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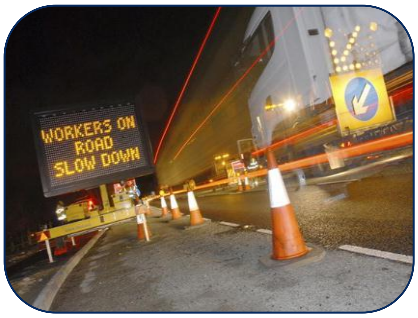


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Trials of the longevity of brine and pre-wetted salt winter service treatments on typical UK road surfacings

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Quality approved:

Matthew Evans	Barry Cleave
(Project Manager)	(Technical Referee)

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Contents

Executive Summary

In the light of recent work in Europe, Transport Scotland (TS) working with the Highways Agency (HA), now Highways England at the time of report publishing, and the National Winter Service Research Group (NWSRG), have promoted an initiative to further investigate the potential merit of using brine on the Scottish and English trunk road networks. The NWSRG is responsible for overseeing and co-ordinating winter service research and providing guidance relevant for all roads in the UK. Both Transport Scotland and the Society of Chief Officers of Transportation in Scotland (SCOTS) as well as Highways England (formerly Highways Agency) are represented on the NWSRG.

The purpose of this study was to examine the longevity of salt spread on the trunk road and motorway networks operated by Transport Scotland and the HA. This was achieved by carrying out trials in conditions of humidity and temperature representing road surface states close to freezing. The trials were not designed to measure the effectiveness of treatment rates; such work could form part of a further set of trials if the results of this work showed benefits in using brine as compared to pre-wet salting treatments.

The main surfacing types found on Scottish and English trunk roads are Hot Rolled Asphalt (HRA) and UK specification Proprietary Thin Surfacing or UKPTS (similar to an SMA but with a higher void content and less binder to deliver texture requirements). UKPTS has become the material predominantly used for new roads and resurfacing schemes on the TS and HE networks (although local roads predominantly use HRA). The UKPTS surfacing materials commonly used in the UK have a different specification to that generally used for SMA in Europe, the main difference affecting winter service being that UKPTS has a much higher interconnected void content than SMA and HRA. Scotland has more recently surfaced some of their network with a type of SMA (TS2010 SMA) similar to that typically specified in Germany, however this was not trialled in this experiment.

The NWSRG, through TRL Ltd as their research contractor, have co-ordinated trials on three sites across the UK during the 2014/2015 winter season to compare the longevity (or more correctly the rate of loss) of brine and pre-wet salt spread on trunk roads in conditions close to freezing.

Transport Scotland selected two trial sites, the A1 at East Linton (near Dunbar), a section of dual carriageway with UKPTS surfacing and the A9 at Aviemore, a single carriageway section with HRA surfacing. The HA provided a site on the M27 at Parkgate, a 3 lane section of motorway with UKPTS surfacing. The trial sites have therefore incorporated road surfacings relevant to both trunk road operators and local authorities.

Each trial site was split into two adjacent areas for the brine and pre-wetted salt spreading which were then subjected to the same trafficking during the trial.

Measurements of residual salt were carried out immediately before and after spreading, and then after various lengths of trafficking time as shown below.

Trial Location	Residual salt measurement times (hours of trafficking)
A1 Trial 1	Immediately before, then 0, 2 and 3
A1 Trial 2	Immediately before, then 0, 2 and 5.5
A9	Immediately before, then 0, 2 and 6
M27	Immediately before, then 0 and 2

As the amount of salt present on the road surface at any given time is of great importance to the treatment decision process and paramount in obtaining accurate results in such trials as these, it was decided to take this opportunity to undertake a comparison of different methods of residual salt measurement. A desk study of several available methods was carried out and from this, a short list of 3 methods were selected for comparison as part of the trial. The methods selected were:

- The VTI Wet Dust Sampler (WDS)
- The Boschung SOBO-20 meter (SOBO)
- The TRL Wet Wash Method (WW)

Following the trials, further work was carried out in the laboratory to determine how much liquid is absorbed into a typical 14mm UKPTS (with a texture depth within the range of values and representative of the different trial site surface textures) and how much can be recovered using the TRL Wet Wash method of recovery as trialled. This was undertaken for three main purposes:

- To determine how much brine may be absorbed by the UKPTS when spread
- To determine how much of this brine might reasonably be recovered
- To determine how much brine may not be available for anti-icing due to the absorption into UKPTS

Carrying out trials on a live network, in freezing conditions and using an un-trialled technique for UK conditions, presented a risk of ice occurrence. Treatment rates used in the trials were designed to ensure ice formation would not occur. However, as an additional precaution, when freezing conditions were forecast, monitoring of the road surface state was carried out along the full length of the trial sites using the mobile Vaisala DSP310 condition patrol.

Fixed weather stations within each trial site also provided atmospheric and road surface state and temperature information to support the trial.

In considering the results of these trials, recent work in Europe was reviewed and a critique of the methodology and results included in this report. In summary, there are several reasons why the European work is not fully representative of some UK conditions and surfacings, which partly accounts for the differences between the trials carried out for this project, other trials carried out in the UK and the European findings.

Commentary and Conclusions

The following conclusions are based on data from a limited set of trials and should be considered more as a guide to likely behaviours and characteristics rather than being definitive. However, the analysis of the data collected has provided a useful insight into how further work can be focussed to provide guidance on the effectiveness of brine and pre-wet treatments on typical UK road surfacings.

Treatment longevity

- The results of the trials have indicated a difference in the behaviour of residual salt levels after spreading on the HRA and UKPTS surfacing.
- Residual salt levels after brine spreading on HRA would appear to exhibit greater longevity than salt levels after pre-wetted spreading. It would also seem feasible that a similar behaviour would be seen on other dense surfacing, such as the denser types of SMA specified in Europe and Transport Scotland's TS2010 SMA Surface course.
- In the first 2 hours of spreading there is a higher rate of salt loss for the pre-wetted salt in direct comparison to the brine in the UKPTS trials, then similar loss for each treatment type over the next few hours. (However, it must be considered that this direct comparison is between a higher salt spread rate for the pre-wetted salt than the brine). Rainfall affected the HRA trial before the final set of readings could be taken so conclusions cannot be drawn beyond the first two hours.
- Based on the trial results, and discounting existing background levels, it cannot currently be concluded that there would be a significant difference between the percentage salt losses measured for brine and pre-wetted salt on UKPTS if equivalent amounts of salt were spread by each treatment method.
- When background levels are included in the analyses, the percentage losses are smaller for the brine spreading compared to the pre-wetted spreading on UKPTS (but consistent in proportion to the differences in the amount of salt spread). This is as might be expected as the smaller amount of salt spread by the brine will be a smaller fraction of the background level.

The amount of spread salt that remains after a length of time is of interest. However, it is important that the salt is present in sufficient quantity to remain effective in the predicted road and weather conditions. Where the amount of salt remaining is not sufficient to prevent ice formation it can be used to calculate a reduced spread rate for subsequent treatments.

- When considering the longevity of treatments it is important to understand the amount of salt required on the road to be effective in the predicted road and weather conditions. In marginal conditions, the amount of salt required is relatively small, in the region of 2.5g/m² when there has been good distribution through traffic, for example. This is far less than the recommended spread rates that allow for losses.
- Where salt has recrystallised on the road after spreading due to loss of moisture it is more likely to adhere to the road surface and therefore last longer under the action of traffic or wind. Therefore, the road surface state, in terms of moisture, will have a significant effect on the longevity of treatments, from total removal by

rain to minimal removal of recrystallised salt when dry. This must be considered when making any assumptions on longevity of treatment types based on anecdotal or incomplete information, particularly where spreading and measurements have been made in warm, low-humidity conditions.

- Further monitoring of brine treatments under a range of winter conditions, where treatments would normally be carried out, will provide more confidence in the effectiveness and longevity of brine treatments, including where greater amounts of surface moisture were present.

Effect of surfacing

- UKPTS absorbs a significant proportion of brine into the void structure. It is not currently known how much of this would be available for de-icing, for example by the pumping action of tyres bringing the salt back to the surface. Conversely the collection methods (and in particular the Wet Dust Sampler) may be collecting more salt from the voids than would be available for de-icing in normal road conditions. Therefore, it is possible that the amounts of salt measured during these trials may be significantly more or less (dependent on the measurement method and precise conditions relating to the surface) than the "effective" amount of salt present available to prevent the formation of ice for the actual and/or forecast conditions.
- Testing has shown correlation between lower recovery with the Wet Wash method and higher texture depths of UKPTS with recovery rates ranging from 59 to 76% for volumetric patch texture depths ranging from 1.75 to 2.5mm
- Brine travelling through the UKPTS void structure may redistribute the brine from higher to lower areas or allow the brine to drain from the road
- Estimations of residual salt need to account for absorption and brine migration through the void structure to avoid over estimation of residual salt
- HRA does not have the same voids issues as UKPTS and therefore the concept of effective salt held in voids is insignificant on HRA surfaces (and will be insignificant on other surfaces that are similar in this respect).

Comparison of measurement methods

- Comparison of the results from each trial has shown a clear and consistent difference between the residual salt measurements with each method, with WDS measuring higher levels than the Wet Wash and both measuring higher levels than the SOBO.
- It is considered that there are two main reasons for the above: the amount of salt within the void structure of UKPTS type surfaces that can be extracted by the different methods; and the seal between the measuring instrument and the road surface for both UKPTS and HRA when using the WDS and SOBO.
- It is considered that WDS measurements on UKPTS may potentially include some salt from within the void structure that would not normally be available for anti-icing.

Spreading

- Measurements and observations of the brine distribution have shown that redistribution of salt or brine poorly distributed by the spreader cannot be relied on shortly after spreading, particularly where traffic counts are low.
- Brine spraying distribution patterns require to be designed and checked for full coverage without relying on redistribution.
- The trials again demonstrated the importance of proper calibration of spreaders to ensure accurate distribution and rate of delivery which must be competently carried out and audited.
- Traffic levels affecting the loss of salt appear to be lower than anticipated from earlier experiments and trials. The effects of traffic on salt loss are evident after only a small number of vehicle passes i.e. less than 50 vehicles.

Business Case

The decision to adopt brine spreading will need to be based on a sound business case. Some of the key factors to consider are outlined below:

- For brine spreading ~75% of the load carried (by weight) is water.
- For pre-wet spreading ~23% of the load carried (by weight) is water.
- In marginal conditions brine spreading may offer the opportunity to spread at rates that more closely reflect the actual amount of salt required to prevent ice forming rather than the practical limits/losses considered to achieve a minimum evenly distributed amount of salt from conventional pre-wet spreading. The amount of evenly distributed salt required on the road surface in conditions down to -2ºC is between 1.7g/m² for a damp road surface (0.05mm water film) and 3.4g/m² for a wet road surface (0.1mm water film). Recommended pre-wet spread rates for well calibrated spreaders and salt in good condition are 8g/m² (6.15g/m² of NaCl). However, when recommended brine spread rates are being considered, it will be important to account for potential losses on UKPTS or losses/uneven distribution due to wind and vehicle draughts as well as dilution due to humidity, surface wetness or precipitation, in the same way that losses are accounted for in the recommended pre-wet spread rates.
- Brine spreading alone or a combined pre-wet and brine spreading capability would require a significant investment:
    - As more depots (for brine production and spreader location) would be required, because of the more limited range (length of carriageway that can be covered) of brine spreaders, to avoid long runs before a route is started
    - As less than an optimum location of depots will increase the number of spreaders required due to "down time" when travelling to and from a route
    - As brine production and/or storage capacity would need to be increased to match the highest spread rates used in a given time period (worst case scenario)
    - As routes would require to be designed for the highest spread rates

- As spreader capacity (number of spreaders) would need to be matched to worst case scenario
- As an expanded mixed brine and pre-wet capacity, where brine is only used at the lower end of salt requirement (marginal conditions), would be the most likely scenario in which a positive business case might be made
- Examples:
  1. For marginal conditions and assuming brine spread rates could be 50% of pre-wet spread rates due to a reduction in losses when spreading (noting that this study does not support rate reduction for UKPTS to allow for absorption into the voids) then
     a. 20g/m² of brine would need to be spread to equate to 10g/m² of pre-wet.
     b. 2 times the spreading capacity would be required
     c. 7 times the brine production/storage capacity would be required for marginal conditions alone
  2. Assuming like for like spread rates (i.e. no salt saving with brine spreading then:
     a. 40g/m² of brine would need to be spread to equate to 10g/m² of pre-wet.
     b. 4 times the spreading capacity would be required
     c. 13 times the brine production/storage capacity would be required for marginal conditions alone

Environmental Issues

- Additional energy and fuel used, increasing carbon footprint, for:
  - Brine production
  - Transporting/spreading brine
- Use of potable water in brine production (and consequent energy and environmental issues)
- Brine - Reduction in "wasted" salt entering receiving waters and damaging flora and fauna when compared to pre-wet
- Brine – less salt to be transported to depots reducing fuel used and carbon footprint

Recommendations

The result of these trials have provided some useful information on the residual salt behaviour after spreading brine and pre-wetted salt on UKPTS and HRA surfacing. However, a full picture of losses with time for different spread rates in different conditions over a winter season cannot be extrapolated from the limited data collected so far. This work and work recently reported in Europe indicate that there is potential for using brine only treatments in certain circumstances. Therefore, further work is warranted to determine whether brine-spreading capabilities provide operational advantages and economies. This work would further explore the range of conditions these advantages and economies may apply to, what level of treatments may be needed and what the initial and ongoing costs versus savings might be. To proceed to this point, where specific recommendations and guidance can be developed, a range of trials and experiments for different UK conditions and UK surfacings would need to be carried out. This would build a sufficiently large dataset with repeat results under similar conditions necessary to provide the necessary confidence for operational level recommendations. Furthermore, in order to be able to make reasonable comparisons between the brine and pre-wet technologies, both systems would need to be reviewed at the same time, in broadly the same conditions and on the same surfacing types. The trials would require to be carried out over a winter season and would need to allow for collection of residual salt data at regular intervals. As this is currently highly disruptive due to requirements for road closures and diversions it is recommended that a study into minimising disruption while retaining the ability to collect meaningful results is undertaken.

The outcome from this further work should ultimately aim to provide information to support the following topics:

- Guidance on treatment rates for brine spreading
- Guidance on effectiveness of treatment methods for different conditions
- Guidance on developing economic evaluations and business cases considering both brine only and pre-wet spreading methods
- Guidance on risks and their mitigation when adopting brine spreading capabilities

1 Background

For most non-extreme road surface ice forecasts, many local authorities in the UK presently spread dry salt while the trunks roads in Scotland and England are mainly treated with pre-wetted salt. Recent National Guidance for the UK has noted the advantages in using pre-wet salting methods over dry salting, while brine spreading has not been considered as a practical and economic alternative in most situations. Local authorities that are able to make a robust business case and with available funding have been moving to pre-wet spreading technology. The National Guidance is principally based on research and consultancy tasks carried out for the NWSRG, Highways Agency (HA) and Transport Scotland (TS). It includes review of research papers, projects or trials worldwide and the experience of expert practitioners. TS and HA winter service specifications and policy also reflect the above research and consultancy work. This information was also used in the development of UK National Guidance.

For winter service treatments, using sodium chloride to prevent ice forming on road surfaces, roads authorities in Europe and North America have increased the use of liquid only (brine) spreading, along with continued use of the more common dry and pre-wet treatment options. Considering the use of brine on their network, work was carried out for the Highways Agency on the efficacy of using brine on the HA network in 2009. The purpose of this was to establish both effectiveness of brine treatments and a business case review to determine the likely costs compared to the benefits and pre-wet treatments. Recent studies in Europe have focussed on the durability of liquid brine only spreading compared to pre-wetted salt. They concluded that for precautionary salt treatments, especially on dry and moist surfaces, that sodium chloride brine only spreading requires less salt and a greater proportion stays longer on the surface.

2 Introduction

In the light of the more recent work in Europe, Transport Scotland, working with the Highways Agency, now Highways England at the time of report publishing, and the National Winter Service Research Group (NWSRG), have promoted an initiative to further investigate the potential merit of using brine on the Scottish and English trunk road networks. The principal aim of the work was to assess the effectiveness and longevity of precautionary treatments using sodium chloride brine versus pre-wetted salt for UK climatic conditions and on road surfacing types representative of the wider UK network.

The NWSRG is responsible for overseeing and co-ordinating winter service research and providing guidance relevant for all roads in the UK. Transport Scotland and the Society of Chief Officers of Transportation in Scotland (SCOTS) as well as Highways England (formerly Highways Agency) are represented on the NWSRG.

The NWSRG, through TRL Ltd as their research contractor, have co-ordinated trials on three sites across the UK this winter season to compare the longevity (or more correctly the rate of loss) of brine and pre-wet salt spread on trunk roads.

3 Trial site details

The main surfacing types found on Scottish and English trunk roads are Hot Rolled Asphalt (HRA) and UK specification Proprietary Thin Surfacing or UKPTS (similar to an SMA but with a higher void content and less binder to deliver texture requirements) with UKPTS becoming the material predominantly used for new roads and resurfacing schemes. Therefore, the UKPTS that is commonly used in the UK has a different specification to that generally used for SMA in Europe. The main difference affecting winter service being that UKPTS has a much higher interconnected void content than SMA and HRA allowing absorption of brine into the voids. Scotland has more recently surfaced some of their network with a type of SMA similar to that typically specified in Germany, however this was not trialled in this experiment.

Trials were carried out at three sites to compare the performance of brine and pre-wetted salt for a range of road surfacing types and trial conditions. Transport Scotland selected two trial sites, the A1 at East Linton (near Dunbar) with UKPTS surfacing and the A9 at Aviemore with HRA surfacing. The HA provided a site on the M27 at Parkgate with UKPTS surfacing.

The trial site information is summarised in Table 1.

Table 1. Trial site information

Test site	Surface material	Surface specifications	Road type	Mean texture depth (SMTD)
A1	UKPTS	14mm Masterphalt P	2 lane dual	0.98
A9	HRA		Single lane (60mph speed limit)	1.48
M27	UKPTS	10mm Masterpave	3 lane motorway	1.60

4 Spreaders used and their characteristics

Schmidt Stratos combi spreaders were used to spread both the brine only and pre-wetted salt treatments for each trial. The brine treatment was applied through nozzles mounted on the rear of each spreader, as shown in Figure 1 of the spreader used for the trials on the A1.

A separate vehicle was used for each trial site. These were supplied by Amey (A1 trial site), BEAR Scotland (A9 trial site) and EM Highway Services (M27 trial site).

Before the trials all spreaders were calibrated, including monitoring the discharge rate and a visual check of the brine and pre-wetted salt distribution. For liquid only spreading, the spreaders routinely spread and are calibrated for Potassium Acetate. Before commencing the trials, a Schmidt engineer calibrated each spreader for sodium chloride brine spreading.

Figure 1. Brine spreading from the combi spreader

5 De-icing chemicals

The pre-wetted salt for each trial comprised 6.3mm dry rock salt and brine in the ratio 70:30 by weight.

The brine used for the trials was supplied from a saturator at each of the trial depots and the concentration measured before each trial using a refractometer. Samples of brine were taken and the salt concentration was measured to be between 19 and 23 per cent as shown in Table 2.

The 6.3mm salt used for the A1 trials was supplied by Cleveland Potash obtained from a stockpile at the Amey Bilston Glen Depot. The 6.3mm salt used for the A9 trial was supplied by Irish Salt Sales from a stockpile at the BEAR Kingussie depot. The 6.3mm salt used for the M27 trial was Thawrox 6 supplied by Compass Minerals from a stockpile at the EM Highways Park Gate depot.

Samples were taken and the moisture content measured. The salt types and moisture contents are shown in Table 2.

Table 2. Salt moisture content and brine concentration

Trial Location	Salt Type	Salt moisture content (%)	Brine concentration (%)
A1	6.3mm	2.0	19
A9	6.3mm	2.4	23
M27	6.3mm	2.6	20

6 Trial Methodology

6.1 Spreading over the trial site

Each trial site was split into two areas for the brine and pre-wetted salt spreading. A schematic diagram of the site and trial areas is given in Figure 2.

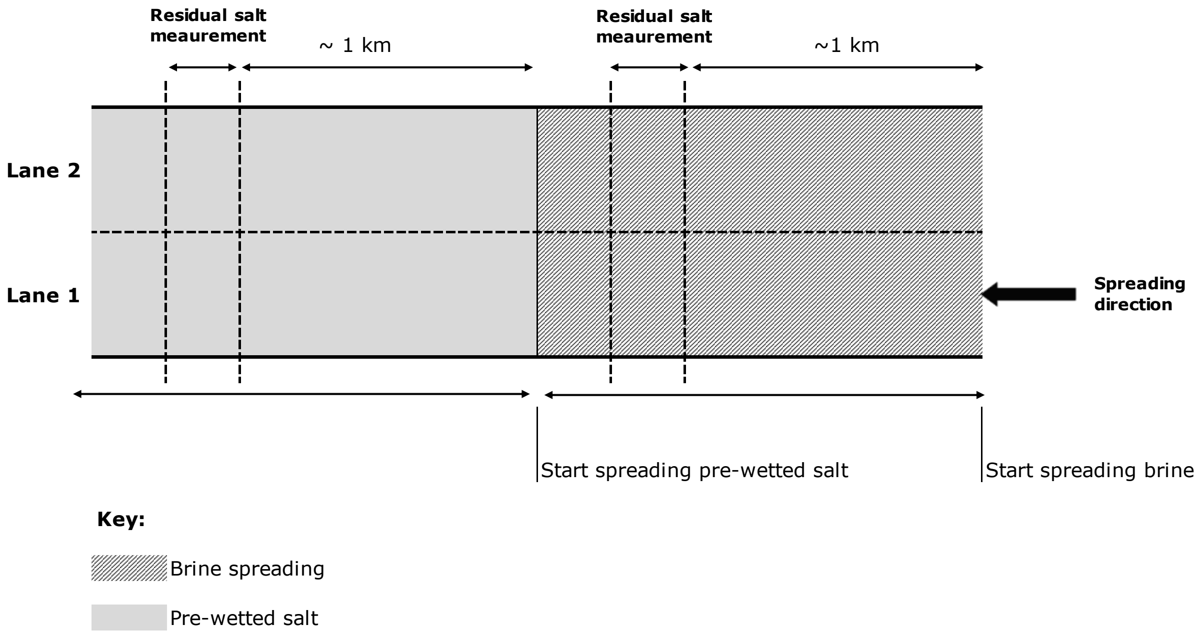

Figure 2. Locations of brine and pre-wetted salt spreading and measurement areas within each trial site

The entire trial site length was subject to a full carriageway closure at the start of each trial. Once the closure was in place, the trial team entered the site and the positions where brine and pre-wetted salt were to be collected were identified and marked out on the carriageway. Reflective signs were placed at the road side to indicate the start and stop positions for spreading.

For each trial the spreader was operated by personnel from the Operating Company/Service Provider and spreading was carried out with the trial site closed to traffic.

The details of the spread rates and widths used for each trial are summarised in Table 3.

Table 3. Spreading characteristics for each trial

Trial Location	Spreading speed (mph)	Brine		Pre-wetted salt	
		Spread rate (g/m^2)	Spread width (m)	Spread rate (g/m^2)	Spread width (m)
A1 Trial 1	30	20	7	10	8
A1 Trial 2	30	40	7	20	8
A9	30	20	7	10	6
M27	40	20	7	10	12.8

For Trial 1 on the A1 (2 lane dual), brine and pre-wetted spreading was carried out from lane 1 while spreading asymmetrically to two lanes.

For the trial on the A9 (on a single carriageway road0 spreading was from the southbound carriageway across both lanes.

For Trial 2 on the A1, pre-wetted spreading at 20g/m² was required on the network during the trial period and the pre-wetted spread rate on the trial site was required to be at the same rate. The brine spread rate was increased to 40g/m² to ensure a representative comparison. For this trial, the brine and pre-wetted salt were spread in two passes, each of half the total spread rate, the first pass in lane 1 and the second pass driving in the opposite direction in lane 2.

For the trial on the M27 (3 lane motorway) brine spreading was carried out from lane 1 across lane 1 and lane 2. Pre-wetted salt was spread symmetrically from lane 2 across all lanes of the carriageway.

6.2 Residual salt measurements

As the amount of salt present on the road surface at any given time is of paramount importance, particularly in such trials as these, it was decided to take this opportunity to make a comparison between different methods of residual salt measurement. A desk study of several available methods was carried out and from this, a short list of 3 methods were selected for comparison as part of the trial. The methods selected were:

- The VTI Wet Dust Sampler (WDS)
- The Boschung SOBO-20 meter (SOBO)
- The TRL Wet Wash Method (WW)

The results of the desk study are contained in Appendix A.

The Wet Wash and SOBO measurements were carried out by TRL personnel, with the SOBO devices supplied by Boschung and Lincolnshire County Council. The WDS measurements were carried out by personnel from VTI.

For each trial measurements of residual salt were carried out immediately before and after spreading, and then after various lengths of trafficking time as shown in Table 4.

Table 4. Residual salt measurement times

Trial Location	Residual salt measurement times (hours of trafficking)
A1 Trial 1	Immediately before spreading, then 0, 2 and 3
A1 Trial 2	Immediately before spreading, then 0, 2 and 5.5
A9	Immediately before spreading, then 0, 2 and 6
M27	Immediately before spreading, then 0 and 2

For each trial, measurement of residual salt was carried out at the locations shown in Figure 3.

At each location (Strip 1 to 8), measurements were made using a combination of SOBO, Wet Wash and WDS as summarised for each trial in in Appendix B.

Table 5. Summary of methods used at each measurement location

	Measurement location	Measurements made in each of wheel tracks and centre of lane as shown in Figure 4 and Appendix B:	
		A1	A9 and M27
Background	Strip 1	3 x SOBO 1 x Wet Wash 1 x WDS (6 samples per measurement)	3 x SOBO 1 x Wet Wash
Background	Strip 5	3 x SOBO	3 x SOBO
Immediately after spreading	Strip 2	3 x SOBO 1 x Wet Wash 1 x WDS (6 samples per measurement)	3 x SOBO 1 x Wet Wash
Immediately after spreading	Strip 6	3 x SOBO	3 x SOBO 1 x Wet Wash
After 1st trafficking period	Strip 3	3 x SOBO 1 x Wet Wash 1 x WDS (6 samples per measurement)	3 x SOBO 1 x Wet Wash
After 1st trafficking period	Strip 7	3 x SOBO	3 x SOBO 1 x Wet Wash

After 2nd trafficking period	Strip 4	3 x SOBO 1 x Wet Wash 1 x WDS (6 samples per measurement)	3 x SOBO 1 x Wet Wash
	Strip 8	3 x SOBO	3 x SOBO 1 x Wet Wash

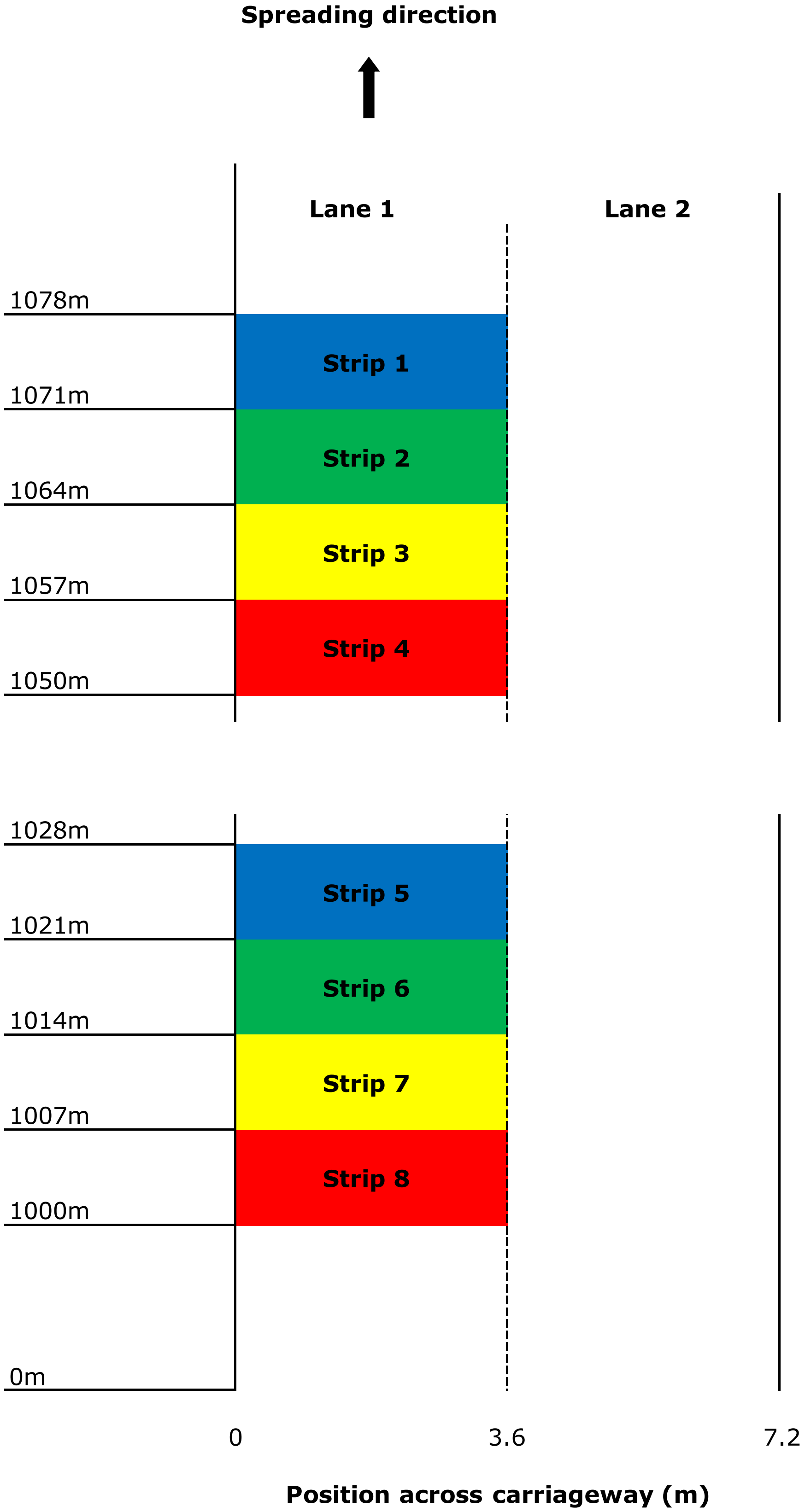

Figure 3. Layout of collection area relative to the start of spreading for each spreading area

Measurements were made in each wheel track and the centre of lane 1 as outlined in Appendix B for each trial and shown in Figure 4 (With WDS omitted on the A9 and M27 trials)

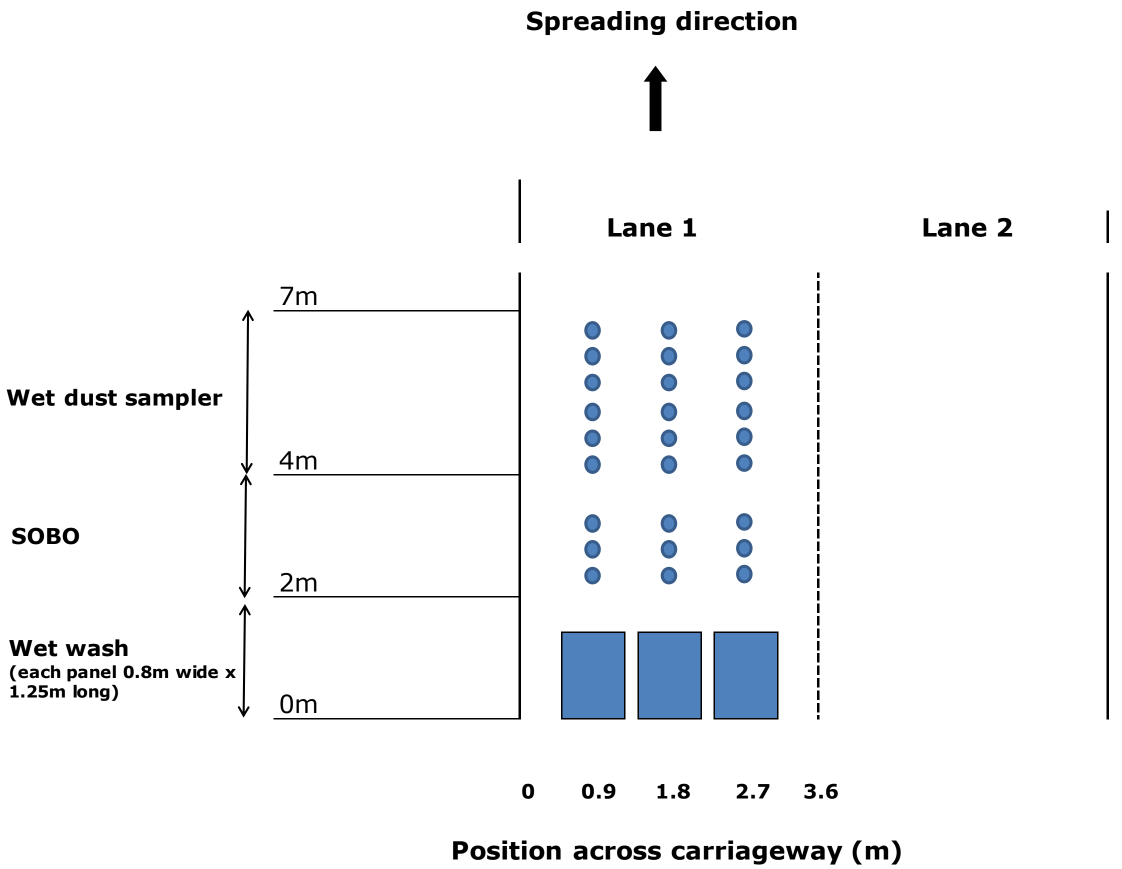

Figure 4. Position of measurements within lane 1

6.3 Monitoring of road surface state

Carrying out trials on a live network, in freezing conditions and using an un-trialled technique for UK conditions, presented a risk of ice occurrence. Treatment rates used in the trials were designed to ensure ice formation would not occur. However, as an additional precaution, when freezing conditions were forecast, monitoring of the road surface state was carried out along the full length of the trial sites using the mobile Vaisala DSP310 condition patrol.

