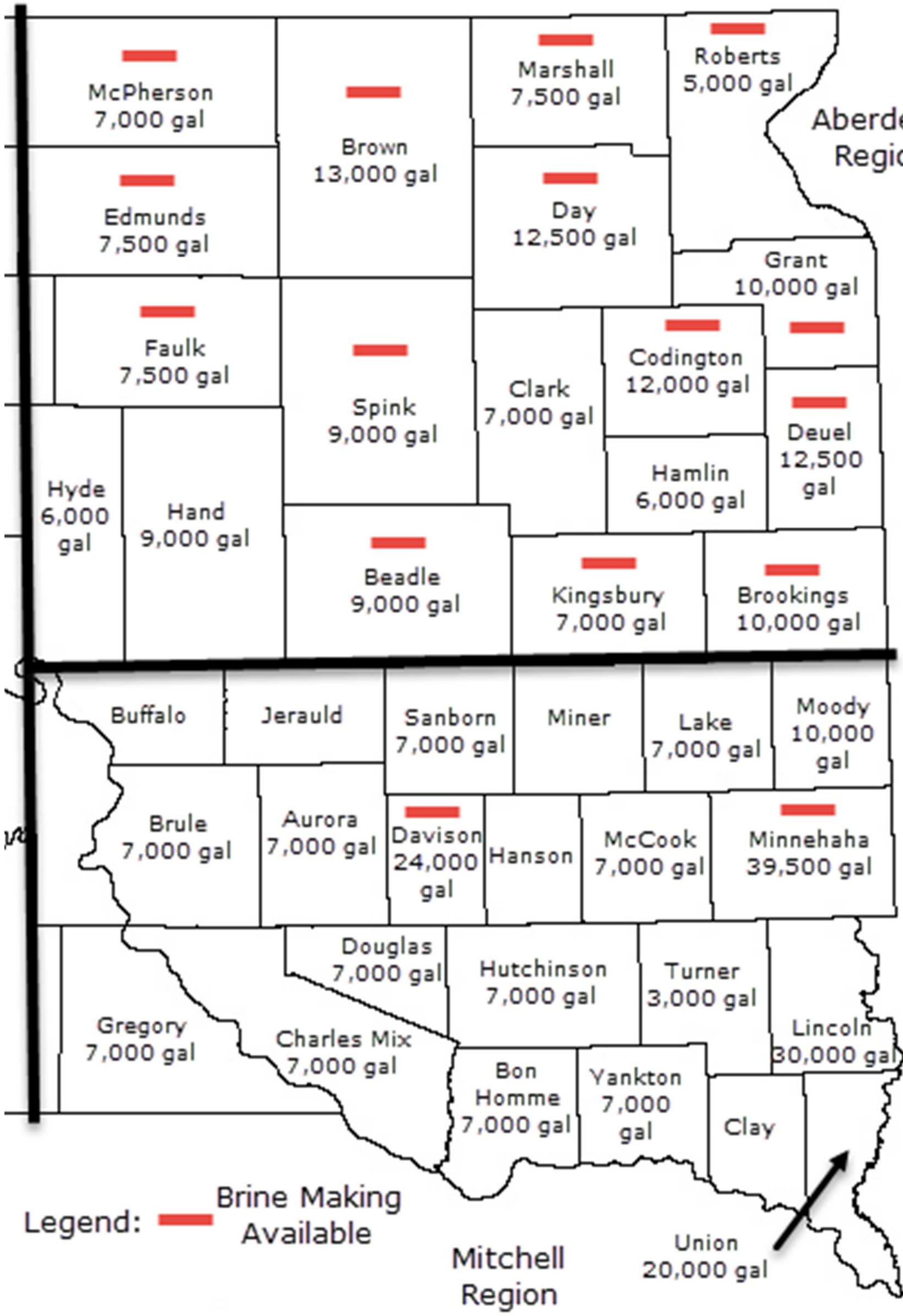

Figure 6.4 Map of the SDDOT maintenance shops in the Aberdeen and Mitchell regions and their respective brine storage capacity

Table 6.3 Locations and brine storage capacity of the SDDOT maintenance shops in the Aberdeen and Mitchell regions

DOT Maintenance Shop Location	Distance from Watertown WTP (miles)	Distance from Water-town DOT (miles)	Brine Making?	County	Region	Storage Capacity (gallons)
Watertown DOT	2.6	0	Yes	Codington	Aberdeen	12,000
Hayti	22.5	23.7	Storage Only	Hamlin	Aberdeen	6,000
Clear Lake	29.2	24.9	Yes	Deuel	Aberdeen	12,500
Clark	34.7	31	Storage Only	Clark	Aberdeen	7,000
Webster	43.3	54.1	Yes	Day	Aberdeen	12,500
Milbank	46.4	41.9	Yes	Grant	Aberdeen	10,000
Brookings	52.7	48	Yes	Brookings	Aberdeen	10,000
De Smet	59.6	56.1	Storage Only	Kingsbury	Aberdeen	7,000
Sisseton	60.1	58.5	Yes	Roberts	Aberdeen	5,000
Madison	68	65.7	Storage Only	Lake	Mitchell	7,000
Redfield	71.3	73.7	Yes	Spink	Aberdeen	9,000
Flandreau	72	72.4	Storage Only	Moody	Mitchell	10,000
Britton	86.4	90.7	Yes	Marshall	Aberdeen	7,500
Huron	90.7	94.4	Yes	Beadle	Aberdeen	9,000
Salem	96.9	97.5	Storage Only	McCook	Mitchell	7,000
Aberdeen	98.7	99.2	Yes	Brown	Aberdeen	13,000
Sioux Falls	110	102	Yes	Minnehaha	Mitchell	39,500
Faulkton	113.5	113	Yes	Faulk	Aberdeen	7,500
Woonsocket	115	118	Storage Only	Sandborn	Mitchell	7,000
Miller	120	117	Storage Only	Hand	Aberdeen	9,000
Lennox	120.4	118	Storage Only	Lincoln	Mitchell	15,000
Hurly	120.6	121	Storage Only	Turner	Mitchell	3,000
Ipswich	124.4	127	Yes	Edmunds	Aberdeen	7,500
Mitchell	135	131	Yes	Davison	Mitchell	24,000
Beresford	137	133	Storage Only	Lincoln	Mitchell	15,000
Menno	140	140	Storage Only	Hutchinson	Mitchell	7,000
Leola	140.6	142	Yes	McPherson	Aberdeen	7,000
Highmore	142	139	Storage Only	Hyde	Aberdeen	6,100
Plankinton	156.9	158	Storage Only	Aurora	Mitchell	7,000
Junction City	157	153	Storage Only	Union	Mitchell	20,000
Yankton	158	158	Storage Only	Yankton	Mitchell	7,000
Tyndall	176.1	174	Storage Only	Bon Homme	Mitchell	7,000
Armour	183.8	177	Storage Only	Douglas	Mitchell	7,000
Platte	200	200	Storage Only	Charles Mix	Mitchell	7,000
Chamberlain	202.2	188	Storage Only	Brule	Mitchell	7,000
Bonesteel	238.8	226	Storage Only	Gregory	Mitchell	7,000

