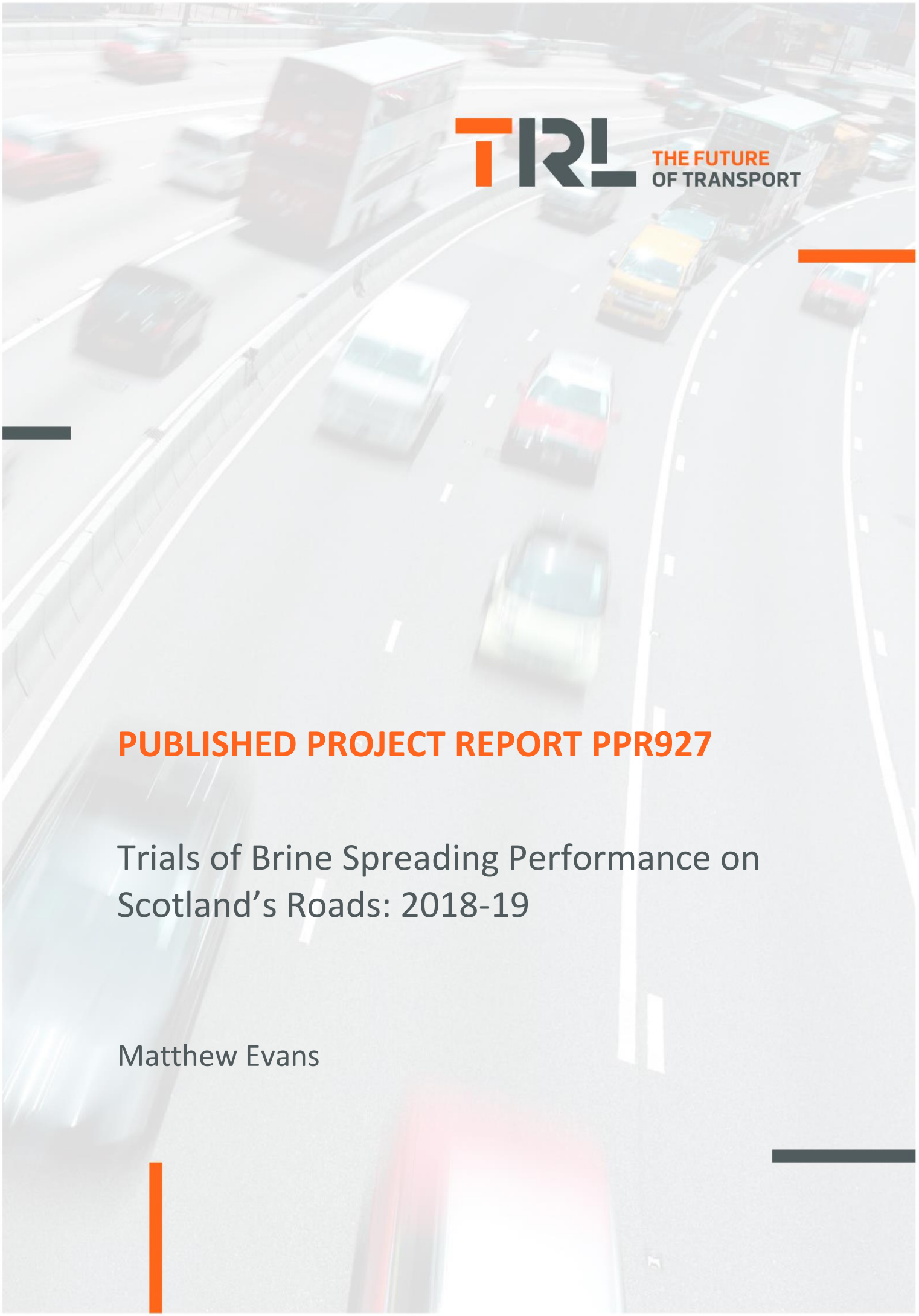

THE FUTURE OF TRANSPORT

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Trials of Brine Spreading Performance on Scotland's Roads: 2018-19

Matthew Evans

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Executive Summary

Live brine trials have been carried out over the previous three winter seasons on the Transport Scotland network, monitoring the effectiveness of routine brine treatments and comparing them to equivalent pre-wetted salt treatments. The Scottish Roads Research Board (SRRB) allocated funding for contribution to the National Winter Service Research Group (NWSRG) for further brine spreading trials during winter 2018/19.

The overall aim of the trial was to assess the suitability of full liquid treatments for the next generation of trunk road contracts in Scotland and also to inform the development of operational guidance for liquid spreading, for inclusion in the NWSRG practical guidance. As part of this overall aim, the trials investigated any limits of effectiveness for brine spreading in comparison to current pre-wetted and dry salt and, where limits are identified, assessed other options that can be applied e.g. higher brine ratio for pre-wetted salt.

Trials were carried out as part of routine winter treatments on Precautionary Treatment Route 20-8 within the North West Trunk Road Unit. This route runs between Inverness and Ullapool and typically records the lowest Road Surface Temperature (RST) on the Scottish trunk road network.

Brine spreading was carried out using a Schmidt Stratos Combi Flex Spreader, the same vehicle as used in the 2017/18 winter trials, modified by the addition of a spray bar for application of brine only treatments (instead of spreading brine directly from the disc as used during the 2017/18 trials). The vehicle provided the capability to deliver brine only or pre-wetted treatments. The brine ratio for the pre-wetted salt could also be varied from the standard 70:30 dry salt:brine to provide a greater proportion of brine for pre-wetted treatments. This was achieved by spreading pre-wetted salt from the spinning disc and brine from the spray bar at the same time.

The brine distribution from the spray bar was observed to provide a good distribution across the full carriageway width. Spreading during treatment runs was carried out at the standard speed of 30mph (50km/h) and some observations were also carried out at higher speeds up to 50mph indicating a reasonable distribution was still obtained. The distribution to the adjacent lane of the spreader can be affected by wind and will need to be monitored carefully during operations in high winds.

Brine spreading carried out using current treatment guidelines has provided effective precautionary treatments on dry, damp and wet roads (<0.1mm water). Observations and sensor measurements, including operator feedback, indicated that standard and higher brine share pre-wetted treatments provided improved performance over brine only spreading on very wet roads and snow conditions. On low trafficked routes such as the A835 trial site, and in very wet and snow/slush conditions, the loss of the salt particles in dry and pre-wetted salt caused by traffic will be reduced compared to treatments on drier and/or more highly trafficked routes.