Prior to the trial, and also before the trial site was opened to trafficking after each set of measurements, monitoring was carried out of all lanes of the trial site by Operating Company staff using the condition patrol. During the trafficking periods, measurements were carried out within each lane at intervals of approximately 60 minutes.

Continuous real time monitoring of the surface state would identify any need for retreatment or road closure if ice is detected.

The fixed weather stations within each trial site also provided atmospheric and road surface state and temperature information to support the trial.

7 Weather conditions

7.1 A1 Trial 1 24/25th February

Time	RST (°C)	Surface state	Air T (°C)	Dew T (°C)	Relative Humidity (%)	Precipitation	Wind Sp. (m/s)	Wind Dir.
21:30 (Background measurement)	-0.2	trace	1.8	-1.9	76	none	4.1	SW
23:00 (Immediately after spreading)	0.9	trace	3	-1.1	75	none	3.2	SW
02:30 (1st trafficking period)	0	trace	2	-0.9	81	none	1.9	SW
04:40 (2nd Trafficking period)	-0.3	trace	1.7	-0.5	85	none	1	SW

7.2 A1 Trial 2 25/26th February

Time	RST (°C)	Surface state	Air T (°C)	Dew T (°C)	Relative Humidity (%)	Precipitation	Wind Sp. (m/s)	Wind Dir.
20:00 (Background measurement)	1	moist	2.2	-1.3	77	none	4.9	SW
21:30 (Immediately after spreading)	0.5	moist	2.3	-1.5	76	none	3.7	SW
01:00 (1st trafficking period)	-0.4	trace	2.1	-1.3	78	none	5	SW
05:30 (2nd Trafficking period)	-0.5	trace	2.7	-0.7	79	none	5.4	SW

7.3 A9 5th March

Time	RST (°C)	Surface state	Air T (°C)	Dew T (°C)	Relative Humidity (%)	Precipi tation	Wind Sp. (m/s)	Wind Dir.
20:00 (Background measurement)	5.4	moist	7	3.9	81	none	0.5	SSW
21:00 (Immediately after spreading)	4	moist	5.7	3.6	86	none	1	SSW
00:00 (1st trafficking period)	1.3	moist	3.3	1.7	90	none	0.2	SSW
05:00 (2nd Trafficking period)	4	wtrtd	6.1	5.3	95	Light	2.2	SSW

7.4 M27 18th March

Time	RST (°C)	Surface state	Air T (°C)	Dew T (°C)	Relative Humidity (%)	Precipi tation	Wind Sp. (m/s)	Wind Dir.
23:00 (Background measurement)	4.9	dry	4	0.9	80	none	0.2	N
00:00 (Immediately after spreading)	4.3	dry	3.6	1.3	85	none	0	N
03:00 (1st trafficking period)	6	dry	5.7	2.3	79	none	0.3	N

8 Traffic levels during trials

Traffic data for the trial in Scotland on the A1 and A9 was collected from automatic counters located on the trial site. For the trial on the M27 a manual traffic count was taken by TRL staff from the motorway over-bridge at Junction 9.

The numbers of light and heavy vehicles within each lane during the two trials are shown in Table 6. Light vehicles (LVs) are cars, taxis, vans etc. and heavy vehicles (HVs) are all other goods vehicles, buses and coaches. Motorcycles are not included.

Table 6. Number of light and heavy vehicles during trafficking period

Trial	Hours of trafficking	Lane 1		
		LV	HV	Total
A1 - Trial 1	2	14	5	19
	3	19	8	27
A1 - Trial 2	2	53	10	63
	5.5	95	31	126
A9	2	39	12	51
	6	91	53	144
M27	2	106	58	164

9 Results

9.1 Comparison of brine and pre-wetted

A comparison of the residual salt (expressed in g/m² of sodium chloride) for brine and pre-wetted spreading are shown for:

A1 Trial 1: Figure 5 to Figure 7 for Wet Wash, WDS and SOBO respectively

A1 Trial 2: Figure 8 to Figure 10 for Wet Wash, WDS and SOBO respectively

A9: Figure 11 to Figure 12 for Wet Wash and SOBO respectively

M27: Figure 13 to Figure 14 for Wet Wash and SOBO respectively

9.1.1 A1 Trial 1

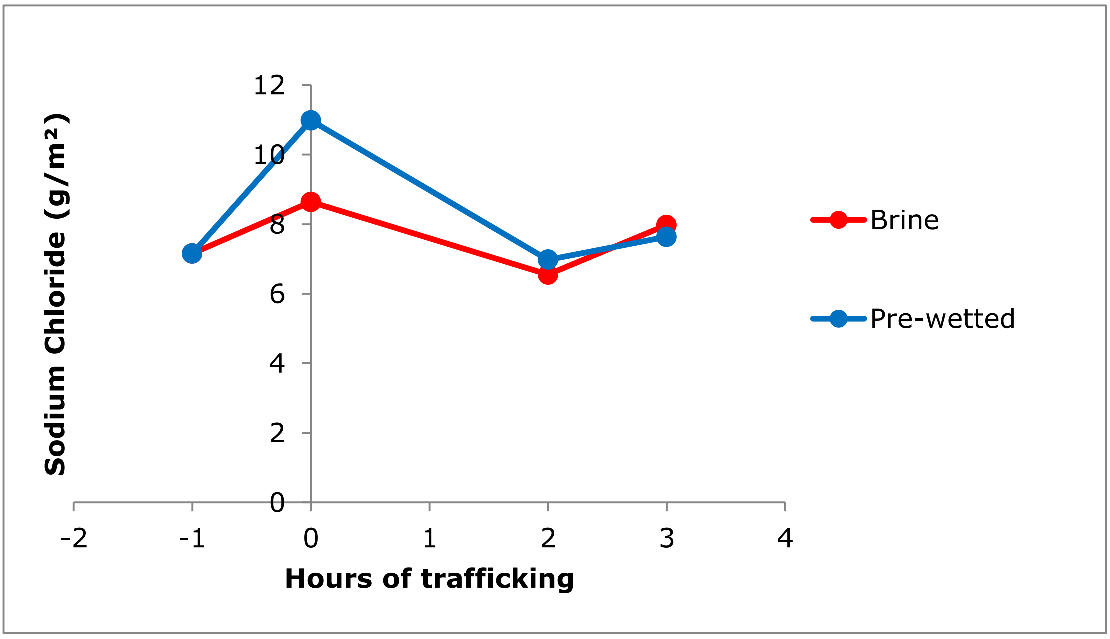

Figure 5. A1 Trial 1 residual salt variation with trafficking, Wet Wash average for Lane 1

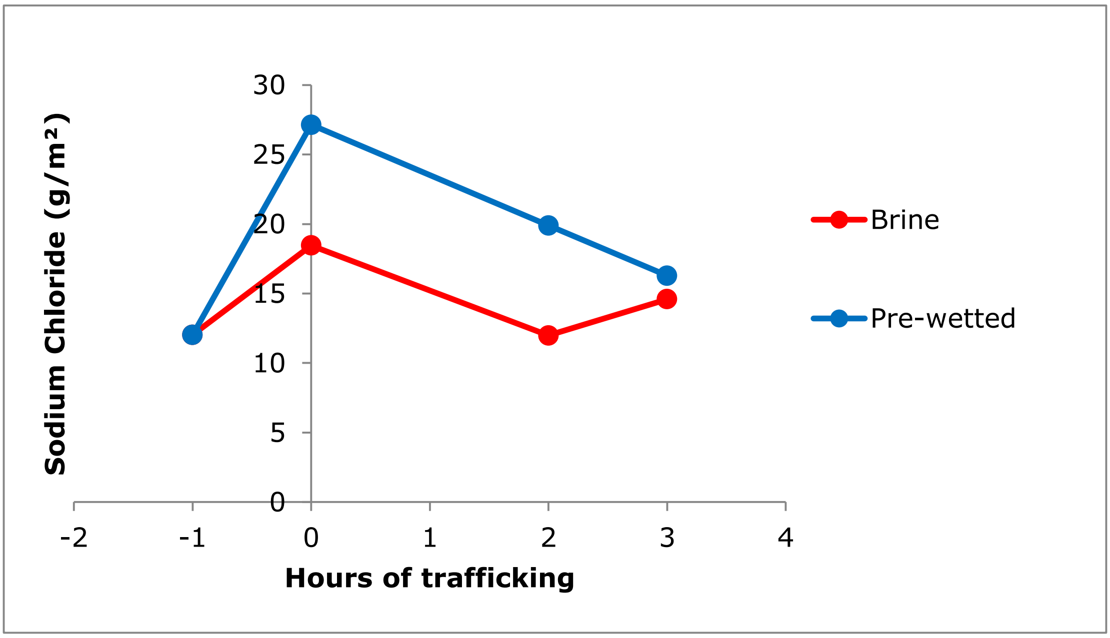

Figure 6. A1 Trial 1 residual salt variation with trafficking, WDS average for Lane 1

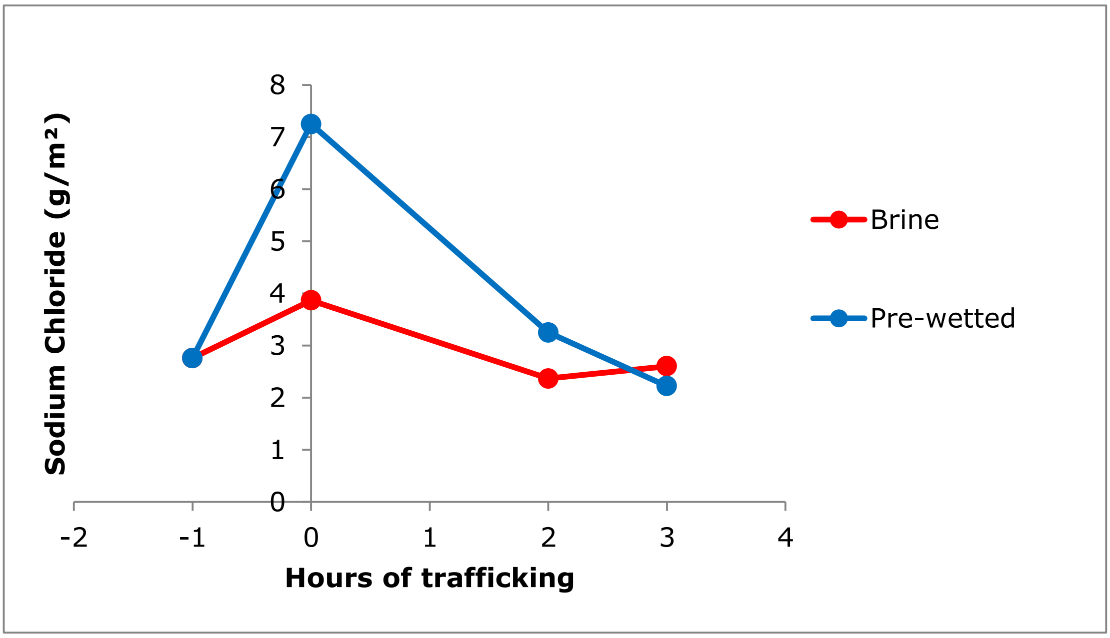

Figure 7. A1 Trial 1 residual salt variation with trafficking, SOBO average for Lane 1

9.1.2 A1 Trial 2

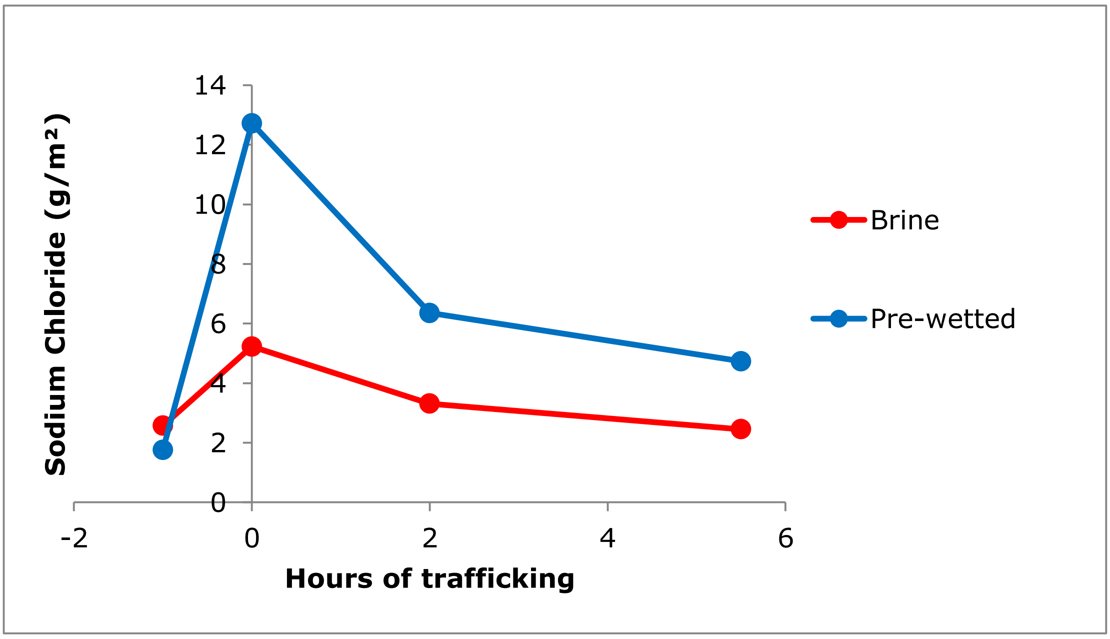

Figure 8. A1 Trial 2 residual salt variation with trafficking, Wet Wash average for Lane 1

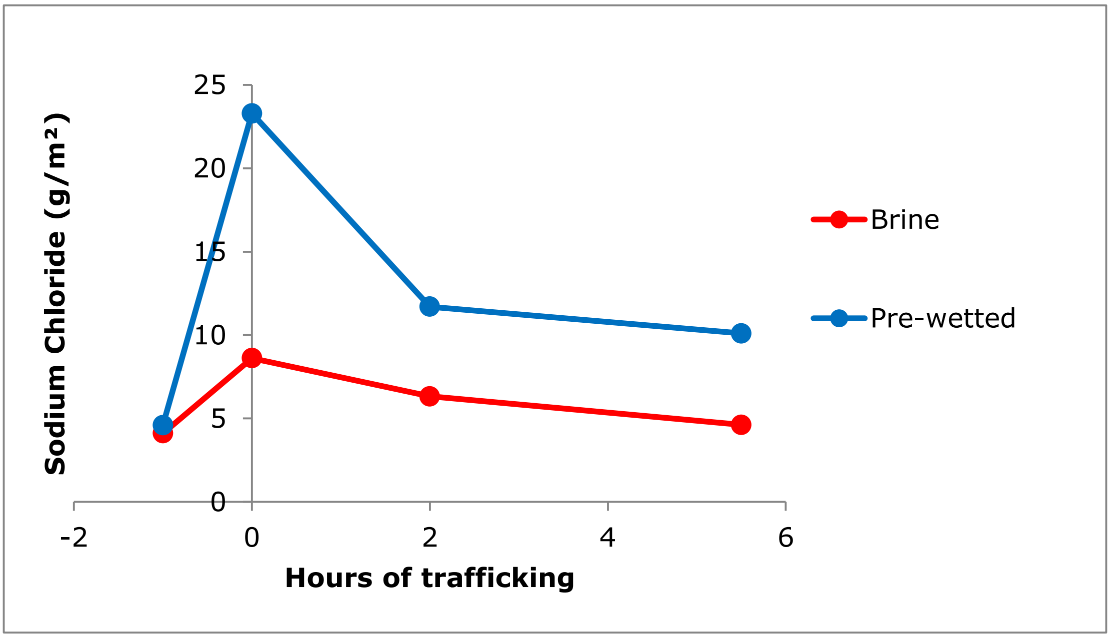

Figure 9. A1 Trial 2 residual salt variation with trafficking, WDS average for Lane 1

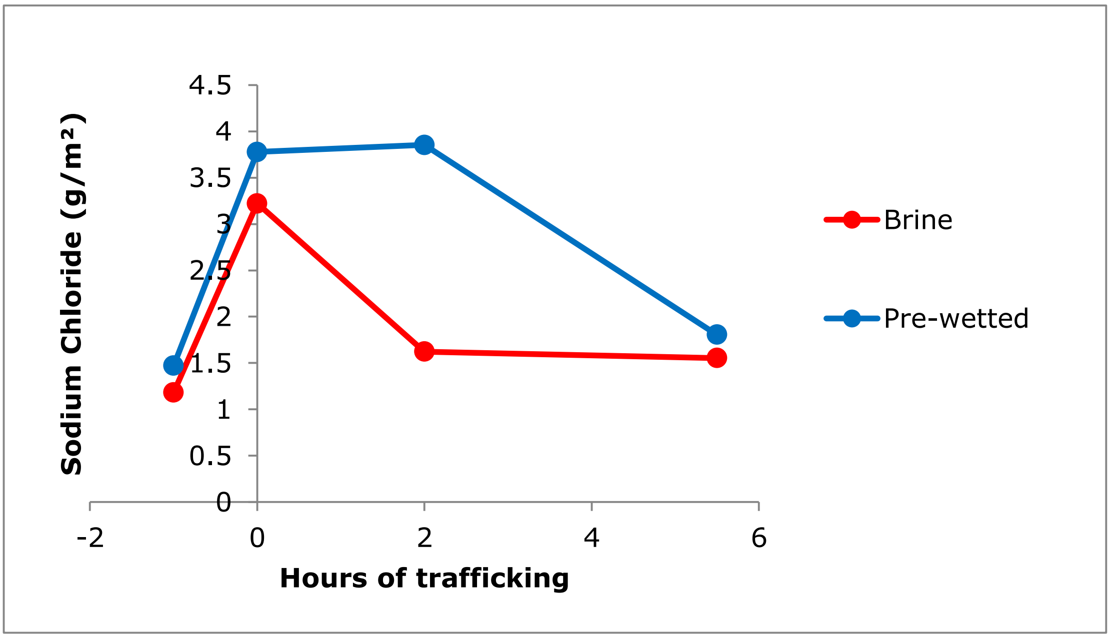

Figure 10. A1 Trial 2 residual salt variation with trafficking, SOBO average for Lane 1

9.1.3 A9

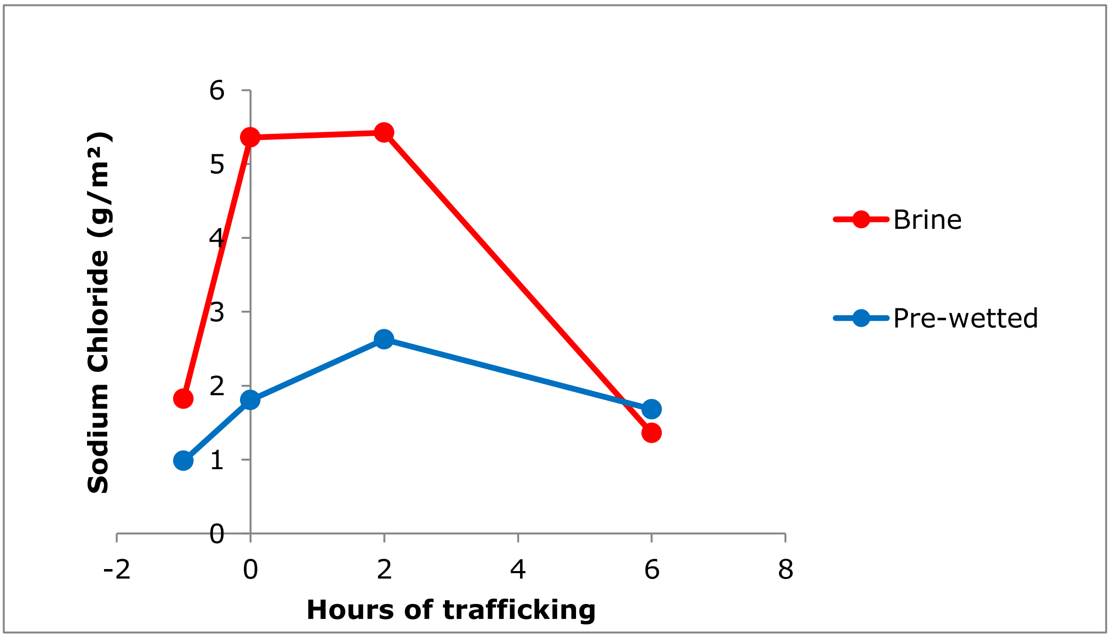

Figure 11. A9 residual salt variation with trafficking, Wet Wash average for Lane 1

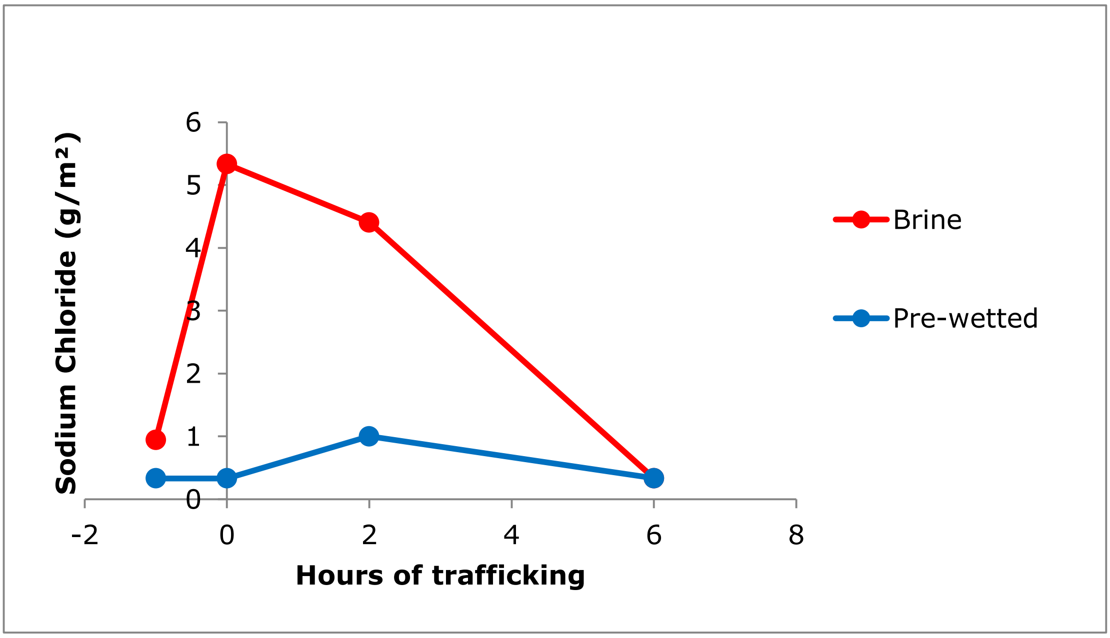

Figure 12. A9 residual salt variation with trafficking, SOBO average for Lane 1

9.1.4 M27

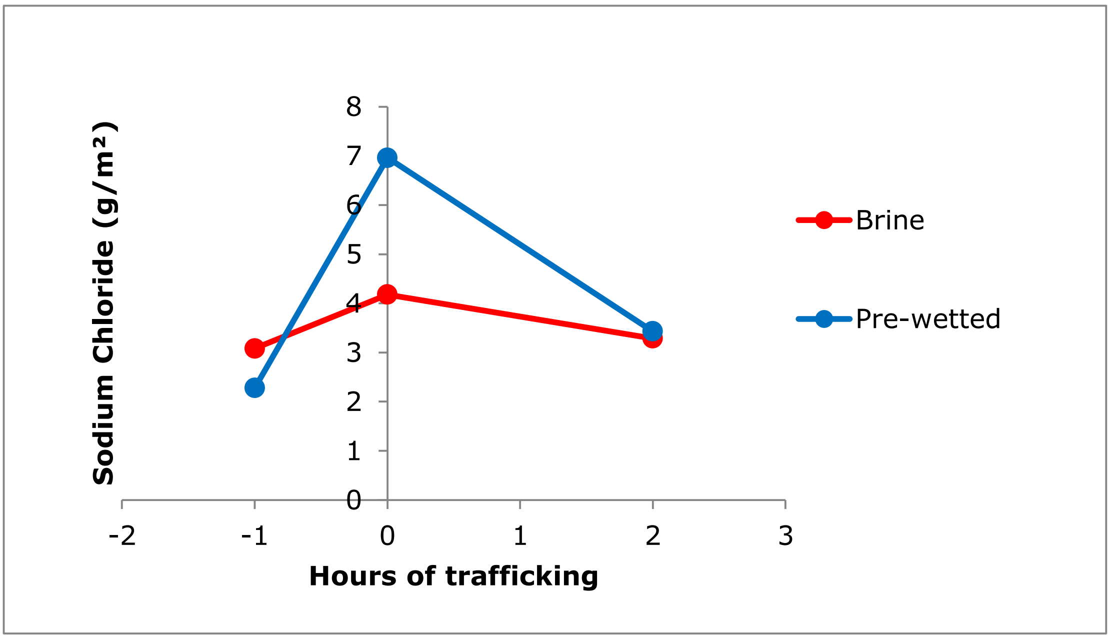

Figure 13. M27 residual salt variation with trafficking, Wet Wash average for Lane 1

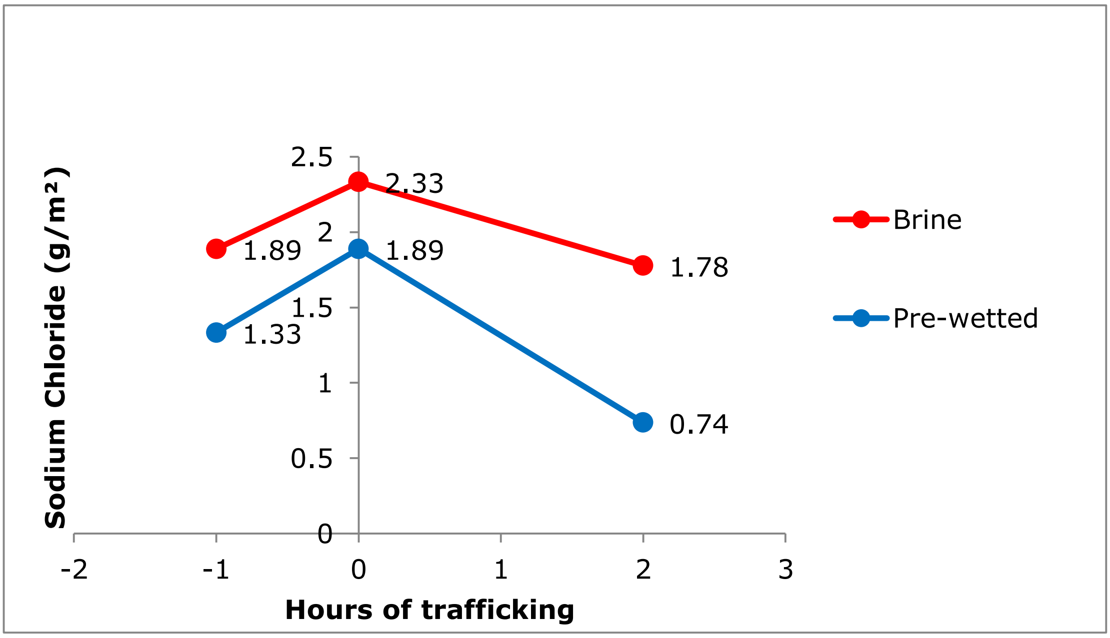

Figure 14. M27 residual salt variation with trafficking, SOBO average for Lane 1

9.2 Salt loss after trafficking

The percentage of the salt spread that could not be collected after trafficking has been calculated by comparing the amount of salt measured after trafficking with the amount measured immediately after spreading.

The losses have been measured for both the case where the background salt level before spreading is included and where the background level has been subtracted, shown in Table 7 to Table 12.

For the Wet Wash measurement method, plots of salt loss against the total equivalent number of LV are shown for trials on the UKPTS in Figure 15 and Figure 16 for brine and pre-wetted salt respectively. The equivalent LV count has been calculated assuming 1 HV is equivalent to 5 LV passes.