6.5.2 Economic Benefits of MIEX® Brine Reuse

(1) SDDOT

For winter roadway maintenance, the SDDOT is responsible for producing brine which involves the purchase of both salt and municipal water. In addition to using these materials, the DOT is also responsible for the financial operations and management costs associated with their trucks that spread salt and transport brine from different locations. Reusing the MIEX® brine can reduce the DOT's salt and water costs. However, the added cost of transporting the brine to the end storage locations should be considered for the economic analysis. The SDDOT in the Aberdeen region has 3 or 4 1,800-gallon skid mounted tank trucks for transporting brine between maintenance shops. The Mitchell region has 5,000 gallon trucks available for brine transportation. The brine transportation costs are \$3/mile and \$2/mile for the 1,800-gallon and 5,000-gallon trucks, respectively (Table 6.4). These prices include labor, fuel and truck maintenance and repairs. In addition to the transportation cost, an annual rental cost of \$1,400 is needed for each 5,000-gallon truck. These values have been calculated by the South Dakota Department of Finance as an estimate of truck usage costs.

Table 6.4 SDDOT brine transportation cost in the Mitchell and Aberdeen regions

SDDOT Trucks	Truck Transportation Cost
Aberdeen Region Truck Size (gal)	1,800
Mitchell Region Truck Size (gal)	5,000
1,800-gallon Truck Cost (\$/mile)	\$3.00
5,000-gallon Truck Cost (\$/mile)	\$2.00
1,800-gallon Truck Annual Cost (\$/year)	\$0.00
5,000-gallon Truck Annual Cost (\$/year)	\$1,400

The cost savings for SDDOT by reusing MIEX® brine result from the reduced consumption of rock salt and municipal water for brine making. Table 6.5 shows materials savings for SDDOT as a result of MIEX® brine reuse. For the MIEX® brine with 6.55% salt content under normal operation conditions, the total material savings would be $3,393 per year. It was assumed that the total annual MIEX® brine production (150,000 gal) is completely reused.

Table 9.5 Cost savings for SDDOT of using the MIEX® brine

SDDOT Salt and Water Savings	
MIEX® Brine NaCl (%)	6.55%
Total MIEX® Brine Production (gal/year)	150,000
Salt Costs ($/tons)	$65
Water Costs ($/gal)	0.0036
Salt Savings ($/year)	$2,853
Water Savings ($/year)	$540
Total SDDOT Materials Savings ($/year)	$3,393

(2) Watertown Municipal Water Treatment Plant

The WMWTP is currently charged $6,000 per year for disposing 150,000 gallons of their MIEX® waste brine to the sanitary sewer. If some or all of the MIEX® brine could be reused, a portion or all of the discharge fee could be waived. The total annual savings for the WMWTP is $6,000 assuming that all of the MIEX® brine is reused. The WMWTP currently does not have brine storage tanks that can be accessed by the brine transportation trucks. Therefore, the WMWTP would need to make a capital investment to purchase and install brine storage tanks and associated piping, pumping and related hardware to store the waste brine for reuse. Considering the MIEX® brine production rate at the WMWTP and the available trucks at the SDDOT, we recommend that a minimum 5,000-gallon brine storage capacity should be provided at the WMWTP.

9.5.3 Transportation Cost Analysis of MIEX® Brine Reuse

The MIEX® brine is produced during the summer season at the WMWTP. The waste MIEX® brine needs to be transported to the SDDOT maintenance shops for brine making during the summer, and the final brine product will be stored on site and used for pre-wetting the rock salts during the winter. The existing brine making and storage facilities in the Aberdeen and Mitchell regions could be used for the MIEX® brine reuse. New facilities are not required for this reuse option. The only cost associated with MIEX® brine reuse for the SDDOT is the brine transportation between WMWTP and the SDDOT maintenance shops. The key factors that affect the economic analysis for this MIEX® reuse practice are the storage capacity and distance from the WMWTP to each SDDOT maintenance shop.

Three alternative scenarios were evaluated for the economic analysis of MIEX® brine reuse. In the first scenario, all of the MIEX® brine will be transported by SDDOT from the WMWTP to the Watertown DOT maintenance location. From there the brine is fully processed to the final 23% product, and then the SDDOT will distribute the finished brine to other locations in the Aberdeen and Mitchell regions. Priorities are given to the locations that are close to the Watertown DOT maintenance shop. In the second scenario, all of the MIEX® brine will be directly transported by SDDOT to the brine making facilities in the Aberdeen and Mitchell Regions according to each location’s storage capacity and distance to the WMWTP. In the third scenario, the MIEX® brine will only be used by the maintenance shops in the Aberdeen Region that are close to the

Watertown DOT maintenance shop to reduce the transportation cost. The MIEX® brine will be processed to 23% salt product at the Watertown DOT maintenance location and transported to nearby locations with storage only. For locations with brine making capabilities, the brine would be directly transported by the SDDOT from the WMWTP to the end maintenance location. For all three MIEX® reuse scenarios, the brine transportation costs using 1,800 gal and 5,000 gal trucks were analyzed. We also assume that the WMWTP will install a minimum storage capacity of 5,000-gallons for reusing the MIEX® brine.

