Transport Research Laboratory

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2	16/07/10	Incorporating comments from TR and Chris Plumb/Joanne Edwards following progress meeting	ME	
3	23/07/10	Second Technical Review	ME	BVC
4	27/08/10	Incorporating comments from Chris Plumb/Joanne Edwards on Version 3	ME	
5	19/04/11	Amendments resulting from further review of trials as part of brown water task. Incorporating comments on Appendix A	ME	BVC, BM

Contents

Executive summary

Background

As part of a project to investigate benefits of (i) pre-wetted salting with uniformly graded salt and (ii) liquid (brine) treatments, TRL prepared a business case which examined the economic viability of using brine treatments on the Highways Agency's motorway and trunk road network (Jordan, 2011).

The analysis considered the savings that might be obtained when whole routes are treated with brine rather than pre-wetted salt, and estimated the potential savings from the following options:

- Pre-wetted salting replaced with brine treatments using brine spreaders
- Pre-wetted salting replaced with brine treatments or pre-wetted salting using combination spreaders

The business case concluded that there could be operational and financial benefits if the Agency had some spreaders capable of spreading brine over whole routes.

With brine spreaders, it was found that there may not always be direct cost benefits, but the overall cost benefit to society could be high when indirect costs (i.e. the cost of corrosion to vehicles and structures and environmental damage) were included in the analysis. However, the overall cost benefit was estimated to be much higher with combination spreaders capable of spreading brine in addition to dry, pre-wetted and treated salt.

For this reason it was concluded that combination spreaders were the most suitable for brine treatments over whole routes, particularly where there was a significant risk of heavy icing and snowfall. The Agency is currently replacing its winter fleet and there may be an opportunity to purchase some combination spreaders to enable the brine treatment of whole routes in addition to pre-wet spreaders as part of the replacement procurement process.

To undertake the business case it was necessary to make a number of assumptions regarding, for example, the loss of brine and pre-wetted salt due to trafficking, the minimum coverage of de-icer across the carriageway, and the performance of spreaders. These assumptions were based on previous research by TRL, a comprehensive review of relevant literature and discussions with winter service experts. However, it was clear that the values assigned to some of the parameters in the analysis had an important influence on the outcome of the business case, it was therefore important that a further programme of research was undertaken to check, and if necessary modify, the values used in the analyses.

Brine treatments were suggested for slip road areas that are lightly trafficked, especially in low humidity and low temperature conditions. They were also suggested for Managed Motorway hard shoulders as these must be free of ice before being opened to traffic but they are without the benefit of trafficking that encourages the dissolution of solid de-icers prior to opening. The treatment of narrow spread widths (e.g. hard shoulders and slip roads) with brine using the current pre-wet spreader fleet would reduce the expenditure on spreaders for brine treatments. Therefore, if the efficacy of such treatments could be proven, it would be possible to introduce them across the whole of the Agency's network.

Recommendations for further work were contained in the business case (Jordan, 2011), and TRL was subsequently commissioned by the Agency to investigate these key areas. The work undertaken is described in this report. The work programme included:

- Performance trials on a spreader with a brine spreading capability to determine the brine distribution profile immediately after spreading, including the minimum spread rate and maximum spreader speed that can provide a sufficiently uniform distribution

- Road trials with a spreader with a brine spreading capability to investigate residual salt levels of brine after trafficking and further investigation of trials reported in the literature
- Trials to determine the effect of traffic adjacent to the spreader when spreading brine
- A survey of the saturators and the salt types being used by Service Providers to produce brine for pre-wetted salting, including an assessment of whether brine can be produced efficiently and cost effectively with brown salt from UK sources
- Identification of the routes most suitable for combination treatments
- Trials to investigate the feasibility of spreading brine using the pre-wet spreaders from the new winter fleet, to determine if they can be used to treat slip roads and the hard shoulders of Managed Motorways. (Based on the results of this work, guidance for Service Providers has been developed for inclusion in the Network Management Manual)

A brief summary of the findings of the research is given below. Based on the findings of the work, some of the assumptions in the original business case were modified. The findings of the revised business case are presented in this report and are summarised at the end of this Executive Summary.

Performance trials on a brine spreader

Trials were carried out on the TRL Test Track to determine the brine distribution profile immediately after spreading with a brine spreader. The brine spreading mechanism on the brine spreader used was the same as that on combination spreaders supplied by the same manufacturer. The main aims of the trials were to determine:

- The brine distribution when spreading a three lane motorway symmetrically from Lane 2 and a two lane road asymmetrically from Lane 1
- Whether brine treatments can be carried out at a faster speed than 64km/h
- Confirm brine can be spread effectively at a minimum spread rate of 10g/m² as assumed in the business case

The trials were carried out on both 14mm stone mastic asphalt (SMA) negatively-textured thin surfacing and hot rolled asphalt (HRA) surfacing. The volumetric patch texture depth of the SMA was high at 2.5mm. A proportion of the brine spread on the negatively-textured SMA could not be collected using TRL's wet wash vacuuming method. A correction factor was applied to the results from the performance trials to account for the under recovery and determine the brine distribution after spreading.

The trials showed that brine can be spread evenly to the lanes when two and three lane spreading with a brine spreader. However, the distribution profile was not uniform across the target spread width and there were distinct dips in the profile at the edges of each lane. The brine was targeted within the lanes effectively with very little wastage (<10 per cent) and it is anticipated that the distribution could be better optimised for brine spreading by adjustments to the nozzle alignment/position.

Comparison of the results from trials with the same spread rate and spread width has clearly demonstrated very similar distributions when spreading at 64km/h and 80km/h. There was no significant difference in the uniformity of the brine spread across and along the carriageway at the two speeds. The jets of brine spread to the outer lanes appeared to be disrupted more by the increased spreading speed, however this was not seen as detrimental to the final distribution. The results therefore showed that spreading can be carried out at 80km/h as effectively as at 64km/h.

There was no evidence of any significant change in the uniformity or targeting of the lanes when spreading at a target spread rate of 10g/m² compared to the higher rates, demonstrating that brine can be just as effectively spread at this rate.

Road trials to investigate residual salt levels after trafficking

Based on previous work in Europe by Bolet (2008), a 15 per cent loss of brine after two hours of trafficking had been assumed in the original business case prepared by TRL. In order to investigate this assumption on the type of road surfacing found on the Agency's network, two road trials were carried out on the M3 in Hampshire to measure residual salt levels after two hours of trafficking after spreading. Lane 1 of the trial site was surfaced with a negatively-textured thin surfacing with a volumetric patch texture depth estimated to be 2mm and Lane 2 surfaced with HRA.

Using the same brine spreader as used in the performance trials, brine was spread at 80km/h with the road open to traffic. The target spread rate was 20g/m² with spreading from Lane 1 across both Lanes 1 and 2.

The brine collected in each lane in the road trials was compared with the brine distribution measured in the performance trial, which was assumed to be the initial distribution on the road. The percentage loss in Lane 1 (negatively-textured thin surfacing) was estimated to be 53 and 59 per cent in Trial 1 and Trial 2 respectively. For Lane 2 (HRA surfacing) the loss was estimated to be 36 and 44 per cent in Trial 1 and Trial 2. For the lanes overall, the average loss was very consistent between the trials at 48 per cent in Trial 1 and 49 per cent in Trial 2.

The strip to strip variation in the brine collected was very low, the maximum minus the minimum amount collected from the strips being 26 cent of the average in Trial 1 and 12 per cent in Trial 2. This is lower than the 30 per cent measured in road trials carried out by TRL with 6.3mm pre-wetted salt (Jordan et al, 2011A)

Averaged for both trials, the loss for the negatively-textured thin surfacing was 56 per cent and for the HRA surface 40 per cent. The losses in these trials were therefore significantly greater than the 15 per cent loss for brine measured in the previous studies and which was assumed in the original business case for brine spreading.

Trials to determine the effect of traffic on brine distribution

Observations of driver behaviour during day-time liquid spreading (with potassium acetate that is considered to be representative of brine spreading) were taken when the weather was very poor with heavy snow/sleet. Drivers appeared unconcerned with the spreader and overtook without hesitation. Due to the poor visibility conditions it is likely the drivers were less aware of what was being spread than they would be on a clear day. The effect of the traffic on the de-icer distribution would likely have been minimal in this scenario.

Observations during night-time spreading were when the liquid being spread was more visible and the drivers showed more awareness of the spreading. Drivers appeared to be more hesitant on approaching the spreader, in particular when not following another vehicle. Drivers were often observed to hang back before over-taking, although not in the immediate area that the de-icer was being applied to the road surface. Once passing through the spray, vehicles tended to pass quickly and typically passed through within three seconds. When the spreader was spreading Lane 1 and Lane 2 of a four lane section, drivers would typically move in to Lane 3 to avoid the area being sprayed.

Survey of saturators and salt types used by Service Providers

A survey of saturators used on the Agency's network was carried out to determine the types of saturator and brine salt being used by Service Providers to produce brine for pre-wetted salting and obtain information on their operational experiences. The survey found that the current brine production capacity for pre-wetted salting is mostly sufficient for combination treatments. However, production reliability has yet to be fully tested as the majority of the saturators have been operational for a maximum of two winter seasons. Also, the use of brine has been limited because many treatments last winter were with dry salt rather than pre-wetted salt.

The increased use of saturators for combination treatments will increase the likelihood of failures and problems occurring and hence likely result in additional maintenance costs. However, the cost of cleaning the saturator and removing insolubles is likely to be proportional to the amount of brine produced.

Although brown rock salt is low in cost and generally easily available, its cost effectiveness as a brine salt will be affected by the cost of extra maintenance required to remove impurities from the saturator. Most saturators are designed for use with purer white salt and the manufacturers recommended that only this type of salt be used for brine production. The experience of Service Providers using saturators that can use brown salt is insufficient to recommend the use of brown salt and discussions with salt suppliers have indicated that the production rate would be reduced by the need to remove impurities on a regular basis, in particular if removal has to occur during a period of use. No data have been found that would suggest that the use of brown salt is cost effective. Therefore, white salt is recommended for brine production.

The potential for brine from industrial processes to be supplied directly to Service Providers was investigated. It was thought that continuity of supply may be a problem and much storage may be required at depots to ensure sufficient brine was available at times of high demands.

Revised business case

In revising the business case it has been assumed that a combination spreader would be available to make brine treatments or for pre-wetted salting. Brine spreaders have not been considered because the previous work by TRL shows they are not economically viable on the Agency’s network under current circumstances.

Four revised factors have a significant effect on the business case:

- The brine loss due to trafficking
- The cost and type of salt that can be used for brine production
- The minimum spread rate for pre-wetted salting
- The number of saturators used for brine production

The factor that has the greatest effect on the revised calculations is the brine loss due to trafficking. In the revised business case, the loss of brine due to trafficking has been increased from 15 to up to 40 per cent for brine treatments on typical surfacing. Losses of 30 and 50 per cent have been used, respectively, for denser and more open textured surfacing than typical surfacing.

The saturator survey found that brine production with indigenous UK brown salt is not likely to be economically viable largely due to the additional maintenance costs. Therefore, it has been assumed that white salt would be used for brine production. However, two severe winters in recent years have increased the demand for imported white salt and fuel costs have also risen, resulting in an increase in the cost of white salt for brine production. When the higher brine loss due to trafficking and the higher cost of salt are taken into account, it is estimated that there would be very few weather conditions where the direct cost of brine treatments would be less than that of pre-wetted salt. The number of weather conditions where brine treatments would be the best option would be slightly higher if the indirect costs due to vehicle and structural corrosion and environmental damage are taken into account. However, the calculations only considered the number of weather conditions where a direct cost saving to Service Providers would be obtained for brine treatments.

The original business case also considered the use of white salt for the dry salt component of pre-wetted salt. For these calculations, it was assumed that white dry salt would be used only if it enabled the minimum spread rate at which pre-wetted salt could be spread uniformly to be lower if the dry salt component was white salt rather than UK brown salt, i.e. where the use of white salt would reduce the amount of salt required for pre-wetted salting. However, a number of Service Providers have obtained supplies of imported white salt during the recent salt shortages and this might continue if UK supplies cannot meet current demands. In addition, a minimum spread rate of 8g/m^2 has been adopted on the Agency's network for pre-wetted salting with brown salt, thereby reducing the potential de-icer cost savings when brine treatments are made, since the business case assumed a minimum of 10g/m^2. Both of these factors have been taken into account in the revised calculations.

The other factor that has had an effect on the business case is the number of saturators used to produce brine. It should not be necessary to purchase additional saturators because those already in use for pre-wetted salting should have sufficient capacity for the number of brine treatments estimated. However, the amount of brine required each year for combination treatments (i.e. brine treatments and pre-wetted salting) would be higher than that required for just pre-wetted salting and an additional annual maintenance cost has been allowed for the saturators, due to increased usage.

The main conclusions from the revised calculations (based on the use of a combination spreader) are as follows:

1. Based on the revised business case, the use of combination spreaders is not recommended where brown salt is used for the dry component of pre-wetted salt.
2. If brown dry salt and white brine salt are used, it is estimated that there will be no direct cost savings if the brine loss due to trafficking is 30 per cent or more (i.e. on all types of surfacing on the Agency's network).
3. If white dry salt and white brine salt are used, there should be direct cost savings in areas where the weather conditions are not too severe, although this is more likely in such areas if white salt costs more than £46/tonne (c.f. £25/tonne for brown salt)
4. If brown dry salt and white brine salt are used, there will be an overall (direct and indirect) cost saving if the brine loss due to trafficking is 40 per cent in areas where the weather conditions are not too severe. In areas with the most severe weather conditions considered in the calculations, there will be an overall cost saving if the brine loss due to trafficking is 30 per cent or less (i.e. on dense surfacing)
5. If white dry salt and white brine salt are used there will be an overall cost saving if the brine loss due to trafficking is 40 per cent or less (i.e. on typical or dense surfacing). There should be an overall cost saving if the brine loss due to trafficking is 50 per cent (i.e. on open textured surfacing) in areas where the weather conditions are not too severe.

Assessment of routes most suitable for brine treatments

The combination spreaders available from the suppliers of the new winter fleet can spread brine to one, two or three lanes, but it is not currently possible to spread three lanes and a hard shoulder.

An analysis was carried out of winter service routes on the Agency's network in Areas 1 and 2; two areas where the climate is likely to be suitable for combination treatments. At least 22 routes have been identified in these areas which have no sections with more than three lanes which would be suitable for brine treatments with combination spreaders from suppliers of the new winter fleet.

The feasibility of brine spreading with pre-wet spreaders

Trials were carried out on the TRL Test Track to investigate the feasibility of spreading brine with pre-wet spreaders from the Agency's current winter fleet. The main aims were to determine:

- The feasibility of spreading the hard shoulder of a Managed Motorway for the following scenarios:

  a) Spreading from the hard shoulder and

  b) Spreading from Lane 1 into the hard shoulder

- The feasibility of spreading a two lane slip road asymmetrically from Lane 1, e.g. top-up treatments in low humidity and low temperature conditions

When driving and spreading from the hard shoulder, the trials showed that it is possible to achieve the target rate within the lane the spreader is driving in. To achieve the target spread rate, the wastage outside the lane is relatively high and the total amount of brine discharged will therefore be required to be greater than the target amount for one lane. The uniformity of the brine distribution along the carriageway is comparable with trials with a brine spreader. Overall, the results of the trials would indicate there is potential to drive and spread brine in the hard shoulder using pre-wet spreaders.

Based on the results from these trials, spreading brine from Lane 1 to the hard shoulder would not seem to be a feasible method when using pre-wet spreaders with the current settings for pre-wetted salting. It may be that different settings or modification of the spreaders, e.g. the design of the spinner, would result in a better distribution. A more effective option would likely be the addition of nozzles to the pre-wet spreaders which could spray brine to the hard shoulder while driving in Lane 1.

The distribution profile across two lanes was clearly less flat compared with the distribution for the brine spreader. As a result, to achieve the target spread rate across the whole width of the carriageway would require significant overspreading in the centre of the lanes. If brine spreading was to be carried out as the only treatment on a section of carriageway, more work would be required to try and optimise the two lane distribution. However, with the distribution as measured at present, there would be potential for use as a top up treatment to areas previously treated with dry or pre-wetted salt.

Based on the results, guidance for Service Providers has been developed for inclusion in the Network Management Manual for brine treatments with pre-wet spreaders. Without accurate information on residual salt levels, surface temperatures and surface conditions to optimise the spread rate, it is recommended that treatments are made at the maximum brine spread rate that can be achieved with pre-wet spreaders, namely 40g/m^2 for one-lane spreading and 20g/m^2 for two-lane spreading.

1 Introduction

In 2009, TRL investigated whether there was a business case for the use of sodium chloride brine treatments on the Agency's motorway and trunk road network, either with liquid (brine) spreaders or combination type spreaders (Jordan (2010). A literature review was undertaken to identify the advantages and disadvantages of brine treatments, and the potential salt savings and cost implications were determined for a range of weather conditions.

If brine treatments were to be introduced on all or part of the Agency's road network, depots would need to be equipped with brine production or storage facilities, and brine, combination or modified pre-wet spreaders. The study concluded that brine spreaders would not be effective for the treatment of whole routes because of the amount of brine that would be required for treatments at temperatures less than -5°C and because brine treatments are not suitable for heavy icing and snow. However, it was found that combination spreaders could bring overall (direct and indirect) cost savings if brine was used on marginal nights whilst pre-wetted salt was used at other times.

Brine treatments were also suggested for:

(i) Slip road areas that are lightly trafficked, especially in low humidity and low temperature conditions

(ii) Managed Motorway hard shoulders, because these must be free of ice before being opened to traffic but may be without the benefit of trafficking at the time of spreading that encourages the dissolution of solid de-icers

Whether there are direct cost savings was shown to be largely dependent on the cost of the salt used to make the brine. Jordan (2010) suggested that brine production would be more cost effective using UK indigenous brown salt than white imported salt, providing that the cost of saturators and any additional maintenance costs associated with the use of brown salt were not too high. It was also indicated that the carbon footprint of winter service could increase if imported rather than indigenous salt was used for brine production.

As well as the cost of the salt, there are other costs associated with the infrastructure required for brine treatments. Areas already spreading pre-wetted salt are equipped with brine production facilities, but these existing production and storage facilities may require upgrading to facilitate the larger scale operation of brine treatments. e.g. it may be necessary to add another saturator.

To prepare the business case it was necessary to make a number of assumptions based on the data available at the time. However, Jordan (2010) recommended further work be undertaken to investigate the validity of some of these assumptions. These investigations have been completed and their findings are described in this report; the investigations included:

- Trials to determine the brine distribution profile immediately after brine spreading with a brine spreader
- Trials to determine the residual salt levels after brine spreading following a period of trafficking and further investigation of trials reported in the literature
- A survey of the saturators being used by Service Providers to produce brine for pre-wetted salting and an assessment of their suitability for brine treatments
- An investigation of the efficacy and cost of brine production with UK indigenous brown salt
- Identification of the routes most suitable for combination treatments
- Trials to investigate the effectiveness of brine treatments in preventing ice formation on the hard shoulders of Managed Motorways and lightly trafficked slip roads

The treatment of narrow widths (e.g. hard shoulders and slip roads) with brine using existing pre-wet spreaders will reduce the expenditure on spreaders for brine treatments. Trials were therefore carried out to determine the efficacy of brine spreading using pre-wet spreaders and guidance for Service Providers has been developed for inclusion in the Network Management Manual.

During the course of this study the severe winter of 2009/10 resulted in the depletion of UK salt stocks and the use of imported salt for the dry salt component of pre-wetted salt. The implications of this have also been considered in this report.

The assumptions made as part of the original business case were described in detail in Jordan (2011), which was a Client Project Report for the Agency. That report has not been published since it included commercially sensitive information. To provide some context for the work described in this report, a brief summary of the findings is given in Section 2. Section 3 describes the implications brine-only spreading would have for the current winter fleet. The work carried out to investigate the assumptions in the original business case is given in Section 4 to 7. The brine spreading trials and road trials are reported in Sections 4 and 5. The saturator survey and the findings on the suitability of brown salt for brine production are given in Section 6. Based on the findings of the investigations, a revised business case is presented in Section 7. An assessment of routes suitable for brine spreading is made in Section 8. The trials of the feasibility of using pre-wet spreaders is reported in Section 9, including guidance for the use of pre-wet spreaders spreading the hard shoulders of Managed Motorways. Laboratory trials of the effectiveness of brine are described in Section 10. The conclusions and recommendations are given in Section 11.

2 Summary of business case for brine treatments

2.1 General

This section summaries the findings of the original business case for brine treatments, prepared as part of the Salt Grading and Liquid Treatments Project (Jordan, 2011). The report included commercially sensitive information and so has not been published. Some of the assumptions required testing and the findings have meant revision of the advantages and disadvantages and by implication a revision of the business case, which is explained in Section 7.

2.2 Advantages and disadvantages of brine treatments

A review of brine treatments identified the following advantages:

- Effective in low humidity conditions

  If the atmosphere has little moisture to offer and the road surface is dry, there is a danger that dry salt and, to a lesser extent, pre-wetted salt may not enter solution sufficiently rapidly to provide the required and expected anti-icing protection.

- Effective for treatments carried out at low temperatures

  Solid sodium chloride enters solution at a very low rate when spread at temperatures below about -7°C. Brine treatments are effective immediately when made at temperatures down to at least -15°C

- Suitable for low dosage treatments for marginal nights

  A large proportion of winter treatments in England are precautionary rather than curative and brine could be effective for many treatments, since accurate coverage can be achieved at low spread rates

- Effective more quickly

  Brine treatments become effective more quickly than solid de-icer treatments because they are sufficiently concentrated at the point of application, whereas dry or pre-wetted materials must absorb moisture from the road surface, from the atmosphere or in the case of pre-wetted salt from the applied brine to become effective at preventing ice formation. Brine can be applied as a preventative treatment to the road closer to the risk period for ice formation because it does not require any additional time to become effective

- More accurate spreading and less wastage, hence reduced salt usage and reduced impact on the environment

  Overall, the amount of salt required for an effective brine treatment is less than required for either pre-wet or dry salting because of the increased accuracy of spreading and the lower rate of loss due to trafficking, informed by the work of others. This reduces the potential for the corrosion of highway infrastructure and damage to the environment. The corrosive effect on vehicles using the highway is unlikely to change because the amount of chloride on the road in the form of brine is likely to be similar for brine treatments as for dry or pre-wet treatments

- There is the potential for spreading brine at faster speeds and hence with less congestion on the network as a result

The disadvantages of brine treatments were identified as:

- May require either purer and more expensive white salt than UK brown rock salt to produce the brine, or increased saturator maintenance to remove impurities, or an extra saturator if brown rock salt is used (these costs may be outweighed by costs savings due to lower spread rates and better distribution)

- Passing vehicles may deflect the spray away from the target area (this is also a problem for dry and pre-wet salting)

  Brine may not be redistributed by trafficking as easily as solid de-icers, so the impact of vehicles passing spreaders on the salt distribution profile is likely to be greater for brine treatments. Brine sprayed onto passing vehicles may also be carried away rather than reaching the road surface

- Not well suited to heavy de-icing operations, and not recommended for snow, sleet or treatments during freezing rain events

  Brine is less suitable for dealing with thick layers of ice or snow because the melt water quickly reduces the brine concentration thus reducing its de-icing properties. Therefore, brine cannot penetrate ice layers and debond them from the surface as effectively as solid de-icers. However, brine is effective if spread before snow or freezing rain

- Require dry/pre-wet equipped vehicles to be available or the use of combination spreaders for treatment of snow and thick ice
- Additional storage facilities may be required in operational depots for either additional vehicles or demountable tanks when not in use
- Vehicle service and operating costs may increase if brine or combination spreaders are employed or pre-wet spreaders are modified for brine treatments
- May require either brine production or brine storage facilities to be made available in depots over and above that required for pre-wetted salting

The work carried out in this project has prompted the amendment of some of these advantages and disadvantages in Section 7.

2.3 Cost-benefit analysis in business case

2.3.1 General

Analyses were undertaken as part of the original business case to examine the savings that might be obtained when whole routes are treated with brine rather than pre-wetted salt. A whole-life costing approach was used to estimate the savings from the following options:

- Pre-wetted salting replaced with brine treatments using brine spreaders
- Pre-wetted salting replaced with brine treatments or pre-wetted salting using combination spreaders

The method used to estimate the potential savings was to calculate the spread rates that would be required for the various treatments, taking into account the concentration of brine formed from the salt and water present on the road surface, for a range of different weather conditions (i.e. different road surface temperatures and varying amounts of water on the road surface).

Once the required spread rates were calculated for each type of treatment, the costs of applying these spread rates over a winter season were calculated for a notional 'typical depot', which was defined as a depot having:

- 4 brine or combination or pre-wet spreaders
- 1 saturator for use with pre-wet spreaders
- 2 saturators for use with brine or combination spreaders

- a requirement to treat a route length of 150 km, with an average spread width of 10m

The savings, in terms of both the amount of salt used per year and the overall financial cost per year, were estimated for each option.

In addition, whole-life costs analyses were undertaken to calculate the costs associated with each treatment option over a 30 year period (i.e. 30 winter seasons). The analyses included both the direct costs of providing the winter service over that period and the indirect costs associated with the impact of salt on vehicles, structures and the environment.

The direct costs took into account the following factors:

- The amount of salt required for each spread rate for each treatment option
- The effect of assuming different weather conditions over a winter season
- The cost of the salt
- The cost of the spreaders required to spread the brine and/or pre-wetted salt
- The performance of the spreaders, i.e. the minimum spread rate at which a sufficiently uniform salt distribution profile can be achieved
- The capacity of the spreaders
- The service life of the spreaders
- The operational costs, including the number of turnouts and fuel consumption
- The cost of brine production facilities and maintenance

The indirect costs took into account the following:

- Vehicle corrosion
- Structural corrosion/damage
- Environmental damage

A detailed description of the cost calculations, and the assumptions underlying them, is given in Appendix A. The main conclusions were:

1. Overall, combination spreaders were estimated to be more cost effective than brine spreaders, especially for more severe weather conditions. This is because brine treatments require more salt and a greater number of turnouts than pre-wetted salting in severe weather conditions
2. For combination spreaders, there was a direct cost saving in a number of cases when the minimum pre-wetted salting spread rate was 10g/m^2. However, there were very few cases where there was a direct cost saving when the minimum spread rate was 8g/m^2, which the Agency has now adopted as the norm.
3. Sources of white salt that are suitably graded for efficient brine production are not available in the UK at competitive prices and imported white salt is more expensive than UK brown salt. The calculations showed that in most cases there was a cost benefit if UK indigenous brown salt is used for brine production and the dry salt component of pre-wetted salt. However, a key factor in this calculation is the cost of any additional maintenance required for saturators when using brown salt rather than white salt. If there were significant additional maintenance costs, there would be little or no benefit in using UK brown salt
4. For combination spreaders, the analyses indicated that there is a significant cost saving for all cases considered when the direct and indirect costs are taken into

account. Thus the use of combination spreaders would always result in a benefit to society as a whole. However, it is likely that the direct cost of winter service provision would be higher

5. A factor to be recognised in the use of brine may be one of public perception. Brine spreading may require additional signing on spreaders, and spreading what appears to be water on the carriageway may need to be promoted to the public to gain understanding and acceptance

2.3.2 Assumptions used in the original business case

To undertake the cost comparisons for the two treatment options described above, it was necessary to make a number of assumptions when determining the required spread rates for each treatment, and when considering the application of those rates over a winter season. The main assumptions made in the analyses are shown in Table 1

Table 1. Assumptions made in original business case

Parameter used in analyses	Assumed value	Value reviewed
Sodium chloride concentration of brine	23%	Section 6
Sodium chloride concentration of salt used to produce brine	98%	Section 6
Brine loss due to trafficking	15%	Section 5
Minimum coverage of brine across carriageway as percentage of nominal spread rate	90%	Section 4
Sodium chloride content of dry salt component of pre-wetted salt	90%	Section 6
Loss of dry salt component of pre-wetted salt due to trafficking	40%	Section 5
Minimum coverage of dry salt component in pre-wetted salt across carriageway as percentage of nominal spread rate	90%	

The values shown in the table were selected through the knowledge and experience of TRL's winter service team, the findings of a comprehensive review of relevant literature, and discussions with winter Service Providers, salt suppliers and spreader manufacturers. However, it was clear that the value chosen for some of these parameters had an important bearing on the outcome of the business case, it was therefore important that a further programme of research was undertaken to check, and if necessary modify, the values used in the analyses.

This research programme has been completed and is described in this report. Table 1 indicates the section of the report which addresses each particular assumption.

Based on the findings of the research programme described in this report, some of the assumed values were modified. The effect of these modifications is described in detail in Appendix A2, and summarised in the revised business case presented in Section 7.

3 Implications of brine treatments for new winter fleet

3.1 Background

The Agency has nearly completed the replacement of its winter fleet with pre-wet equipment with a minimum reserve capacity of 10 per cent within each area. If brine or combination spreaders are to be used, either additional spreaders must be purchased or part of the new fleet must be modified. The following reviews the implications of the different approaches.

3.2 Brine spreaders

Jordan (2010) concluded that brine spreaders would be unsuitable for the treatment of whole routes. This conclusion can also be drawn from an assessment of the winter service requirements. The brine option would require either:

(i) Modification of the existing spreaders by replacing the existing body with a tanker type body complete with spray bars

(ii) Fitting a "drop in" tank within the existing hopper body and replacing the existing spinner assembly with a spray bar set up

(iii) Purchasing additional new purpose built vehicles

The first two options are cheaper but would require the hydraulic capacity and pump assembly to be up-rated.

A further consideration when using brine spreaders is the increased volume and weight of the product needed to carry out the equivalent de-icing when compared to using dry salt or pre-wetted salt. This in practice means that the existing 6x4 and 4x4 spreaders would not be able to treat the same area of carriageway as with the pre-wet system. This would require more vehicles to meet the treatment time requirements or the requirements would need to be relaxed. However, if the requirements were relaxed, under some conditions the operating of the network could be compromised due to the increased time between repeat treatments.

The routes most suited to brine vehicles would be in areas where heavy frost and snow conditions are infrequent. However, this would not appear to be a favourable option in the light of the past two winters. British weather is not stable enough for these conditions to be accurately predicted.

For reasons of practicality, the Agency's fleet must have a "catch all capability" (except for certain areas such as bridge decks and sensitive structures which may have very specific requirements). The current fleet is a compromise, designed to meet and cope with the many types of winter weather encountered across the country, without too much specialisation.

This practical approach must extend to the reserve fleet. The Service Provider needs to know that when an additional vehicle is required either to meet a breakdown or deal with severe weather, the nearest vehicle is "fit for purpose" without requiring the need for specialised loading equipment or unique spreading materials and methods. For this reason a brine area would not be easy to service in a severe weather event when additional vehicles have to be drafted in from outside. Similarly, vehicles from a brine area may be unsuitable to supplement the capacity of an adjacent pre-wet only area.

3.3 Combination spreaders

The current pre-wet spreaders could be converted to combination spreaders by either:

(i) Re-bodying together with additional spray bars and upgrades to the hydraulics and brine pump

(ii) Partitioning the current body and dropping a tank into the front part of the existing body together with fitting spray bars and hydraulic upgrade

Both options would require additional cost and software modifications.

Any recommended treatment for a spreader should be able to be easily determined by the decision maker or else automated. When faced with a treatment matrix with a choice between "damp/moist road surface down to -5°C" or "damp/moist/wet road surface down to -2°C" the decision maker may err on the cautious side and treat the worst case. The routes on the Agency's network quite often may have any or all of the above variables existing at a particular treatment time, so worst case treatment may generally be adopted. Without a simple method to identify whether the road surface is damp, moist or wet while the spreader travels along the route combined with the ability to not only change the dose but the treatment method of applying the de-icer it is not surprising the decision maker may opt for "worst case scenario". Therefore, it is likely that there will be few nights when forecast conditions are constant for a route and even fewer when brine would be the worst case treatment for the predicted conditions. Thus, the savings that can be made in theory using combination spreaders may not be realised in practice.

Potentially savings would be maximised with spreaders equipped with live route forecasts actively coupled into the body control system to vary and change the type and dose of material spread to match the prevailing and forecast conditions at the time. Near live road surface temperatures are recorded by the Agency's spreaders and these could be fed into the route forecast. Similar work has been carried out on less sophisticated machines so it should be possible on the new winter fleet. A small scale trial over, say, a minimum of three winters, could give definitive costs, reliability and confidence in the equipment and route based forecasts. This would, in turn, give confidence to invest in this equipment and treatment method in future. It would also indicate whether the capacity of the vehicles is sufficient to satisfy all weather conditions encountered. Such a trial would also have the advantage of providing results which could be applied to pre-wet only spreading Areas.

4 Performance trials with a brine spreader

4.1 Introduction

Trials were carried out on the TRL Test Track to determine the brine distribution profile immediately after spreading with a liquid (brine) spreader. Although a liquid spreader was used the results are expected to be representative of those for a combination spreader from the same manufacturer which has the same brine spreading mechanism. The trials were carried out in December 2009 and April 2010.

The main aims of the trials were to:

- Determine the brine distribution when spreading a three lane motorway symmetrically from Lane 2 and a two lane road asymmetrically from Lane 1
- Determine whether brine treatments can be carried out at a faster speed than 64km/h
- Confirm brine can be spread effectively at a minimum spread rate of 10g/m² as assumed in the business case

4.2 Trial site description

The trial site was located on a level section within the central area of the TRL Test Track as shown in Figure 1.

Most of the surfacing in the central area is hot rolled asphalt (HRA) and the initial trials in December 2009 were carried out on this surfacing. Following the initial trials the decision was taken to resurface the trial site with a 14mm SMA, a negatively-textured thin surfacing that is representative of the majority surfacing on the Agency’s network. All subsequent trials were carried out during April 2010 on this new surfacing.

The volumetric patch texture depth of the new surfacing was measured to be 2.5mm. Being new, none of the surface voids were filled with detritus which can be the case on trafficked roads. The current Specification requires new surfacing to have a minimum volumetric patch texture depth of 1.3mm. Until recently, the minimum was 1.5mm. It is concluded that the new surfacing in the trial site is fairly open and has a higher air voids content than some surfacing on the Agency’s roads.

A proportion of the brine spread on an open, negatively-textured surface drains into the surfacing and may not be available for preventing ice formation on the road surface. Tests were carried out on both the older HRA surfacing and the new SMA surfacing in the trial site to investigate the proportion of brine spread that may be lost in this way. The results of these tests are discussed in Section 4.4.

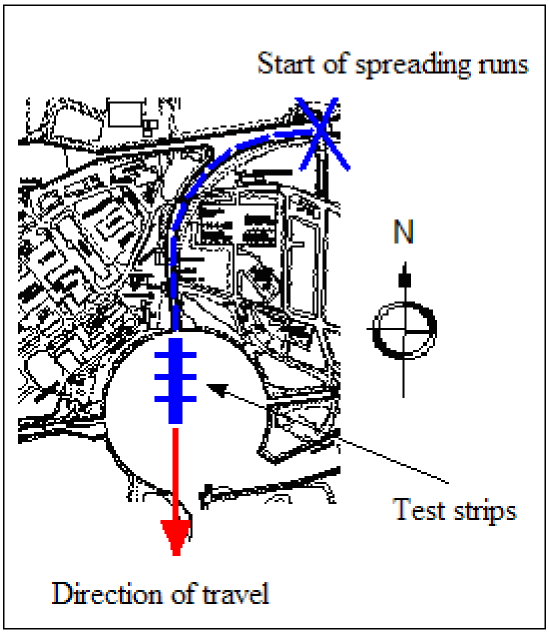

Figure 1 Layout of the TRL Test Track for brine spreading trials

4.3 Brine spreaders and spreader characteristics

The spreader used for the trials was a Schmidt Straliq liquid spreader, provided by and operated during the trials by the HA Area 3 Service Provider. This type of spreader, shown in Figure 2, discharges brine through variable flow nozzles mounted on the rear of the spreader as shown in Figure 3. A separate set of 4 nozzles is directed to each lane, allowing spraying of any individual lane (3.5m wide spread), the driven lane and any one outer lane (7m spread) or over all three lanes (10.5m spread). The spreader control panel indicates the length over which brine has been spread and the predicted amount discharged. The spreader is typically limited to spreading at speeds up to 64km/h and at rates down to 15g/m². For the purposes of the trials, the speed limitation was removed to allow spreading at 80km/h and the control system was adjusted to allow spreading at rates down to 10g/m².

The spreader was supplied from the Ower Depot in Area 3 and the brine obtained from a saturator at the same depot. Samples of brine were taken during each trial and the salt concentration measured to be in the range 22 to 23 per cent.

Before commencing the trials, a Schmidt engineer visited the Area 3 depot to calibrate the spreader for sodium chloride brine spreading and provide training to the Area 3 personnel who would be involved in the trials.

Figure 2. Schmidt Straliq liquid spreader

Figure 3. Mounting of nozzles on Straliq spreader

4.4 Brine collection method and recovery rate

The brine spread during each trial was collected from a series of test panels by vacuuming using the wet wash method developed by TRL. The standard method involves the following steps:

1. Dry vacuum the panel in one direction
2. Switch on the vacuum cleaner spray and “wet” vacuum the panel in two directions, perpendicular to each other
3. Switch off the vacuum cleaner spray and “dry” vacuum the panel in three directions, perpendicular to each other

This method has been used extensively for previous salting trials and validated by testing with untreated and treated rock salt.

For trials using the brine spreader, the number of wet passes with the vacuum (step 2 above) was increased from two to three to make sure that as much brine as possible was collected. Tests using known amounts of brine spread on the HRA surfacing during trials in December 2009 had shown that a brine recovery rate of 90 per cent or greater could be achieved, which provided confidence in this method of collection.

However, during the brine spreader trials, carried out in early April 2010 on the new SMA surfacing, tests using known amounts of brine indicated that on average around 59 per cent of the brine was being recovered.

More details on the testing and the results obtained are included in Appendix B.

4.5 Trial procedure

The spreader was operated during the trials by trained Area 3 personnel.

The trials investigated spreading at two spread widths, 7m (two lanes) and 10.5m (three lanes), spread rates ranging from 10g/m² to 40g/m², and two spreading speeds of 64 and 80km/h.

The first three trials were carried out on the HRA surfacing and all subsequent trials were carried out on the new SMA surfacing. Details of each trial are shown in Table 2.

Table 2. Brine spreader trial details

Trial no.	Trial date	Spread width (no. of lanes)	Brine spread rate (g/m^2)	Spreading speed (km/h)
B1*	10/12/2009	3 symmetric	40	64
B2*	10/12/2009	2 asymmetric	15	64
B3*	10/12/2009	2 asymmetric	40	64
B4	07/04/2010	2 asymmetric	10	64
B5	07/04/2010	2 asymmetric	10	80
B6	07/04/2010	2 asymmetric	20	64
B7	08/04/2010	2 asymmetric	20	80
B8	08/04/2010	3 symmetric	20	80
B9	08/04/2010	2 asymmetric	40	80

* Trials on HRA surfacing

The test site was marked out for collection of the brine from three strips running transversely to the direction of travel of the spreader. The positions of the test strips and panels used for the collection of the brine are shown in Figure 4 and Figure 5 for three lane and two lane spreading, respectively. The lanes marked out were 3.6m wide, the standard lane width on the network, although the spreader was set to spread over a 3.5m width for each lane.

For each trial, the spreader used a length of the TRL Test Track to achieve the correct speed before starting to spread. The spreader commenced spreading 50m before the first strip and spreading stopped 50m after the last strip.

After spreading, the brine was collected from the panels by vacuuming using the wet wash method (three wet passes as described in Section 4.4). Between trials, a road sweeper was used to remove the residual brine from before and between the strips to prevent brine being carried by the wheels of the spreader into the test panels in subsequent trials.

Conductivity analysis of the saline solutions recovered from each panel was used to determine the effective amount of brine in each panel, i.e. the amount of brine that would have resulted in the conductivity measured.

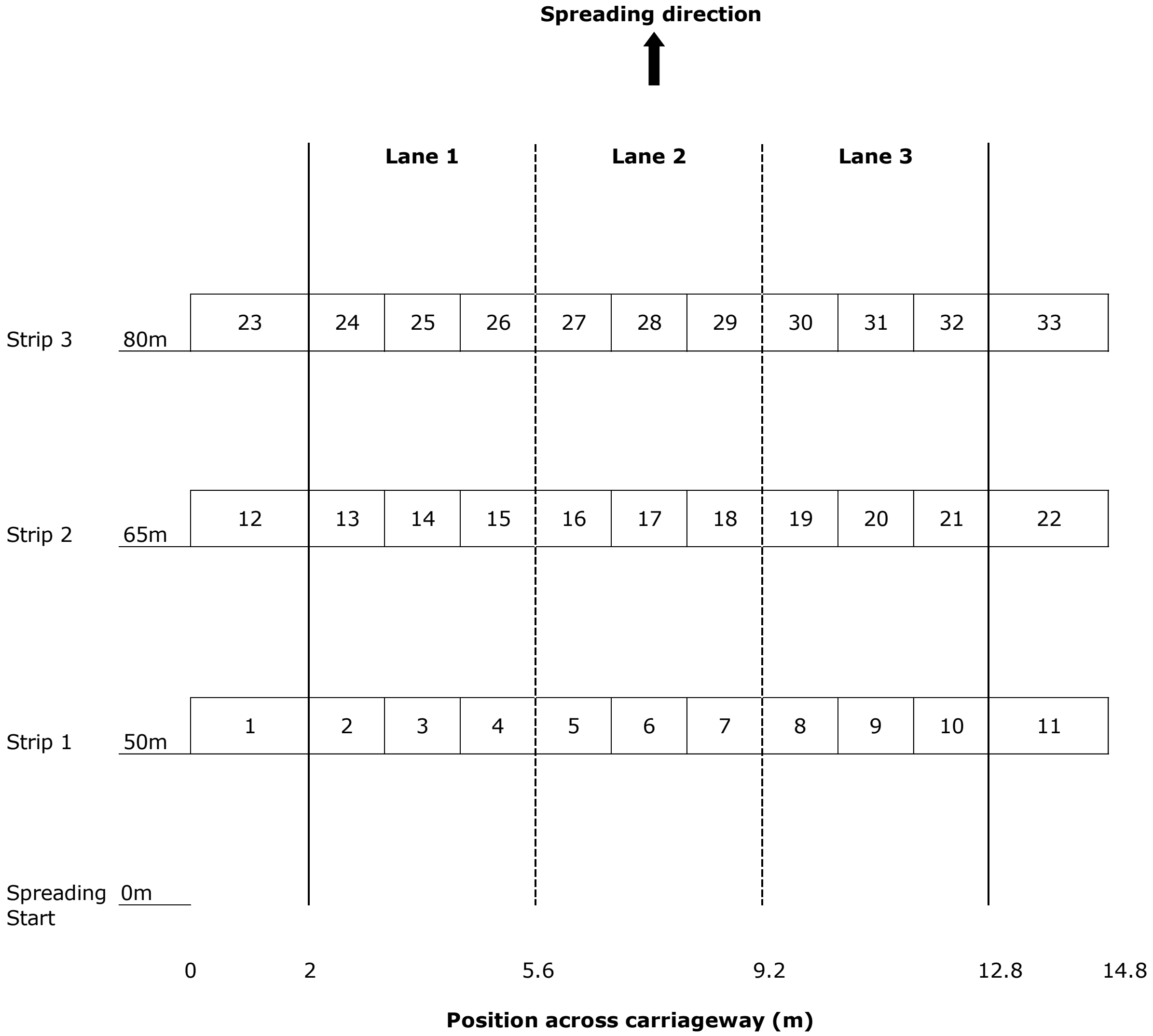

Figure 4. Layout of collection panels for three lane spreading

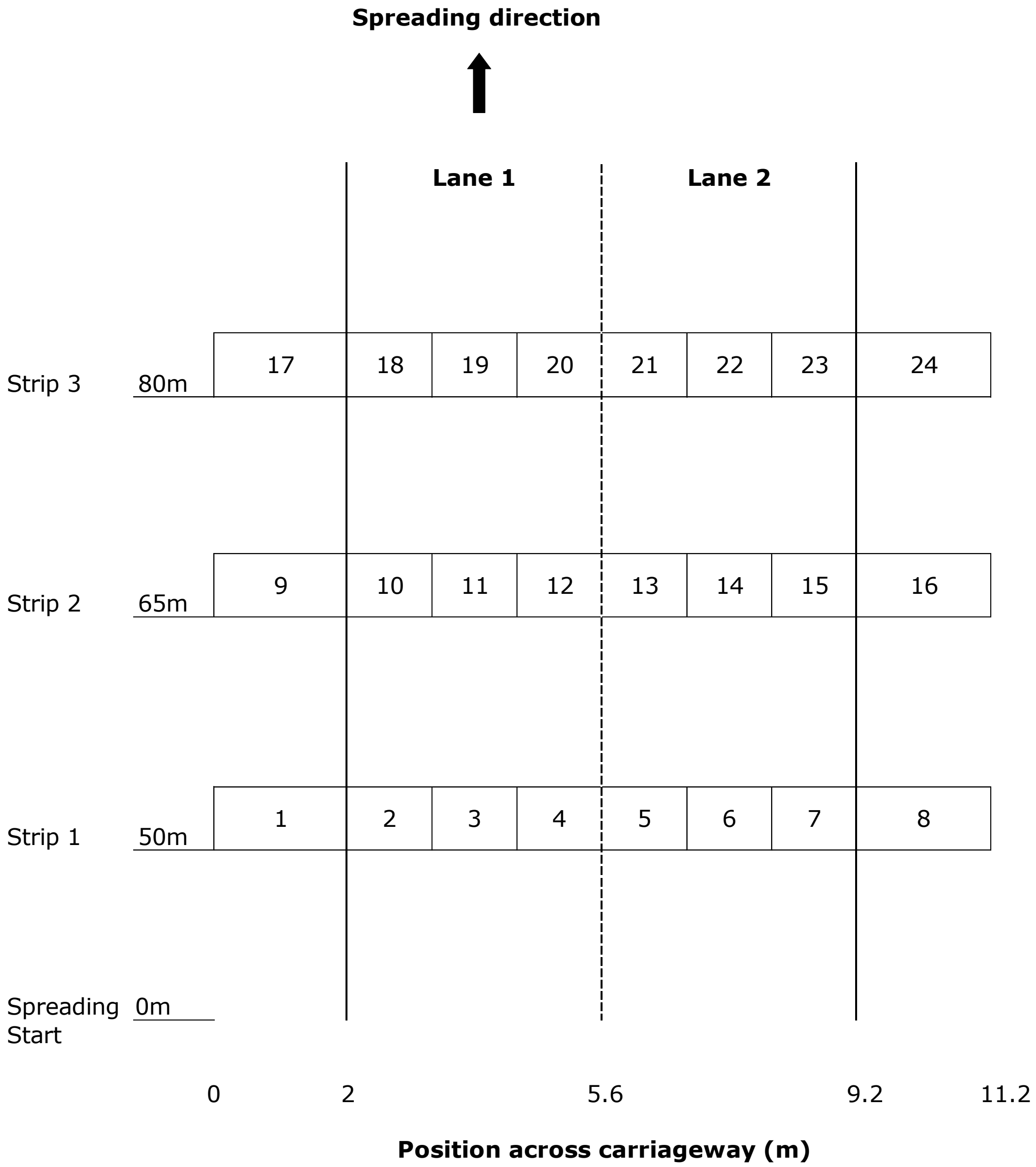

Figure 5. Layout of collection panels for two lane spreading

4.6 Weather conditions

The wind speed and direction for each trial are shown in Table 3.

Table 3. Brine spreader trial climatic information

Trial no.	Mean wind speed (gust) (mph)	Direction	Direction relative to site
B1	1 (2)	W	Lane 3 to Lane 1
B2	1 (2)	W	Lane 3 to Lane 1
B3	1 (2)	W	Lane 3 to Lane 1
B4	4 (5)	N	In spreading direction
B5	2 (3)	N	In spreading direction
B6	1 (2)	N	In spreading direction
B7	1 (2)	N	In spreading direction
B8	1 (2)	N	In spreading direction
B9	1 (2)	N	In spreading direction

4.7 Results

4.7.1 Recovery correction

The aim of the performance trials was to determine the amount and the distribution of the brine being spread. As discussed in Section 4.4, tests showed that a very high proportion of the brine spread on the HRA surfacing could be recovered, but the open texture of the new SMA surfacing meant that only about 59 per cent of the brine spread could be recovered using the wet wash recovery method used in the trials.

In the following analysis it has been assumed that 100 per cent of the brine spread was recovered for the HRA surfacing. For the SMA surfacing, the amount of brine recovered from each panel has been increased by a factor of 1.69 (=100/59) to account for the losses due to the porous nature of the surfacing.

4.7.2 Brine distribution profiles

The average brine distribution profiles for the strips in each trial are compared in Figure 6 to Figure **11**. The results for the brine collected from each strip in each trial are shown in Appendix C. The results for trials B4 to B9 have been increased by the factor of 1.69 to account for the brine that was not collected but drained into and was "absorbed" by the porous texture. In each figure, the target spread rate is indicated by a horizontal line.