As an example, if a background level of 2g/m² is measured before spreading, 7g/m² immediately after spreading and 5g/m² after 2 hours of trafficking:

- The loss calculation where background is included, expressed as percentage loss = (7-5)/7 x 100 = 28.6% loss
- The loss calculation where background is subtracted, expressed as percentage loss = (7-2) – (5-2) / (7-2) x 100 = 40% loss

9.2.1 Wet Wash measurements

Table 7. Percentage of residual salt lost after trafficking, background levels included

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	18	38	32	35	24	36
	3	59	3	33	15	27	8	30
A1-Trial 2	2	103	44	43	10	61	37	50
	5.5	250	59	62	33	64	53	63
A9	2	99	-11	-33	12	-83	-1	-46
	6	356	71	18	80	-26	75	7
M27	2	396	18	59	25	36	21	51

Table 8. Percentage of residual salt lost after trafficking, background levels subtracted

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	400	122	92	82	141	105
	3	59	57	106	42	63	45	88
A1-Trial 2	2	103	81	52	28	67	72	58
	5.5	250	108	75	88	70	104	73
A9	2	99	-17	-65	18	-292	-2	-100
	6	356	109	34	119	-90	113	15
M27	2	396	66	79	103	66	81	75

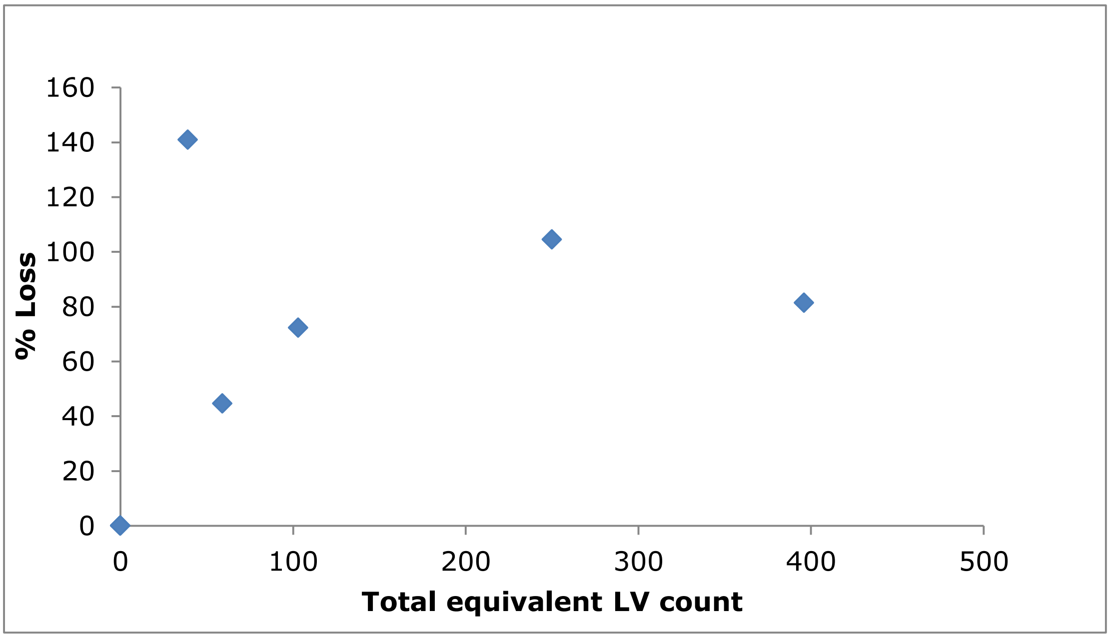

Figure 15. Salt loss (background levels subtracted) against the total equivalent number of LV for brine spreading on UKPTS

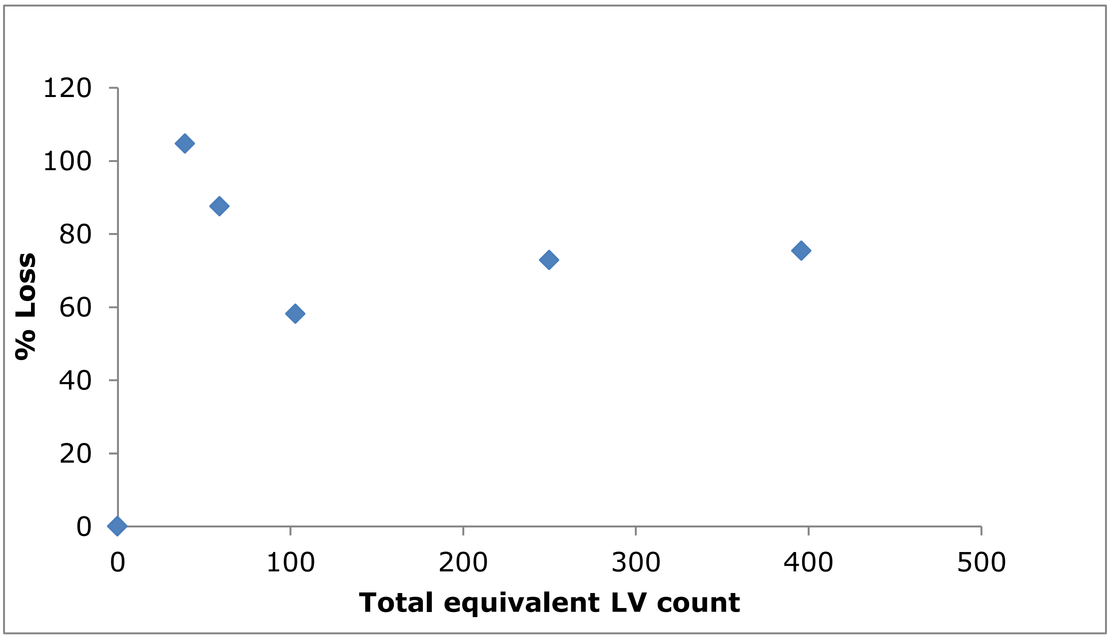

Figure 16. Salt loss (background levels subtracted) against the total equivalent number of LV for pre-wetted spreading on UKPTS

9.2.2 Wet Dust Sampler measurements

Table 9. Percentage of residual salt lost after trafficking, background levels included

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	35	40	35	-49	35	27
	3	59	25	60	13	-78	21	40
A1-Trial 2	2	103	29	58	20	35	27	50
	5.5	250	51	56	37	57	46	57

Table 10. Percentage of residual salt lost after trafficking, background levels subtracted

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	106	60	92	-	101	48
	3	59	76	92	35	-	60	72
A1-Trial 2	2	103	52	74	47	41	51	62
	5.5	250	90	72	85	68	89	71

9.2.3 SOBO measurements

Table 11. Percentage of residual salt lost after trafficking, background levels included

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	46	60	22	40	39	55
	3	59	36	72	25	60	33	69
A1-Trial 2	2	103	57	-7	31	5	50	-2
	5.5	250	67	46	11	61	52	52
A9	2	99	18	-	16	-	17	-
	6	356	92	-	96	-	94	-
M27	2	396	20	89	26	92	24	61

Table 12. Percentage of residual salt lost after trafficking, background levels subtracted

Trial	Hours of traffic	Equi-valent total LV count	Percentage loss (%)					
			Wheel tracks		Centre of lane		Total Lane Average	
			Brine	Pre-wet	Brine	Pre-wet	Brine	Pre-wet
A1-Trial 1	2	39	155	92	83	78	135	89
	3	59	122	111	94	117	114	112
A1-Trial 2	2	103	77	-10	83	9	78	-3
	5.5	250	92	70	29	114	82	86
A9	2	99	22	-	20	-	21	-
	6	356	109	-	119	-	114	-
M27	2	396	100	267	140	119	125	208

9.3 Comments on each trial

A1 Trial 1

Trial 1 on the A1 was carried out in dry conditions and no precipitation, with RST between 0 and -2.4ºC and relative humidity increasing from 75% at the time of spreading to between 85 and 90% at the time of the final measurements.

During the afternoon immediately preceding the trial (time approx. 15.00) there had been a precautionary pre-wetted treatment carried out at a spread rate of 20g/m². As a result of this treatment there was a significant background residual salt level measured on the trial site before spreading of 7g/m² (Wet Wash) / 12g/m² (WDS).

Brine spreading was carried out at 20g/m², which would have resulted in a salt (sodium chloride) spread rate of 3.8g/m². Pre-wetted spreading was carried out at 10g/m² which would have resulted in a salt spread rate of 6.8g/m² (factoring in a dry salt purity of 90%)

The Wet Wash measurements showed an increase of 3.73g/m² in the centre of the lane immediately after brine spreading, in good agreement with the target amount. However, there was a smaller increase measured in the left and right wheel tracks of 0.34 and 0.95g/m² respectively, significantly less than the target amount. The WDS results showed an increase in the centre of the lane of 7.38g/m², and increases of 5.3 and 6.63g/m² in the left and right wheel track respectively, all greater than the target amount. Both measurement methods showed greater salt levels in the centre of the lane than the wheel tracks after spreading.

The plots of sodium chloride level against time of trafficking presented in Figure 5 to Figure 7 for each measurement method clearly show the higher sodium chloride levels for pre-wetted salt immediately after spreading. This would be expected as a result of the higher amount of sodium chloride being spread as compared to the brine spreading. After trafficking, the salt levels on the brine and pre-wetted salt trial sections decreased and the measured values for each section converged. After 3 hours trafficking, an average residual salt level of 7.98g/m² was measured by the wet wash method for the brine section as compared to 7.63g/m² on the pre-wetted section. The WDS measured a residual salt level of 14.59g/m² on the brine section and 16.28g/m² on the pre-wetted section.

All the measurement methods showed an increase in the residual salt levels on the brine section between 2 and 3 hours after spreading. The wet wash method also showed a similar increase on the pre-wetted section. This unexpected result may be explained by variation in the background levels or brine redistribution. It was also observed that the humidity increased during the final period of trafficking and that the dew point temperature and RST converged. This would have encouraged the dissolution of recrystallized salt, which potentially could have brought more of the background salt to the surface, although this cannot be stated with certainty without further observations of a similar effect.

A1 Trial 2

Trial 2 on the A1 was carried out in dry conditions and no precipitation, with RST between 1 and -2.5ºC and relative humidity around 80% over the course of the night.

A pre-wetted treatment of 20g/m² was carried out on the network on the evening of the trial. The trial section was left untreated and there was rainfall earlier in the day. As a result background residual salt levels were lower than for Trial 1, measured at 2.57g/m² and 4.11g/m² on the brine trial section by the Wet Wash and WDS respectively. Background levels on the pre-wetted section were 1.75 and 4.6g/m² as measured by the Wet Wash and WDS respectively.

Brine spreading was carried out at 40g/m², which would have resulted in a salt (sodium chloride) spread rate of 7.6g/m². Pre-wetted spreading was carried out at 20g/m² which would have resulted in a salt spread rate of 13.6g/m². To achieve the required spread rate, the brine was spread in 2 passes each at 20g/m². Firstly, the spreader drove in Lane 1 (the lane where the measurements were made) and then returned in the opposite direction spreading from lane 2. The pre-wetted salt was spread in the same manner with each pass spreading at 10g/m².

The Wet Wash measurements showed an increase of 1.32g/m² in the centre of the lane immediately after brine spreading, and increases in the left and right wheel tracks of 0.74 and 5.90g/m² respectively. The WDS results showed an increase in the centre of the lane of 3.7g/m², and increases of 2.35 and 7.45g/m² in the left and right wheel track respectively. Both measurement methods showed significantly greater salt levels in the right hand wheel track after spreading. The amount of residual salt measured was also less than the target amount across the lane.

The plots of sodium chloride level against time of trafficking presented in Figure 8 to Figure 10 for each measurement method show significantly higher sodium chloride levels for pre-wetted salt immediately after spreading, with the difference in salt levels between the brine and pre-wetted sections decreasing with trafficking. An average residual salt level of 3.31 and 2.45g/m² was measured on the brine section after 2 and 5.5 hours trafficking respectively by the Wet Wash method, as compared to 6.35 and 4.73g/m² on the pre-wetted section. The WDS measured a residual salt level of 6.32 and 4.62g/m² on the brine section after 2 and 5.5 hours trafficking respectively, compared to 11.70 and 10.10g/m² on the pre-wetted section.

At the end of the night of Trial 2 the salt distribution was measured across lane 1 using the SOBO. It was clear from this profile as shown in Figure 17 that there was significantly more residual salt between the right wheel track and the centre of the lane. The area of the carriageway in this region also appeared visibly damper than the other areas of the lane. The measurements immediately after spreading had also indicated significantly more salt in the right had wheel track. It would appear that the brine was not evenly distributed across the lane, and this may have been a consequence of the spreading of the brine from lane 2 to lane 1 in the second pass when spreading. The brine was spread to the adjacent lane in discrete lines from the nozzles, rather than the even spread from the fan spray when spreading in the lane the spreader is driving in. The observed distribution indicates the brine was not significantly redistributed across the dry road surface after trafficking.

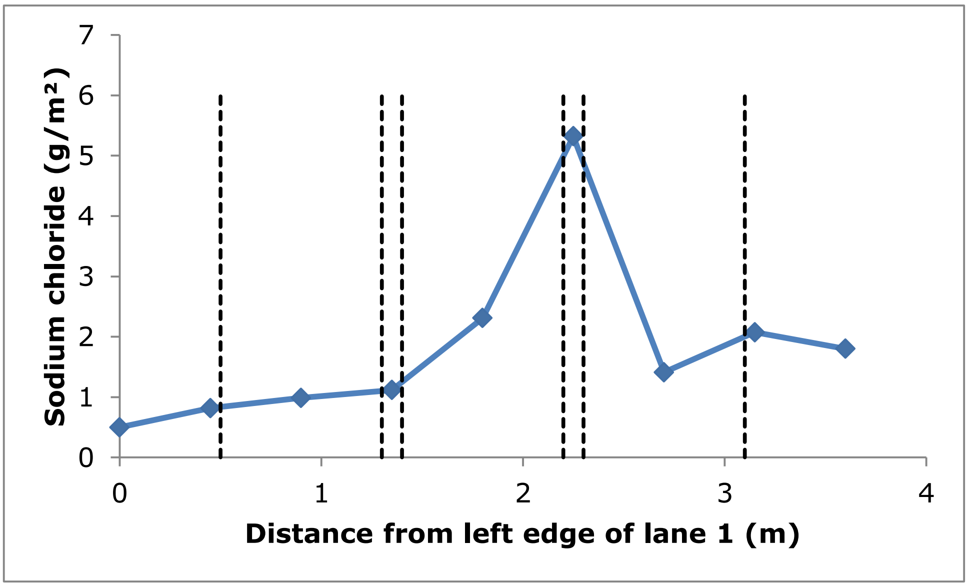

Figure 17. Residual salt level (SOBO) across lane 1 after 5.5 hours trafficking

A9

There was light rainfall for around 2 hours immediately before the trial, resulting in a very damp/wet surface although without spray generated by vehicles.

RST was around 4ºC at the time of spreading, decreasing to a minimum of 1ºC after the first period of trafficking before increasing to 4ºC at the end of the trial.

Following the second collection of salt, rainfall occurred at approximately 03.00 and continued until just prior to the final salt collection at 05.00. This resulted in a very wet road surface, with standing water within the wheel tracks.

Brine spreading was carried out at 20g/m², which would have resulted in a salt (sodium chloride) spread rate of 4.6g/m². Pre-wetted spreading was carried out at 10g/m² which would have resulted in a salt spread rate of 6.9g/m² (factoring in a dry salt purity of 90%)

Very low residual salt measurements were recorded in lane 1 of the pre-wetted trial section after spreading. The Wet Wash measurements showed an increase of 0.38g/m² in the centre of the lane immediately after brine spreading, and increases in the left and right wheel tracks of 0.34 and 1.74g/m² respectively. After the 1st period of trafficking, increased amounts of salt were measured in the left and centre of the lane with similar levels measured in the right hand wheel track as immediately after spreading.

After the 1st period of trafficking, SOBO measurements were taken in Lane 2 of the pre-wetted section. An average SOBO reading of 3.6g/m² was measured in lane 2, a significantly higher salt level than in lane 1 (measured at less than 1g/m²). It was apparent that the initial salt distribution had been predominantly into lane 2 rather than symmetrically between the lanes.

On the brine section, the Wet Wash measurements showed an increase of 4.6g/m² in the centre of the lane immediately after brine spreading, and increases in the left and right wheel tracks of 1.9 and 4.1g/m² respectively. The SOBO results showed an increase in the centre of the lane of 6g/m², and increases of 1.4 and 5.8g/m² in the left and right wheel track respectively. Both measurement methods showed less salt in the left hand wheel track as compared to the centre of the lane and right hand wheel track.

There was low loss measured over the first 2 hours of trafficking, with an average residual salt level of 5.4 and 4.4g/m² measured after trafficking by the Wet Wash and SOBO respectively. The salt levels in the left hand wheel track were still relatively lower than the rest of the lane, measured at 4.1 and 2g/m² by the Wet Wash and SOBO respectively.

SOBO measurements were taken in lane 2 of the brine section, with an average residual salt level measurement of 4.7g/m², very similar to the measurement in lane 1.

There was significant rainfall during the 2nd period of trafficking which resulted in standing water on the road surface and low residual salt levels on both the brine and pre-wetted sections.

M27

The trial on the M27 was carried out in dry conditions and no precipitation, with RST around 5ºC and relative humidity of 80% at the time of spreading and varying between 80 and 85% through the course of the trial.

Brine spreading was carried out at 20g/m², which would have resulted in a salt (sodium chloride) spread rate of 4g/m². Pre-wetted spreading was carried out at 10g/m² which would have resulted in a salt spread rate of 6.9g/m² (factoring in a dry salt purity of 90%).

The Wet Wash measurements showed an increase of 1.4g/m² in the centre of the lane and 0.9 and 1g/m² in the left and right wheel track respectively immediately after brine spreading. This was significantly less than the target rate across the lane.

Again, the plots of sodium chloride level against time of trafficking presented in Figure 13 and Figure 14 show the higher sodium chloride levels for pre-wetted salt immediately after spreading. This would be expected as a result of the higher amount of sodium chloride being spread as compared to the brine spreading. After trafficking, the salt levels on the brine and pre-wetted salt trial sections decreased and the measured values for each section converged. After 2 hours trafficking, an average residual salt level of 3.3g/m² was measured by the wet wash method for the brine section as compared to 3.4g/m² on the pre-wetted section.

9.4 Brine Recovery Tests

Tests were carried out on a typical 14mm UKPTS surfacing that had been laid within the Pavement Test Facility at TRL. The volumetric patch texture depth of the surfacing was measured to be 1.75mm.

Known amounts of brine were applied using a pressure sprayer to test panels of dimension 0.8m x 1.2m, the same dimensions as used in the road trials.

The brine was then collected using the same Wet Wash collection technique as in the road trials.

Figure 18 shows the brine recovery measured at different spread rates after applying to the test surface.

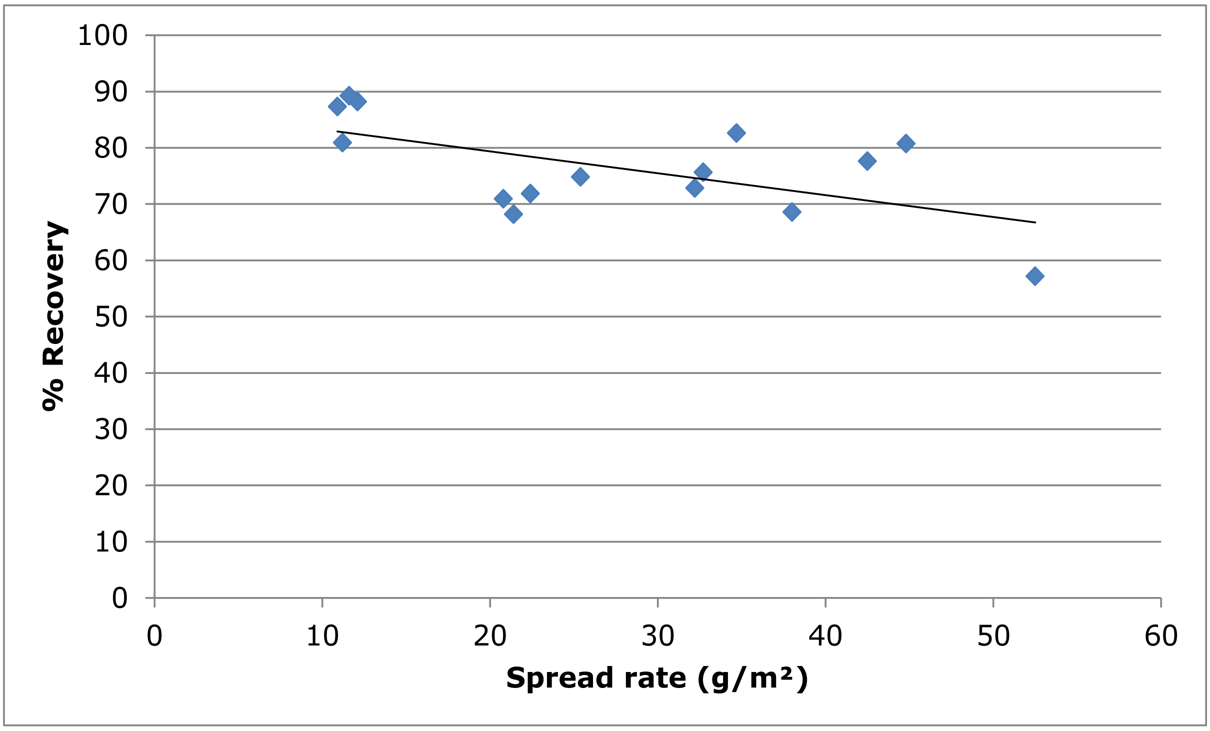

Figure 18. Brine recovery after spraying on test surface.

On average, a 76% recovery rate was measured on the UKPTS surface. Tests undertaken by TRL on a dense, impermeable surface showed recovery rates of at least 95%.

In addition to tests where the brine was sprayed evenly over the surface, the following spreading scenarios and recovery rates were also tested:

- Brine spread in small droplets only on the top of the aggregate and not in the surface texture voids: 94% recovery rate
- Brine spread in small droplets only within the voids between aggregate: 53% recovery rate
- Brine spread evenly with pressure sprayer on dry surface and left for 2 hours before collection: 65% recovery rate
- Brine spread evenly with pressure sprayer on damp surface and left for 2 hours before collection: 72% recovery rate

10 Discussion

10.1 Comparison of measurement methods

A comparison of the residual salt levels before and after trafficking, for each measurement method, are shown in Figure 19 to Figure 22. The salt levels are expressed as the percentage of the target amount which includes the background salt level that was already on the road immediately before spreading i.e. if the spread rate is 10g/m² and the background level is 5g/m² the target amount will be 15g/m².

For each plot the measurements are included for each of the measurement methods (Blue = Wet Wash, Red = WDS, Green = SOBO).

The measurements are also included for both brine ▲ and pre-wetted ■

Each point on the plots shown is also annotated with the amount of salt measured in g/m².

Included in Appendix C are further detailed comparison plots of the results by cross-sectional position across the lane.

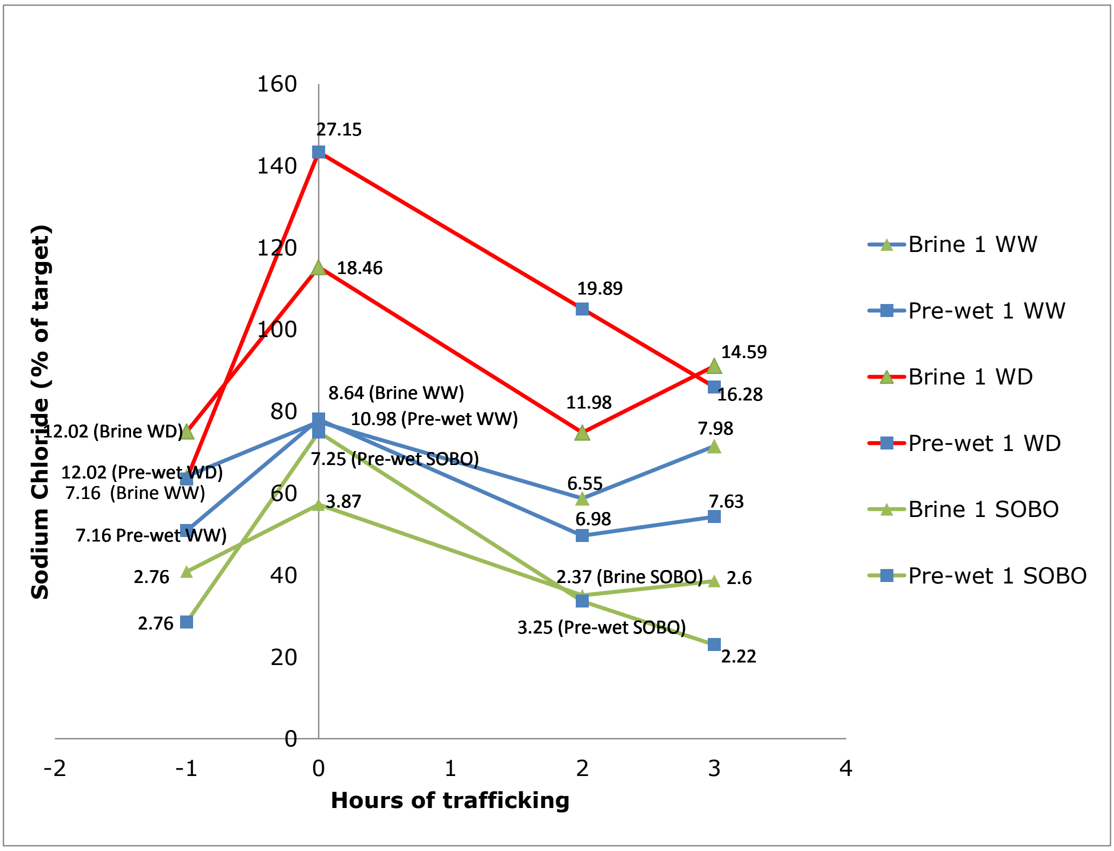

Figure 19. Residual salt levels for Trial 1 on the A1

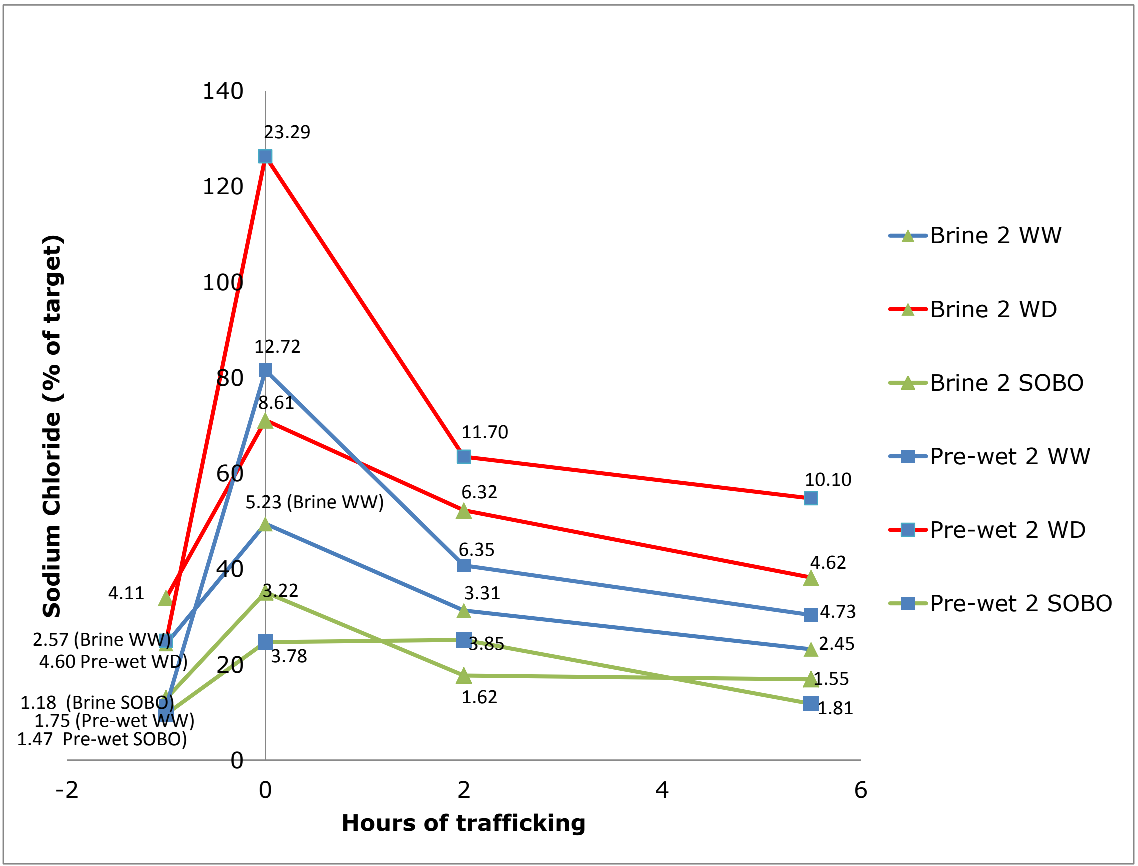

Figure 20. Residual salt levels for Trial 2 on the A1

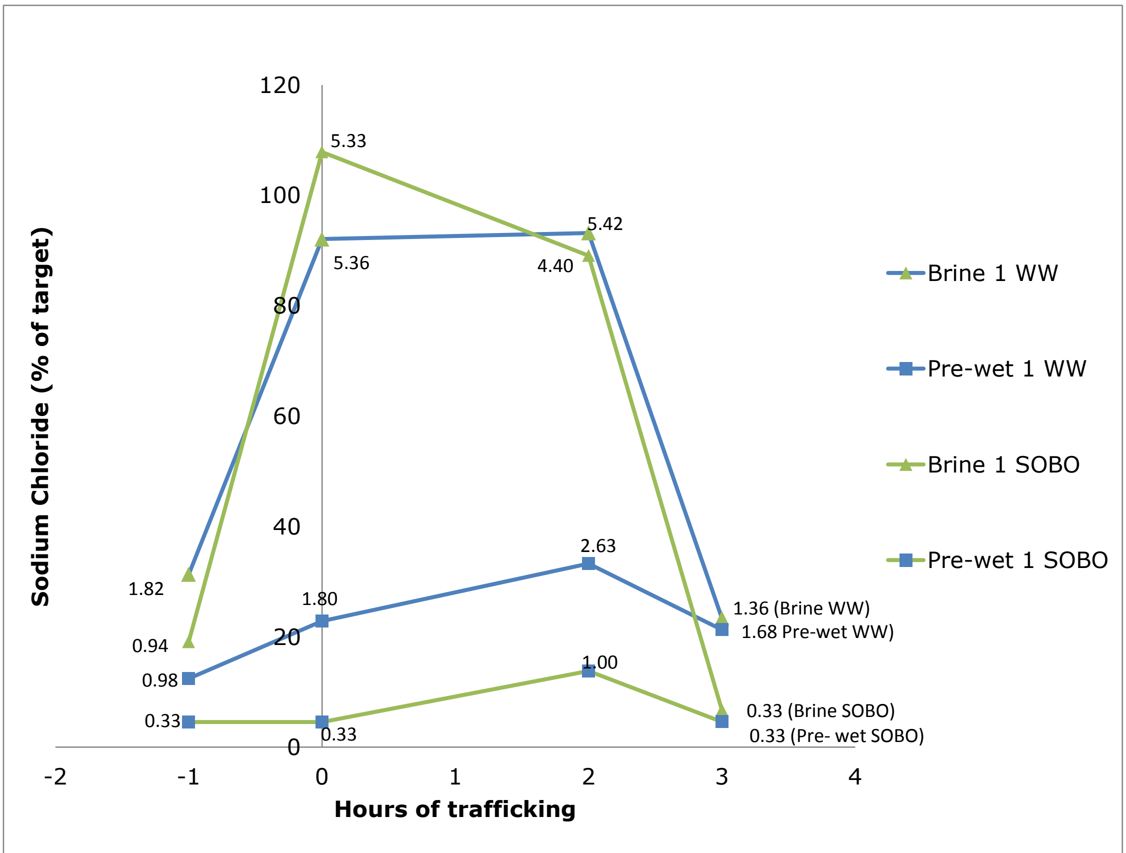

Figure 21. Residual salt levels for the A9

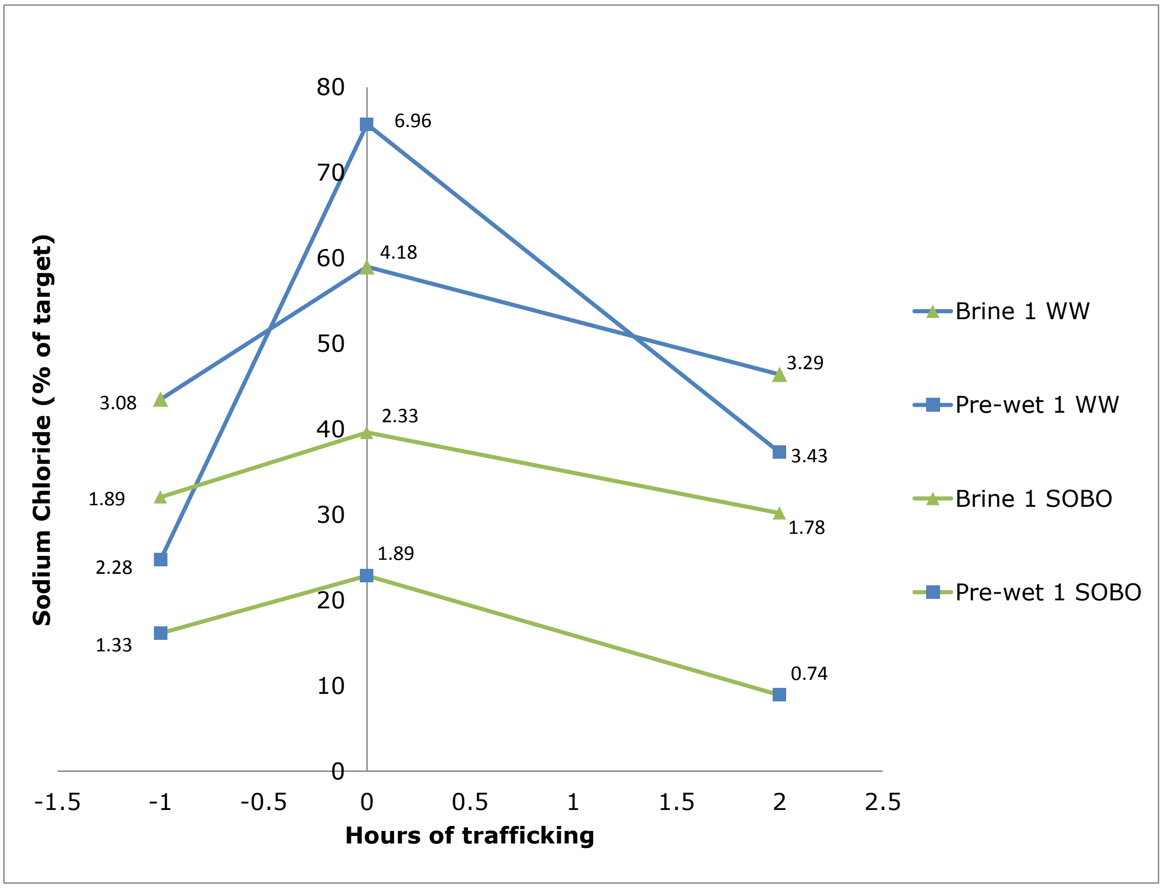

Figure 22. Residual salt levels for the M27

Comparison of the results from each trial has shown a clear and consistent difference between the residual salt measurements with each method. It can be seen that the WDS measures higher levels than the Wet Wash and both measure higher levels than the SOBO.

For the A1 trials, the WDS measurements were on average 77% higher than the Wet Wash for brine and 85% higher for pre-wetted salt. In comparison to the SOBO, the Wet Wash method showed 137% higher residual salt levels on average for brine and 144% higher for pre-wetted.

From Figure 19 and Figure 20 it is clear that the WDS measured significantly greater amounts of salt than the target amount for both brine and pre-wetted salt in Trial 1 and for pre-wetted salt in Trial 2.

Testing and verification of the Wet Wash method during these trials and in previous work has demonstrated that, on HRA surfaces, greater than 90% of the brine spread can be recovered. On open textured UKPTS type surfaces the proportion of brine spread is reduced although repeatable measurements are still obtained. Testing on a section of open textured surface during brine trials for the Highways Agency (Evans et al, 2011) showed an average recovery rate of 59%. Further tests on a different UKPTS test surfacing at TRL, described in Section 9.4, showed an average recovery of 76% using the same Wet Wash collection method. The volumetric patch texture depth of the surface tested in the Highways Agency trial was high at 2.5mm, compared to 1.75mm on the laboratory test surface in the brine trials reported here. Higher recovery was therefore obtained on the lower texture surface.

