PROJECT REPORT RPN

A review of recent research and operational experience in the use of brine and other liquid de-icers

J Peeling and M Evans
Report details

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1 Introduction

As part of the 2016/17 program of Severe Weather research and development, Highways England is looking to investigate two key questions:

- Is there a case for implementing more brine only treatments on the trunk road network?
- Should the provision for alternative de-icers be maintained in the Severe Weather Plan treatment matrix?

As part of previous work for Highways England, Transport Scotland and the NWSRG, TRL has carried out reviews of the use of brine and other alternative liquid de-icers by road authorities internationally.

A review was carried out to update the knowledge in this area and to ensure all recent work is considered.

2 Review of international practice

2.1 Type of de-icers used

Table 1 presents a summary of the international use of liquid de-icers (including as the liquid component of pre-wetted salt or as liquid only spreading) including details of concentrations and spread rates used. More details on de-icers used in the US are provided in Appendix A.

The most common methods for spreading de-icers on the roads are as follows:

- Dry salt – Sodium Chloride (NaCl)
- Pre-wetted salt – Salt and a range of pre-wetting additives used such as Sodium Chloride (NaCl) brine, Calcium Chloride (CaCl₂), Magnesium Chloride (MgCl₂) and agricultural by-products (ABPs)
- Liquid only spreading – NaCl brine and other additives such as MgCl₂, CaCl₂ or ABPs

Most countries use a combination of the three methods depending on the prevailing weather conditions.

The use of dry salt only is being phased out in countries such as Austria, Denmark, Finland, Sweden and New Zealand due to environmental concerns. For example in Finland, areas of groundwater are vulnerable to high concentrations of salt and incentives are used to restrict the amount of salt spread on the roads (Finish Transport Agency, 2015). Alternative treatments, with a reduced impact on the environment, have included the use of Potassium Carbonate in Austria, formates in Finland, and acetates such as Calcium Magnesium Acetate in New Zealand.

In Sweden, the consumption of dry salt has generally been on a downward trend since the 2003/2004 season (see Figure 1) while over the same time period, the use of brine has generally been increasing (see Figure 2) (Trafikverket, 2014).
Figure 1 – Salt consumption on A-roads in Sweden (Graph from Trafikverket, 2014)

Figure 2 – Salt consumption, total brine and brine by percentage in Sweden (Graph from Trafikverket, 2014)
Many countries are now equipped for spreading brine on the roads, which is becoming more prevalent in countries such as the US and France. Various studies, including by the Michigan Department of Transportation (Clear Roads, 2015) found that the spreading of pre-wetted salt with liquid brine was more likely to stay on the road surface, thus providing substantial savings in salt application rates (World Road Association, 2014; Clear Roads, 2015).

CaCl₂ and to a lesser extent MgCl₂ is used as a liquid for pre-wetting salt in many countries. This is often in extreme cold temperatures; for example, in Slovenia, pre-wetted salt with MgCl₂ solution is used below -8°C and CaCl₂ solution is used below -18°C (CEDR, 2015). In other countries such as Estonia and Finland, it is used in small amounts for the moistening of brine or to treat black ice (World Road Association, 2014). The use of CaCl₂ and MgCl₂ is more common in the US; for example, Jahan et al. (2012) conducted a survey of 15 states which found that 58% used MgCl₂ and 46% used CaCl₂.

ABPs are increasingly being selected for de-icer operations, often produced through the fermentation and processing of beet juice, molasses, corn and other agricultural products (Muthumani et al., 2015). ABPs can be used as additives or blended with other more common de-icers such as salt or brine; for example, in the survey of US states conducted by Jahan et al. (2012), half of the states were using ABPs.

2.2 Spreading considerations

In the USA, operational guidance is to spread brine in conditions such that the brine will dry on the road surface. For example, Nixon and Devries have produced an Anti-icing Application Decision Flowchart for use of brine or brine blends. The guidance states 3 major considerations for liquid treatments:

- whether the event will begin as rain
- minimum pavement temperature at which to apply and
- moisture in the air and on the roadway.