MIEX Brine Reuse Scenario 1

In Scenario 1, the MIEX® brine from the WMWTP will first be transported to the Watertown DOT maintenance shop where the MIEX® brine will be used as a feed solution to produce finished brine solution. The finished brine product will be stored in the storage tank (12,000 gallons) at the Watertown DOT shop. Then, the finished brine is transported by SDDOT to others DOT maintenance locations. This process is continued until the completion of the operation of the MIEX® system at the WMWTP during the summer. Figure 6.5 shows a schematic overview of this MIEX® brine reuse scenario.

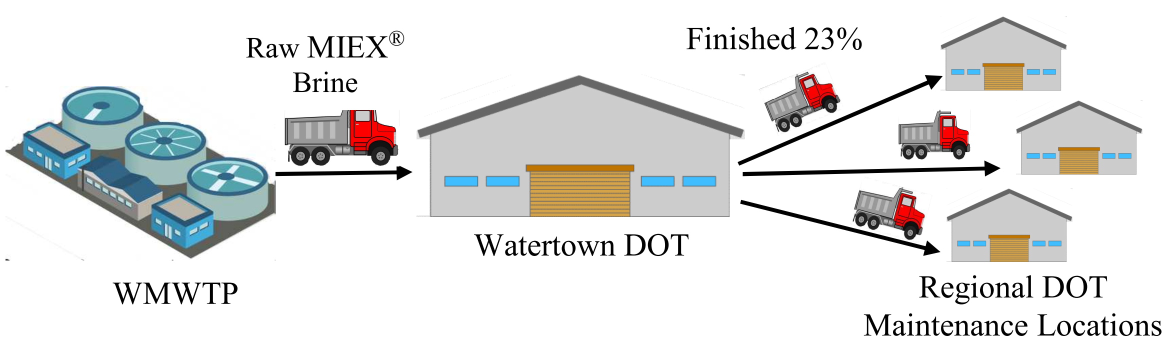

Figure 6.5 An overview of MIEX® brine reuse scenario 1

Table 6.6 presents the transportation cost analysis for the first MIEX® brine reuse scenario using an 1,800-gallon truck. The number of round trips and transported brine volume for each SDDOT location were determined based on the distance from the Watertown DOT shop and the storage capacity. The transportation cost for using the 1,800-gallon truck is $3 per mile. The resulting brine transportation cost for each location is summarized in Table 6.6. For some SDDOT locations with brine storage only, this brine reuse practice also results in some cost savings by reducing the normal brine transportation. These cost savings are shown as negative values in the cost analysis in Table 6.6. Overall, the total transportation cost for reusing 150,000 gallons of MIEX® brine by 1,800 gallon trucks in Scenario 1 was determined to be $28,315.

A more efficient transport option is to use the 5,000-gallon truck. This truck costs $2/mile. The number of round trips for each location can be substantially reduced as well. The transportation cost analysis using 5,000 gallon trucks for Scenario 1 is presented in Table 6.7. The total transportation cost for reusing 150,000 gallons of MIEX® brine was determined to be $7,103, which is significantly lower than that using the 1,800-gallon truck. During this economic analysis, a full truck load of brine was used for each trip, which was more efficient than delivering a partial load to various sites.

Table 6.6 Brine transportation costs for Scenario 1 using the 1,800-gallon truck

Maintenance Shop Location	Distance Watertown DOT (Miles)	County	Region	Storage (gal)	Trips	Brine (gal)	Cost*
WMWTP to Watertown DOT	2.6	Codington	Aberdeen	12,000	84	150,000	$1,310
Watertown	2.6	Codington	Aberdeen	12,000	7	12,000	Included Above
Hayti	23.7	Hamlin	Aberdeen	6,000	3	5,000	$427
Watertown to Hayti	23.7	Hamlin	Aberdeen	6,000	3	-	-$427
Clear Lake	24.9	Deuel	Aberdeen	12,500	7	12,500	$1,046
Clark	31	Clark	Aberdeen	7,000	4	7,000	$744
Watertown to Clark	31	Clark	Aberdeen	7,000	4	-	-$744
Milbank	41.9	Grant	Aberdeen	10,000	6	10,000	$1,508
Brookings	48	Brookings	Aberdeen	10,000	6	10,000	$1,728
Webster	54.1	Day	Aberdeen	12,500	7	12,500	$2,272
De Smet	56.1	Kingsbury	Aberdeen	7,000	4	7,000	$1,346
Huron to De Smet	33.7	Kingsbury	Aberdeen	7,000	4	-	-$809
Sisseton	58.5	Roberts	Aberdeen	5,000	3	5,000	$1,05
Madison	65.7	Lake	Mitchell	7,000	4	7,000	$1,577
Sioux Falls to Madison	49.3	Lake	Mitchell	7,000	4	-	-$1,183
Redfield	73.7	Spink	Aberdeen	9,000	5	9,000	$2,211
Flandreau	72.4	Moody	Mitchell	10,000	6	10,000	$2,606
Sioux Falls to Flandreau	44.7	Moody	Mitchell	10,000	2	-	-$179
Britton	90.7	Marshall	Aberdeen	7,500	4	7,200	$2,177
Huron	94.4	Beadle	Aberdeen	9,000	5	9,000	$2,832
Salem	97.5	McCook	Mitchell	7,000	4	7,000	$2,340
Mitchell to Salem	33.4	McCook	Mitchell	7,000	2	-	-$134
Aberdeen	99.2	Brown	Aberdeen	13,000	7	12,600	$4,166
Sioux Falls	102	Minnehaha	Mitchell	39,500	4	7,200	$2,448
Totals						**150,000**	**$28,315**

*Negative cost values are the savings from the reduction in normal brine transportation.