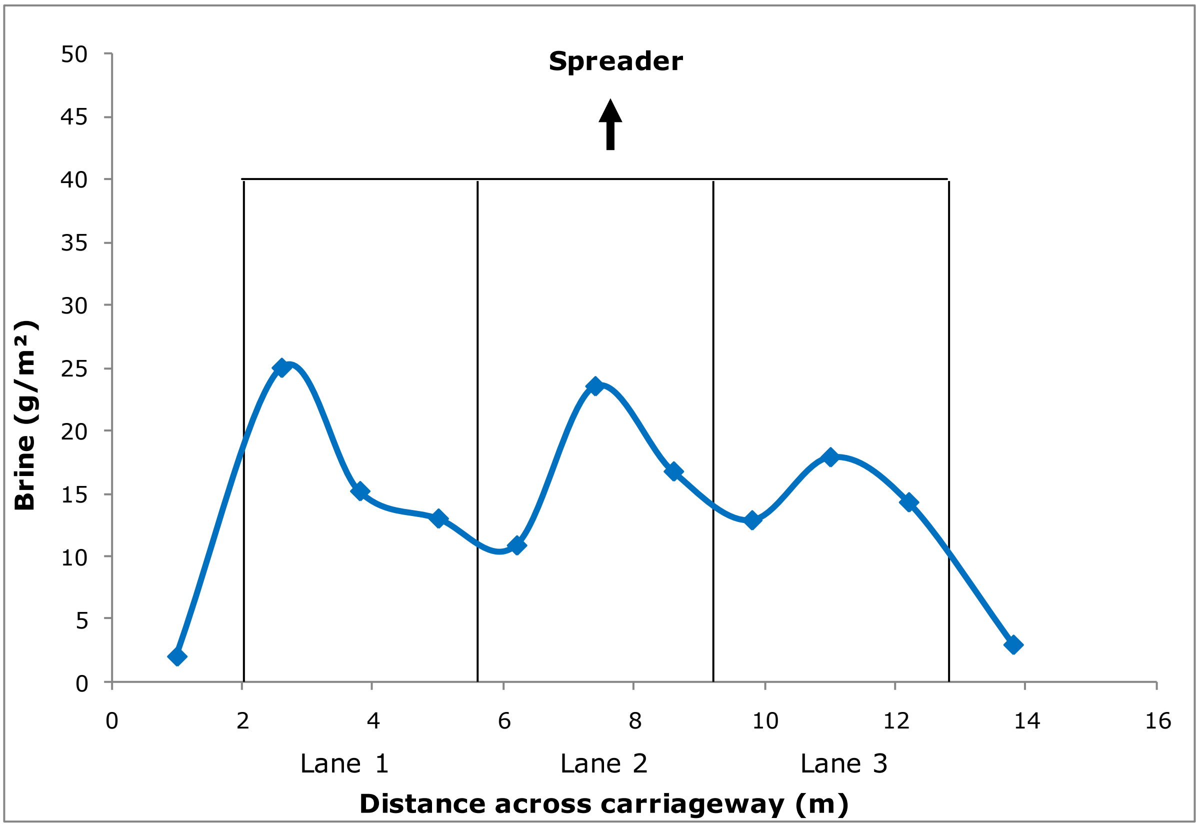

Figure 6. Spreading three lanes symmetrically, 40g/m², 64km/h (Trial B1)

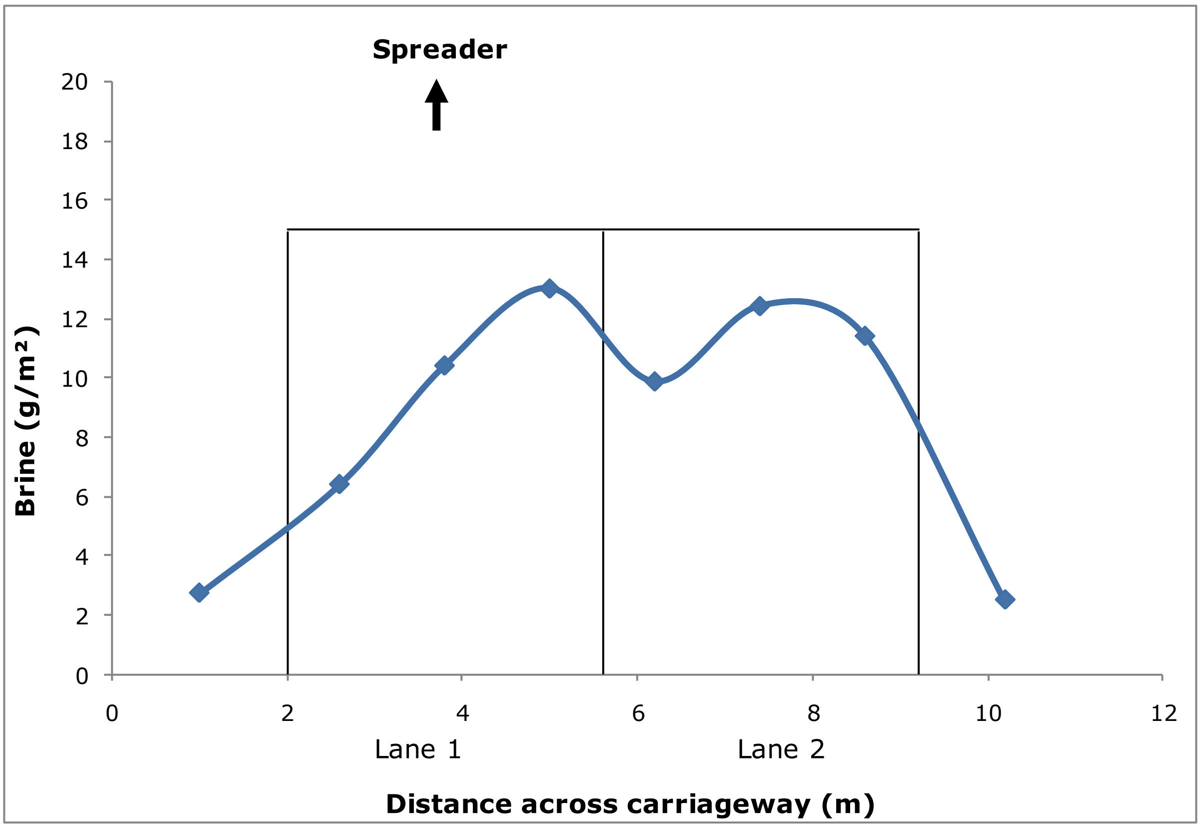

Figure 7. Spreading two lanes asymmetrically, 15g/m², 64km/h (Trial B2)

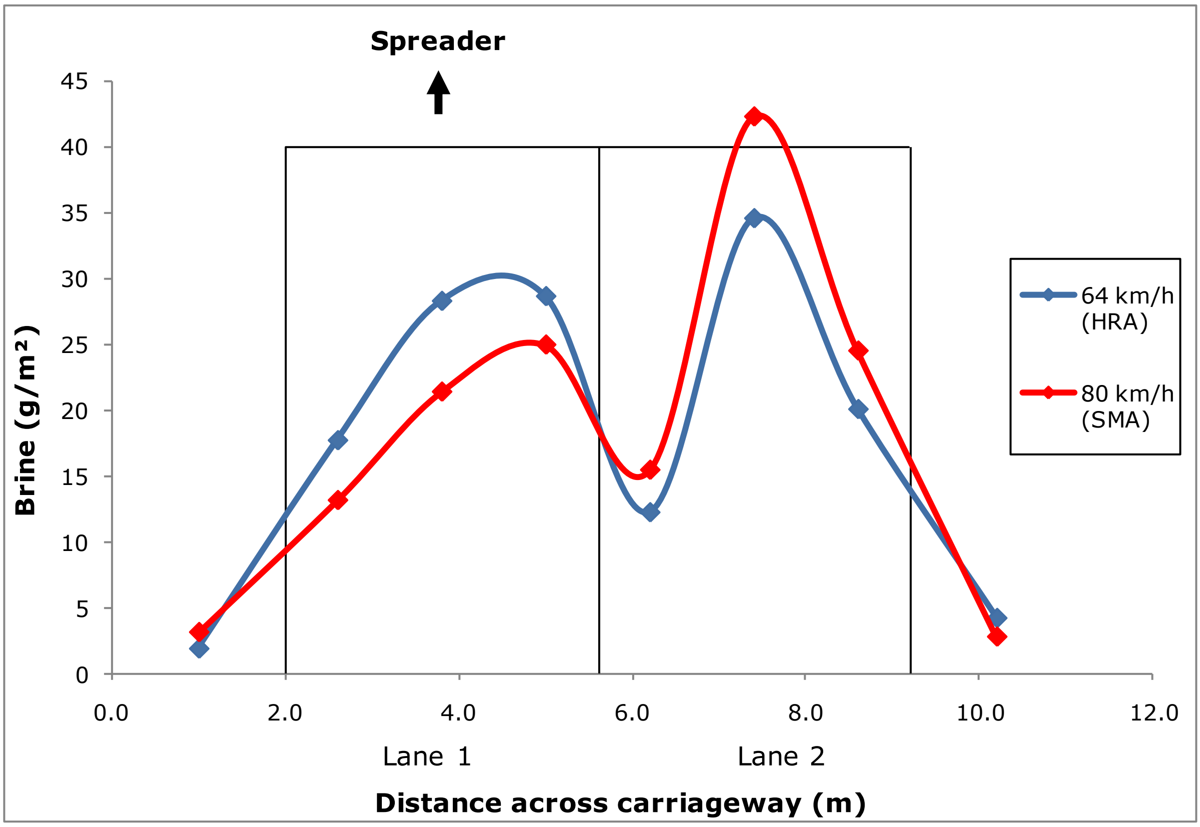

Figure 8. Spreading two lanes asymmetrically, 40g/m², at 64km/h on HRA surfacing (Trial B3) and 80km/h on SMA surfacing (Trial B9)

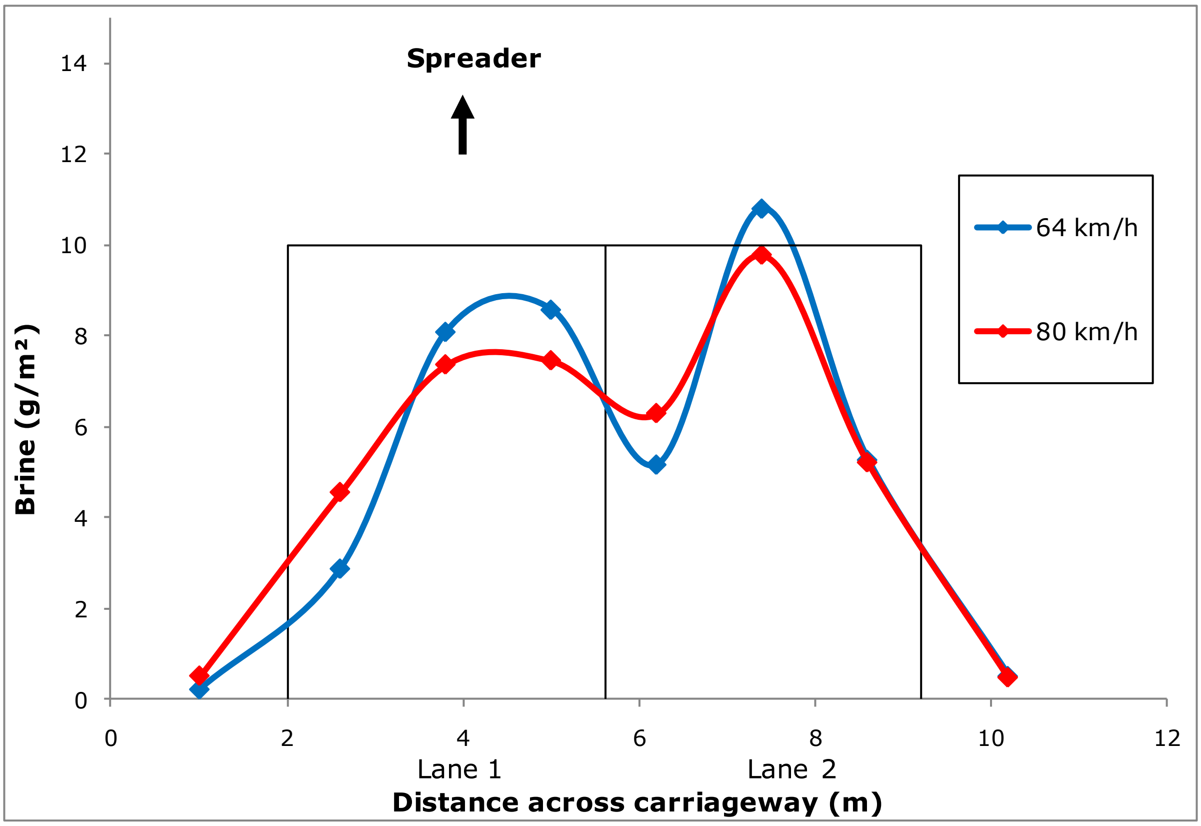

Figure 9. Spreading two lanes asymmetrically, 10g/m², at 64km/h (Trial B4) and 80km/h (Trial B5)

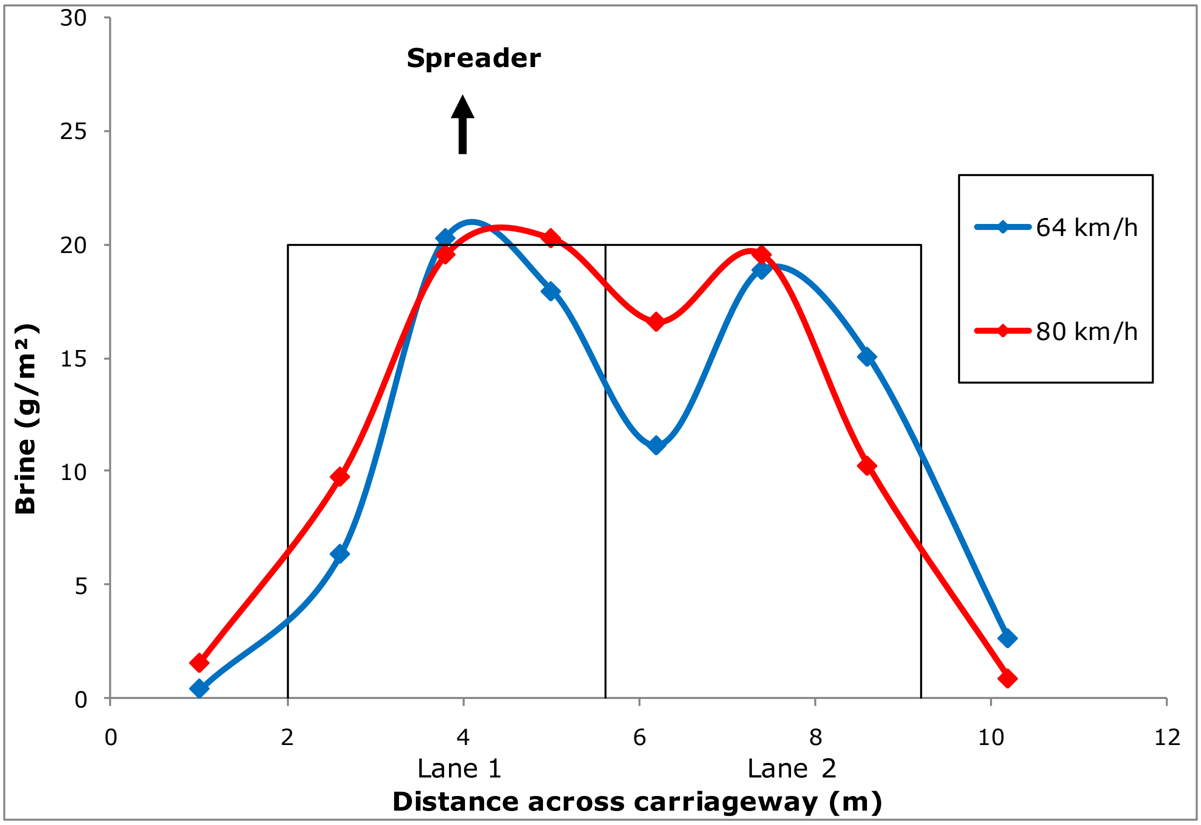

Figure 10. Spreading two lanes asymmetrically, 20g/m², at 64km/h (Trial B6) and 80km/h (Trial B7)

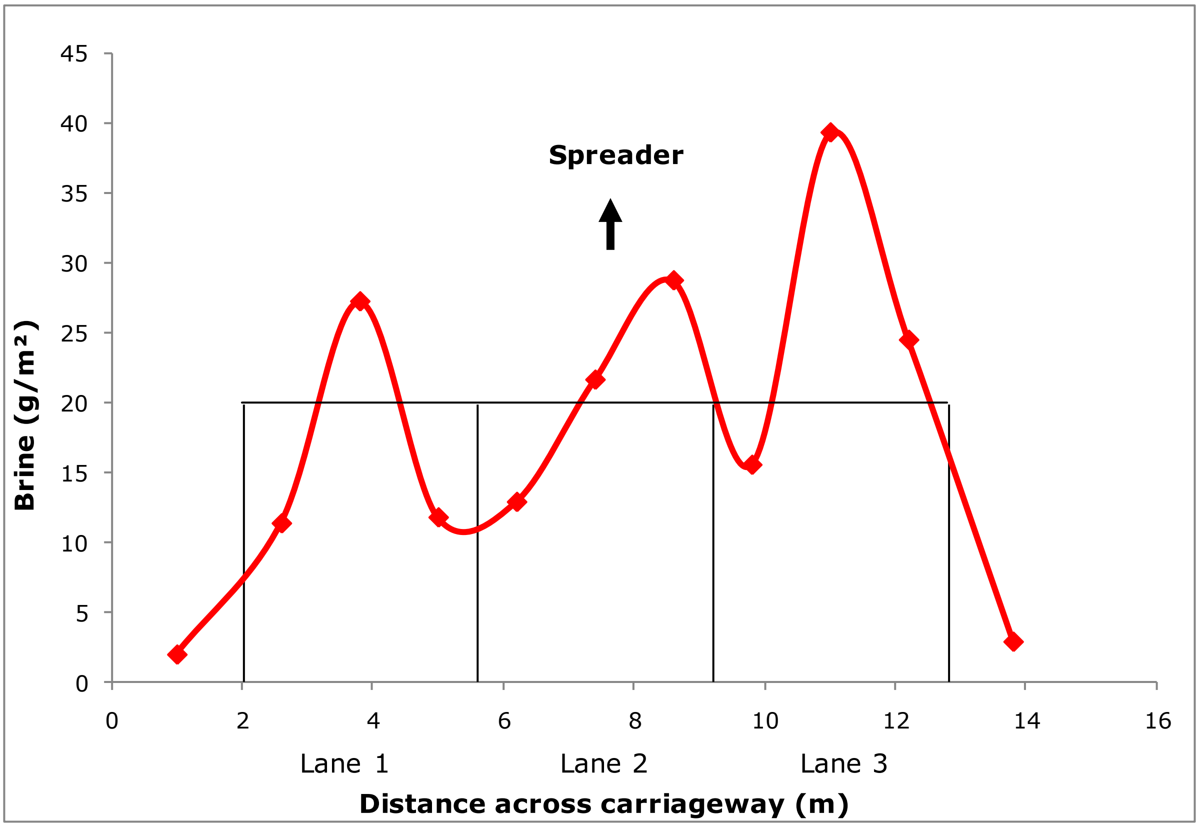

Figure 11. Spreading three lanes symmetrically, 20g/m², 80km/h (Trial B8)

4.7.3 Brine discharged

To determine whether the total amount of brine discharged during the trials corresponded to the target amount, a 2km discharge test run was carried out during the testing on the 7th and 8th of April. The spreader was weighed before and after spreading at a local weighbridge and the amount of brine discharged, as indicated by the brine counter on the spreader, was compared with the difference in weight measured on the weighbridge.

The discharge test was carried out at 80km/h when spreading three lanes (i.e. 10.5m spread width) at 20g/m². The target amount of brine discharged was therefore 420kg (= 20g/m² x 10.5m x 2000m).

The difference in weight measured on the weighbridge was 420kg. This could be in error by ± 40kg because the weighbridge measurement had a resolution of 20kg. The spreader therefore discharged the correct amount of brine to within an accuracy of 10 per cent.

The brine counter indicated that 355 litres of brine had been discharged. Therefore, assuming a brine density of 1200kg/m³, the brine counter was also in agreement with weight discharged to an accuracy of 10 per cent.

4.7.4 Brine collected

Table 4 summarises the results from each trial by lane. Column 8 shows the difference between the maximum and minimum values of coverage per lane expressed as a percentage of the mean coverage within the lanes. This gives an indication of the uniformity of the distribution across the lanes.

Table 5 shows the factored total amount of brine collected in each trial. Column 4 expresses the total amount of brine collected as a percentage of the target amount. Column 5 shows the percentage of the total amount collected that was collected from the lanes. Columns 6 and 7 show the amount of brine collected from the left and right verges, expressed as a percentage of the total amount collected.

Table 6 shows the strip to strip variation in the amount of brine collected from the whole strip. Columns 4 to 6 show the amount collected from each whole strip as a percentage of the mean of the three strips. Column 7 shows the maximum minus the minimum variation for the whole strips which gives an indication of the longitudinal snaking.

Table 4. Coverage by lane

Trial no.	Target spread rate (g/m²)	Speed (km/h)	Spread rate as % of target spread rate				Max – Min as % of mean for Lanes
			Lane 1	Lane 2	Lane 3	Lanes 1 to 3	
B1*	40	64	44	43	38	42	16
B2*	15	64	66	75	-	71	12
B3*	40	64	62	56	-	59	11
B4	10	64	65	71	-	68	8
B5	10	80	65	71	-	68	9
B6	20	64	74	75	-	75	1
B7	20	80	83	77	-	80	7
B8	20	80	84	105	132	107	45
B9	40	80	50	69	-	59	32

* Trials on HRA surfacing

Table 5. Amount collected and wastage

Trial no.	Target spread rate (g/m²)	Speed (km/h)	Accuracy (% of target)	Brine in Lanes Factored total collected (%)	Wastage	
					Left (%)	Right (%)
B1*	40	64	45	95	2	3
B2*	15	64	83	88	6	6
B3*	40	64	65	93	2	5
B4	10	64	72	97	1	2
B5	10	80	72	96	2	2
B6	20	64	84	95	1	4
B7	20	80	89	96	3	1
B8	20	80	115	96	2	2
B9	40	80	65	94	3	3

* Trials on HRA surfacing

Table 6. Strip by strip variation

Trial no.	Target spread rate (g/m²)	Speed (km/h)	Full width of strip			
			Percentage of mean (%)			Max - Min of Strips as % of Mean
			Strip 1	Strip 2	Strip 3	
B1*	40	64	113	84	103	30
B2*	15	64	91	-	109	18
B3*	40	64	94	-	106	12
B4	10	64	80	112	108	31
B5	10	80	87	90	122	35
B6	20	64	91	101	108	18
B7	20	80	112	89	99	24
B8	20	80	107	108	86	22
B9	40	80	80	106	114	34

* Trials on HRA surfacing

4.8 Discussion

The distribution to the lanes was generally very even, in particular for spreading over two lanes where the maximum minus the minimum spread rate in a lane, as a percentage of the average, was generally less than 10 per cent. The same indicator of the spread distribution showed values of 16 per cent and 45 per cent for the two trials carried out over three lane spreading.

The strip to strip variation in the brine collected, expressed as the maximum minus minimum amount divided by the average, was 25 per cent averaged across all the trials. This degree of variation was similar to the average value of 27 per cent measured when spreading 6.3mm pre-wetted salt in distribution trials on spreaders from the Agency's new winter fleet (Evans et al, 2010B).

The distribution profile was not uniform across the target spread width and there were distinct dips in the profile at the edges of each lane. This appears to be a result of how the brine was discharged from the nozzles used to spread to each lane. Brine is discharged in a fan shape from each nozzle spreading the lane directly behind the spreader, resulting in an even spread of brine across the lane width. In order to distribute brine to the outer lanes, the brine is sprayed in distinct 'jets' as clearly shown in Figure 3. This appears to result in a less even spread across the lane, with the brine applied in more distinct lines along the carriageway and a gap between where the brine is spread in the lane behind the spreader and where the brine is distributed to each outer lane. It is possible that the brine distribution across the lanes will be evened out to some extent by the action of traffic. While the spreader was calibrated for the purposes of spreading brine for these trials, it is likely that the distribution could be further optimised to produce a more even spread.

Comparison of the distribution profiles when spreading at 64km/h and 80km/h, as shown in Figure 8, Figure 9 and Figure 10, indicates that the dip between the lanes is less pronounced when spreading at the higher speed, possibly as a result of the increased turbulence behind the spreader and the speed differential with the surrounding air disrupting the jets of brine. Otherwise the distribution profiles were very similar for spreading at the two speeds.

Wastage of the brine by spreading outside the lanes was very low, with more than 90 per cent of the total brine being collected from within the lanes in all but one of the trials. This compares well with the wastage in the performance trials that were carried out in accordance with contractual arrangements for the Agency's new winter fleet. In the trials with pre-wetted salt, typically only 80 per cent of the total salt spread was within the lanes, although the spread width was 13m for the pre-wetted salting so salt was spread to the hard shoulder.

Despite the low wastage, the amount collected from the lanes was significantly lower than the target amount for most trials. Trial B8, where spreading was at 20g/m² and 80km/h over three lanes, showed reasonable agreement with the target amount. The discharge test over 2km had also shown that the correct amount of brine was being discharged when spreading at 80km/h over three lanes at 20g/m². Therefore, this gave confidence that the spreader performed consistently for each spread rate and width setting. Hence, it may be that optimisation of the spreader settings are required for each setting.

Overall assessment

In summary, with reference to the main aims of the trial:

1) Determine the brine distribution for spreading a three lane motorway symmetrically from Lane 2 and a two lane road asymmetrically from Lane 1:

The trials show that brine can be spread fairly evenly to two or three lanes. However, the brine distribution profile is less flat than the distribution profile for pre-wetted salt; there was a distinct dip in the distribution between each lane and a rapid fall off towards the edge of the carriageway. The brine was targeted within the lanes effectively with very little wastage (<10 per cent).

While the spreader was calibrated for the purposes of spreading brine for these trials, it is likely that the distribution could be further optimised to produce a more even spread.

2) Determine if brine treatments can be carried out at a faster speed than 64km/h

Comparison of trials with the same spread rate and spread width at 64km/h and 80km/h have clearly demonstrated very similar distributions at the two speeds. There was no significant difference in the uniformity of the distribution across and along the carriageway at the different speeds. The jets of brine spread to the outer lanes appeared to be disrupted more by the increased spreading speed however this was not seen as detrimental to the final distribution. The results therefore show that spreading can be carried out at 80km/h as effectively as 64km/h.

3) Confirm a minimum spread rate of 10g/m² can be spread effectively

There was no evidence of any significant change in the uniformity or targeting of the lanes when spreading at a target spread rate 10g/m² compared to the higher rates. In fact, the mean spread rate was 6.8g/m² in Trials B4 and B5 so a reasonably uniform distribution can be achieved when spreading at less than 10g/m². However, when spreading at low rates, it will be necessary to ensure that the spreader performance is optimised to ensure the correct spread rate is achieved within the lanes.

5 Road trials to determine residual salt levels after trafficking

5.1 Introduction

In the business case prepared by TRL for brine treatments on the Agency's network, estimates were made regarding the effect of trafficking on residual salt levels after brine treatments. Based on work carried out in Europe, a 15 per cent loss was assumed after 2 hours trafficking. In order to investigate the accuracy of this figure in relation to the type of road surfacing found on the Agency's network, two road trials were carried out on the M3 in Hampshire measuring the effect of trafficking on residual salt levels two hours after spreading.

Traffic travelling adjacent to spreaders when they are spreading brine may also prevent the brine reaching some areas of the carriageway. The effect of traffic during spreading was therefore investigated by visual assessment of the spreading of liquid de-icer on the Second Severn Crossing and Avonmouth Bridge in Area 2. The observations are discussed in Section 5.8.

5.2 M3 trial site description

The trial site was on a section of the two-lane southbound carriageway of the M3 between the exit and entry slip roads at Junction 9. The longitudinal gradient and crossfall of the carriageway were negligible. There was a slight curvature, but this was not considered significant in terms of the initial brine distribution and trafficking effects. The surfacing material was a negatively-textured thin surfacing system in Lane 1 and a dense HRA surfacing in Lane 2. In Lane 1, the surfacing changed from an HRA surfacing to the negatively-textured surfacing at the start of the test site.

The mean texture depths (SMTD) in Lane 1 and Lane 2, according to data in the Highways Agency's Pavement Management System (HAPMS), are shown in Table 7. Measurements by TRL on a range of surfacings have found that, on average, the SMTD is 0.78 times the volumetric patch texture depth (although this value may not be precisely accurate for the thin surfacing system at the trial site). However, assuming a value of 0.78 as reasonable, the volumetric patch texture depths have been calculated from the SMTD values and are included in the table. A low SMTD is considered to be 0.8mm. The texture depth is lower than the SMA surfacing on the TRL Test Track (see Section 4.2) but still relatively high compared to the minimum requirement of 1.3mm for new surfacing.

Table 7. M3 texture depth

Lane	Texture depth (mm)	
	SMTD	Estimated volumetric patch
1	1.57	2.01
2	1.48	1.90

5.3 Brine spreader and spreader characteristics

The road trials used the same Schmidt Straliq liquid spreader that was used for the performance trials described in Section 4.

The brine used for the road trials was obtained from the Area 3 Dummer depot at Junction 7 of the M3. Measurements of the brine showed the concentration to be 23 per cent, the same brine concentration used for the performance trials.

5.4 Trial procedure

5.4.1 Spreading over the trial site

The spreader was operated by personnel from Area 3, with a TRL representative also travelling in the spreader. The spreading was carried out with the trial site open to traffic.

For both trials, spreading was carried out at 20g/m² and 80km/h, spreading from Lane 1 across both Lane 1 and Lane 2. Spreading took place over a distance of at least 1.5km and therefore continued beyond the trial site. The weight of the spreader was measured before and after spreading at the Dummer Depot using a single axle weighbridge. The distance over which the brine was spread and the amount of brine discharged was also recorded using the spreader's brine counter.

Spreading was carried out at 9.30pm in Trial 1 and 8.30pm in Trial 2.

5.4.2 Residual brine measurements after trafficking

Approximately 2 hours after spreading, the trial site was closed to traffic and the positions where brine was to be collected were identified and marked out on the carriageway. For each trial, brine was collected from four strips spaced 40m apart. Each strip comprised 8 adjacent panels, of dimension 1m long (in the direction of travel) x 1.2m wide, with two panels in the hard shoulder and three in each lane.

A length of carriageway at the start of the trial site was left unsalted to allow measurements of the background salt level to be made across the lanes and hard shoulder. These background measurements were taken from a strip of 8 panels similar to the test strips described above. The positions of the test strips and the panels from which background salt was collected are shown in Figure 12. Spreading in Trial 2 started 50m after spreading in Trial 1 so that background levels could be measured that included what was spread in Trial 1. The salt was collected by vacuuming using the same wet wash method as used for the performance trials, as detailed in Section 4.

Conductivity analysis of the saline solutions recovered from each panel was used to determine the effective amount of brine in each panel. i.e. the amount of brine that would have resulted in the conductivity measured.

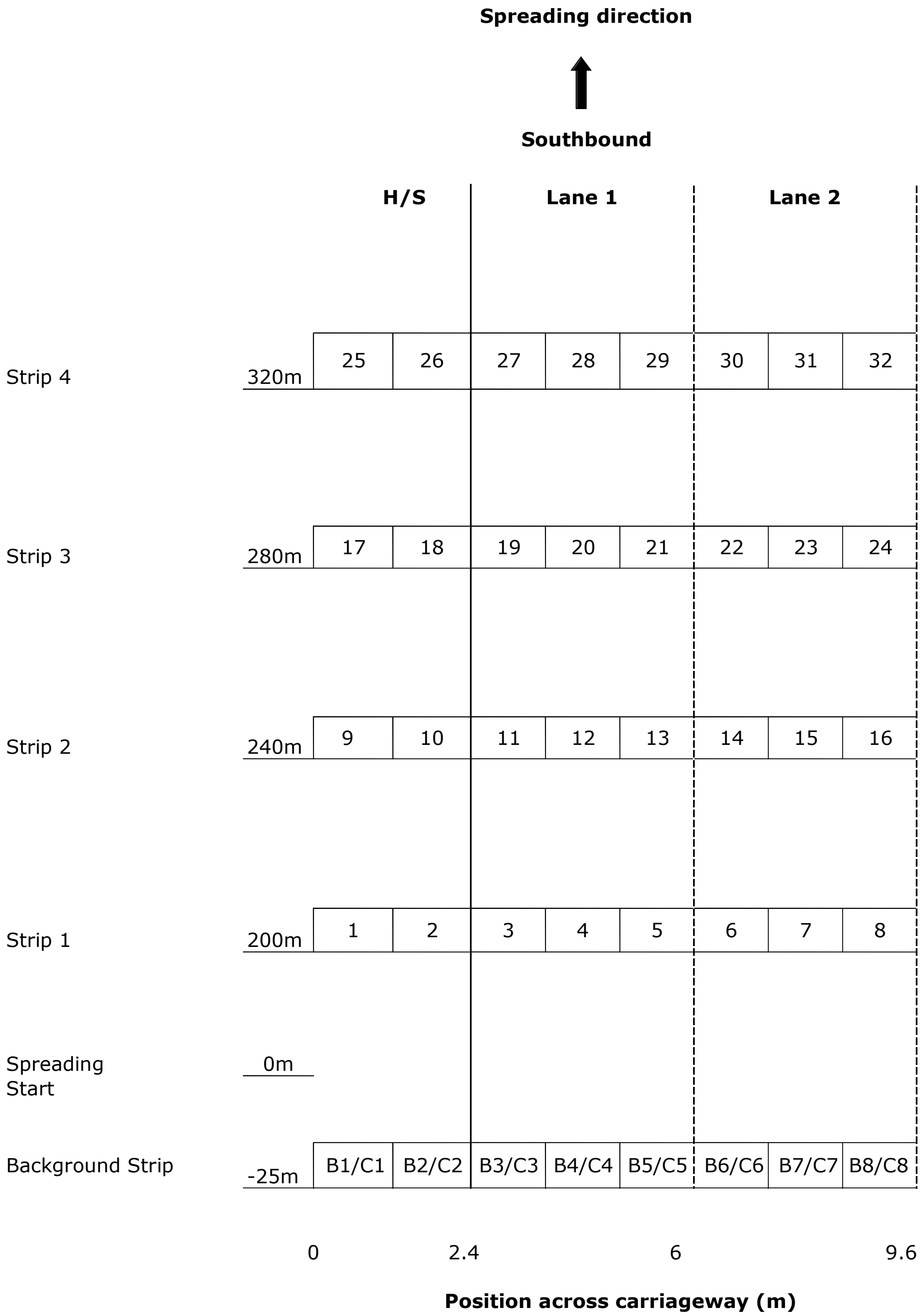

Figure 12. Salt collection positions: after 2 hours trafficking

5.4.3 Traffic counts after spreading

Traffic counts of the numbers of light and heavy vehicles in each lane passing through Junction 9 of the M3 were undertaken during the two hour period following spreading and before the site was closed to traffic. The counting was done manually by TRL staff from the over bridge and back-up footage was recorded by a video camera.

5.4.4 Weather conditions

During spreading and each salt collection, measurements were made of the wind speed and direction, the air temperature and the relative humidity at the trial site.

Generally, the conditions were similar at the time of spreading during both trials. During Trial 1, the temperature was around 11°C, the relative humidity was 60 per cent and there was a low wind speed of 1 mph. During Trial 2 the temperature was around 9°C, the relative humidity was 75 per cent and the wind speed was less than 1 mph.

For both trials the surface was dry during spreading. Trial 2 was carried out two days after Trial 1 and moderate rainfall occurred during the night following Trial 1.

5.5 Results

5.5.1 Total brine discharged

The amounts of brine discharged as recorded by the brine counters and measured on the weighbridge are shown in Table 8. The weighbridge measurement in Trial 1 showed good agreement with the target amount, however in Trial 2 the measurement was significantly lower at 63 per cent of the target.

Repeat measurements on the weighbridge indicated a potential 60kg range in each reading obtained, therefore a 120kg uncertainty in the difference between measurements. This is a significant uncertainty compared to the amount of brine discharged in the trials. The weighbridge readings were therefore not considered sufficiently accurate to draw definite conclusions on the amount of brine discharged.

Table 8. Amount of brine discharged in each trial as recorded on brine counters and calculated from weighbridge measurements

Trial	Date	Vehicle speed (km/h)	Distance spread (m)	Brine discharged (l)		Target (l)
				Brine counter	Weighbridge measurement*	
1	25/05/10	80	1572	183	192	183
2	27/05/10	80	1706	215	125	199

* Litres calculated assuming a brine density of 1200kg/m³

5.5.2 Background salt levels before spreading

Table 9 shows the average amount of background salt measured in each road trial, expressed as the equivalent amount of brine spread that would produce the same conductivity reading.

Table 9. Background residual salt levels, material type in brackets

Trial	Residual salt, expressed as equivalent amount of brine (g/m²)		
	Hard shoulder (HRA)	Lane 1(SMA)	Lane 2(HRA)
1	0.3	2.7	0.4
2	0.3	1.5	0.3

There is a clear difference between Lane 1 and Lane 2, with a higher residual salt level in Lane 1. This would appear to be a result of the differing material types across the two lanes, with the negatively-textured surface in Lane 1 retaining more, although little, salt. This was despite there being no recent salting activities.

The background levels in Lane 1 were lower in Trial 2 than Trial 1, despite including any residual salt from the first trial. As discussed, there was moderate rainfall between the trials which would likely have washed away much of the residual salt from Trial 1. Another potential factor was the variation in the type of surfacing along Lane 1. The surfacing in Lane 1 changed from HRA surfacing to negatively-textured surfacing at the start of the trial site. The background strips for Trial 1 were located within 10m of the surfacing change. Solid de-icer has a greater tendency to get trapped in the surface texture of negatively-textured surfacing than in (on) HRA surfacing. Because of this, residual salt levels tend to stay higher for longer on negatively-textured than on thin surfacing (see Table 9). Therefore, any solid de-icer spread during normal spreading before Trial 1 that was transported along the HRA surfacing and was carried over onto the negatively-textured thin surfacing would have had a tendency to get trapped in the surface texture. It is thought that this effect would have been responsible for an atypical increase in the residual salt at the start of the negatively-textured section. Background measurements for Trial 2 were taken from 50m further along the carriageway and would have been less subject to this effect. For this reason, the background level for Trial 2 is considered more representative and this level has been used to estimate losses due to trafficking.

5.5.3 Traffic levels during trials

The numbers of light and heavy vehicles within each lane during the two trials are shown in Table 10. Light vehicles (LVs) are cars, taxis, small vans etc. and heavy vehicles (HVs) are all other goods vehicles, buses and coaches. Motorcycles are not included.

It can be seen that, as might be expected, traffic was higher in Lane 1 than Lane 2 and the majority of heavy vehicles travelled in Lane 1. Traffic levels were much higher in Trial 2 compared to Trial 1; spreading was earlier in the evening in Trial 2.

Table 10. Number of light and heavy vehicles during 2 hour trafficking period

Trial	Lane 1			Lane 2			Total
	LV	HV	Total	LV	HV	Total	
1	638	80	718	262	0	262	980
2	1124	106	1230	733	4	737	1967

5.5.4 Brine distributions after trafficking

Figure 13 shows the average brine distributions measured after trafficking for both trials, with the background levels included. Figure 14 and Figure 15 show the distributions with the background levels measured in Trial 1 and Trial 2, respectively, subtracted. Both background levels have been assumed to cover the range of background levels present along the trial site. Figure 16 to Figure 21 show the distribution for each strip in each trial, again with the background levels included and with the background levels for both Trial 1 and Trial 2 subtracted. In all figures the target spread rate is indicated by the horizontal bar.

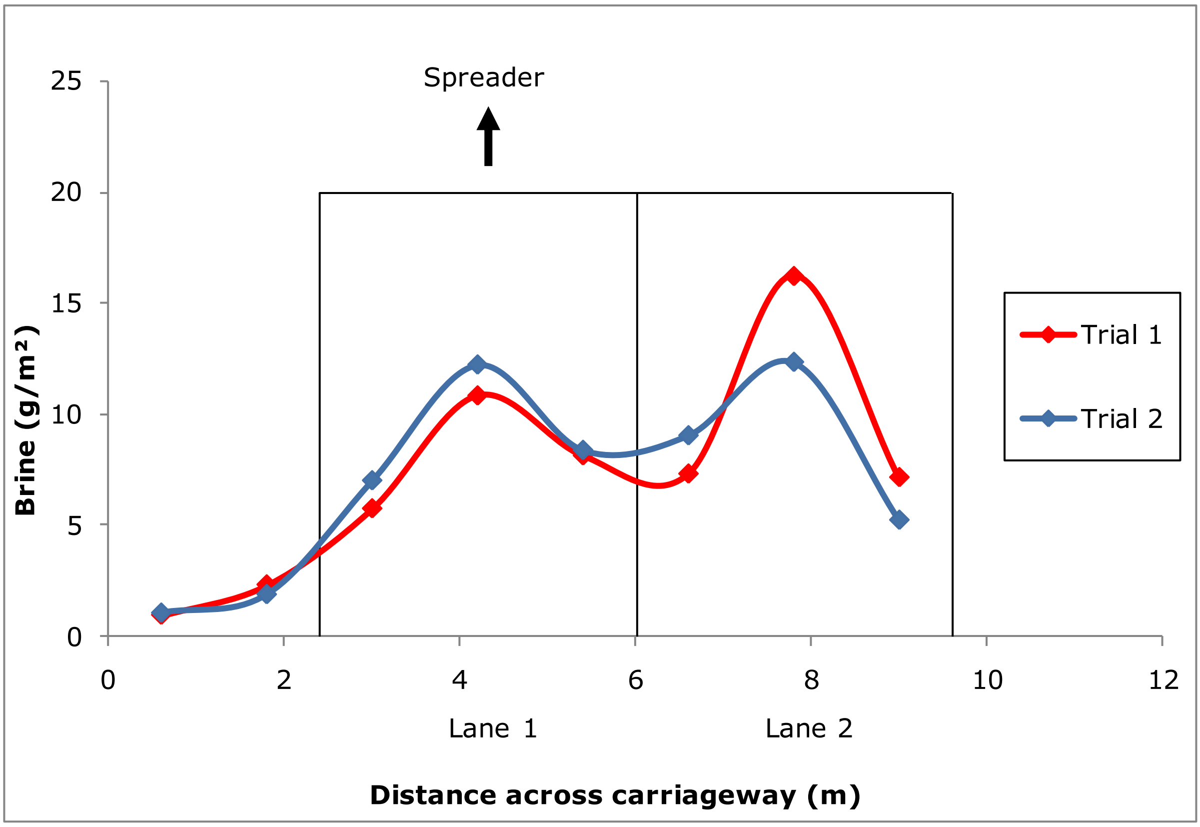

Figure 13. Comparison of average brine distribution after trafficking – background levels included

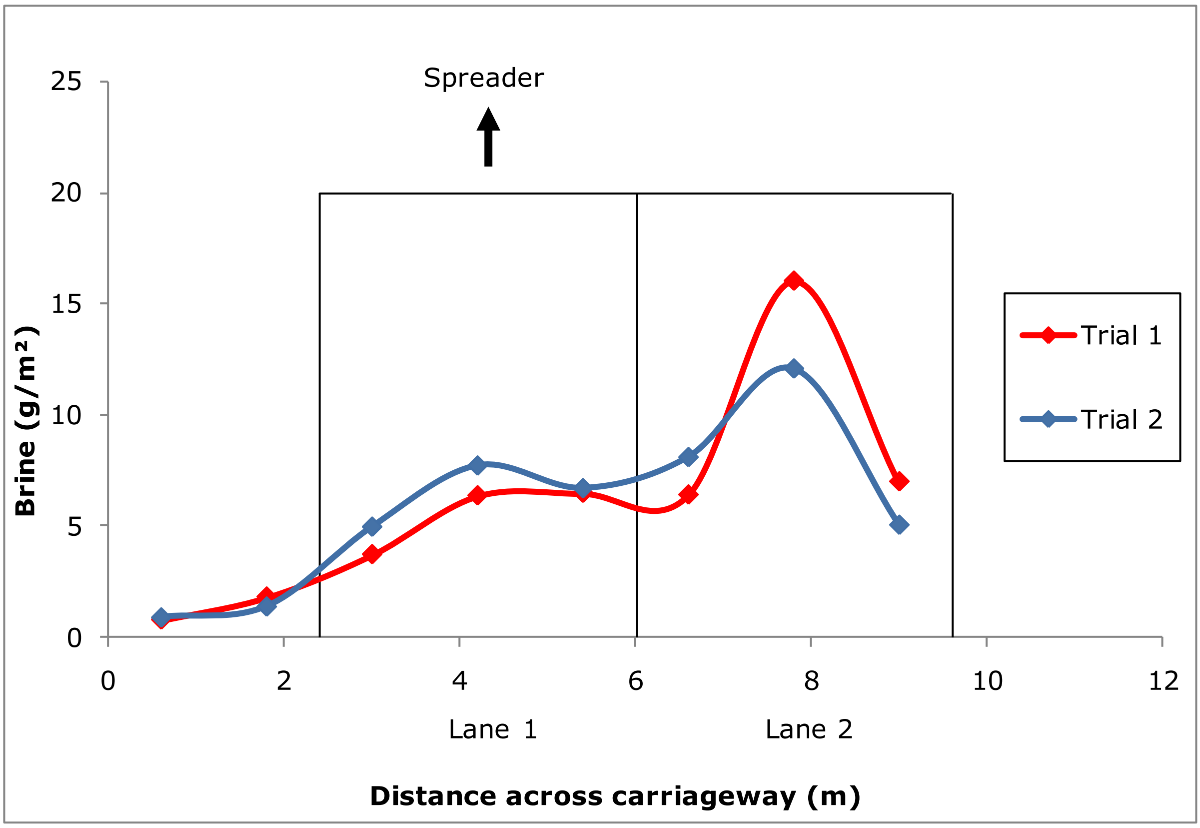

Figure 14. Comparison of average brine distribution after trafficking – Trial 1 background levels subtracted

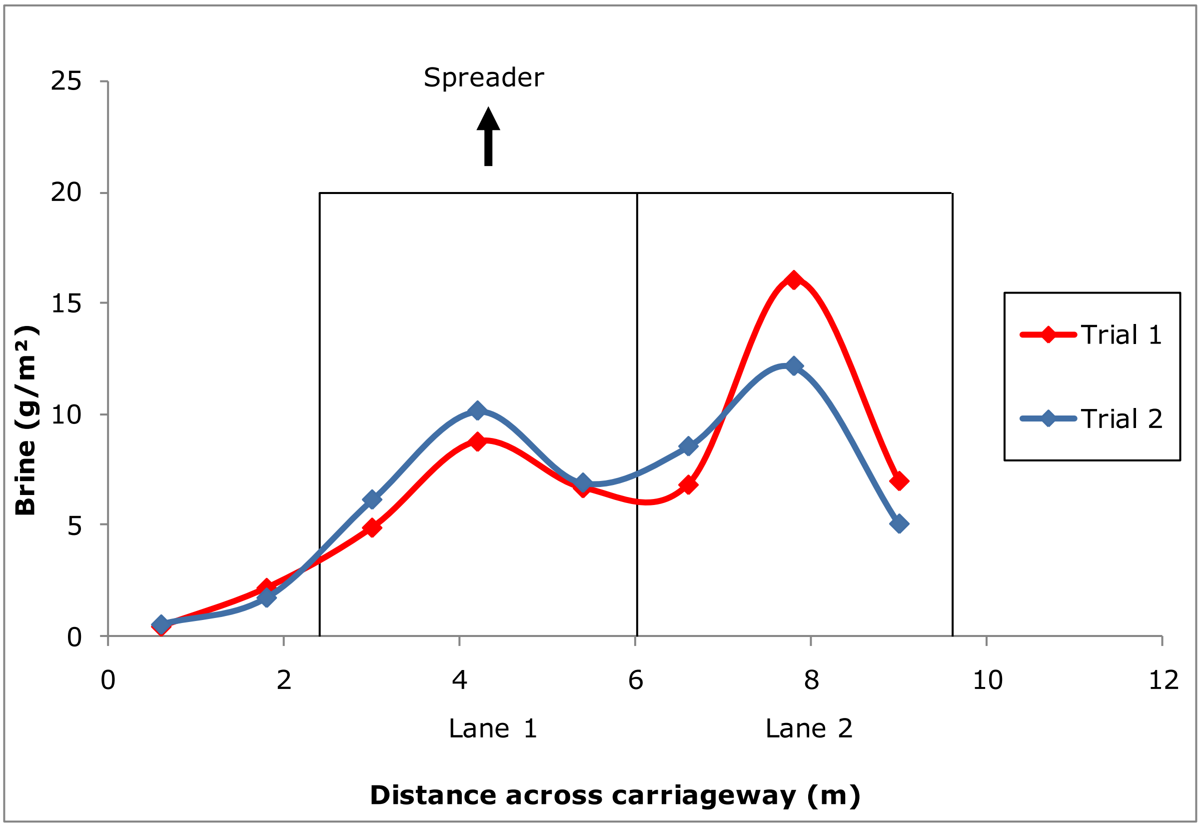

Figure 15. Comparison of average brine distribution after trafficking – Trial 2 background levels subtracted

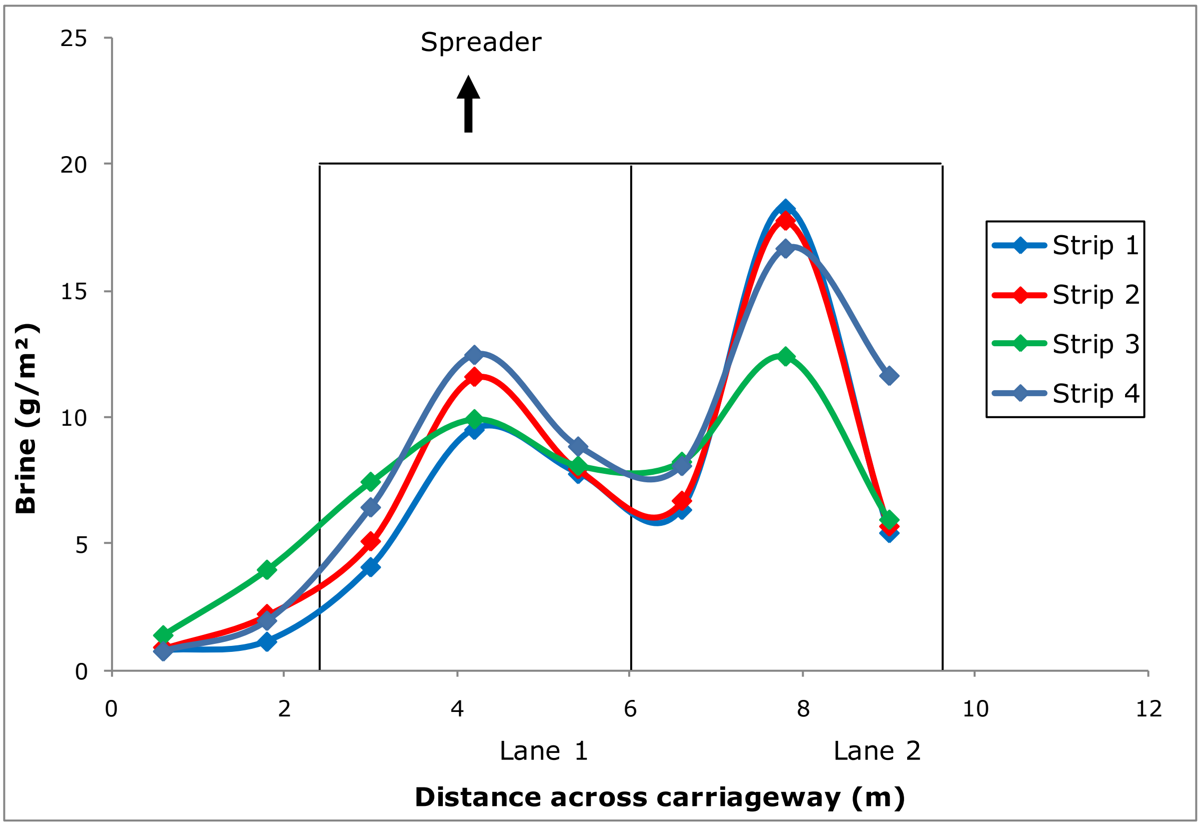

Figure 16. Trial 1 brine distribution after trafficking – background levels included