Conditions where brine is suitable for use are stated to be under the following conditions:

- Pavement temperatures greater than 15°F/-9.4°C
- Dew point at least 3 degrees below the air temperature
- Humidity less than 70%
- Dry pavement surface
- Wind less than 15mph

It is stated by Nixon and Devries that for a liquid spreading program to be successful an agency must follow very specific policies and have knowledge of the current weather conditions including pavement temperature, dew points, wind speeds and general road conditions.

Other key documents providing guidelines for winter maintenance in the USA include the FHWA ‘Manual of Practice for an Effective Anti-icing Program’. The guidance is to spread liquids when temperatures are greater than -5°C – below this temperature it is stated that
liquids can be used at higher spread rates but the cost effectiveness will need to be assessed on a case by case basis.

Another important guidance document in the USA is NCHRP 526 ‘Snow and Ice Control: Guidelines for materials and methods’. It is recommended in this guidance that liquid only precautionary treatments should not be used when temperatures will fall below 20°F/-6.7°C. Guidelines are provided for making treatment decisions based on the pavement temperature and dilution potential in the presence of precipitation.

Spread rates for several countries are documented in World Road Association (2014) with rates reported between 5 and 40g/m² with higher spread rates for extreme cold temperatures and in wet conditions. Average spread rates of about 15 g/m² were reported in Belgium, France, the Netherlands, Switzerland and France for pre-wetted salt with increased dosages depending on temperature, moisture and locality; for example in Belgium, localised maximums of up to 40g/m² have been reported. In Estonia, much higher spread rates were reported with up to 60g/m² after snow removal and up to 70g/m² after wet snow removal at temperatures of -7°C.

Variance in spread rates for NaCl brine were noted; for example in Finland, spread rates of up to 40g/m² for saline solutions were reported, while in Switzerland and the US (Arizona Department of Transportation, 2014), much smaller amounts were used; for example in Switzerland, average spread rates of NaCl brine are between 5 and 10 g/m².

2.3 Equipment and infrastructure

Best practices for storing salt are commonly on an impervious surface and covered in a facility such as a storehouse or a barn. Any run-off should be contained to reduce the impact on the surrounding environment (Clear Roads, 2015). Salt can also be stored in silos which allows for the quick loading of spreaders such as in Switzerland (World Road Association, 2014).

Liquid de-icers must be stored appropriately in storage tanks that have the necessary longevity (for at least a couple of years) and be made of resistant materials to maintain their condition. It is also important to schedule maintenance, ensure the condition of the storage tank and prevent any spillage/leakage into the surrounding the environment (Evans et al., 2011; Kasich and Taylor, 2013).

The use of portable tanks or trailers can be used to store liquid de-icers such as MgCl₂ during the winter. For example, flexible pillow tanks, which can be folded up when not in use to reduce space, are made of robust materials and can typically hold up to 75,000 litres (Portable Tanks, n.d.).

Storing more than one type of material in the same facility will likely improve efficiency; for example, a facility in Indiana, USA accommodates for brine production and liquid loading of trucks all in the same facility (see Figure 3) (Clear Roads, 2015).
Figure 3 – Multi-purpose facility in Indiana, USA (Photo from Clear Roads, 2015)
Table 1 – International examples of de-icer use and spread rates