There has been laboratory testing to assess the SOBO (Lysbakken and Lalagüe, 2013) and to directly compare the WDS and SOBO (Blomquist and Gustafsson, 2012). This work concluded that the SOBO and the WDS produced accurate measurements on wet road surfaces, however the WDS was preferred for measuring of dry or recrystallized salt where the SOBO underestimated the true amounts of salt.

An issue noted with the WDS in the laboratory testing was that when measuring dry salt crystals some of the measurement points were largely underestimated. It was concluded this was due to the larger salt crystals not being transferred to the sampling bottle during the collection process. This issue was addressed by VTI for the brine trials by collection of the larger salt grains (>5mm) from the surface by hand prior to the wet sampling using the WDS.

Because of the nature of each measurement technique the amount of salt within the void structure of UKPTS type surfaces that can be extracted will vary and this is considered the key factor in the differences between the methods. The WDS incorporates a downward jet of water from a pressure sprayer followed by the use of compressed air to transfer the liquid into the container which is considered likely to further aid extraction of brine from the lower level voids in the UKPTS. Therefore, it is considered this method is likely to release greater amounts of salt (from current and previous treatments) from within the void structure than the other techniques including release of more of the brine that has penetrated deeper into the surface than the other techniques.

The Wet Wash method uses a more angled spray to the top of the road surface in comparison to the WDS. Using the Wet Wash method, testing in the laboratory has demonstrated greater than 95% recovery for brine spread only on top of the aggregate on the UKPTS type surface (an experiment designed to eliminate any salt entering the void structure or gaps between the aggregate). When brine was spread only within the gaps between the aggregate (and not on the surface) the recovery rate was reduced to 53%. This is consistent with the 76% recovery rate when spraying evenly over the surface, which is between these two values, and it is assumed that the brine that could not be recovered is retained within the void structure.

The SOBO has been demonstrated to underestimate measurements of dry salt crystals and recrystallised salt, however better results have been obtained of salt in solution. The trials on the A9 were carried out on a wet, impermeable road surface where the background salt would have been in solution. Under these conditions much closer agreement was seen between the Wet Wash and SOBO measurements for this trial section than on the UKPTS and/or in drier conditions.

A factor that impacts on all of the methods is loss of water into the open texture and voids within UKPTS surfacing. Testing on UKPTS at TRL has demonstrated that 15% of the water that is sprayed onto the surface during the collection procedure is lost into the surfacing. The WDS accounts for this loss by discharging a set amount of water and calculating the total amount of salt by multiplication of the concentration of salt in the collected solution by the total volume discharged i.e. although the amount of water collected is less than was discharged, it is assumed that any water lost contains salt in the same concentration as that collected, however this may not hold true for a variety of reasons. These may include solid grains escaping or a higher concentration of brine from the initial "wash" escaping leaving an overall lower concentration being collected.

It should also be considered that the WDS and SOBO measure a smaller area of the road surface, and if there is variation in the brine distribution across the carriageway this may cause differences in the salt measured. For example, as was seen from the brine measurements in Trial 2 on the A1, there was a narrow region of higher salt concentration in the right half of the lane. The Wet Wash method measured across a 0.8m wide width of the carriageway for each measurement, which may average out localised regions of higher and lower concentration, in comparison to the smaller diameter of the WDS and SOBO.

In summary, factors affecting the residual salt levels during the trials will include:

- Different methods will extract different levels of the salt from the UKPTS void structure
- A proportion of this salt extracted from the voids may not be available/effective for de-icing
- Methods based on a pre-determined quantity of water are susceptible to loss of water and brine when measuring (SOBO)
- Methods based on post measurement of liquid collected are susceptible to loss of brine during collection through flow over or through the surfacing (WW and WDS). This is only of consequence if the concentration of the brine lost is different to that collected.
- Methods requiring a good seal against the road surface will be affected by the voids in UKPTS and the texture of HRA. This is variable depending on individual surface types and conditions, making any calibration/offset/allowance in results difficult. (WDS and SOBO)
- On UKPTS it is likely water/brine will enter voids during collection and the amount recovered from the voids will vary dependent on the voids, detritus in the voids and collection method. Thus, issues of both under and over measurement of "effective" salt may occur depending on the method and conditions. (All)
- Methods relying on relatively rapid dissolution of solid salt grains or recrystallised salt during a short measurement process are liable to fail to dissolve all the salt when testing (SOBO)
- Methods relying on collection of brine and salt over a longer period of time are liable to loss of salt content through flow over the surface or through voids (WW)
- Methods using conductivity of the brine solution collected may be affected by other salts and contaminants in the brine collected (All)
- Methods relying on a very small area of the road surface being tested are subject to greater variance through:
  - errors in salt distribution,
  - the effect of the distribution of granular salt particularly before time and trafficking has allowed significant dissolution to occur,
  - uneven salt loss due to trafficking (e.g. in the wheel tracks and not in-between them)
  - Sample size (number of tests in the same area)
    (WDS and SOBO)

10.2 Comparison of residual salt levels for brine and pre-wetted spreading

Despite differences in the amounts of salt measured, the different measurement methods have shown consistent behaviour for the relative variation of the residual salt levels with trafficking as shown in Figure 5 to Figure 14.

For each trial, immediately after spreading there were higher levels of residual salt measured on the pre-wetted salt sections. This was to be expected as comparatively more salt was spread by pre-wetted salt than by brine for each trial. The plots of residual salt level against time of trafficking for both brine and pre-wetted salt exhibit the typical behaviour measured in previous trials, with a higher initial higher rate of salt loss followed by a flatter region of more stable salt levels against time.

In the first 2 hours after spreading there is a higher rate of salt loss for the pre-wetted salt in comparison to the brine in all the trials, then similar loss for each treatment type over the next few hours. However, it must be considered that this direct comparison is between a higher salt spread rate for the pre-wetted salt than the brine.

A key question is does the brine exhibit lower loss when spread at the equivalent salt spread rate? e.g. if spreading pre-wetted salt at 10g/m² this is equivalent to 7.69g/m² of salt. This would be equivalent to a brine (23% concentration) spread rate of 33.4g/m².

Another key question is making direct comparison between specified treatment rates for the conditions. Currently there is no national guidance for brine only spread rates for forecast conditions. However, as current spread rate guidance is based on the properties of salt, losses when spreading and variations in distribution approximate equivalent spread rates for further trials could be calculated.

The average percentage loss within the lane is shown in Table 13 and Table 14 with the background residual salt levels subtracted and included respectively. The results have been calculated based on the Wet Wash measurements for each trial.

Table 13. Percentage salt loss after trafficking – background levels subtracted

Trial	Hours of traffic	Percentage loss (%)	
		Brine	Pre-wet
A1-Trial 1	2	141	105
	3	45	88
A1-Trial 2	2	72	58
	5.5	104	73
A9	2	-2	-
	6	113	-
M27	2	81	75

Table 14. Percentage salt loss after trafficking – background levels included

Trial	Hours of traffic	Percentage loss (%)	
		Brine	Pre-wet
A1-Trial 1	2	24	36
	3	8	30
A1-Trial 2	2	37	50
	5.5	53	63
A9	2	-1	-
	6	75	-
M27	2	21	51

With the background levels subtracted, based on these results it cannot be concluded that there is a significant difference between the percentage salt losses measured for brine and pre-wetted salt in each trial. Therefore, if equivalent amounts of salt were spread by each treatment method there would be similar residual salt levels measured.

With background levels included, the percentage losses are smaller for the brine spreading compared to the pre-wetted spreading, as might be expected as the smaller amount of salt spread by the brine will be a relatively smaller fraction of the background level.

Measurements have not been made of the background level variation over the course of the trials. By subtracting the background from the total amount of salt spread this assumes an unchanging background level during the full duration of the trial. While this is likely to be correct during dry, lower humidity conditions during the day, it may not be the case during the trial period where humidity is higher (around 80%) and more moisture is available. In these conditions the residual salt may more readily enter solution and be lost into UKPTS surfacing. Spraying of brine into the surface may also help to dissolve or soften any background salt through the additional moisture added to the road surface or absorbed from the atmosphere after spraying. In particular for less saturated brine (20% concentration) there will be greater potential for further dissolution of salt already present on the road.

Any reduction in the background levels will have a more significant effect, and higher losses measured as a result, for the brine trial sections where relatively less salt was spread than for the pre-wetted salt. The most significant effect may be on the results from Trial 1 on the A1, where a treatment had been made around 5 hours before the road closure for the trial, and there was consequently greater potential for further reduction in the residual salt from this treatment over the course of the trial (and higher losses measured as a result).

It should be considered that the percentage losses are calculated relative to the level of salt immediately after spreading. Table 15 shows the percentage of the target amount of residual salt immediately after spreading. This target amount is the background level plus the amount of salt spread based on the spread rate used for each trial.

Table 15. Percentage of target amount immediately after spreading

Trial	Percentage of target amount (%)	
	Brine	Pre-wet
A1-Trial 1	77	78
A1-Trial 2	50	82
A9	92	-
M27	59	76

Clearly, on the UKPTS the levels of salt measured immediately after spreading are less than the target amount. The spreaders used in the trials were calibrated and it is to be assumed that the correct amount of salt was discharged during the trials, although it was not possible to confirm this. The lower levels measured are likely an indication of the loss of salt into the open texture and voids which is not then able to be collected by the measurement methods.

The results of the trials have indicated a difference in the behaviour of residual salt levels after spreading on the HRA and UKPTS surfacing. On the HRA surface, very low loss of residual salt from brine spreading was measured after 2 hours of trafficking and the salt levels measured immediately after brine spreading on the HRA surface were also significantly greater than those measured on the UKPTS surface. This is likely as a result of the brine not being able to flow into voids as they are not present in the dense HRA surface and remaining available for collection.

The direct comparison with pre-wetted spreading was complicated on the HRA trial section by the poor distribution of pre-wetted salt. SOBO measurements within lane 2 of the pre-wetted section after 2 hours trafficking showed a residual salt level of 3.6g/m^2 averaged over the lane. If it is assumed that the spread rate within lane 2 was at least 10g/m^2 (6.9g/m^2 of sodium chloride) this would indicate a loss of approximately 50% after spreading. Previous trials of pre-wetted salt loss on HRA and UKPTS surfacing, carried out by the NWSRG and others, has indicated losses of 30 percent and greater after 2 hours of trafficking (including low traffic levels).

Based on this trial result, residual salt levels after brine spreading on HRA may appear to exhibit greater longevity than salt levels after pre-wetted spreading. However, the very limited amount of data needs to be taken into account preventing the drawing of more definitive conclusions. If further testing confirms these results it would also seem feasible that a similar behaviour would be seen on other dense surfacing, such as the denser types of SMA specified in Europe and Transport Scotland's TS2010 SMA Surface course.

10.3 Effectiveness and longevity of treatments

The trials have measured the amount of residual salt based on the salt that could be collected by the measurement methods. Based on the measurements made in the trials and on test surfaces where known amounts of brine were sprayed, it is clear that UKPTS absorbs a significant proportion of brine into the void structure and a proportion of the salt absorbed may not be available and therefore effective for anti-icing. Thus, there is a concept of "effective" salt that may be more or less than that measured dependant on measurement method and conditions. HRA does not have the same voids issues as UKPTS.

While the residual salt levels that have been measured give an indication of the longevity and effectiveness of the treatment, it is not currently known how much of the brine that could not be collected would be available for de-icing, for example by the pumping action of tyres bringing the salt back to the surface.

The trials on the A1 were carried out under conditions where RST went down to as low as -2ºC, and treatments were required on the network during the same period as the trial. Monitoring of the trial sites by the Vaisala mobile patrol did not indicate any instances of ice present during the periods where there was a risk of ice formation, and the treatments applied were effective in the conditions tested. However, because of the relatively dry conditions this would have been considered a low risk and unlikely to have occurred. Further monitoring of brine treatments under a range of conditions will provide more confidence in the brine effectiveness under a range of conditions, including where greater amounts of surface moisture was present.

The longevity of a treatment needs to be considered not only in terms of the length of time a proportion of salt remains available after spreading, but that it is also present in sufficient quantity to be effective either in its own right or by being topped up by a lower treatment rate than forecast conditions require.

For example, for Trial 1 on the A1 and the trial on the M27 the final residual salt levels after trafficking were similar for the brine and pre-wetted sections, which could indicate better longevity for the brine treatments considering the lower amounts of salt that were spread. However, the level of residual salt increase above the initial background level in both cases was less than 1 g/m².

It should also be considered that, as marginal conditions only require quite small amounts of salt that are impractical to spread with currently available technology, lower levels of background residual salt may be sufficient to prevent ice formation, obviating the need for a further treatment. It would need to be ascertained that sufficient background salt is available over the whole route (or part of a route that may not be further treated).

Assuming that the required amount of salt is properly distributed on the road surface at the time of treatment, the following factors affect longevity:

a. Road surface wetness

   i. Brine – the amount of water already on the road surface for HRA and UKPTS and within the voids of UKPTS will affect the concentration of the brine after spreading and therefore the length of time an effective concentration of brine is available

ii. Brine – where UKPTS is dry and contains no or little liquid (brine or water) in the voids then some brine will be "lost" within the void structure. This is a process that will continue over time in certain conditions reducing the salt available for anti-icing

iii. Pre-wet – pre-wet salting requires additional water to complete the dissolution process. Therefore, some additional water on the road surface is beneficial provided it is not excessive. Thus effectiveness increases initially as salt dissolves but other process described here will affect longevity

b. Precipitation

i. Brine & pre-wet – Significant precipitation is sufficient to remove salt from the road (2mm is quoted by Met Office but will depend on local factors such as slope/crossfall)

ii. Brine – Any precipitation will reduce the concentration of the brine and therefore effectiveness immediately and over time

iii. Brine & pre-wet – low precipitation may fill voids with water which further dilutes the brine spread or formed through dissolution

iv. Brine & pre-wet – Low precipitation may wash residual salt on the surface into voids in UKPTS where it may or may not become available later (see "pumping" below)

c. Traffic

i. Brine & pre-wet – Losses due to traffic from brine in conditions of dry roads are likely to be less than pre-wet where the salt will remain in granular form and subject to wind and vehicle draughts

ii. Brine – Losses due to traffic in conditions of wet roads are likely to be high due to spray which exacerbates the situation of reduced concentration due to wetness

iii. Brine & pre-wet – some of the brine held in the voids of UKPTS will be drawn to the surface by the action of traffic (referred to as pumping"). The amount that may be "pumped" to the surface is not fully understood at this time and is therefore difficult to quantify when developing guidance on spread rates and mitigating losses on UKPTS

iv. Brine & pre-wet – As the road dries, pumping may bring brine to the surface where some may be removed by the action of traffic reducing the background residual salt available and any brine contained in the voids

v. Pre-wet – the action of traffic crushes grains and increases the rate of dissolution. Salt becomes more effective sooner but longevity may be affected by other processes described here

vi. Pre-wet – Traffic may crush salt grains into voids slowing dissolution or reducing the salt available for anti-icing

vii. Pre-wet – Wet roads are likely to increase losses due to spray

d. Wind and Vehicle Draughts:

i. Brine & pre-wet – Where spray is formed this increases the likelihood of losses reducing effectiveness over time

ii. Pre-wet – solid grains are susceptible to movement particularly smaller particles (fines tend to be absorbed or wetted by the brine element) but this is not considered a significant factor except for infrequent very high air speeds.

iii. Brine & Pre-wet – Where the brine or fully dissolved pre-wet salt has dried out (where conditions allow) the recrystallised salt tends to bond to the road surface and is not easily disturbed. This provides more significant longevity in dry conditions thus retaining more salt for when it is needed.

e. Humidity:

i. Brine – Brine solutions will absorb water from the atmosphere reducing concentration over time, particularly where the brine is being "mixed" by action such as traffic where spray will also create a larger surface area to absorb water.

ii. Pre-wet – Pre-wet salt requires further moisture in order for full dissolution. Humidity above 80% is considered essential for this process to be effective for road salt.

iii. Pre-wet – when full dissolution has occurred the brine formed will reduce in concentration through absorption of further water from the atmosphere when humidity is high.

10.4 Brine Distribution

The trials have highlighted the importance of correct calibration and distribution of de-icer on the road surface.

When spreading brine in the lane the spreader is driving, the liquid is spread from fan jets. It was observed that this spread covered approximately 2.5m of the lane width and redistribution would be required to cover the full lane. To spread to adjacent lanes, the brine is distributed by jets from nozzles and applied in discrete lines along the road surface, again requiring redistribution after spreading to cover the full lane width.

An uneven brine distribution was measured in Trial 2 on the A1, where brine had been spread to the lane in two passes, it was concluded this was a result on lack of redistribution of the brine spread from the jets when driving in the adjacent lane.

This may be an effect of the open textured surface, where brine can collect in the texture/voids and be less susceptible to movement by vehicle tyres. It is considered this will be a more significant effect on dry surfaces than on damp or wet surfaces which will likely enable easier redistribution. Similarly, trials in Germany (Hausmann, 2012) had observed that only limited cross-distribution of the brine takes place as a result of traffic in low humidity or dry conditions.

10.5 Effect of trafficking

The pre-wetted salt losses measured in the trials are comparable with previous trials with significantly higher traffic levels and could indicate that the effects are evident after only a small number of vehicle passes i.e. less than 50 vehicles. Again, a similar finding was reported in trials carried out in Germany (Hausmann, 2012) where it was concluded that the speed of the vehicle may be the significant factor rather than the number of vehicles passing.

10.6 Comparison with European brine trial results

A review of work carried out in Europe shows similar results, in some instances, to those achieved in these trials (where road and weather conditions are similar). It should be noted that the work considers losses from the total salt on the road, not just the recently spread salt/brine (i.e. the background residual salt plus the recently spread salt). This does not account for important factors including:

a) The original spreading of salt to achieve the background level will have been subject to losses whose value is not included in their methodology, therefore underestimating total losses of salt.

b) Using the larger number of combined background and spread salt to calculate current loss gives a smaller percentage value for overall reported loss. This appears to be misleading, particularly where background salt levels are high.

c) The background salt being measured is salt that has remained on the road after trafficking and other actions since first spread. This may indicate that it has already adhered to the road (e.g. recrystallisation) and be less susceptible to further loss than freshly spread salt/brine.

d) The potential influence of this factor (in c) above) may then be exacerbated by the fact that some or all of the background salt will not dissolve into the concentrated brine solution when just spread, therefore leaving it in a state of "adherence" until sufficient water is present to dissolve it. (Which may or may not occur over the period of the trial measurements)

e) Particularly where background salt levels are high, some of the background salt will be lost in some conditions. However, without control measurements of the loss of background salt alone, this was not quantified in the trials. Furthermore, some trials made no measurement of background salt as it was considered to be negligible, although some salt may have been present. A more robust method would still have measured the background salt to prove none was present.

Some of the trials carried out were in dry and warm conditions, much different to those expected in winter anti-icing operations. In such conditions the water will dry from brine relatively quickly and it the salt will recrystallise on the road to which it is likely to adhere becoming far less susceptible to removal by traffic, wind and vehicle draughts. Conversely, the majority of the salt spread in a pre-wet operation will not dissolve. The grains will be crushed by vehicle action and the resulting fines be highly susceptible to removal by wind and vehicle draughts.

It was observed that some of the results for pre-wet match with those observed in UK trials for HRA which is considered reasonable as the SMA in Europe more closely matches HRA in terms of void content

The totality of this overview of the European work appears to indicate that the savings to be made by brine spreading on HRA and SMA may not be as great as those indicated by the percentage values given in the summary graph of the work. In fact considering the results from the trials that are closest to more normal conditions supports this supposition.

Finally, none of the trials carried out were on surfacings similar to the UKPTS systems in use on Scottish and English trunk roads, thus direct comparisons cannot be made with their work for UKPTS although results may be similar for HRA where the trial conditions were closest to winter norms.

It is recognised that the UK has different weather conditions relating to winter service conditions, different road surfacing materials and legal requirements to Europe and North America. (Although unlike England, Scottish conditions are closer to some conditions experienced in coastal areas of northern Europe). These factors have a significant impact on the requirements for winter service and therefore the UK National Guidance that has been developed.

11 Conclusions

The following conclusions are based on data from a limited set of trials and should be considered more as a guide to likely behaviours and characteristics rather than being definitive. However, the analysis of the data collected has provided a useful insight into how further work can be focussed to provide guidance on the effectiveness of brine and pre-wet treatments on typical UK road surfacings.

Treatment longevity

- The results of the trials have indicated a difference in the behaviour of residual salt levels after spreading on the HRA and UKPTS surfacing.
- Residual salt levels after brine spreading on HRA would appear to exhibit greater longevity than salt levels after pre-wetted spreading. It would also seem feasible that a similar behaviour would be seen on other dense surfacing, such as the denser types of SMA specified in Europe and Transport Scotland's TS2010 SMA Surface course.
- In the first 2 hours of spreading there is a higher rate of salt loss for the pre-wetted salt in direct comparison to the brine in the UKPTS trials, then similar loss for each treatment type over the next few hours. (However, it must be considered that this direct comparison is between a higher salt spread rate for the pre-wetted salt than the brine). Rainfall affected the HRA trial before the final set of readings could be taken so conclusions cannot be drawn beyond the first two hours.
- Based on the trial results, and discounting existing background levels, it cannot currently be concluded that there would be a significant difference between the percentage salt losses measured for brine and pre-wetted salt on UKPTS if equivalent amounts of salt were spread by each treatment method.
- When background levels are included in the analyses, the percentage losses are smaller for the brine spreading compared to the pre-wetted spreading on UKPTS (but consistent in proportion to the differences in the amount of salt spread). This is as might be expected as the smaller amount of salt spread by the brine will be a smaller fraction of the background level.

The amount of spread salt that remains after a length of time is of interest. However, it is important that the salt is present in sufficient quantity to remain effective in the predicted road and weather conditions. Where the amount of salt remaining is not sufficient to prevent ice formation it can be used to calculate a reduced spread rate for subsequent treatments.

- When considering the longevity of treatments it is important to understand the amount of salt required on the road to be effective in the predicted road and weather conditions. In marginal conditions, the amount of salt required is relatively small, in the region of 2.5g/m^2 when there has been good distribution through traffic, for example. This is far less than the recommended spread rates that allow for losses.
- Where salt has recrystallised on the road after spreading due to loss of moisture it is more likely to adhere to the road surface and therefore last longer under the action of traffic or wind. Therefore, the road surface state, in terms of moisture, will have a significant effect on the longevity of treatments, from total removal by

rain to minimal removal of recrystallised salt when dry. This must be considered when making any assumptions on longevity of treatment types based on anecdotal or incomplete information, particularly where spreading and measurements have been made in warm, low-humidity conditions.

- Further monitoring of brine treatments under a range of winter conditions, where treatments would normally be carried out, will provide more confidence in the effectiveness and longevity of brine treatments, including where greater amounts of surface moisture were present.

Effect of surfacing

- UKPTS absorbs a significant proportion of brine into the void structure. It is not currently known how much of this would be available for de-icing, for example by the pumping action of tyres bringing the salt back to the surface. Conversely the collection methods (and in particular the Wet Dust Sampler) may be collecting more salt from the voids than would be available for de-icing in normal road conditions. Therefore, it is possible that the amounts of salt measured during these trials may be significantly more or less (dependent on the measurement method and precise conditions relating to the surface) than the "effective" amount of salt present available to prevent the formation of ice for the actual and/or forecast conditions.
- Testing has shown correlation between lower recovery with the Wet Wash method and higher texture depths of UKPTS with recovery rates ranging from 59 to 76% for volumetric patch texture depths ranging from 1.75 to 2.5mm
- Brine travelling through the UKPTS void structure may redistribute the brine from higher to lower areas or allow the brine to drain from the road
- Estimations of residual salt need to account for absorption and brine migration through the void structure to avoid over estimation of residual salt
- HRA does not have the same voids issues as UKPTS and therefore the concept of effective salt held in voids is insignificant on HRA surfaces (and will be insignificant on other surfaces that are similar in this respect).

Comparison of measurement methods

- Comparison of the results from each trial has shown a clear and consistent difference between the residual salt measurements with each method, with WDS measuring higher levels than the Wet Wash and both measuring higher levels than the SOBO.
- It is considered that there are two main reasons for the above: the amount of salt within the void structure of UKPTS type surfaces that can be extracted by the different methods; and the seal between the measuring instrument and the road surface for both UKPTS and HRA when using the WDS and SOBO.
- It is considered that WDS measurements on UKPTS may potentially include some salt from within the void structure that would not normally be available for anti-icing.

Spreading

- Measurements and observations of the brine distribution have shown that redistribution of salt or brine poorly distributed by the spreader cannot be relied on shortly after spreading, particularly where traffic counts are low.
- Brine spraying distribution patterns require to be designed and checked for full coverage without relying on redistribution.
- The trials again demonstrated the importance of proper calibration of spreaders to ensure accurate distribution and rate of delivery which must be competently carried out and audited.
- Traffic levels affecting the loss of salt appear to be lower than anticipated from earlier experiments and trials. The effects of traffic on salt loss are evident after only a small number of vehicle passes i.e. less than 50 vehicles.

Business Case

The decision to adopt brine spreading will need to be based on a sound business case. Some of the key factors to consider are outlined below:

- For brine spreading ~75% of the load carried (by weight) is water.
- For pre-wet spreading ~23% of the load carried (by weight) is water.
- In marginal conditions brine spreading may offer the opportunity to spread at rates that more closely reflect the actual amount of salt required to prevent ice forming rather than the practical limits/losses considered to achieve a minimum evenly distributed amount of salt from conventional pre-wet spreading. The amount of evenly distributed salt required on the road surface in conditions down to -2ºC is between 1.7g/m² for a damp road surface (0.05mm water film) and 3.4g/m² for a wet road surface (0.1mm water film). Recommended pre-wet spread rates for well calibrated spreaders and salt in good condition are 8g/m² (6.15g/m² of NaCl). However, when recommended brine spread rates are being considered, it will be important to account for potential losses on UKPTS or losses/uneven distribution due to wind and vehicle draughts as well as dilution due to humidity, surface wetness or precipitation, in the same way that losses are accounted for in the recommended pre-wet spread rates.
- Brine spreading alone or a combined pre-wet and brine spreading capability would require a significant investment:
    - As more depots (for brine production and spreader location) would be required, because of the more limited range (length of carriageway that can be covered) of brine spreaders, to avoid long runs before a route is started
    - As less than an optimum location of depots will increase the number of spreaders required due to "down time" when travelling to and from a route
    - As brine production and/or storage capacity would need to be increased to match the highest spread rates used in a given time period (worst case scenario)
    - As routes would require to be designed for the highest spread rates

- As spreader capacity (number of spreaders) would need to be matched to worst case scenario
- As an expanded mixed brine and pre-wet capacity, where brine is only used at the lower end of salt requirement (marginal conditions), would be the most likely scenario in which a positive business case might be made
- Examples:
  3. For marginal conditions and assuming brine spread rates could be 50% of pre-wet spread rates due to a reduction in losses when spreading (noting that this study does not support rate reduction for UKPTS to allow for absorption into the voids) then
     a. 20g/m² of brine would need to be spread to equate to 10g/m² of pre-wet.
     b. 2 times the spreading capacity would be required
     c. 7 times the brine production/storage capacity would be required for marginal conditions alone
  4. Assuming like for like spread rates (i.e. no salt saving with brine spreading then:
     a. 40g/m² of brine would need to be spread to equate to 10g/m² of pre-wet.
     b. 4 times the spreading capacity would be required
     c. 13 times the brine production/storage capacity would be required for marginal conditions alone

Environmental Issues

- Additional energy and fuel used, increasing carbon footprint, for:
  - Brine production
  - Transporting/spreading brine
- Use of potable water in brine production (and consequent energy and environmental issues)
- Brine - Reduction in “wasted” salt entering receiving waters and damaging flora and fauna when compared to pre-wet
- Brine – less salt to be transported to depots reducing fuel used and carbon footprint

Recommendations

The result of these trials have provided some useful information on the residual salt behaviour after spreading brine and pre-wetted salt on UKPTS and HRA surfacing. However, a full picture of losses with time for different spread rates in different conditions over a winter season cannot be extrapolated from the limited data collected so far. This work and work recently reported in Europe indicate that there is potential for using brine only treatments in certain circumstances. Therefore, further work is warranted to determine whether brine-spreading capabilities provide operational advantages and economies This work would further explore the range of conditions these advantages and economies may apply to, what level of treatments may be needed and what the initial and ongoing costs versus savings might be. To proceed to this point, where specific recommendations and guidance can be developed, a range of trials and experiments for different UK conditions and UK surfacings would need to be carried out. This would build a sufficiently large dataset with repeat results under similar conditions necessary to provide the necessary confidence for operational level recommendations. Furthermore, in order to be able to make reasonable comparisons between the brine and pre-wet technologies, both systems would need to be reviewed at the same time, in broadly the same conditions and on the same surfacing types. The trials would require to be carried out over a winter season and would need to allow for collection of residual salt data at regular intervals. As this is currently highly disruptive due to requirements for road closures and diversions it is recommended that a study into minimising disruption while retaining the ability to collect meaningful results is undertaken.

The outcome from this further work should ultimately aim to provide information to support the following topics:

- Guidance on treatment rates for brine spreading
- Guidance on effectiveness of treatment methods for different conditions
- Guidance on developing economic evaluations and business cases considering both brine only and pre-wet spreading methods
- Guidance on risks and their mitigation when adopting brine spreading capabilities

12 Acknowledgements

The work described in this report was carried out in the Infrastructure division of the Transport Research Laboratory.

The assistance of the following was much appreciated: Keith McKune and Nicholas Russell of Amey; Kevin Campbell of BEAR Scotland; Brian Davis of Vaisala; Goran Blomquist and Mats Gustafsson of VTI; Peter Casey and Simon Gamma of Boschung; Ian Bastin of EM Highways in Area 3; Steve Stace of Highways England, Martin Thomson of Transport Scotland and David Davies of Lincolnshire County Council.

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Hausmann (2012). Recommendations for the correct spreading of melting salt solutions. Berichte der Bundesanstalt für Straßenwesen, Heft V 218,Bergisch Gladbach.

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Appendix A Review of residual salt measurement methods

A.1 Recommendations

The wet wash and SOBO 20 methods are the most fully researched and understood methods (including understanding of the limitations) and recommended to be used in the trial.

Other methods can potentially be used in conjunction with the Wet wash and SOBO 20, but limitations for these methods are highlighted as follows:

- Use of the Wet Dust Sampler will require collaboration with VTI. Uncertain weather and trial timing may present logistical difficulties as equipment and personnel will need to travel from Europe. Costs are uncertain and could be high
- The use of handheld refractometers will require development of a suitable method, checking and calibration. The method is likely to involve adding of water to the surface to allow measurements to be carried out.
- Mobile measurement methods typically require sufficient moisture on the road surface to generate spray. Uncertain weather and trial timing may present logistical difficulties as equipment and personnel will need to travel from Europe. Costs are again uncertain and could be high.
- All the methods considered, apart from the Wet Wash, SOBO 20 and embedded sensors have limited information on accuracy and repeatability of results. Greater certainty as to their reliability and accuracy would be required before they could be recommended.

A.2 Summary

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
SOBO 20	✗	✓	✓ ✓	✓ ✓	✓	✓ **(To be confirmed)**	Accuracy is dependent on surface type. Only measures small area, but provides the option for numerous measurements. Underestimates amount of solid salt.
Wet wash	✓ ✓	✓ ✓	✓	✗	✗	✓	Will need to be set up for use in freezing conditions. Accurate measurement of effective residual salt. Limitations on measurement speed and more personnel required.

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
Embedded road sensor	✗	✗	✓ ✓	✓ ✓	✓	Dependent on site selection	Not considered a reliable measurement – would be useful to provide an indication of residual salt and for ice warning
Wet dust sampler	✓	✓	✓	✓	✗ Dependent on collaboration with VTI/MORS project	✗ Dependent on collaboration with VTI/MORS project	Sufficient information not available from literature to fully assess accuracy. Accurate measurement of dissolved salt suggested through trials by VTI – some examples of underestimation for measuring of dry salt. Need to confirm suitability for

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
							freezing temperatures. Provides the option for more measurements than wet wash, smaller measurement area. Availability will be an issue.
Refractive index (Manual measurement)	Dependent on development of method		Dependent on development of method	✔	✔	✔	A method will need to be developed where water is added to road surface, then trialled to verify accuracy. Could be a very good method if proven, may not be practical in terms of ease of use.