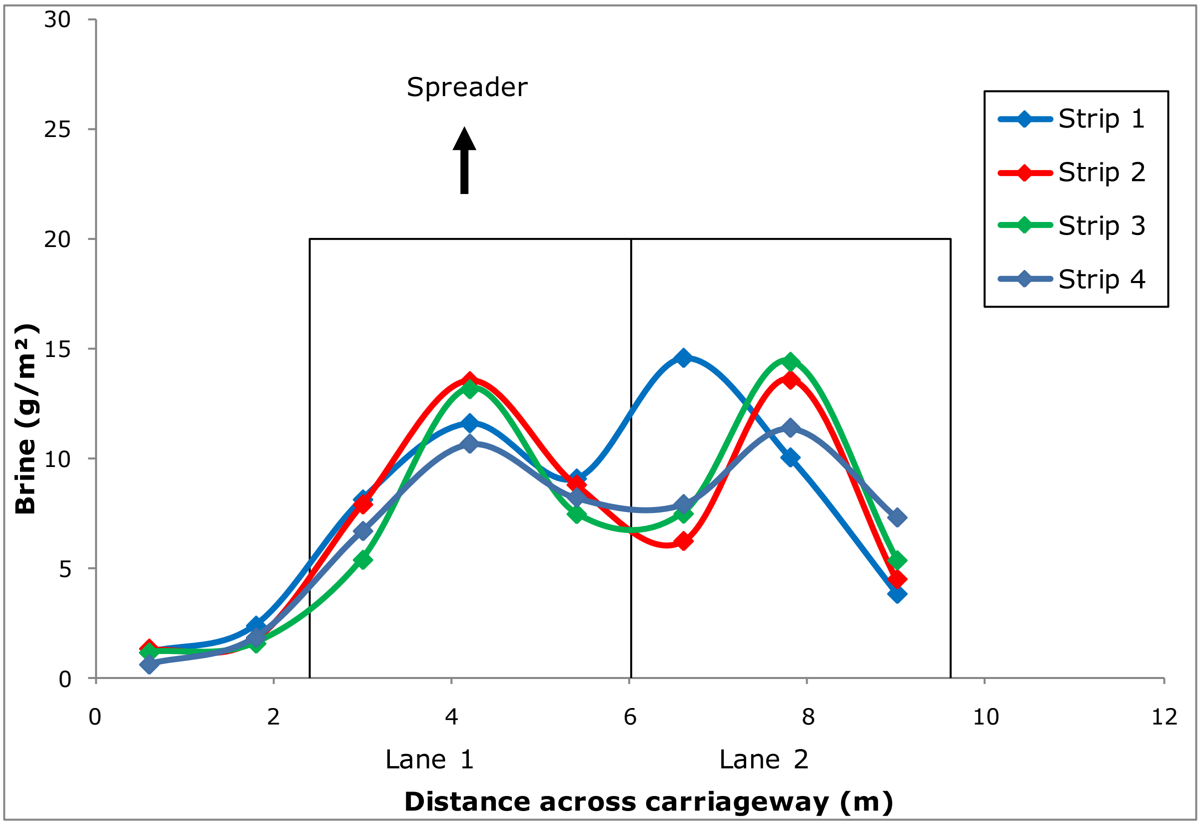

Figure 17. Trial 2 brine distribution after trafficking – background levels included

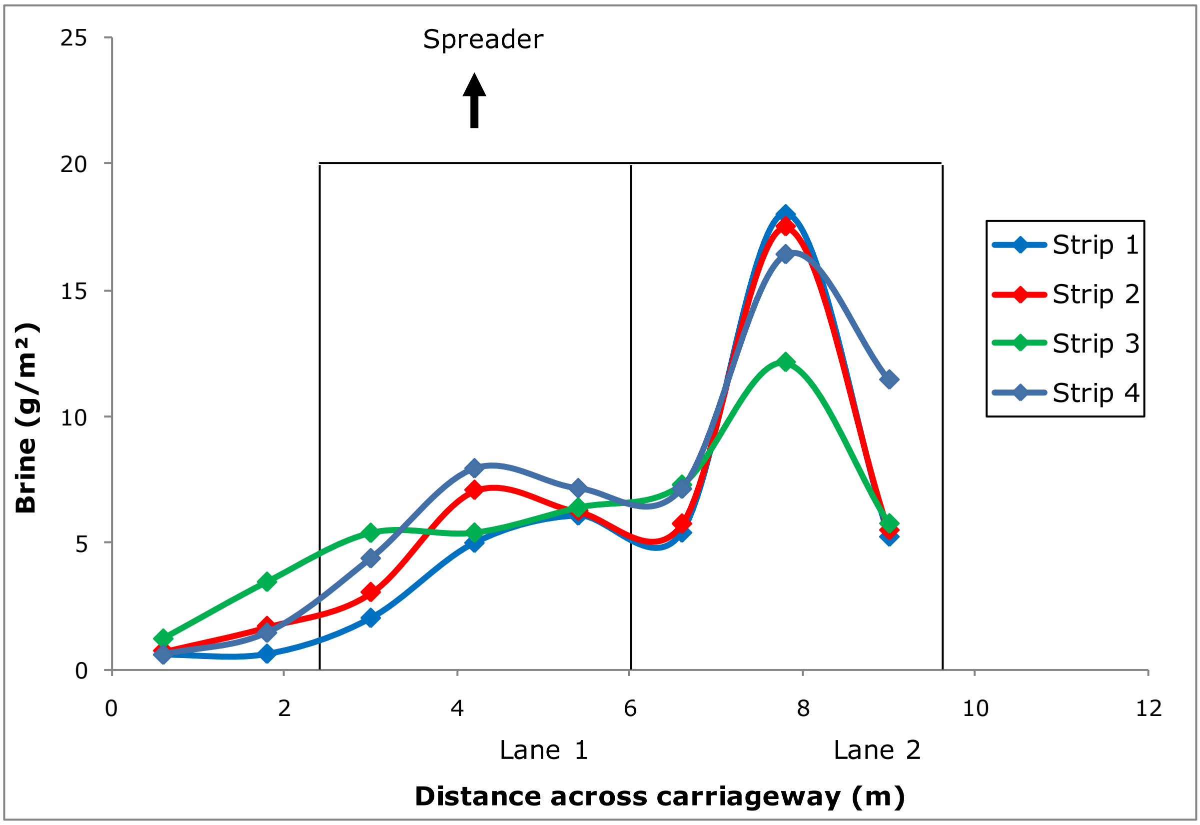

Figure 18. Trial 1 brine distribution after trafficking – Trial 1 background levels subtracted

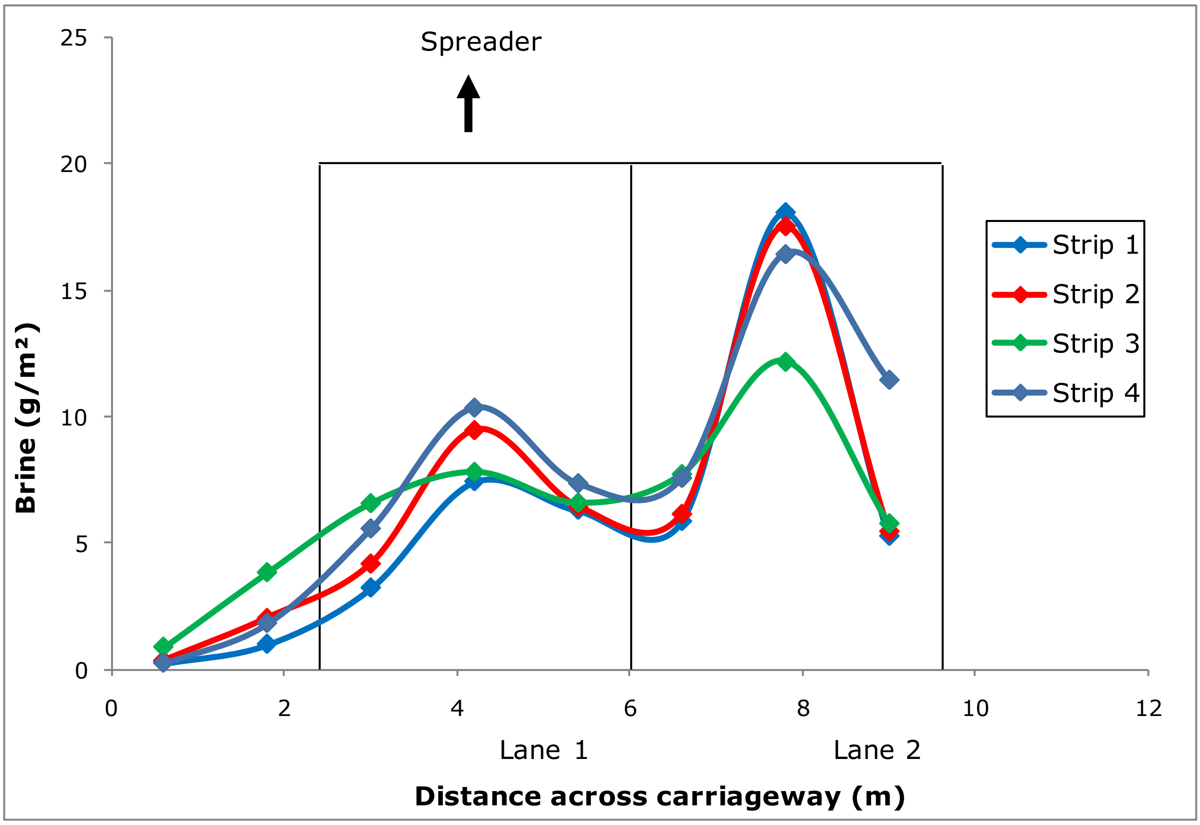

Figure 19. Trial 1 brine distribution after trafficking – Trial 2 background levels subtracted

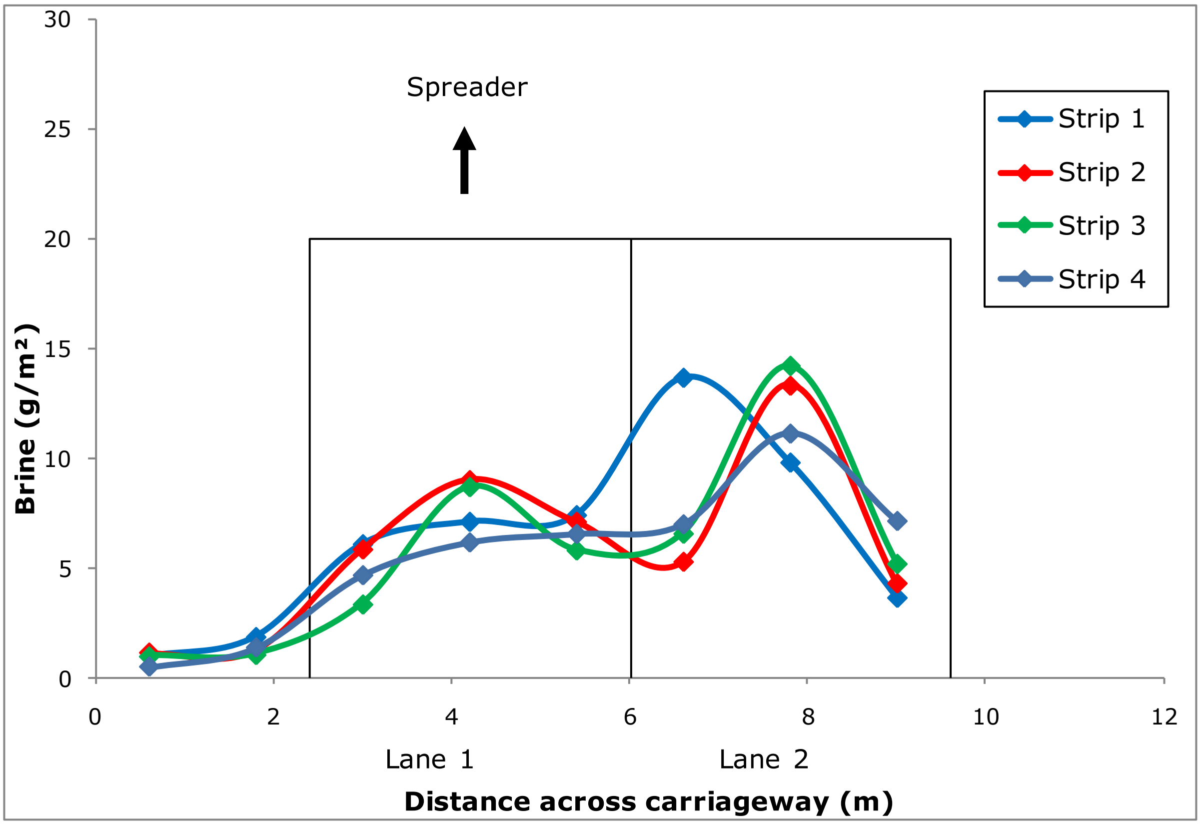

Figure 20. Trial 2 brine distribution after trafficking – Trial 1 background levels subtracted

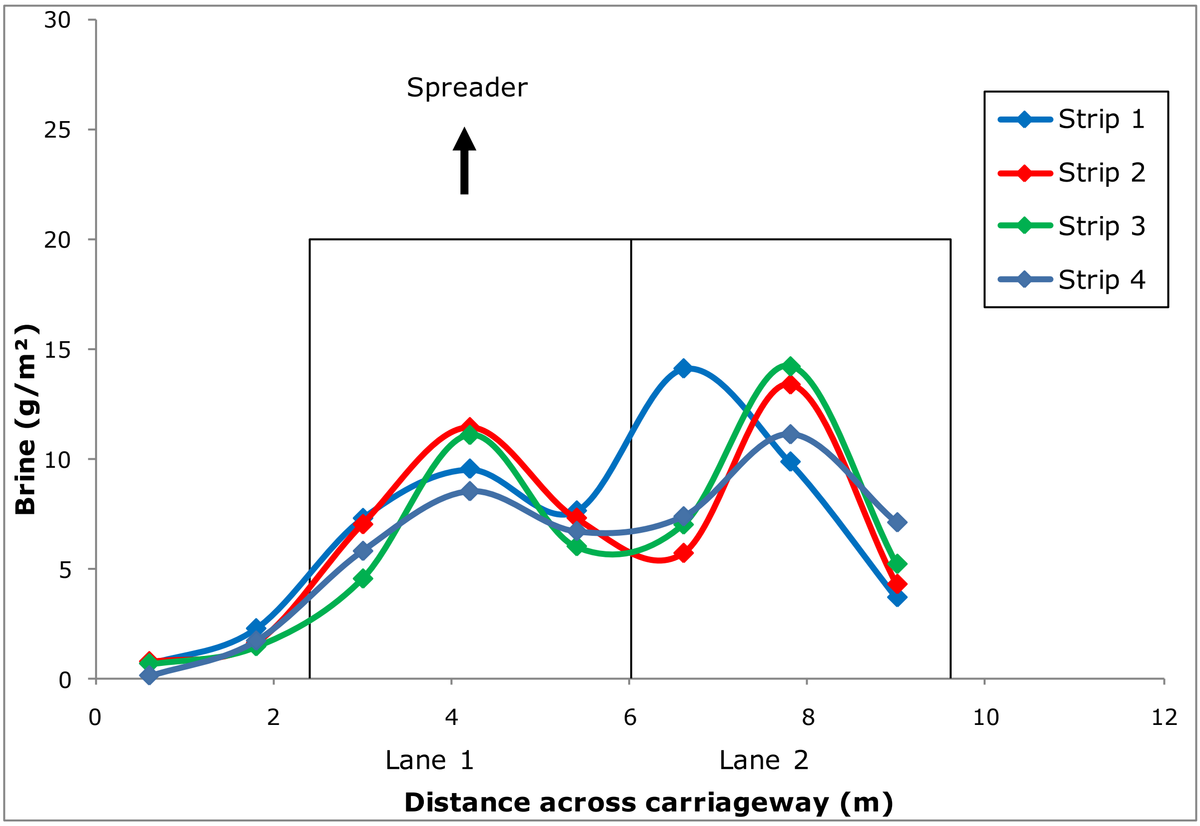

Figure 21. Trial 2 brine distribution after trafficking – Trial 2 background levels subtracted

5.5.5 Brine levels after trafficking

The brine collected after trafficking, averaged for the four strips in each lane, is shown in Table 11 with the background levels included, and in Table 12 and Table 13 with the levels from Trial 1 and Trial 2, respectively, subtracted.

Table 11. Percentage of target spread rate remaining after trafficking, background levels included

Trial	Percentage of target spread rate (%)			
	HS	Lane 1	Lane 2	Lanes 1 to 2
1	-	41	51	46
2	-	46	44	45

Table 12. Percentage of target spread rate remaining after trafficking, Trial 1 background level subtracted

Trial	Percentage of target spread rate (%)			
	HS	Lane 1	Lane 2	Lanes 1 to 2
1	-	28	49	38
2	-	32	42	37

Table 13. Percentage of target spread rate remaining after trafficking, Trial 2 background level subtracted

Trial	Percentage of target spread rate (%)			
	HS	Lane 1	Lane 2	Lanes 1 to 2
1	-	34	50	42
2	-	39	43	41

The amount of brine in each strip in Lanes 1 and 2 and the hard shoulder is shown in Table 14, Table 15 and Table 16, again with the background levels included and the levels from Trial 1 and Trial 2 subtracted, respectively. The final column, which gives the maximum minus the minimum amount of salt in the four strips expressed as a percentage of the mean for all four strips, indicates the variability in the distribution along the trial site.

Table 14. Percentage of target spread amount remaining within each strip after trafficking, background levels included

Trial	Percentage of mean (%)				
	Strip 1	Strip 2	Strip 3	Strip 4	Max - Min of Strips as % of Mean
1	91	98	98	114	23
2	106	100	98	95	11

Table 15. Percentage of target spread amount remaining within each strip after trafficking, Trial 1 background levels subtracted

Trial	Percentage of mean (%)				
	Strip 1	Strip 2	Strip 3	Strip 4	Max - Min of Strips as % of Mean
1	89	98	97	117	28
2	108	100	98	94	13

Table 16. Percentage of target spread amount remaining within each strip after trafficking, Trial 2 background levels subtracted

Trial	Percentage of mean (%)				
	Strip 1	Strip 2	Strip 3	Strip 4	Max - Min of Strips as % of Mean
1	90	98	97	115	26
2	107	100	98	95	12

5.5.6 Brine loss after trafficking

The percentage of the brine spread that could not be collected after trafficking has been calculated by comparing the brine levels after 2 hours of trafficking with the assumed amount of brine that was spread.

As described in Section 4, performance trials were carried out on the TRL track with the same spreader as for the road trials, spreading with the same settings and at the same speed – 20g/m², two lane asymmetric spread at 80km/h. The results from this trial (Trial B7) are shown in Table 17. Included are the results shown in Table 4 that were calculated by applying the factor 1.69 to account for the brine spread that could not be collected. Also shown are the results without applying the correction factor (i.e. the amounts collected without adjustment).

Table 17. Schmidt Straliq spreader performance trial results: Coverage by lane

Trial no.	Spread rate (g/m²)	Speed (km/h)	Amount collected	Total as % of target spread rate			Max – Min as % of mean for Lanes
				Lane 1	Lane 2	Lanes 1 to 2	
B7	20	80	Factor 1.69	83	77	80	7
			No adjustment	49	46	47	7

No changes had been made to the spreader between the performance and road trials. The only difference in the set up was that the brine used in the road trials came from a different Area 3 depot compared to the one that supplied the performance trial. However, the brine concentration was measured to be the same for both trials and this was not considered to be a factor that could affect the brine distribution or spread rate.

The brine distribution profile measured in the performance trial, i.e. the relative amounts in each lane, was therefore assumed to be the same as the initial spread distribution in both road trials. In terms of the total amount of brine spread within lanes 1 and 2, the performance trials had indicated that this was 80 per cent of the target amount after adjusting by the factor 1.69, and 47 per cent without adjustment. The loss under trafficking was therefore calculated for both these cases. It was considered that the background residual salt measurement from Trial 2 was more representative of the background level across the trial site as the measurement in this trial was made further away from the HRA to SMA surfacing change.

The calculated salt losses after trafficking, assuming the two cases above for the initial amounts of brine spread, are shown in Table 18 for both lanes and for Lane 1 only in Table 19.

Table 18. Percentage of brine lost after 2 hours of trafficking – compared to performance trial distribution with adjustment factor 1.69

Trial	Percentage loss (%)		
	Lane 1	Lane 2	Lanes 1 to 2
1	59	36	48
2	53	44	49

Table 19. Percentage of brine lost after 2 hours of trafficking – compared to performance trial distribution without adjustment

Trial	Percentage loss for Lane 1 (%)
1	31
2	21

5.5.7 Discussion

Comparing the brine collected with the initial brine distribution reported in the performance trial (factored by 1.69 to account for the brine which could not be collected), the percentage loss in Lane 1 (negatively-textured thin surface) was calculated to be 53 and 59 per cent in Trial 1 and Trial 2 respectively. For Lane 2 (HRA surface) the loss was calculated as 36 and 44 per cent in Trial 1 and Trial 2 respectively. The average loss for both lanes together was very consistent between the trials at 48 per cent in Trial 1 and 49 per cent in Trial 2.

By comparing the amount collected in the road trials with the lower unadjusted performance trial result (shown in Table 17) the loss in Lane 1 was 26 per cent on average. However, it is assumed the initial distribution on the road would be the higher adjusted amount.

Traffic levels were relatively high compared to previous trials with pre-wetted salt by TRL (Jordan et al, 2011A), with at least 700 vehicles in each lane except Lane 2 in Trial 1. The traffic levels in Trial 2 were also significantly higher than in Trial 1. Previous trials by TRL and others with dry, pre-wetted and treated salt have found that losses are not directly proportional to the amount of traffic. After a high rate of loss over the first few hundred vehicles, the loss has been found to change much more slowly. There may have been a similar effect with brine and the trafficking would have been sufficient for the rate of loss to be low after 2 hours of trafficking in each lane for each trial. This can be seen from comparing the loss in Lane 1 for each trial; the loss in Lane 1 for Trial 2 was 53 per cent compared to 59 per cent in Trial 1 despite the traffic levels in Trial 2 being almost twice the level in Trial 1.

It is likely that the loss for the negatively-textured surfacing in Lane 1 included not only the effect of trafficking, i.e. brine being collected by car tyres and also sprayed outside the lane, but also the loss of brine into the surfacing as was experienced in the performance trials on the TRL Test Track. Indeed it is possible that most of the loss in Lane 1 was due to drainage into the surfacing. However, it is thought that there would have been much less drainage into the HRA surfacing in Lane 2 than into the surfacing in Lane 1 such that the principal loss mechanism would have been through trafficking in Lane 2. The loss in Lane 1 in Trial 1 was calculated to be 59 per cent and the loss in Lane 2 in Trial 2 calculated to be 44 per cent, with similar traffic levels in each of these lanes as shown in Table 10. Therefore, since the loss on the HRA surfacing in Lane 2 was fairly high, it is considered that the loss on the negatively-textured surfacing in Lane 1 due to trafficking alone would have been at least half the total loss.

The strip to strip variation in the brine collected was very low, the maximum minus the minimum amount collected from the strips being 26 cent of the average in Trial 1 and 12 per cent in Trial 2. This is lower than the 30 per cent measured in road trials carried out by TRL with 6.3mm pre-wetted salt (Jordan et al, 2011A).

Averaged for both trials, the loss for the negatively-textured thin surfacing was 56 per cent and for the HRA surface 40 per cent. The losses calculated in these trials were therefore significantly greater than the 15 per cent measured in previous studies by others (Bolet, 2008) for brine and which was assumed in the original business case for brine spreading. The losses were also more comparable with those estimated for pre-wetted salting (50 per cent) in previous TRL trials (Jordan et al, 2011A).

Table 19 shows that a much lower percentage loss is calculated if the brine collected in the performance trials without adjustment for under recovery is compared with the brine collected after two hours of trafficking in the road trials. This comparison is equivalent to comparing what is collected immediately after spreading and what is collected after trafficking. However, not only does this comparison give an inaccurate estimate of the true loss of what was spread, the results in Table 19 are influenced by the different permeabilities of the 14mm surfacing on the TRL Test Track and the road trial site. The results for Lane 2 are not shown because it has HRA surfacing.

5.6 Further information of overseas trials

As previously discussed, the assumptions used in the original business case regarding brine loss after spreading were based on the results reported by Bolet (2008). These were substantially lower than the rates of loss measured by TRL in the road trials. Therefore a further investigation of the brine losses reported by other researchers was carried out. The aim of the work was to:

- Understand the reasons behind the higher losses measured by TRL in comparison to other results;
- Assess the implications for the rates of brine loss used in the business case.

In order to relate the brine losses reported by other researchers to the Agency's network, it was important to have detailed information on the methods used in their studies to measure the residual salt, the type of road surfacing used in the trials and the traffic and climatic conditions prevailing during the trials.

Further information was sought from Lars Bolet on the methodology used for the trials in Denmark and the type of road surfacing on which the trials were carried out. From correspondence with Bolet it was confirmed that the Danish trials were carried out on traditional Danish hot rolled asphalt. This is a dense surfacing in comparison with the Agency's network, which predominantly consists of negatively-textured thin surfacing. In the Danish trials, the average annual daily traffic (AADT) for the brine spreading trial section was 7200; the precise level of traffic during and after spreading would have depended on what time of the day spreading took place, but no measurements were made of the amount of traffic within the specific periods after spreading. It was confirmed by Bolet that the salt spreaders were calibrated, but the amount of brine spread was not measured. In calculating the brine losses it was therefore assumed that the correct amount of brine was spread (i.e. 20ml/m² of brine equating to 4.6g/m² of sodium chloride). Measurements of the residual salt on the road surface were made using a SOBO-20 meter.

Further information was also sought on other trials that may have been carried out since the original brine business case was prepared. Trials are currently taking place in Germany to investigate the effect of trafficking on residual salt levels after spreading brine. Sensors have been installed on a section of the German motorway network to allow monitoring of the residual salt levels across the full width of the carriageway and measurements have also been made using a wet vacuuming technique similar to the TRL method. It has been reported that residual salt levels are higher after brine spreading than after spreading of pre-wetted salt (Hausmann and Badelt, 2010). It was further indicated (KommunalTechnik, 2010) that 80 per cent of the salt spread through brine remained on the road surface after one hour and 70 per cent after four hours. This compared to only 30 per cent of pre-wetted salt remaining after 1 hour and 20 per cent after four hours. From correspondence between TRL and Gunter Hausmann it was confirmed that the German research on brine spreading is yet to be published. However, it was stated that results have shown that the spreading distribution of brine is better than pre-wetted salt and that the level of retention on the road surface is significantly higher (but Hausmann has measured a higher loss for pre-wetted salt than was measured on the Agency's network (Jordan et al, 2011A). It was further commented that brine has been increasingly used since 2009 and that the experience is very positive.

A summary of all the brine loss measurements available to TRL is shown in Table 20.

Table 20. Summary of all brine loss measurements

Country	Surfacing type	Time after spreading (hrs)	Vehicles	% loss	Measurement method
UK	Negatively-textured thin surfacing	2	718 (80 HGV)	59	Wet wash vacuum
			1230 (106 HGV)	53	
	HRA	2	262 (0 HGV)	36	
			737 (4 HGV)	44	
Germany	Dense thin surfacing	1	Unknown	20	Road sensors
		4	Unknown	30	
Finland	Unknown	3	1000	14	SOBO-20 meter
		3	1000	66	
USA	Portland Cement Concrete (PCC)	7	1500	50	SOBO-20 meter
	Micro-seal Asphalt Concrete (AC-MS)	9	2000	50	
	Nova-Chip Asphalt Concrete (AC-NC)	2	1000	95	
Denmark	Hot Rolled Asphalt	2	AADT 7,200 E_{10} 575 (Low traffic period)	11	SOBO-20 meter
		5		31	
		10		53	
	Hot Rolled Asphalt	2	AADT 7,200 E_{10} 575 (High traffic period)	16	
		5		36	
		10		58	

5.7 Discussion

Because the Danish trials were carried out on a hot rolled asphalt surfacing, it is possible that little brine would have been lost by drainage into the surface, as would have been likely in the TRL trials. This could partly explain the lower losses measured in the Danish trials.

The average daily traffic figures also suggest that the Danish trial sections might have been less heavily trafficked than the M3 trial site. The average traffic count of 7200 vehicles would suggest that less than 1000 vehicles (total for both lanes of a two lane highway) would have trafficked the Danish trial sites in the initial two hours after spreading; based on the likely levels of trafficking it is thought that the results obtained after five hours of trafficking in the Danish trials are more likely to be comparable to the TRL trial data. However, as there were no traffic counts taken, this cannot be confirmed. After five hours, losses in the Danish trials were 31 to 36 per cent in low and high traffic periods respectively. This is comparable to the 36 per cent loss measured by TRL in Trial 1 on the HRA surface.

Previous trials on pre-wetted and dry salt, carried out by TRL on behalf of the Agency, have shown that there is a relatively high rate of salt loss immediately after spreading with the amount of residual salt then levelling off with time. A small increase in traffic can therefore be significant in this initial period of higher loss before the dry salt particles have entered solution or become retained in the surface texture. The results from the TRL brine trials would seem to indicate that with brine there is a high initial loss followed by a lower rate of loss thereafter.

For the two trials, the loss in Lane 1 was 59 and 53 per cent with traffic levels of 718 and 1230 respectively. Because the rate of loss was similar in Lane 1 for the two trials (at about 50 to 60 per cent), even though the traffic levels differed, it suggests that in both trials the traffic levels had exceeded the levelling off stage, and the additional trafficking in Trial 2 made relatively little difference to the total loss.

In Lane 2, however, the levels of traffic were lower than Lane 1 and may not have reached the levelling off point. In Lane 2 the rate of loss was affected by traffic level, with 36 per cent loss when there were 262 vehicles and 44 per cent loss associated with 737 vehicles.

The spreaders used in the Danish trials were calibrated and it was assumed that on average the correct amount of brine was being discharged over the duration of the trials. If the initial dosage in the lanes was not at the target amount this would clearly also influence the results.

The surfacing used on the German national road network is typically a dense SMA surface. As is the case with HRA, it is possible that the drainage of brine into this surface was less than for the typical surfacing on the Agency's network (including the trial site). This may partly explain the lower losses measured in the German trials. Another factor to consider for the German trials is that measurements were made using sensors embedded in the road surface. It is conceivable that the collection of brine on these sensors (rather than being allowed to drain into the surface) could result in a higher residual salt level being measured than would be the case with the wet wash vacuum method or the use of the SOBO-20 meter; with the latter methods some of the brine that has penetrated into the surface may not be measured.

The tests on brine recovery carried out on the TRL test site have also shown that the type of surface has a significant effect on the brine recovery rate, with greater than 90 per cent recovery measured for the HRA surface compared to between 59 and 71 per cent recovery for the negatively-textured surfacing depending on the number of wet washes used as part of the recovery method. Increasing the number of wet washes from three to four resulted in a 20 per cent increase in the amount of salt recovered from the thin surfacing (i.e. from 59 to 71 per cent). Following the brine spreading trials, further performance trials were carried out by TRL on behalf of the Agency to investigate the spreading performance of imported salt (Jordan et al, 2011B). These trials were carried out on the same negatively-textured TRL test track surface as used for the brine spreading trials. As with the brine trials, these performance trials found that it was not possible to recover all of the salt applied to the trial site due to the open texture of the surface. To determine the recovery rate, tests were carried out in the same manner as for the brine trials, in which known weights of salt were applied to a number of panels, and these were compared with the amount of salt recovered by the wet wash method. Rock salt and marine salt were used in the trials and it was found that, on average, 80.3 per cent of the rock salt and 84.6 per cent of the marine salt could be recovered from the surface. This dry salt would clearly not have drained away, as has been assumed for the brine; it may be, therefore, that with open textured surfacing some of the salt (whether dry or in the form of brine) enters the open voids and cannot be recovered by wet wash vacuuming. If this is the case, it might be that a proportion of the brine not collected by the wet wash method had not drained away and was still available within the surface for de-icing.

5.7.1 Brine losses for use in the business case

The further information obtained regarding the brine loss trials in Denmark and Germany would appear to highlight the importance of the road surface properties on the brine losses measured, with the denser surfaces exhibiting a lower loss. As discussed in Section 5.2, the texture depth of the M3 trial site surfacing was relatively high compared to the minimum value specified for new surfacing. It is considered that the trial site surfacing was a more open textured surface than typical for the Agency's network and would be more freely draining. Therefore it may be appropriate to assume a lower loss of salt for other parts of the Agency's network (compared to the trial site) and this lower value would be more appropriate for use in the brine business case.

In determining the losses applicable to brine spreading on the Agency's network, it would seem reasonable to apply a correction factor to the amount of brine collected during the road trials. This is a similar approach to that applied to the amounts of brine spread during the performance trials.

In the road trials, this correction would account for:

1. Residual salt that was still available within the surface for de-icing but not collected using the wet wash method.
2. The increased drainage of the trial site in comparison to the Agency network

The brine recovery tests on the TRL test track showed that 71 per cent of the brine was recovered using the same recovery method as that used during the road trials (four wet washes). The upper limiting case for applying a correction factor would be that all of the uncollected brine is still available for de-icing. This would require the application of a correction factor of 100/71 (i.e. 1.41) to the amounts of brine collected. While this may be applicable to the negatively textured surfacing of Lane 1, it is considered that a lower maximum correction factor would apply to the HRA surfacing in Lane 2.

Applying a correction factor of between 1.2 and 1.3 would seem to be a reasonable estimate, taking into account the brine and dry salt recovery tests that have been carried out. Table 21 shows that applying a correction factor of 1.2 to the amount of brine collected from the negatively textured surfacing gives a brine loss of 48 per cent averaged over the two trials. Applying a correction factor of 1.3 gives a loss of 43 per cent on average. Applying a correction factor of 1.4, the maximum that is considered feasible, gives a loss of 39 per cent on average.

It is therefore considered inappropriate to assume a loss of 15 per cent (as measured by Bolet on a dense surfacing) for the Agency's network. The available information indicates that for typical surfacing on the Agency's network it is difficult to justify a loss of less than 40 per cent for the business case for brine spreading. However, losses of 30 and 50 per cent could also be used, respectively, for denser and more open textured surfacing than typical surfacing.

Table 21. Effect of applying correction factors to the amount of brine collected

Trial	Correction factor to brine recovery	Percentage loss (%)	
		Lane 1	Lane 2
1	0	59	36
	1.1	55	29
	1.2	51	23
	1.3	47	-
	1.4	43	-
2	0	53	44
	1.1	49	39
	1.2	44	33
	1.3	39	-
	1.4	34	-

5.8 Effect of traffic during spreading

A visual assessment was made of driver behaviour and the effect on the de-icer distribution during spreader turn outs on the Second Severn Crossing and Avonmouth Bridge. Video footage was taken of the spreading by Area 2 personnel travelling in a car behind the liquid spreader spreading a potassium acetate solution. The behaviour of drivers to brine spreading is expected to be comparable to their behaviour spreading this liquid.

One spreading run was observed during the day (see Figure 22) It was snowing and as a result with a wet road surface. Four spreading runs were observed at night with the road surface dry and with no precipitation. The four night-time observations were all carried out on the same night, when travelling both ways on the Avonmouth Bridge and the Second Severn Crossing.

Figure 22 Video footage of spreading on the Severn Crossing

The following spreading scenarios were videoed:

1) Three lane section: Treating lanes 1, 2 and 3, driving in Lane 2
2) Two lane section: Treating Lanes 1 and 2, driving in Lane 2
3) Four lane section: Treating Lanes 1 and 2, driving in Lane 2
4) Four lane section: Treating Lanes 3 and 4, driving in Lane 3

During the day time, when the weather was very poor with heavy snow/sleet, drivers appeared unconcerned with the spreader and overtook without hesitation. Due to the poor conditions it is likely the drivers were less aware of what was being spread, i.e. liquid rather than dry salt. The effect of the traffic on the initial de-icer distribution would likely have been minimal in this scenario.

During the night time spreading, the liquid being spread was more visible and the drivers appeared to be more awareness of it. Drivers appeared to be more hesitant on approaching the spreader, in particular when not following another vehicle. Before over-taking, drivers were often observed to hang back, although not in the immediate area that the de-icer was being applied to the road surface. Once passing through the spray, vehicles tended to pass quickly and typically passed through within three seconds. When the spreader was spreading Lane 1 and Lane 2 of a four lane section, drivers would typically move into Lane 3 to avoid the area being sprayed. Survey of saturator types and brine salts used by Service Providers

6 Survey of saturator types and brine salts used by Service Providers

6.1 Introduction

The introduction of brine treatments would require Service Providers to review the suitability of their brine production facilities in terms of their capacity and the brine salt used for such treatments.

With regard to capacity, data provided by Jordan (2010) showed that the maximum amount of brine required for combination treatments is estimated to be 15,000 litres/treatment for a typical depot (see Table A.9). Two such treatments per day would require 30,000 litres. The amount of brine required for the worst case combination treatment is estimated to be more than that required for pre-wetted salting treatments for road surface temperatures down to -6°C.

Table A.10, again using data from Jordan (2010), shows that the amount of brine required for combination treatments over a winter season is estimated to be up to three times as much as the amount required for pre-wetted salting.

With regard to the salt used for brine production, the brine required for pre-wetted salting is usually produced from white salt as discussed in Section 6.2.2. However, suitable sources of white salt (e.g. of the correct grading) are not generally available in the UK at competitive prices. Imported white salt can be used but it is more expensive than UK brown salt and its widespread use (instead of brown salt) could have an impact on the viability of UK salt producers. Furthermore, Jordan (2010) concluded that the potential for Service Providers to make direct cost savings when carrying out combination treatments rather than pre-wetted salting treatments would be greater if brine could be produced efficiently and cost effectively with brown rock salt from UK sources. However, this would be the case only if saturator maintenance costs were not significantly higher with brown salt than with white salt. Jordan (2010) also concluded that there was more potential for reductions in carbon emissions if UK brown salt rather than imported salt was used.

To investigate these factors, a survey was undertaken to determine the types of saturator and brine salt used by Service Providers and obtain information on their operational experiences. This section describes the methods used to obtain the information and the findings of the work.

6.2 Data collection

The following information was requested from each of the Agency's Service Providers employing pre-wetted spreading:

- The types of saturator used
- The production rate of each saturator
- The storage capacity of each saturator
- The type of brine salt used
- The performance of the saturators
- Saturator maintenance requirements and costs
- The results of brine production using different salts

The questionnaire was sent to the eight Areas in England with brine production facilities for pre-wetted salting, and replies were received from all of them. Those already using brown salt were asked for specific information on the maintenance and cost implications, and any problems encountered.

The results showed that, within the eight Areas, there are 42 depots and within these there is a total of 44 saturators servicing a fleet of 159 vehicles. A more detailed breakdown of the results is given in the following sections.

The data obtained from the questionnaires were supplemented by information obtained from discussions with saturator manufacturers on the different types of saturator. In addition, the saturator manufacturers and maintenance contractors were consulted to determine the maintenance requirements if brine production were to be increased for brine treatments (i.e. over and above that required for pre-wetted salting) using either white salt or brown salt.

6.2.1 Saturator types

Although there are differences in the design and details of the various saturators being used by Service Providers, they all perform the same task of producing brine by dissolving solid sodium chloride in water. There are two basic systems for producing brine in a saturator; the up-flow system and the down-flow system.

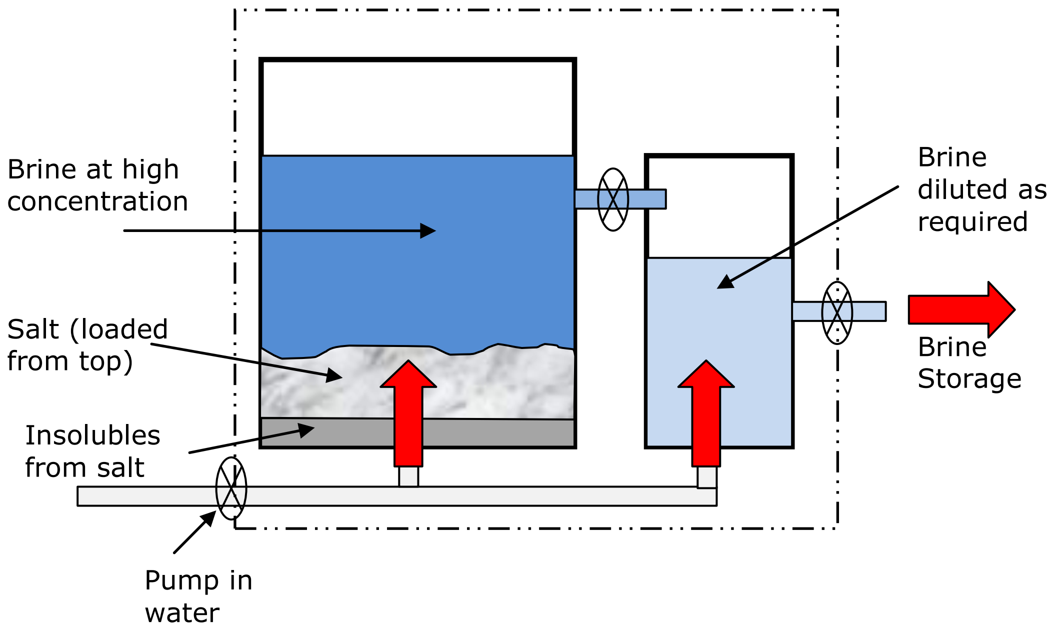

Figure 23: Up-flow system

A generic up-flow system is shown schematically in Figure 23 although the exact location of each component will vary between manufacturers and models. Salt is placed in a mixing tank, where water is pumped directly into the bottom of the tank. The water dissolves the salt as it flows upwards through it, producing a near saturated solution of brine. The maximum concentration that can be achieved will vary slightly with temperature (see Figure 24), but the brine concentration is often tested. The brine moves from the mixing tank into a dilution chamber where water is added to bring the concentration down to the required level (usually between 20 and 23 per cent). It is then transferred to a storage tank. Any insoluble particles in the brine salt sink to the bottom of the mixing tank where they can be removed as a part of the regular maintenance regime.

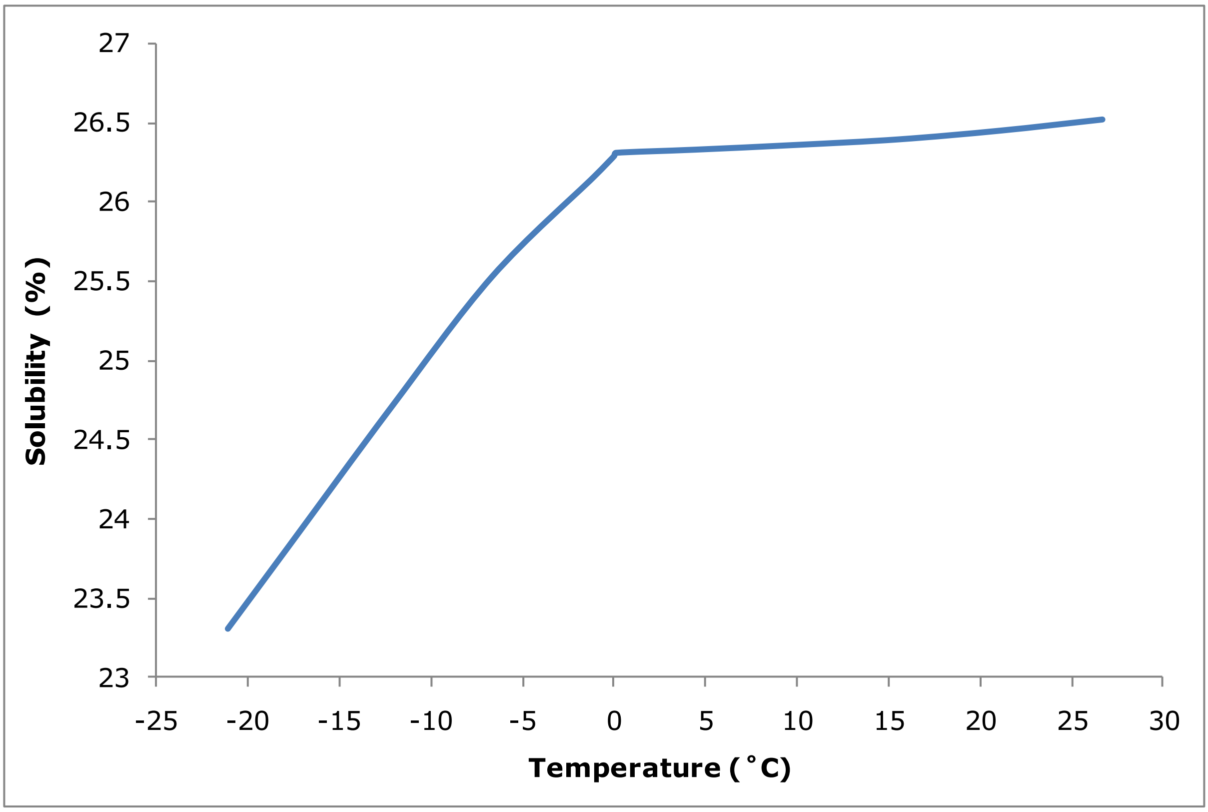

Figure 24: The variation in the solubility of salt with temperature

In the down-flow system (shown in Figure 25), salt is placed into the mixing tank on top of layers of graded gravel located at the base of the tank. Water is pumped into the top of the tank and dissolves the salt as it flows downwards. The brine produced flows through the graded gravel layers, which trap the impurities from the salt. The brine solution is then collected from the bottom of the tank and is sent to a storage tank. In some systems, the solution is re-circulated to obtain the required concentration.

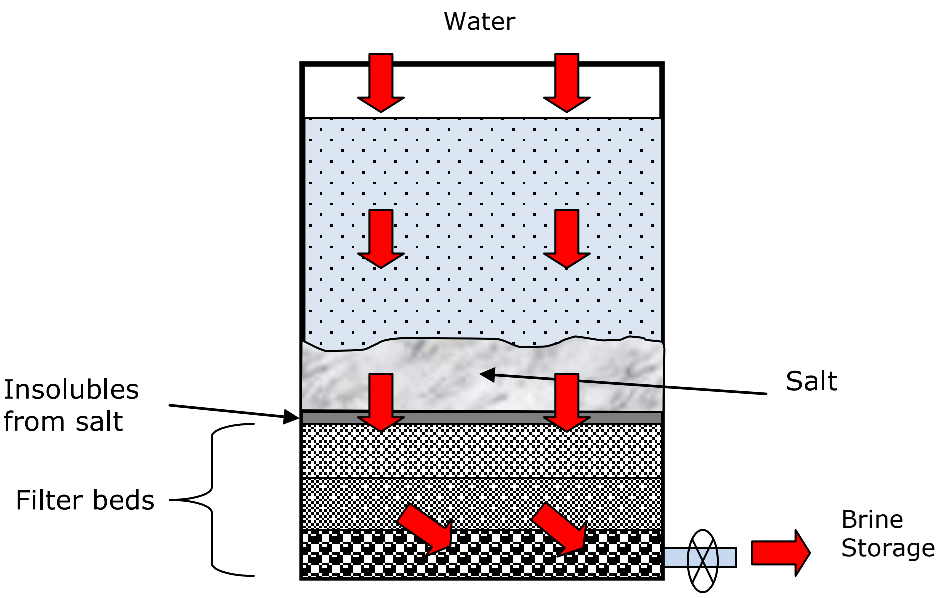

Figure 25: Down flow system

A summary of the saturator types used at the Area depots is given in Table 22. It can be seen that there are six different types of saturators in use, with the Peacock Multisol being the most commonly used.

Table 22: Saturator manufacturer and models

Saturator manufacturer	Saturator type/model	Quantity
Flockton	S6	9
Natural Salt	203	7
Natural Salt	208 Twin	2
Peacock	Ecosol LE8	7
Peacock	Multisol	15
Salinity	SL07	4

The information obtained from the questionnaire showed that the saturators manufactured by Natural Salt were being used at nine separate depots across two maintenance areas. These were the only saturators being used to manufacture brine with brown salt.

6.2.2 Salt types for brine production

Table 23 and Table 24 show the type of salt used for brine production by the Service Providers.

Almost 80 per cent of the depots use marine salt. This is produced from sea basins, where the water is evaporated leaving salt crystals. These are washed, refined and screened before use. The sodium chloride content of this type of salt is high and there are few impurities or insolubles. The purity of marine salt typically exceeds 99 per cent.

The rock salt used at the other depots was mined from underground deposits at the Winsford Mine in Cheshire. Depending upon the location of the mine, rock salts can have more impurities than marine salt, resulting in a higher percentage of insoluble material. The purity of UK rock salt ranges typically from about 92 to 95 per cent and the insolubles range from about 2.5 to 5.5 per cent.

Table 23: Salt used in saturators

Salt	Grading	Number of depots	Cost per tonne (Jan 2010)
Marine (white)	-	8	£56.00
Marine (white)	3mm	9	-
Marine (white)	6mm	10	£55.00
Marine (white)	6.3mm	8	£85.50
Rock (brown)	6.3mm	2	£23.00
Rock (brown)	6.3mm	7	£25.00

Table 24: Saturators and the salt grading being used

Salt	Grading	Flockton	Natural Salt		Peacock		Salinity
		S6	203	208 Twin	Ecosol LE8	Multisol	SL07
Marine	-					8	
Marine	3mm	9					
Marine	6mm				2	4	4
Marine	6.3mm				5	3	
Rock	6.3mm			2			
Rock	6.3mm		7				

Another source of salt that has been considered for brine production is vacuum pad salt. This is produced by pumping water through a salt stream, and collecting the saturated brine, which is then filtered and dried to produce salt crystals.

Pad salt, also known as vacuum road salt (VRS), is available all year round and is a by-roduct from salt production for domestic and industrial uses. It has been used by some local and Scottish authorities mixed with rock salt and grit when other salt supplies have been limited.

Saturator manufacturers indicated that the grading of the salt used to produce brine is important. The optimal salt grading was reported to be from 3mm to 6mm. Larger particles take longer to dissolve than smaller particles, and may need additional agitating. Finely graded salts often cake whilst in storage. Any clumps so formed may not break apart within the saturator and small clumps can pass into storage tanks and spreaders. Finer particles may dissolve quicker but may not produce the right concentration of brine because the water will tend to form channels through the salt. VRS is finely graded, with a maximum particle size of about 1mm, and therefore it is not thought to be suitable for brine production using the saturators currently being used by Service Providers.