<table>
<thead>
<tr>
<th>Country</th>
<th>De-icer use and concentrations</th>
<th>Spread rates and spreading guidelines</th>
<th>Document links</th>
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</thead>
<tbody>
<tr>
<td>Austria</td>
<td>NaCl had previously been favoured but more recently the use of chlorides has been reduced to avoid environmental impacts. K₂CO₃ has been used instead of NaCl in Vienna, as well as the use of brine.</td>
<td>Types of spreading include:</td>
<td>Hoffman et al. (2012) World Road Association (2014)</td>
</tr>
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</table>
| Belgium          | NaCl and CaCl₂ used with the latter along regional networks. Brine is also spread with 80% dry salt and 20% pre-concentrated brine (with 22% of NaCl).                                                                                                                                         | Anti-icing spreading – General spreading of pre-wetted salt on the network of 7-15 g/m²  
Curative spreading – Spreading of de-icers of 20 to 25 g/m² (localised rates of up to 40 g/m²)  
Spreaders must be equipped for the spreading of brine in Belgium and have a system to accurately adjust spread width and rate.                                                                                           | World Road Association (2014)                                                                             |
<p>| Czech Republic   | A mixture of NaCl, CaCl₂ and brine are used. Salt storehouses for NaCl can hold 2,000-3,500 tonnes for use over an entire year.                                                                                                                                                                         |                                                                                                                                                                                                                                                                    | Marius Pedersen (n.d.) World Road Association (2014)                                                   |
| Denmark          | Dry salt, pre-wetted salt, brine or a combination is used depending on the weather conditions. Recent research shows potential in salt reduction with the use of brine instead of pre-wetted salt in situations of black ice.                                             | 210 spreaders used – mostly pre-wet spreaders but a couple of combination and liquid spreaders are used (CEDR, 2015)                                                                                                                                               | World Road Association (2014) CEDR (2015)                                                               |</p>
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<thead>
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<tr>
<td>Estonia</td>
<td>NaCl is used for de-icing because of price and ease of use. CaCl₂ is used for moistening of brine</td>
<td>Spread rates of up to 60g/m² and 70g/m² after snow removal and after wet snow removal conditions respectively for temperatures below -7°C (see Appendix B).</td>
<td>World Road Association (2014)</td>
</tr>
</tbody>
</table>
| Finland   | Use of CaCl₂ allowed in small amounts for moistening/black ice, but pre-wetted salt and brine (in the amount of 25-30% by weight of salt) generally used. Damage to groundwater is pertinent issue in Finland; the use of dry salt is therefore restricted and formates are preferred. In order to restrict use, the Finnish Transport Agency applies restrictions on groundwater areas. | Spread rates between 5 and 20 g/m² for pre-wetted salt based on wetness of road condition. Spread rates of between 10 and 40g/m² for saline solutions based on wetness of road condition (see Appendix B). | World Road Association (2014)  
                                              |                                                                                           | Pukhlov (2014)  
<pre><code>                                          | Finnish Transport Agency (2015) |
</code></pre>
<p>| France    | Removable spreaders equipped for wet salt (brine and pellet salt) most of the time. In 99% of cases, NaCl or NaCl brine are used and in exceptional situations (e.g. cold temperatures and freezing rain), solid NaCl and CaCl₂ brine is used. The proportion of brine can be set between 15 and 30%. | For preventive applications, average spread rates are 15g/m². For curative applications, average spread rates are 25 to 30g/m². Most spreading in France is with pre-wetted salt and ratios between dry salt and brine can be altered on the spreaders. Automatic brine spraying is used on short motorway segments. | World Road Association (2014)         |