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
Mobile measurement - Frensor	N/A		✔ ✔	✔ ✔	N/A	N/A	Sufficient information not available from literature to assess accuracy. Requires enough moisture to generate vehicle spray. Provides a measure of the salt concentration of the road surface moisture but not the amount of salt If available, would be a useful comparison. Measurements can be carried out during trafficking periods.
Mobile measurement – Spectroscopic	N/A		✔ ✔	✔ ✔	✖ Dependent on	✖ Dependent on	System at experimental stage. Sufficient

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
(Mario Marchetti)					collaboration	collaboration	information not available from literature to assess accuracy. Provides a measure of the salt concentration of the road surface moisture but not the amount of salt If available, would be a useful comparison. Measurements can be carried out during trafficking periods.
Mobile measurement – Refractometer (Yamada Giken	N/A		✔ ✔	✔ ✔	✖ Dependent on collaboration	✖ Dependent on collaboration	Sufficient information not available from literature to assess accuracy.

Method	Accuracy		Ease of use	Speed	Cost	Availability	Comments on suitability for trial
	Solid	Dissolved					
Co. ltd)							Requires enough moisture to generate vehicle spray. Provides a measure of the salt concentration of the road surface moisture but not the amount of salt If available, would be a useful comparison. Measurements can be carried out during trafficking periods.
Mobile measurement – Luminescence (University of Madrid)	N/A		✔ ✔	✔ ✔	✖ Dependent on collaboration	✖ Dependent on collaboration	Only measures dry salt so not suitable for these trials.

A.3 SOBO 20

Assessment Factor	Comments
Accuracy and precision	Measurements can be made with the following precision: • ±0.5g/m² in the measurement range 0-15g/m² • ±1.5g/m² in the range 15-45g/m². Research has shown the device can measure dissolved salt accurately on a smooth dense surface, but significantly underestimates undissolved and recrystallized salt. The accuracy further depends on the smoothness and permeability of the surface – from previous trials, the recommendation was to perform calibration measurements on the specific road surface of interest. However, accuracy of "effective residual salt" may further depend on the amount of brine and its concentration in the voids and whether any of this is measured. Measures a small surface area (Diameter of measurement area is 6cm). This means that the measurement is highly dependent on distribution and dissolution of pre-wet salt Quick measurement time will enable averaging of multiple measurements but may not improve accuracy if there is inherent bias.
Ease of use and speed of measurement	The device is easy to use and measurements can be taken relative quickly in comparison to other manual methods by a single operator. Information from the supplier states that 35 measurements can be made before refilling of the measuring solution is required. Measuring solution will need to be transported on site – of the order of 10 litres for 200 measurements. Portable or hand held lighting will be required.
Limitations	Can only measure dissolved salt accurately. Dependent on surface roughness and permeability. Unlikely to measure concentration of brine in voids near the surface which may be available as an "effective" de-icer.
Cost and availability	A new device is likely to be in the region of £6000 delivered, calibrated and set up for use. TRL and Lincolnshire have older devices which, on confirmation of proper functioning and

	carrying out calibration checks, could be used.

A.4 Wet-wash method (TRL and German trial method)

Assessment Factor	**Comments**
Accuracy and precision	Trials show accurate measurements can be made with a precision greater than 1%. The accuracy has been verified on denser surfacing. On very open textured surfacing full retrieval of all salt spread has not been possible due to salt retained in the road texture (this will be an issue for all techniques). However, it is strongly suggested that, as the salt/brine not recovered is in the voids of the surface material it would not all be effective in preventing ice formation at the road surface. This is considered likely to improve the reliability of results by measuring only "effective residual salt" with this method. Provides a measurement of all the salt on the road – including dissolved, undissolved and recrystallized – but no distinction between these. (This is common to the Wet Dust Sampler. Other methods measure the amount of salt in solution but do not take account of undissolved salt). Measurement area is typically between 1 to1.5m² per individual measurement.
Ease of use and speed of measurement	Time for each measurement is approx. 10 minutes. Requires two personnel to wash out the device. Requires a generator for each vacuum and associated equipment, washing out water (with de-icer), and storage bottles for the samples. Each measurement generates an approximately 2 litre sample)

	Portable lighting will be required.
Limitations	Provides a measure of the total salt on the road surface, but does not differentiate between solid and salt already in solution. Number of measurements depend on the available time for salt collection, number of personnel and machines. Will need setting up to prevent freezing in sub-zero temperatures. This will require the use of suitable anti-freeze in the water supply.
Cost and availability	Main costs are: • Personnel required to operate • Associated equipment and transport costs • Sample analysis

A.5 Embedded road sensors (Passive and active sensors)

Assessment Factor	Comments
Accuracy and precision	Measurements considered unreliable because: • Sensors typically require a minimum wetness on the sensor to provide reliable results • There is uncertainty in the water film thickness reported by sensors • Only measures a small area which may not be representative of the full carriageway and subject to greater variation • May collect brine running over the surface to a low point which is unrepresentative of the true residual salt level/brine concentration.
Ease of use	Test sites will be required that have sensors installed No requirement for additional on-site equipment
Speed of measurement	Continuous measurement possible but inaccurate
Limitations	Can only measure the salt in solution – minimum level of wetness required Only measures on small point of the carriageway See accuracy section above
Cost	Low cost where sensors already installed.
Availability	Dependent on being available on test sites

A.6 Wet dust sampler

Assessment Factor	Comments
Accuracy and precision	Trials carried out by VTI have shown the wet dust sampler can be used to measure residual salt accurately on asphalt test surfaces for salt in solution. For testing of undissolved salt particles the VTI trials showed some measurements were underestimated, with the conclusion this was probably due to whether the salt crystals were transferred to the sampling bottle or not. Accuracy on open textured surfaces is unknown. There are ongoing trials as part of the MORS project. There will be the same issues with salt loss into open textured surfacing voids as for all the techniques. There has been development of the method to improve the seal formed around the measurement area to prevent leakage. Measurements on small areas may need several measures in the same general area to get statistically accurate results
Ease of use	The device can be operated from a single vehicle to provide power supply from a battery.
Speed of measurement	Measurements time is not given in the literature, but is considered likely to be somewhere between the SOBO 20 and the wet wash method. Time will be required to set up the equipment and move between test areas – for example if a single WDS is required to measure more than one trial section.
Limitations	Provides a measure of the total salt on the road surface, but not how much in solution. Only measures salt on a small point of the carriageway – suggests multiple samples in same location will be required. Portable lighting will be required.
Cost	Costs of bringing equipment and personnel from Sweden.

	Costs for sample analysis.
Availability	Dependent on collaboration with VTI

A.7 Refractive index – manual measurement using hand held refractometer

Assessment Factor	**Comments**
Accuracy and precision	The concentration of samples of salt solution can be measured using a hand held refractometer. However, measurement is only of a very small area of the carriageway and therefore subject to variation. (So many measures in the same general area may be required) Samples will need to be collected from the road surface and placed on the refractometer. e.g. through use of a pipette. Sufficient moisture (wet roads) would be needed to allow collection from the road surface i.e. a wet road surface. On dry and damp surfaces, known amounts of water will need to be added to a known surface area to provide a salt solution. This method will need to be verified and will be subject to loss of liquid into permeable surfacing.
Ease of use	Dependent on development of a suitable method and verification. In principal, it appears that a practical method could be developed.
Speed of measurement	Dependent on the method developed, and requirement for addition of water to the surface. Potential for a quick measurement. May be relatively slow due to complexity and need to add water.
Limitations	If measurements from solution already present on the road surface:

	• dependent on a wet road surface • measurement only from one small point on the road – many measurements will be needed to provide a representative measurement. • Other pollutants may affect the readings Portable lighting will be required.
Cost	Relatively low cost
Availability	Hand held refractometers are relatively inexpensive and readily available.

A.8 Mobile measurement techniques

Spectroscopic

An experimental, vehicle based system developed in France (Mario Marchetti, CÉTÉ de l'Est – Laboratoire Régional des Ponts et Chaussées de Nancy).

The system measures the concentration of salt solution on the road, using a spectroscopic tool. Measurements to date have been reported with a 25 m-spatial frequency, and carried out at a speed consistent with spreader speeds.

Measurement of spray

Yamada Giken Co.,Ltd have developed a vehicle based system for measuring the salt concentration of surface spray based on measurement of the refractive index of road spray from the vehicle tyres.

Combitech manufacture the ‘Frensor’ vehicle mounted freezing point sensor. Spray from the vehicle tyres is collected and the freezing point measured using a Peltier element.

Both systems can only work when the road is wet and will only provide a measure of the salt concentration of the road surface moisture, not the amount of salt which will depend on the amount of water present on the road surface.

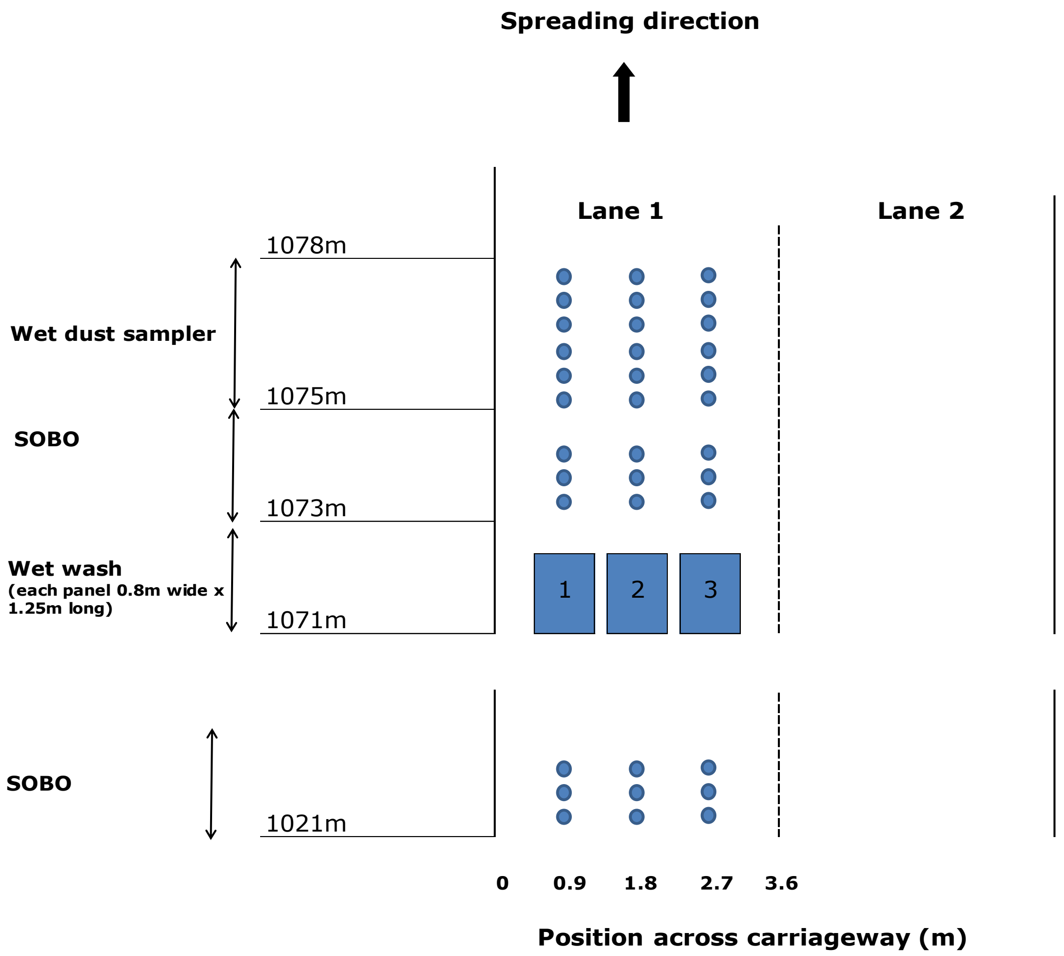
Luminescence

An experimental technique has been developed in Spain – this measures dry salt so is not considered applicable to this trial

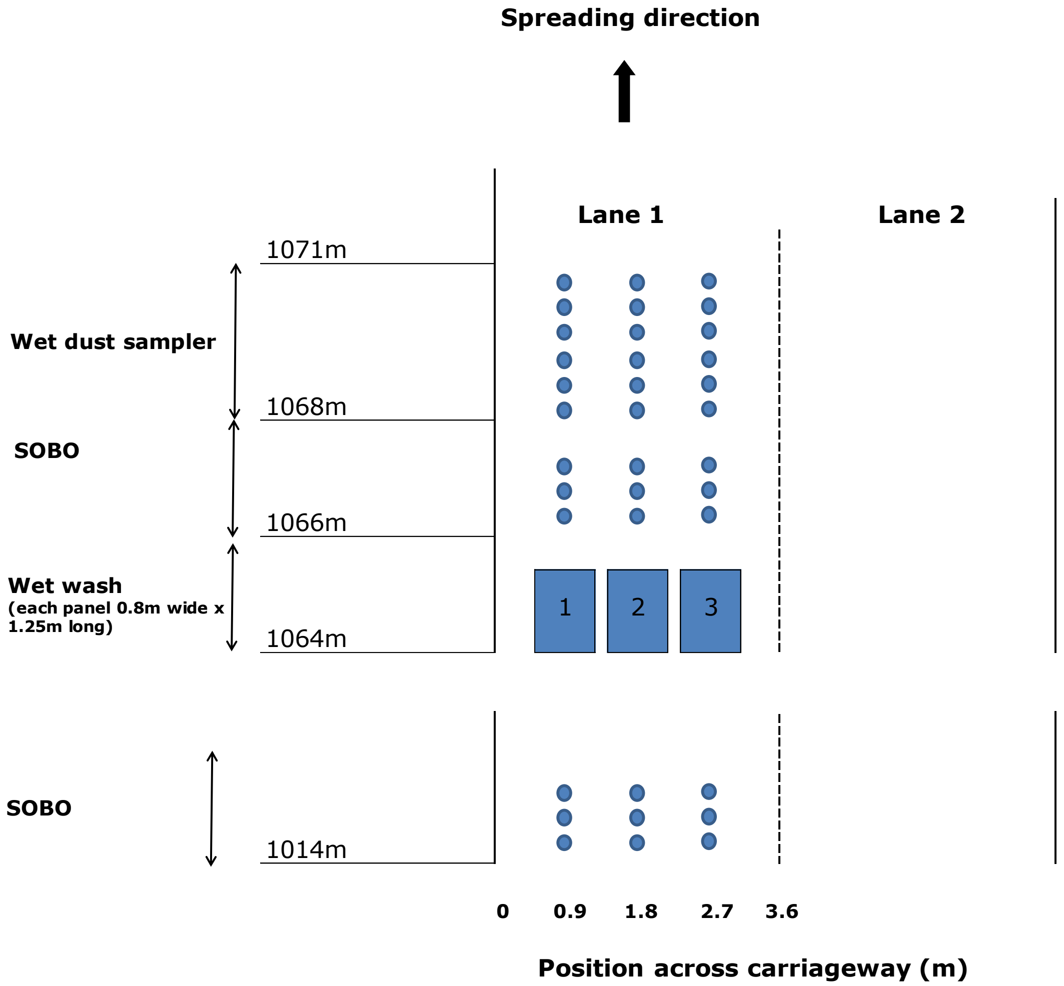
Appendix B Details of measurement locations