If brine use was to increase, it may be possible to use other sources of pre-mixed brine. For example, brine can be obtained from salt solution mining, in which water is forced down a drilled bore hole into the salt bed. This dissolves the salt and the saturated brine is then pumped out.

Brine is also produced as a part of the mining process for potash. The Boulby potash mine in the North York Moors National Park currently pumps out the waste brine from the potash extraction into the North Sea.

Currently these two sources of brine are not used for winter service in the UK. However, they could provide some advantages to depots, especially in terms of the capital cost of saturators, and the salt. There could be other savings associated with training and maintenance for saturators. However in order to remain an economical option, any cost savings would need to offset the cost of transporting the brine and the additional storage required at depots. As shown in Table A9, the maximum amount of brine required for combination treatments is estimated to be 15,000 litres/treatment/four spreader depot. Storage that is five or six times this amount is still likely to require frequent deliveries although such deliveries are likely to be economical within a small distance from the production site.

6.2.3 Salt cost

Table 23 also shows the cost of the brine salt used by Service Providers. Salt prices are traditionally at their lowest in the summer to encourage procurement when demand is low. For this reason, Service Providers often stock up on salt over the summer months and top up their supply when required throughout the season. Prices can vary greatly throughout a winter season, depending on demand. However, prices will also vary with the type of supply contract, which may include or omit other costs such as transportation.

The price on delivery of UK indigenous rock salt has remained fairly constant over the past few years at about £25/tonne. Marine salt is transported from the continent or further field, and the transportation cost is reflected in the price. Table 23 shows that marine salt has cost Service Providers more than twice as much as UK rock salt. However, a major supplier of marine salt has indicated that it should be possible to obtain bulk supplies at £46/tonne out of season. Nevertheless, if the salts were assessed on cost alone, the advantages of using rock salt can be easily justified.

6.2.4 Brine concentration

According to Area Management Memo 115, the optimum concentration of brine for pre-wetted salting is 23 per cent, although lower concentrations exceeding 20 per cent are acceptable. A concentration towards the upper limit is preferable for brine treatments. Table 25 shows that the brine concentration achieved by the saturators used by Service Providers was generally within the limits specified, although some re-circulation was needed to achieve 23 per cent with a downflow system.

Service Providers check the concentration of the brine at frequent intervals, and there are annual calibrations.

Table 25: Method of measuring concentration

Saturator manufacturer	Saturator type/model	Brine concentration (%)	Frequency of concentration level checks	Method of concentration check
Flockton	S6	19 – 23	Each use	LCD on control panel
Natural Salt	203	23	Every 2nd treatment not less than 1x / week	Hygrometer
Natural Salt	208 Twin	-	Daily	Manual
Peacock	Ecosol LE8	20 – 23	Each batch	Refractometer
Peacock	Multisol	20 – 23	Automated Control / continuously	Refractometer
Salinity	SL07	21 - 22	Fortnightly	Hydrometer

Several different methods can be used to measure the concentration of the brine. For example, a refractometer measures the critical angle of refraction through a brine sample (the angle varies with the concentration of the solution) whilst a hydrometer measures the relative density of the solution, which is then used to determine the concentration.

6.2.5 Brine production

Table 26 summarises the production capabilities of the saturators used. The Peacock Ecosol LE8 saturator has batch production, whereas all the other saturators produce brine continuously. Table 26 shows that all the saturators are able to produce a minimum of 1,000 litres of brine per hour. When the storage capacity is taken into account, most saturators should be able to supply enough brine for two treatments per day requiring 15,000 litres each. However, some saturators may not be able to supply sufficient quantities of brine for successive days with two such treatments. Therefore, additional capacity may be required at some depots for brine treatments.

Table 26: Production values

Saturator manufacturer	Saturator type/ model	Quantity	Tank capacity (litres)	Daily production rate (litres/hr)	Peak production rate (litres/hr)	No. of spreaders
Flockton	S6	9	20,000	-	2,000*	29
Natural Salt	203	7	20,000	**	**	32
Natural Salt	208 Twin	2	20,000	**	1,200	8
Peacock	Ecosol LE8	7	8,900	2,000	2,000	17
Peacock	Multisol	2	10,000	From 1,000**	from 1,000**	7
Peacock	Multisol	9	15,000	From 1,000**	From 1,000**	35
Peacock	Multisol	4	20,000	From 1,000**	From 1,000**	15
Salinity	SL07	4	15,000	2,000	8,000	16

*theoretical output

** varies with pressure

6.2.6 Saturator maintenance

Discussions with saturator manufacturers confirmed that an increase in brine production would increase maintenance needs, but the extent could not be determined.

The costs paid by Service Providers for annual maintenance varied from £500 to £2,000, but it should be noted that the level of service provided for these charges varied. Other maintenance costs for the repair and replacement of parts vary from saturator to saturator. Some parts are more exposed to wear than other.

Manufacturers suggested that if production was increased for combination treatments, a mid-season inspection might be required in addition to the pre-season inspection. An increase in brine production would also require more frequent removal of impurities from the saturator if brown salt was used.

Because many saturators have only been operational for one or two seasons, the full maintenance costs are yet to be realised.

6.2.6.1 Saturators using white salt

Most of the saturators have built-in systems which diagnose any errors. Following consultation with manufacturers, it is claimed that the cause of a failure is often operator error, or lack of training.

All manufacturers provide an annual maintenance service as a part of the supply contract. Prices start at £300-500 per saturator for a season for basic annual maintenance and repair, but this could also include telephone support throughout the year. Calibration services are often carried out at the same time as the annual maintenance and, depending on the contract, could cost an additional £100 (approximately). Manufacturers do provide more comprehensive services at additional cost, but have found that Service Providers favour the cheapest option.

Table 27 shows some typical repair costs for defects that render a saturator inoperable. Manufacturers stated that these were often due to incorrect operator use.

Table 27: Repairs

Problem	Repairs	Preventive measures
Burst pipes are often caused by a frozen pipe or a pump operating against a closed valve.	Approx £300-500 for pipe repair plus the cost of replacing any components. Potentially more damage with brine leaking and causing corrosion.	Heated valve and pipes will stop them freezing. Some saturators are supplied with automated pump valves (at an additional cost).
Damage to the loading hose if a spreader is driven away whilst still connected to the saturator or storage tank	Brine leaking, if flow is not stopped. Approximately £150 to replace hose plus additional connections.	Breakaway technology is available (at an additional cost).
Pump breakage	Pump may need to be replaced entirely at approximately £1000, plus any additional pipe work required	Operator training and reduce blockage.

6.2.6.2 Saturators using brown rock salt

The insolubles found in brown salt leave a marly residue in the base of saturators which must be removed periodically. The manufacturers of the saturators for which Service Providers use white salt stated that they would not recommend the use of brown salt. They stated that the maintenance costs would be much higher for brown salt than white salt and they may be unwilling to provide a maintenance contract covering the use of brown salt.

The saturators using brown salt can also use white salt. They have a drainage sludge tanker to extract the residue and cleaning is recommended after producing 400 thousand litres of brine, i.e. after using approximately for 100 tonne of brine salt.

The annual maintenance cost of approximately £2,000 covers the cost of call outs, and a yearly service and inspection of the machines. The problems outlined in Table 27 are also applicable, but prices are based on white salt.

It has been difficult for Service Providers to assess the performance of saturators with brown salt. Pre-wet spreaders were supplied to the Areas concerned during the last winter but, due to the severity of the weather since then, much salting was undertaken with dry salt rather than pre-wetted. Therefore, brine production has been limited. Initial usage has indicated that it is possible to produce brine at the required concentration.

6.3 Final comments

The survey found that the current brine production capacity for pre-wetted salting is mostly sufficient for combination treatments. However, production values have yet to be fully tested as the majority of the saturators have been operational for a maximum of two winter seasons. Also, the use of brine has been limited because many treatments last winter were with dry salt.

The increased use of saturators for combination treatments will increase the likelihood of failures and problems occurring and hence likely result in additional maintenance costs. However, the cost of cleaning the saturator and removing solubles is likely to be proportional to the amount of brine produced.

Although brown rock salt is low in cost and easily available, its cost effectiveness will be affected by the extra maintenance required to remove impurities from the saturator. Some saturator manufacturers recommended that only white salt be used. The experience of Service Providers is insufficient to recommend the use of brown salt and discussions with salt suppliers have indicated that the production rate would be reduced by the need to remove impurities on a regular basis. Therefore no data have been found that would suggest that the use of brown salt is cost effective.

7 Revision of the business case

The results of the road trials, further investigation of the trials reported in the literature, and the saturator survey have shown that some of the assumptions made when preparing the original business case require updating to reflect the new information. The original business case, Jordan (2011), has been revised as part of this report to take account of the new findings, and full details of the revised calculations are given in Appendix A.2.

In revising the business case it has been assumed that a combination spreader would be available to make brine treatments or for pre-wetted salting. Brine spreaders have not been considered because they are not economically viable.

Four factors have had a significant effect on the business case:

- The brine loss due to trafficking
- The cost and type of salt that can be used for brine production
- The minimum spread rate for pre-wetted salting
- The number of saturators used for brine production

The factor that has had the greatest effect on the revised calculations has been the brine loss due to trafficking. In the revised business case, the loss of brine due to trafficking has been increased from 15 to up to 40 per cent for brine treatments on a typical surfacing. Losses of 30 and 50 per cent have been used, respectively, for denser and more open textured surfacing than typical surfacing.

The saturator survey found that brine production with indigenous UK brown salt is not likely to be economically viable. Therefore, it has been assumed that white salt would be used for brine production. However, two severe winters in recent years have increased the demand for imported white salt and fuel costs have also risen, resulting in an increase in the cost of salt for brine production.

When the higher brine loss due to trafficking and the higher cost of salt are taken into account, it is estimated that there would be very few weather conditions where the direct cost of brine treatments would be less than that of pre-wetted salt. The number of weather conditions where brine treatments would be the best option would be slightly higher if the indirect costs due to vehicle and structural corrosion and environmental damage are taken into account. However, the calculations only considered the number of weather conditions where a direct cost saving to Service Providers would be obtained for brine treatments.

The original business case also considered the use of white salt for the dry salt component of pre-wetted salt. For those calculations it was assumed that white salt would be used only if it enabled the minimum spread rate at which pre-wetted salt could be spread uniformly to be lower if the dry salt component was white salt rather than UK brown salt, i.e. when the use of white salt would reduce the amount of salt required for pre-wetted salting. However, a number of Service Providers have obtained supplies of imported white salt during the recent salt shortages and this might continue if UK supplies cannot meet current demands. In addition, a minimum spread rate of $8g/m^2$ has been adopted on the Agency's network for pre-wetted salting with brown salt, thereby reducing the potential de-icer cost savings when brine treatments are made, since the business case assumed a minimum of $10g/m^2$. Both of these factors have been taken into account in the revised calculations.

The other factor that has had an effect on the business case is the number of saturators used to produce brine. It should not be necessary to purchase additional saturators because those used for pre-wetted salting should have sufficient capacity for the number of brine treatments estimated. However, the amount of brine required each year for combination treatments (i.e. brine treatments and pre-wetted salting) would be higher than that required for just pre-wetted salting and an additional annual maintenance cost has been assumed for the saturators, to allow for increased usage.

The main conclusions from the revised calculations (based on the use of a combination spreader) are as follows:

1. If brown dry salt and white brine salt are used, it is estimated that there will be no direct cost savings if the brine loss due to trafficking is 30 per cent or more (i.e. on all types of surfacing on the Agency's network).
2. If white dry salt and white brine salt are used, there should be direct cost savings in areas where the weather conditions are not too severe, although this is more likely in such areas if white salt costs more than £46/tonne (c.f. £25/tonne for brown salt)
3. If brown dry salt and white brine salt are used, there will be an overall (direct and indirect) cost saving if the brine loss due to trafficking is 40 per cent in areas where the weather conditions are not too severe. In areas with the most severe weather conditions considered in the calculations, there will be an overall cost saving if the brine loss due to trafficking is 30 per cent or less (i.e. on dense surfacing)
6. If white dry salt and white brine salt are used there will be an overall cost saving if the brine loss due to trafficking is 40 per cent or less (i.e. on typical or dense surfacing). There should be an overall cost saving if the brine loss due to trafficking is 50 per cent (i.e. on open textured surfacing) in areas where the weather conditions are not too severe.

8 Assessment of routes most suitable for brine treatments

The combination spreaders available from the suppliers of the new winter fleet can perform brine-only spreading to one, two or three lanes, but it is not currently possible to spread three lanes and a hard shoulder. Many routes treat at least one three lane section with a hard shoulder. Table 28 summarises the routes from Areas 1 and 2; two areas where the climatic conditions are likely to be suitable for combination treatments.

None of the 11 routes in Area 1 have sections with more than three lanes (i.e. with three or more lanes and a hard shoulder). In Area 2, 11 of the 32 routes have no sections with more than three lanes and another two have only short sections of 3-lane slip road. Therefore, there are at least 22 routes in Area 1 and 2 that would suitable for brine treatments with combination spreaders from suppliers of the new winter fleet.

It is likely that there are routes in other areas without sections with more than three lanes that are suitable for brine treatments. However, it was beyond the scope of this study to identify them.

Table 28. Summary of spreading routes in Area 1 and 2 with details of sections with more than three lanes

Depot	Route	Route length	Total treated	3, 4 and 5 lane motorway and 4 lane slip road	3 lane dual carriageway	3 lane slip road
Area 1						
Pridhamsleigh	Route 1	95.07	33.32	0	0	0
	Route 2	77.68	40.41	0	0	0
Notter Bridge	Route 1	109.37	52.95	0	0	0
	Route 2	100.12	42.03	0	0	0
Tolpetherwin	Route 1	88.63	46.46	0	0	0
	Route 2	92.35	45.01	0	0	0
Bodmin	Route 1	98.19	48	0	0	0
	Route 2	98.34	52.73	0	0	0
	Route 3	89.09	37.48	0	0	0
Scorrier	Route 1	94.4	21.33	0	0	0
	Route 2	103.07	51.78	0	0	0

Depot	Route	Route length	Total treated	3, 4 and 5 lane motorway and 4 lane slip road	3 lane dual carriageway	3 lane slip road
Area 2						
Badbury	BA	92.16	42.45	36.93	0	1.26
	BB	92.27	36.68	35.2	0	0
Edithmead	EA	73.08	44.22	37.87	0	0
	EB	121.08	46.62	18.55	0	0
	EC	91.61	31.3	17.08	0.15	0.56
Falfield	FA	92.58	19.62	0	0	0
	FB	126.37	23.96	22.12	0	0
Tolpetherwin	TA	88.63	46.46	0	0	0
	TB	92.35	45.01	0	0	0
Bamfurlong	GA	99.52	30.9	25.46	0	0
	GB	112.71	27.99	20.13	0	0
	GC	76.48	35.2	32.16	0	0
	GD	77.18	36.37	0	0	0
Huntworth	HA	106.43	43.18	36.42	0	0
	HB	108.26	37.16	0	0	0.89
Clevedon	CA	152.42	61.12	45.63	0	0.82
	CB	102.05	32.56	28.15	0	0
Podimor	PA	91.06	44.29	0	0	0.03
Rockbeare	RA	82.58	27.77	0	0	0
Chelston	SA	89.04	50.08	48.76	0	0
	SB	97.73	35.49	32.45	0	0.63
	SC	106.49	34.48	31.15	0	0
Tomarton	TA	113.79	32.06	10.75	0	1.42
	TB	78.56	38.69	0	0	0
	TC	93.99	25.37	7.48	0	0
	TD	97.27	28.38	25.51	0	0.12
	TE	88.08	21.78	20.16	0	0
Wylye	WA	97.72	55.58	0	0	0
	WB	99.98	43.37	0	0	0
	WC	98.5	55.04	0	0	0
	WD	116.97	37.12	0	0	0
	WE	101.23	35.6	0	0	0

9 Feasibility of brine spreading with pre-wet spreaders

9.1 Background

Spreaders in the new winter fleet are designed to spread pre-wetted salt as the preferred choice. This technology is well proven on the continent and is increasingly being used in the UK as is evidenced by the Agency's new winter fleet and it now being the Agency's preferred treatment.

For the safety of vehicles needing to use them in emergencies, the hard shoulders of motorways are treated routinely during normal spreading operations when the rest of the carriageway is being treated. The target spread rate for the hard shoulder is half the carriageway spread rate. Hard shoulders on Managed Motorways need to be treated at the full spread rate appropriate to the forecast conditions. This could be higher than the spread rate for the carriageway, dependent on the forecast surface temperatures and wetness of the carriageway and hard shoulder. Potentially, the treatment of the hard shoulder could be by an additional treatment with brine immediately prior to hard shoulder running being implemented by either:

(i) Driving down the hard shoulder, spreading only the hard shoulder

(ii) Driving the spreader down Lane 1 with the spreading mechanism set to cover two lanes and spreading to the near side

During the winter of 2008/09, certain areas experienced very low temperatures where high doses of salt had been applied but reports of freezing roads were still received. In the main these incidents occurred in areas where the new pre-wet vehicles were not deployed or not yet operating in pre-wet mode. They happened in very cold weather and when traffic volumes were particularly low and on lightly trafficked roads such as slip roads. In addition, relative humidity values were low which inhibited (or prevented in extreme circumstances) salt entering into solution. By applying brine to these relatively short sections of carriageway the brine would act immediately on the ice and also accelerate the dissolution of the dry salt already present.

One method of treating hard shoulders and lightly trafficked areas could be to use the existing pre-wet spreaders to spread just brine, although the vehicles have not been designed to operate in this way. Liquid spreading using a spinning disc has been used for some time on airfields and is proven technology. This method is however subject to width restrictions. The advantages of spreading brine is that, subject to the conditions on the road and the brine dosage, it is virtually instant in its de-icing action, is not dependent on the action of traffic to activate de-icing, and within a short time of application the road is rendered ice free. This method could also be used to spot treat isolated areas of reported ice caused by "frost pockets". Though measures are taken to avoid these occurring, some are recorded every year.

Trials were therefore carried out to investigate the feasibility of spreading only brine with pre-wet spreaders from the Agency's winter fleet. The main aims were to determine:

- The efficacy of spreading the hard shoulder of a Managed Motorway for the following scenarios:
    - (i) Spreading from the hard shoulder and
    - (ii) Spreading from Lane 1 into the hard shoulder
- The efficacy of spreading a two lane slip road asymmetrically from Lane 1

Based on the results, guidance for Service Providers on spreading the hard shoulders of Managed Motorways has been developed for inclusion in the Network Management Manual.

9.2 Trial site description

The trial site was the same as that used for the brine spreading trials (Figure 1). The surfacing was 14mm SMA.

9.3 Brine spreaders and spreader characteristics

Two types of spreader were used for the trials, one from each of the providers of the Agency's new winter fleet; a Schmidt Stratos 18 tonne 4x4 pre-wet spreader as shown in Figure 26 and a Romaquip Ultima 26 tonne 6x4 spreader as shown in Figure 27. The spread width and asymmetry for both spreaders are varied by adjusting the spinner speed and the orientation of the chute/spinner assembly. An on-board weighing system monitors the combined weight of the hopper and brine tanks. Predicted amounts of dry salt and brine discharged at the chosen settings (to form the pre-wet mixture) can displayed on counters for the Schmidt spreader.

Figure 26. Schmidt Stratos 4x4 pre-wet spreader spreading brine

Figure 27. Romaquip Ultima 6x4 pre-wet spreader spreading brine

9.4 Trial procedure

The spreaders were operated by engineers from Schmidt and Romaquip during all of the trials. The spreaders were operated with the typical settings (spinner speed, chute position) for spreading 6.3mm pre-wetted rock salt over either one lane or two lanes. During the trials the hoppers were empty and the brine tanks were full.

Details of the trials are shown in Table 29 and Table 30 respectively. For the trials attempting to spread the hard shoulder from Lane 1 (Trials 5S and 6S for the Schmidt spreader and Trial 6R for the Romaquip spreader) it was not possible to set either spreader to just target the hard shoulder. The spreaders were therefore set to spread two lanes, i.e. spreading asymmetrically to Lane 1 and Lane 2 while driving in Lane 2.

It was possible to set the Romaquip spreader to spread brine when there is dry salt in the hopper using the spreader's control box. Currently, the Schmidt spreader does not allow brine to be discharged without dry salt without bypassing the control box, however it is expected that a simple modification would allow only brine to be spread.

Before each trial, the spread distribution was visually assessed while statically discharging at a simulated test speed of 64km/h. To confirm that the correct amount of brine was being discharged, a 1km discharge test was also carried out before each trial in which the amount of brine discharged was measured using the spreader's on board weighing system. To verify the accuracy of the on-board weighing systems, each spreader was weighed on a weighbridge before and after a series of test runs and the change in weight compared with that indicated by the on-board weighing systems.

Following the visual assessment of the Romaquip spreader spreading from Lane 1 to the hard shoulder, the spinner speed was doubled from the typical setting to increase the amount of brine distributed to the left of the spreader. This increased spinner speed was used only for Trial 6R.

Table 29. Schmidt trial runs, spreading at 64km/h

Trial no.	Trial date	Spread width (no. of lanes)	Brine spread rate (g/m^2)
1S	13/04/2010	1 symmetric	20
2S	13/04/2010	1 symmetric	40
3S	13/04/2010	2 asymmetric	20
4S	13/04/2010	2 asymmetric	40
5S	28/04/2010	2 (Lane 1 and HS)	20
6S	28/04/2010	2 (Lane 1 and HS)	40

Table 30. Romaquip trial runs, spreading at 64km/h

Trial no.	Trial date	Spread width (no. of lanes)	Brine spread rate (g/m^2)
1R	28/04/2010	1 symmetric	10
2R	27/04/2010	1 symmetric	20
3R	27/04/2010	2 asymmetric	10
4R	28/04/2010	2 asymmetric	10
5R	27/04/2010	2 asymmetric	20
6R*	28/04/2010	2 (Lane 1 and HS)	20

Spinner speed x 2

The test site was marked out for collection of the brine from three strips. The positions of the test strips and panels used for the collection are shown in Figure 28 and Figure 29 for one lane and two lane spreading respectively.

As with the brine spreader trials, the pre-wet spreaders used a length of the TRL Test Track to achieve the correct speed before starting to spread. The spreaders commenced spreading within the central area, at a starting point 50m before the first strip, and stopped spreading 50m after the last strip.

After spreading, the brine was collected from the panels by vacuuming using the wet wash method. Because of the under-recovery experienced in the brine spreading trials, the number of wet wash passes was increased from three to four to attempt to collect a greater proportion of the brine. On average, the results showed a 71 per cent recovery rate with four passes. Increasing the number of passes further was not considered feasible due to the extra time required for each brine collection.

Between trials, a road sweeper was used to remove the residual salt from before and between the strips to prevent salt being carried by the wheels of the spreader into the test panels.

Conductivity analysis of the saline solutions recovered from each panel was used to determine the effective amount of brine in each panel, i.e. the amount of brine that would have resulted in the conductivity measured.

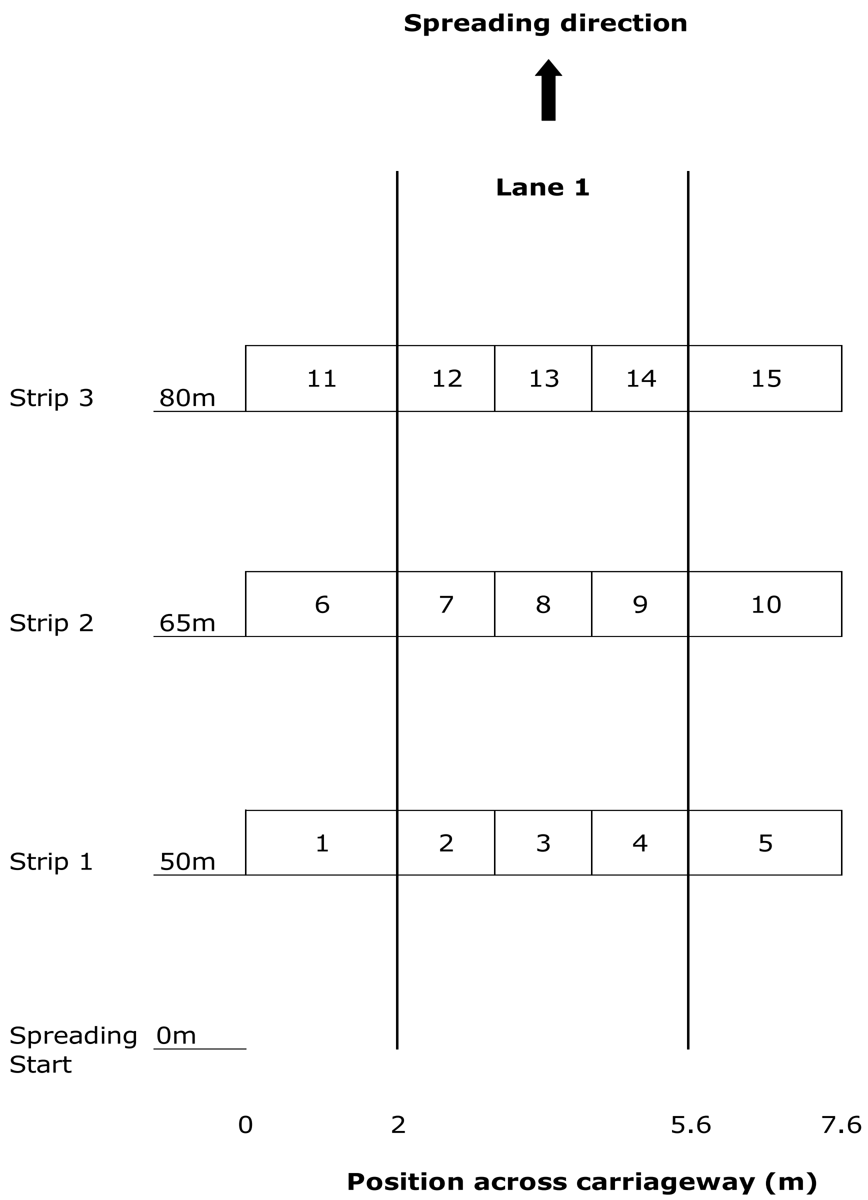

Figure 28. Layout of collection panels for one lane spreading

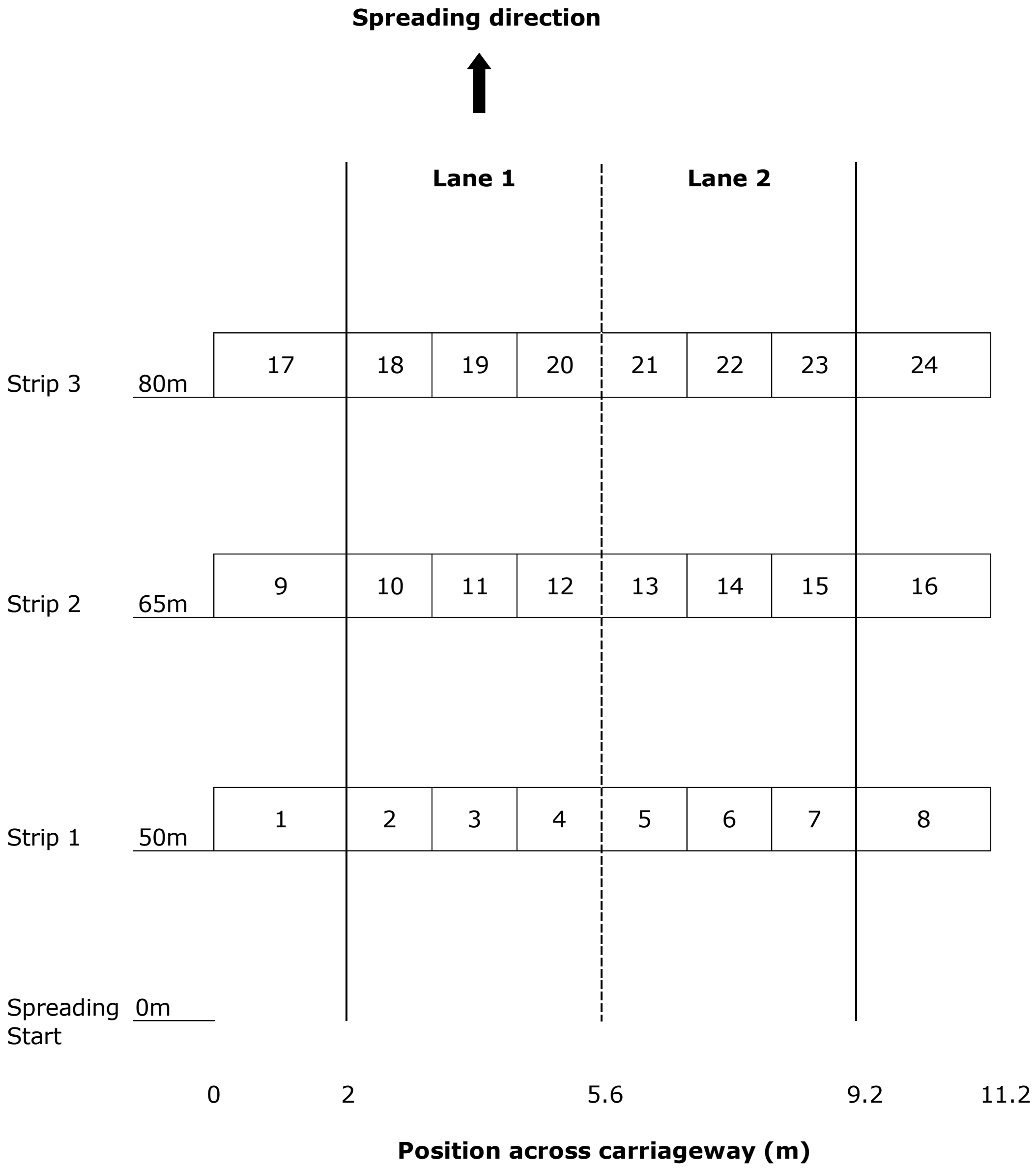

Figure 29. Layout of collection panels for two lane spreading

9.5 Weather conditions

The wind speed and direction for each trial are shown in Table 31 and Table 32.

Table 31. Schmidt spreader trials weather information

Trial no.	Mean wind speed (gust) (mph)	Direction	Direction relative to site
1S	4 (8)	NE	Lane 1 to Lane 3
2S	5 (8)	NE	Lane 1 to Lane 3
3S	5 (7)	NE	Lane 1 to Lane 3
4S	5 (7)	NE	Lane 1 to Lane 3
5S	3 (9)	S	Against spreading direction
6S	2 (8)	S	Against spreading direction

Table 32. Romaquip spreader trials weather information

Trial no.	Mean wind speed (gust) (mph)	Direction	Direction relative to site
1R	3 (6)	S	Against spreading direction
2R	2 (5)	W	Lane 3 to Lane 1
3R	0 (1)	W	Lane 3 to Lane 1
4R	3 (6)	S	Against spreading direction
5R	0 (1)	W	Lane 3 to Lane 1
6R	3 (6)	S	Against spreading direction

9.6 Results

9.6.1 Recovery correction

As explained above, tests measured a 71 per cent recovery rate using the recovery method described in Section 4.4 with four wet passes. Therefore, the amount of brine collected in each panel has been increased by the factor 100/71 = 1.41.

9.6.2 Brine distribution profiles

The average brine distribution profiles for each trial are compared in Figure 30 to Figure 37. The horizontal bar on each of the figures shows the target spread rate. The results for the brine collected from each strip in each trial are shown in Appendix C.

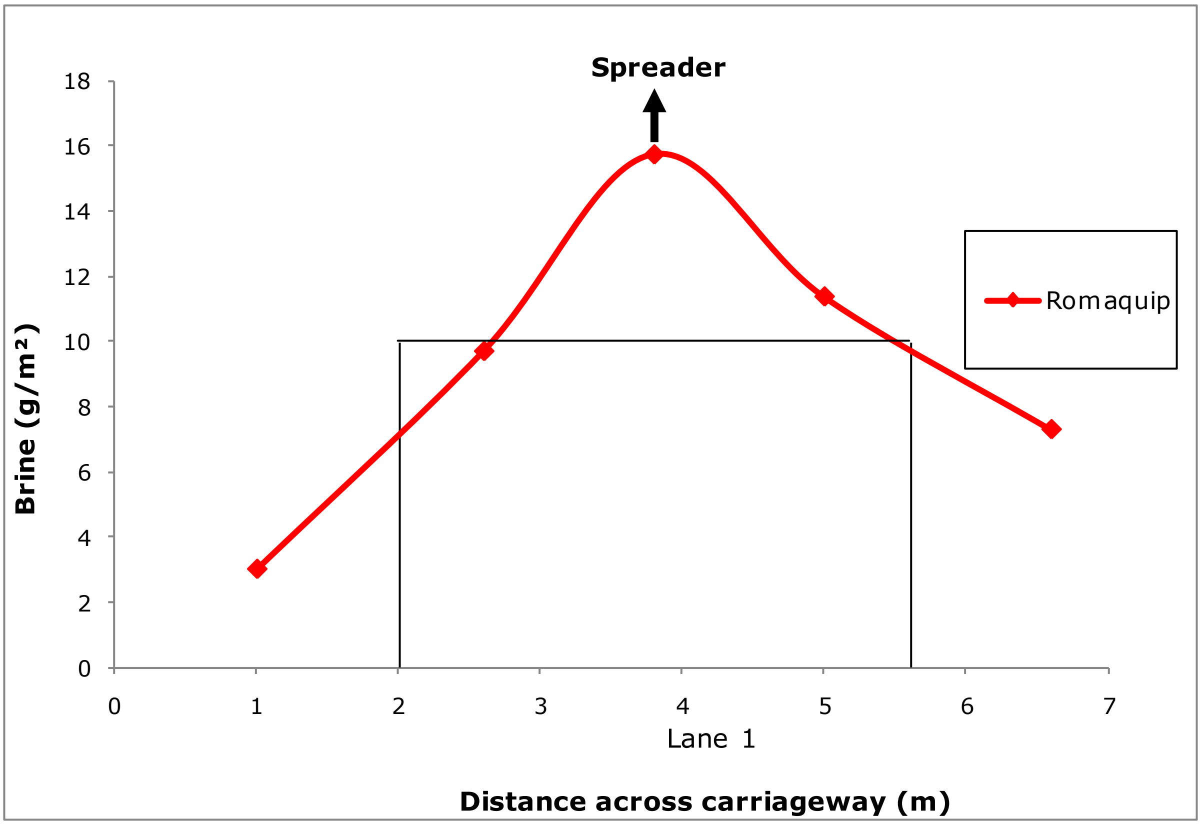

Figure 30. Spreading one lane symmetrically, 10g/m² (Trial 1R)

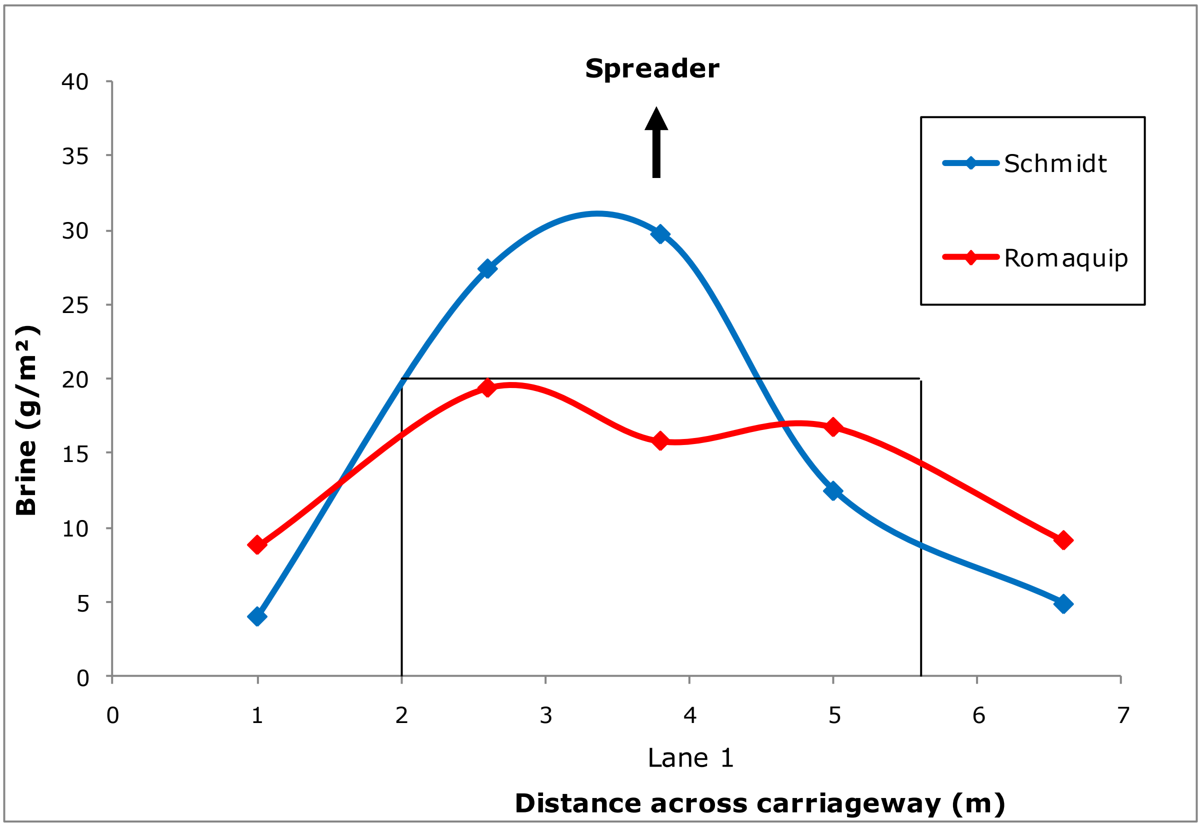

Figure 31. Spreading one lane symmetrically, 20g/m² (Trials 1S and 2R)

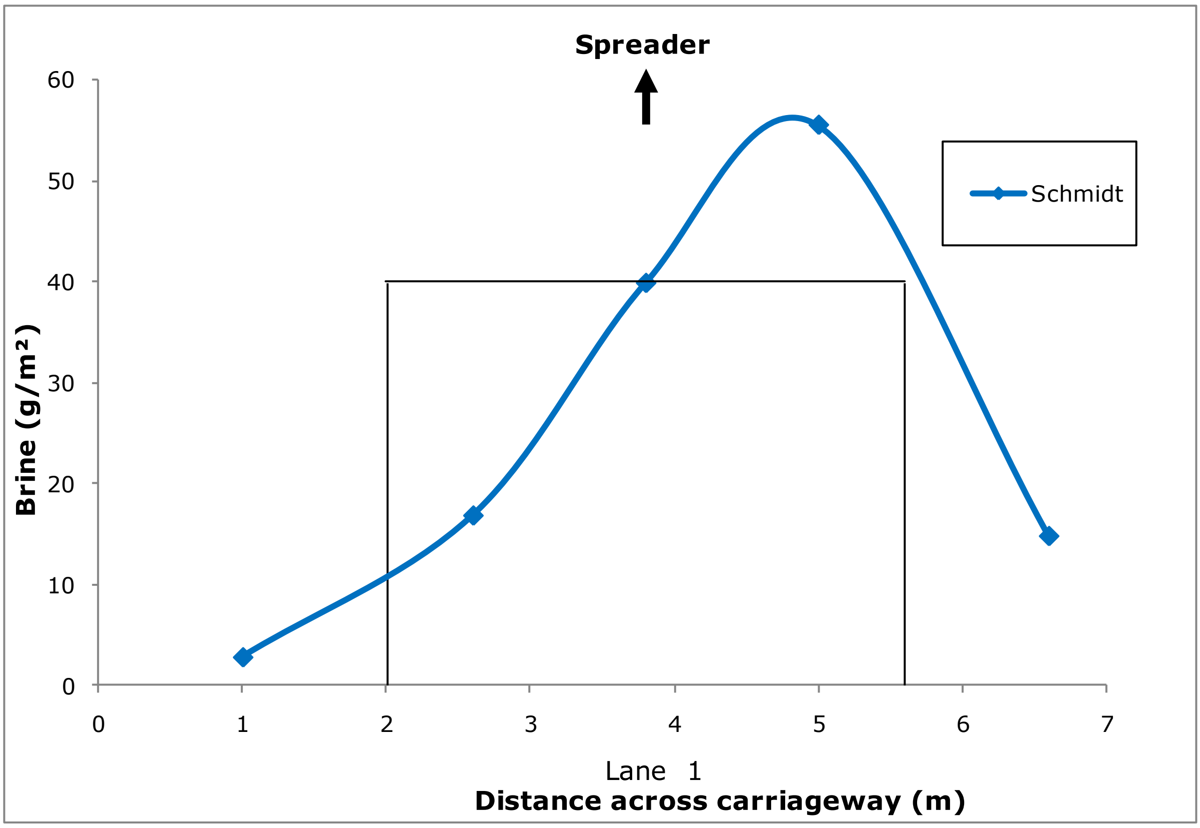

Figure 32. Spreading one lane symmetrically, 40g/m² (Trial 2S)

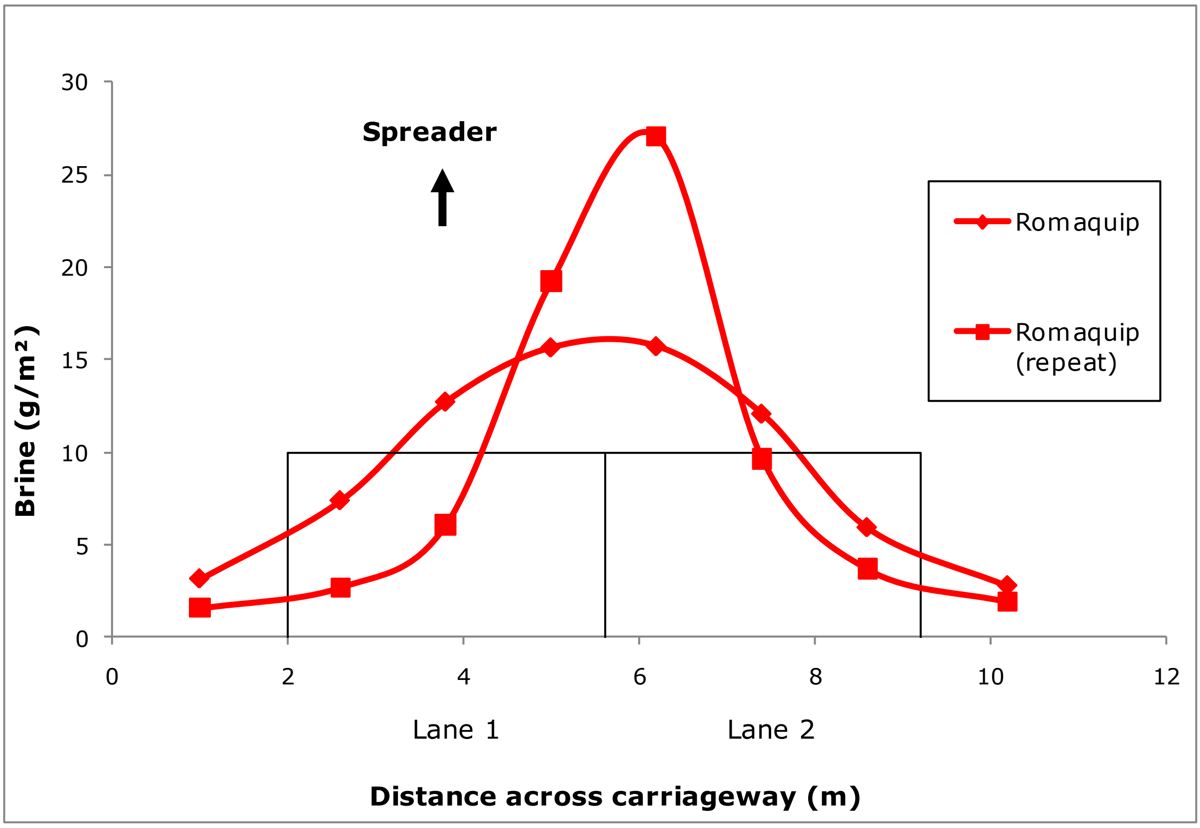

Figure 33. Spreading two lanes asymmetrically, 10g/m² (Trials 3R and 4R)

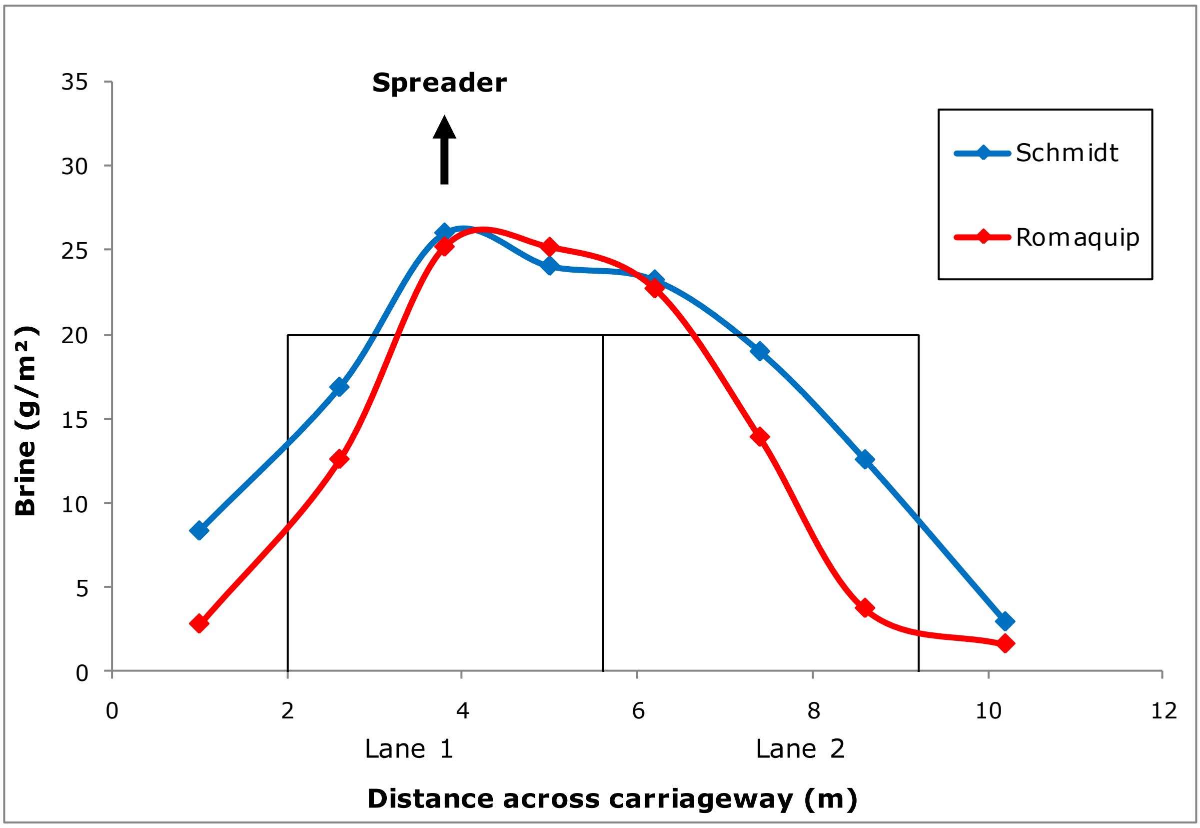

Figure 34. Spreading two lanes asymmetrically, 20g/m² (Trials 3S and 5R)

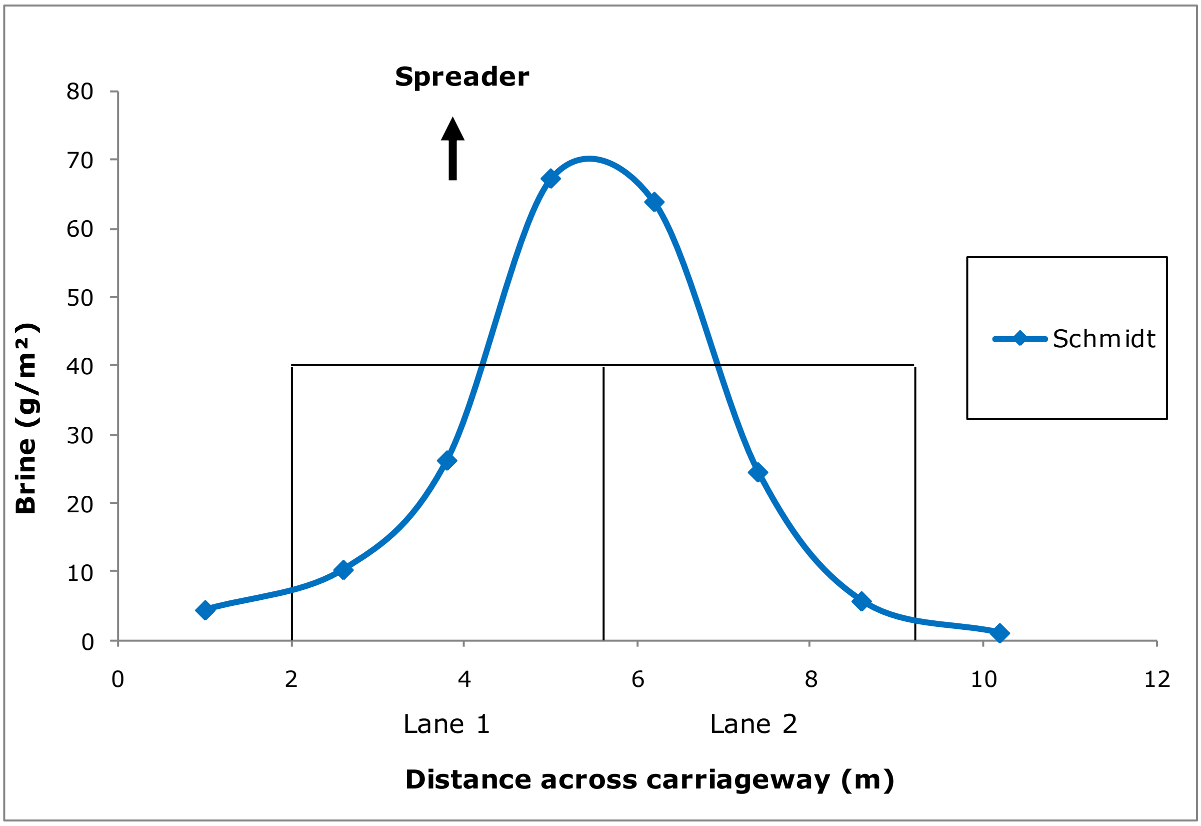

Figure 35. Spreading two lanes asymmetrically, 40g/m² (Trial 4S)

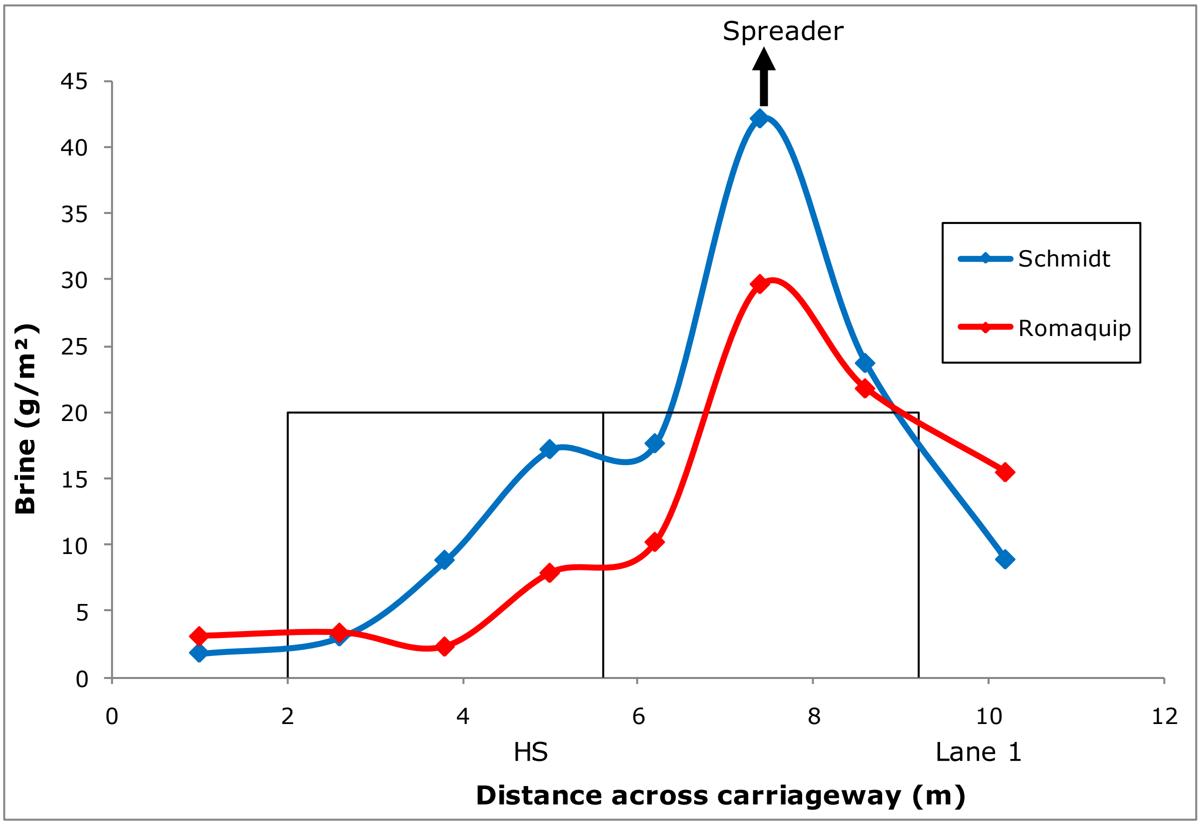

Figure 36. Spreading two lanes asymmetrically from lane 2, 10g/m² (Trials 5S and 6R – 2 x normal spinner speed)

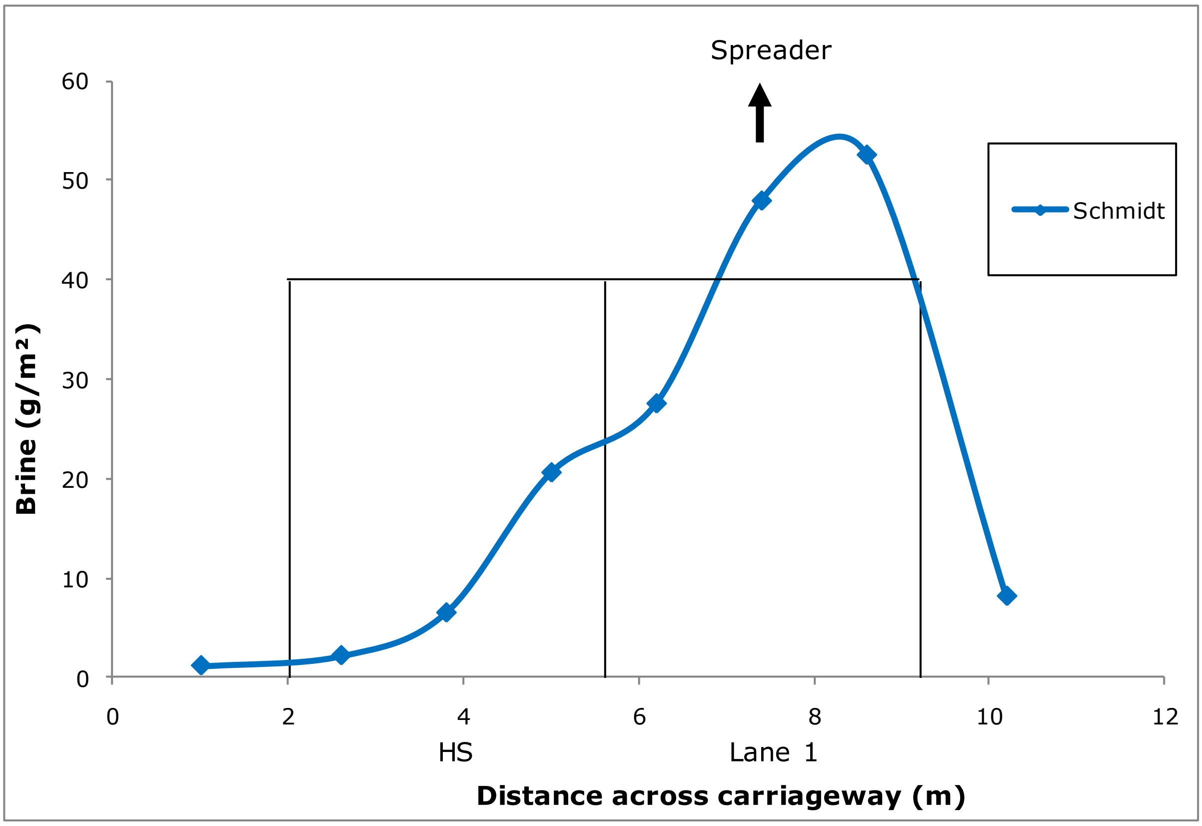

Figure 37. Spreading two lanes asymmetrically from lane 2, 40g/m² (Trial 6S)

9.6.3 Brine discharge tests

The amounts of brine discharged in the discharge tests are shown in Table 33 and Table 34 for the Schmidt and Romaquip spreader, respectively. The on-board weighing system and weighbridge measurements are compared in Table 35 and Table 36 for the two spreaders, respectively.