| Germany   | Pre-wetted salt with 30% brine is common practice in Germany. In recent years, liquid spraying of salt brine has been used based on intensive research and practical experiences. |                                                                                                       | World Road Association (2014)         |</p>
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<tr>
<th>Country</th>
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<tr>
<td>Lithuania</td>
<td>Dry NaCl, pre-wetted NaCl and pre-wetted NaCl with CaCl₂ solution used. When the temperature falls below -8°C, roads are spread with NaCl and CaCl₂ in the proportion of 88:12.</td>
<td>Spread rates vary between 7 and 20g/m² depending on road condition with higher spread rates for icing treatments, glazed frost and snow after removal (see Appendix B).</td>
<td>World Road Association (2014) Ratkevičius et al. (2014)</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Salt is pre-wetted with either NaCl or CaCl₂ solution. This is spread at a concentration of 16% CaCl₂ or 20% NaCl in the ratio of 2.5:1 dry salt:brine. The wet component is often produced from NaCl (dry) in salt barns. When road slipperiness occurs, brine is sprayed. Several bridges are supplied with a fixed anti-icing brine spraying system linked to a road weather information system.</td>
<td></td>
<td>World Road Association (2014) Jahan et al. (2012)</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Salt hasn’t been used since the 1980’s due to environmental/public concern with only grit now used for ice conditions. Calcium magnesium acetate (CMA) has been used since the mid-1990’s. Extensive monitoring of its application has found no harmful effects.</td>
<td>Pre-treatment applications rates of CMA range from 7.55mg/m² up to 30mg/m². Abrasives/grit are used as the main treatment for minor roads, either by itself or combined with calcium magnesium acetate.</td>
<td>World Road Association (2014)</td>
</tr>
<tr>
<td>Norway</td>
<td>NaCl is used for chemical de-icing, but pre-wetting and spreading brine is becoming more prevalent. Sand, gravel or crushed stones are used in snow/ice conditions.</td>
<td></td>
<td>World Road Association (2014) Vignisdöttir et al. (2016)</td>
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<tr>
<td>Slovenia</td>
<td>NaCl is used and to a smaller extent, CaCl₂ and MgCl₂. NaCl is used down to -8°C, wet salting with a mix of NaCl and MgCl₂ solution down to -18°C and a mix of NaCl and CaCl₂ solution down to -22°C. Roads can also be sprayed with a saline solution to prevent salt being blown off under heavy traffic conditions.</td>
<td></td>
<td>World Road Association (2014) CEDR (2015)</td>
</tr>
<tr>
<td>South Korea</td>
<td>The Korea Expressway Corporation (KEC) has introduced spreading of salt pre-wetted with CaCl₂. In the winter of 2011/12, &gt;108,000 tons of NaCl used and &gt;19,000 tons of CaCl₂.</td>
<td></td>
<td>World Road Association (2014)</td>
</tr>
<tr>
<td>Sweden</td>
<td>NaCl commonly used for de-icing/anti-icing with 70:30 ratio of salt to liquid used for brine. Sand is used for mechanical de-icing with about 2% by weight salt. Salt use has been on the decline since 2004 on low-traffic roads with increased use of brine.</td>
<td>900 salt spreaders and 1,000 sand spreaders used in Sweden (Trafikverket, 2014)</td>
<td>World Road Association (2014) Trafikverket (2014) Jahan et al. (2012)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>NaCl, CaCl₂, MgCl₂, urea, methanol, abrasives and wood chips have all been used. CaCl₂ is used with salt for temperatures below -8°C. Progress on the use of brine is being made (salt &amp; brine mixed on the spinner) with 90% of all motorway maintenance centres using this technique by 2005. Salt is stored under shelter, either in barns or silos.</td>
<td>Spread rates vary between 5 and 20g/m² with highest spread rates for the use of dry and pre-wetted salt at temperatures below -8°C. Smaller spread rates are used for brine with on average between 5 and 10 g/m² (see Appendix B).</td>
<td>SwissInfo (2010) World Road Association (2014)</td>
</tr>
<tr>
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<td>United States</td>
<td>Solid chemicals (dry and pre-wetted), liquid chemicals and abrasives are used. Chemicals include NaCl, CaCl₂, MgCl₂ and acetates. Survey of 15 states found 83% used NaCl, 58% used MgCl₂, 50% used ABPs and 46% used CaCl₂. More details in Appendix A.</td>
<td>Spread rates of 75 to 400 gal/mile for NaCl (solid or pre-wet) between 0 and -9°C, 40-80 gal/mile for NaCl brine between 0 and -6°C and 15-40 gal/mile for MgCl₂.</td>
<td>Jahan et al. (2012) World Road Association (2014) ADOT (2014)</td>
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3 De-icer performance trials