Table 6.7 Brine transportation costs for Scenario 1 using the 5,000-gallon truck

Maintenance Shop Location	Distance Watertown DOT (Miles)	County	Region	Storage (gal)	Trips	Brine (gal)	Cost*
WTP to Watertown DOT	2.6	Codington	Aberdeen	12,000	30	150,000	$312
Watertown	2.6	Codington	Aberdeen	12,000	3	12,000	Included above
Hayti	23.7	Hamlin	Aberdeen	6,000	1	5,000	$95
Watertown to Hayti	23.7	Hamlin	Aberdeen	6,000	1	-	-$95
Clear Lake	24.9	Deuel	Aberdeen	12,500	3	12,500	$299
Clark	31	Clark	Aberdeen	7,000	2	7,000	$248
Watertown to Clark	31	Clark	Aberdeen	7,000	2	-	-$248
Milbank	41.9	Grant	Aberdeen	10,000	2	10,000	$335
Brookings	48	Brookings	Aberdeen	10,000	2	10,000	$384
Webster	54.1	Day	Aberdeen	12,500	3	12,500	$649
De Smet	56.1	Kingsbury	Aberdeen	7,000	1	5,000	$224
Huron to De Smet	33.7	Kingsbury	Aberdeen	7,000	1	-	-$135
Sisseton	58.5	Roberts	Aberdeen	5,000	1	5,000	$234
Madison	65.7	Lake	Mitchell	7,000	1	5,000	$263
Sioux Falls to Madison	49.3	Lake	Mitchell	7,000	1	-	-$197
Redfield	73.7	Spink	Aberdeen	9,000	1	5,000	$295
Flandreau	72.4	Moody	Mitchell	10,000	2	10,000	$579
Sioux Falls to Flandreau	44.7	Moody	Mitchell	10,000	2	-	-$358
Britton	90.7	Marshall	Aberdeen	7,500	1	5,000	$363
Huron	94.4	Beadle	Aberdeen	9,000	2	9,000	$755
Salem	97.5	McCook	Mitchell	7,000	1	5,000	$399
Mitchell to Salem	33.4	McCook	Mitchell	7,000	1	-	-$134
Aberdeen	99.2	Brown	Aberdeen	13,000	2	10,000	$794
Sioux Falls	102	Minnehaha	Mitchell	39,500	5	22,000	$2,040
Totals						**150,000**	**$7,092**

*Negative cost values are the savings from the reduction in normal brine transportation.

MIEX® Brine Reuse Scenario 2

In the second scenario, the MIEX® brine is transported by SDDOT directly to the DOT maintenance locations that have brine making and onsite storage capability. When the MIEX® brine is delivered, the finished 23% product is generated and stored on site. This process also occurs during the summer when the MIEX® system is in operation. Figure 6.6 shows a schematic overview of the second MIEX® brine reuse scenario.

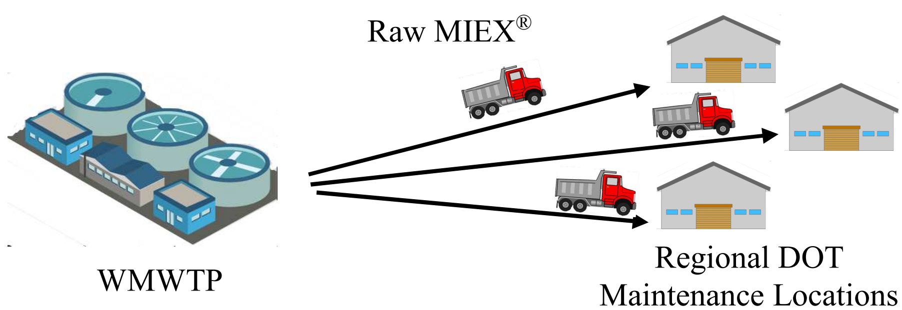

Figure 6.6 An overview of MIEX® brine reuse scenario 2

The transportation cost analysis was performed for the MIEX® brine reuse scenario 2 using the approach similar to Scenario 1. Tables 6.8 and 6.9 present brine transportation costs for Scenario 2 using the 1,800-gallon truck and the 5,000-gallon truck, respectively. The resulting total costs for reusing 150,000 gallons of MIEX® brine are $37,362 and $9,677 for using the 1,800-gallon truck and the 5,000-gallon truck. Similar to Scenario 1 the use of the 5,000-gallon truck is much more efficient. Scenario 2 costs more than Scenario 1 because the MIEX® brine has to be transported to the maintenance locations that have brine making capability, which requires higher total mileage, and the overall strength is weaker than a traditional brine.

Table 6.8 Brine transportation costs for Scenario 2 using the 1,800-gallon truck

Maintenance Shop Location	Distance Watertown WTP (Miles)	County	Region	Storage (gal)	Truck Trips	Brine (gal)	Cost
Watertown DOT	2.6	Codington	Aberdeen	12,000	7	12,000	$109
Clear Lake	29.2	Deuel	Aberdeen	12,500	7	12,500	$1,226
Webster	43.3	Day	Aberdeen	12,500	7	12,500	$1,819
Milbank	46.4	Grant	Aberdeen	10,000	6	10,000	$1,670
Brookings	52.7	Brookings	Aberdeen	10,000	6	10,000	$1,897
Sisseton	60.1	Roberts	Aberdeen	5,000	3	5,000	$1,082
Redfield	71.3	Spink	Aberdeen	9,000	5	9,000	$2,139
Britton	86.4	Marshall	Aberdeen	7,500	4	7,200	$2,074
Huron	90.7	Beadle	Aberdeen	9,000	5	9,000	$2,721
Aberdeen	98.7	Brown	Aberdeen	13,000	7	12,600	$4,145
Sioux Falls	110	Minnehaha	Mitchell	39,500	28	50,200	$18,480
Total						**150,000**	**$37,362**