Table 33 Brine discharged in Schmidt discharge test runs from on-board weights, spreading at 64km/h over a distance of 1km

Date	Spread rate (g/m²)	Spread width (m)	Brine discharged (kg)	Target (kg)
13/04/10	40	3.6	150	144
28/04/10	20	3.6	86	72
13/04/10	20	7.2	135	144
28/04/10	40*	7.2	258	288

* Following the trial it was ascertained that the maximum capacity of the pump on the spreader was 200l/min, whereas spreading at 40g/m² would require a discharge rate of 240l/min

Table 34. Brine discharged in Romaquip discharge test runs from on-board weights, spreading at 64km/h over a distance of 1km

Date	Spread rate (g/m²)	Spread width (m)	Brine discharged (kg)	Target (kg)
27/04/10	20	3.5	75	70
27/04/10	20	7	135	140
27/04/10	10	7	75	70

Table 35 Comparison of weighbridge and Schmidt on-board weighing

	Weighbridge (kg)	On-board weight (kg)
Measurement 1	10760	2130
Measurement 2	10240	1630
Difference	520	500

Table 36 Comparison of weighbridge and Romaquip on-board weighing

	Weighbridge (kg)	On-board weight (kg)
Measurement 1	15600	17470
Measurement 2	14320	16185
Difference	1280	1285

9.6.4 Brine collected

Table 37 and Table 38 summarise the results for each spreader by lane. Column 7 gives the maximum minus the minimum coverage in Lanes 1 and 2 expressed as a percentage of the mean coverage for the two lanes. This gives an indication of the uniformity of the distribution across the lanes.

Table 39 and Table 40 show the total amount of brine collected in each trial for each spreader. Column 4 expresses the amount collected as a percentage of the target amount. Column 5 shows the percentage of the total amount collected that was collected from the lanes. Columns 6 and 7 show the amount collected from the left and right verges, expressed as a percentage of the total amount collected.

Table 41 and Table 42 show the strip to strip variation in the brine collected from the whole strip for each spreader. Columns 4 to 6 show the variation for each whole strip from the mean of the three strips. Column 7 shows the maximum minus the minimum variation for the whole strips.

Table 37. Coverage by lane: Schmidt

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Total as % of target spread rate			Max – Min as % of mean for Lanes
			Lane 1	Lane 2	Lanes t to 2	
1S	20	1 symmetric	116	-	116	-
2S	40	1 symmetric	93	-	93	-
3S	20	2 asymmetric	112	91	101	21
4S	40	2 asymmetric	86	78	82	10
5S*	20	2 (Lane 1 and HS)	48	139	94	97
6S*	40	2 (Lane 1 and HS)	24	107	66	126

* Driving in Lane 1

Table 38. Coverage by lane: Romaquip

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Total as % of target spread rate			Max – Min as % of mean for Lanes
			Lane 1	Lane 2	Lanes 1 to 2	
1R	10	1 symmetric	123	-	123	-
2R	20	1 symmetric	87	-	87	-
3R	10	2 asymmetric	119	112	116	6
4R	10 (repeat)	2 asymmetric	94	135	114	36
5R	20	2 asymmetric	105	67	86	44
6R*	20	2 (Lane 1 and HS)	23	103	63	128

* Driving in Lane 1

Table 39. Amount of brine collected and wastage: Schmidt

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Accuracy (% of target)	Brine in Lanes Factored total collected (%)	Wastage	
					Left (%)	Right (%)
1S	20	1 symmetric	141	82	8	10
2S	40	1 symmetric	118	79	3	17
3S	20	2 asymmetric	117	87	10	4
4S	40	2 asymmetric	86	96	4	1
5S*	20	2 (Lane 1 and HS)	108	86	2	11
6S*	40	2 (Lane 1 and HS)	72	91	1	8

* Driving in Lane 1

Table 40. Amount of brine collected and wastage: Romaquip

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Accuracy (% of target)	Brine in Lanes Total collected (%)	Wastage	
					Left (%)	Right (%)
1R	10	1 symmetric	182	68	9	23
2R	20	1 symmetric	129	64	18	19
3R	10	2 asymmetric	136	88	7	6
4R	10 (repeat)	2 asymmetric	128	92	4	4
5R	20	2 asymmetric	95	93	4	2
6R*	20	2 (Lane 1 and HS)	91	71	5	24

* Driving in Lane 1

Table 41. Strip by strip variation: Schmidt

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Full width of strip			
			Variation relative to mean (%)			Max - Min of Strips as % of Mean
			Strip 1	Strip 2	Strip 3	
1S	20	1 symmetric	99	100	101	3
2S	40	1 symmetric	111	90	99	21
3S	20	2 asymmetric	98	110	93	17
4S	40	2 asymmetric	92	101	107	15
5S*	20	2 (Lane 1 and HS)	112	97	91	21
6S*	40	2 (Lane 1 and HS)	112	114	74	39

* Driving in Lane 1

Table 42. Strip by strip variation: Romaquip

Trial no.	Spread rate (g/m²)	Spread width (no. of lanes)	Full width of strip			
			Variation relative to mean (%)			Max - Min of Strips as % of Mean
			Strip 1	Strip 2	Strip 3	
1R	10	1 symmetric	81	93	126	44
2R	20	1 symmetric	117	91	92	26
3R	10	2 asymmetric	101	89	110	21
4R	10 (repeat)	2 asymmetric	108	94	98	14
5R	20	2 asymmetric	117	77	106	40
6R*	20	2 (Lane 1 and HS)	78	103	119	41

* Driving in Lane 1

9.7 Discussion

Visual assessment of the spread pattern during the trials indicated that the brine could be spread over sufficient width for both one and two lane spreading. Observations during the trials also suggested that the brine was not discharged in such a controlled manner compared to when spreading with the brine spreader; the brine was observed to cascade off the spinner onto the surfacing rather than be distributed in a uniform spray. However, it should be noted that the spreaders have not been designed to spread only brine from the spinning disc in this manner.

The amount of brine discharged in the 1km discharge tests, as measured by the spreaders' on-board weighing systems, generally showed good agreement with the target amounts for both one and two lane spreading. The Schmidt spreader discharged 30kg less than the target amount when spreading over two lanes at 40g/m². However, following the trial it was ascertained that the maximum capacity of the pump on the spreader was 200l/min, whereas spreading at 40g/m² would require a discharge rate of 240l/min. This would explain the lower discharge measured in the test and also the lower than target amount of brine collected in the 2 lane trial spreading at 40g/m². Omitting this result, the average amount discharged by the Schmidt spreader was 106 per cent of the target amount. The average for the Romaquip discharge tests was 104 per cent of the target amount.

For spreading in one lane, directly behind the spreader, the factored total brine collected within the lanes ranged from 93 to 116 per cent of the target amount for the Schmidt spreader and from 87 to 123 per cent for the Romaquip spreader. However, with the pre-wet spreaders there was higher wastage to the left and right of the lanes as compared with the brine spreader. For the Schmidt spreader the total amount of brine collected from outside the lanes, as a percentage of the total collected, was on average 19 per cent. For the Romaquip spreader, the amount collected from outside the lanes was on average 34 per cent of the total collected.

For spreading across two lanes, asymmetrically from Lane 1, the total brine collected within the lanes ranged from 82 to 101 per cent of the target amount for the Schmidt spreader and 86 to 116 per cent for the Romaquip spreader. There was less wastage for the two lane spreading as compared to one lane, with on average 8 per cent of the brine collected outside the lanes for the Schmidt and 9 per cent for the Romaquip spreader. However, the lower wastage appeared to be a result of a reduction in brine spread towards the edge of the lanes. In general, the two lane spread distribution profiles exhibited a high spread rate in the centre of the lanes quickly falling off towards the edges.

The strip to strip variation in the brine collected, expressed as the difference between the maximum and minimum amount in a strip divided by the average, was 19 per cent for the Schmidt spreader and 31 per cent for the Romaquip, averaged over all trials. This was similar to the brine spreader variation and the variation in the performance trials with pre-wetted salt carried out in accordance with contractual arrangements for the Agency's new winter fleet. However, visual observations indicated that the brine distribution along the full length of the test site was less uniform when the pre-wet spreaders rather than the brine spreader spread brine. Therefore, it is possible that the position of the test strips was such that the measured variation did not reflect the magnitude of the variation along the trial site.

Poor results were obtained when attempting to spread asymmetrically to the left of the spreader, replicating spreading to the hard shoulder from Lane 1. In Trials 5S and 6S (for the Schmidt spreader) only 48 and 24 per cent respectively of the target spread rate was achieved in the lane to the left of the spreader. For the Romaquip spreader in Trial 6R only 23 per cent was achieved in the left hand lane, despite increasing the spinner speed to widen the distribution.

Brine spreading tends to be more susceptible to the effects of wind compared to spreading pre-wetted, treated or dry salting. An indication of this effect is shown in the distribution profile for Trial 2S, where the peak of the distribution was clearly shifted to the right side of the lane, likely as a result of the 5mph crosswind from left to right during this trial.

Overall assessment

With reference to the specific aims of the trial:

1) Determine the efficacy of spreading the hard shoulder of a Managed Motorway for the following scenarios:

a) Driving and spreading from the hard shoulder

The trials have shown that it is possible to achieve the target rate within the lane the spreader is driving in. To achieve the target spread rate, the wastage outside the lane is relatively high and the total amount of brine discharged will therefore be required to be greater than the target amount for one lane. The uniformity of the brine distribution along the carriageway is comparable with that in the trials with a brine spreader. Overall, the results of the trials would indicate there is potential to spread brine to the hard shoulder from the hard shoulder using pre-wet spreaders.

b) Spreading from Lane 1 into the hard shoulder

Based on the results from these trials, spreading brine from Lane 1 to the hard shoulder would not seem to be a feasible method when using pre-wet spreaders at present. It may be that modification of the spreaders, e.g. the design of the spinner, would result in a better distribution, but this may not compromise the distribution when pre-wetted salting. A more effective option would likely be the addition of nozzles to the pre-wet spreaders which could spray brine to the hard shoulder while driving in Lane 1.

2) Determine the efficacy of spreading a two lane slip road asymmetrically from Lane 1

The distribution profile across two lanes was clearly less uniform compared with the distribution for the brine spreader. As a result, to achieve the target spread rate across the whole width of the carriageway would require significant overspreading in the centre of the lanes. If brine spreading was to be carried out as the only treatment on a section of carriageway, more work would be required to try and optimise the two lane distribution. However, with the distribution as measured at present, there would be potential for use as a top up treatment to areas previously treated with the target amount of dry or pre-wetted salt.

9.8 Guidance for brine spreading with pre-wet spreaders

9.8.1 Proposed guidance based on findings from performance trials

Pre-wet spreaders can be used to spread only brine as top-up treatments on:

- Lightly trafficked slip roads
- Managed Motorway hard shoulders before they have been opened to traffic

With little or no traffic in these areas, it is possible that solid de-icers, especially dry salt and to a lesser extent pre-wetted salt, may not dissolve and become effective at low spread rates in low temperature and low humidity conditions. Brine is effective immediately after spreading and can reduce the risk of ice formation.

Service Providers should contact the spreader manufacturer for instructions on how to set up pre-wet spreaders to spread only brine with solid de-icer in the hopper. An additional electronic control programme is likely to be required for the Schmidt vehicles.

Two lane slip roads may be spread with brine by driving in Lane 1 and spreading to Lanes 1 and 2. A one lane slip road or the hard shoulder of a managed motorway may be spread with brine by driving in that lane or the hard shoulder. In both cases, the standard spinner settings for pre-wetted salting one lane or two lanes asymmetrically from Lane 1 to Lanes 1 and 2 can be used. Tests have shown that it is not possible to spread brine to a hard shoulder from Lane 1 with the standard settings for pre-wetted salting.

The optimum concentration of sodium chloride brine for brine spreading is 23 per cent. But unlike pre-wetted salting the concentration of the brine is more important because lower concentrations have a greater effect on the amount of salt on the highway. For example, if the brine concentration is 20 per cent, the amount of salt spread will be reduced significantly (by 13 per cent).

Without modification to the brine pump, the pre-wet spreaders in the new winter fleet can be set to spread brine at a maximum spread rate of approximately 40g/m^2 to a single 3.6m wide lane or 20g/m^2 to two lanes of total width 7.2m. Assuming a brine concentration of 23 per cent, this equates to a nominal salt spread rate of 9.2g/m^2 and 4.6g/m^2, respectively.

The carriageway or hard shoulder lengths that can be treated by pre-wet spreaders in the new winter fleet are shown in Table 43.

Table 43 Lengths that can be treated with brine by pre-wet spreaders

Spreader	Length that can be treated (km)			
	Nominal brine spread rate: 20g/m^2		Nominal brine spread rate: 40g/m^2	
	Number of lanes of width 3.6m		Number of lanes of width 3.6m	
	1	2	1	2
6x4 pre-wet	50	25	25	12.5
4x4 pre-wet	33.3	16.7	16.7	8.3

Tests with pre-wet spreaders spreading at 64km/h found that the minimum coverage in a single lane corresponded to about 90 per cent of the nominal spread rate. The minimum coverage in one lane when spreading to two lanes was about 70 per cent of the nominal spread rate. Brine spreading is likely to be more susceptible to the effects of wind than pre-wetted salting, so lower coverage is possible in windy conditions. Assuming no salt is present from previous treatments, Table 44 shows the minimum road surface temperatures at which brine treatments will prevent freezing at two road surface conditions.

Table 44 Effectiveness of brine treatments

Surface Condition	Water film thickness (mm)	Minimum road surface temperature at which freezing will not occur (°C)					
		Nominal brine spread rate: 40g/m^2		Nominal brine spread rate: 20g/m^2		Nominal brine spread rate: 20g/m^2	
		Minimum lane coverage for one lane spreading (% of nominal spread rate)		Minimum lane coverage for one-lane spreading (% of nominal spread rate)		Minimum lane coverage for two-lane spreading (% of nominal spread rate)	
		90	**80**	**90**	**80**	**70**	**60**
Damp	0.05	-5.9	-5.4	-3.6	-3.3	-2.9	-2.6
Wet	0.10	-3.6	-3.3	-2.0	-1.9	-1.7	-1.4

Because brine treatments with pre-wet spreader should be top-up treatments, the residual salt from earlier treatments should prevent freezing to temperatures lower than those in Table 44. However, the effectiveness of any residual salt without trafficking in low temperature and low humidity conditions is likely to be difficult to determine.

Careful consideration must also be given to possible differences in temperature between the untrafficked hard shoulder of a managed motorway and the running lanes of the carriageway. The temperature in Lane 3 of a three lane motorway can be up to 3°C lower than Lane 1 because of the lighter traffic flows. Without traffic the temperature difference can be even greater such that an untrafficked hard shoulder can be up to 5°C lower than Lane 1; this is particularly evident on concrete carriageways. Similar temperature differences may be evident on slip roads.

Further consideration must be given to the surface condition. Shortly after rainfall, untrafficked areas are likely to remain wetter for longer than trafficked areas. Furthermore, many hard shoulders are on the low side of crossfalls so large areas of carriageway can drain over them. Pre-wetted salting is the preferred treatment in such conditions.

Without accurate information on residual salt levels, surface temperatures and surface conditions to optimise the spread rate, it is recommended that treatments are made at the maximum brine spread rate that can be achieved with pre-wet spreaders, namely 40g/m^2 for one-lane spreading and 20g/m^2 for two-lane spreading.

The installation of remote sensors along the hard shoulder of managed motorways to monitor surface temperatures and surface conditions is recommended to aid decision making.

To ensure hard shoulders and slip roads are ice free, or rather have sufficient grip/friction, checks can be carried out using mobile equipment which measures the friction of the road surface. Devices have been developed to measure water film thickness and friction statically at discrete points. Over the last two years these have been successfully developed as mobile instruments. They are mounted on any suitable van or small service vehicle and driven down the carriageway at speeds up to 50 mph. The surface friction and water film can be measured at regular intervals and the information transmitted back to a base station to verify that the friction is within pre-defined parameters.

9.8.2 Safety considerations

This section covers some of the safety issues when treating the hard shoulders of managed motorways. It may be inappropriate to include them in the Network Management Manual until they are fully resolved.

Hard shoulder running is not allowed under motorway regulations but safety inspections are routinely carried out from hard shoulders as are many other maintenance activities. Brine spreading in the hard shoulder at 64km/h would need to be fully assessed for safety and be accepted by the Association of Chief Police Officers. Alternatively, treatments could be at a lower speed than normal, but this would increase treatment times.

Consideration has been given to have spreaders activate the matrix signals as they pass each gantry for a set time and create a rolling warning following the progress of the spreader. This could be used on managed motorways which have gantries every one kilometre. In addition, Traffic Officers could be requested to give rolling block cover behind the spreader. Crash cushions could also be deployed to the rear of the spreader as is normal practice for sweeping the hard shoulder.

If it becomes impractical to treat hard shoulders with brine before they are opened to traffic, treatments must be made before the hard shoulder is closed to traffic. These treatments could be with pre-wetted salt, ensuring a full dosage spread to the hard-shoulder running lane, or, if there is likely to be little traffic after treatment, with brine.

10 Brine effectiveness trials

As mentioned in the previous section, brine treatments are being considered for the treatment/top-up treatment of the hard shoulders of Managed Motorways. This is because hard shoulders opened after treatments with solid de-icers will not have benefitted from the trafficking required to help dissolve the de-icers. If solid de-icers have not dissolved, it may be necessary to delay their opening if there is a risk that ice may be present.

It may be necessary to carry out brine treatments many hours before a hard shoulder is opened to traffic in the morning, even making the treatments during the late evening before the hard shoulder is closed to traffic. It is normally assumed that brine precautionary treatments are effective immediately if they are made before ice forms. However, it is not known whether such treatments are effective if they are made well in advance of freezing conditions.

A series of trials was planned to investigate the effectiveness of brine treatments in preventing ice formation in order to address the concerns described above, with the aim to assist the development of guidance on the timing of treatments for the hard shoulders of Managed Motorways.

10.1 Trial procedure

For operational reasons, it was impractical to conduct the trials on the network. Testing was therefore carried out in the laboratory in an environmental chamber at TRL.

The aim was to replicate freezing of water on a carriageway surface under a range of conditions of temperature and humidity that would typically be encountered on the road network.

The principal aims were to investigate brine effectiveness:

1. During formation of frost on a dry surface
2. During freezing after rainfall

Testing was carried out on newly constructed 300mm square specimens of 10mm and 14mm SMA surfacing.

A Vaisala Spectro remote sensing device purchased for water film thickness measurements in an earlier project was used to detect the presence of ice as well as measure water film thicknesses on the surface of the specimens.

10.1.1 Frost conditions

To replicate brine spreading before frost conditions, it was proposed to spray dry specimens with brine at different spread rates that would prevent freezing at temperatures between -2 and -6°C if the frost was 0.03mm thick (the maximum thickness assumed by Evans et al (2010A) for well trafficked roads) or greater. Other specimens would be left untreated.

The aim was to replicate conditions when spreading 6 hours before a frost formed. After applying the brine, the specimens were to be placed in the environmental cabinet and the relative humidity and temperature maintained at 95 per cent and 2°C, respectively, for a period of 6 hours before the temperature was reduced slowly to -6°C over a period of 4 hours. By carefully adjusting the air temperature so there were periods when the surface temperature was lower than the air temperature it was hoped to form a frost on the untreated specimens of thickness not less than 0.03mm.

10.1.2 Freezing after rainfall

To replicate freezing after rainfall, the test specimens were to be sprayed with water to obtain a certain film thickness. The target water film thicknesses were 0.05 and 0.1mm. Some specimens were to be left untreated and others treated with brine at two different spread rates that would, with thorough mixing of the water and brine, prevent freezing at temperatures of -2 and -6°C.

Again, the aim was to replicate conditions when spreading 6 hours before ice might form. The specimens were to be placed in the environmental cabinet and the relative humidity and temperature maintained at 95% and 2°C, respectively, for a period of 6 hours before the temperature was reduced slowly to -6°C over a period of 4 hours.

10.2 Results and discussion

10.2.1 Frost conditions

Before commencing the laboratory trials a number of specimens were placed outside overnight when a hard frost formed on surrounding vegetation. However, no frost was observed to form on the dry specimen surfaces or the surrounding paved surfaces, presumably because the temperature of these surfaces was not lower than the air temperature. Measurements with the Vaisala Spectro device also indicated no ice had formed. At the time of the measurements, the air and specimen temperatures were approximately -3°C. To verify the Vaisala device could measure ice formation, water was sprayed onto the specimen surface and the water and ice thickness measured as the water froze as shown in Figure 38. This therefore provided confidence in the operation of the Vaisala device.

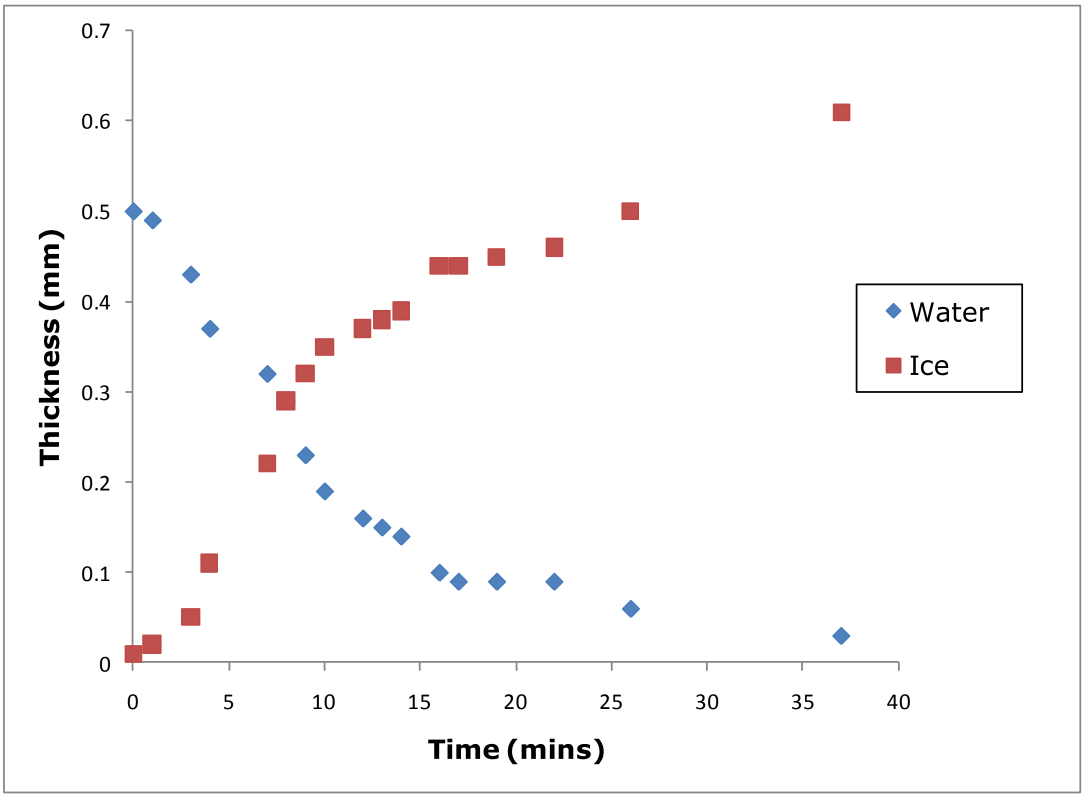

Figure 38 Freezing of water film on 10mm asphalt slab surface at -3°C

In order to form a frost on the surface of the laboratory specimens in the environmental changing, the chamber temperature was set to cycle between 2°C and -6°C, with the humidity kept at a minimum of 95 per cent. This was designed to produce periods when the surface temperature was colder than the air temperature, as required to form a frost. However, despite experimentation with the rate of cooling and heating and the length of time held at each temperature it was not possible to produce a frost.

Replicating conditions of frost formation as would be experienced in the normal environment was therefore found not to be possible using the facilities available to this study.

10.2.2 Freezing after rainfall

The amount of water needed to form a film of thickness 0.05mm or 0.1mm of dimension 300mm x 300mm, the area of the specimen surfaces, was calculated. As near as possible to this amount was then sprayed evenly over the specimens. The Vaisala device has a measurement resolution and minimum thickness measurement of 0.01mm, however tests on both the 10mm and 14mm SMA specimens showed either no water film thickness measurement or at most 0.01mm. The water was also observed to form into beads on the bituminous surface of the slab rather than form an even layer. Only by significantly wetting the surface was it possible to produce thickness measurements in the range 0.05 to 0.1mm and these quickly reduced to a zero thickness reading as the water drained in to the surface.

Tests were carried out on a specimen where the new bituminous surface was roughened by applying dust, and another specimen was grit blasted to remove the bitumen from the surface aggregate. By these methods, a more even water film was formed and less wetting was required to form a thicknesses in the range 0.05mm to 0.1mm.

However, when water was applied to the SMA specimens at this thickness (as measured using the Vaisala device), the water drained through quickly leaving only 0.01 to 0.02mm of water after approximately 10 minutes. There was clearly an issue with the porous nature of the thin surfacing material used to produce the slabs. (Water films were produced on hard, impermeable surfaces which were found to be longer lasting.)

After wetting the specimens, a series of tests were carried out to attempt to produce a measureable ice layer on the surface. The specimens were cooled to 2°C before applying the water. However, with the low levels of water remaining on the surface, the specimens were still found to drain/dry out over the period required to freeze any moisture present. Some simple tests were carried out where varying amounts of water were placed in open containers in the environmental chamber and frozen. These tests showed the amount of water lost during freezing because of the air circulation within the chamber was equivalent to a water thickness of approximately 0.2mm.

A number of set-ups were tested to try and overcome this drying out effect, including enclosing the specimens within a container inside the chamber. A water bath was placed inside the container to achieve the highest humidity possible while cooling the specimens. No measurable ice layer was formed in this way.

Some cores of 6mm, 10mm and 14mm negatively-textured surfacing were obtained from trafficked roads to try and form a more stable water film with the reduced drainage and rougher surfaces of the cores. Again, a measureable ice layer could not be formed on the core surfaces.

10.3 Conclusions

In the laboratory, it was not possible to form a frost or a measurable ice layer on any specimen tested. The specimens of SMA surfacing have been found to be too free draining to allow a thick enough water film to be formed that can freeze on the surface.

The difficulties in sustaining a water film on the surface of the test specimens are consistent with drainage of brine into the 14mm surfacing during the performance trials.

11 Conclusions

Brine spreader distribution

1. The performance trials have shown that brine can be spread evenly to the lanes when two or three lane spreading
2. There was no significant difference in the distribution when spreading at 64km/h or 80km/h.
3. The brine distribution profile across the lanes was less flat than the distribution profile obtained with pre-wetted salt in the performance trials carried out by TRL. There were distinct dips in the brine distribution at the edges of each lane.
4. The trial results have shown that there is potential to treat the network with brine, spreading at 80km/h and brine spread rates as low as 10g/m², subject to further optimisation of the spread pattern.
5. If brine spreading was to be implemented, performance requirements would be required for brine spreading similar to those specified for dry, pre-wetted and treated salting for the new winter fleet.
6. Tests have shown a significant proportion (30 per cent) of the brine spread on an open textured thin surfacing cannot be collected using the wet wash collection method used in the performance and road trials. It is thought that this is because some of the brine drains into the surfacing. A correction factor was applied to the results from the performance trials to account for the under recovery and determine the brine distribution after spreading.

Brine loss after trafficking

7. In two road trials, the average loss of brine during two hours of trafficking was 56 per cent for a negatively-textured thin surfacing and 40 per cent for an HRA surfacing.
8. The brine distribution along the carriageway was very uniform after trafficking, with the maximum minus the minimum amount collected from the strips being 26 cent of the average in Trial 1 and 12 per cent in Trial 2. This is lower than the 30 per cent measured in road trials carried out by TRL with 6.3mm pre-wetted salt (Jordan et al, 2011A
9. The calculated losses in these trials were greater than the 15 per cent loss reported in the literature that was used in the original business case for brine spreading.
10. In practice, drainage of brine into the surfacing will be a significant factor along with the effect of trafficking on brine loss, especially on the negatively-textured surfacing which was considered to be more open textured on the trial site than the typical surfacing on the Agency’s network.
11. In determining the losses applicable to brine spreading on the Agency’s network, a correction factor was applied to the amount of brine collected during the road trials to account for:
    a. Residual salt that was still available within the surface for de-icing but not collected using the wet wash method.
    b. The increased drainage of the trial site in comparison to the Agency network
12. In the revised business case, the loss of brine due to trafficking has been increased from 15 to up to 40 per cent for brine treatments on typical surfacing.
13. Losses of 30 and 50 per cent have been used, respectively, for denser and more open textured surfacing than typical surfacing.

Survey of types of saturator

14. A survey of brine production facilities found that those being used by Service Providers for pre-wetted salting are sufficient for brine treatments (and pre-wetted salting) with combination spreaders.
15. The increased use of saturators for combination treatments will increase the likelihood of failures and problems occurring and hence likely result in additional maintenance costs. However, it is claimed some maintenance may be prevented with better operator training.
16. Brown rock salt is low in cost and easily available, however its cost effectiveness for the production of brine needs to include the cost of extra maintenance required to remove impurities from the saturator.
17. Currently, the experience of Service Providers is insufficient to make a recommendation (or otherwise) on the use of brown salt and no data have been found that would suggest that the use of brown salt is cost effective. Therefore, white salt is recommended for brine production.
18. The potential for brine from industrial processes to be supplied directly to Service Providers was investigated. It was thought that continuity of supply may be a problem and much storage may be required at depots to ensure sufficient brine was available at times of high demands.

Revised business case

19. Based on the revised business case, the use of combination spreaders is not recommended where brown salt is used for the dry salt component of pre-wetted salt. It is estimated they will not reduce the cost of winter service operations, although there may be an overall cost saving to society in areas where the weather conditions are not too severe.
20. Where white salt is to be used each winter for the dry salt component of pre-wetted salt, the use of combination spreaders will reduce the cost of winter service operations where the winter conditions are not too severe and they will bring benefits to society as a whole.
21. At least 22 routes have been identified in Area 1 and 2 which have no sections with more than three lanes. These routes, which are in areas where the climatic conditions are likely to be suitable for brine treatments, would be suitable for brine treatments with combination spreaders from suppliers of the new winter fleet.

Brine spreading using pre-wet spreaders

22. Performance trials have shown that it is possible to spread only brine with pre-wet spreaders in the new winter fleet using the standard settings for pre-wetted salting.
23. The brine distribution profile was reasonably uniform when driving and spreading in the same lane.
24. Spreading brine asymmetrically to the left, e.g. from Lane 1 to the hard shoulder, was not shown to be effective using the spreaders as currently configured.
25. The brine distribution profile across two lanes was less flat than the distribution with the brine spreader. To achieve an acceptable spread rate across a two lane width, using the standard settings for pre-wetted salting, it is likely that significant over spreading would be required in the centre of the lanes.
26. The trials have shown potential for spreading brine over one lane directly behind the spreader, as would be required if driving and spreading from the hard shoulder of a Managed Motorway.

27. Spreading across two lanes asymmetrically, as required for spreading a two lane slip road from Lane 1, would be feasible for topping up areas which have already been treated especially if ice formation is suspected.

28. Guidance has been produced for brine spreading on the hard shoulders of Managed Motorways and on slip roads. Without accurate information on residual salt levels, surface temperatures and surface conditions to optimise the spread rate, it is recommended that treatments are made at the maximum brine spread rate that can be achieved with pre-wet spreaders, namely $40g/m^2$ for one-lane spreading and $20g/m^2$ for two-lane spreading.

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Appendix A Cost-benefit analysis

This Appendix is split into two parts, A.1 and A.2. The former explains the build-up of the original business case, including the various assumptions made, and presents the findings. The latter presents a revised business case using the findings from the various trials and surveys conducted as part of this report.

A.1 Calculations from original business case

A.1.1 Brine and pre-wetted salting treatment rates

In order to estimate the potential for salt savings when whole routes are treated with brine rather than pre-wetted salt, the spread rates required for different weather conditions (road surface temperatures and amounts of water on the road surface) were calculated by considering the concentration of the brine formed from the salt and water assumed to be present at the road surface. The sodium chloride – water phase coordination diagram was then used to determine the temperature at which the brine solution would freeze. The same approach was used by Evans et al (2011) to calculate spread rates for dry and pre-wetted salting.

The assumptions made in the calculations were as follows:

- Sodium chloride concentration of salt used to produce brine (allowing for impurities and moisture content): 98%, i.e. white salt stored in low humidity conditions
- Brine sodium chloride concentration: 23%
- Minimum coverage of brine across carriageway: 90% of nominal spread rate (assumed)
- Brine loss due to trafficking before minimum road surface temperature: 15% for brine treatments and brine in pre-wetted salt
- Sodium chloride content of dry salt component of pre-wetted salt (allowing for impurities and moisture content): 90%, i.e. UK indigenous brown rock salt
- Loss of dry salt component of pre-wetted salt due to trafficking before minimum road surface temperature: 40% of the amount spread
- Minimum coverage of dry salt component in pre-wetted salt across carriageway: 90% of nominal spread rate (measured for new winter fleet).

Table A.1 shows the required spread rates for brine and pre-wetted salt based on these assumptions. The table gives exact ('idealised') spread rates and, because it would be impractical to set up spreaders to spread de-icer at the 'idealised' rates, more 'practicable' rates rounded to integer values. Jordan (2011) considered minimum brine spread rates of 5g/m^2 and 10g/m^2. These are dependent on the performance of the spreaders in the new winter fleet, which has been investigated in this project. However, a minimum brine spread rate of no less than 10g/m^2 (i.e. 2.3g/m^2 of salt) was thought to be appropriate for the Agency's network, and has been assumed in the analyses described in this report, because anything lower would spread very little salt. Also shown in the table are the 'practicable' spread rates estimated for pre-wetted salting. The minimum spread rate of 8g/m^2 introduced on the Agency's network from January 2010 was assumed.

Table A.1 'Idealised' and 'practicable' spread rates for brine treatments

Road surface temperature (°C)	Assumed water film thickness (mm)	'Idealised' brine spread rate (g/m^2)	'Practicable' brine spread rate (g/m^2)	'Practicable' pre-wetted salting spread rate (g/m^2)
To -2°C	0.02	4.57	10	8
	0.05	11.43	12	8
	0.10	22.87	25	10
To -4°C	0.02	10.92	12	8
	0.05	27.29	30	10
	0.10	54.59	60	20
To -6°C	0.02	19.46	20	8
	0.05	48.66	50	15
	0.10	97.32	100	30

The requirements for brine treatments were estimated for a 'typical depot' with 4 spreaders and a treatment length of 150km by assuming numbers of treatments in different weather conditions throughout a winter season. The annual salt savings were estimated for the following treatment options:

- Pre-wetted salting replaced with brine treatments using brine only spreaders
- Pre-wetted salting replaced with brine treatments or pre-wetted salting using combination spreaders

A.1.2 Brine spreaders

The capacity of the spreaders will determine the number of turn outs required to treat a whole route. The salt and brine capacities of the spreaders specified in the new winter fleet procurement contract are given in Table A.2. The vehicles are described as 4x4 or 6x4 vehicles where the number before the 'x' refers to the number wheels and the number after the 'x' refers to the number of wheels that are driven.

Table A.2 Capacities of spreaders specified in new winter fleet procurement contract

Spreader type	Hopper volume (m^3)	Dry salt capacity (kg)	Brine tank capacity (litres)
Pre-wet 4x4 (see Figure A.1)	6	8,000	2,000
Pre-wet 6x4 (see Figure A.2)	9	12,000	3,000
Potassium acetate 4x4 (suitable for brine) (see Figure A.3)	0	0	7,200
Brine 6x4	0	0	12,000
Combination 6x4 (see Figure A.4)	9	12,000	5,000

Figure A.1. Schmidt Stratos 18 tonne 4x4 pre-wet spreader

Figure A.2. Romaquip Ultima 26 tonne 6x4 pre-wet spreader

Figure A.3. Schmidt Stratos 18 tonne 4x4 liquid treatment spreader

Figure A.4 Schmidt Stratos 26 tonne 6x4 combination spreader

A.1.3 Salt savings and de-icer cost savings

Table A.3 shows the estimated salt required to treat the area treated by the 'typical' depot when the 'practicable' spread rates shown in Table A.1 were assumed. Large salt savings were estimated for road surface temperatures down to -2°C, primarily because it was assumed that it would not be possible to obtain a sufficiently uniform distribution when spreading pre-wetted salt at very low spread rates (i.e. below 8g/m^2) so more pre-wetted salt than required must often be spread.

Table A.3 also shows the de-icer cost savings when brine treatments replace pre-wetted salting. It was assumed that UK indigenous brown salt costing £25/tonne would be used for the dry salt component of pre-wetted salt, whereas white salt costing £35/tonne would be used for brine production. These were the costs in 2008/09.

Brine treatments were estimated to cost more than pre-wetted salting at some conditions, even though less salt was sometimes required for the former.

Table A.3 Estimated de-icer cost savings when brine treatments replace pre-wetted salting assuming 'practicable' spread rates shown in Table A.1 and minimum pre-wetted salting spread rate of 8g/m^2: brown dry salt, white brine salt

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		De-icer cost saving (£)*
		Salt used (tonnes)	De-icer cost (£)	Salt used (tonnes)	Salt cost (£)	
To -2°C	0.02	3.52	134.76	9.24	242.34	107.58
	0.05	4.22	161.72	9.24	242.34	80.63
	0.10	8.80	336.91	11.56	302.93	-33.98
To -4°C	0.02	4.22	161.72	9.24	242.34	80.63
	0.05	10.56	404.29	11.56	302.93	-101.36
	0.10	21.12	808.59	23.11	605.86	-202.73
To -6°C	0.02	7.04	269.53	9.24	242.34	-27.19
	0.05	17.60	673.82	17.33	454.39	-219.43
	0.10	35.20	1,347.64	34.67	908.79	-438.86

* A negative value indicates that a brine treatment costs more than pre-wetted salting

A.1.4 Weather conditions

In order to estimate the net de-icer cost savings over a winter season, data on the total number of treatments in different weather conditions were estimated. Four treatments scenarios that are defined in Table A.4 were considered, each comprising 80 treatments over a winter season.

In the whole-life cost analyses, 56, 64, 72 and 88 treatments per winter season were assumed by scaling the annual de-icer cost savings estimated for 80 treatments.

Table A.4 Brine treatments assumed for different treatments scenarios

Road surface temperature (˚C)	Assumed water film thickness (mm)	Brine spread rate (g/m²)	No. of treatments			
			'Baseline Marginal'	'Wetter Marginal'	'Colder'	'Dry Marginal'
To -2°C	0.02	10	15	0	9	15
	0.05	12	30	40	18	35
	0.10	25	5	10	3	
To -4°C	0.02	12	6	0	12	6
	0.05	30	12	16	24	14
	0.10	60	2	4	4	
To -6°C	0.02	20	3	0	3	3
	0.05	50	6	8	6	7
	0.10	100	1	2	1	

A.1.5 Estimated annual de-icer cost savings with brine treatments

Table A.5 shows the estimated net annual de-icer cost savings over the 80 treatments defined for the 'Baseline Marginal' scenario in Table A.4 for the 'typical' depot when brine treatments replace pre-wetted salting. The cost savings in column 4 are the last column of Table A.3. The cost savings in column 5 assume that UK indigenous brown salt costing £25/tonne would be used for both the dry salt component of pre-wetted salt and for brine production. The net annual de-icer cost saving is the sum of the product of column 3 and column 4 or column 5.

If brine only spreaders are utilised for all treatments, some brine treatments would cost more than the equivalent pre-wetted salting. The cost penalty associated with these treatments partially offsets the savings from other treatments.

Table A.5 Estimated de-icer cost savings for the 'Baseline Marginal' scenario when brine treatments replace pre-wetted salting if minimum pre-wetted salting spread rate is 8g/m²

Road surface temperature (˚C)	Assumed water film thickness (mm)	No. of treatments ('Baseline Marginal')	De-icer cost saving per 150km x 10m treatment (£)*	
			Brown dry salt £25/tonne White brine salt £35/tonne	Brown dry salt £25/tonne Brown brine salt £25/tonne
To -2°C	0.02	15	107.58	128.39
	0.05	30	80.63	106.91
	0.10	5	-33.98	26.26
To -4°C	0.02	6	80.63	106.91
	0.05	12	-101.36	-27.44
	0.10	2	-202.73	-54.87
To -6°C	0.02	3	-27.19	21.01
	0.05	6	-219.43	-94.84
	0.10	1	-438.86	-189.69
Net annual de-icer cost saving for all treatments		80	888	4,771

* A negative value indicates that a brine treatment costs more than pre-wetted salting

A.1.6 Estimated annual de-icer cost savings with combination treatments

Table A.6 shows the estimated annual de-icer cost savings that would be realised if combination spreaders were available for pre-wetted salting as well as brine treatments. It has been assumed that when combination spreaders are available, brine treatments would be made rather than pre-wetted salting (i) when there would be a de-icer cost saving and (ii) when brine treatments would not require more turnouts than pre-wetted salting. The brine treatments that are shown in Table A.5 to attract a cost penalty (i.e. the cost saving is negative) that would be replaced by pre-wetted salting are marked with a dash in Table A.6. Some brine treatments would give a de-icer cost saving but would require two turnouts to achieve the required dosage because the amount of brine required is greater than the capacity of the brine tanks on a 6x4 combination spreader. These treatments are marked with [0.00] in the tables. The final rows of the two tables show the net annual de-icer cost savings for the 'Baseline Marginal' scenario assuming that the treatments marked with [0.00] would be (i) with brine and (ii) with pre-wetted salt in square brackets.

De-icer cost savings were estimated to be greater when combination spreaders rather than brine only spreaders are used because cost ineffective brine treatments, for the most severe conditions, can be replaced with pre-wetted salting. Also, the number of turnouts is minimised when combination spreaders are used.

Table A.6 Estimated annual de-icer cost savings for the 'Baseline Marginal' scenario if combination spreaders are available and minimum pre-wetted salting spread rate is 8g/m^2

Road surface temperature (°C)	Assumed water film thickness (mm)	No. of treatments	De-icer cost saving per 150km x 10m treatment (£)*	
			Brown dry salt £25/tonne White brine salt £35/tonne	Brown dry salt £25/tonne Brown brine salt £25/tonne
To -2°C	0.02	15	107.58	128.39
	0.05	30	80.63	106.91
	0.10	5	-	26.26 [0.00]
To -4°C	0.02	6	80.63	106.91
	0.05	12	-	-
	0.10	2	-	-
To -6°C	0.02	3	-	21.01 [0.00]
	0.05	6	-	-
	0.10	1	-	-
Net annual de-icer cost saving for all treatments		80	4,516	5,969 [5,775]

- Indicates that a treatment is with pre-wetted salt because there is no de-icer cost saving

[0.00] Indicates pre-wetted salting because a brine treatment requires more turnouts

Table A.7 shows the estimated annual de-icer cost savings over 80 treatments with combination spreaders for all four treatments scenarios for the different salt types assuming that the treatments marked with [0.00] would be with pre-wetted salt [in square brackets].