The performance and effectiveness of de-icers at different temperatures has been tested in a number of recent field trials and laboratory tests.

3.1 Field trials

Hausmann (2012) presented an example from Germany where the durability of NaCl brine was compared to the use of pre-wetted salt. The results of the study found that 70% of the brine (compared to only 20% pre-wetted salt) was maintained on the road a couple of hours after being spread (see Figure 4) although it was also recognised there was a high variation between measurements on different days and locations. These trials also included some spreading of CaCl$_2$ solution and there was an indication, although low confidence, that the CaCl$_2$ provided for a longer lasting treatment than NaCl brine.

![Figure 4 – Comparing the effectiveness of pre-wetted salt and liquid brine by the amount of salt that remains on the surface several hours after spreading (Photo from Hausmann, 2012)](image)

BAM (2015) reported on operational brine spreading carried out on sections of the Irish trunk road network. Key conclusions were that brine spreading was a suitable treatment and, based on observations, it was concluded that the salt deposited on the road surface from brine treatments remained on the road surface longer than salt from dry salt spreading and pre-wetted salt spreading. There was not an observed difference in effectiveness on different surface types and brine spreading was able to be carried out at greater speeds.

Hossain (2015) carried out an extensive field test of de-icers in one of the car parks of the University of Waterloo in Ontario over three winter seasons of 2011/2012, 2012/2013 and
A variety of solid materials and liquid treatments such as NaCl brine were tested. The results showed that a relatively low application rate of 31/1000 sqft for brine was found to be sufficient for anti-icing operations.

A recent study by Evans (2016) for Transport Scotland carried out brine spreading trials for the winter season of 2015/2016 with the aim to assess the effectiveness and longevity of precautionary treatments using NaCl brine.

Continuous monitoring of the surface at all the trial sites was possible through the investment in non-invasive weather sensors and road weather stations. NaCl brine and pre-wetted salt was spread using a combi-spreader.

During the months of February, March and April, brine treatments were possible on the majority of days. Using a staged approach, spread rates were reduced during the study. At a concentration of 20 to 23%, the following brine treatments were reported as being effective:

- Spreading of 15ml/m² of brine between -2°C and -3°C
- Spreading of 30ml/m² of brine between -4°C and -5°C

Wainwright and Edwards (2016) conducted a trial for Highways England of pre-wet treatments using MgCl₂ during the winter season of 2015/2016. The aim of the trial was to compare performance levels against the standard treatment of NaCl pre-wetted with NaCl brine.

Due to higher than average temperatures during the trial period, the extreme cold temperatures required to effectively test NaCl and MgCl₂ were not encountered for a sustained period of time. Data from the mobile condition sensors and driver observations showed that MgCl₂ outperformed NaCl on certain occasions in snowy-icy conditions with no instances of ice formation on roads treated with MgCl₂. The stationary sensors did not provide evidence of MgCl₂ outperforming NaCl.

In conclusion, it was recommended that NaCl continue to be used for pre-wet treatments and MgCl₂ used as an option for extreme conditions until further research has been carried out on the latter, particularly at extreme cold temperatures.

### 3.2 Laboratory tests

Druschel (2012) evaluated the ice melt capacity and field performance factors of de-icers and de-icer blends. Ice melt capacity tests were carried out for NaCl brine and different blends of NaCl with CaCl₂ in ratios of 90/10%, 80/20% and 70/30% respectively at different temperatures between -2°C and -18°C. While individual de-icers did not show substantial improvement over rock salt for ice melt capacity, brine blends did show an improvement in ice melt capacities, likely due to increases in the additive in the total de-icer.

A study by Bulevičius (2014) tested the efficiency of five different snow melting materials in the laboratory on the loss of ice mass. The materials tested were:

- NaCl
- CaCl₂
- MgCl₂
• A mixture of Na and Ca modified Chlorides
• A mixture of sodium acetate and sodium formate

Ice samples were tested at different temperatures and time intervals. Two types of measures were used:

• The percentage of ice mass loss
• The percentage per minute of ice melting intensity.

Relatively speaking, the results showed that NaCl had a higher ice melting efficiency at -3°C compared to MgCl$_2$ and CaCl$_2$. At extreme cold temperatures of -15°C and -20°C, while still low, MgCl$_2$ and CaCl$_2$ had a higher ice melting efficiency compared to NaCl.
4 Survey of service providers

Responses to the service provider questionnaire have been received from Areas 2, 3, 7, 9, 12, 14.

Of the 6 Areas responding to date, none currently have stocks of alternative de-icer other than Potassium Acetate.

3 of the Areas currently use Potassium Acetate at corrosion sensitive areas, including:

- Severn Bridge
- Hindhead tunnel
- Meir Tunnel

Areas of potential benefit for liquid spreading identified included:

- Use for dynamic hard shoulder sections, where there are often queries by the Traffic Officer Service if they are “safe to open”. One Area was considering a trial of brine only top up treatments at around 04:00 on such nights.

With regard to treatment effectiveness in extreme cold conditions, one Area reported using standard treatments during the winter of 2009/10 with RST’s down to -14°C. Treatments were carried out at 10g/m² every 12 hours and there were no incidents on the network during 14 day period of dry, cold conditions.

Some scenarios were identified where standard treatments have not been effective:

- Slippery surfaces were experienced following multiple treatments during a low temperature/low humidity period. It was commented the slipperiness only manifested on tight radi and not necessarily when the lowest RHs or lowest temperatures were being observed.