B.1 A1 Trial

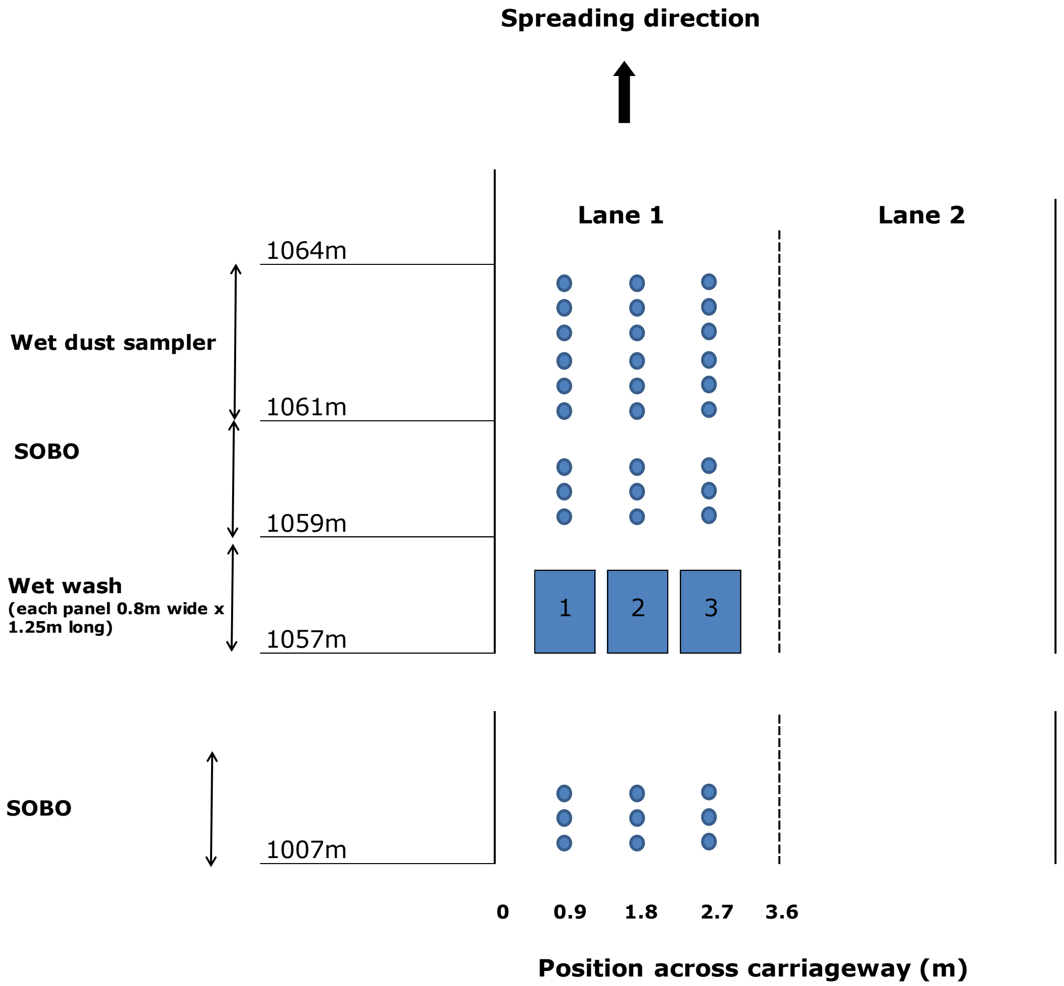
B.1.1 Background



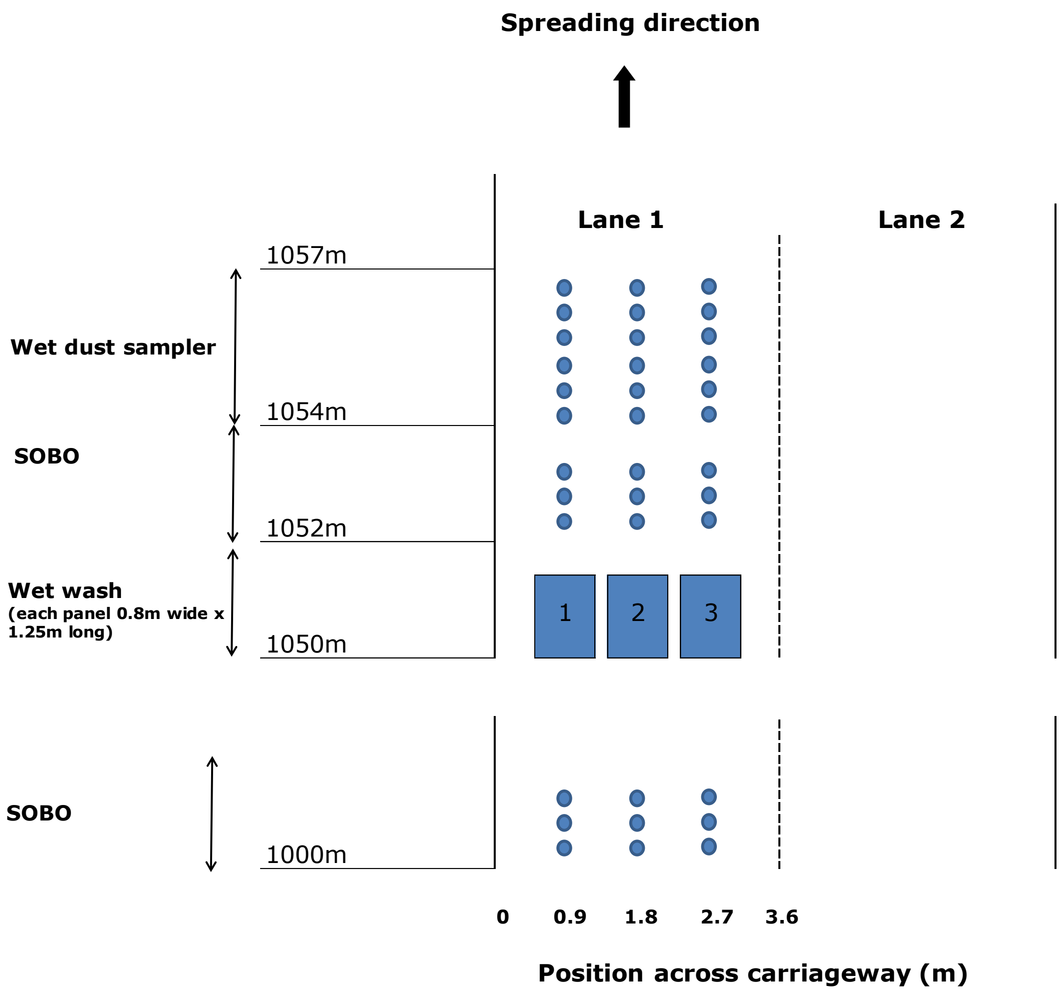
B.1.2 Immediately after spreading



B.1.3 After 1st period of trafficking

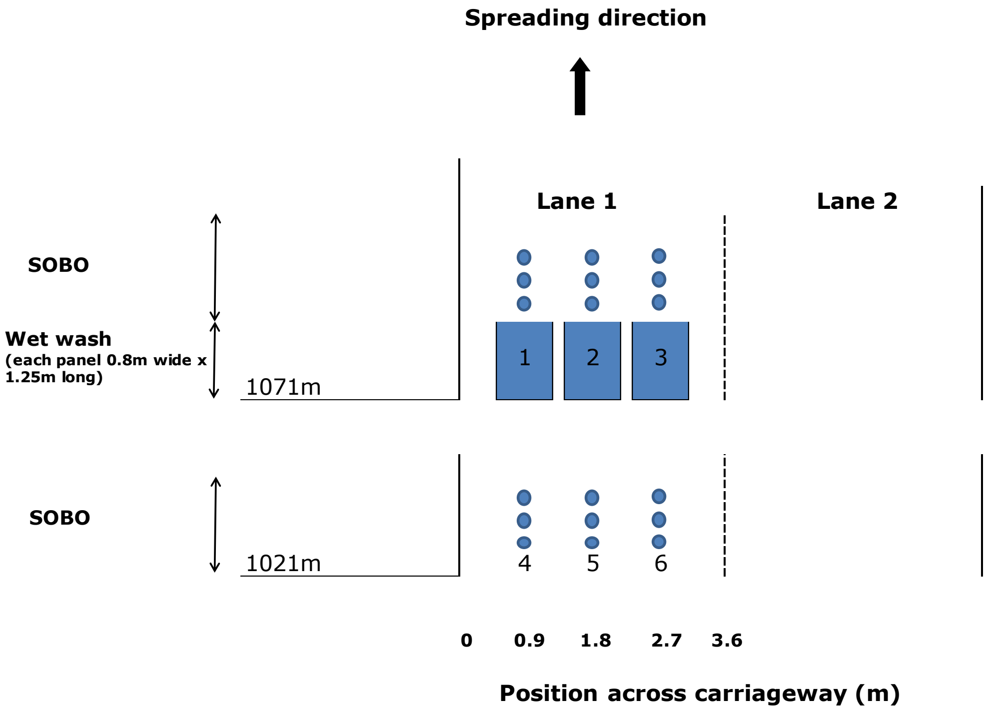


B.1.4 After 2nd period of trafficking

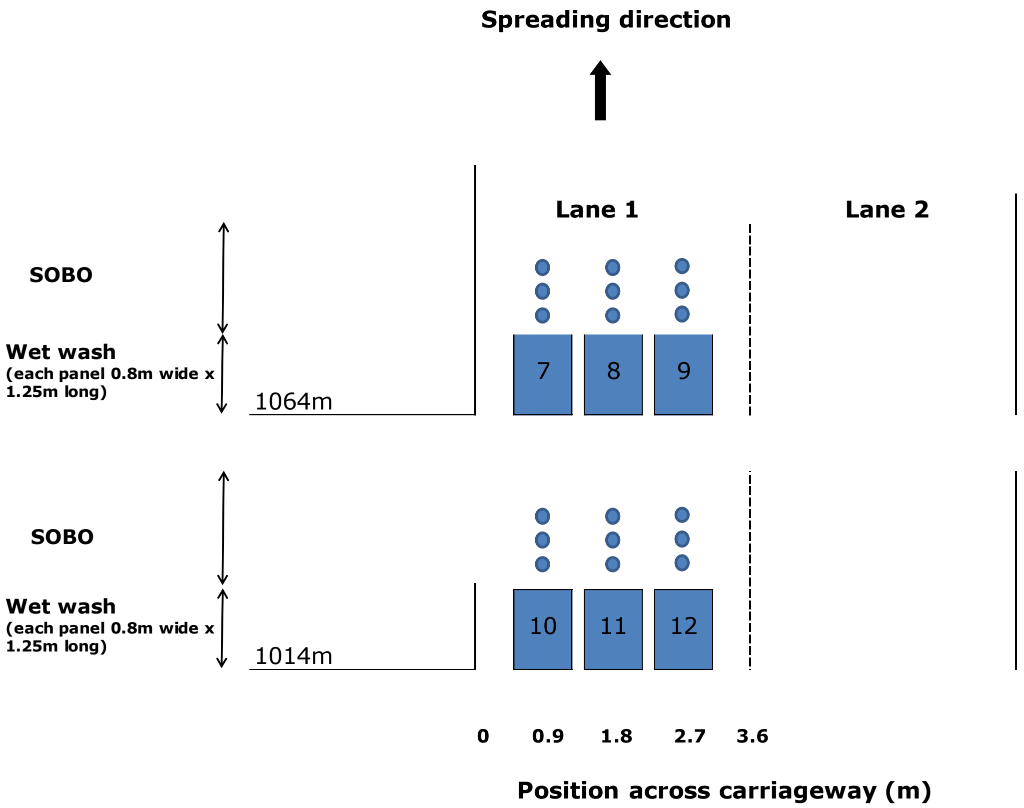


B.2 A9 Trial

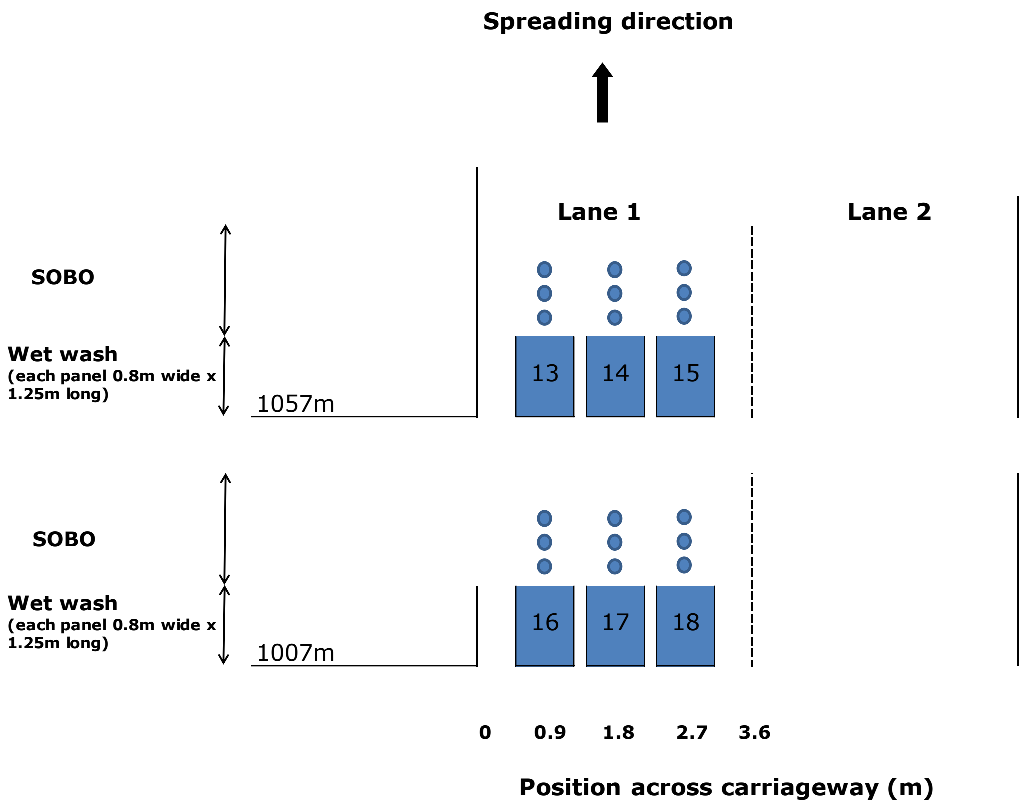
B.2.1 Background



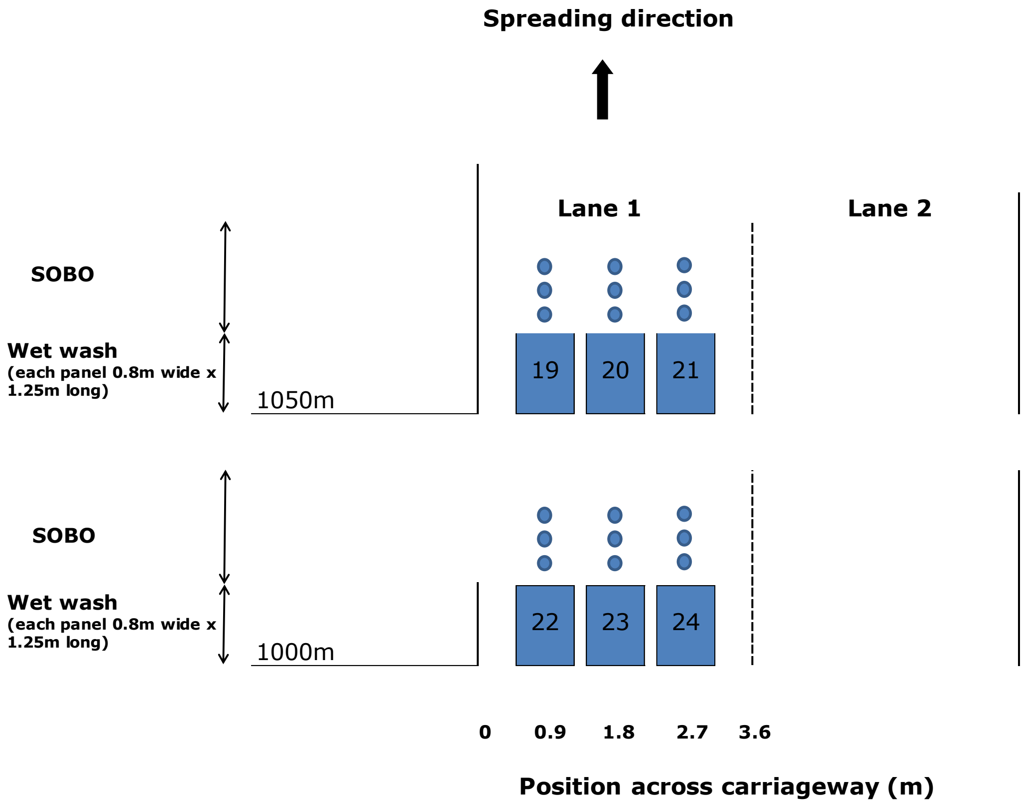
B.2.2 Immediately after spreading



B.2.3 After 1st period of trafficking

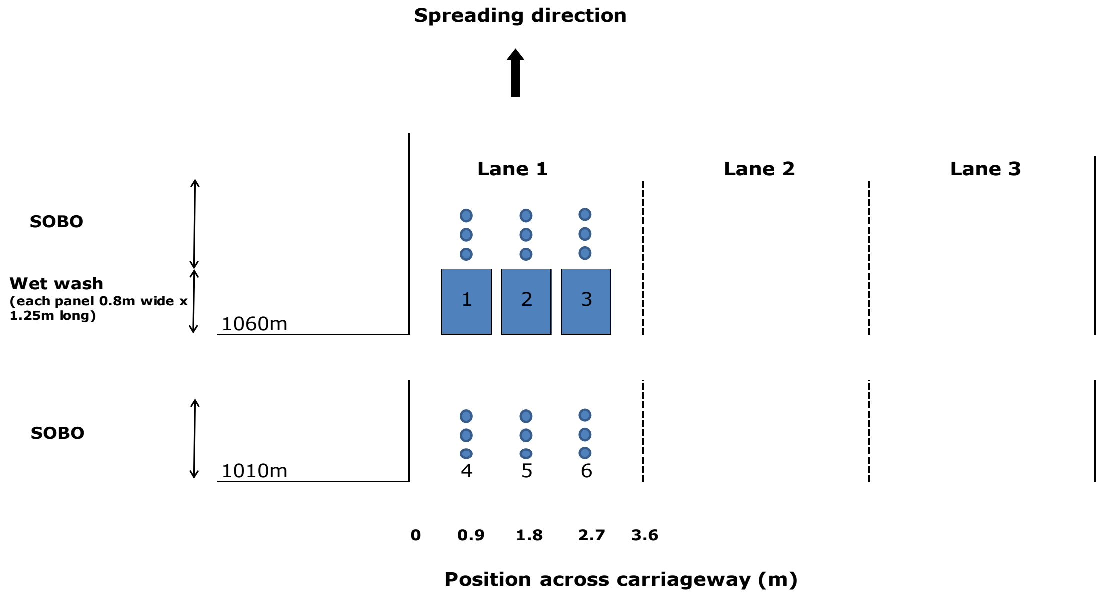


B.2.4 After second period of trafficking

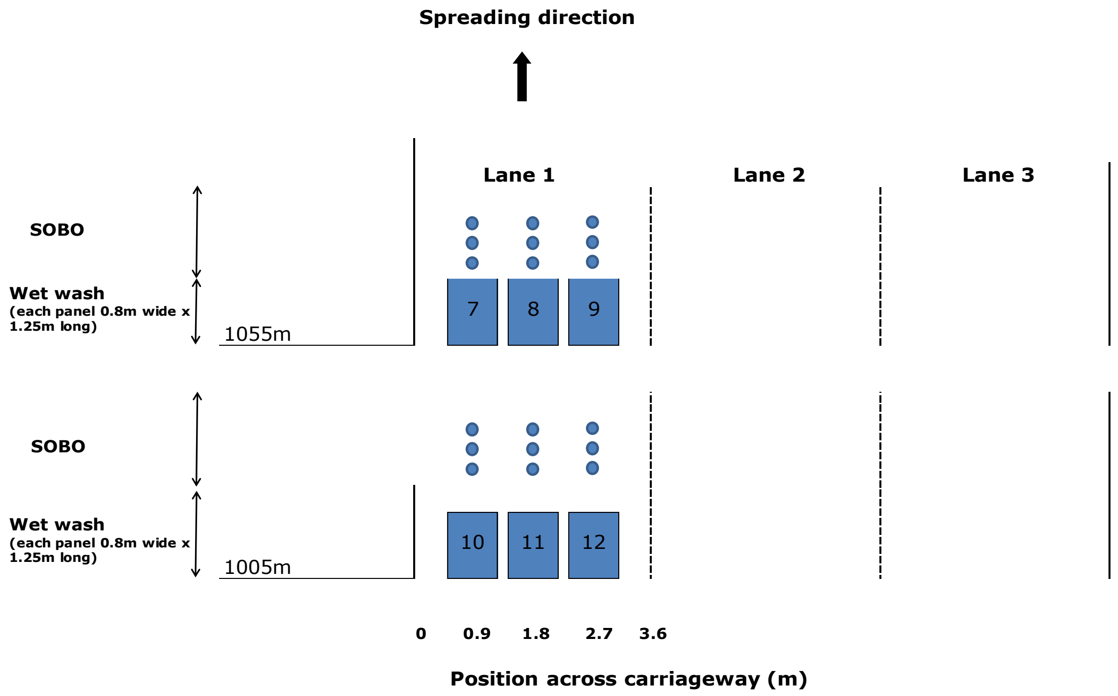


B.3 M27 Trial

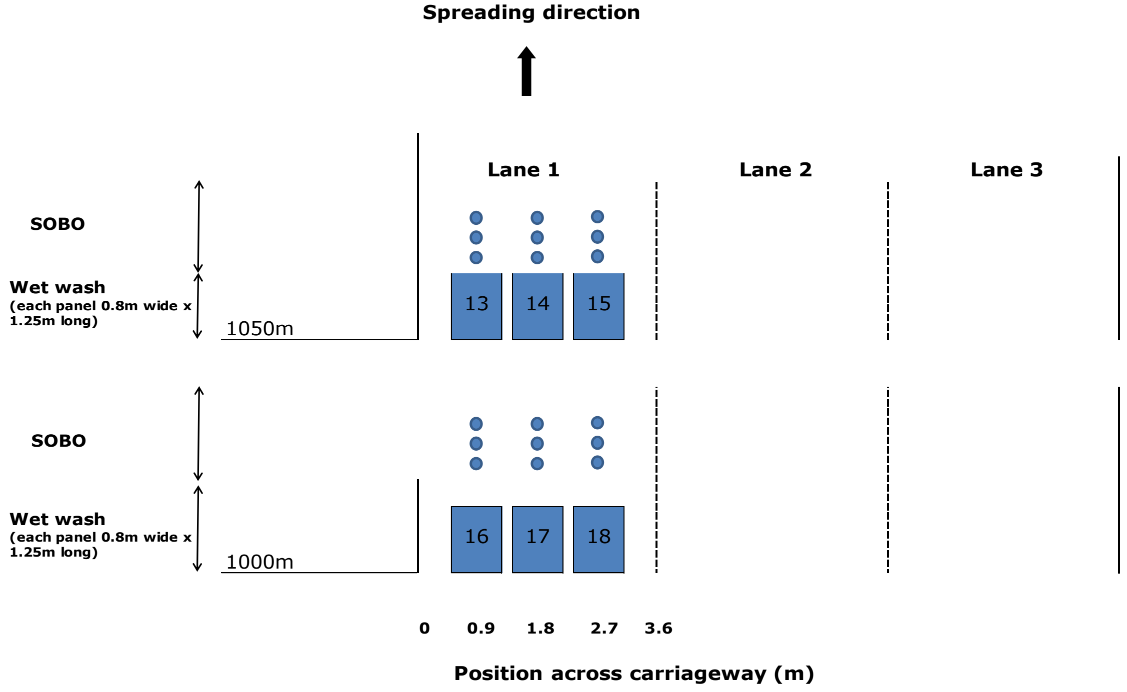
B.3.1 Background



B.3.2 Immediately after spreading



B.3.3 After 1st trafficking period



Appendix C Comparison of measurement methods

C.1 A1 Trial 1

Brine Spread rate = 20g/m²

Pre-wet spread rate = 10g/m²

C.1.1 Brine

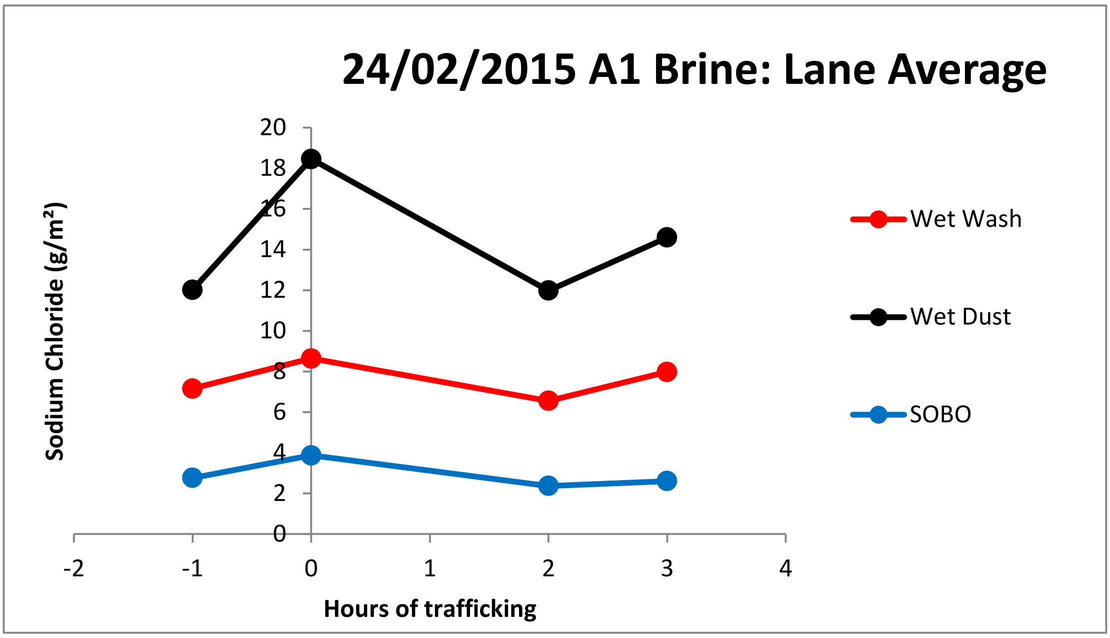


Figure 23. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

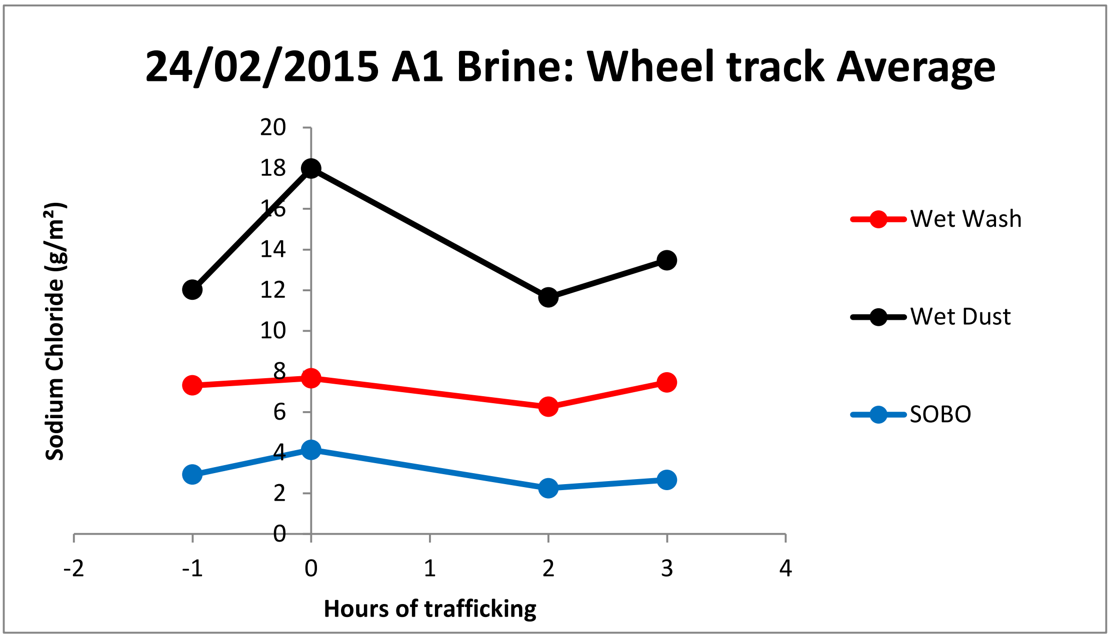


Figure 24. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

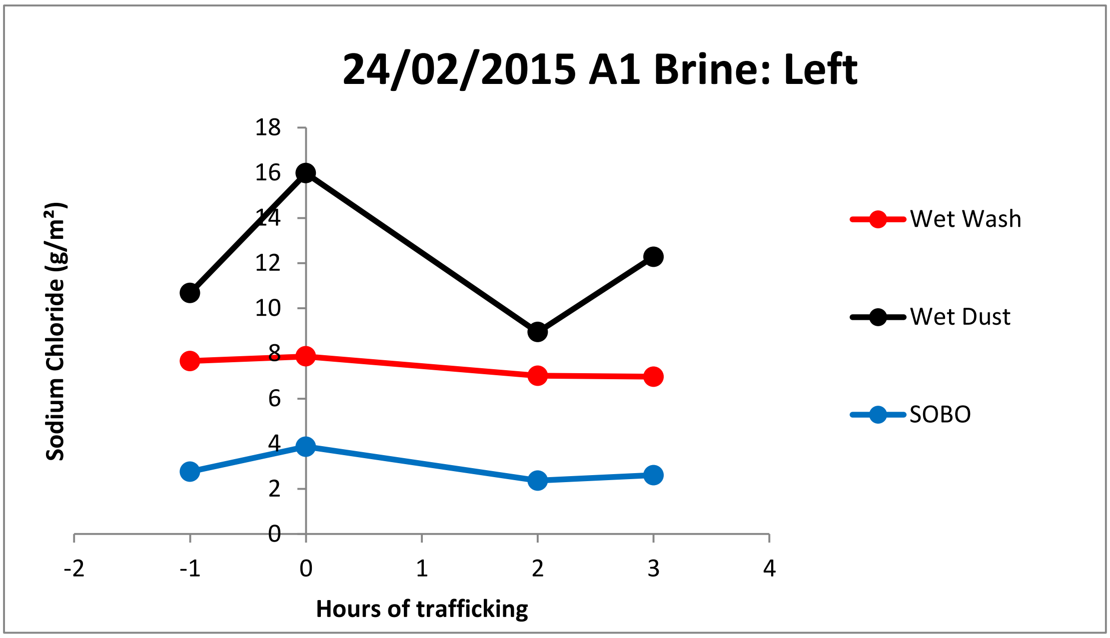


Figure 25. A1 Trial 1 residual salt variation with trafficking for left wheel track

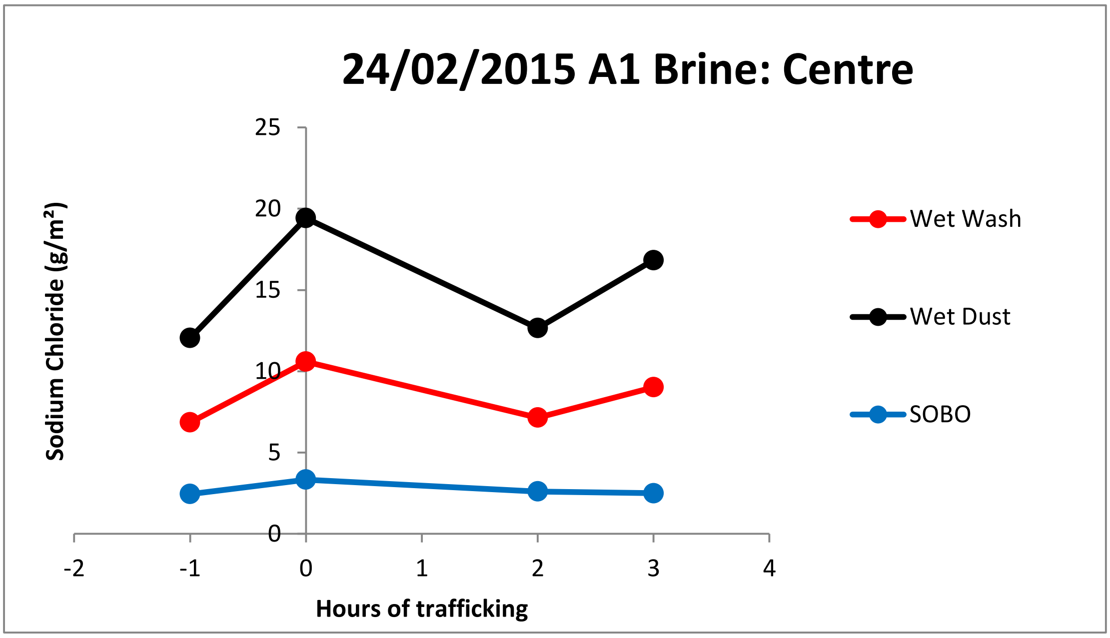


Figure 26. A1 Trial 1 residual salt variation with trafficking for centre of lane

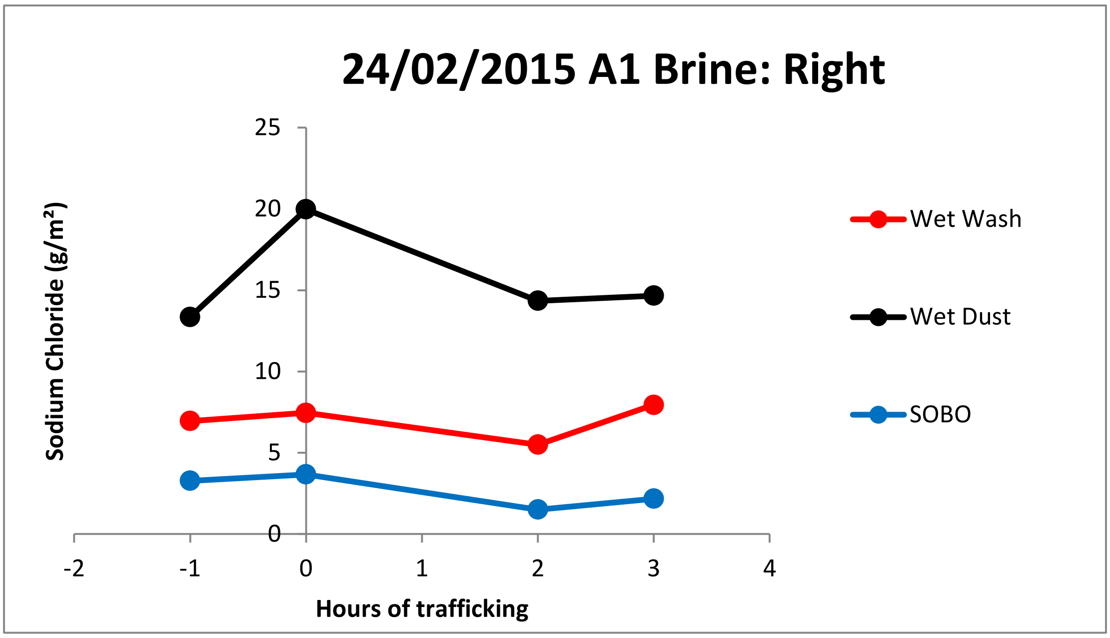


Figure 27. A1 Trial 1 residual salt variation with trafficking for right wheel track

C.1.2 Pre-wetted

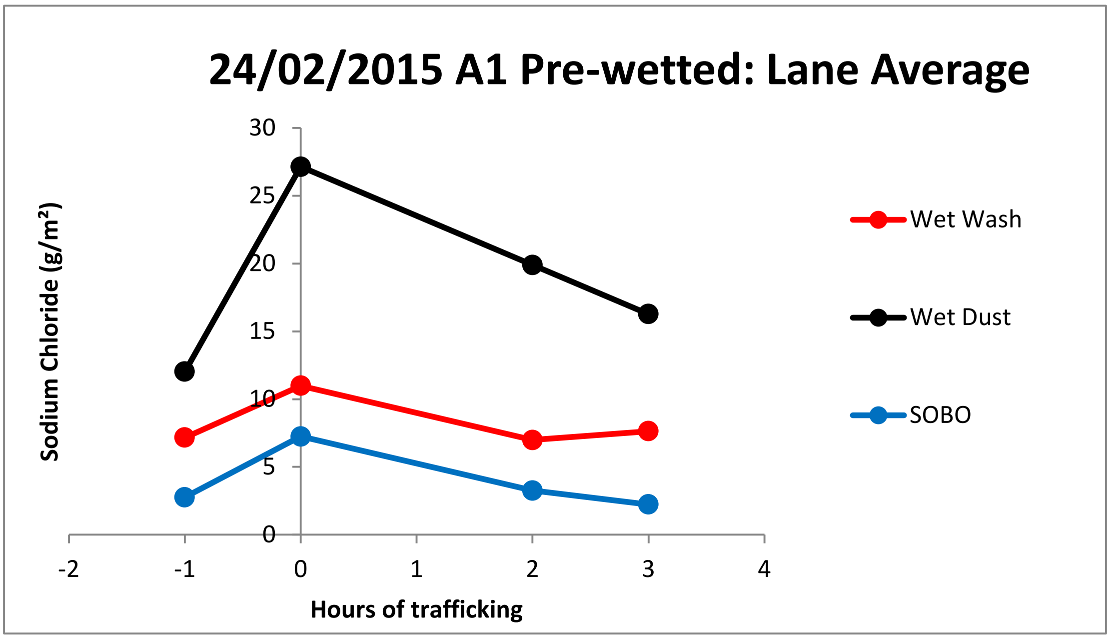


Figure 28. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

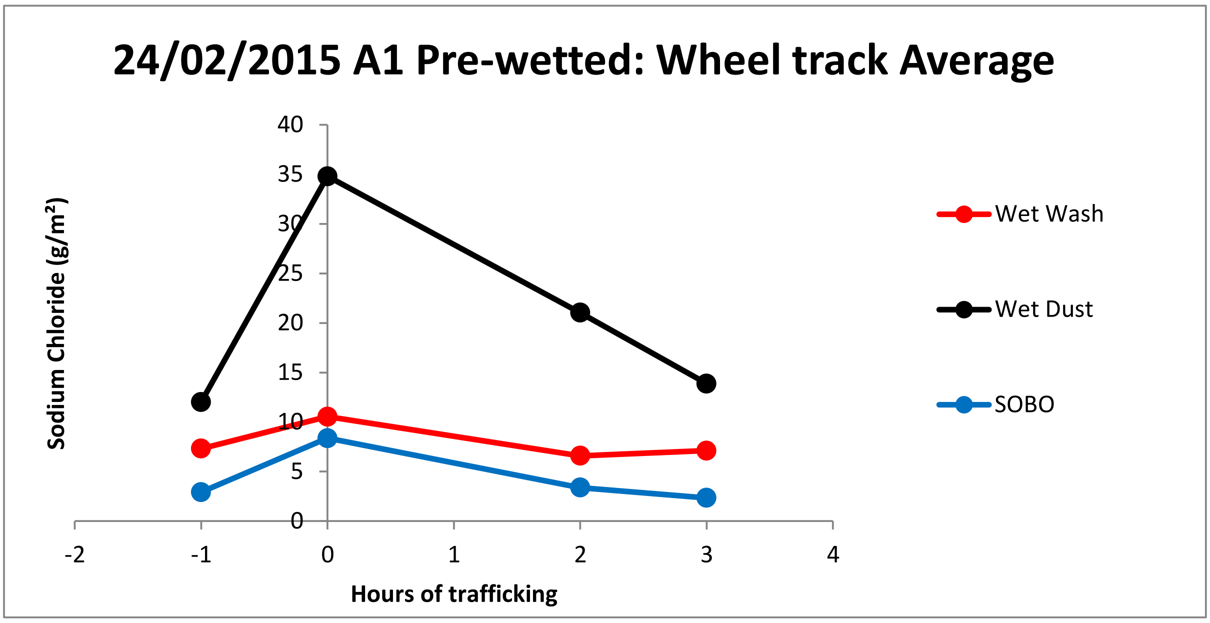


Figure 29. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

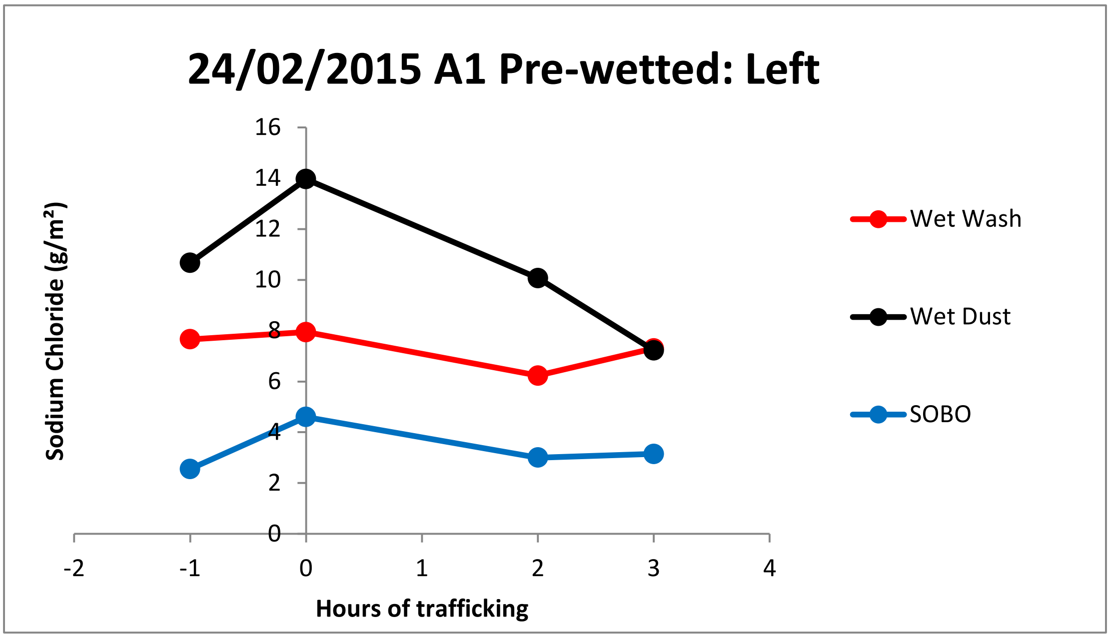


Figure 30. A1 Trial 1 - residual salt variation with trafficking for left wheel track

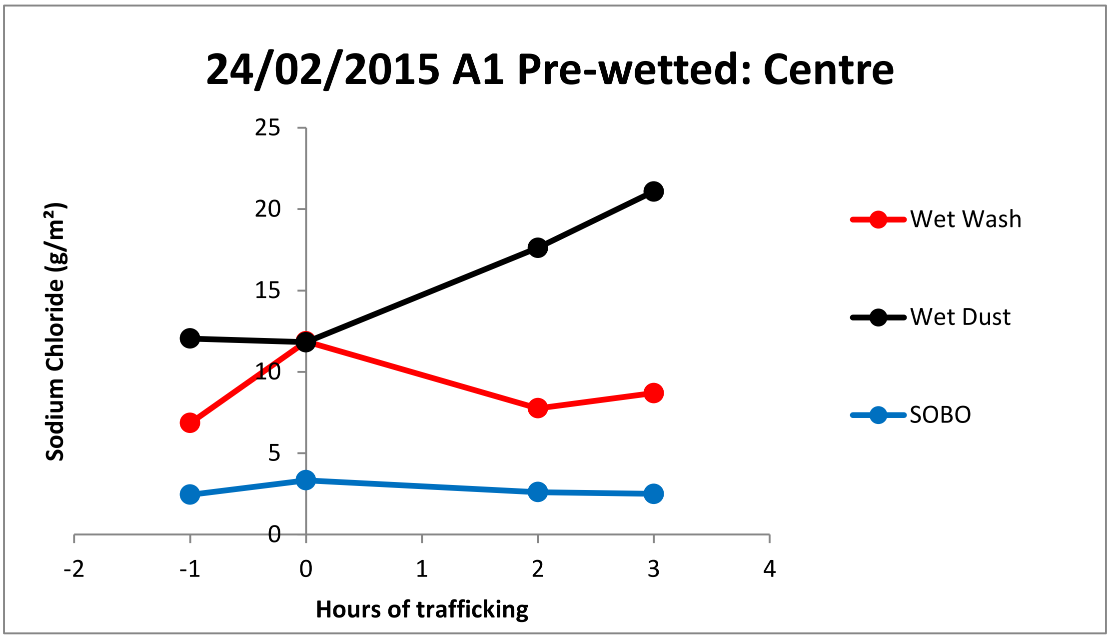


Figure 31. A1 Trial 1 Brine - residual salt variation with trafficking for centre of lane

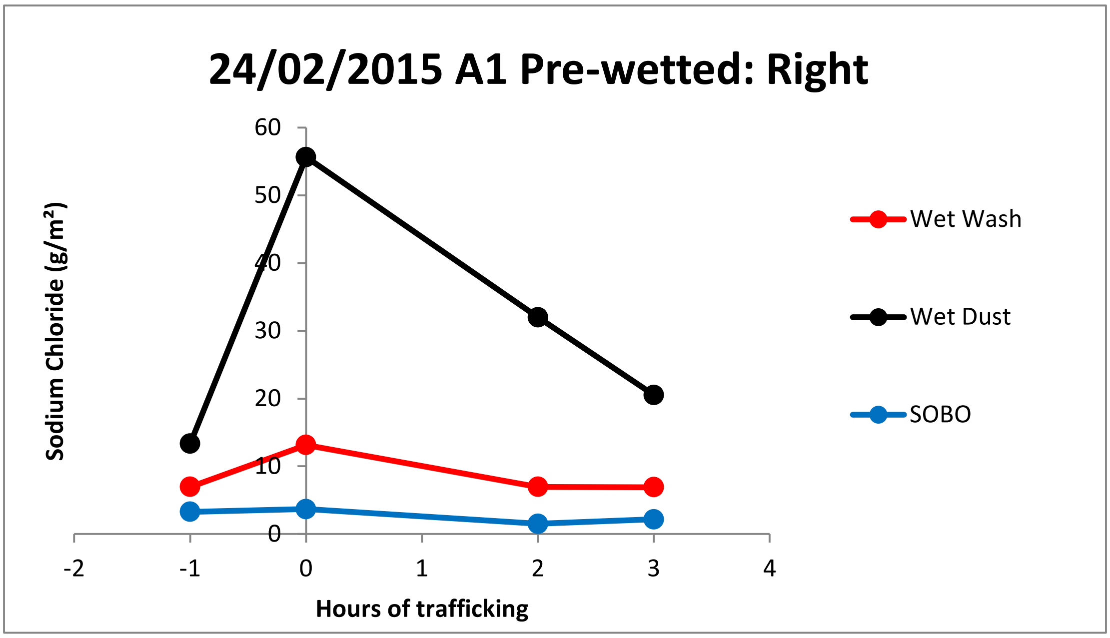


Figure 32. A1 Trial 1 Brine - residual salt variation with trafficking for right wheel track

C.2 A1 Trial 2

Brine Spread rate = 40g/m² (2 passes at 20g/m²)

Pre-wet spread rate = 20g/m² (2 passes at 10 g/m²)

C.2.1 Brine

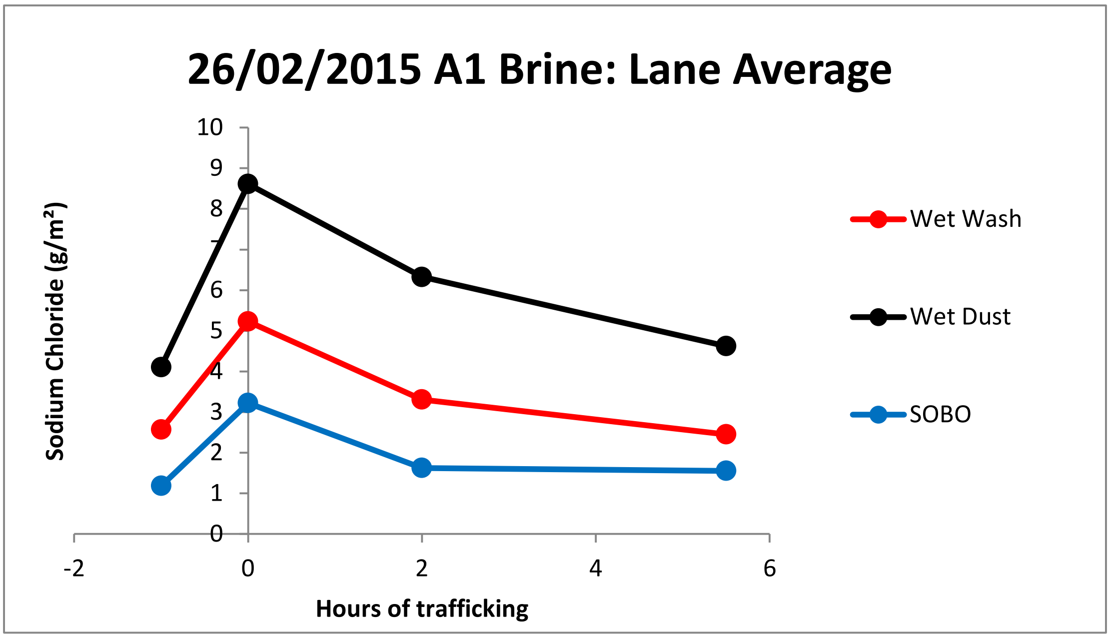


Figure 33. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

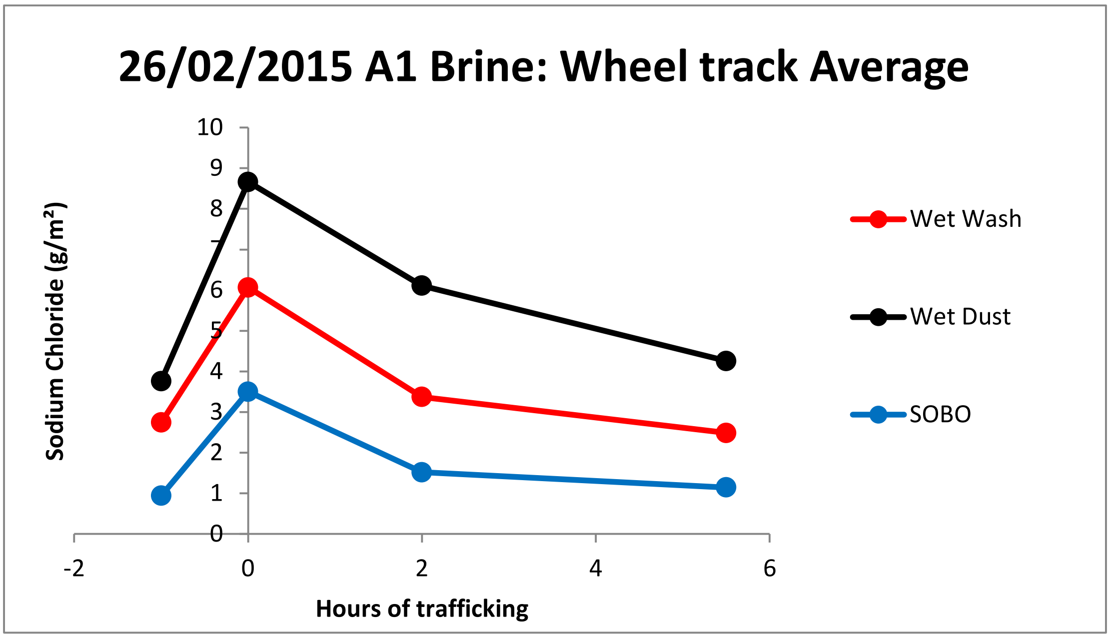


Figure 34. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

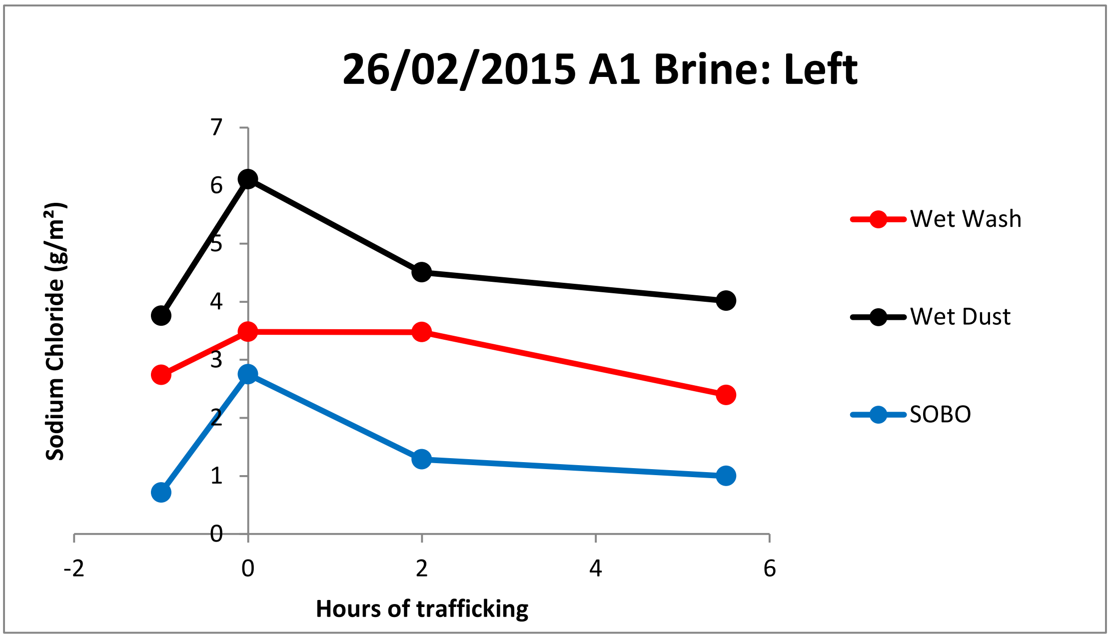


Figure 35. A1 Trial 1 residual salt variation with trafficking for left wheel track