Table A.7 Estimated annual de-icer cost savings over 80 treatments for different treatments scenarios, salt types and salt costs if combination spreaders are available

No of treatments at stated road surface temperature and water film thickness	Dry salt (£/tonne) (Type)	Brine salt (£/tonne) (Type)	Annual de-icer cost savings if minimum brine spread rate is 10g/m^2
'Baseline Marginal': 15 @ -2°C/0.02mm 30 @ -2°C/0.05mm 5 @ -2°C/0.10mm 6 @ -4°C/0.02mm 12 @ -4°C/0.05mm 2 @ -4°C/0.10mm 3 @ -6°C/0.02mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	25 (Brown)	35 (White)	4,516
	25 (Brown)	40 (White)	3,707
	25 (Brown)	30 (White)	5,325
	25 (Brown)	25 (Brown)	5,775
	35 (White)	35 (White)	8,682
	30 (White)	30 (White)	7,366
'Wetter Marginal': 40 @ -2°C/0.05mm 10 @ -2°C/0.10mm 16 @ -4°C/0.05mm 4 @ -4°C/0.10mm 8 @ -6°C/0.05mm 2 @ -6°C/0.10mm	25 (Brown)	35 (White)	3,225
	25 (Brown)	40 (White)	2,549
	25 (Brown)	30 (White)	3,901
	25 (Brown)	25 (Brown)	4,276
	35 (White)	35 (White)	6,486
	30 (White)	30 (White)	5,496
'Colder': 9 @ -2°C/0.02mm 18 @ -2°C/0.05mm 3 @ -2°C/0.10mm 12 @ -4°C/0.02mm 24 @ -4°C/0.05mm 4 @ -4°C/0.10mm 3 @ -6°C/0.02mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	25 (Brown)	35 (White)	3,387
	25 (Brown)	40 (White)	2,760
	25 (Brown)	30 (White)	4,014
	25 (Brown)	25 (Brown)	4,363
	35 (White)	35 (White)	6,572
	30 (White)	30 (White)	5,574
'Dry Marginal': 15 @ -2°C/0.02mm 35 @ -2°C/0.05mm 6 @ -4°C/0.02mm 14 @ -4°C/0.05mm 3 @ -6°C/0.02mm 7 @ -6°C/0.05mm	25 (Brown)	35 (White)	5,813
	25 (Brown)	40 (White)	4,919
	25 (Brown)	30 (White)	4,026
	25 (Brown)	25 (Brown)	6,309
	35 (White)	35 (White)	9,493
	30 (White)	30 (White)	8,053

The estimated total amounts of salt required annually for the treatments scenarios and the salt types covered in Table A.7 are shown in Table A.8. The estimated salt savings range from 19 to 35 per cent.

Table A.8 Estimated total amount of salt used annually over 80 combination or pre-wetted salting treatments for different treatments scenarios and salt types

Assumed treatments over a season	Brine salt type	Dry salt type	Total salt used annually in combination treatments (tonnes)	Total salt used annually in pre-wetted salting (tonnes)	Annual salt saving if brine treatments replace pre-wetted salting (tonnes)
'Baseline Marginal'	White	Brown	614	881	267
	Brown	Brown	636	888	252
	White	White	619	882	263
'Wetter Marginal'	White	Brown	770	971	201
	Brown	Brown	790	979	189
	White	White	775	973	198
'Colder'	White	Brown	729	931	202
	Brown	Brown	748	939	191
	White	White	734	933	200
'Dry Marginal'	White	Brown	537	829	292
	Brown	Brown	559	835	276
	White	White	542	830	288

A.1.7 Amount of brine required for brine treatments and pre-wetted salting

Although not included in Jordan (2010), Table A.9 gives the amount of brine required by the 'typical' depot for brine treatments and pre-wetted salting. It was assumed that brown salt costing £25/tonne would be used for the dry salt component of pre-wetted salt, whereas white salt costing £35/tonne would be used for brine production. The treatments in black would be made. Those in red would not be made for the reasons given above but they have been included for completeness. For example, brine treatments would be made when the minimum forecast road surface temperature is -2°C and the water film thickness is 0.05mm or less. No brine treatments would be made when the minimum forecast road surface temperature is less than -4°C.

Table A.9 Brine required for brine treatments and pre-wetted salting

Road surface temp. (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting			
		Brine spread rate (g/m²)	Brine required (litres)[1]	De-icer spread rate (g/m²)	Dry salt spread rate (g/m²)	Brine spread rate (g/m²)	Brine required (litres)[1]
To -2°C	0.02	10	12,500	8	5.6	2.4	3,000
	0.05	12	15,000	8	5.6	2.4	3,000
	0.10	25	31,250	10	7	3	3,750
To -4°C	0.02	12	15,000	8	5.6	2.4	3,000
	0.05	30	37,500	10	7	3	3,750
	0.10	60	75,000	20	14	6	7,500
To -6°C	0.02	20	25,000	8	5.6	2.4	3,000
	0.05	50	62,500	15	10.5	4.5	5,625
	0.10	100	125,000	30	21	9	11,250

[1] Assumes 150km is treated over a spread width of 10m, the brine sodium chloride concentration is 23 per cent and none of the impurities remain in the brine salt.

A.1.8 Amount of salt required for brine treatments and pre-wetted salting

Table A.10 shows the total amounts of brine that would be required over a winter season by the 'typical' depot for the treatments specified in Table A.4. The amounts are the same whether brown or white dry salt is used.

Table A.10 Estimated total amount of brine require annually for 80 combination or pre-wetted salting treatments for different treatments scenarios and salt types: minimum brine spread rate – 10g.m²

Assumed treatments over a season	Minimum pre-wetted salting spread rate (g/m²)	Total brine used annually in combination treatments (litres/10³)	Total brine used annually in pre-wetted salting (litres/10³)
'Baseline Marginal'	8	860	286
'Wetter Marginal'	8	795	315
'Colder'	8	748	302
'Dry Marginal'	8	903	269

A.1.9 Number of turnouts required annually by combination and pre-wet spreaders

Table A.11 shows the estimated annual number of turnouts that must be made by 4x4 or 6x4 pre-wet spreaders and 6x4 combination spreaders of the types specified in Table A.2 in order to achieve the 'practicable' spread rates shown in Table A.1. The annual extra fuel costs for the 'typical' depot are also shown.

When 4x4 pre-wet spreaders are used, it is estimated that some treatments would require more than one turnout to treat a route at the highest spread rate. This would not normally be the case in practice because routes would be optimised. However, rather than assume the possible need for additional spreaders, the approach used has only assumed additional fuel costs resulting from the route optimisation.

Table A.11 Annual number of turnouts required over 80 combination or pre-wetted salting treatments with 6x4 spreaders for different treatments scenarios and dry salt types

Assumed treatments over a season	Annual number of turnouts for combination treatments with 6x4 combination spreaders @7.5mpg	Annual number of turnouts for pre-wetted salting with 6x4 pre-wet spreaders @7.5mpg (4x4 pre-wet spreaders @8.5mpg)	Annual extra turnouts	Annual extra fuel costs (£)
'Baseline Marginal'	80	80 (81)	0 (-1)[1]	0 (347)[1]
'Wetter Marginal'	80	80 (82)	0 (-2)	0 (311)
'Colder'	80	80 (81)	0 (-1)	0 (347)
'Dry Marginal'	80	80 (80)	0 (0)	0 (383)

[1] Numbers in parenthesis apply if 6x4 combination spreaders and 4x4 pre-wet spreaders are used. The extra fuel costs allow for the different fuel consumption of the two spreaders.

A.1.10 Corrosion and environmental impact – indirect costs

In 2003, TRL compared the cost benefit of pre-wetted salting and dry salting (Burtwell et al, 2003). The annual cost of the vehicle corrosion, structural corrosion and environmental damage that can be attributed to dry salting was estimated as shown in Table A.12.

Table A.12 Annual indirect costs for 500,000 tonnes of de-icer (from Burtwell et al, 2003)

Annual indirect cost	Value (£)
Vehicle corrosion associated with dry salting	47,440,000
Structural corrosion/damage associated with dry salting	20,000,000
Environmental damage associated with dry salting	250,000

It was assumed that the cost of the structural corrosion and environmental damage is directly proportional to the total amount of sodium chloride spread. Assuming that the sodium chloride content of the brown dry salt spread in 2003 was 90 per cent, the 500,000 tonnes of salt spread contained 450,000 tonnes of sodium chloride. As the annual cost of the structural corrosion and environmental damage was estimated to be £20,250,000 in 2003, the annual cost was £45.00/tonne of sodium chloride spread.

It was assumed that the cost of vehicle corrosion is dependent on the amount of chloride that remains on the road after spreading in the form of brine that can be deposited on vehicles, rather than on the total amount of chloride spread. In order to determine the impact of treatments on corrosion, assumptions were made about the loss of sodium chloride after spreading. For the business case, the comparison was made at the minimum road surface temperature when what remains on the road surface has entered solution.

In road trials on the M62 with dry untreated brown salt and dry brown salt treated with Safecote, the average salt loss in the first 2 hours of trafficking was estimated to be 55 per cent. Assuming the same loss before the minimum road surface temperature is reached, the annual amount of sodium chloride that remains on the road surface at the minimum road surface temperature from the 500,000 tonnes of dry salt spread each year was estimated to be 202,500 tonnes. Because the cost of vehicle corrosion in 2003 was estimated to be £47,440,000 for 500,000 tonnes of salt spread, the annual cost of vehicle corrosion was estimated to be £234.27/tonne of sodium chloride on the road.

From 2003 to 2008, the Retail Price and Consumer Price Indices increased by 18.5 and 12.2 per cent, respectively. Assuming that the indirect costs increase according to the mean increase for both indices, the annual costs of vehicle corrosion were estimated to be approximately £270.19/tonne of sodium chloride on the road, whereas the annual cost of structural corrosion and environmental damage are £51.90/tonne of sodium chloride spread.

Table A.13 shows the estimated annual indirect cost savings for the 'practicable' spread rates shown in Table A.1 when the minimum pre-wetted salting spread rate is 8g/m^2 and the minimum brine spread rate is 10g/m^2.

Table A.13 Estimated annual indirect cost savings when brine treatments replace pre-wetted salting assuming 'practicable' spread rates shown in Table A.9 and minimum pre-wetted salting spread rate of 8g/m^2

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -2°C	0.02	179.06	792.34	435.34	1,415.76	1,828.18
	0.05	214.87	950.81	435.34	1,415.76	685.42
	0.10	447.64	1,980.86	544.17	1,769.70	-114.62
To -4°C	0.02	214.87	950.81	435.34	1,415.76	685.42
	0.05	537.17	2,377.03	544.17	1,769.70	-600.32
	0.10	1,074.33	4,754.06	1,088.35	3,539.41	-1,200.64
To -6°C	0.02	358.11	1,584.69	435.34	1,415.76	-91.70
	0.05	895.28	3,961.72	816.26	2,654.55	-1,386.18
	0.10	1,790.55	7,923.44	1,632.52	5,309.11	-2,772.37

* A negative value indicates that the indirect costs are higher for a brine treatment than for pre-wetted salting

Table A.14 shows the estimated annual indirect cost savings over 80 treatments with combination spreaders for all four scenarios and dry salt types assuming that the treatments marked with [0.00] would be with pre-wetted salt.

Table A.14 Estimated annual indirect cost savings over 80 treatments for different treatments scenarios and dry salt types when combination spreaders are available

No of treatments at stated road surface temperature and water film thickness	Dry salt type	Annual indirect cost savings for vehicle corrosion, structural corrosion and environmental damage (£)	Annual indirect cost savings for structural corrosion and environmental damage (£)
'Baseline Marginal': 15 @ -2°C/0.03mm 30 @ -2°C/0.05mm 5 @ -2°C/0.10mm 6 @ -4°C/0.03mm 12 @ -4°C/0.05mm 2 @ -4°C/0.10mm 3 @ -6°C/0.05mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	Brown White	37,871 43,372	11,781 13,115
'Wetter Marginal': 40 @ -2°C/0.05mm 10 @ -2°C/0.10mm 16 @ -4°C/0.05mm 4 @ -4°C/0.10mm 8 @ -6°C/0.05mm 2 @ -6°C/0.10mm	Brown White	27,417 31,731	8,819 9,865
'Colder': 9 @ -2°C/0.05mm 18 @ -2°C/0.05mm 3 @ -2°C/0.10mm 12 @ -4°C/0.05mm 24 @ -4°C/0.05mm 4 @ -4°C/0.10mm 3 @ -6°C/0.05mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	Brown White	28,480 32,687	8,921 9,941
'Dry Marginal': 15 @ -2°C/0.02mm 35 @ -2°C/0.05mm 6 @ -4°C/0.02mm 14 @ -4°C/0.05mm 3 @ -6°C/0.02mm 7 @ -6°C/0.05mm	Brown White	41,298 47,338	12,884 14,348

A.1.11 Whole-life cost analysis

Whereas brine or combination treatments were estimated to bring cost savings, brine only spreaders or combination spreaders must be purchased instead of less costly pre-wet spreaders if full routes are to be treated with brine. Also, depots must be equipped with facilities of sufficient capacity for brine production, which could involve both capital and increased operating costs.

Whole life cost analyses were carried out to determine the net present values (NPVs) of the direct costs including de-icer cost savings, extra fuel costs, spreader costs, saturator costs and maintenance costs (direct cost NPVs) on selected routes. An accounting period of 30 years and a discount rate of 3.5 per cent were assumed. HM Treasury specifies that a discount rate of 3.5 per cent should be assumed for the first 30 years of any whole life costing assessment of projects they fund (HM Treasury, 2007).

A number of assumptions were made in the analyses that are detailed in the Table A.15.

Table A.15 Assumptions made in whole life cost analyses

Parameter	Value (in 2008/09)
Cost of 6x4 pre-wet spreader relative to cost of 4x4 pre-wet spreader	+£7,000
Cost of 6x4 combination spreader relative to cost of 4x4 pre-wet spreader	+£21,000
Annual vehicle maintenance costs	Cost neutral
Service life of body of pre-wet spreader	14, 20, 26 years
Service life of body of combination spreader	14 (12, 16), 20,(18, 22), 26 (24, 28) years
Service life of pre-wet spreader chassis	7, 10, 13 years
Service life of combination spreader chassis	7 (6, 8), 10,(9, 11), 13 (12,14) years
Residual value of spreader bodies and chassis	£0
Cost of additional saturator	£15,000
Additional annual saturator maintenance costs	£500 for extra saturator +£500 per saturator with brown salt
Service life of saturator	20 years
Residual value of saturator	£0
Cost of brown salt	£25
Cost of white salt	£30, £35, £40 (i.e. £5, £10, £15 more than brown salt)

The whole life cost analyses estimated that combination spreaders would be more cost effective than brine only spreaders, especially when there are concerns about the severity of the weather conditions. The net present values of the direct costs including de-icer cost savings, extra fuel costs, spreader costs, saturator costs and maintenance costs (direct cost NPVs) are greater than zero (i.e. there is a cost saving) when combination spreaders replace 4x4 pre-wet spreaders for all but the most severe weather conditions assumed.

In most cases, the direct cost NPVs were estimated to be highest when brown dry and brown brine salt are used. However, this is dependent on the additional cost of saturator maintenance when brown brine salt is used, which may have been underestimated.

Most of the estimated overall cost NPVs (the direct and indirect cost NPVs) excluding the indirect cost savings associated with vehicle corrosion indicated a saving at the severest weather conditions assumed in the analyses. However, the estimated overall cost NPVs indicated that there would be a significant cost saving when the cost of vehicle corrosion is included. For example, Table A.16 and Table A.17 and Figure A.5 and Figure A.6 show the estimated indirect cost saving and direct cost NPVs when brine and pre-wetted treatments with 6x4 combination spreaders replace pre-wetted salting with 4x4 pre-wet spreaders assuming:

- 'Wetter Marginal' scenario
- Brown dry salt at £25/tonne and white brine salt at £40/tonne (i.e. £15/tonne more than brown dry salt)
- Minimum pre-wetted salting spread rate is 8g/m^2
- Minimum brine spread rate is 10g/m^2
- Additional annual saturator maintenance costs £500

NOTE: The key to Figure A.5 and Figure A.6 denotes the chassis life being considered in each case e.g. Comb 7/Pre-wet 7 refers to a 7 year service life for both spreader types

The annual de-icer cost savings are £2,549 (from Table A.7), and the annual extra fuel costs are £311 (from Table A.11). Therefore, the net annual direct cost savings are estimated to be £2,238.

The annual indirect cost savings for structural corrosion and environmental damage are £8,819 (from Table A.14). Therefore, the overall annual cost savings were estimated to be £11,057. These represented the lowest overall cost savings for all the treatments scenarios, salt types and salt costs considered. Even for these most pessimistic assumptions, the indirect cost savings and direct cost NPVs were estimated to be greater than zero for most of the spreader service lives assumed as shown in Table A.16 and Figure A.5. They were estimated to be less than zero when, for example:

- The number of treatments is less than 60 when the service lives of the chassis of the combination and pre-wet spreaders are 7 years
- The number of treatments is less than 57 when the service lives of the chassis of the combination and pre-wet spreaders are 12 and 13 years, respectively
- The number of treatments is less than 72 when the service lives of the chassis of the combination and pre-wet spreaders are 9 and 10 years, respectively

However, when the costs of vehicle corrosion were included, the annual overall cost savings were estimated to be £29,655 and as shown in Table A.17 and Figure A.6 show that all of the indirect cost savings and direct cost NPVs were estimated to be greater than zero.

Table A.16 Estimated indirect cost savings for structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting ('Wetter Marginal' scenario, minimum brine spread rate is 10g/m^2, minimum pre-wetted salting spread rate is 8g/m^2, brown dry salt at £25/tonne and white brine salt at £40/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders)

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	-7,951	13,096	34,144	55,192	76,240
10	10	17,698	38,746	59,794	80,842	101,890
13	13	33,540	54,588	75,635	96,683	117,731
8	7	83,643	104,691	125,739	146,787	167,835
11	10	61,979	83,027	104,075	125,123	146,171
14	13	64,227	85,274	106,322	127,370	148,418
6	7	-131,812	-110,764	-89,716	-68,668	-47,620
9	10	-39,823	-18,776	2,272	23,320	44,368
12	13	-773	20,275	41,322	62,370	83,418

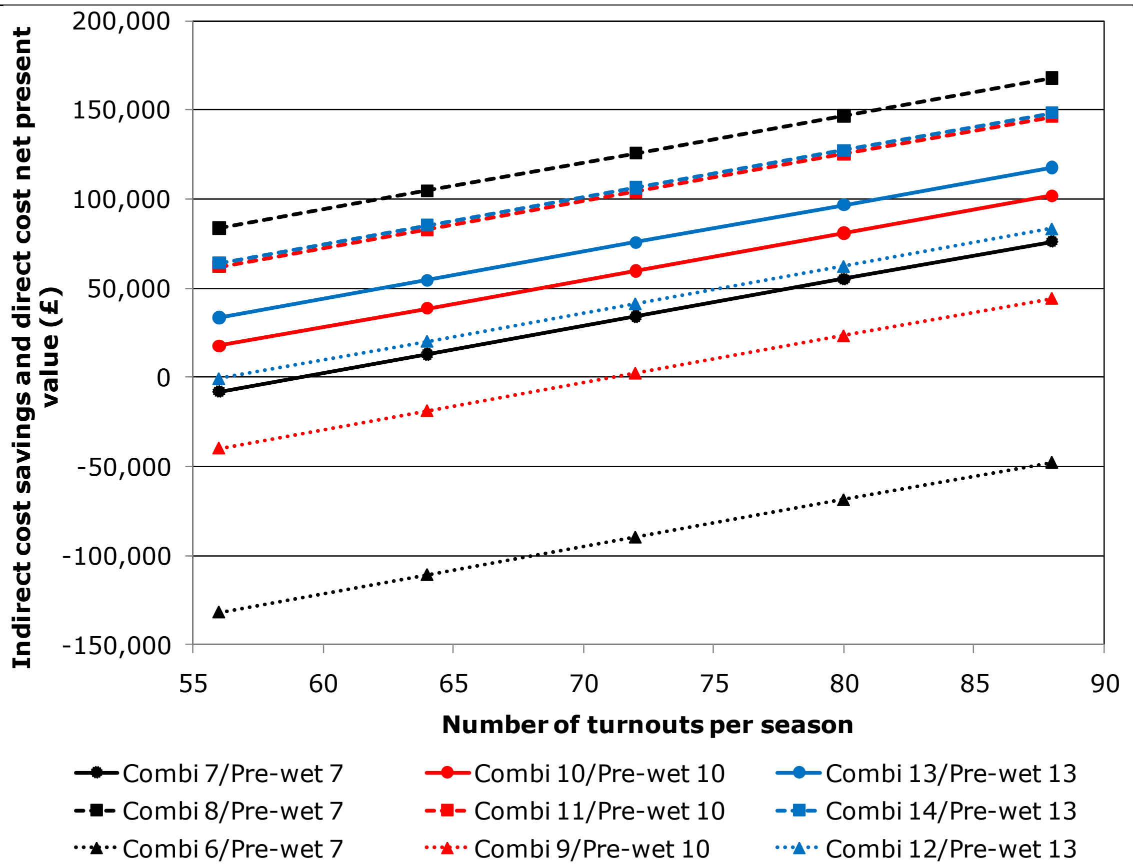

Figure A.5 Estimated indirect cost savings for structural corrosion and environmental damage and direct cost NPVs when brine only treatments replace pre-wetted salting ('Wetter Marginal' scenario, minimum brine spread rate is 10g/m^2, minimum pre-wetted salting spread rate is 8g/m^2, brown dry salt at £25/tonne and white brine salt at £40/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders)

Table A.17 Estimated indirect cost savings for vehicle corrosion, structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting for ('Wetter Marginal' scenario, minimum brine spread rate is 10g/m^2, minimum pre-wetted salting spread rate is 8g/m^2, brown dry salt at £25/tonne and white brine salt at £40/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders)

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	239,868	296,318	352,769	409,219	465,670
10	10	265,517	321,968	378,418	434,869	491,320
13	13	281,359	337,809	394,260	450,710	507,161
8	7	331,462	387,913	444,364	500,814	557,265
11	10	309,798	366,249	422,699	479,150	535,600
14	13	312,046	368,496	424,947	481,397	537,848
6	7	116,007	172,458	228,909	285,359	341,810
9	10	207,996	264,446	320,897	377,347	433,798
12	13	247,046	303,496	359,947	416,397	472,848

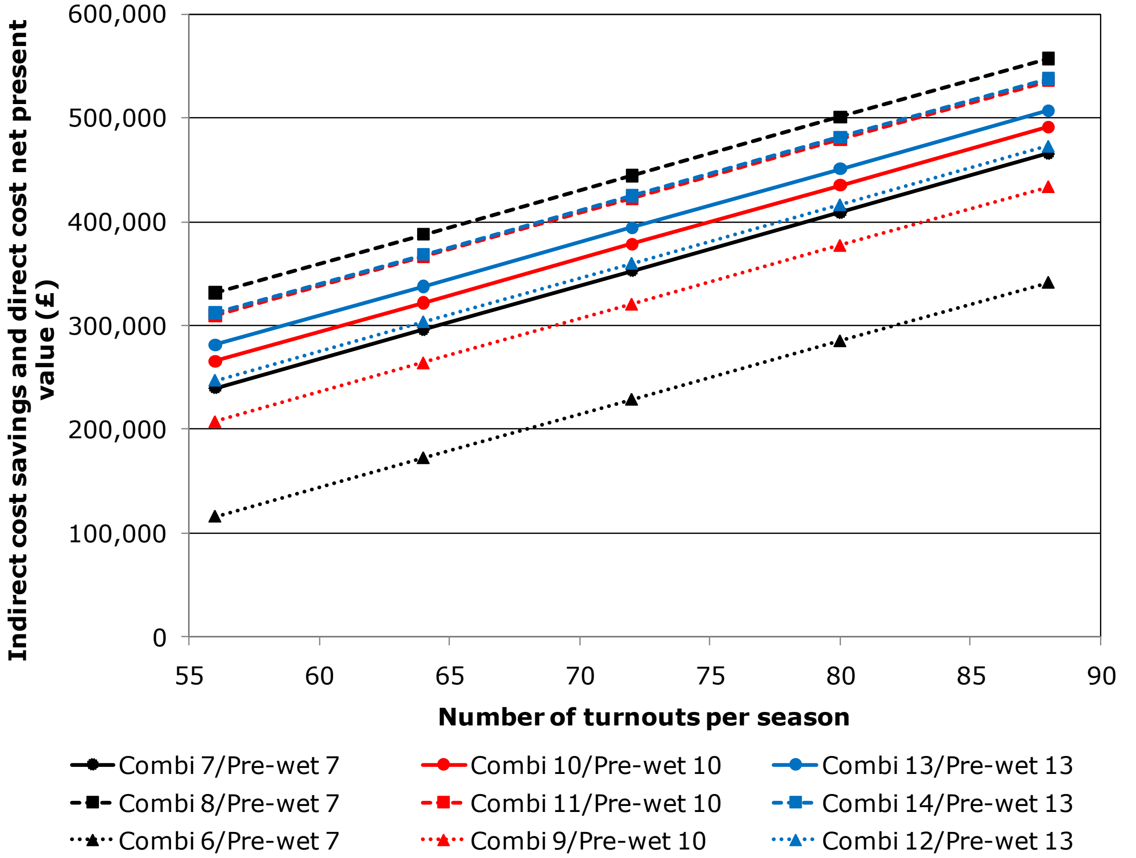

Figure A.6 Estimated indirect cost savings for vehicle corrosion, structural corrosion and environmental damage and direct cost NPVs when brine only treatments replace pre-wetted salting ('Wetter Marginal' scenario, minimum brine spread rate is 10g/m^2, minimum pre-wetted salting spread rate is 8g/m^2, brown dry salt at £25/tonne and white brine salt at £40/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders)

A.2 Revision of the business case

A.2.1 Review of assumptions made previously

The findings from the road trials, further investigation of the trials reported in the literature, and the review of brine production facilities, have shown that some of the assumptions made which were informed by the work of others and academic research needed revising. Therefore, the business case was revisited and the direct and indirect cost NPVs have been recalculated. The main findings from the new analysis are summarised in Section 7.

The revised assumptions (for comparison with those shown in Appendix A.1.1) are as follows:

- Sodium chloride concentration of salt used to produce brine (allowing for impurities and moisture content): 96 per cent, i.e. white salt – brown brine salt would not be used
- Brine loss due to trafficking before minimum road surface temperature: 40 per cent for brine treatments (30 and 50 per cent for denser and more open textured surfacing than typical surfacing) and 15 per cent for brine in pre-wetted salt
- Loss of dry salt component of pre-wetted salt due to trafficking before minimum road surface temperature: 50% of the amount spread

The sodium chloride concentration of the white salt used for brine production has been decreased to account for its higher moisture content; this is based on measurements of suitable sources.

The loss of brine due to trafficking has been increased from 15 to up to 40 per cent for brine treatments. Losses of 30 and 50 per cent have also be used, respectively, for denser and more open textured surfacing than typical surfacing.

A loss of 15 per cent assumed previously for the brine component of pre-wetted salt has been retained, but the loss of the dry salt component of pre-wetted salt due to trafficking has been increased from 40 to 50 per cent. The increase of the latter is so like for like comparisons can be made for similar levels of trafficking. The losses assumed by Jordan (2011) were based on results obtained by Bolet (2008) in pre-wetted salting and brine trials in comparable conditions. The 50 per cent loss assumed for the dry salt component of the pre-wetted salt in this revised case is now the same as the loss assumed by Jordan et al (2011A) in calculating precautionary rates for the Agency's network.

A.2.2 Brine and pre-wetted salting treatment rates

Table A.18, Table A.19 and Table A.20 show the 'idealised' spread rates and more 'practicable' spread rates rounded to integer values that have been calculated using the revised assumptions and brine losses due to trafficking of 50, 40 and 30 per cent, respectively. Two spread rates are given for each pre-wetted salting condition. Those that are not in parenthesis were calculated assuming that brown salt would be used for the dry salt component of pre-wetted salt. Those in parenthesis were calculated assuming that white salt would be used for the dry salt component. These would apply when imported white salt with a sodium chloride content of 96% is used, i.e. the same purity assumed for the salt used to manufacture brine.

It should be noted that in the Table A.18, Table A.19 and Table A.20, the spread rates for pre-wetted salting when the water film thickness is 0.1mm are higher than those given in Jordan et al (2011A). The rates in Jordan et al were calculated assuming that, for precautionary treatments, higher water film thicknesses occur in lightly than in heavily trafficked areas. However, a lower percentage salt loss was assumed for the lightly than for the heavily trafficked areas.

In Table A.18, Table A.19 and Table A.20, the percentage salt loss is assumed to be the same as that for heavily trafficked areas when the water film thickness is 0.1mm.

Because the sodium chloride content of white salt is higher than that of brown salt, it is possible to use lower spread rates for pre-wetted salting when white salt rather than brown salt is used for the dry salt component. The potential salt saving when white salt is used for the dry salt component has been taken into account by reducing the 'practicable' spread rates in the last two rows of Table A.18, Table A.19 and Table A.20. It is possible that lower spread rates could be used for some other treatments in the tables, depending on how the 'idealised' spread rates are rounded. However, it is considered that the reductions in the spread rates shown in the tables give a good indication of the effect of the lower spread rates.

Table A.18 'Idealised' and 'practicable' spread rates for brine and pre-wet treatments assuming 50% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	'Idealised' brine spread rate (g/m^2)	'Practicable' brine spread rate (g/m^2)	'Idealised' pre-wetted salting spread rate (g/m^2)	'Practicable' pre-wetted salting spread rate (g/m^2)
To -2°C	0.03	11.66	12	3.22 (3.06)[1]	8
	0.05	19.44	20	5.37 (5.08)	8
	0.10	38.87	40	10.74 (10.16)	10
To -4°C	0.03	27.84	28	6.74 (6.37)	8
	0.05	46.40	48	11.23 (10.61)	12
	0.10	92.80	90	22.47 (21.23)	22
To -6°C	0.03	49.64	50	10.30 (9.71)	10
	0.05	82.72	80	17.17 (16.20)	18 (16)[1]
	0.10	165.45	160	34.33 (32.40)	35 (32)

[1] Figures in parenthesis assume that white salt would be used for the dry salt component

Table A.19 'Idealised' and 'practicable' spread rates for brine and pre-wet treatments assuming 40% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	'Idealised' brine spread rate (g/m^2)	'Practicable' brine spread rate (g/m^2)	'Idealised' pre-wetted salting spread rate (g/m^2)	'Practicable' pre-wetted salting spread rate (g/m^2)
To -2°C	0.03	9.72	10	3.22 (3.06)[1]	8
	0.05	16.02	16	5.37 (5.08)	8
	0.10	32.93	32	10.74 (10.16)	10
To -4°C	0.03	23.20	24	6.74 (6.37)	8
	0.05	38.67	40	11.23 (10.61)	12
	0.10	77.34	80	22.47 (21.23)	22
To -6°C	0.03	41.37	42	10.30 (9.71)	10
	0.05	68.94	70	17.17 (16.20)	18 (16)[1]
	0.10	137.89	140	34.33 (32.40)	35 (32)

[1] Figures in parenthesis assume that white salt would be used for the dry salt component

Table A.20 'Idealised' and 'practicable' spread rates for brine and pre-wet treatments assuming 30% brine loss due to trafficking

Road surface temperature (˚C)	Assumed water film thickness (mm)	'Idealised' brine spread rate (g/m^2)	'Practicable' brine spread rate (g/m^2)	'Idealised' pre-wetted salting spread rate (g/m^2)	'Practicable' pre-wetted salting spread rate (g/m^2)
To -2˚C	0.03	8.33	10	3.22 (3.06)[1]	8
	0.05	13.89	14	5.37 (5.08)	8
	0.10	27.77	28	10.74 (10.16)	10
To -4˚C	0.03	19.89	20	6.74 (6.37)	8
	0.05	33.15	35	11.23 (10.61)	12
	0.10	66.30	70	22.47 (21.23)	22
To -6˚C	0.03	35.46	35	10.30 (9.71)	10
	0.05	59.10	60	17.17 (16.20)	18 (16)[1]
	0.10	118.19	120	34.33 (32.40)	35 (32)

[1] Figures in parenthesis assume that white salt would be used for the dry salt component

A.2.3 Salt savings and de-icer cost savings

Table A.21, Table A.22 and Table A.23 show the estimated amount of salt required to treat the area treated by a 'typical' depot when the 'practicable' spread rates shown in Table A.18, Table A.19 and Table A.20, respectively, for brown dry salt are assumed. Savings in terms of the total tonnage of salt spread are estimated for the following treatment conditions:

- When brine loss due to trafficking is 50 per cent:
  - Road surface temperature -2°C, water film thicknesses of 0.03mm and 0.05mm
- When brine loss due to trafficking is 40 per cent:
  - Road surface temperature -2°C, water film thicknesses of 0.03mm, 0.05 and 0.1mm
  - Road surface temperature -4°C, water film thickness of 0.03mm
- When brine loss due to trafficking is 30 per cent:
  - Road surface temperature -2°C, water film thicknesses of 0.03mm, 0.05 and 0.1mm
  - Road surface temperature -4°C, water film thickness of 0.03mm, 0.05 and 0.1mm

If it is assumed that UK indigenous brown salt costing £25/tonne would be used for the dry salt component of pre-wetted salt, white salt costing £46/tonne would be used for brine production and water cost £1/tonne would be used for brine production, a cost saving is estimated for only the following treatment conditions:

- When brine loss due to trafficking is 50 per cent:
  - Road surface temperature -2°C, water film thickness of 0.03mm
- When brine loss due to trafficking is 40 per cent:
  - Road surface temperature -2°C, water film thickness of 0.03mm
- When brine loss due to trafficking is 30 per cent:
  - Road surface temperature -2°C, water film thicknesses of 0.03mm and 0.05mm

Table A.21 Estimated de-icer cost savings when brine treatments replace pre-wetted salting assuming 'practicable' spread rates shown in Table A.18 assuming 50% brine loss due to trafficking and brown dry salt

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		De-icer cost saving (£)*
		Salt used (tonnes)	De-icer cost (£)	Salt used (tonnes)	Salt cost (£)	
To -2°C	0.03	4.31	212.24	9.26	252.45	40.21
	0.05	7.19	353.73	9.26	252.45	-101.28
	0.10	14.38	707.45	11.58	315.56	-391.89
To -4°C	0.03	10.78	495.22	9.26	252.45	-242.77
	0.05	17.97	884.31	13.89	378.67	-470.27
	0.10	35.94	1,591.76	27.79	694.23	-897.53
To -6°C	0.03	17.97	884.31	11.58	315.56	-568.75
	0.05	28.75	1414.90	20.84	568.01	-846.89
	0.10	57.50	2,829.80	40.52	1,104.46	-1,725.34

* A negative value indicates that a brine treatment costs more than pre-wetted salting

Table A.22 Estimated de-icer cost savings when brine treatments replace pre-wetted salting assuming 'practicable' spread rates shown in Table A.19 assuming 40% brine loss due to trafficking and brown dry salt

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		De-icer cost saving (£)*
		Salt used (tonnes)	De-icer cost (£)	Salt used (tonnes)	Salt cost (£)	
To -2°C	0.03	3.59	176.86	9.26	252.45	75.58
	0.05	5.75	282.98	9.26	252.45	-30.53
	0.10	11.50	565.96	11.58	315.56	-250.40
To -4°C	0.03	8.63	424.47	9.26	252.45	-172.02
	0.05	14.38	707.45	13.89	378.67	-328.78
	0.10	28.75	1,414.90	25.47	694.23	-720.67
To -6°C	0.03	15.09	742.82	11.58	315.56	-427.26
	0.05	25.16	1,238.04	20.84	568.01	-670.03
	0.10	50.31	2,476.08	40.52	1,104.46	-1,371.62

* A negative value indicates that a brine treatment costs more than pre-wetted salting

Table A.23 Estimated de-icer cost savings when brine treatments replace pre-wetted salting assuming 'practicable' spread rates shown in Table A.20 assuming 30% brine loss due to trafficking and brown dry salt

Road surface temperature (˚C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		De-icer cost saving (£)*
		Salt used (tonnes)	De-icer cost (£)	Salt used (tonnes)	Salt cost (£)	
To -2°C	0.03	3.59	176.86	9.26	252.45	75.58
	0.05	5.03	247.61	9.26	252.45	4.84
	0.10	10.06	495.22	11.58	315.56	-179.66
To -4°C	0.03	7.19	353.73	9.26	252.45	-101.28
	0.05	12.58	619.02	13.89	378.67	-240.35
	0.10	25.16	1,238.04	25.47	694.23	-543.81
To -6°C	0.03	12.58	619.02	11.58	315.56	-303.46
	0.05	21.56	1,061.18	20.84	568.01	-493.17
	0.10	43.13	2,122.35	40.52	1,104.46	-1,017.89

* A negative value indicates that a brine treatment costs more than pre-wetted salting

A.2.4 Estimated annual de-icer cost savings with brine treatments

Table A.24, Table A.25 and Table A.26 show the estimated de-icer cost savings that would be realised for the 'typical' depot over a winter season for the 'Baseline Marginal' treatments scenario if combination spreaders are available and the brine loss due to trafficking is 50, 40 and 30 per cent, respectively. It has been assumed that brine treatments would be made rather than pre-wetted salting (i) when there would be a de-icer cost saving and (ii) when brine treatments would not require more turnouts than pre-wetted salting (c.f. Table A.6).

Table A.24 Estimated de-icer cost savings for the 'Baseline Marginal' scenario if combination spreaders are available and assuming 50% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	No. of treatments	De-icer cost saving per 150km x 10m treatment (£)*	
			Brown dry salt £25/tonne White brine salt £46/tonne	White dry salt £46/tonne White brine salt £46/tonne
To -2°C	0.03	15	40.21	216.61
	0.05	30	-	75.12 [0.00]
	0.10	5	-	
To -4°C	0.03	6	-	-
	0.05	12	-	-
	0.10	2	-	-
To -6°C	0.03	3	-	-
	0.05	6	-	-
	0.10	1	-	-
Net annual de-icer cost saving for all treatments		80	603	5,503 [3,249]

- Indicates that a treatment is with pre-wetted salt because there is no de-icer cost saving

[0.00] Indicates pre-wetted salting because a brine treatment requires more turnouts

Table A.25 Estimated de-icer cost savings for the 'Baseline Marginal' scenario if combination spreaders are available and assuming 40% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	No. of treatments	De-icer cost saving per 150km x 10m treatment (£)*	
			Brown dry salt £25/tonne White brine salt £46/tonne	White dry salt £46/tonne White brine salt £46/tonne
To -2°C	0.03	15	75.58	251.98
	0.05	30	-	145.87
	0.10	5	-	-
To -4°C	0.03	6	-	4.38 [0.00]
	0.05	12	-	-
	0.10	2	-	-
To -6°C	0.03	3	-	-
	0.05	6	-	-
	0.10	1	-	-
Net annual de-icer cost saving for all treatments		80	1,134	8,182 [8,156]

- Indicates that a treatment is with pre-wetted salt because there is no de-icer cost saving

[0.00] Indicates pre-wetted salting because a brine treatment requires more turnouts

Table A.26 Estimated de-icer cost savings for the 'Baseline Marginal' scenario if combination spreaders are available and assuming 30% brine loss due to trafficking

Road surface temperature (˚C)	Assumed water film thickness (mm)	No. of treatments	De-icer cost saving per 150km x 10m treatment (£)*	
			Brown dry salt £25/tonne White brine salt £46/tonne	White dry salt £46/tonne White brine salt £46/tonne
To -2°C	0.03	15	75.58	251.98
	0.05	30	4.84	181.24
	0.10	5	-	49.36 [0.00]
To -4°C	0.03	6	-	75.12 [0.00]
	0.05	12	-	24.25 [0.00]
	0.10	2	-	-
To -6°C	0.03	3	-	-
	0.05	6	-	-
	0.10	1	-	-
Net annual de-icer cost saving for all treatments		80	1,279	10,206 [9,217]

- Indicates that a treatment is with pre-wetted salt because there is no de-icer cost saving

[0.00] Indicates pre-wetted salting because a brine treatment requires more turnouts

Table A.27 shows the estimated annual de-icer cost savings over 80 treatments with combination spreaders for all four treatments scenarios for the different salt types assuming that the treatments marked with [0.00] would be with pre-wetted salt.

The de-icer cost savings are estimated to be much lower when brown rather than white dry salt is assumed. No de-icer cost savings are estimated for 'Wetter Marginal' conditions if the brine loss due to trafficking is 40 per cent or greater when brown dry salt is used. The de-icer cost savings are only slightly higher when the brine loss due to trafficking is 30 rather than 40 per cent, but it is much lower when the brine loss due to trafficking is 50 per cent.

Table A.27 Estimated annual de-icer cost savings over 80 treatments for different treatments scenarios, salt types and salt costs if combination spreaders are available

No of treatments at stated road surface temperature and water film thickness	Dry salt (£/tonne) (Type)	Brine salt (£/tonne) (Type)	Annual de-icer cost savings (£) Brine percentage loss		
			50%	40%	30%
'Baseline Marginal': 15 @ -2°C/0.03mm 30 @ -2°C/0.05mm 5 @ -2°C/0.10mm 6 @ -4°C/0.03mm 12 @ -4°C/0.05mm 2 @ -4°C/0.10mm 3 @ -6°C/0.03mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	25 (Brown)	46 (White)	603	1,134	1,279
	25 (Brown)	56 (White)	86	724	724
	46 (White)	46 (White)	3,249	8,156	9,217
	56 (White)	56 (White)	3,992	10,060	11,337
'Wetter Marginal': 40 @ -2°C/0.05mm 10 @ -2°C/0.10mm 16 @ -4°C/0.05mm 4 @ -4°C/0.10mm 8 @ -6°C/0.05mm 2 @ -6°C/0.10mm	25 (Brown)	46 (White)	0	0	194
	25 (Brown)	56 (White)	0	0	0
	46 (White)	46 (White)	0	5,835	7,250
	56 (White)	56 (White)	0	7,240	8,942
'Colder': 9 @ -2°C/0.03mm 18 @ -2°C/0.05mm 3 @ -2°C/0.10mm 12 @ -4°C/0.03mm 24 @ -4°C/0.05mm 4 @ -4°C/0.10mm 3 @ -6°C/0.03mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	25 (Brown)	46 (White)	362	680	767
	25 (Brown)	56 (White)	51	434	434
	46 (White)	46 (White)	1,950	4,893	5,530
	56 (White)	56 (White)	2,395	6,036	6,802
'Dry Marginal': 15 @ -2°C/0.03mm 35 @ -2°C/0.05mm 6 @ -4°C/0.03mm 14 @ -4°C/0.05mm 3 @ -6°C/0.03mm 7 @ -6°C/0.05mm	25 (Brown)	46 (White)	603	1,134	1,303
	25 (Brown)	56 (White)	86	724	724
	46 (White)	46 (White)	3,249	8,885	10,123
	56 (White)	56 (White)	3,992	10,965	12,454

A.2.5 Amount of salt required for brine treatments and pre-wetted salting

The estimated total amounts of salt required annually by the 'typical' depot for the treatments scenarios and the salt types covered in Table A.27 are shown in Table A.28, Table A.29 and Table A.30 assuming losses due to trafficking of 50, 40 and 30 per cent, respectively. The estimated salt saving ranges from 0 to 8 per cent when the brine loss due to trafficking is 50 per cent, from 0 to 24 per cent when the brine loss due to trafficking is 40 per cent and from 12 to 27 per cent when the brine loss due to trafficking is 30 per cent.

Combination treatments involve spreading of both brine and pre-wetted salt, depending on the conditions (and the de-icer costs savings and number of turnouts).

Table A.28 Estimated total amount of salt required annually for 80 combination or pre-wetted salting treatments for different treatments scenarios and salt types and assuming 50% brine loss due to trafficking

Assumed treatments over a season	Brine salt type	Dry salt type	Total salt used annually in combination treatments (tonnes)	Total salt used annually in pre-wetted salting (tonnes)	Annual salt saving if brine treatments replace pre-wetted salting (tonnes)
'Baseline Marginal'	White	Brown	874	948	74
	White	White	857	931	74
'Wetter Marginal'	White	Brown	1,058	1,058	0
	White	White	1,033	1,033	0
'Colder'	White	Brown	987	1,032	45
	White	White	970	1,014	45
'Dry Marginal'	White	Brown	820	894	74
	White	White	803	878	74

Table A.29 Estimated total amount of salt required annually for 80 combination or pre-wetted salting treatments for different treatments scenarios and salt types and assuming 40% brine loss due to trafficking

Assumed treatments over a season	Brine salt type	Dry salt type	Total salt used annually in combination treatments (tonnes)	Total salt used annually in pre-wetted salting (tonnes)	Annual salt saving if brine treatments replace pre-wetted salting (tonnes)
'Baseline Marginal'	White	Brown	863	948	85
	White	White	740	931	190
'Wetter Marginal'	White	Brown	1,058	1,058	0
	White	White	892	1,033	141
'Colder'	White	Brown	981	1,032	51
	White	White	900	1,014	114
'Dry Marginal'	White	Brown	809	894	85
	White	White	670	878	208

Table A.30 Estimated total amount of salt required annually for 80 combination or pre-wetted salting treatments for different treatments scenarios and salt types and assuming 30% brine loss due to trafficking

Assumed treatments over a season	Brine salt type	Dry salt type	Total salt used annually in combination treatments (tonnes)	Total salt used annually in pre-wetted salting (tonnes)	Annual salt saving if brine treatments replace pre-wetted salting (tonnes)
'Baseline Marginal'	White	Brown	736	948	212
	White	White	719	931	212
'Wetter Marginal'	White	Brown	889	1,058	169
	White	White	864	1,033	169
'Colder'	White	Brown	904	1,032	127
	White	White	887	1,014	127
'Dry Marginal'	White	Brown	661	894	233
	White	White	644	878	233

A.2.6 Amount of brine required for brine treatments and pre-wetted salting

Table A.31, Table A.32 and Table A.33 give the estimated amounts of brine required by the 'typical' depot for brine treatments and pre-wetted salting with brown and white dry salt assuming brine losses due to trafficking of 50, 40 and 30 per cent, respectively. As in Table A.9, the treatments in black would be made because they bring a cost saving, whereas those in red would not. It is considered that the brine required could be produced by the saturators already being used for only pre-wetted salting.

Table A.31 Brine required for brine treatments and pre-wetted salting assuming 50% brine loss due to trafficking

Road surface temp. (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting			
		Brine spread rate (g/m^2)	Brine required (litres)[1]	De-icer spread rate (g/m^2)	Dry salt spread rate (g/m^2)	Brine spread rate (g/m^2)	Brine required (litres)[1]
To -2°C	0.03	12	15,000	8	5.6	2.4	3,000
	0.05	20	25,000	8	5.6	2.4	3,000
	0.10	40	50,000	10	7.0	3.0	3,750
To -4°C	0.03	28	35,000	8	5.6	2.4	3,000
	0.05	48	60,000	12	8.4	3.6	4,500
	0.10	90	112,500	22	15.4	6.6	8,250
To -6°C	0.03	50	62,500	10	7.0	3.0	3,750
	0.05	80	100,000	18 (16)[2]	12.6	5.4	6,750 (6,000)[2]
	0.10	160	200,000	35 (32)	24.5	10.5	13,125 (12,000)

[1] Assumes 150km is treated over a spread width of 10m, the brine sodium chloride concentration is 23 per cent and none of the impurities remain in the brine salt.

[2] Figures in parenthesis assume that white salt would be used for the dry salt component

Table A.32 Brine required for brine treatments and pre-wetted salting assuming 40% brine loss due to trafficking

Road surface temp. (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting			
		Brine spread rate (g/m^2)	Brine required (litres)[1]	De-icer spread rate (g/m^2)	Dry salt spread rate (g/m^2)	Brine spread rate (g/m^2)	Brine required (litres)[1]
To -2°C	0.03	10	12,500	8	5.6	2.4	3,000
	0.05	16	20,000	8	5.6	2.4	3,000
	0.10	32	40,000	10	7.0	3.0	3,750
To -4°C	0.03	24	30,000	8	5.6	2.4	3,000
	0.05	40	50,000	12	8.4	3.6	4,500
	0.10	80	100,000	22	15.4	6.6	8,250
To -6°C	0.03	42	52,500	10	7.0	3.0	3,750
	0.05	70	87,500	18 (16)[2]	12.6	5.4	6,750 (6,000)[2]
	0.10	140	175,000	35 (32)	24.5	10.5	13,125 (12,000)

[1] Assumes 150km is treated over a spread width of 10m, the brine sodium chloride concentration is 23 per cent and none of the impurities remain in the brine salt.

[2] Figures in parenthesis assume that white salt would be used for the dry salt component

Table A.33 Brine required for brine treatments and pre-wetted salting assuming 30% brine loss due to trafficking

Road surface temp. (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting			
		Brine spread rate (g/m^2)	Brine required (litres)[1]	De-icer spread rate (g/m^2)	Dry salt spread rate (g/m^2)	Brine spread rate (g/m^2)	Brine required (litres)[1]
To -2°C	0.03	10	12,500	8	5.6	2.4	3,000
	0.05	14	17,500	8	5.6	2.4	3,000
	0.10	28	35,000	10	7.0	3.0	3,750
To -4°C	0.03	20	25,000	8	5.6	2.4	3,000
	0.05	35	43,750	12	8.4	3.6	4,500
	0.10	70	87,500	22	15.4	6.6	8,250
To -6°C	0.03	35	43,750	10	7.0	3.0	3,750
	0.05	60	75,000	18 (16)[2]	12.6	5.4	6,750 (6,000)[2]
	0.10	120	150,000	35 (32)	24.5	10.5	13,125 (12,000)

[1] Assumes 150km is treated over a spread width of 10m, the brine sodium chloride concentration is 23 per cent and none of the impurities remain in the brine salt.

[2] Figures in parenthesis assume that white salt would be used for the dry salt component

Table A.34 and Table A.35 show the amounts of brine that would be required over a winter season by the 'typical' depot for the treatment scenarios specified in Table A.4 when, respectively, brown and white dry salt are used. It is concluded that the brine required could be produced by the saturators already being used by Service Providers for their current pre-wetted salt operations. Therefore, it should not be necessary to purchase an additional saturator as assumed in the original business case, although additional annual saturator maintenance may be required because of the higher production rate.

Table A.34 Estimated total amount of brine required annually for 80 combination or pre-wetted salting treatments for different treatment scenarios and brown dry salt

Assumed treatments over a season	Total brine used annually in combination treatments (litres/10^3) Brine percentage loss			Total brine used annually in pre-wetted salting (litres/10^3)
	50%	40%	30%	
'Baseline Marginal'	487	450	883	307
'Wetter Marginal'	343	343	923	343
'Colder'	442	420	681	334
'Dry Marginal'	470	432	940	290

Table A.35 Estimated total amount of brine used annually over 80 combination or pre-wetted salting treatments for different treatments scenarios and white dry salt

Assumed treatments over a season	Total brine used annually in combination treatments (litres/10^3) Brine percentage loss			Total brine used annually in pre-wetted salting (litres/10^3)
	50%	40%	30%	
'Baseline Marginal'	482	954	879	302
'Wetter Marginal'	335	1015	915	335
'Colder'	437	720	675	329
'Dry Marginal'	464	1022	934	284

A.2.7 Number of turnouts required annually by combination and pre-wet spreaders

Table A.36 and Table A.37 show the estimated annual number of turnouts that must be made by 4x4 and 6x4 pre-wet spreaders and 6x4 combination spreaders in order to achieve the practicable spread rates shown in Table A.18 to Table A.20. Table A.36 applies when brown dry salt is used whereas Table A.37 applies when white dry salt. The annual extra fuel costs are also shown. The number of turnouts shown in Table A.36 and Table A.37 is the same whichever brine loss due to trafficking is assumed, be it 50, 40 or 30 per cent.