- During a period with RSTs below Dew Temp for most of the night followed by a slight dip below zero, there were reports of ice. Treatments had been in accordance with HE guidance and traffic volumes were low, however not lower than some motorways in the Area routinely experience. This has caused the decision making staff to apply greater pessimism to the decisions. The view of the respondent was that the dew diluted the treatment, but it was commented the sensors did not detect ‘wet road’ throughout.

- One Area reported that the only ice related issues have been around dawn and on the cusp of any ice melting.

- Heavy hoar frost on lightly trafficked Sunday or Bank Holiday mornings.

- Problems were encountered during the 2013/14 winter season associated with low dose infrequent treatments, bands of severe rainfall, very high ground water table, high humidity and low traffic volumes particularly early Saturday and Sunday mornings.

Some other comments received included:
• ‘History probably shows we get the really cold nights when the days don’t come above freezing so we would be out at least three times in any 24 hour period sometimes more at a high dosage of salt.’

• We tend to air on the side of caution..... if we are out treating the vehicle, fuel and driver costs are more or less the same whatever the dosage so we don’t hesitate to increase from say 8gm to 15gm or up to 18g pre-wet.

• 13th December 2014 was a nationwide event, once again a heavy hoar frost on a lightly trafficked morning. This time the nation agreed to increase spread rates over the Christmas embargo period and not to reply on residual salt for longer than 10 hours.
5 Discussion of key points from review

5.1 Brine spreading

Sodium chloride brine is the most commonly used liquid de-icer. It is typically used as a precautionary treatment under clearly specified weather and road conditions.

Brine is typically used for pavement temperatures down to between -5 and -10°C and when the potential for dilution is low. For example, in the USA the aim is to spread brine in conditions where the brine solution will dry on the road surface before freezing or the storm conditions occur.

Examples in the literature have demonstrated the decision making procedures implemented by road authorities to assess the suitability of brine spreading for the expected road and weather conditions.

From the operational experience reported and trial results reviewed, brine spreading has been demonstrated to provide an effective precautionary treatment and can reduce the amount of dry salt consumed when used in appropriate conditions. Typical spread rates in these conditions can provide around a 50% saving in salt usage. However, it must be considered there will be conditions where brine is not suitable and dry or pre-wetted salt will be required.

The use of salt brine blended with other chlorides and ABP type additives is increasing, in particular in the USA. This can potentially result in treatments will longer retention times or lower effective temperatures – and also the potential for slightly lower application rates.

5.2 Calcium chloride and other alternative de-icers

Calcium and magnesium chloride are used in a number of European countries as the liquid component of pre-wetted salt. In the USA they are commonly used as both liquid only treatments and in pre-wetted salt.

Calcium chloride is typically used with a concentration of 28 to 32% (Eutectic Concentration 29.8%) and magnesium chloride with concentration between 30 and 32% (Eutectic concentration 21.6%).

In Europe the use of calcium and magnesium chloride is commonly for extreme cold conditions, although the Netherlands use rock salt pre-wetted with calcium chloride as a standard precautionary treatment (when used in the Netherlands a lower 16% calcium chloride concentration is used).

Liquid de-icers may be combined (often referred to as blending) together to produce an enhanced product. This may commonly include:

- adding an inhibitor to reduce corrosion
- addition of ABP type products to brines to increase the residual effectiveness of the liquid
- Sodium chloride brine combined with small percentage of calcium chloride
5.3 Equipment and infrastructure

The use of brine or other liquids require an agency to have:

- Vehicles with the capability to spread liquids
- Storage facility for liquids and the ability to load liquids into the vehicles
- Brine or other liquid de-icer making facilities or purchase of liquids from vendors

Some options highlighted for consideration include:

- Versatility to change vehicles from solid to liquid only spreading – for example systems are available where flexible brine tanks can be installed in spreader hoppers.
- Brine saturators using cheaper, indigenous rock salt instead of high purity marine or vacuum salt – this would provide a significant cost saving and further information is being sought from manufacturers on the latest developments in this area
- Manual or automatic systems that an agency can build or purchase to carry out blending of different liquid chemicals
6 References