During these trials, because of the spreader's dry salt capacity, it was not possible to use a higher proportion of dry salt than 30%, but spreading at a 50:50 ratio of dry salt:brine might offer further improvements in severe conditions from increased residual salt levels.

Where ice has formed or snow has settled on the road surface, dry or pre-wetted salt (salt:brine ratio of 70:30 or 50:50) is the preferred treatment, to penetrate snow and keep it in a soft and ploughable condition. Brine-only spreading in snow should only be considered for marginal conditions (e.g. temperatures greater than -1°C) and where the road can be kept clear either from frequent ploughing passes (as a minimum every 1 to 2 hours) or where there is sufficient traffic to mix brine into snow or disperse and prevent a hard packed layer from forming.

1 Introduction

Live brine trials have been carried out over the previous three winter seasons on the Transport Scotland network, monitoring the effectiveness of routine brine treatments and comparing them to equivalent pre-wetted salt treatments.

The Scottish Roads Research Board (SRRB) allocated funding for contribution to the NWSRG for further brine spreading trials during winter 2018/19. The Scottish Road Research Board (SRRB) is a partnership between Transport Scotland, the Society of Chief Officers for Transportation in Scotland (SCOTS) and the Scottish Road Works Commissioner (SRWC).

The series of trials carried out over recent winters has enabled experience to be gained in the use of brine in the range of conditions typically experienced on the Scotland network, with each year of trials testing brine in progressively more severe conditions.

The overall aim of the trial remains to assess the suitability of full liquid treatments for delivering the next generation of trunk road contracts in Scotland and also to inform the development of operational guidance for liquid spreading, for inclusion in the NWSRG practical guidance.

As part of this overall aim, the specific objectives of this set of trials were to:

- Assess spreading performance and treatment effectiveness using a spray bar and nozzles for the liquid distribution mechanism
- Understand any limits of effectiveness for brine spreading in comparison to current pre-wetted and dry salt (in terms of lower temperature limit or longevity of treatment), in particular:
    - Effectiveness of brine treatments applied before and during snowfall in combination with effective ploughing down to the road surface (ploughing to black)
    - Effective of treatments on wet roads after precipitation
- Where limits are identified, assess other options that can be applied e.g. higher brine ratio for pre-wetted salt

2 Trial Site

Trials were carried out as part of routine winter treatments on Precautionary Treatment Route 20-8 within the North West Trunk Road Unit. This route runs between Inverness and Ullapool and typically records the lowest Road Surface Temperature (RST) on the Scottish trunk road network.

The A835 was chosen to provide the likelihood of the full range of conditions that are routinely experienced on the Transport Scotland network. The route includes single and dual carriageway sections and reaches an altitude of 284m. The route routinely also experiences significant snow accumulations that can lead to drifting and jack-knifing of articulated vehicles on steep inclines.

The route has a treatment length of 79km and an average width of 6.5m.

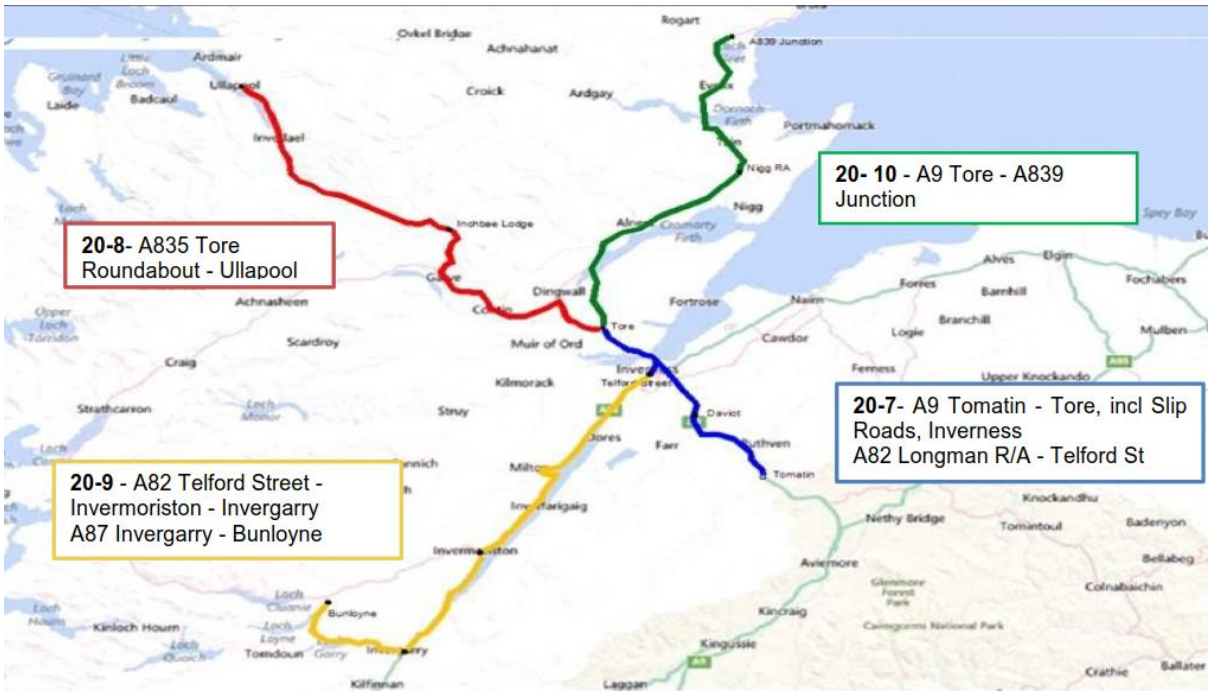


Figure 1. Route 20-8 and other precautionary routes operating from Bridgepoint Depot (Inverness) – taken from North West Unit Winter Service Plan 2018/19