As mentioned in Section A.1.9, when 4x4 pre-wet spreaders are used, it is estimated that some treatments would require more than one turnout to treat a route at the highest spread rate. This would not normally be the case in practice because routes would be optimised. However, rather than assume the possible need for additional spreaders, the approach used has only assumed additional fuel costs resulting from the route optimisation.

Table A.36 Annual number of turnouts required over 80 combination or pre-wetted salting treatments with 6x4 spreaders for different treatments scenarios and brown dry salt

Assumed treatments over a season	Annual number of turnouts for combination treatments with 6x4 combination spreaders @7.5mpg	Annual number of turnouts for pre-wetted salting with 6x4 pre-wet spreaders @7.5mpg (4x4 pre-wet spreaders @8.5mpg)	Annual extra turnouts	Annual extra fuel costs (£)
'Baseline Marginal'	80	81 (83)	-1 (-3)[1]	-41 (275)[1]
'Wetter Marginal'	80	82 (86)	-2 (-6)	-81 (167)
'Colder'	80	81 (85)	-1 (-5)	-41 (203)
'Dry Marginal'	80	80 (80)	0 (0)	0 (383)

[1] Numbers in parenthesis apply if 6x4 combination spreaders and 4x4 pre-wet spreaders are used. The extra fuel costs allow for the different fuel consumption of the two spreaders.

Table A.37 Annual number of turnouts required over 80 combination or pre-wetted salting treatments with 6x4 spreaders for different treatments scenarios and white dry salt

Assumed treatments over a season	Annual number of turnouts for combination treatments with 6x4 combination spreaders @7.5mpg	Annual number of turnouts for pre-wetted salting with 6x4 pre-wet spreaders @7.5mpg (4x4 pre-wet spreaders @8.5mpg)	Annual extra turnouts	Annual extra fuel costs (£)
'Baseline Marginal'	80	80 (83)	0 (-3)[1]	0 (275)[1]
'Wetter Marginal'	80	80 (86)	0 (-6)	0 (167)
'Colder'	80	80 (85)	0 (-5)	0 (203)
'Dry Marginal'	80	80 (80)	0 (0)	0 (383)

[1] Numbers in parenthesis apply if 6x4 combination spreaders and 4x4 pre-wet spreaders are used. The extra fuel costs allow for the different fuel consumption of the two spreaders.

A.2.8 Estimated annual indirect cost savings with combination treatments

Table A.38, Table A.39 and Table A.40 shows the estimated annual indirect cost savings for the 'practicable' spread rates shown in Table A.18, Table A.19 and Table A.20, respectively, and for brown dry salt.

Table A.38 Estimated annual indirect cost savings when brine treatments replace pre-wetted salting with brown dry salt assuming 'practicable' spread rates shown in Table A.18 and 50% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -2°C	0.03	214.87	559.30	435.34	1,211.50	872.67
	0.05	358.11	932.17	435.34	1,211.50	356.55
	0.10	716.22	1,864.34	544.17	1,514.37	-522.02
To -4°C	0.03	501.36	1,305.04	435.34	1,211.50	-159.56
	0.05	859.47	2,237.21	653.01	1,817.24	-626.42
	0.10	1611.50	4,194.76	1197.18	3,331.61	-1,277.47
To -6°C	0.03	895.28	2,330.42	544.17	1,514.37	-1,167.16
	0.05	1,432.44	3,728.68	979.51	2,725.87	-1,455.74
	0.10	2,864.89	7,457.35	1904.61	5,300.29	-3,117.34

* A negative value indicates that the indirect costs are higher for a brine treatment than for pre-wetted salting

Table A.39 Estimated annual indirect cost savings when brine treatments replace pre-wetted salting with brown dry salt assuming 'practicable' spread rates shown in Table A.19 and 40% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -2°C	0.03	179.06	559.30	435.34	1,211.50	908.48
	0.05	286.49	894.88	435.34	1,211.50	465.46
	0.10	572.98	1,789.76	544.17	1,514.37	-304.20
To -4°C	0.03	429.73	1,342.32	435.34	1,211.50	-125.22
	0.05	716.22	2,237.21	653.01	1,817.24	-483.18
	0.10	1,432.44	4,474.41	1,197.18	3,331.61	-1,378.06
To -6°C	0.03	752.03	2,349.07	544.17	1,514.37	-1,042.56
	0.05	1,253.39	3,915.11	979.51	2,725.87	-1,463.12
	0.10	2,506.78	7,830.22	1,904.61	5,300.29	-3,132.10

* A negative value indicates that the indirect costs are higher for a brine treatment than for pre-wetted salting

Table A.40 Estimated annual indirect cost savings when brine treatments replace pre-wetted salting with brown dry salt assuming 'practicable' spread rates shown in Table A.20 and 30% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -2°C	0.03	179.06	652.52	435.34	1,211.50	815.26
	0.05	250.68	913.53	435.34	1,211.50	482.63
	0.10	501.36	1,827.05	544.17	1,514.37	-269.86
To -4°C	0.03	358.11	1,305.04	435.34	1,211.50	-16.31
	0.05	626.69	2,283.81	653.01	1,817.24	-440.26
	0.10	1,253.39	4,567.63	1,197.18	3,331.61	-1,292.22
To -6°C	0.03	626.69	2,283.81	544.17	1,514.37	-851.97
	0.05	1,074.33	3,915.11	979.51	2,725.87	-1,284.07
	0.10	2,148.67	7,830.22	1,904.61	5,300.29	-2,773.99

* A negative value indicates that the indirect costs are higher for a brine treatment than for pre-wetted salting

As an example, Table A.41 shows the estimated annual indirect cost savings for the 'practicable' spread rates shown in Table A.19 for white dry salt. By comparing Table A.39 and Table A.41, it can be seen that the indirect costs are higher for pre-wetted salting with white dry salt than with brown dry salt for the first eight combinations of road surface temperature and water film thickness (for which the spread rates are the same for brown and white dry salt). Therefore, the indirect cost savings are also higher for white dry salt than for brown dry salt. This is because the spread rates in Table A.19 (and Table A.18 and Table A.20) have been rounded to the same value rather than be rounded to the nearest integer for each salt. Therefore, because white salt has more chloride than brown salt, the environmental damage and corrosion are higher for the former.

Table A.41 Estimated annual indirect cost savings when brine treatments replace pre-wetted salting with white dry salt assuming 'practicable' spread rates shown in Table A.19 and 40% brine loss due to trafficking

Road surface temperature (°C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -2°C	0.03	179.06	559.30	461.50	1,279.58	1,002.72
	0.05	286.49	894.88	461.50	1,279.58	559.71
	0.10	572.98	1,789.76	576.87	1,599.48	-186.39
To -4°C	0.03	429.73	1,342.32	461.50	1,279.58	-30.98
	0.05	716.22	2,237.21	692.24	1,919.38	-341.81
	0.10	1,432.44	4,474.41	1269.11	3,518.86	-1,118.88

Road surface temperature (˚C)	Assumed water film thickness (mm)	Brine treatments		Pre-wetted salting		Indirect cost saving (£)*
		Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	Structural and Environm'nt costs(£)	Vehicle corrosion costs (£)	
To -6˚C	0.03	752.03	2,349.07	576.87	1,599.48	-924.75
	0.05	1,253.39	3,915.11	922.99	2,559.17	-1,686.34
	0.10	2,506.78	7,830.22	1,845.98	5,118.34	-3,372.68

* A negative value indicates that the indirect costs are higher for a brine treatment than for pre-wetted salting

Table A.42 shows the estimated annual indirect cost savings over 80 treatments with combination spreaders for all four scenarios and dry salt types assuming that the treatments marked with [0.00] would be with pre-wetted salt.

Table A.42 Estimated annual indirect cost savings over 80 treatments for different treatments scenarios and dry salt types when combination spreaders are available

No of treatments at stated road surface temperature and water film thickness	Dry salt type	Annual indirect cost savings for vehicle corrosion, structural corrosion and environmental damage (£) Brine percentage loss			Annual indirect cost savings for structural corrosion and environmental damage (£) Brine percentage loss		
		50%	40%	30%	50%	40%	30%
'Baseline Marginal': 15 @ -2°C/0.03mm 30 @ -2°C/0.05mm 5 @ -2°C/0.10mm 6 @ -4°C/0.03mm	Brown	13,090	13,627	26,708	3,307	3,844	9,394
12 @ -4°C/0.05mm 2 @ -4°C/0.10mm 3 @ -6°C/0.05mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	White	8,631	31,832	30,949	3,699	9,487	10,561
'Wetter Marginal': 40 @ -2°C/0.05mm 10 @ -2°C/0.10mm 16 @ -4°C/0.05mm	Brown	0	0	19,305	0	0	7,386
4 @ -4°C/0.10mm 8 @ -6°C/0.05mm 2 @ -6°C/0.10mm	White	0	22,388	23,075	0	7,000	8,433
'Colder': 9 @ -2°C/0.05mm 18 @ -2°C/0.05mm 3 @ -2°C/0.10mm 12 @ -4°C/0.05mm	Brown	7,854	8,176	16,025	1,984	2,307	5,630
24 @ -4°C/0.05mm 4 @ -4°C/0.10mm 3 @ -6°C/0.05mm 6 @ -6°C/0.05mm 1 @ -6°C/0.10mm	White	5,179	19,099	18,569	2,220	5,692	6,337
'Dry Marginal': 15 @ -2°C/0.02mm 35 @ -2°C/0.05mm 6 @ -4°C/0.02mm	Brown	13,090	13,627	29,121	3,307	3,844	10,307
14 @ -4°C/0.05mm 3 @ -6°C/0.02mm 7 @ -6°C/0.05mm	White	8,631	34,637	33,833	3,699	10,362	11,615

A.2.9 Whole-life cost analysis

A.2.9.1 Revised assumptions

As indicated previously, the findings from the road trials and the review of brine production facilities have shown that some of the assumptions made by Jordan (2010) were inaccurate. The revised assumptions (for comparison with those shown in Appendix A.1.11) are as follows:

- The cost of an additional saturator has been excluded
- Only white salt has been assumed for brine production
- The additional annual saturator maintenance cost is £500 to account for the additional production for combination treatments using a single saturator
- The cost of brown salt is £25/tonne
- The cost of white salt is £46 or £56/tonne

A.2.9.2 Case 1: Estimated cost savings assuming 50 per cent brine loss due to trafficking and brown dry salt

This first case assumes that combination treatments with 6x4 combination spreaders replace pre-wetted salting with 4x4 pre-wet spreaders, the 'Baseline Marginal' treatments scenario and white brine salt at £46/tonne.

The annual de-icer cost savings are £603 (from Table A.27), and the annual extra fuel costs is £275 (from Table A.36). Therefore, the annual net cost savings are estimated to be £328 (=£603 - £275). Without taking into account the additional saturator maintenance and extra spreader costs, it is clear that there would be no direct cost saving.

Table A.42 shows that the annual indirect cost savings excluding vehicle corrosion are £3,307. Therefore, the annual net direct and indirect cost savings are £3,635. Table A.43 shows the indirect cost savings for structural corrosion and environmental damage and direct cost NPVs are mostly less than zero indicating no benefit with combination treatments. However, when the costs of vehicle corrosion are included, the annual overall cost savings are estimated to be £13,418, and Table A.44 and Figure A.7 show that most of the indirect cost savings and direct cost NPVs are estimated to be greater than zero.

Table A.43 Estimated indirect cost savings for structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, brown dry salt at £25/tonne and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	-86,983	-80,064	-73,144	-66,225	-59,305
10	10	-61,334	-54,414	-47,495	-40,575	-33,656
13	13	-45,492	-38,573	-31,653	-24,734	-17,814
8	7	4,611	11,531	18,450	25,370	32,289
11	10	-17,053	-10,133	-3,214	3,706	10,625
14	13	-14,805	-7,886	-966	5,953	12,873
6	7	-210,844	-203,924	-197,005	-190,085	-183,166
9	10	-118,855	-111,936	-105,016	-98,097	-91,177
12	13	-79,805	-72,886	-65,966	-59,047	-52,127

Table A.44 Estimated indirect cost savings for vehicle and structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, brown dry salt at £25/tonne and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	43,375	68,918	94,460	120,002	145,544
10	10	69,025	94,567	120,110	145,652	171,194
13	13	84,867	110,409	135,951	161,493	187,035
8	7	134,970	160,512	186,055	211,597	237,139
11	10	113,306	138,848	164,390	189,933	215,475
14	13	115,553	141,096	166,638	192,180	217,722
6	7	-80,485	-54,943	-29,400	-3,858	21,684
9	10	11,503	37,046	62,588	88,130	113,672
12	13	50,554	76,096	101,638	127,180	152,722

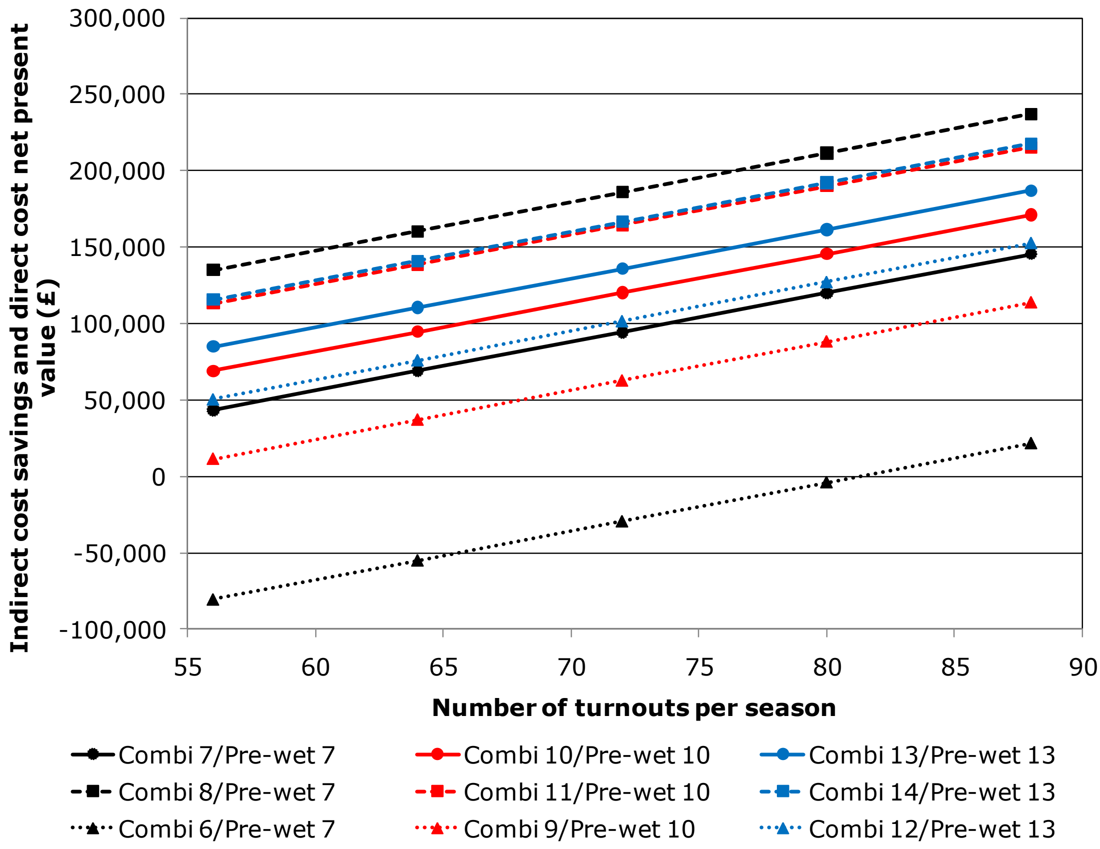

Figure A.7 Estimated indirect cost savings for vehicle and structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, brown dry salt at £25/tonne and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

A.2.9.3 Case 2: Estimated cost savings assuming 50 per cent brine loss due to trafficking and white dry salt

The second case considers the same assumptions as those for the first case except it is assumed that white dry and white brine salt at £46/tonne would be used.

The annual de-icer cost savings are £3,249 (from Table A.27), and the annual extra fuel costs is £275 (from Table A.37). Therefore, the annual net cost savings, including the additional saturator maintenance costs, are estimated to be £2,974. As for the first case, when the extra spreader costs are taken into account, there would be no direct cost saving.

Table A.42 shows that the annual indirect cost savings excluding vehicle corrosion are £3,699. Therefore, the annual net direct and indirect cost savings are £6,673. Table A.45 and Figure A.8 show that the indirect cost savings for structural corrosion and environmental damage and direct cost NPVs are greater than zero only for the more optimistic spreader service lives assumed. However, when the costs of vehicle corrosion are included, the annual overall cost savings are estimated to be £11,605, and Table A.46 (as Table A.44) shows that most of the indirect cost savings and direct cost NPVs are estimated to be greater than zero.

Table A.45 Estimated indirect cost savings for structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, white dry salt and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	-46,502	-33,799	-21,097	-8,394	4,308
10	10	-20,852	-8,150	4,553	17,255	29,958
13	13	-5,011	7,692	20,394	33,097	45,799
8	7	45,093	57,795	70,498	83,201	95,903
11	10	23,429	36,131	48,834	61,536	74,239
14	13	25,676	38,379	51,081	63,784	76,486
6	7	-170,362	-157,660	-144,957	-132,254	-119,552
9	10	-78,374	-65,671	-52,969	-40,266	-27,564
12	13	-39,324	-26,621	-13,919	-1,216	11,486

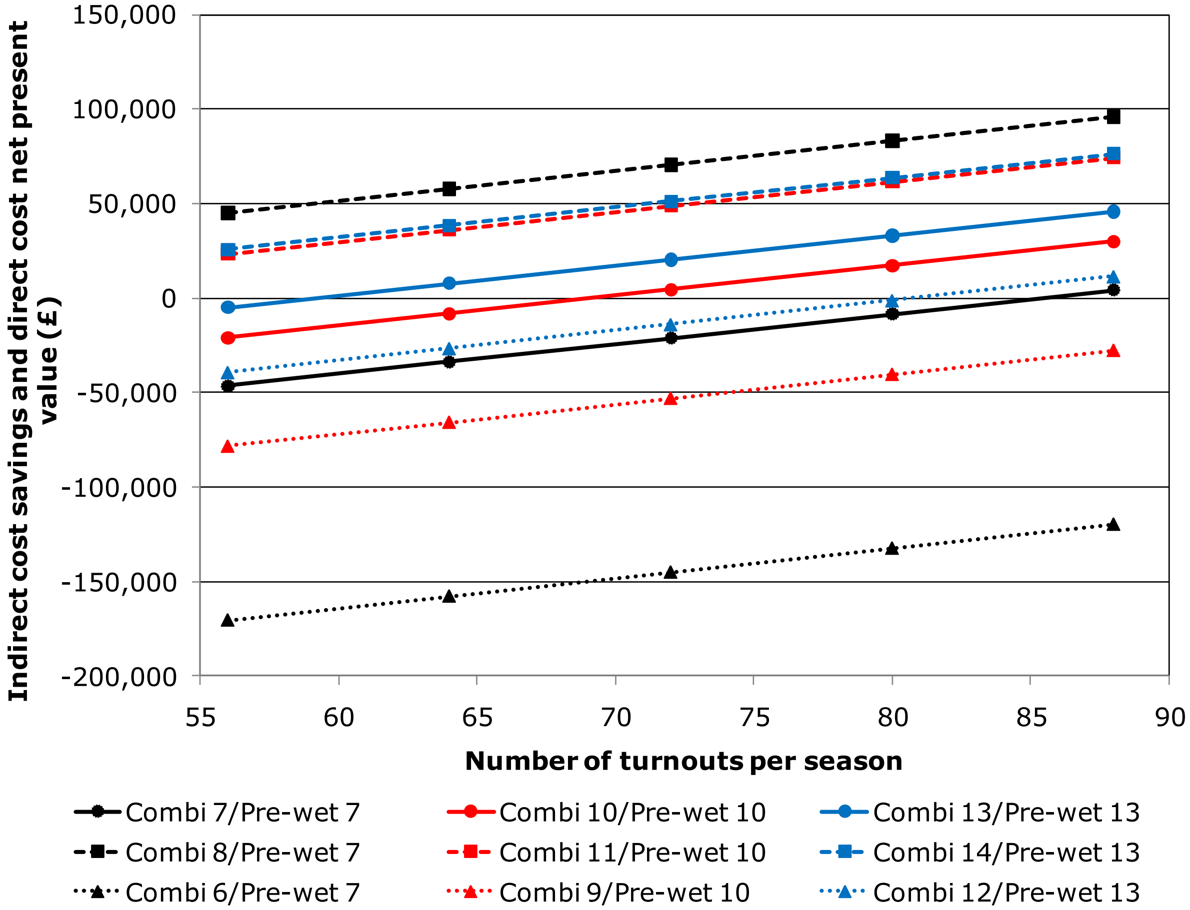

Figure A.8 Estimated indirect cost savings for structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, white dry salt and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Table A.46 Estimated indirect cost savings for vehicle and structural corrosion and environmental damage and direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, white dry salt and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Indirect cost savings and direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	19,217	41,308	63,399	85,490	107,581
10	10	44,867	66,958	89,049	111,140	133,231
13	13	60,708	82,799	104,890	126,981	149,072
8	7	110,812	132,903	154,994	177,085	199,176
11	10	89,148	111,239	133,330	155,421	177,512
14	13	91,395	113,486	135,577	157,668	179,759
6	7	-104,643	-82,552	-60,461	-38,370	-16,279
9	10	-12,655	9,436	31,527	53,618	75,709
12	13	26,395	48,486	70,577	92,668	114,759

A.2.9.4 Case 3: Estimated direct cost savings assuming 30 per cent brine loss due to trafficking and white dry salt

The third case considers the same assumptions as those for the second case except that the brine loss due to trafficking is 30 per cent.

The annual de-icer cost savings are £9,217 (from Table A.27), and the annual extra fuel costs is £275 (from Table A.36). Therefore, the annual net direct cost savings, including the additional saturator maintenance costs, are estimated to be £8,942.

Table A.47 and Figure A.9 show that the direct cost NPVs are mostly greater than zero when the service lives of the combination spreaders is not less than those of the pre-wet spreaders

Table A.47 Estimated direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, white dry salt and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

Service life of chassis of combination spreaders (years)	Service life of chassis of pre-wet spreaders (years)	Direct cost NPV (£)				
		Number of treatments				
		56	64	72	80	88
7	7	-16,268	754	17,776	34,798	51,820
10	10	9,382	26,404	43,426	60,448	77,469
13	13	25,224	42,245	59,267	76,289	93,311
8	7	75,327	92,349	109,371	126,393	143,414
11	10	53,663	70,685	87,707	104,728	121,750
14	13	55,910	72,932	89,954	106,976	123,998
6	7	-140,128	-123,106	-106,084	-89,062	-72,040
9	10	-48,139	-31,118	-14,096	2,926	19,948
12	13	-9,089	7,932	24,954	41,976	58,998

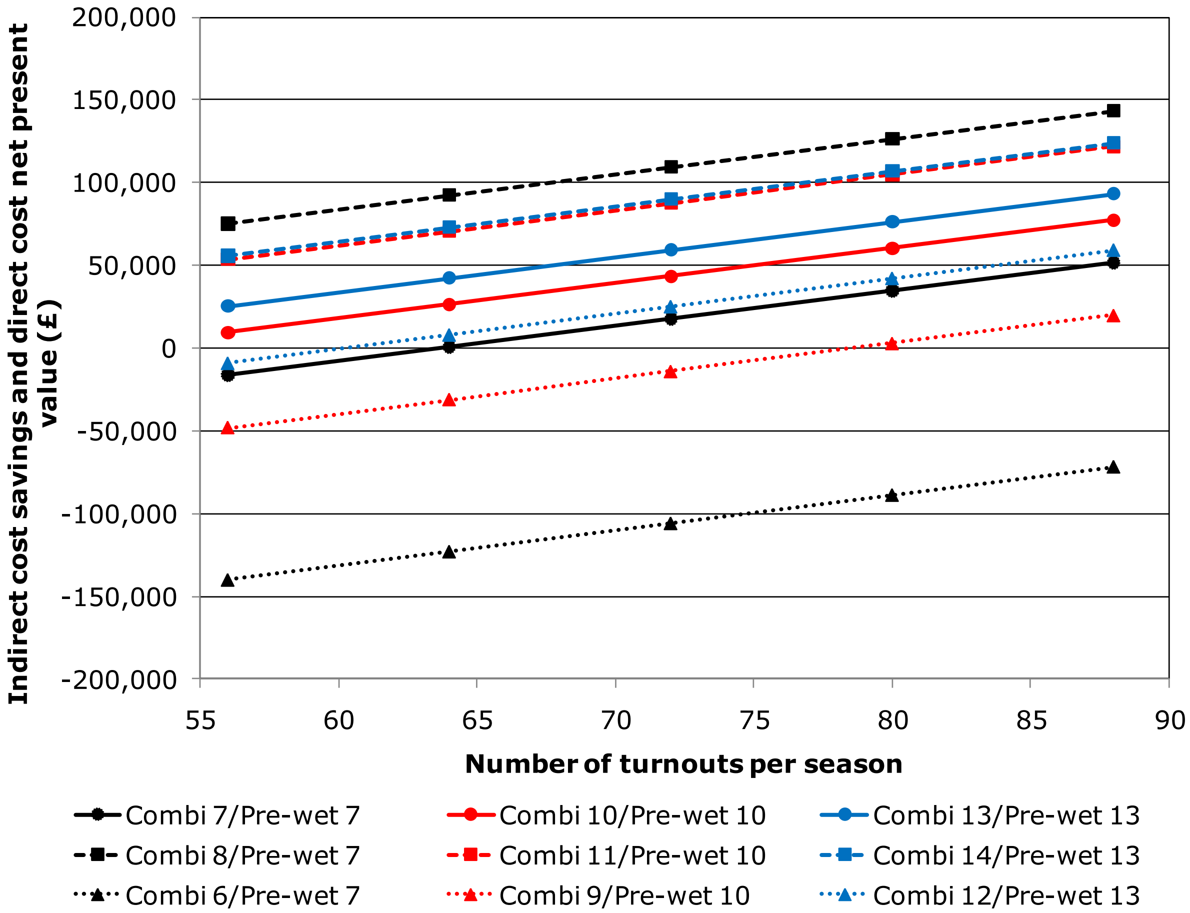

Figure A.9 Estimated direct cost NPVs when combination treatments replace pre-wetted salting assuming 'Baseline Marginal' scenario, white dry salt and white brine salt at £46/tonne, 6x4 combination spreaders, 4x4 pre-wet spreaders

A.2.9.5 Overview

The annual net direct cost savings or the annual indirect and direct cost savings used to calculate the NPVs for Cases 1 to 3 are £3,635, £6,673, £8,942, £11,605 and £13,418. These values were chosen to give a good indication of when combination treatments are likely to result in a direct and/or overall (direct and indirect) cost saving.

An annual cost saving of £6,673 is estimated to be too low for combination treatments to provide a real cost benefit. When the annual cost saving is £8,942, there should be a cost benefit unless the service lives of combination spreaders are less than those of pre-wet spreaders. However, when the annual cost saving is £11,605, there should be a considerable cost benefit unless the service lives of combination spreaders are less than those of pre-wet spreaders and they are low.

From the data in Table A.27 and Table A.42 it is possible to estimate when combination spreaders are likely to bring a cost benefit. The following is concluded for the assumptions made:

Direct costs

- If brown dry salt and white brine salt are used, it is estimated that there will be no direct cost savings if the brine loss due to trafficking is 30 per cent or more (i.e. on all types of surfacing on the Agency's network).
- If white dry salt and white brine salt are used, there should be direct cost savings if the weather conditions correspond to the 'Baseline Marginal' and 'Dry Marginal' treatments scenarios and the brine loss due to trafficking is 40 per cent or less. This is more likely in such areas if white salt costs more than £46/tonne (c.f. £25/tonne for brown salt)

Direct costs and indirect costs associated with structural corrosion and environmental damage

- There will not be an overall cost benefit if brown dry salt is used unless the brine loss due to trafficking is 30 per cent or less.
- There will be an overall cost benefit if white dry salt is used and the brine loss due to trafficking is 40 per cent or less, even if the brine loss due to trafficking is 30 per cent.

Direct costs and indirect costs associated with vehicle and structural corrosion and environmental damage

- There will be an overall cost benefit if brown dry salt is used if the weather conditions correspond to the 'Baseline Marginal' and 'Dry Marginal' treatments scenarios and, if the brine loss due to trafficking is 30 per cent of less, for the 'Wetter Marginal' and 'Colder' treatments scenarios.
- There will be an overall cost benefit if white dry salt is used and the brine loss due to trafficking is 40 per cent or less. There should be an overall cost benefit if the brine loss due to trafficking is 50 per cent and the weather conditions correspond to the 'Baseline Marginal' and 'Dry Marginal' treatments scenarios.

Appendix B Brine recovery tests

Following the brine spreader trials, carried out with the Schmidt Straliq liquid spreader on the 7th and 8th April 2010, there were concerns regarding the amount of brine recovered from the 14mm SMA surfacing.

For the brine spreader trials, the wet wash collection method involved the following procedure for each panel: 1 dry vacuum over entire panel, 3 wet vacuums (spraying water and vacuuming), followed by a final 2 dry vacuums.

For the subsequent trials with pre-wet spreaders in brine mode, the collection method was modified to increase the number of wet vacuum passes. The method involved the following procedure for each panel: 4 wet vacuums followed by a final dry vacuum.

A series of recovery tests were carried out on the 14mm SMA surfacing to investigate how much of the brine spread was recovered by the two collection methods.

1m x 1.2m control panels were marked out on the surfacing and wet vacuumed to remove any residual salt, as was the case during the performance trial. Known amounts of brine were spread within the panels. Within 1 hour after spreading, as during the performance trials, brine was recovered using the methods described above.

Figure B.1, Figure B.2, Table B.1 and Table B.2 compare the amounts of brine spread with the amounts recovered for both methods. On average, the results showed a 59 per cent recovery rate for the brine trial method, and a 71 per cent rate for the pre-wet trial method. These figures have been used in Sections 4.7 and 5.5 to calculate the amount of brine spread in the trials from the amount of brine collected.

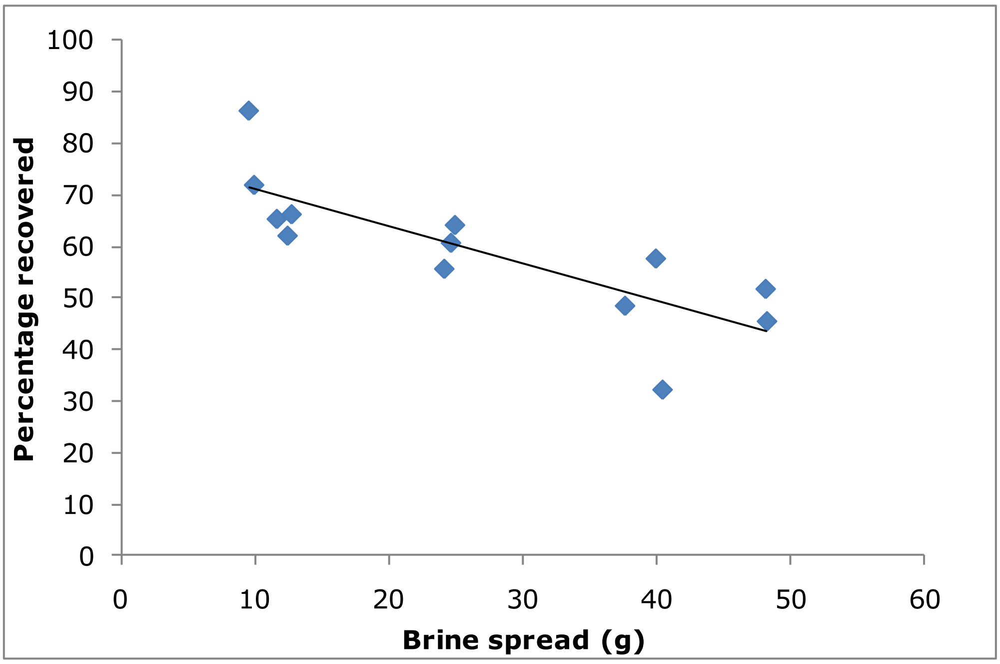

Figure B.1. Brine recovery for brine spreader, within 1 hour of spreading (3 wet washes)

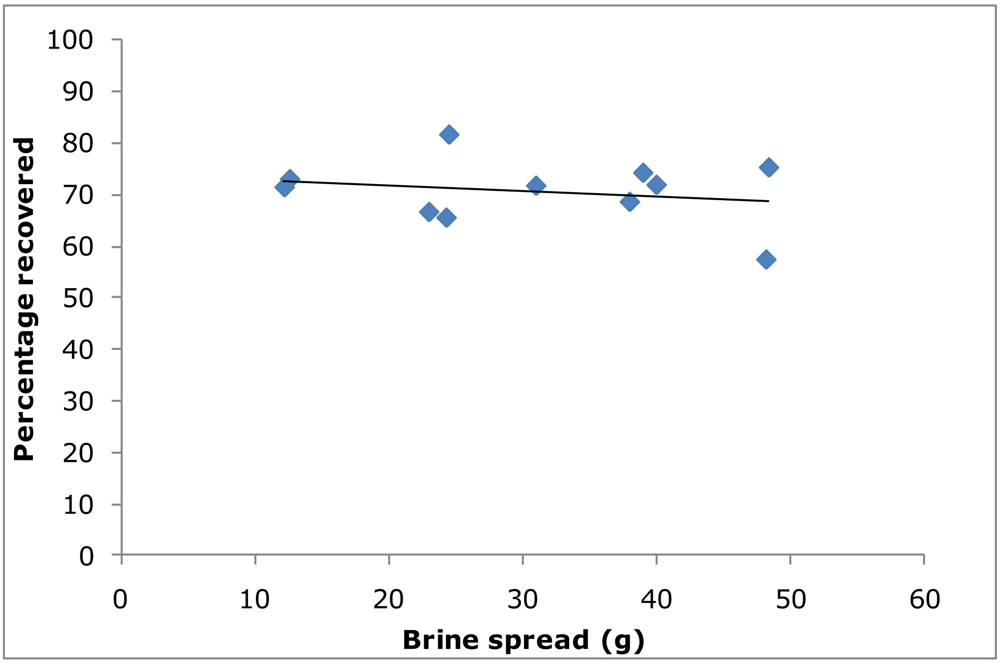

Figure B.2. Brine recovery for pre-wet spreaders, within 1 hour of spreading (4 wet washes)

Table B.1. Brine collected within 1 hour after spreading: Brine spreader

Brine spread (g)	% collected
12.50	62.11
24.70	60.72
48.20	51.72
12.80	66.30
24.20	55.64
48.30	45.42
11.70	65.38
9.60	86.51
40.50	32.06
37.70	48.43
10.00	72.02
25.00	64.19
40.00	57.65
Average	**59%**

Table B.2. Brine collected within 1 hour after spreading: Pre-wet spreader

Brine spread (g)	% collected
12.20	71.49
24.50	81.63
48.40	75.30
12.60	73.04
24.30	65.62
48.20	57.56
23.00	66.71
31.00	71.77
38.00	68.67
40.00	71.94
39.00	74.26
Average	**71%**