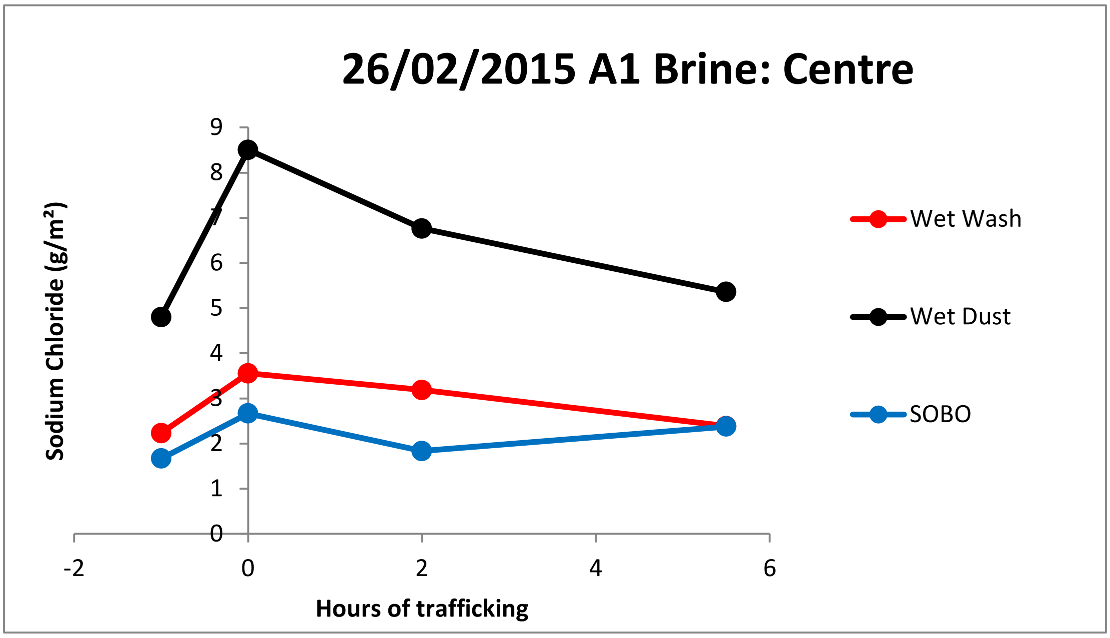


Figure 36. A1 Trial 1 residual salt variation with trafficking for centre of lane

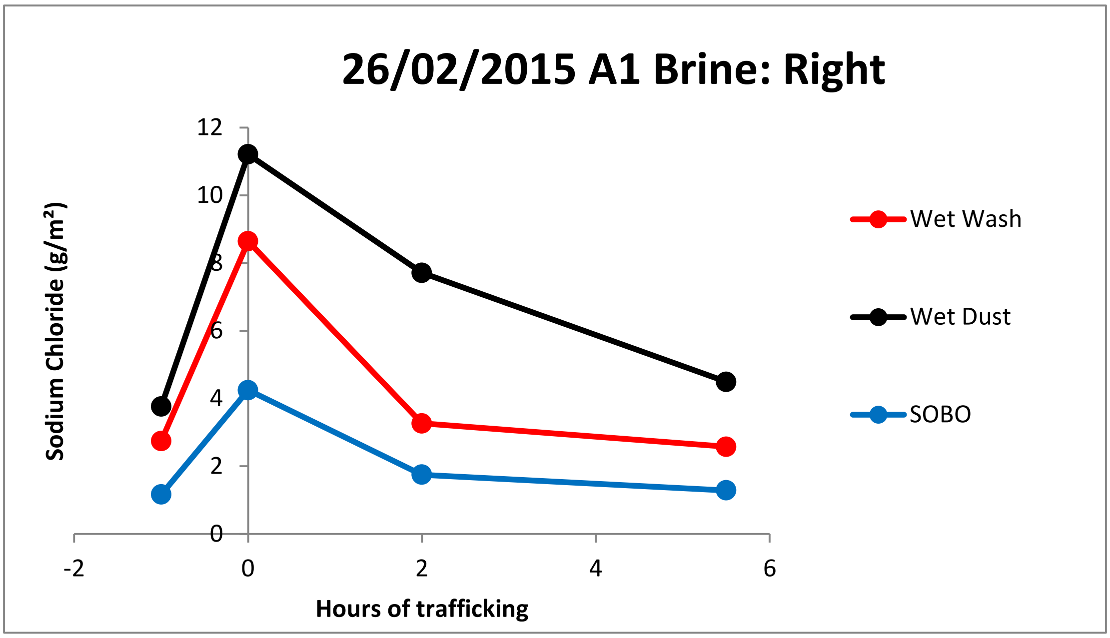


Figure 37. A1 Trial 1 residual salt variation with trafficking for right wheel track

C.2.2 Pre-wetted

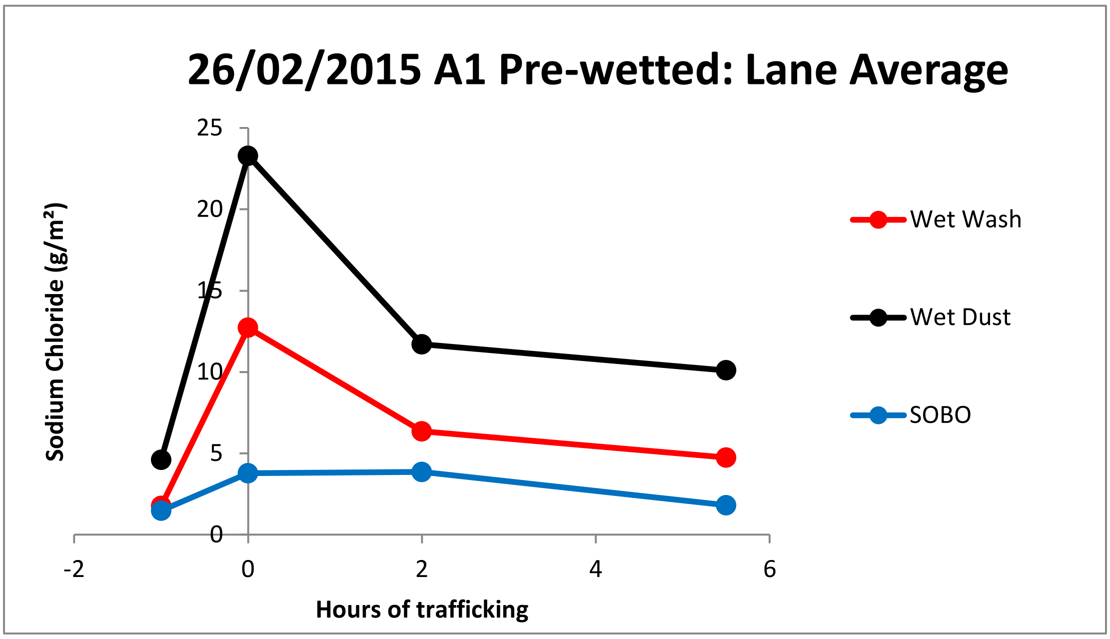


Figure 38. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

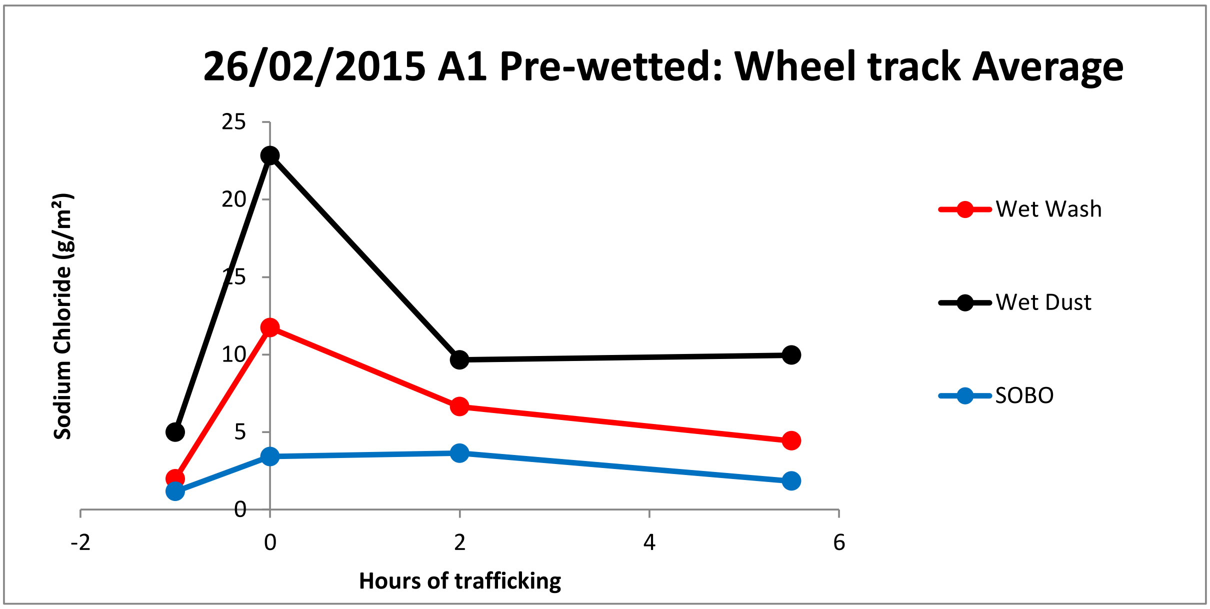


Figure 39. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

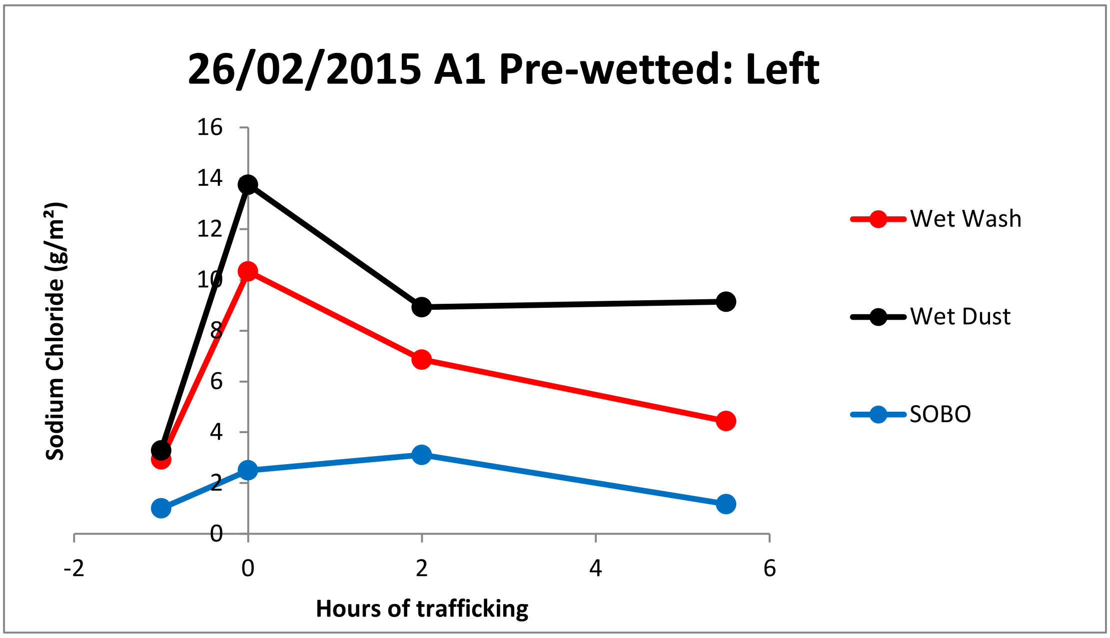


Figure 40. A1 Trial 1 - residual salt variation with trafficking for left wheel track

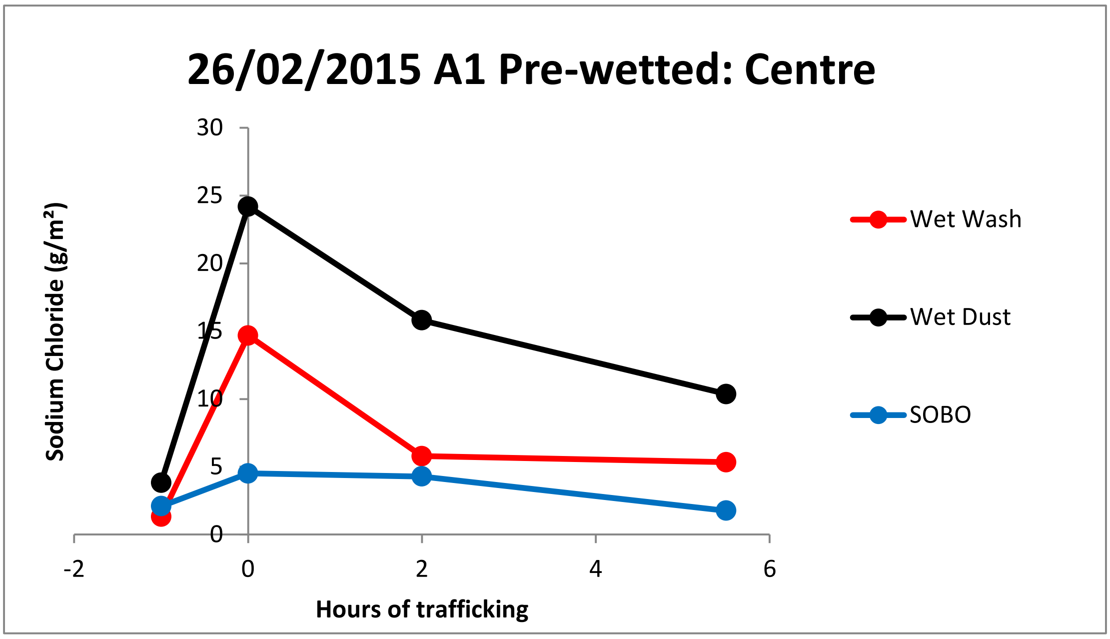


Figure 41. A1 Trial 1 Brine - residual salt variation with trafficking for centre of lane

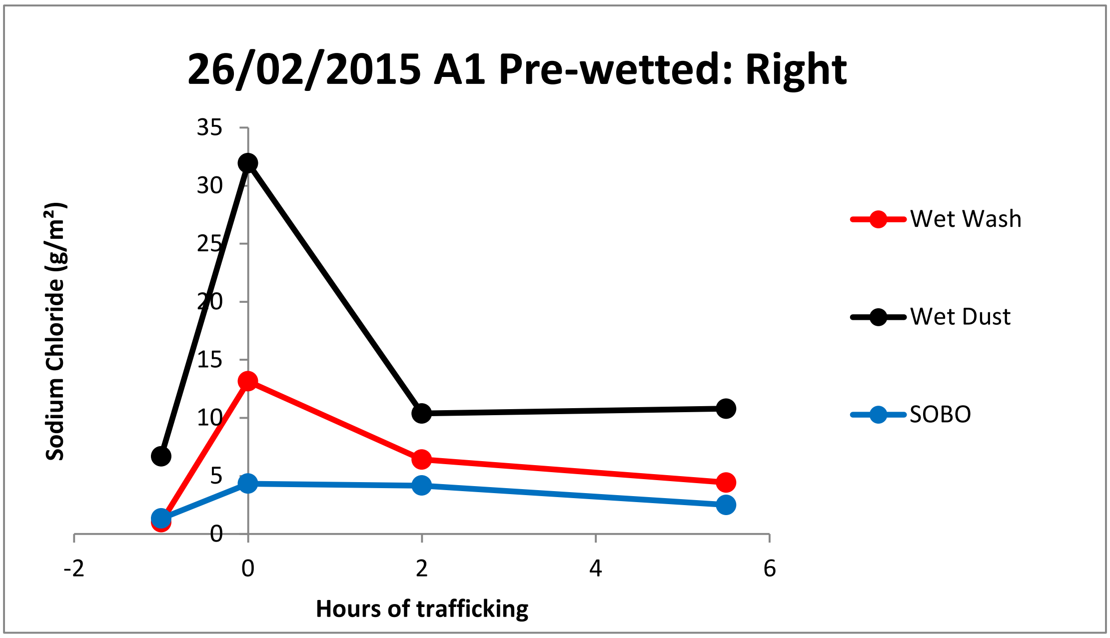


Figure 42. A1 Trial 1 Brine - residual salt variation with trafficking for right wheel track

C.3 A9

Brine Spread rate = 20g/m²

Pre-wet spread rate = 10g/m²

C.3.1 Brine

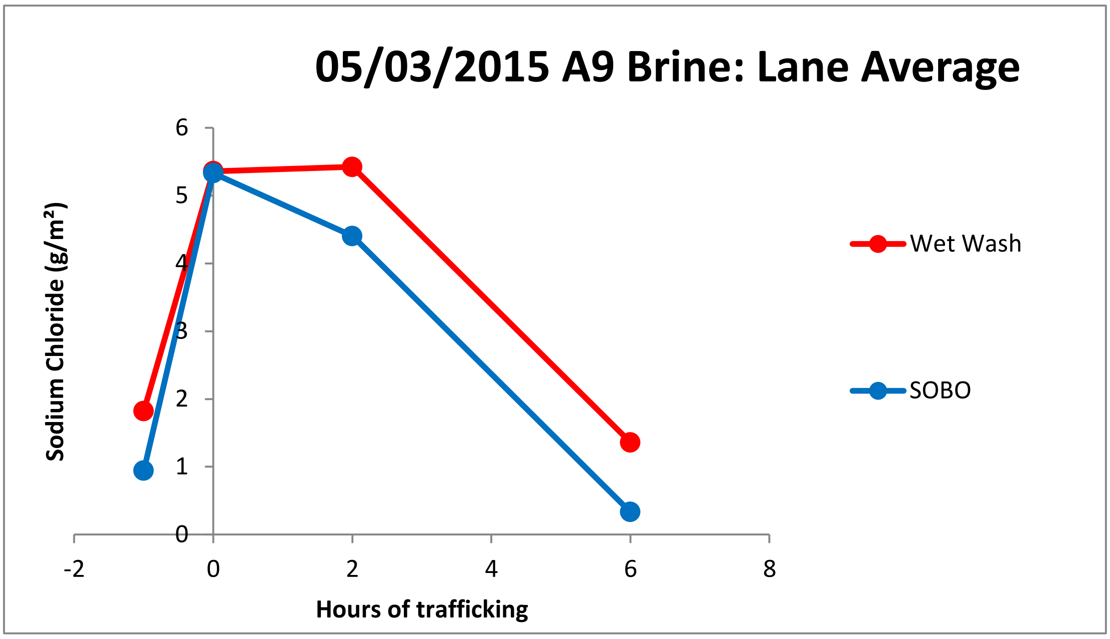


Figure 43. A9 residual salt variation with trafficking, average for Lane 1

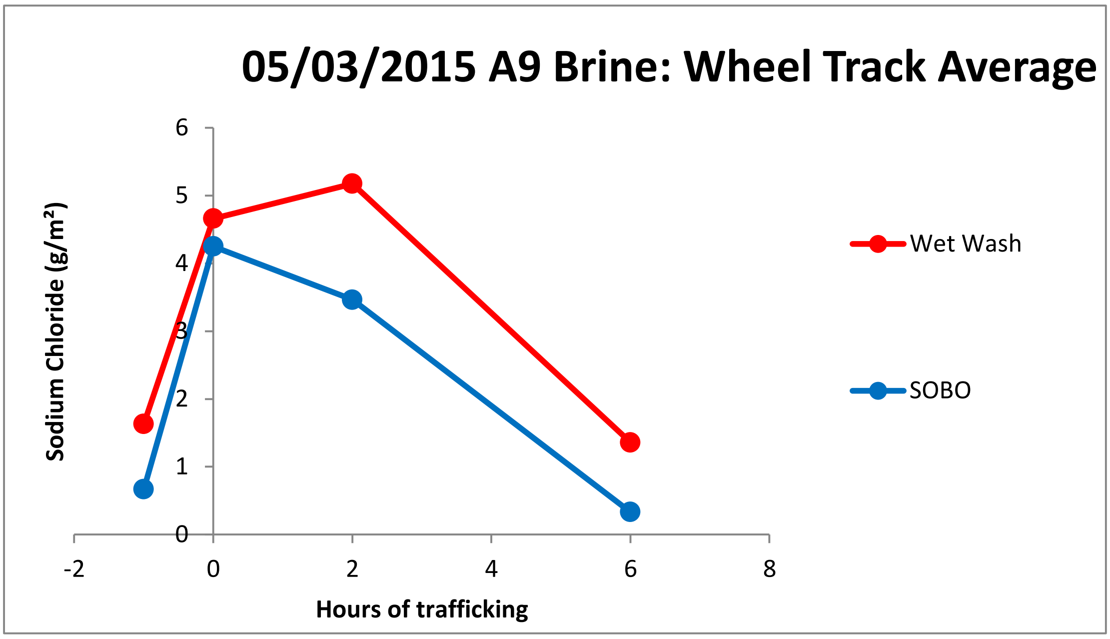


Figure 44. A9 residual salt variation with trafficking, average for wheel tracks

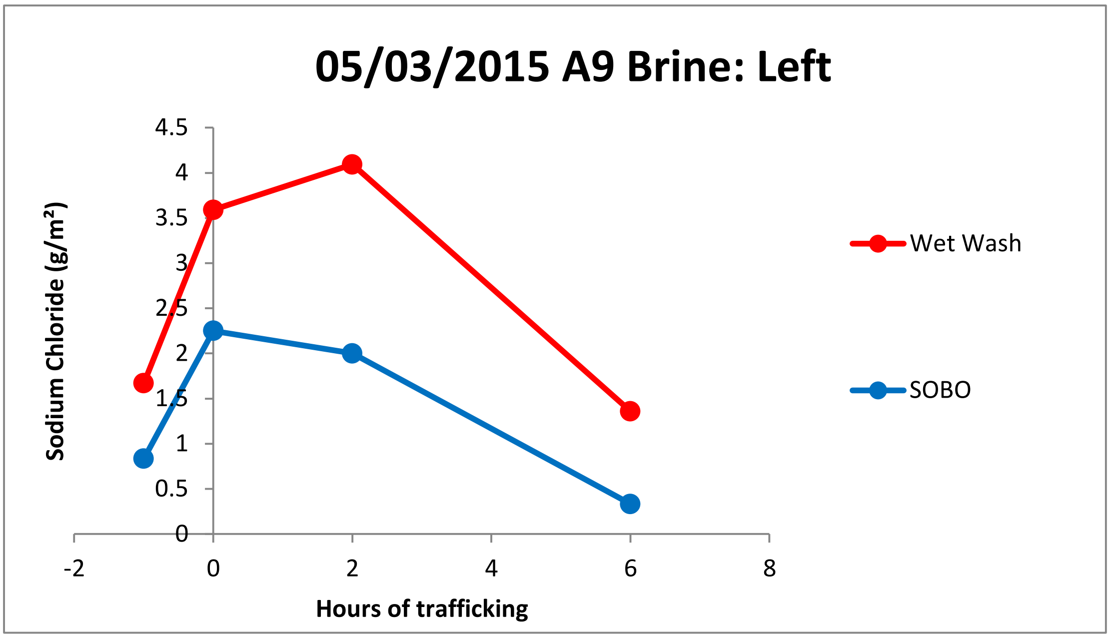


Figure 45. A1 Trial 1 residual salt variation with trafficking for left wheel track

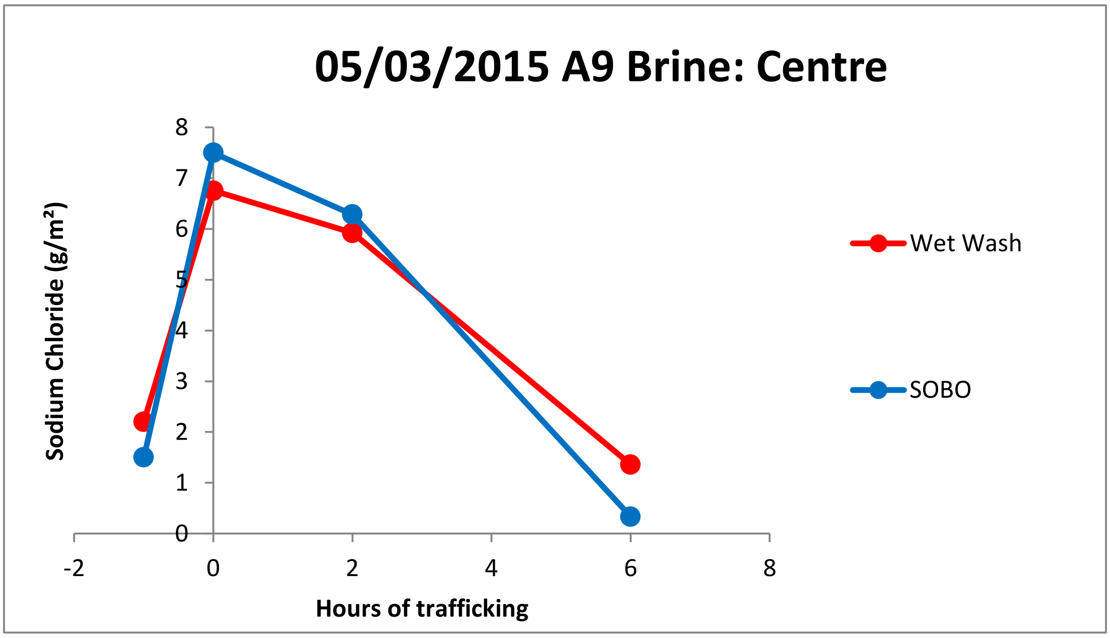


Figure 46. A1 Trial 1 residual salt variation with trafficking for centre of lane

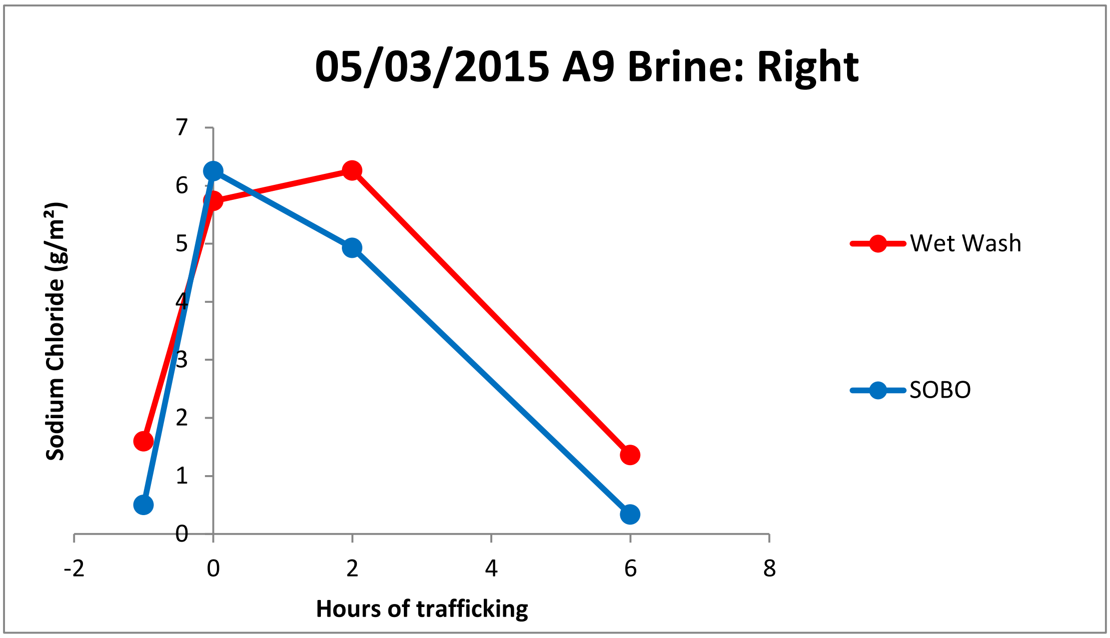


Figure 47. A1 Trial 1 residual salt variation with trafficking for right wheel track