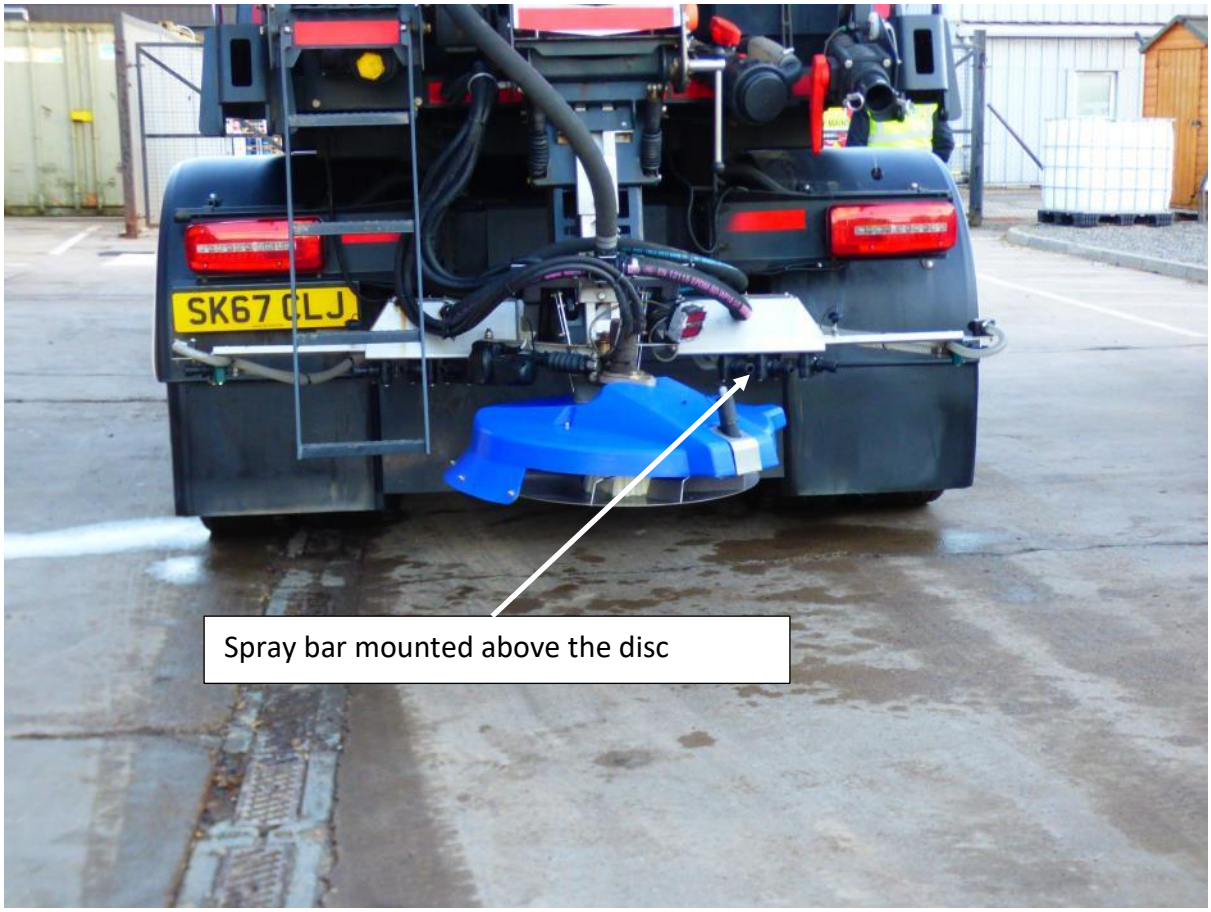
3 Spreader and de-icing chemical

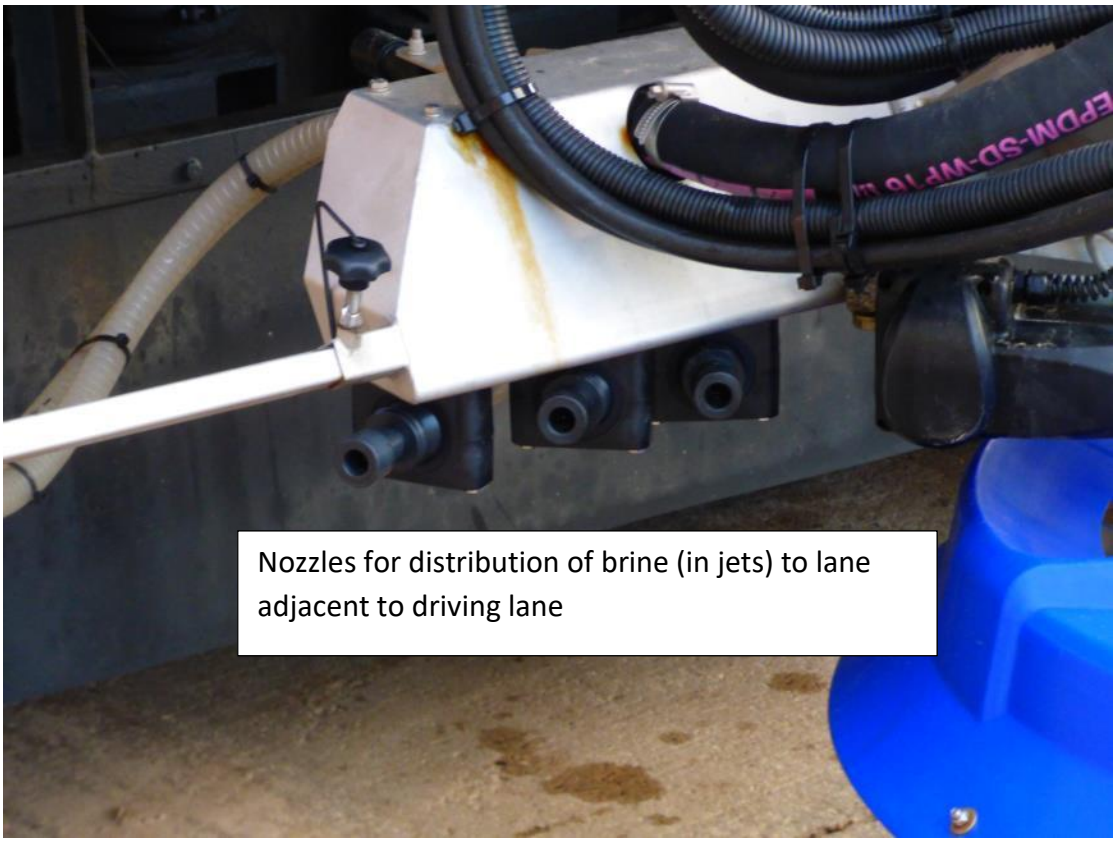
Brine spreading was carried out using a Schmidt Stratos Combi Flex Spreader, the same vehicle as used in the 2017/18 winter trials as shown in Figure 2.

Figure 2. Schmidt Stratos Combi Flex Spreader

The vehicle provided the capability to deliver brine only or pre-wetted treatments. The brine ratio for the pre-wetted salt could also be varied from the standard 70:30 dry salt:brine to provide a greater brine share for pre-wetted treatments.