Evans, M. (2016). “Trials of the longevity of brine and pre-wetted salt winter service treatments on typical UK road surfacings: Phase 2”, PPR795


## Appendix A

### US Summary Table

<table>
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<th>State</th>
<th>De-icer use and concentrations</th>
<th>Spread rates</th>
<th>Document links</th>
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<tr>
<td>Arizona Department of Transportation</td>
<td>Liquid MgCl₂ typically used for anti-icing operations.</td>
<td>ADOT uses nozzle spreaders to distribute liquid additives. Spread rates of 10 to 90 gallons per lane per mile recommended. Table in appendix for spread rates for MgCl₂. First applied at temperatures falling below 0 for light snow storm and black ice, and NaCl pre-wet for moderate snow storm (15-35 gallon per lane mile but increasing to 20-40 for lower temperatures)</td>
<td>ADOT (2014)</td>
</tr>
<tr>
<td>Colorado Department of Transportation</td>
<td>Two primary compounds used for anti-icing and de-icing: NaCl with sand and MgCl₂ liquid deicer. MgCl₂ has also been used with corn-based agricultural additives</td>
<td>Jahan et al. (2012)</td>
<td></td>
</tr>
<tr>
<td>Illinois Department of Transportation</td>
<td>NaCl and CaCl₂ are the two de-icers used. CaCl₂ applied as brine (as a 32% concentration) directly on brine decks or as a pre-wetting agent on salt for pavements.</td>
<td>Illinois Department of Transportation Bureau of Materials and Physical Research (2009)</td>
<td></td>
</tr>
<tr>
<td>Minnesota Department of Transportation</td>
<td>NaCl is most commonly used de-icer chemical, but CaCl₂, MgCl₂, acetates and various blends of chemicals are also used.</td>
<td>Ice Ban 200 (Liquid MgCl₂) – 25-35 gallons per road mile</td>
<td>Minnesota Department of Transportation (2015)</td>
</tr>
<tr>
<td>State</td>
<td>De-icer use and concentrations</td>
<td>Spread rates</td>
<td>Document links</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------</td>
</tr>
</tbody>
</table>
| Arizona Department of       | Liquid MgCl₂ typically used for anti-icing operations.                                        | ADOT uses nozzle spreaders to distribute liquid additives. Spread rates of 10 to 90 gallons per lane per mile recommended.  
Table in appendix for spread rates for MgCl₂  
First applied at temperatures falling below 0 for light snow storm and black ice, and NaCl pre-wet for moderate snow storm (15-35 gallon per lane mile but increasing to 20-40 for lower temperatures) | ADOT (2014)                              |
| Transportation              |                                                                                               |                                                                                                                                                |                                       |
| Ohio Department of          | Clearlane (NaCl and MgCl₂) – 20-40% lower application rate to just NaCl                       | Ice Slicer – For de-icing 100-400lbs per mile  
C1000 PRO (liquid CaCl₂) – Anti-icing 20-30 gallons per lane mile  
Document has lots of different blends | Ohio DOT (2012)                          |
<p>| Transportation              |                                                                                               |                                                                                                                                                |                                       |
| Washington State            | Brine for anti-icing made up of 23.3% solution of salt, 20% de-sugared molasses and 5% CaCl₂. |                                                                                                                                                | Jahan et al. (2012)                    |
| Wisconsin Department of     | Used brine                                                                                     | 8-10 gallons of liquid brine per cubic yard of salt                                                                                           | Jahan et al. (2012)                    |
| Transportation              |                                                                                               |                                                                                                                                                |                                       |</p>
<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>Arizona</td>
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<td>ADOT (2014)</td>
</tr>
<tr>
<td>Iowa</td>
<td>Used over 7 million gallons of salt brine for snow and ice control in 2002-3</td>
<td>All 879 snow plow trucks have the ability to pre-wet dry materials.</td>
<td>Jahan et al. (2012)</td>
</tr>
</tbody>
</table>
## Appendix B  Spread rate tables

Tables from World Road Association (2014)