C.3.2 Pre-wetted

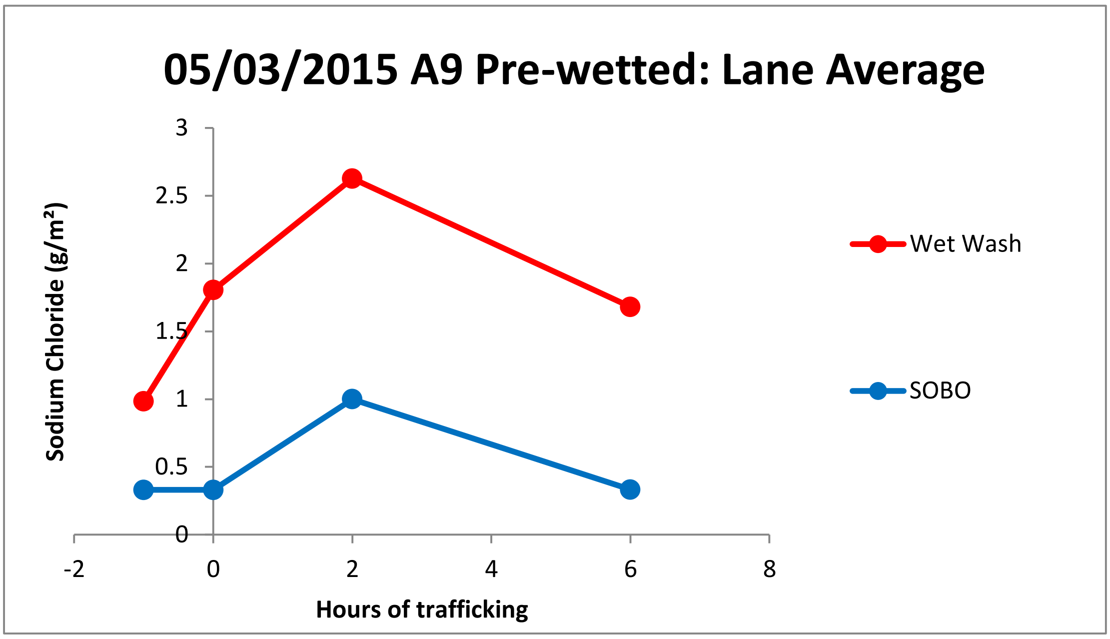


Figure 48. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

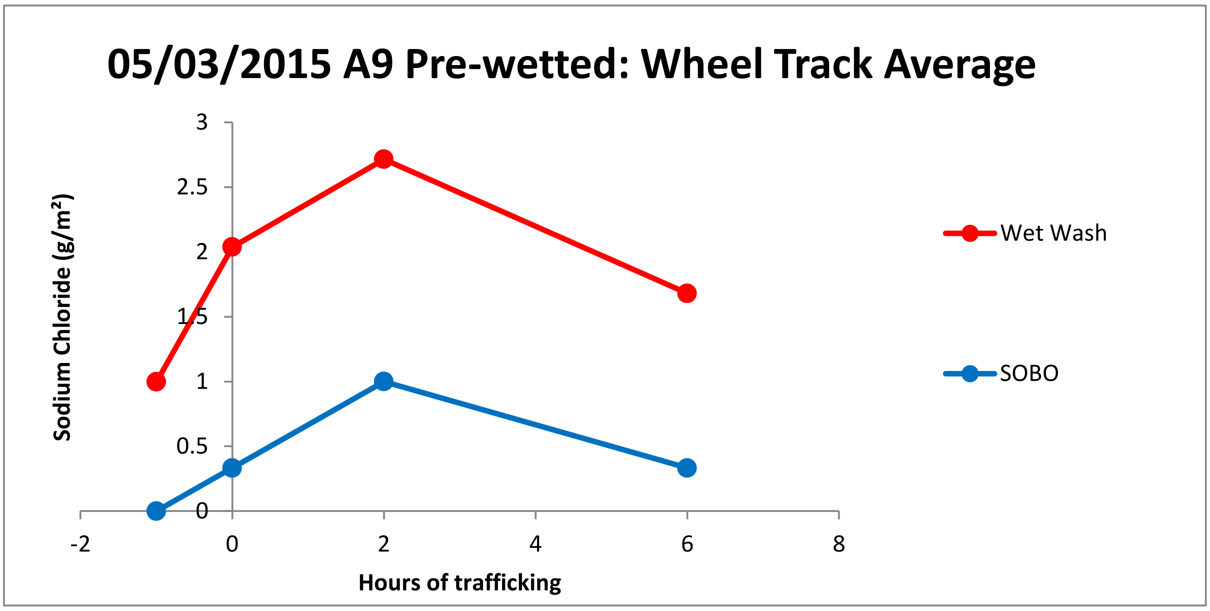


Figure 49. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

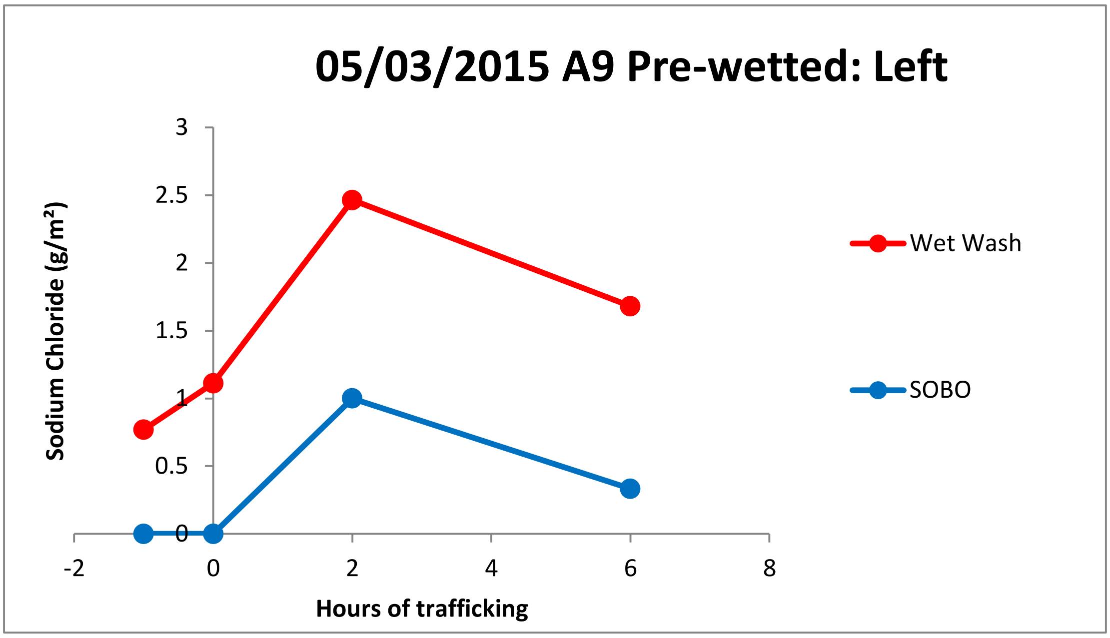


Figure 50. A1 Trial 1 - residual salt variation with trafficking for left wheel track

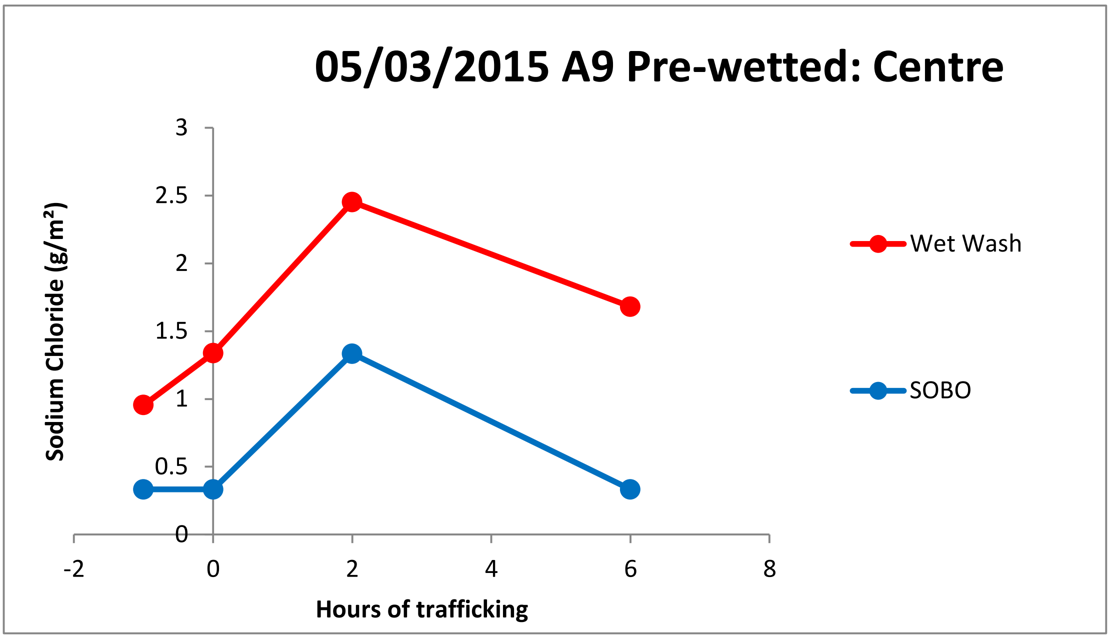


Figure 51. A1 Trial 1 Brine - residual salt variation with trafficking for centre of lane

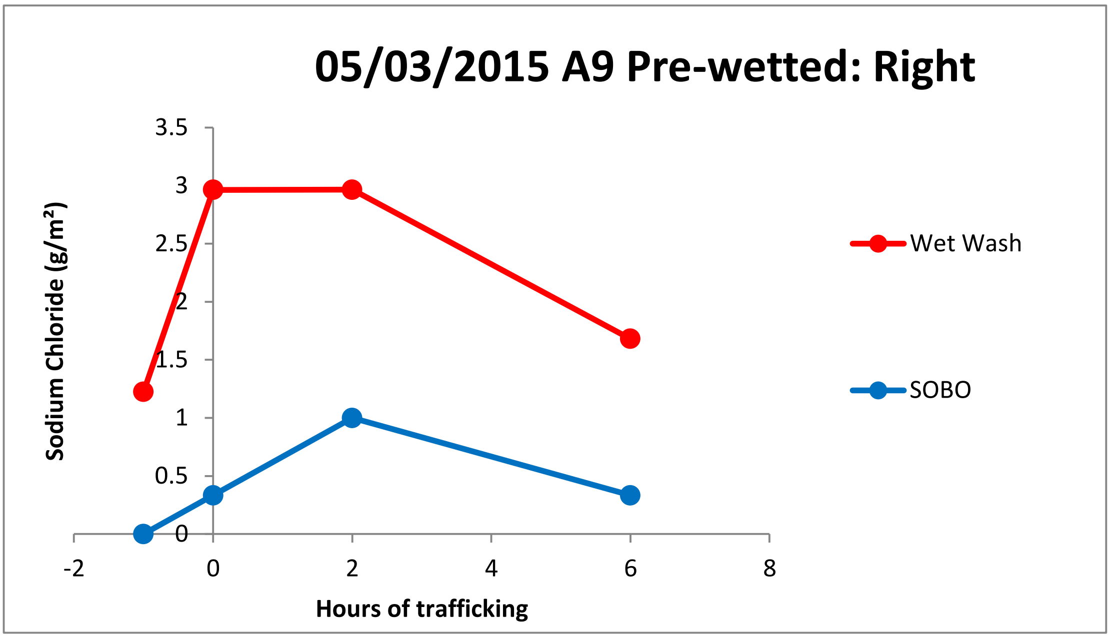


Figure 52. A1 Trial 1 Brine - residual salt variation with trafficking for right wheel track

C.4 M27

Brine Spread rate = 20g/m²

Pre-wet spread rate = 10g/m²

C.4.1 Brine

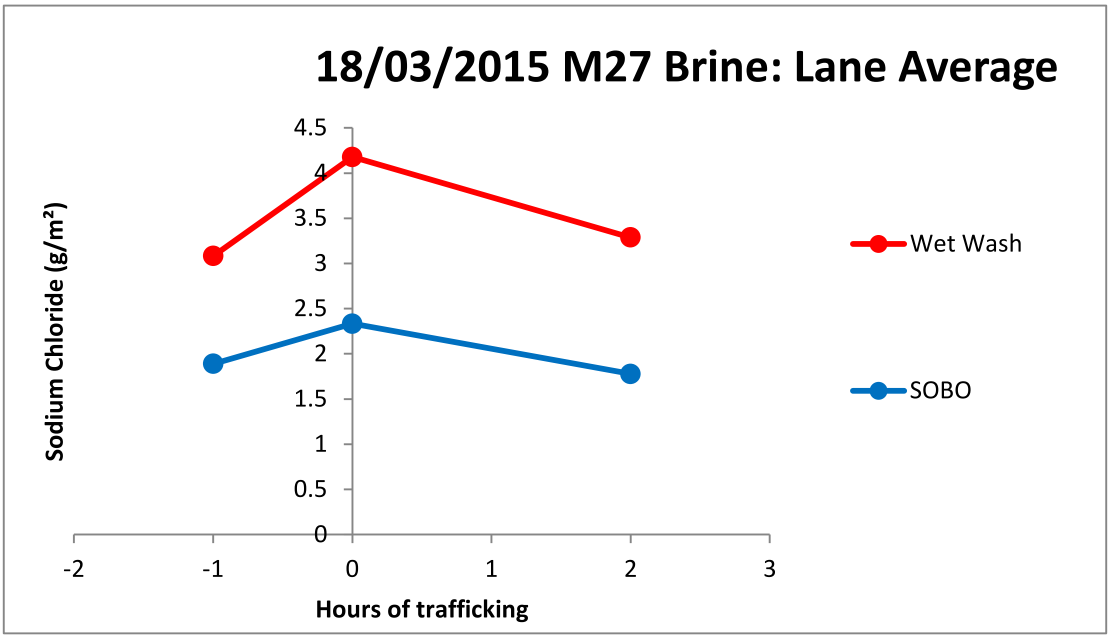


Figure 53. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

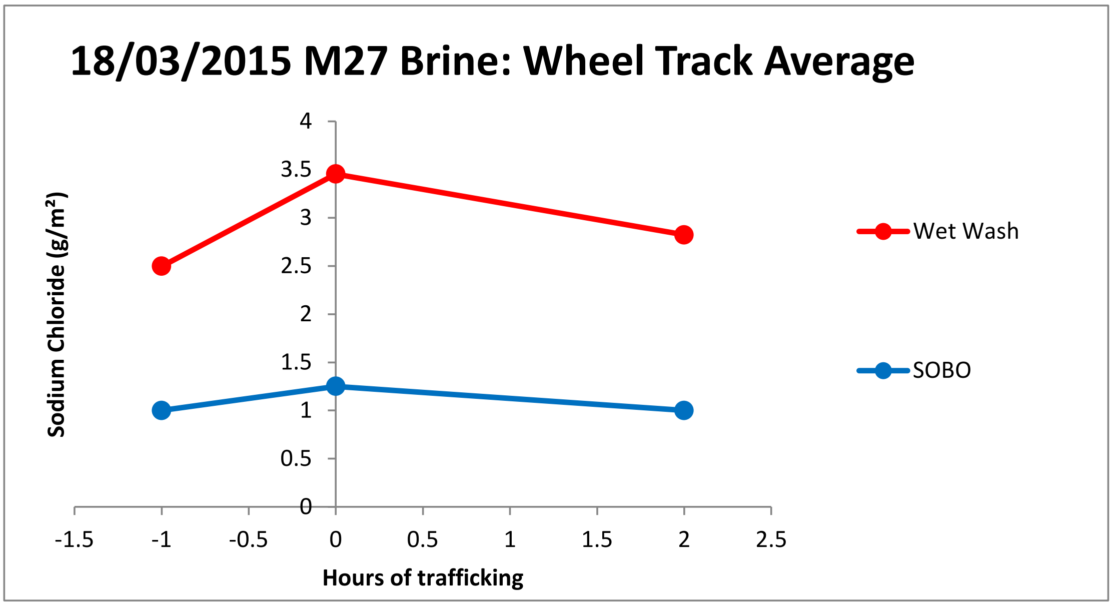


Figure 54. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

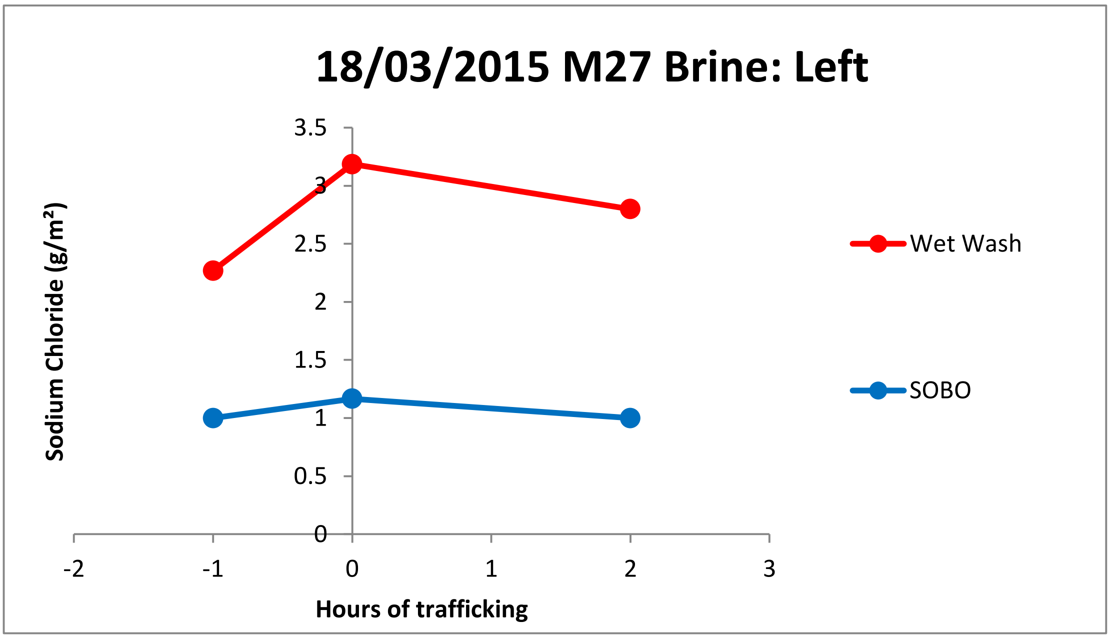


Figure 55. A1 Trial 1 residual salt variation with trafficking for left wheel track

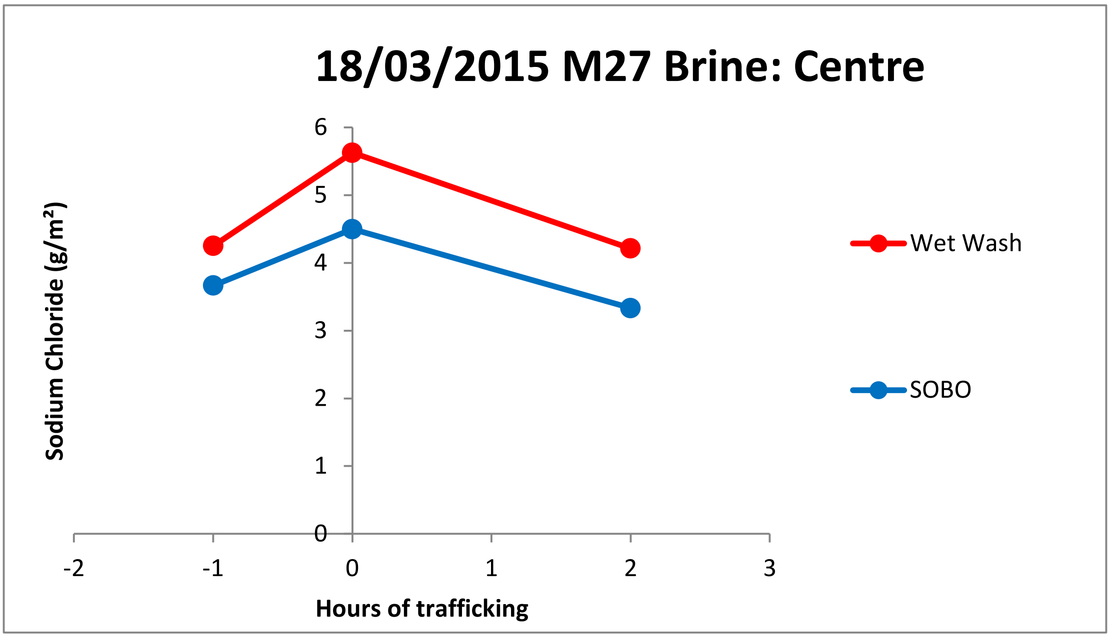


Figure 56. A1 Trial 1 residual salt variation with trafficking for centre of lane

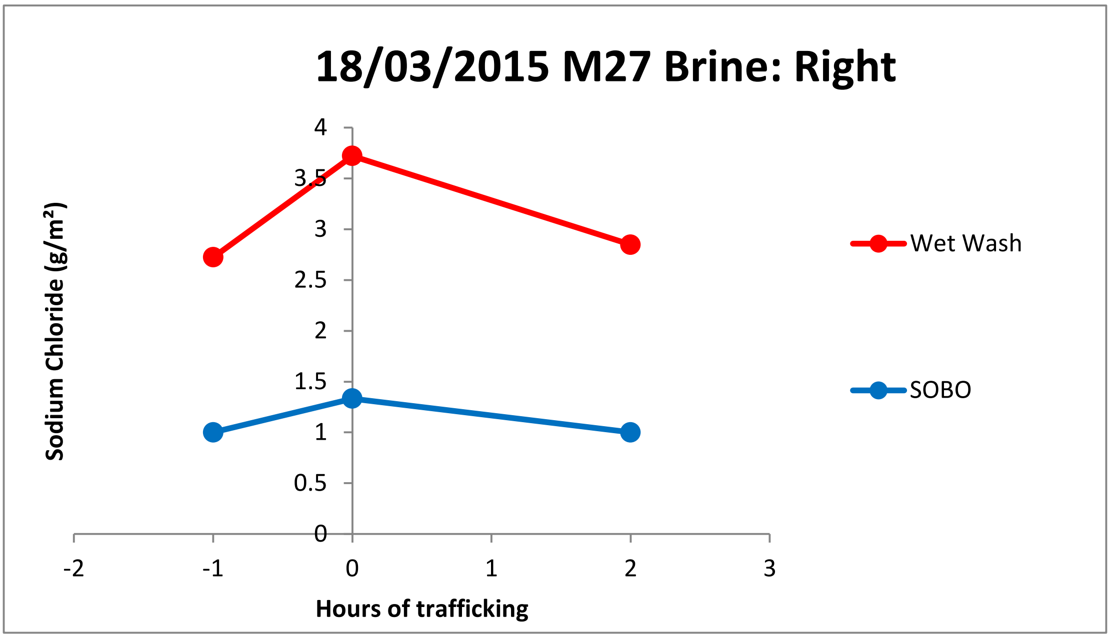


Figure 57. A1 Trial 1 residual salt variation with trafficking for right wheel track

C.4.2 Pre-wetted

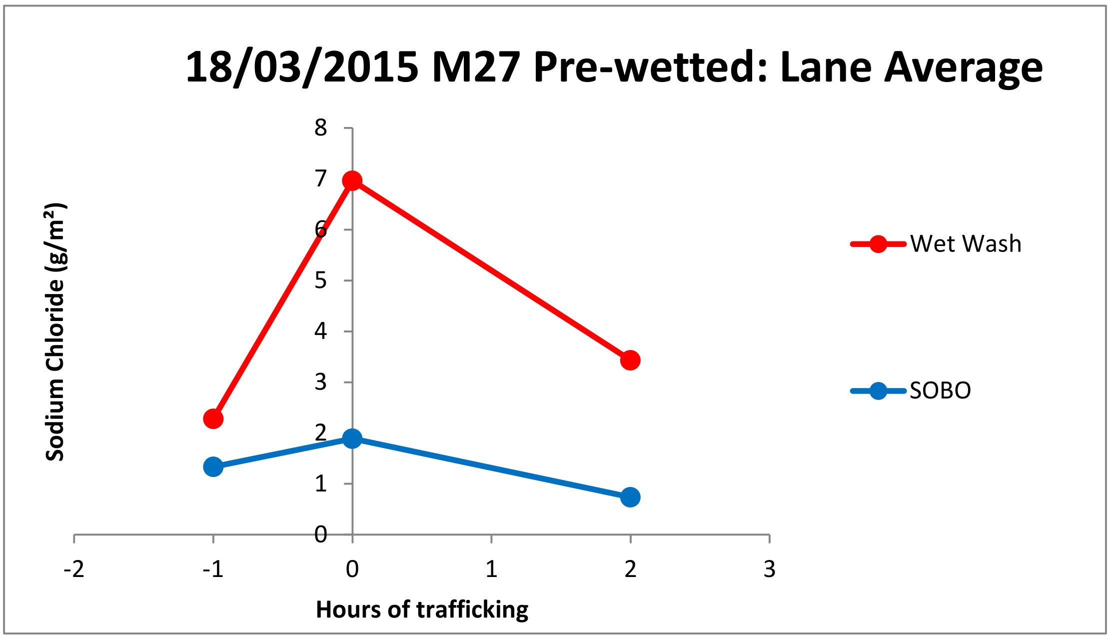


Figure 58. A1 Trial 1 residual salt variation with trafficking, average for Lane 1

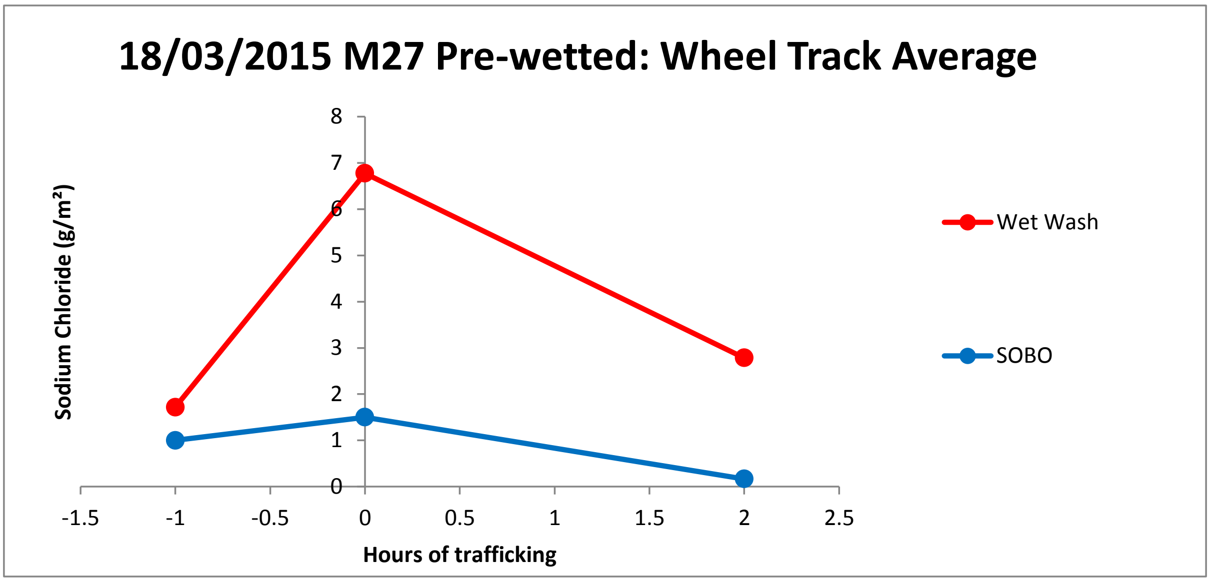


Figure 59. A1 Trial 1 residual salt variation with trafficking, average for wheel tracks

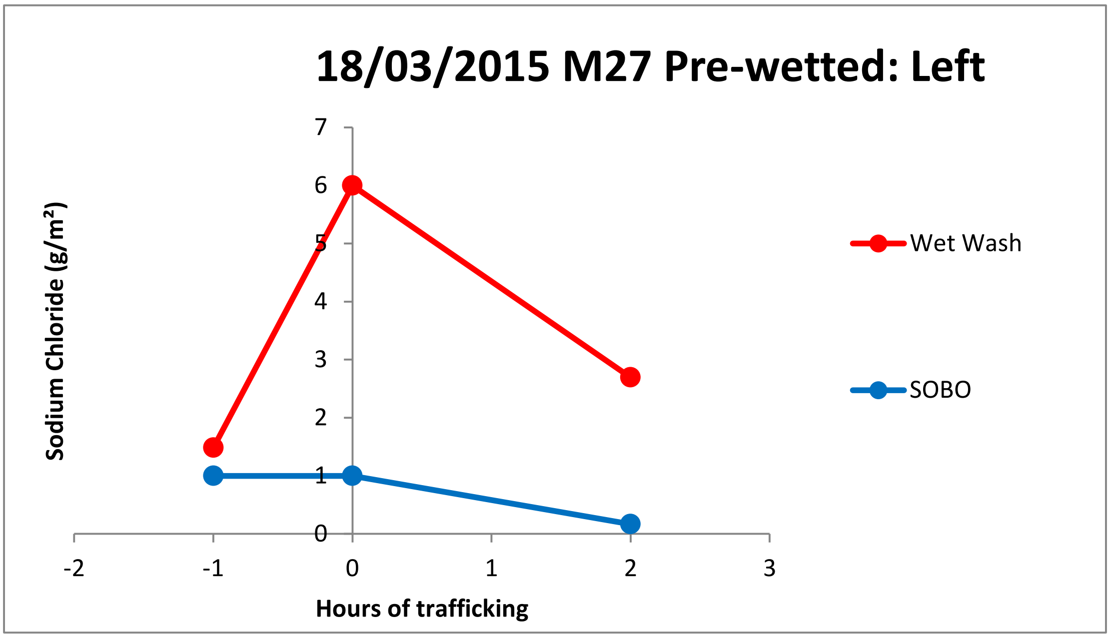


Figure 60. A1 Trial 1 - residual salt variation with trafficking for left wheel track

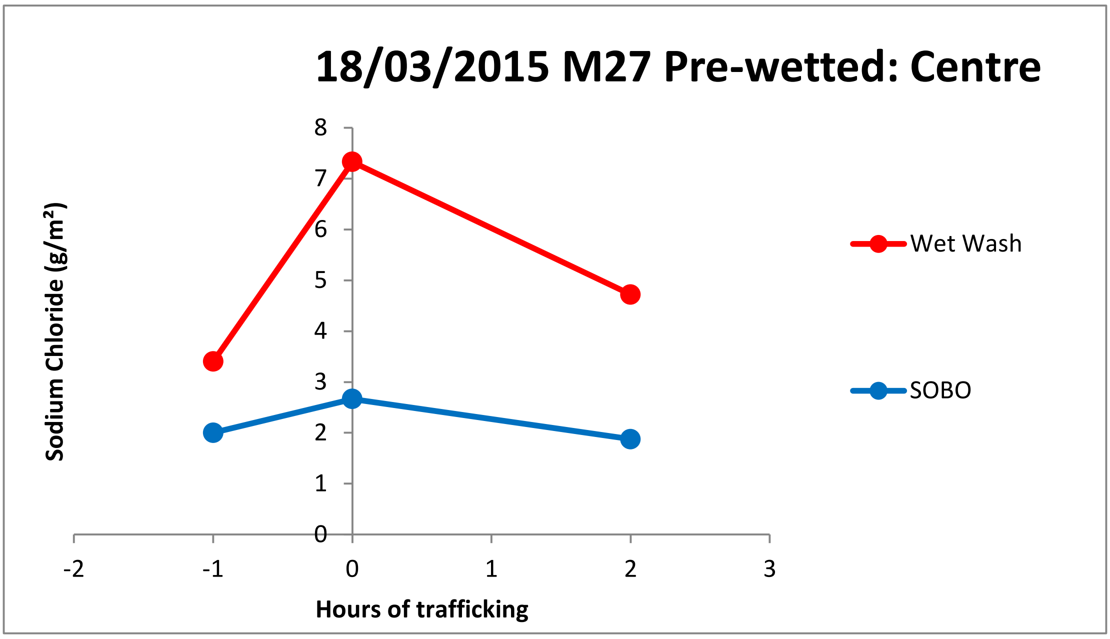


Figure 61. A1 Trial 1 Brine - residual salt variation with trafficking for centre of lane

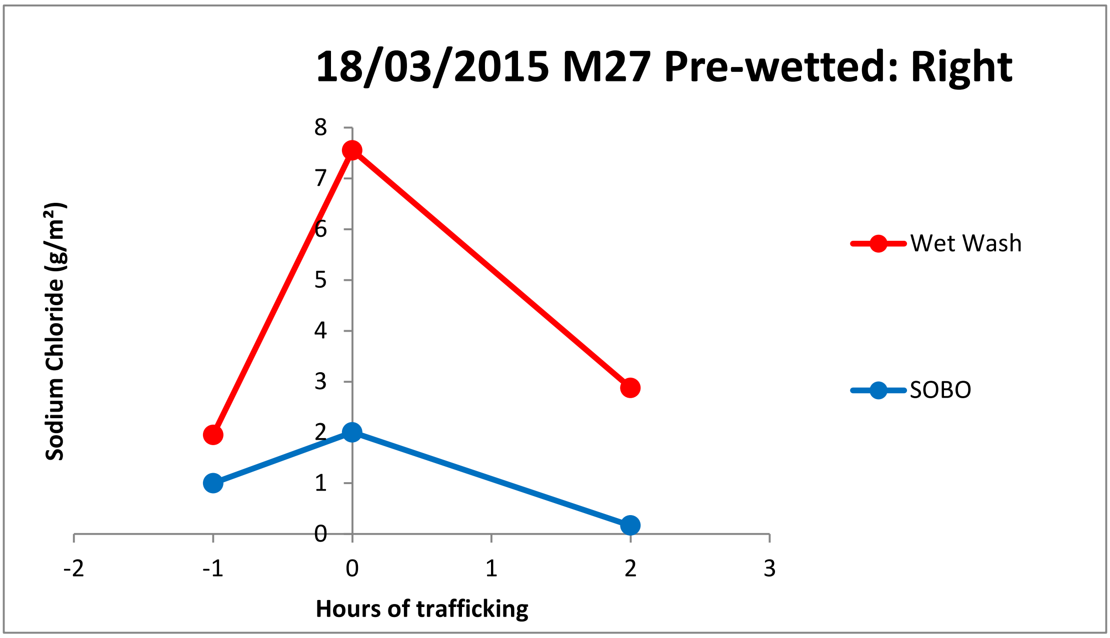


Figure 62. A1 Trial 1 Brine - residual salt variation with trafficking for right wheel track