For this set of trials, the vehicle was modified by the addition of a spray bar for application of brine only treatments instead of spreading brine directly from the disc as used during the 2017/18 trials.





Before the trials all spreaders were calibrated; this including monitoring the discharge rate and carrying out a visual check of the brine and pre-wetted salt distribution.

The vehicle provided the option for spreading pre-wetted salt from the disc, in combination with brine spreading from the spray bar at the same time. The total proportion of brine and dry salt being output can be varied through the spreader control system.

The vehicle was fitted with a 3 metre SNK snowplough, with Kuper GK7 rubber-ceramic edges as shown in Figure 3.

Figure 3. Plough set-up

Brine was produced and stored at the Inverness depot for pumping into the combi spreader when required.

Spread rates were dependent on a brine concentration of 20 to 23%.

The time required for loading the spreader was checked, to ensure turnaround and response time targets could be achieved.

The saturator and an additional brine storage tank are shown in Figure 4.

Figure 4. Saturator and brine storage tank

4 Trial methodology

Prior to the trial commencing, a treatment matrix was agreed with BEAR Scotland and Transport Scotland for both precautionary treatments and for snow and ice.

Brine treatments were carried out in accordance with the standard decision matrix shown in Figure 5.

Spread rates for precautionary treatments and snow clearance are shown in Table 1 and Table 2 respectively.

Records of treatment timings and spread rates were obtained from the Vaisala RoadDSS Manager system.

<table>
<tr><th colspan="4">Decision Matrix</th></tr>
<tr><th></th><th colspan="3">Predicted Road Conditions</th></tr>
<tr><th>Road Surface Temperature</th><th>Wet</th><th>Wet Patches</th><th>Dry</th></tr>
<tr><td>May fall below 1ºC</td><td rowspan="3">Salt before frost</td><td>Salt before frost (see Note A)</td><td>No action likely, monitor weather (see Note A)</td></tr>
<tr><td rowspan="4">Expected to fall below 1ºC</td><td colspan="2">Salt before frost (see Note B)</td></tr>
<tr><td colspan="3">Salt after rain stops</td></tr>
<tr><td colspan="3">Salt before frost and after rain stops (see Note C)</td></tr>
<tr><td colspan="2">Salt before frost</td><td>Monitor weather conditions</td></tr>
<tr><td>Expected snow</td><td colspan="3">Salt before snow</td></tr>
<tr><td rowspan="3">Freezing rain</td><td colspan="3">Salt before rain (see Note C)</td></tr>
<tr><td colspan="3">Salt during rain (see Note C)</td></tr>
<tr><td colspan="3">Salt after rain (see Note C)</td></tr>
</table>

Figure 5. Decision matrix - taken from North West Unit Winter Service Plan 2018/19

The decision to undertake precautionary treatments may be adjusted to take account of residual salt or surface moisture.

Note A: Particular attention should be given the possibility of water running across carriageways. Such locations will be monitored and treated as required.

Note B: When a weather warning contains reference to expected hoarfrost close monitoring will be required, with particular attention given to timings of precautionary treatments as salt deposited on dry roads may be dispersed before it can become effective.

Note C: Under these circumstances rain will freeze on contact with running surfaces and full pre-treatment should be provided even on dry roads, with continuous monitoring throughout the danger period.

Table 1. Spreading rates for precautionary treatments

Spreading rates for precautionary treatments with brine (ml/m²)		
Road surface condition	**Frost Susceptible/surface water run-off area**	**Road Surface Wet**
A. RST higher than plus 1°C	0	0
B. RST lower than or equal to plus 1°C but higher than minus 2°C	10	20
C. RST lower than or equal to minus 2°C but higher than minus 5°C	10 to 20	20
D. RST lower than or equal to minus 5°C	10 to 20	20
E. RST lower than or equal to plus 1°C but higher than minus 2°C following rain (see note 1)	20	30
F. RST lower than or equal to minus 2°C but higher than minus 5°C following rain (see note 1)	30	30
G. RST lower than or equal to minus 5°C following rain (see note 1)	30	30
H. Hoar Frost	20	20
I. Freezing Fog	10	20

J. Freezing Rain	30	30
K. Snow Accumulations up to 30mm	30	30
L. Snow Accumulations over 30mm	30	30
M. Hard Packed Snow/Ice	See clearance matrix	See clearance matrix

Note 1 Treatments will be carried out after water has dispersed and road surface classed as damp.

Table 2. Clearance matrix

Minimum brine spread rates for Snow or Ice Clearance			
Road surface condition	**Spreading (ml/m²)**	**Ploughing**	**Blowing**
Ice formed	30	No	No
Snow covering of less than 30mm	30	Yes	No
Snow covering exceeds 30mm	30	Yes	No
Snow accumulations due to prolonged snowfall	30	Yes (continuous)	Where applicable

Hard packed snow/ice less than 20mm thick	Salt 40g/m² (successive)	No	No
Hard packed snow/ice	Salt/abrasive (successive)	No	No

5 Monitoring of road conditions

5.1 Fixed monitoring sites

The Braemore, Aultguish and Brahan fixed weather stations were used to monitor road surface conditions on the A835. The locations of the weather stations are shown in Figure 6. Monitoring equipment included:

- Non-invasive DSC111 and DST111 sensors to remotely monitor road condition (wetness, snow, ice) and surface temperature (Aultguish only)
- Road weather station including wind speed, embedded DRS 511 sensor (road condition and temperature), CCTV
- Addition of an active freezing point sensor at Aultguish

The road condition from the fixed sensors was continuously and automatically monitored every 10 minutes and the data collated and analysed.

All weather station and patrol data was fed back to the Operating Company control centre and access to weather station data was available through the Vaisala RoadDSS system.

Figure 6. Weather station locations – taken from North West Unit Winter Service Plan 2017/18

5.2 Patrols

The trial site was a Category B patrol route. Category B Patrols are designed to monitor conditions, provide salt treatments and plough as required with a 3 hour cycle: once during the 00.00 – 03.00, 03.00 – 06.00 and 06.00 – 09.00 periods specified.

6 Spreading distribution

The brine distribution from the spray bar was observed to provide a good distribution across the full carriageway width as shown in Figure 7.