Table 6.9 Brine transportation costs for Scenario 2 using the 5,000-gallon truck

Maintenance Shop Location	Distance Watertown WTP (Miles)	County	Region	Storage (gal)	Truck Trips	Brine (gal)	Cost
Watertown DOT	2.6	Codington	Aberdeen	12,000	3	12,000	$31
Clear Lake	29.2	Deuel	Aberdeen	12,500	3	12,500	$350
Webster	43.3	Day	Aberdeen	12,500	3	12,500	$520
Milbank	46.4	Grant	Aberdeen	10,000	2	10,000	$371
Brookings	52.7	Brookings	Aberdeen	10,000	2	10,000	$422
Sisseton	60.1	Roberts	Aberdeen	5,000	1	5,000	$240
Redfield	71.3	Spink	Aberdeen	9,000	2	9,000	$570
Britton	86.4	Marshall	Aberdeen	7,500	1	5,000	$346
Huron	90.7	Beadle	Aberdeen	9,000	1	5,000	$363
Aberdeen	98.7	Brown	Aberdeen	13,000	3	13,000	$1,184
Sioux Falls	110	Minnehaha	Mitchell	39,500	12	56,000	$5,280
Total						**150,000**	**$9,677**

$MIEX^{®}$ Brine Reuse Scenario 3

The cost analysis for Scenarios 1 and 2 suggests that the transportation cost is the limiting factor for $MIEX^{®}$ brine reuse. The total transportation cost for 150,000 gallon $MIEX^{®}$ brine far exceeds the materials savings for SDDOT regardless of the truck sizes. In the third scenario, we propose a limited $MIEX^{®}$ brine reuse in the Aberdeen region only. In this scenario, the $MIEX^{®}$ brine from the WMWTP will be transported to the Watertown DOT maintenance shop to produce finished brine solution. The finished brine product will be stored in the storage tank at the Watertown DOT maintenance shop. Then, the finished brine is transported by SDDOT to the nearby SDDOT maintenance locations such as Hayti, Clear Lake, Clark, Milbank, Brookings, and Webster. Figure 6.7 shows a schematic overview of the third $MIEX^{®}$ brine reuse scenario.

Figure 6.7 An overview of $MIEX^{®}$ brine reuse scenario 3

In Scenario 3, the finished brine product made from the $MIEX^{®}$ brine will first fill the storage tank (12,000 gallons) at the Watertown DOT maintenance shop. Additional production of the finished brine product will be transported to nearby SDDOT maintenance locations. A 6.55% salt strength was used for the analysis of material savings in Scenario 3. Figure 6.8 shows the material savings and brine transportation cost using the 1,800-gallon truck as a function of the volume of brine that is transported. The breakeven point for transporting the brine using the 1,800-gallon truck only allows a total of approximately 23,000 gallons of brine to be transported to the Watertown and Hayti and Clear Lake maintenance locations. Note that there is no increase in cost for transporting the brine from the Watertown DOT shop to Hayti (Hamlin County) or Clark (Clark County) since these counties do not make their own brine. Brine is already delivered to these shops, so the cost does not increase, which is represented by the longer flat portion of the graph in both Figures 6.8 and 6.9. The shorter flat portions indicate the brine being transported and net costs are shown by the jumps in the graphs. Figure 6.9 shows the material savings and brine transportation cost using the 5,000-gallon truck as a function of the volume of brine that is transported. When the 5,000-gallon truck is available, approximately 70,000 gallons of brine may be transported before the breakeven point, thus satisfying all of the maintenance locations storage capacities for Watertown, Hayti, Clear Lake, Clark, Milbank, Brookings and most of Webster.

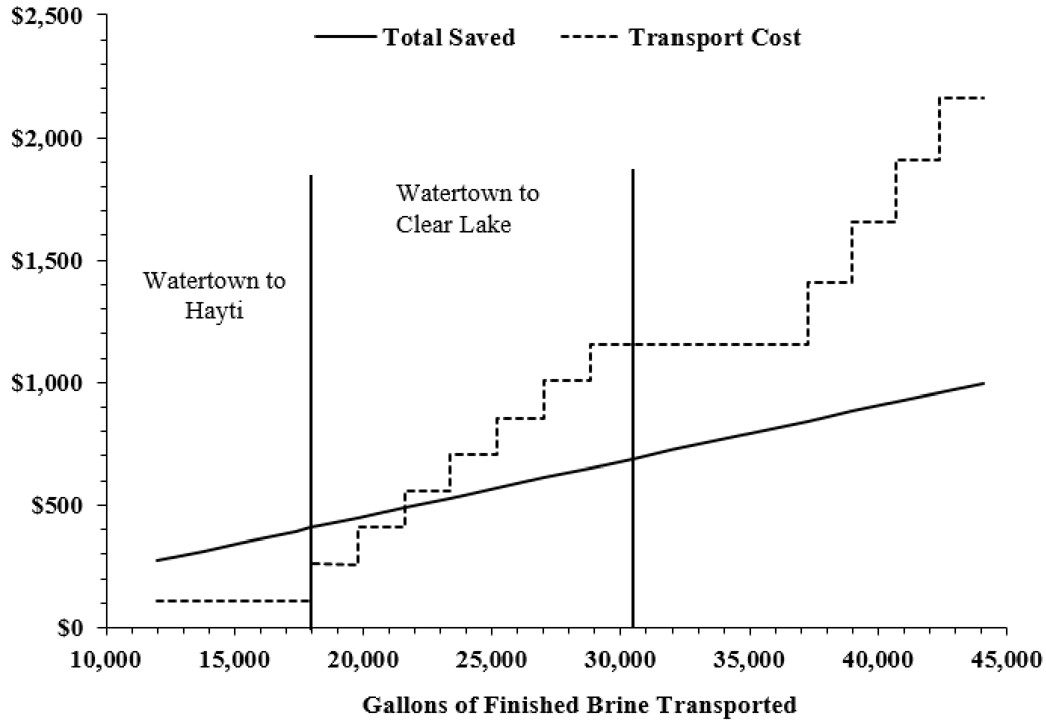

Figure 6.8 Transportation cost analysis for MIEX® brine reuse in Aberdeen region using 1,800 gallon trucks.