Appendix C Brine spreader distribution profiles

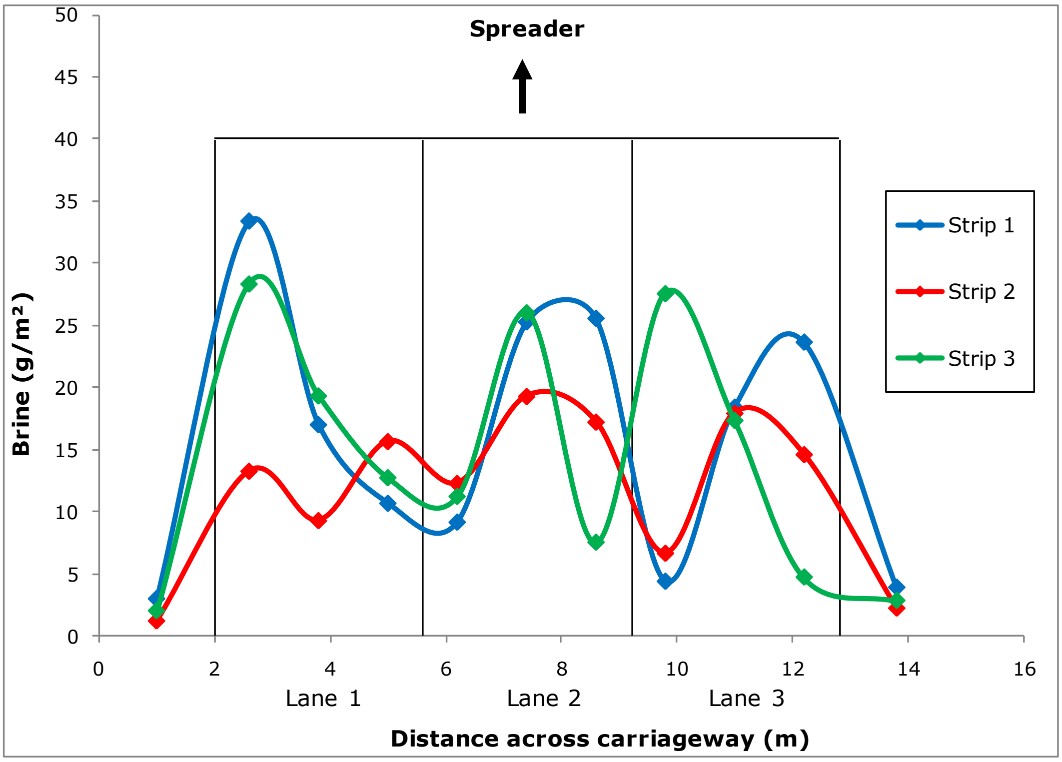

Figure C.1. Trial B1: Spreading three lanes symmetrically, 40g/m², 64km/h

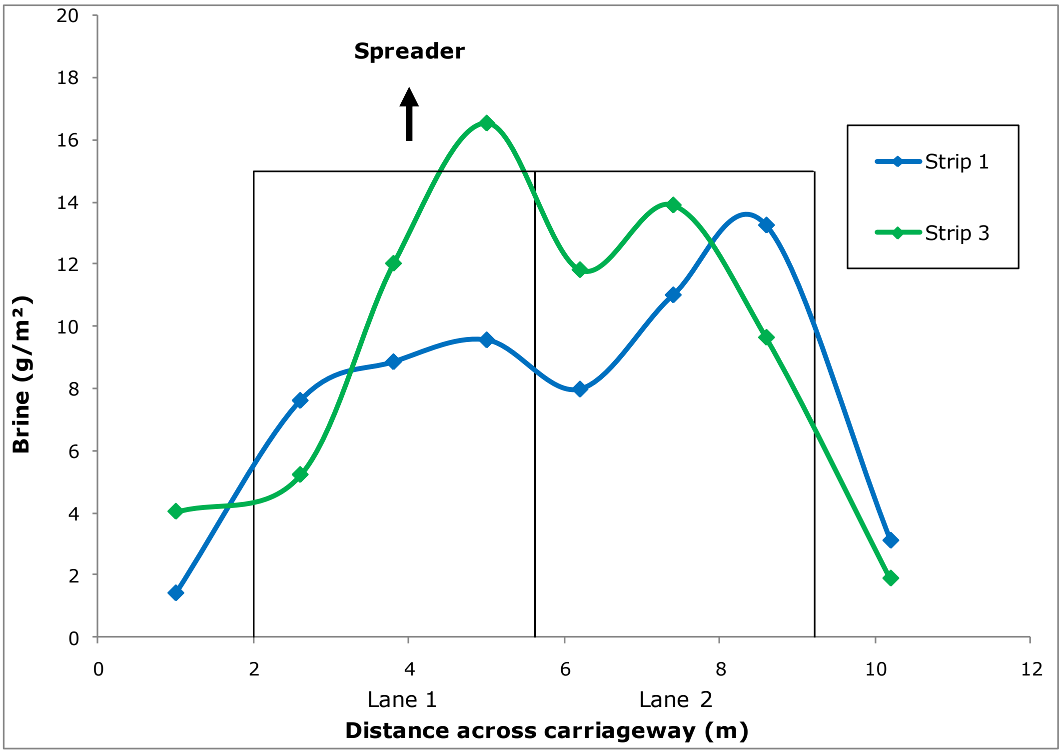

Figure C.2. Trial B2: Spreading two lanes asymmetrically, 15g/m², 64km/h

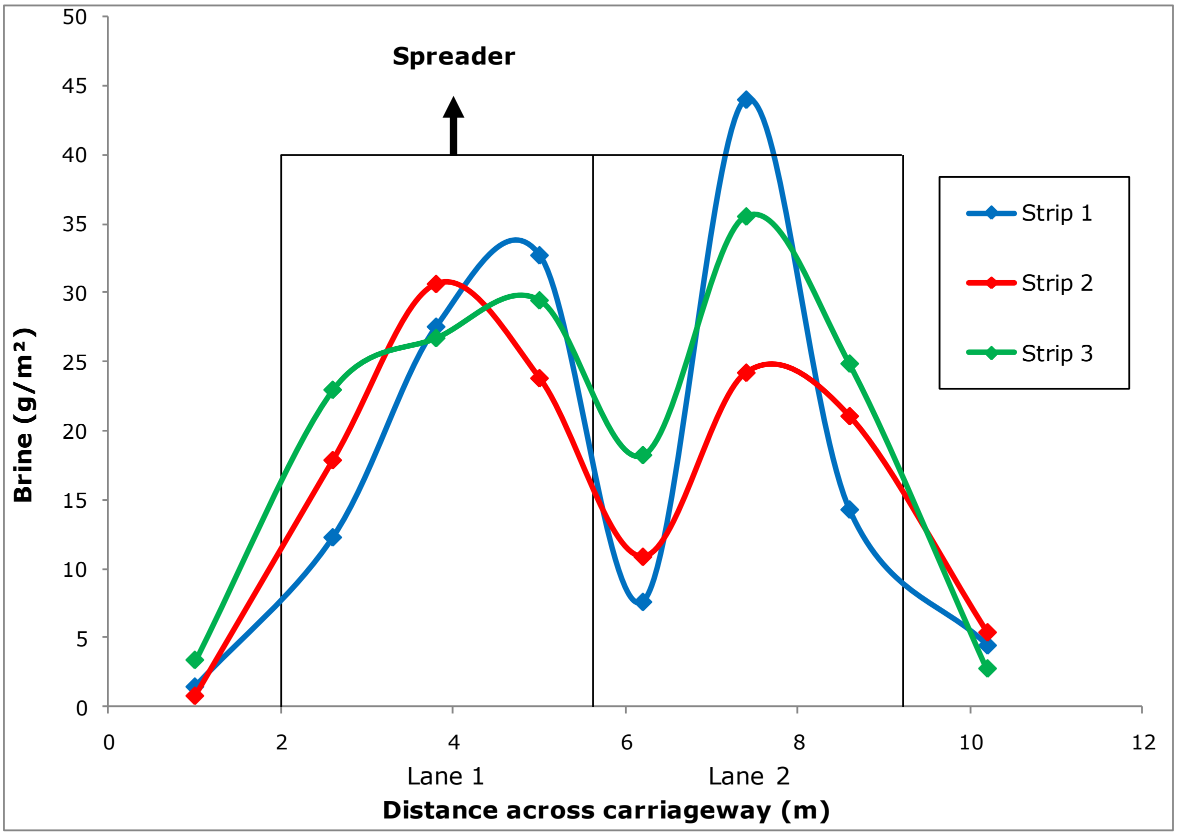

Figure C.3. Trial B3: Spreading two lanes asymmetrically, 40g/m², 64km/h

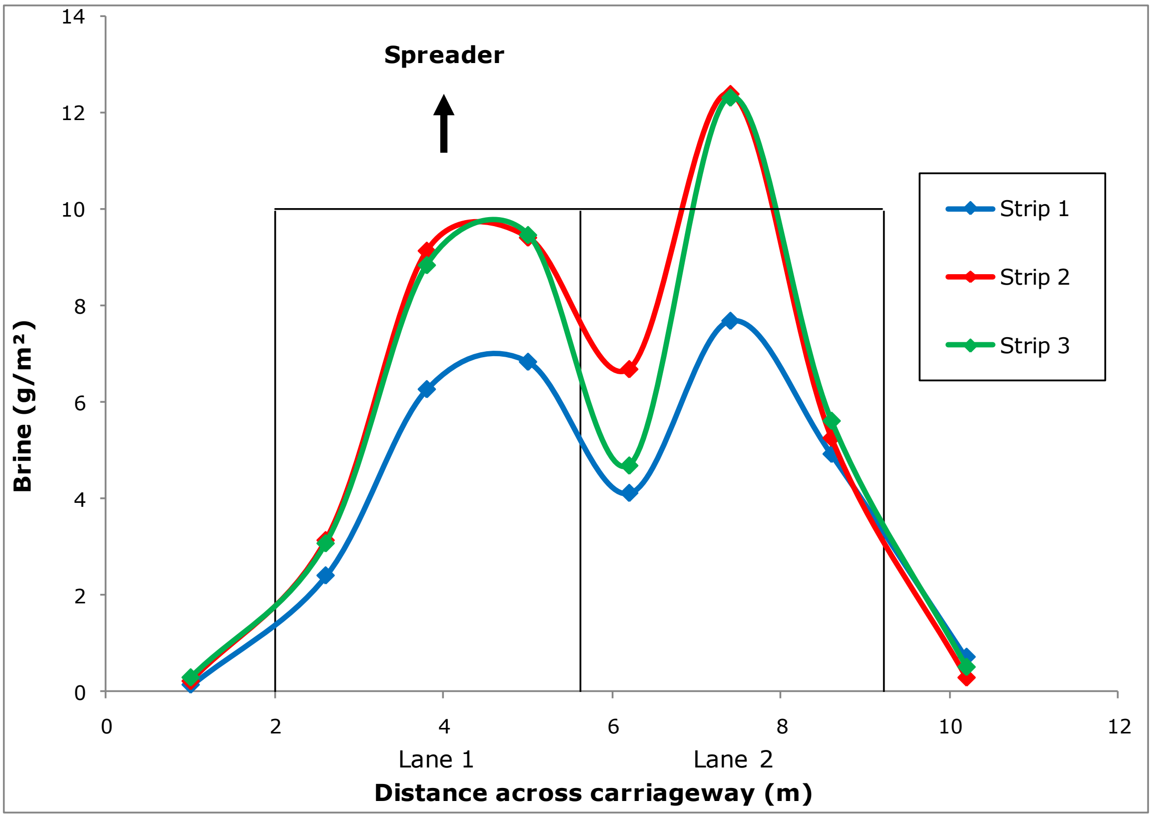

Figure C.4. Trial B4: Spreading two lanes asymmetrically, 10g/m², 64km/h

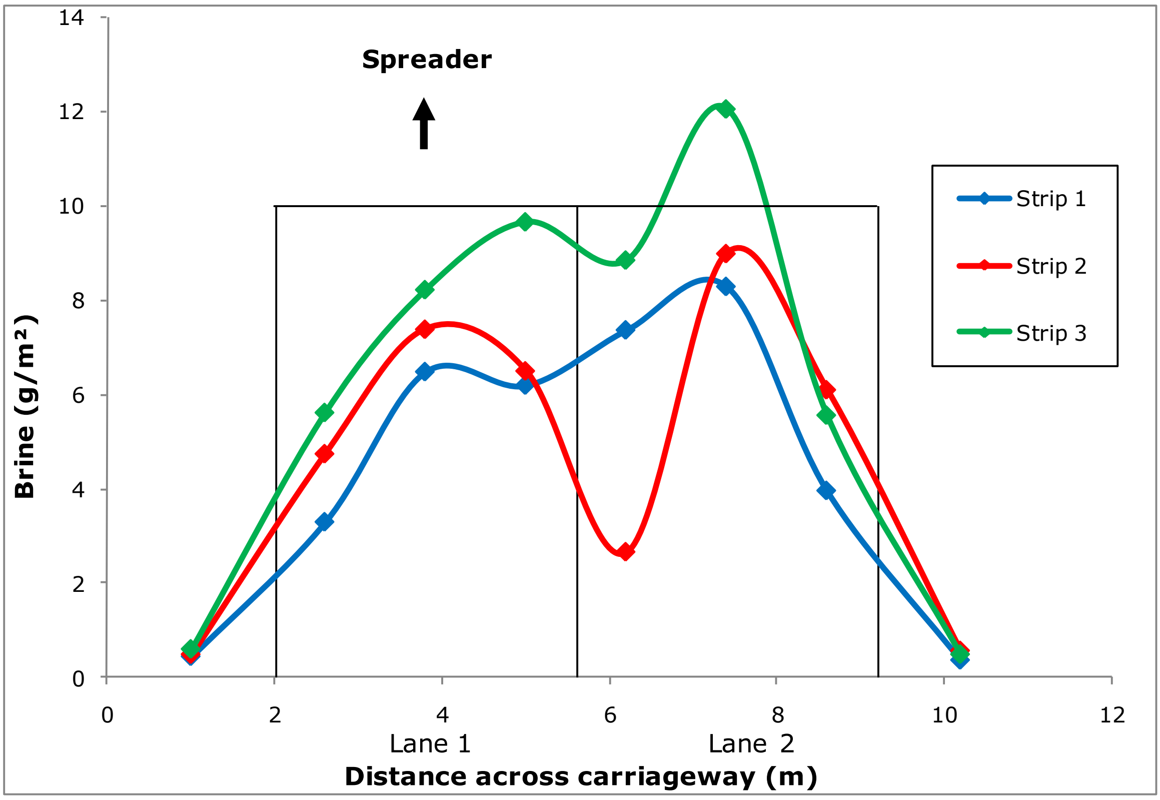

Figure C.5. Trial B5: Spreading two lanes asymmetrically, 10g/m², 80km/h

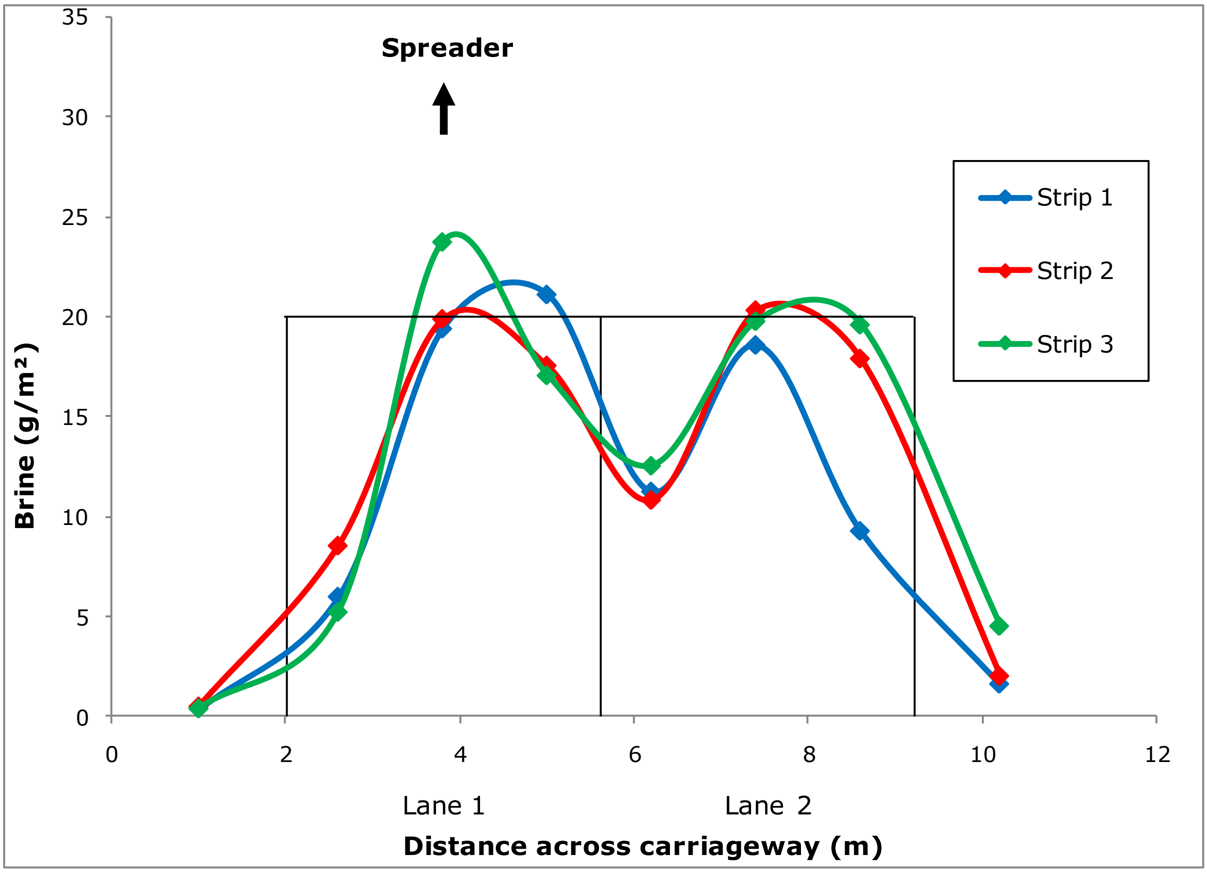

Figure C.6. Trial B6: Spreading two lanes asymmetrically, 20g/m², 64km/h

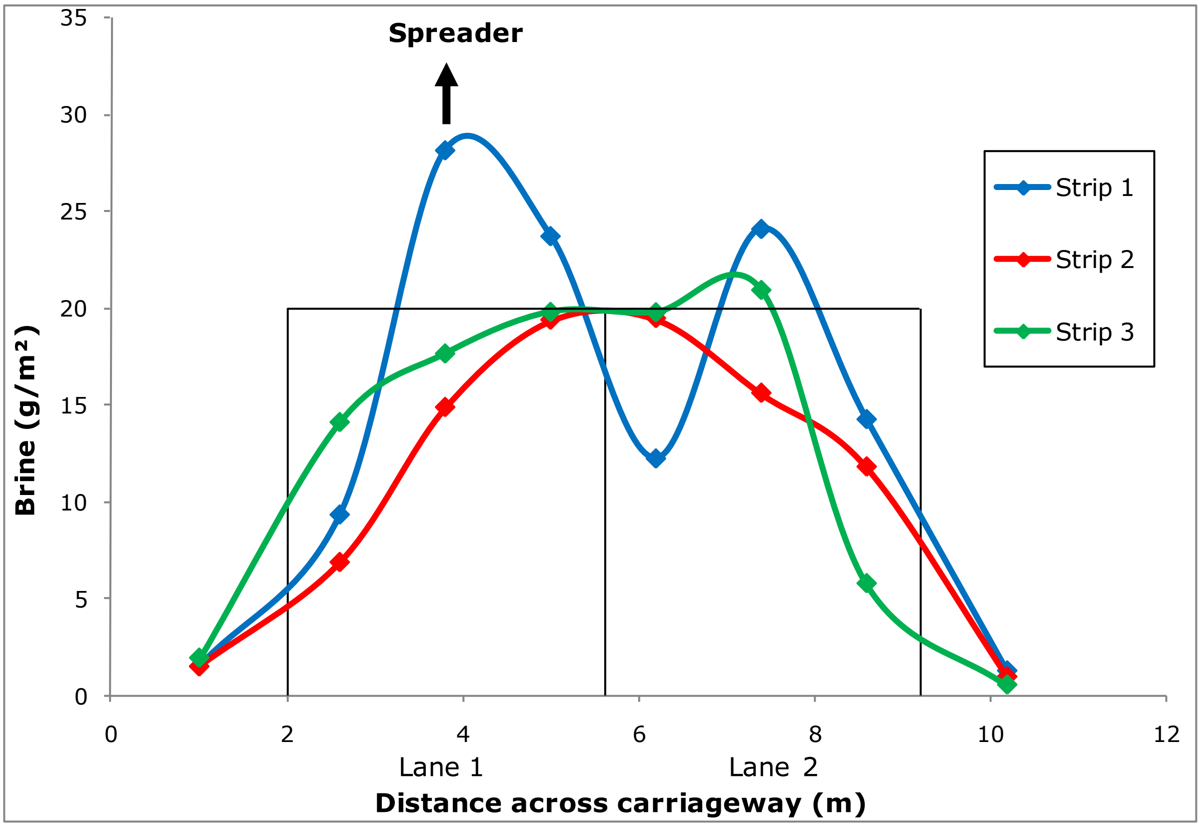

Figure C.7. Trial B7: Spreading two lanes asymmetrically, 20g/m², 80km/h

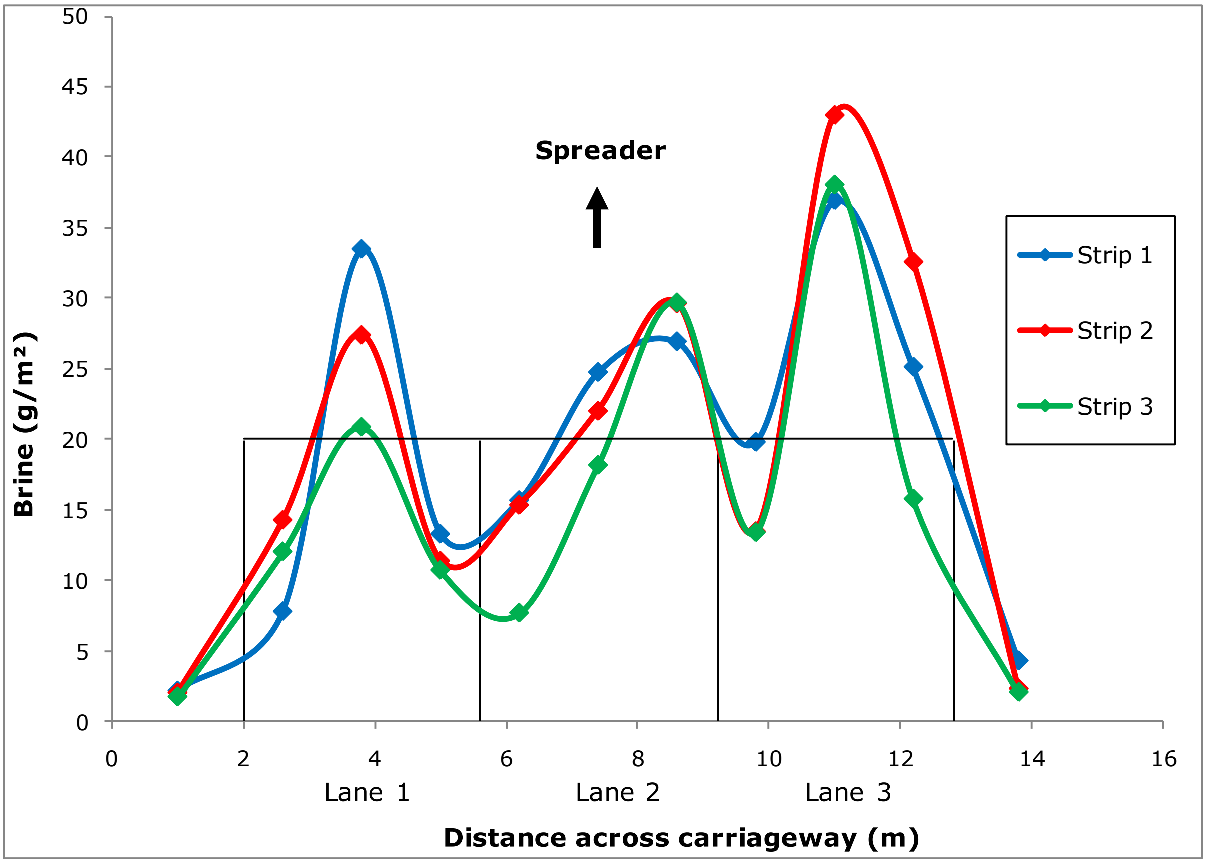

Figure C.8. Trial B8: Spreading three lanes symmetrically, 20g/m², 80km/h

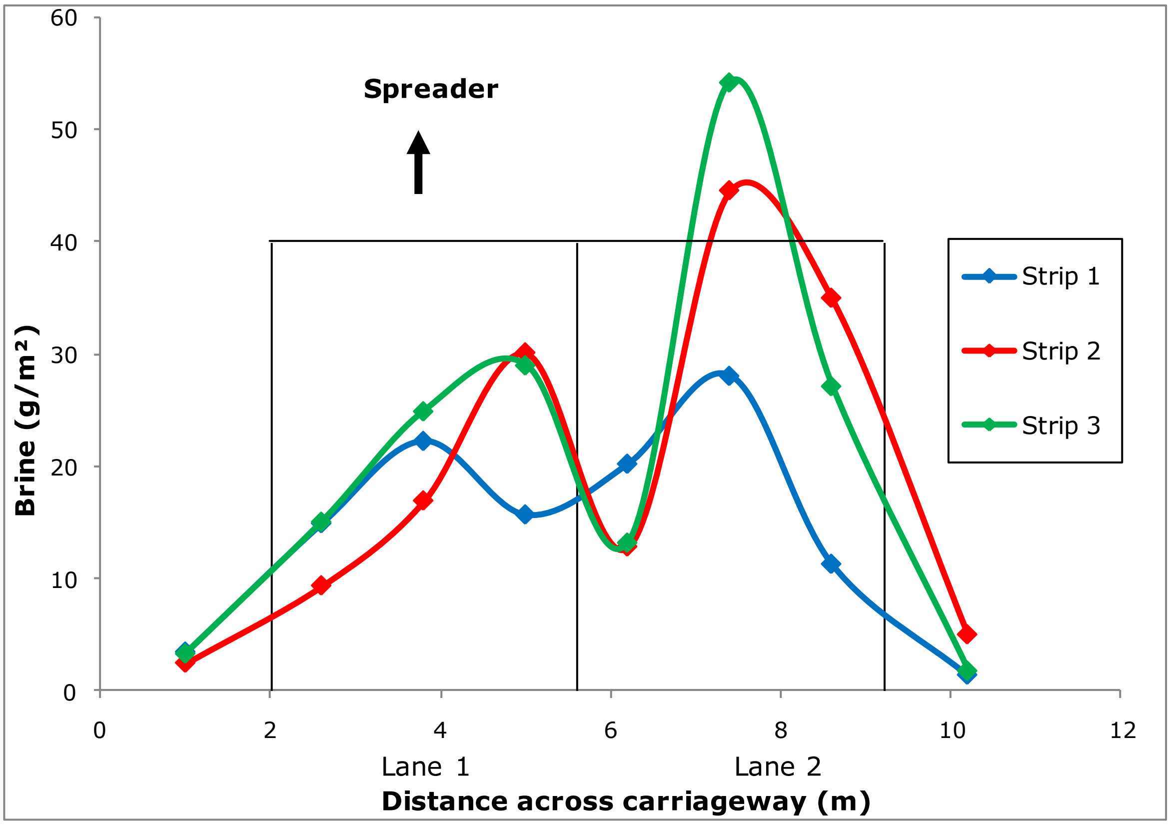

Figure C.9. Trial B9: Spreading two lanes asymmetrically, 40g/m², 80km/h

Appendix D Pre-wet spreader distribution profiles

D.1 Schmidt spreader distribution profiles

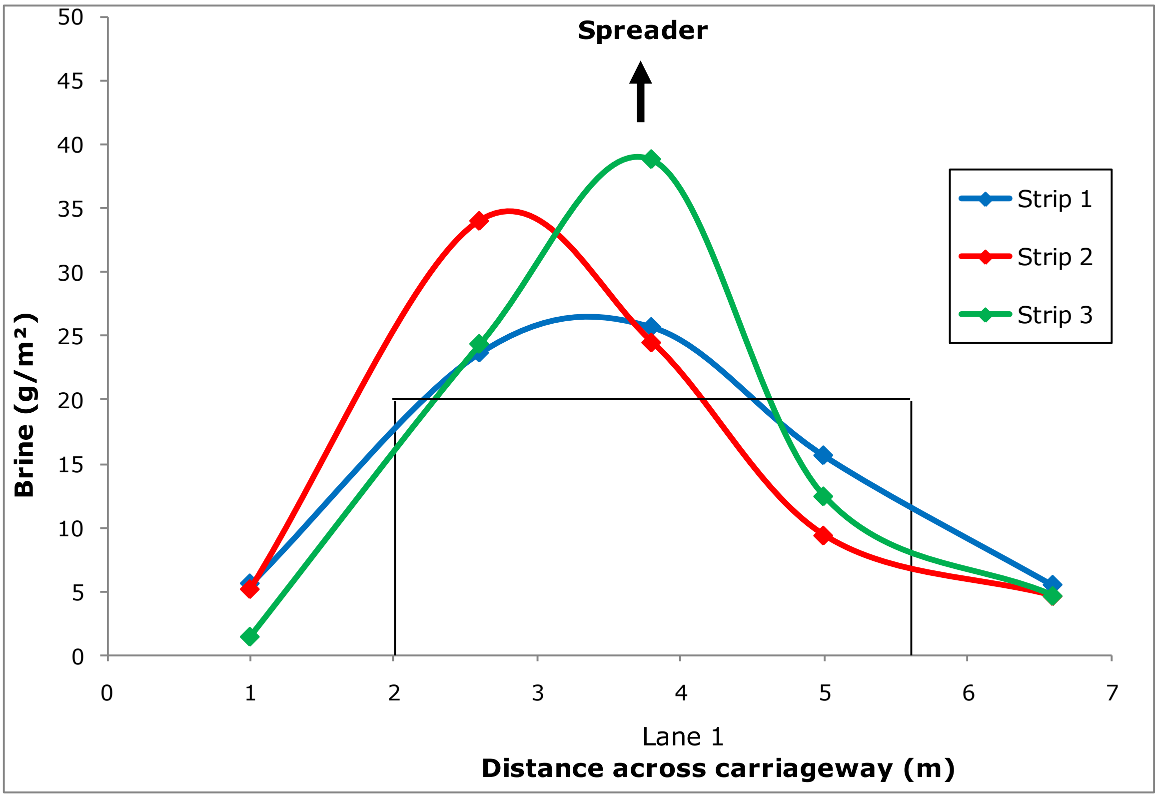

Figure D.1. Trial 1S: Spreading one lane, 20g/m²

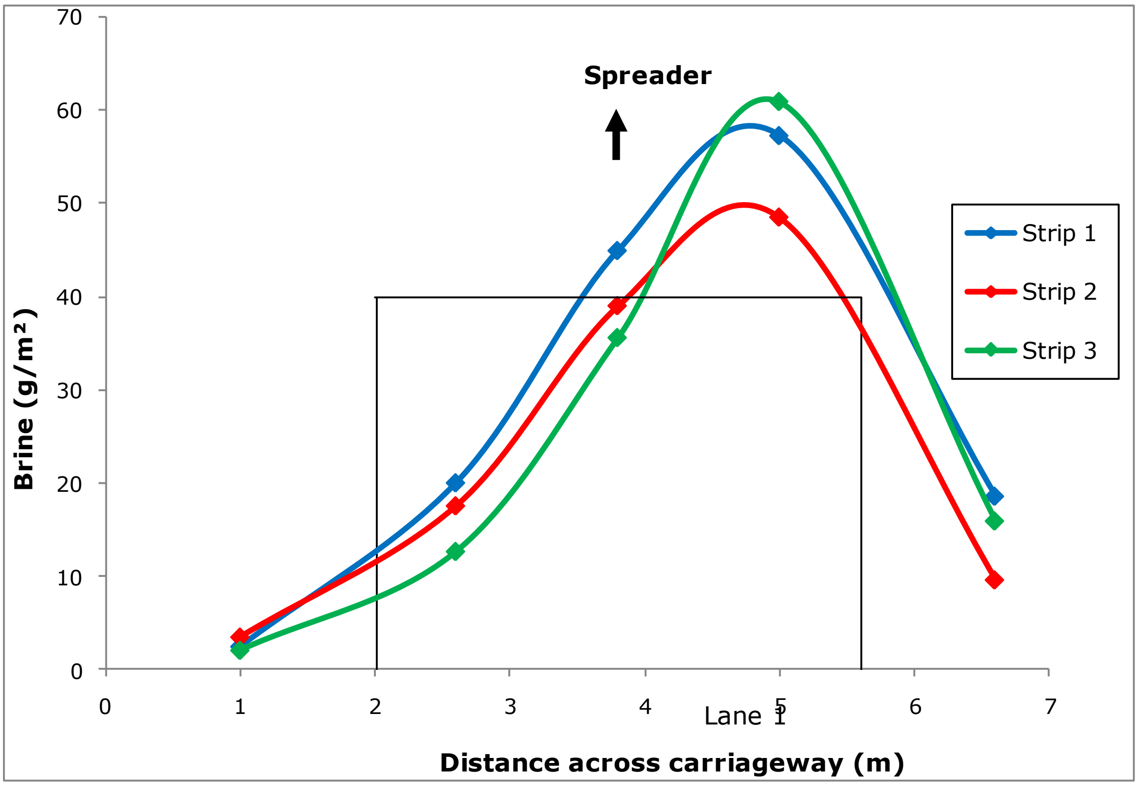

Figure D.2. Trial 2S: Spreading one lane, 40g/m²

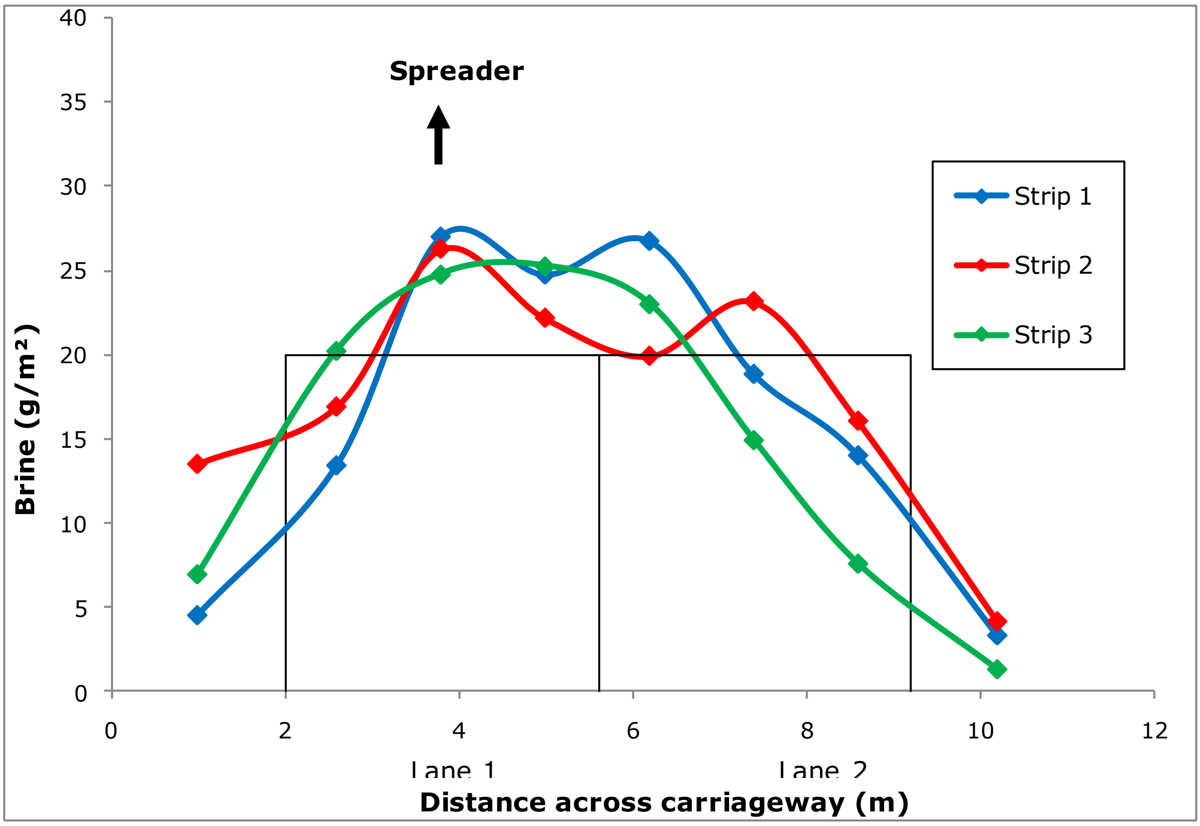

Figure D.3. Trial 3S: Spreading two lanes, 20g/m²

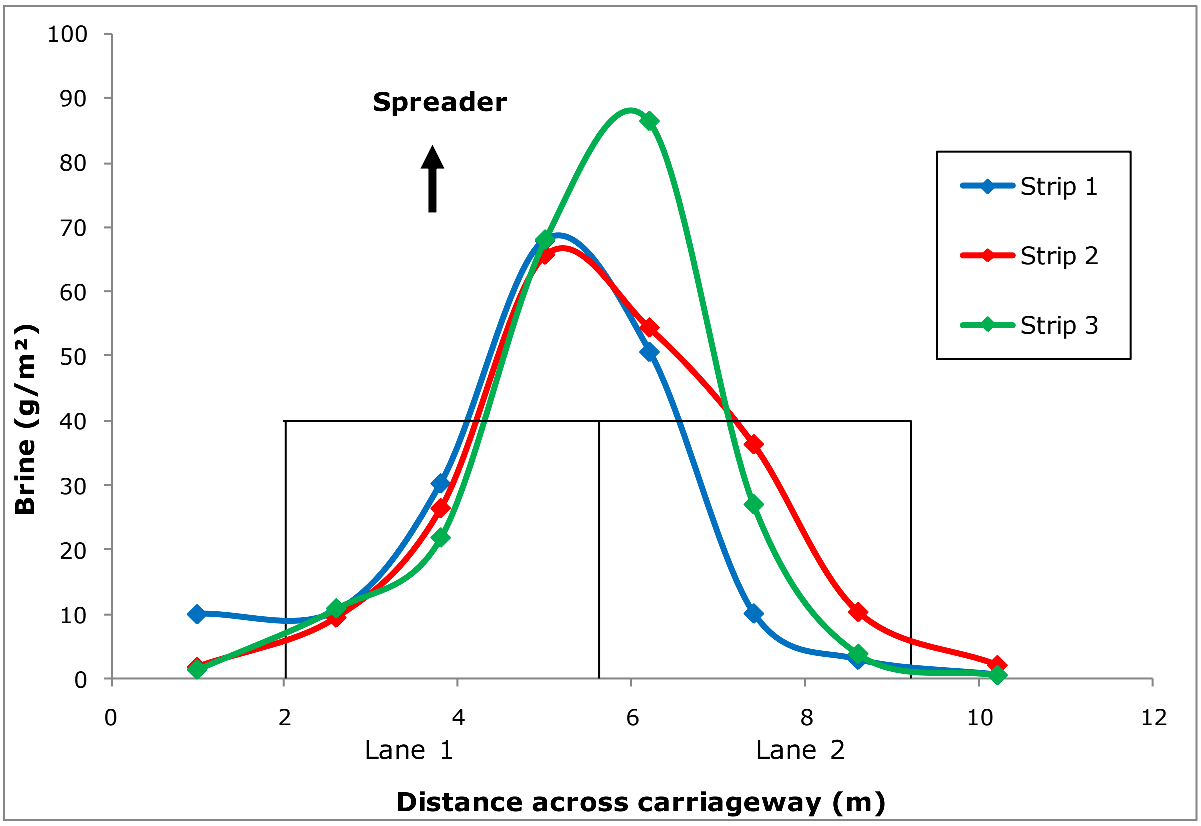

Figure D.4. Trial 4S: Spreading two lanes, 40g/m²

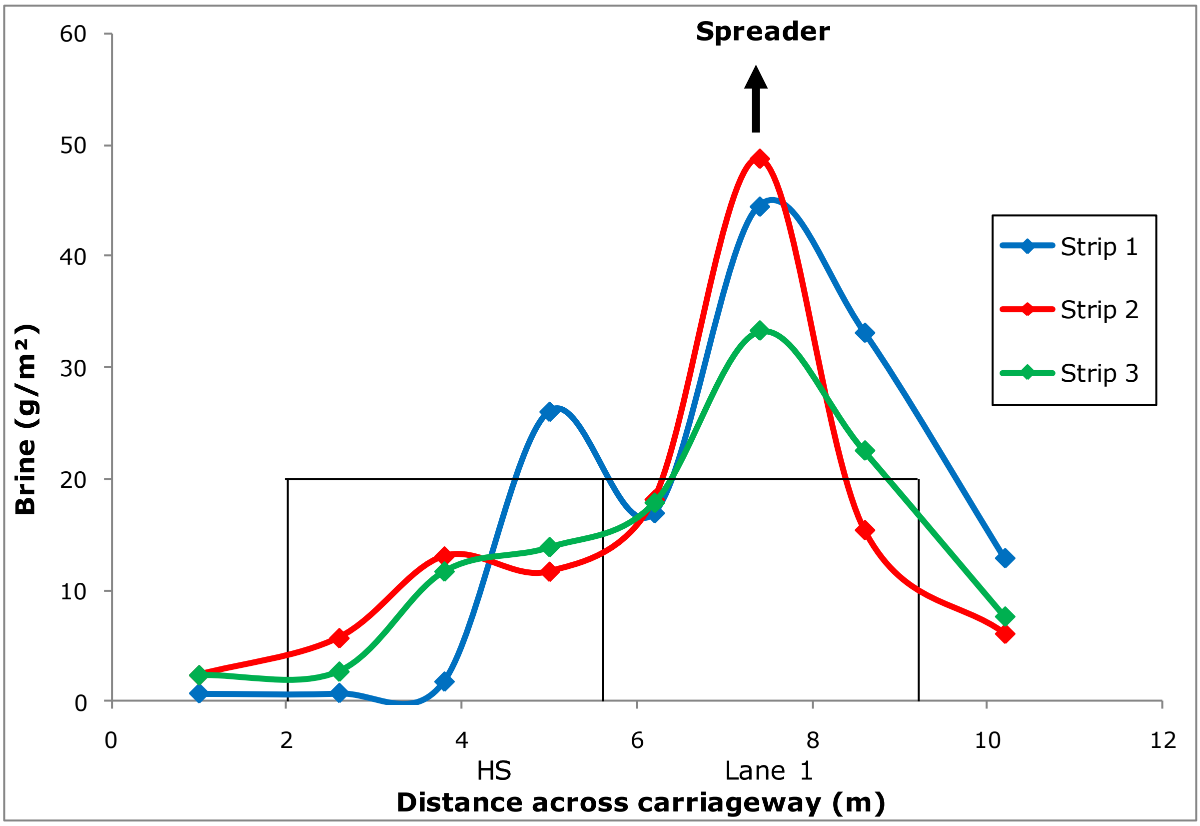

Figure D.5. Trial 5S: Spreading two lanes – Lane 1 to HS, 20g/m²

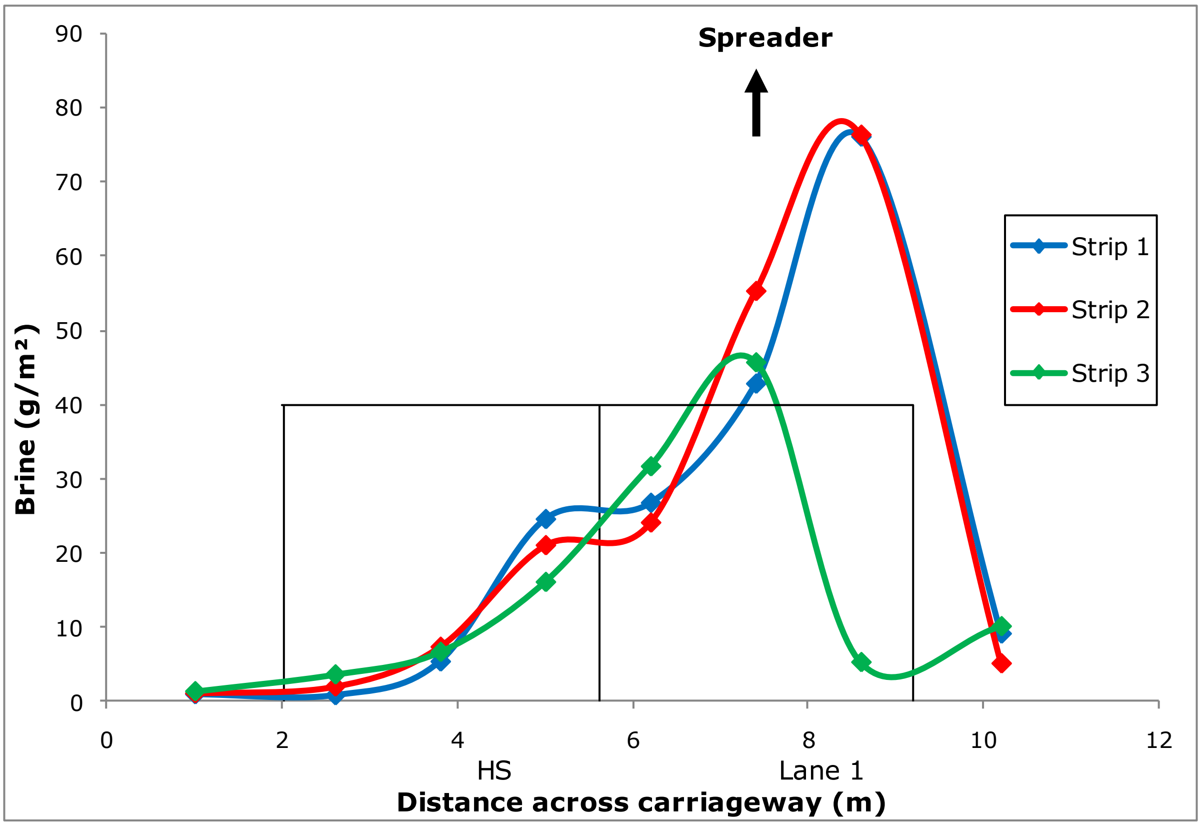

Figure D.6. Trial 6S: Spreading two lanes – Lane 1 to HS, 40g/m²

D.2 Romaquip spreader distribution profiles

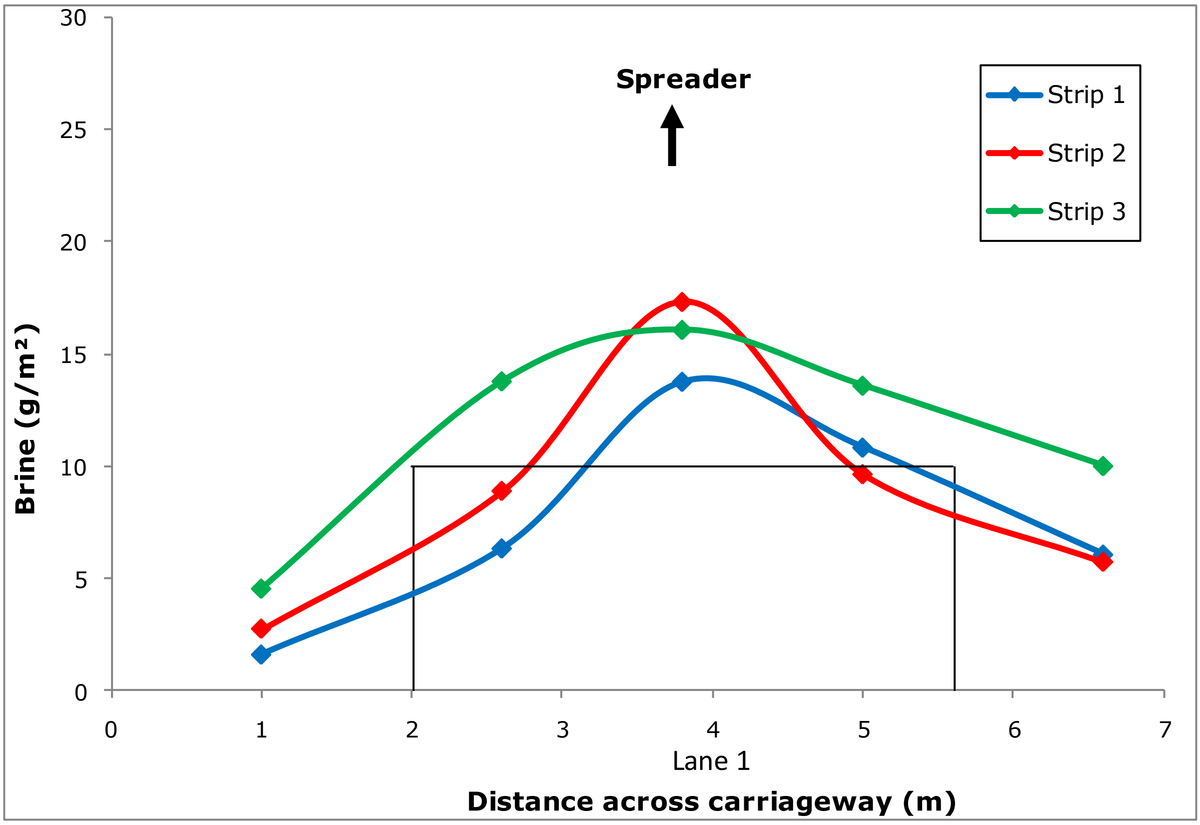

Figure D.7. Trial 1R: Spreading one lane, 10g/m²

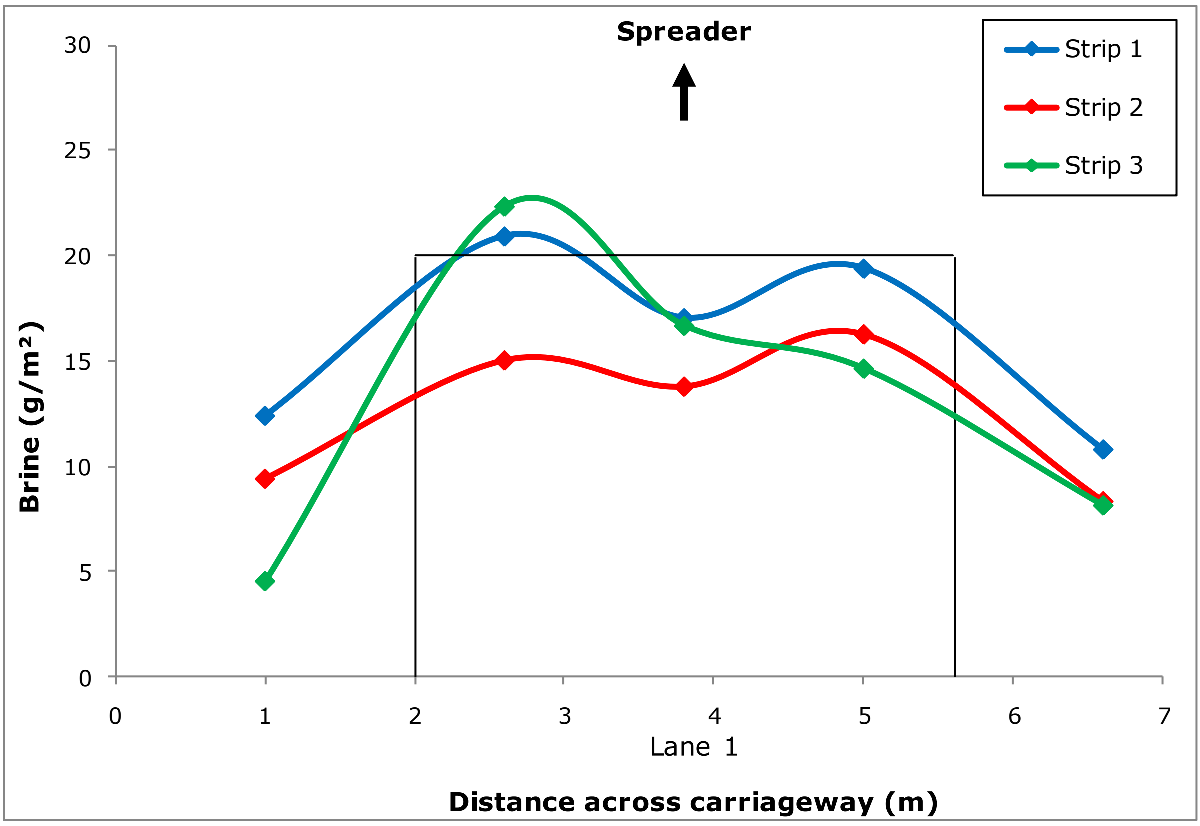

Figure D.8. Trial 2R: Spreading one lane, 20g/m²

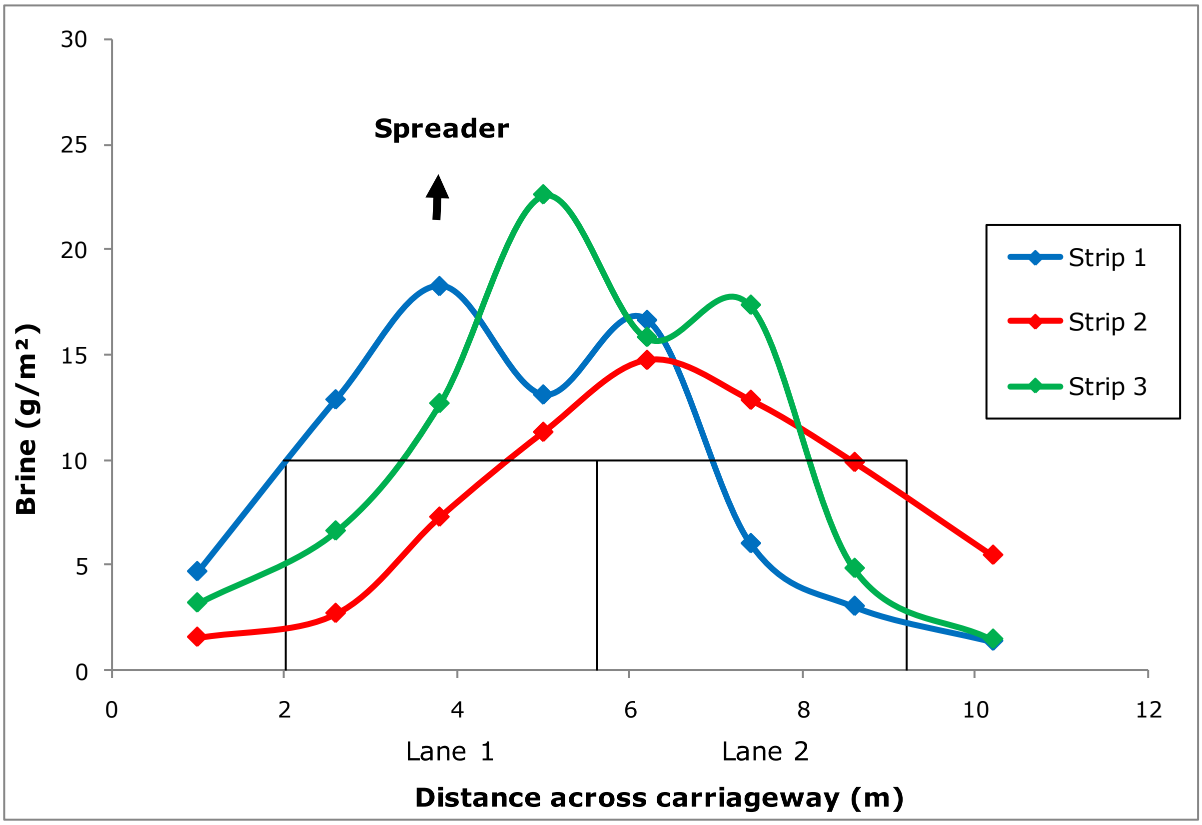

Figure D.9. Trial 3R: Spreading two lanes, 10g/m²

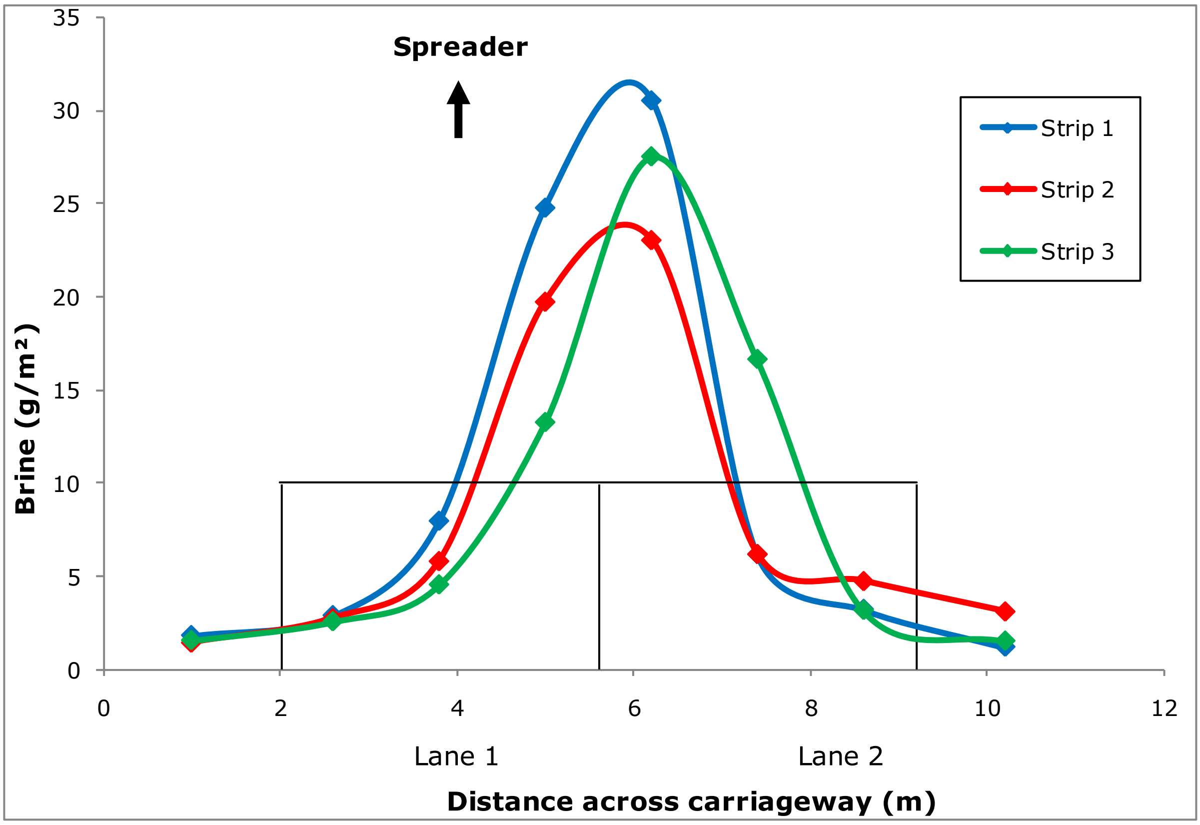

Figure D.10. Trial 4R: Spreading two lanes, 10g/m² (repeat)

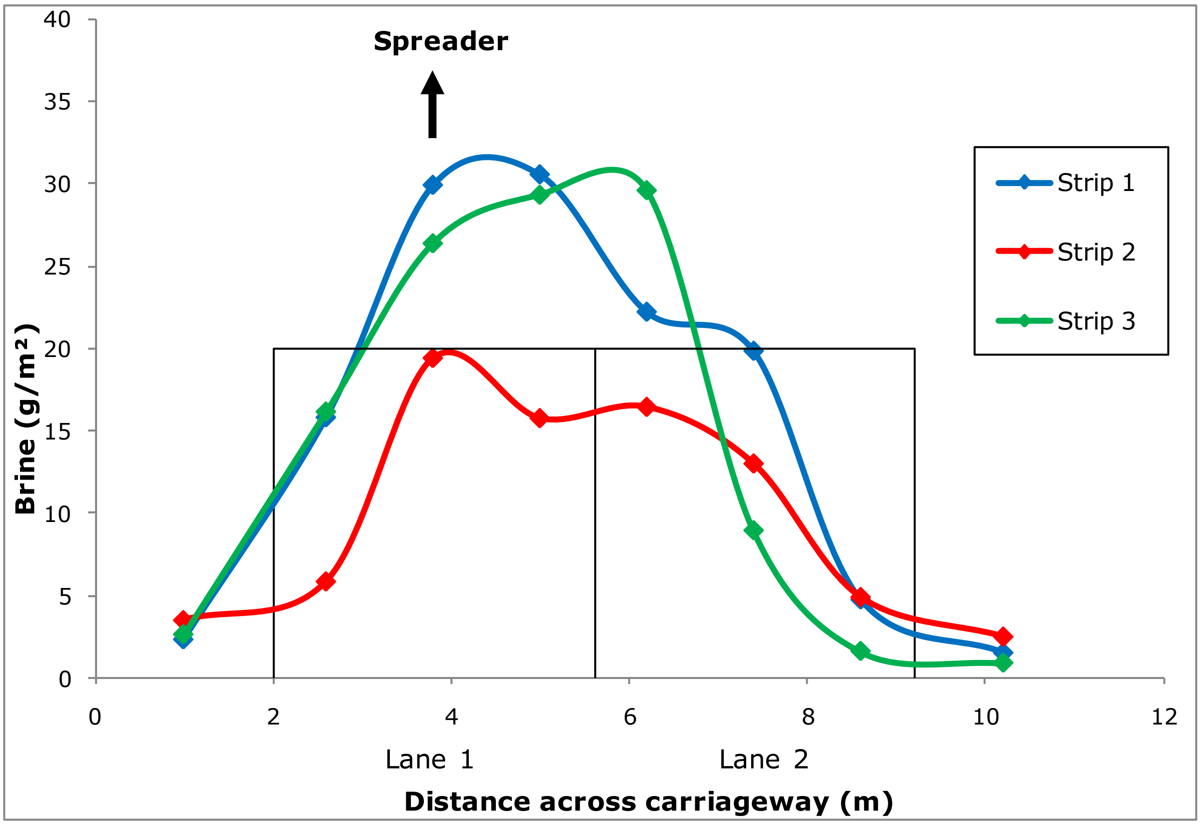

Figure D.11. Trial 5R: Spreading two lanes, 20g/m²

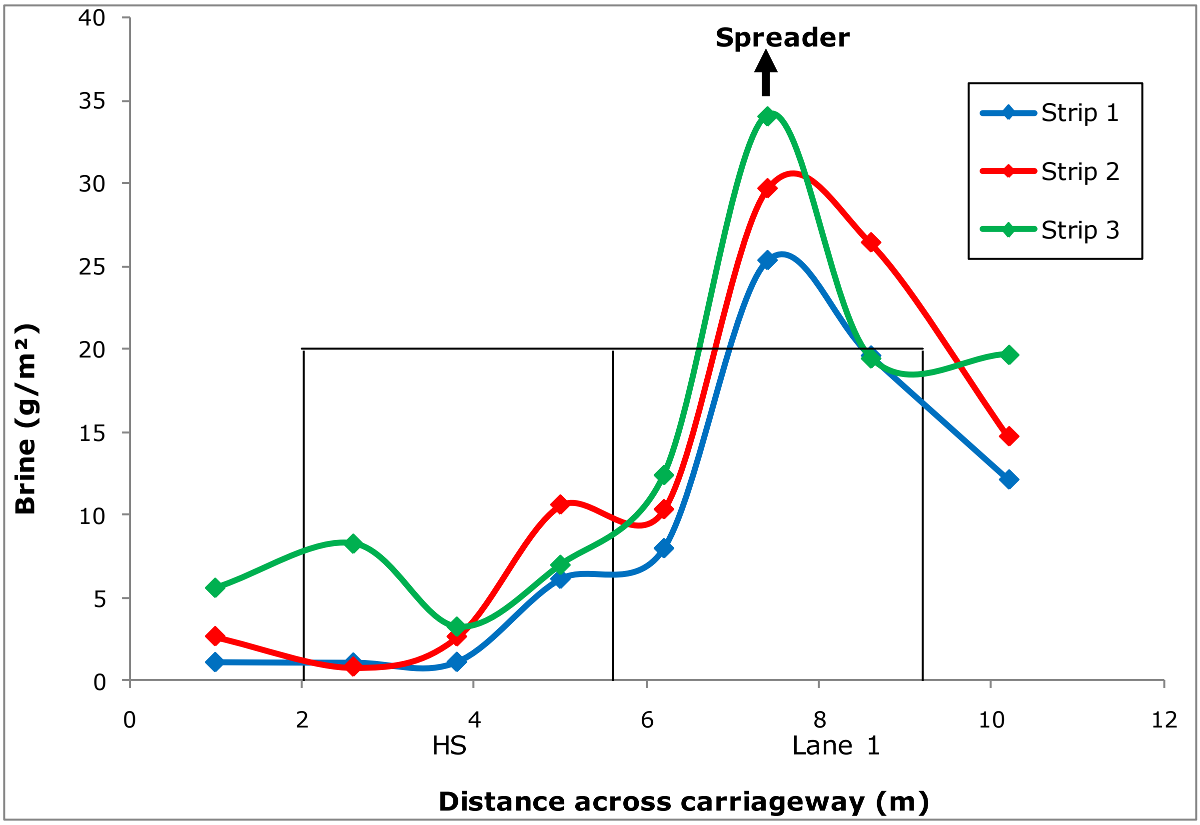

Figure D.12. Trial 6R: Spreading two lanes – Lane 1 to HS, 20g/m²