Figure 7. Brine spreading distribution from spray bar

Spreading during treatment runs was carried out at the standard speed of 30mph (50km/h). Some observations were also carried out at higher speeds up to 50mph. While the spreader had not been set-up and optimised for spreading at the higher speeds, the observations indicated a reasonable distribution was still obtained. Previous work (Evans et al, 2010) has also identified that brine only spreading at 50mph is considered a suitable option using a spray bar. Subject to optimisation of the spread pattern for the higher speed, spreading of standard and higher brine share pre-wetted salt at 40mph is considered a feasible option.

The distribution from the spray bar was assessed to be less affected by wind than the distribution from the spinning disc used in the 2017/18 trial. The distribution to the adjacent lane of the spreader can still be affected by wind, with the side jets of brine observed to be visibly deflected in wind speeds greater than 10mph (Figure 8). When winds are greater than 20mph it was not possible to achieve coverage across the full width, as the jets of brine were observed to be significantly deflected.

Spreading in high winds will be an issue irrespective of the treatment method as it can affect the salt distribution (dry or pre-wetted spreading) at the time of spreading and, in dry conditions, lead to increased salt losses after spreading as a result of the salt particles being blown from the road surface. Salt particles may also be removed from the road surface by the action of tyres and vehicle draughts (draughts are more of an issue for dry salting or pre-wetted salting in dry and windy conditions).

The latest NWSRG spread rates guidance (NWSRG, 2019) recognises the issue of high wind speeds. The guidance recommends, when practical, that authorities avoid spreading during the predicted high wind period, i.e. periods when mean wind speeds are predicted to be 20mph or more. When treatments during high wind conditions are necessary, the NWSRG guidance recommends that authorities monitor residual salt levels and carry out re-treatments if and where necessary. If this issue is considered to pose a significant risk, authorities may also wish to increase spread rates when carrying out precautionary salting operations during periods when forecast mean wind speeds are 20mph or higher.

Junctions with a middle lane for right turning traffic required spreading over two adjacent lanes to the spreader. This was not achievable with the brine only spreading and the spreader was required to spread pre-wetted salt across these junctions to provide sufficient spread width (Figure 9).

Figure 8. Brine spreading distribution in wind speeds approx. 5 – 10mph. Some deflection in brine jets visible.

Figure 9. Spreading of pre-wetted salt required across junctions incorporating middle lane for right hand turning traffic.

Spreading of the high brine share pre-wetted salt was observed to provide good distribution of both brine and salt across the full carriageway, an example of the spreading shown in Figure 10 with distribution both from the spinning disc and spray bar.

Figure 10. Spreading of high brine share pre-wetted salt.

7 Assessment of treatment effectiveness and longevity

Sensor measurements and observations of road conditions have enabled an assessment to be carried out of the conditions under which brine has provided an effective treatment and where limits have been identified for brine only, standard pre-wetted and high brine share pre-wetted treatments.

The key sensor measurements and observations available for assessing treatment effectiveness and longevity on the trial site included:

- Freezing point of any water on the road surface, measured from active sensor embedded in the road surface at the Aultguish weather station location
- Measurements of the amount of salt on the road surface from passive sensors embedded in the road at the weather station locations
- Measurements of 'Grip' and surface condition from non-invasive sensor mounted roadside at Aultguish
- Surface state (wetness, snow, ice) reported from embedded passive sensors
- Ice reports from spreader drivers/public/police

Appendix A includes a summary of the sensor measurements of freezing point and amounts of salt after different treatment methods at the Aultguish sensor location plotted against time after spreading.

Appendix B includes a summary of the sensor measurements of freezing point and amounts of salt after different treatment methods at the Aultguish sensor location plotted against water thickness at time of measurement.

Appendix C includes a summary of the minimum temperatures, maximum water layer thicknesses and total amounts of precipitation measured at the Aultguish sensor location.

Some caution is needed when drawing conclusions from measurements from sensors embedded in the road surface. Only a small area is measured which might not be representative of the conditions across the full carriageway width or along the length of road at that location. Sufficient moisture is also required on the sensors to enable an accurate measurement of salt amounts and freezing points. As can be seen from the plots in Appendix A, freezing point measurements in particular can fluctuate quite rapidly with time. This is mainly a result of changing amounts of water on the sensor surface which, for thin films of water, can result in significant changes in salt concentration and hence freezing point and sensor output. Considering the sensor measurements over a larger number of events can start to build a picture of how the amounts of salt and the freezing point varies for different treatment methods and road surface conditions.

In the NWSRG Spread Rates guidance (NWSRG, 2019a) a wet road is currently defined as having a water thickness less than 0.1mm, and described as: *A road on which traffic produces fine spray but not small water droplets. This would be typical of a well-drained road when there has been rainfall up to 3 hours before the treatment time.)*

Where none or very light (less than 0.1mm rainfall equivalent) precipitation occurred the roads remained dry, damp or wet and with water thickness measured to be less than 0.1mm

(except where the road was very wet at time of spreading). Based on the sensor measurements reported, all of the treatment options (brine only, standard pre-wetted and higher brine share pre-wetted) spreading were assessed to provide comparable residual salt levels and freezing point measurements on dry, damp or wet roads using the spread rate matrices specified for the trial.

Except for the cases of very light precipitation (0.1 mm rainfall or less), all precipitation events that occurred during or after spreading on the trial site resulted in very wet roads (road wetness levels greater than 0.1mm).

Figure 11, Figure 12 and Figure 13 summarise the road wetness and surface temperature measurements taken at Aultguish for brine only, high brine share pre-wetted salt (FS70) and standard pre-wetted salt(FS30). For each point on the plots, the road wetness reported is the maximum value that occurred at any time between spreading and the time of the temperature measurement.

Figure 14, Figure 15 and Figure 16 summarise the amount of precipitation that occurred and surface temperatures. For each point on the plots, the amount of precipitation reported is the total amount measured between spreading and the time of temperature measurement.

The plots also highlight the conditions where road surface temperatures were measured to be below the freezing point of the water on the road (where it is considered there will be a higher risk of ice formation) and also where any ice formation was reported by embedded or non-invasive sensors. Ice was only reported by the embedded sensor for one short period, during light snowfall and extremely low surface temperatures of -8°C, when treatments were carried out using standard pre-wetted salt (70:30 salt:brine).

For treatments on very wet roads and during precipitation, the brine only treatments while initially providing comparable performance (for 1-2 hours after treatment) were not assessed to provide as long lasting treatments as standard or higher brine share pre-wetted spreading as shown from the residual salt and freezing point measurements reported in Appendix A.