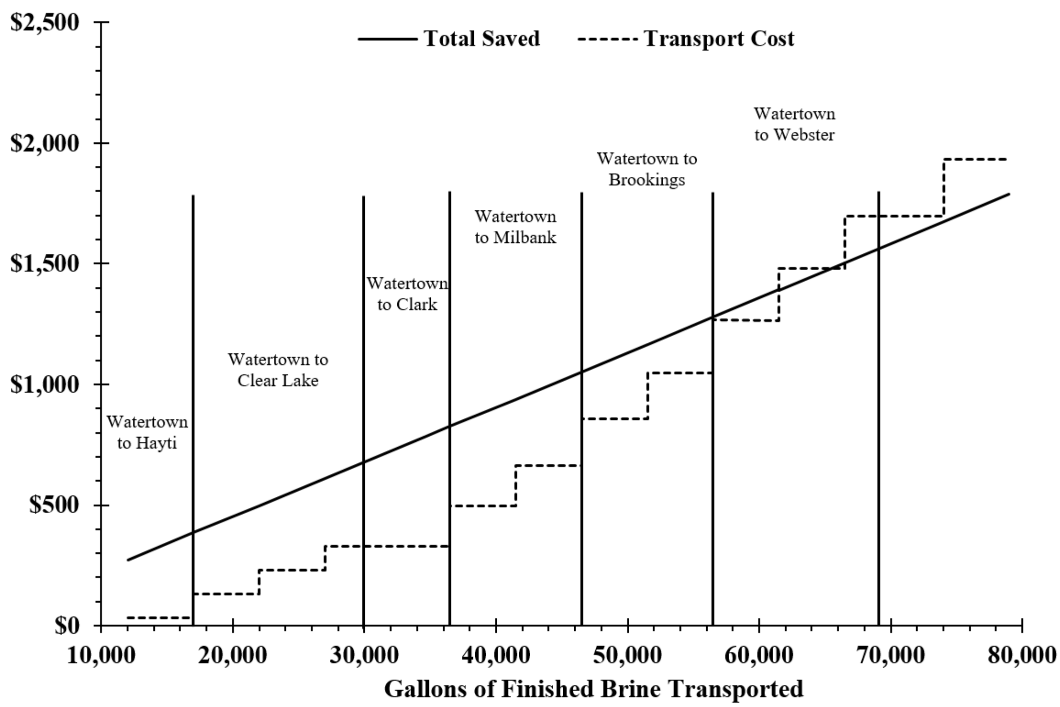

Figure 6.9 Transportation cost analysis for MIEX® brine reuse in Aberdeen region using 5,000 gallon trucks.

6.5.4 Summary of the Economic Analysis for MIEX® Brine Reuse

Table 6.10 presents a summary of the economic analysis for the three alternative MIEX® brine reuse scenarios. This economic analysis is based on several assumptions. The WMWTP will install a storage tank with a minimum storage capacity of 5,000 gallons and the installed tank can be accessed by the SDDOT trucks for brine collection. The annual production of the MIEX® brine is 150,000 gallons and the normal salt strength of the MIEX® brine is 6.55%. The raw material costs for brine making at SDDOT facilities include $65/ton for rock salts and $0.0036/gallon for municipal water. The brine transportation costs are $3/mile for the 1,800-gallon truck and $2/mile for the 5,000-gallon truck. The total disposal cost charged by the Watertown Municipal Wastewater Treatment Plant are $6,000 per 150,000 gallons of brine discharged. In addition, the added capital cost to add a 5,000 gallon tank was estimated at $15,000 by the WMWTP. The economic analysis was conducted for three reuse scenarios based on the above assumptions.

In Scenario 1, the total MIEX® brine from the WMWTP will first be transported to the Watertown DOT maintenance shop to produce finished brine solution. The finished brine will be transported by SDDOT to others DOT maintenance locations. In Scenario 2, the total MIEX® brine will be transported by SDDOT directly to the DOT maintenance locations that have brine making and onsite storage capability. In Scenario 3, a portion of the produced MIEX® brine will be transported to the Watertown DOT maintenance shop to produce finished brine solution. The finished brine is transported by SDDOT to the nearby maintenance locations in Aberdeen region. The results of the economic analysis suggest that MIEX® brine reuse Scenarios 1 and 2 will results in net losses from $3,710 to $33,969 for SDDOT depending on the brine delivery truck size. Complete reuse of the total 150,000 gallon MIEX® brine is not economically feasible for the SDDOT due to the high transportation cost. However, it is economically feasible to reuse a portion of the MIEX® brine in Aberdeen region. When the 1,800-gallon truck is used, approximately 23,000 gallons of the MIEX® brine can be reused by SDDOT at Watertown and nearby SDDOT facilities. The MIEX® brine reuse volume can be increased to approximately 70,000 gallons when the 5,000-gallon truck is used. The limited MIEX® brine reuse option will also result in cost savings to the WMWTP due to the reduced waste brine discharge to the sewer system. It should be noted that this economic analysis was based on a MIEX® brine salt strength of 6.55%. The MIEX® brine salt strength may vary depending on the operating conditions of the system. The performance of the MIEX reuse practice can be affected by the variation of the MIEX® brine strength.

Table 6.10 Summary of the economic analysis for MIEX® brine reuse

MIEX® Reuse Scenario		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Truck (gallons)		1,800	5,000	1,800	5,000	1,800	5,000
MIEX® Brine (gallons/year)		150,000	150,000	150,000	150,000	19,800	66,500
SDDOT	Savings ($/year)	$3,393	$3,393	$3,393	$3,393	$500	$1,500
	Cost ($/year)	$28,315	$7,092	$37,362	$9,677	$500	$1,500
	Net Savings ($/year)	-24,924	-3,699	-33,969	-6,284	0	0
Water-town	Capital Investment (5,000 gal tank)	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
	Savings ($/year)	$6,000	$6,000	$6,000	$6,000	Vary	Vary

CHAPTER 7: CONCLUSION

South Dakota has a variety of industries throughout the state that produce aqueous waste products including food and beverage processing, ethanol production, and oil and gas extraction activities. In addition, municipal drinking water and wastewater treatment processes also generate waste streams that need proper treatment and disposal. Many of the aqueous waste streams available in South Dakota can be potentially used in transportation-related applications such as pavement anti-icing and deicing, dust control on unpaved roads and others.