### Switzerland - Spread rates in g/m\(^2\)

<table>
<thead>
<tr>
<th>De-icer</th>
<th>Temperature</th>
<th>0 to -8(^{\circ})C</th>
<th>-8 to -20(^{\circ})C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry salt</td>
<td></td>
<td>7-15</td>
<td>10-20</td>
</tr>
<tr>
<td>Wet salt</td>
<td></td>
<td>7-15</td>
<td>10-20</td>
</tr>
<tr>
<td>Brine</td>
<td></td>
<td>5-10</td>
<td>5-10</td>
</tr>
</tbody>
</table>

### Netherlands - Spread rates in g/m\(^2\)

<table>
<thead>
<tr>
<th>Type of weather condition</th>
<th>Dry salt</th>
<th>Pre-wetted salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preventative spreading</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Fog moisture</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Icing</td>
<td>15-20</td>
<td>7-10</td>
</tr>
<tr>
<td>Glazed frost</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Snow (after removal)</td>
<td>20</td>
<td>-</td>
</tr>
</tbody>
</table>

### Finland - Spread rates in g/m\(^2\)

<table>
<thead>
<tr>
<th>Road surface condition (g/m(^2))</th>
<th>Saline solution</th>
<th>Wetted salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly moist</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>moist</td>
<td>10-20</td>
<td>5-10</td>
</tr>
<tr>
<td>wet</td>
<td>20-40</td>
<td>10-20</td>
</tr>
</tbody>
</table>

### Estonia - Spread rates in g/m\(^2\)

<table>
<thead>
<tr>
<th>Road surface condition</th>
<th>Temperature</th>
<th>0 to -2(^{\circ})C</th>
<th>-2 to -4(^{\circ})C</th>
<th>-4 to -7(^{\circ})C</th>
<th>-7 to -10(^{\circ})C</th>
</tr>
</thead>
<tbody>
<tr>
<td>After snow removal</td>
<td>0-20</td>
<td>10-20</td>
<td>20-40</td>
<td>0-60</td>
<td></td>
</tr>
<tr>
<td>After wet snow removal</td>
<td>10-20</td>
<td>20-30</td>
<td>0-50</td>
<td>50-70</td>
<td></td>
</tr>
<tr>
<td>Icy pavement</td>
<td>0-5</td>
<td>0-10</td>
<td>0-20</td>
<td>0-30</td>
<td></td>
</tr>
</tbody>
</table>

### USA  e.g. Arizona - Spread rates in gal/lane mile

<table>
<thead>
<tr>
<th>De-icer</th>
<th>Temperature</th>
<th>Above 0(^{\circ})C but falling</th>
<th>0 to -6(^{\circ})C</th>
<th>-2 to -6(^{\circ})C</th>
<th>-6 to -9(^{\circ})C</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl (solid or pre-wet)*</td>
<td>75-200</td>
<td>100-325</td>
<td>165-200</td>
<td>175-400</td>
<td></td>
</tr>
<tr>
<td>NaCl liquid**</td>
<td>40-65</td>
<td>40-90</td>
<td>65-80</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>MgCl(_2)***</td>
<td>15-35</td>
<td>20-40</td>
<td>20-40</td>
<td>15-40</td>
<td></td>
</tr>
</tbody>
</table>

Note * - NaCl (solid or pre-wet) ranges in the table apply for all weather conditions

Note** - NaCl liquid only suitable for following weather conditions:
- **Above 0\(^{\circ}\)C but falling** - Light or heavy snow storm, frost or black ice
- **0 to -6\(^{\circ}\)C** - Light snow storm
- **-2 to -6\(^{\circ}\)C** - Frost or black ice

Note*** - MgCl\(_2\) to be used in the following weather conditions:
- **Above 0\(^{\circ}\)C but falling** - MgCl\(_2\) used for light snow storm or frost/black ice. MgCl\(_2\) used as pre-wet for moderate/heavy snow storm and sleet storm
- **0 to -6\(^{\circ}\)C** - MgCl\(_2\) used for light snow storm and frost/black ice. MgCl\(_2\) used as pre-wet for moderate to heavy snow storm and sleet storms
- **-2 to -6\(^{\circ}\)C** - MgCl\(_2\) used for frost/black ice
- **-6 to -9\(^{\circ}\)C** - MgCl\(_2\) used for light snow storms and frost/black ice. MgCl\(_2\) used as a pre-wet moderate to heavy snow storm and sleet storm
A review of recent research and operational experience in the use of brine and other liquid de-icers