Comparison between Figure 11 to Figure 13 and between Figure 14 to Figure 16 show that as road wetness increases above 0.1mm, all treatment types show reduced freezing points of the road surface moisture, with road surface temperatures falling below the freezing point of the moisture for the wetter conditions. However, the plots show that for pre-wetted salt the levels of water thickness and amounts of precipitation are generally greater before this occurs than for brine only spreading i.e. the brine only spreading is more sensitive to road wetness and precipitation.

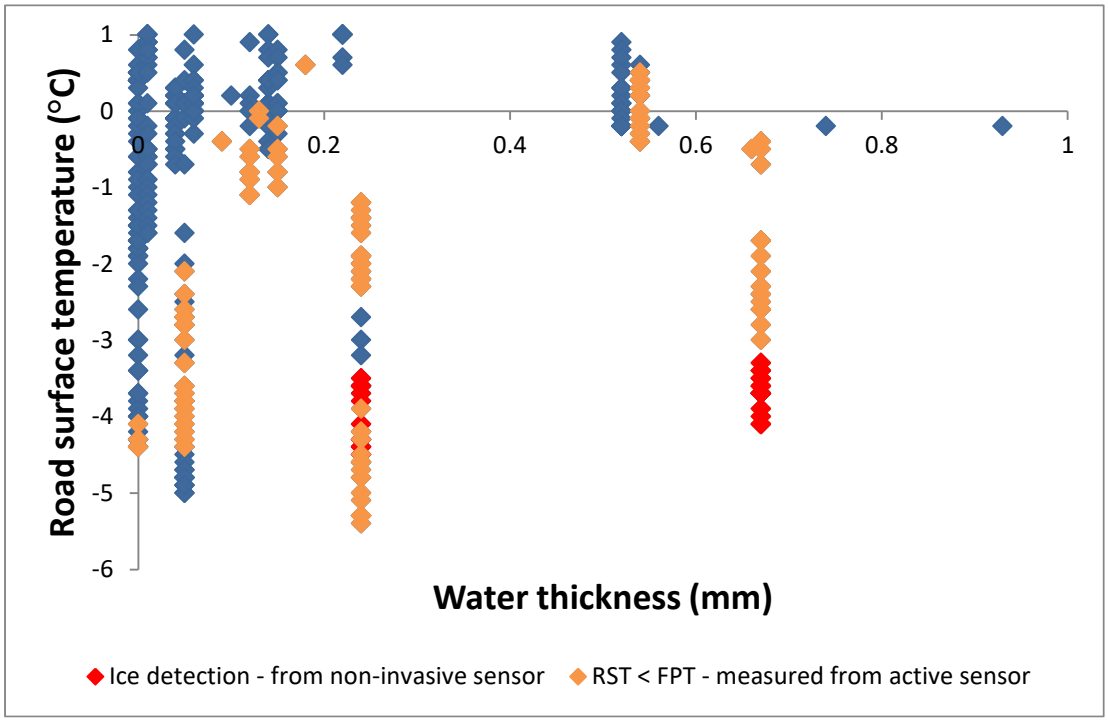


Figure 11. Summary of road wetness following brine only treatments.

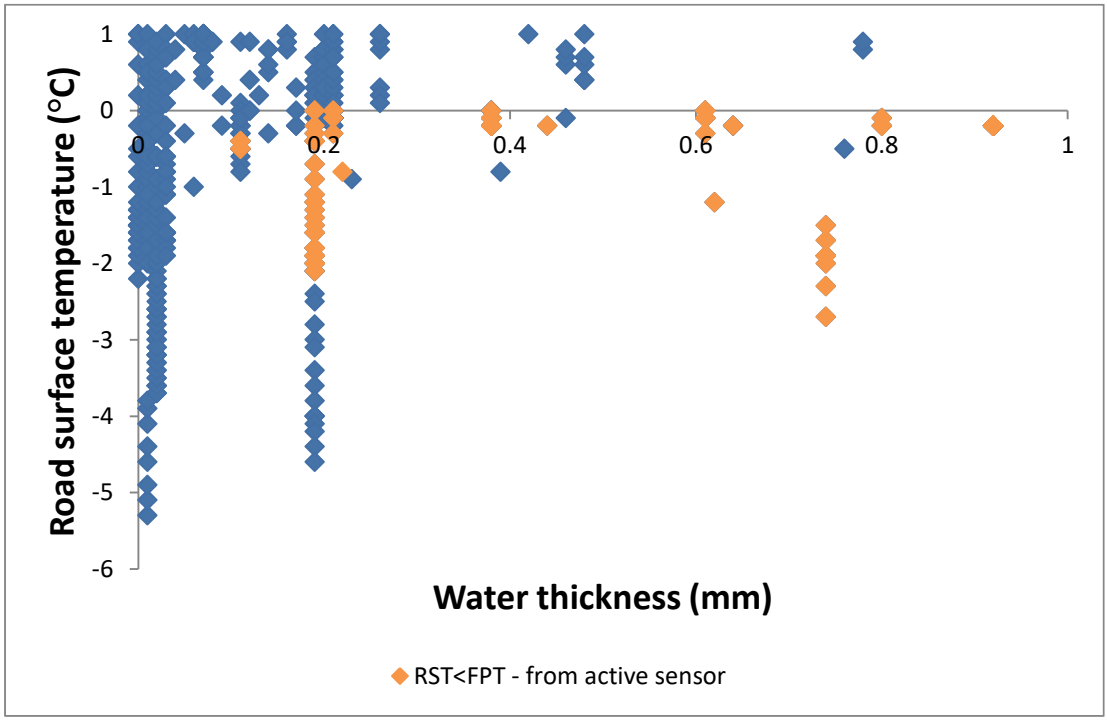


Figure 12. Summary of road wetness following high brine share pre-wetted salt treatments (30:70 dry salt:brine).