Beneficial reuse of waste streams in transportation applications requires a comprehensive evaluation of the effectiveness, safety, economics, environmental benefits and risks, and local, state, and federal regulations. Guidance was developed to evaluate and regulate waste streams for potential reuse in transportation applications in South Dakota. The specific guidelines contained definitions, approval procedure, operating requirements, and reporting requirements. These guidelines can be used to manage the beneficial reuse of waste streams for transportation applications and minimize their environmental impact in South Dakota.

The MIEX® system at the WMWTP produces approximately 150,000 gallons of waste brine during the summer season. The salt concentration of the MIEX® brine under normal operating conditions was 6.55%. The MIEX® brine can be used as a feed solution for brine making at the SDDOT maintenance shops. The results of the economic analysis suggest that complete reuse of the total 150,000 gallon MIEX® brine is not economically feasible due to the high transportation cost. However, it is economically feasible to reuse a portion of the MIEX® brine in Aberdeen region. The 5,000-gallon truck is a better option than the 1,800-gallon tuck for brine reuse because of the reduced transportation cost. The WMWTP will also need to install a brine storage tank with a minimum capacity of 5,000-gallon capacity for the MIEX® brine reuse.

The water quality analysis showed that the MIEX® brine had low levels of the nutrients and most of the heavy metals. Elevated levels of sulfate, molybdenum, selenium, and strontium were observed. The MIEX® brine is currently treated at the Watertown wastewater treatment plant before final discharge to natural water systems. The recommended MIEX® brine reuse option is to pre-wet the rock salts during winter road maintenance. The source, generation, quality, and recommended reuse method of the MIEX® brine will likely result in low environmental risks during reuse at the SDDOT.

REFERENCES

Akin, M. M., Huan, J. M., Shi, X., Veneziano, D., Williams, D., (2013). "Snow Removal at Extreme Temperatures." *Final Rep. 99085/CR11-04,* Montana State University.

Addo, J. Q., Sanders, T. G., and Chenard, M., (2004). "Road Dust Suppression: Effect on Maintenance Stability, Safety and the Environment." *Final Rep. MPC04-156,* Mountain-Plains Consortium, Colorado State University.

Bothast, R. J., and Schlicher, M.A., (2004). "Biotechnological Process for Conversion of Corn into Ethanol." *Appl Microbiol Biotechnol*. 67: 19-25.

Brito, A. G., Joao P., Oliveira, J. M., Oliveira, J. A., Costa, C., Nogueira, R., and Rodrigues, R., "Brewery and Winery Wastewater Treatment: Some Focal Points of Design and Operation." University of Minho, School of Engineering. Braga, Portugal.

Church, C. D., Wilkin, R. T., Alpers, C. N., Rye, R. O., and McCleskey, R. B., "Microbial sulfate reduction and metal attenuation in pH 4 acid mine water." BioMed Central, 2007.

Clark, C. E., and Veil, J. A., (2009). "Produced Water Volumes and Management Practices in the United States." *Final Rep. ANL/EVS/R-09/1.* Argonne National Laboratory. U.S. Department of Energy, Office of Fossil Energy.

Fillaudeau, L., Blanpain-Avet, P., and Daufin G., (2015). "Water, wastewater and waste management in brewing industries." *Journal of Cleaner Production* 14: 463-471.

Fitch, M. G., Smith, J. A., and Clarens, A. F., (2013). "Environmental Life-Cycle Assessment of Winter Maintenance Treatments for Roadways." *Journal of Transportation Engineering – ASCE*. 139, 138-146.

Goetsch, P.A., and Palmer, C.G., (1997). "Salinity Tolerances of Selected Macroinvertebrates of the Sabie River, Kruger National Park, South Africa." Arch. Environ. Contam. Toxicol. 32:32–41.

Guerra, K., Dahm, K., and Dundorf, S., (2011). "Oil and Gas Produced Water Management and Beneficial Use in the Western United States" *Final Rep. S&T Report No. 157*. U.S. Department of the Interior, Bureau of Reclamation.

Han, C., (1992). “Dust Control on Unpaved Roads. Minnesota Local Road Research Board.” Final Report MN/RC – 92/07. Braun Intertec Pavement, Inc.

Hedges, C. J., (2007). “Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts.” *NCHRP Final Rep. 577*. National Cooperative Highway Research Program.

Iowa Department of Transportation, (2004). “Reuse of Lime Sludge from Water Softening and Coal Combustion Byproducts.” *Final Report for Project TR-459.*

Iowa DNR, (2009). *Water Quality Standards Review: Chloride, Sulfate and Total Dissolved Solids*.

Iowa DOT, (2015). “Brine.” Retrieved from: http://www.iowadot.gov/maintenance/pdf/brine.pdf

Irwin, K., Hall, F., Kemner, W., Beighley, E., and Husby, P., (2008). “Testing of Dust Suppressants for Water Quality Impacts.” *Final Rep. – Sep 2008*. U.S. Environmental Protection Agency

Jahan, K., and Mehta, Y., (2012). “Potential for Natural Brine for Anti-Icing and De-Icing.” *Final Rep. C-06-07.* New York State Department of Transportation.

Janke, G.A. and Johnson Jr., W.D., 1997. US Patent No. 5,635,101.

Janke, G.A. and Johnson Jr., W.D., 1998. US Patent No. 5,709,812.

Johnson, R., 2011. Cheese brine helps de-ice Polk County roads. Agri-View, February 10.