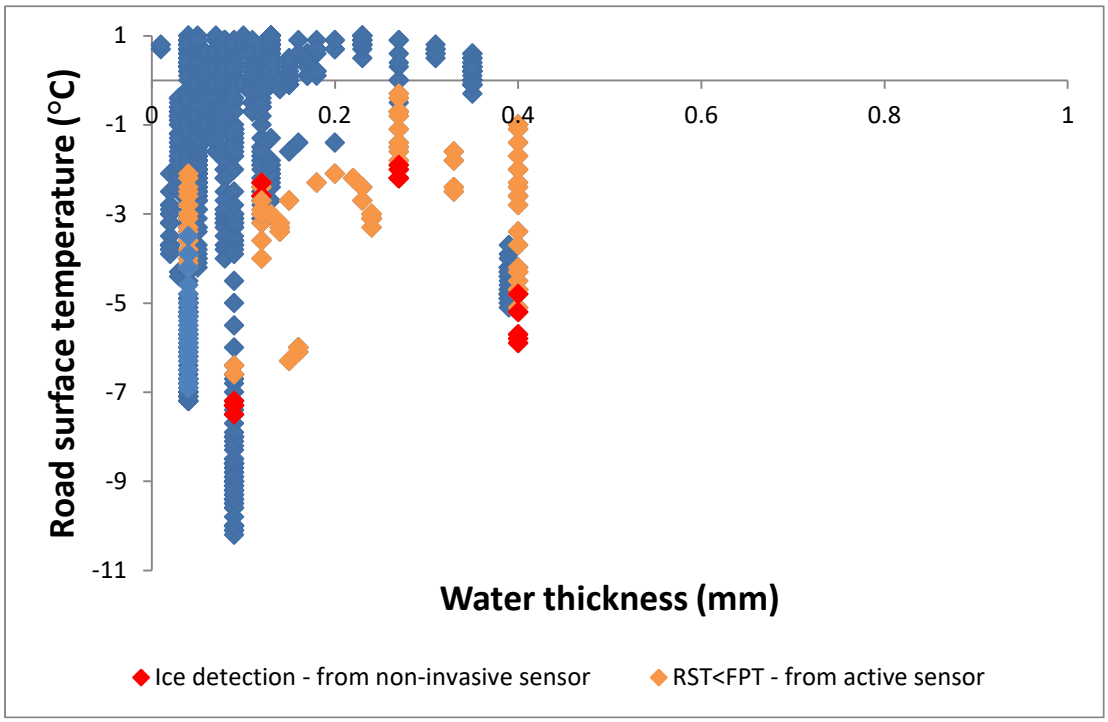


Figure 13. Summary of road wetness following pre-wetted salt treatments (70:30 dry salt:brine).

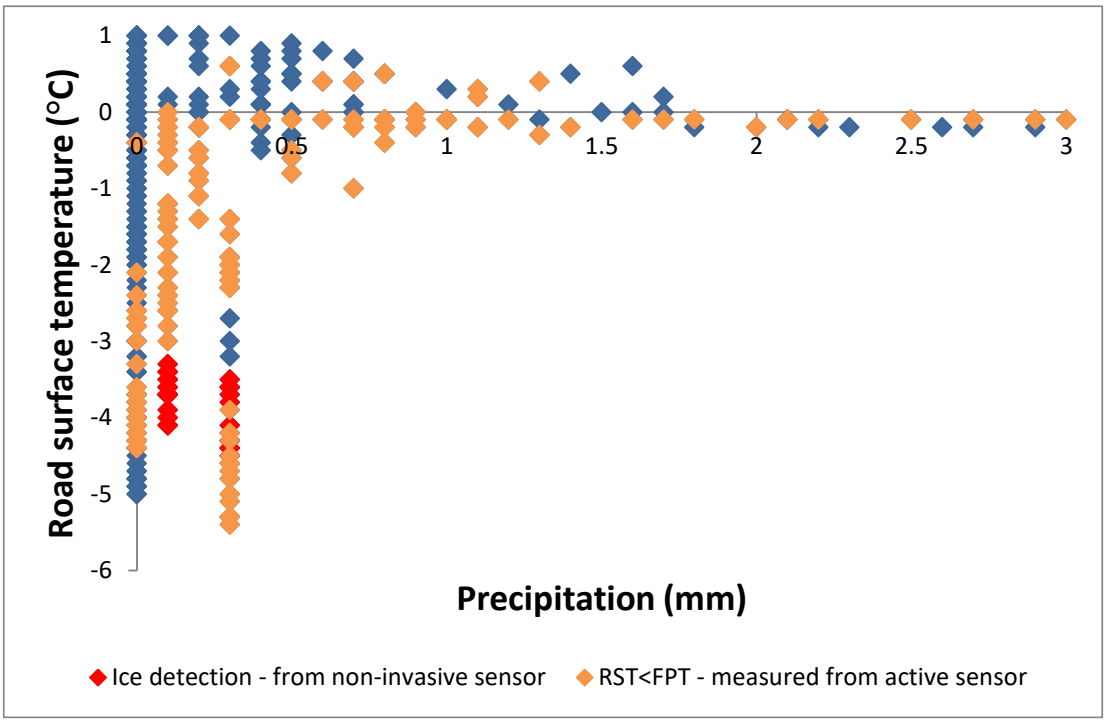


Figure 14. Summary of precipitation amounts following brine only treatments.

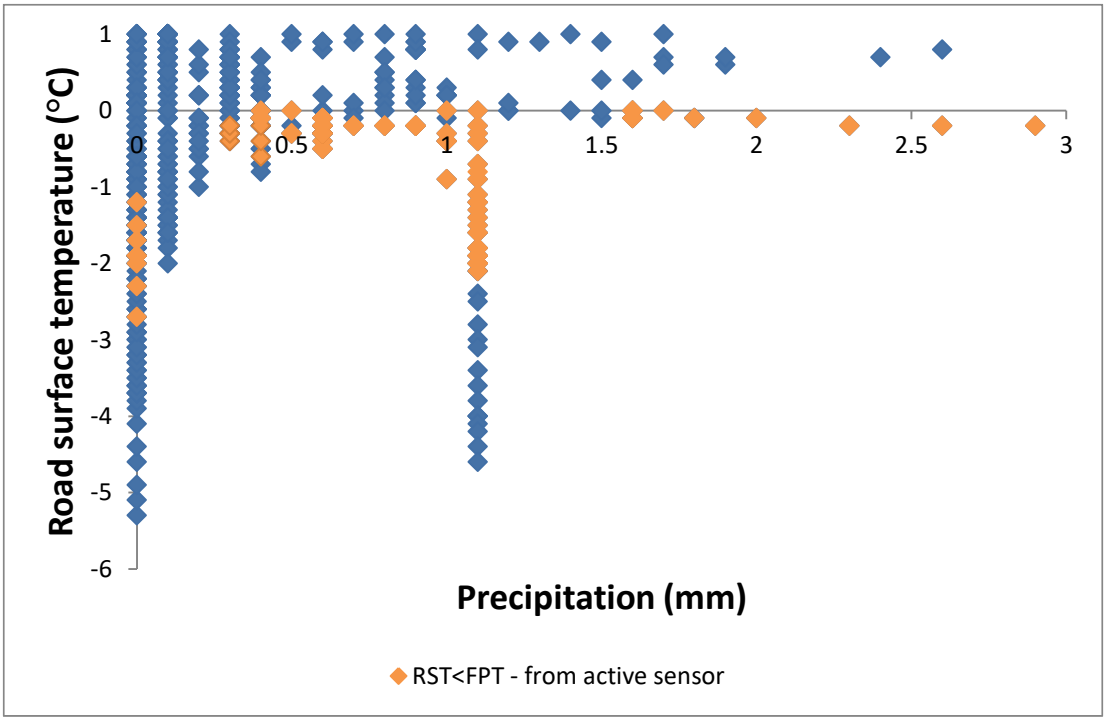


Figure 15. Summary of precipitation amounts following high brine share pre-wetted salt treatments (30:70 dry salt:brine).