Kell, S., Hodges, D., and Tomastik, T., (2004). “Spreading Oil-Field Brine For Dust and Ice Control: A Guidance for Local Authorities.” *Project No. (h) D-19*. Ohio Department of Natural Resources.

Kharshan, M., Gillette, K., Furman, A., Kean, R., and Austin, L., (2012). “Novel Corrosion Inhibitors Derived from Agricultural By-products: Potential Applications in Water Treatment.” *Final Report C2012-0001154.* National Association of Corrosion Engineers International.

Meays, C., and Nordin, R., (2013). “Ambient Water Quality Guidelines For Sulphate.” Ministry of Environment of British Columbia.

Michigan Department of Environmental Quality, (2015). “Guidelines for Selecting Dust Suppressants to Control Dust and Prevent Soil Erosion.”

Minnesota DOT, (2012). “Minnesota Snow and Ice Control: Field Handbook for Snowplow Operators Second Revision.” *Manual Number 2005-01.* Minnesota Local Road Research Board.

Mussatto, S., Dragone, G., and Roberto, I., (2006). “Brewers' Spent Grain: Generation, Characteristics and Potential Applications.” *Journal of Cereal Science* 43: 1-14.

Mustafa, A.F., McKinnon, J.J., and Christensen, D.A., (N.D.) “The Nutritive Value of Thin Stillage and Wet Distillers’ Grains for Ruminants: A Review.” University of Saskatchewan.

Neff, J.M., Lee, K., and Deblois, E., (2010). “Produced Water: Overview of Composition, Fates, and Effects.”

Nevada Department of Conservation & Natural Resources Division of Environmental Protection, (2001). “Interim Guidelines on Dust Palliative Use in Clark County, Nevada.”

Nixon, W., A., Kochumman, G., Qiu, J., Xiong, Jing., “Evaluation of Using Non-Corrosive Deicing Materials and Corrosion Reducing Treatments for Deicing Salts.” *Final Report, TR 471.* Iowa Highway Research Board.

Norby, E., (2010). F & A Dairy Salt Brine Report. Polk County Highway Department.

Orica, Inc., (2012). MIEX® Process Description. IXOM. http://www.miexresin.com/index.asp?page=7.

Pennsylvania Department of Environmental Protection, (2015). “Road spreading of Brine for Dust Control and Road Stabilization.”

Piechota, T., Van Ee, J., Batista, J., Stave, K., and James, D., (2004). “Potential Environmental Impacts of Dust Suppressants: ‘Avoiding Another Times Beach.’” *EPA Report 600R-04031.* U.S. Environmental Protection Agency.

Prentice, G., (2014). “Road Deicers of the Future: Made from Beets, Tomatoes, and Barley?” *Boise Weekly.* http://www.boiseweekly.com/CityDesk/archives/2014/12/29/road-deicers-of-the-future-made-from-beets-tomatoes-and-barley/.

Rodenberg, J., (1998). “Waste Management Issues for Dairy Processors.” State of Wisconsin - Department of Natural Resources.

Salminen, J.M., Nysten, T.H., and Tuominen, S.M., (2011). “Review of Approaches to Reducing Adverse Impacts of Road Deicing on Ground Water in Finland.” *Water Quality Research Journal of Canada*, 46.2-2001.

Shi, X., Fay, L., Gallaway, C., Volkening, K., Peterson, M., M., Pan, T., Creighton, A., Lawlor, C., Mumma, S., Liu, Y., Nguyen, T., A., (2009). “Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers – Phase .” *Final Report, CDOT-2009-1.* Colorado Department of Transportation.

Skorseth, K., and Selim, A.A., (2000). “Gravel Roads: Maintenance and Design Manual. US Department of Transportation: Federal Highway Administration.” Pages 51-56. *Gravel Roads: Maintenance and Design Manual.* South Dakota Local Transportation Assistance Program.

Stempvoort, D., Armstrong, J., and Mayer, B., (n.d.) “Bacterial Sulfate Reduction in Biodegradation of Hydrocarbons in Low-Temperature, High-Sulfate Groundwater, Western Canada.” National Water Research Institute, Komex International Ltd., Department of Geology & Geophysics & Astronomy University of Calgary.

Travnik, W., A., (1991). “State of Art Dust Suppressants/Soil Stabilizers.” In Proceedings of the 42nd Annual Road Builders Clinic, March 5-7, Coeur D’Alene, Idaho.

USDA, (2010). “Corn Steep Liquor” *Technical Evaluation Report*. United States Department of Agriculture.

Van Leeuwen, H., White, D., Baker, R., and Christopher Jones., (2011). “Reuse of Lime Sludge from Water Softening and Coal Combustion Byproducts.” *Final Rep. TR-459*. Iowa State University.

Walworth County Today. (2014). “Kikkoman product to help in de-icing area roads this winter.”http://www.gazettextra.com/20141030/kikkoman_product_to_help_in_de_icing_area_roads_this_winter.

Wisconsin Transportation Bulletin, (2007). “Dust Control on Unpaved Roads.” http://epdfiles.engr.wisc.edu/pdf_web_files/tic/bulletins/Bltn_013_DustControl.pdf

World Health Organization, (2004). “Sulfate in Drinking Water.”

World Health Organization, (2011). “Molybdenum in Drinking Water.”

Withycombe, E., Dulla, R., (2006). “Alaska Rural Dust Control Alternatives.” *Final Rep. SR2006-03-03,* Sierra Research, Inc. Sacramento, CA.

Wood, C., Rosentrater, K., Muthukumarappan, K., and Gu, Z., (2012). “Quantification of Physical and Chemical Properties, and Identification of Potentially Valuable Components from Fuel Ethanol Process Streams.” *Cereal Chemistry* 90, 1: 70-79.

Yan, W., Hoekman, K., S., (2012). “Dust Suppression with Glycerin from Biodiesel Production: A Review.” *Journal of Environmental Protection* 3, 218-224.

Yang, S., (1989). “Pollution Prevention and Waste Minimization in the Dairy Industry Through Novel Uses of Whey Permeate.” Department of Chemical Engineering: The Ohio State University.