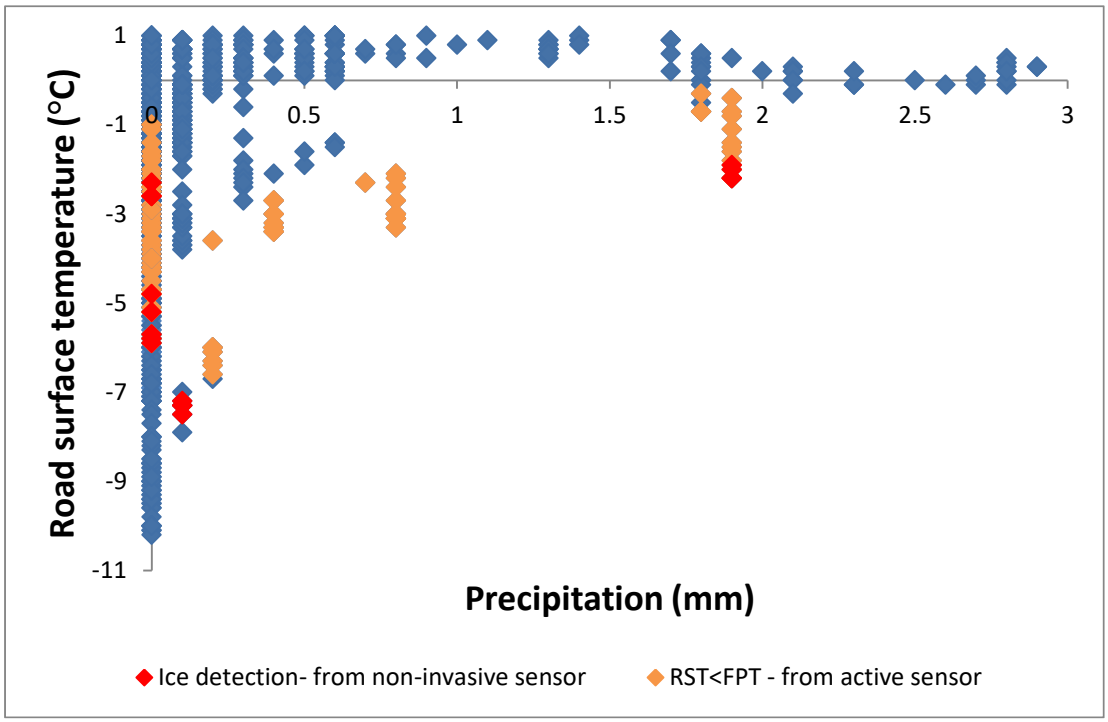


Figure 16. Summary of precipitation amounts following pre-wetted salt treatments (70:30 dry salt:brine).

Table 3 to Table 8 provide a summary of treatments where one or more of the following conditions was observed or measured following the treatments:

- Ice and low 'Grip' reported (non-invasive sensor)
- Road surface temperature measured to be lower than freezing point temperature (active sensor)
- Ice reported from embedded passive sensors
- Ice reports from spreader drivers/public/police

All of the brine spreading events identified in the table were for very wet roads (water thickness>0.1mm) and where snow or other precipitation occurred during or after spreading. In general, the events identified for pre-wetted salt (both standard and higher brine share) were for more severe snow events with lower temperatures down to -10°C in the extreme case.

The trial route provided a severe challenge for winter maintenance, with precipitation and very wet road surfaces occurring during many of the treatments carried out. Low levels of traffic also contributed to the road surface remaining very wet for significant periods after rainfall, with little traffic to disperse water, or to aid the break up and dispersal of snow.

It is considered from these observations and sensor measurements, and also from operator feedback, that the higher brine share treatments provided improved performance over brine only spreading on very wet roads and snow conditions.

During these trials, because of the spreader's dry salt capacity, it was not possible to use a higher proportion of dry salt than 30%. It is anticipated that spreading at a 50:50 ratio of dry salt:brine will offer further improvements in severe conditions comparable to the performance with standard 70:30 pre-wetted salt.

Some events were highlighted for pre-wetted spreading where brine will provide an advantage compared to the standard pre-wetted treatments. The treatments carried out on 14/01/19 and 16/12/18 with pre-wetted salt were on damp roads with falling temperatures. The roads were potentially wet enough for ice to form (although not detected in this case) but the time of treatments meant there was very little traffic to help salt dissolve and the road surface temperature was measured to be less than the freezing point of the solution on the road surface. Brine spreading in such circumstances (e.g. early morning treatments on damp roads or before hoar frost) will not require dissolution of the salt to become effective.

Feedback from spreader drivers was that, while providing an effective treatment for frost conditions, the brine was not considered to be as long lasting in heavy icing conditions. Where brine was spread during snowfall in colder conditions, there has been feedback from the operators that the brine can result in a frozen layer on the snow and cause hard packed rutting, whereas spreading of solid salt can penetrate the snow and is more effective at keeping it in a soft and ploughable condition. On the trial site there was very little traffic during snow events to mix the brine into the snow or disperse it. The higher brine share pre-wetted salt was reported to provide some improvement.

An important issue to consider for brine is the limitation on the maximum amount of salt that can be spread, with only 23% (depending on brine concentration) of the total weight of de-icer comprising salt. While losses after brine spreading will be less, more salt can be delivered to the road surface by other treatment methods from the significantly greater amounts of salt being output from the spreader. On low trafficked routes such as the A835 trial site, and in very wet and snow/slush conditions, the loss of the salt particles in dry and pre-wetted salt from the effects of traffic will be reduced compared to treatments on drier and/or more highly trafficked routes. The remaining solid salt particles remaining can then provide greater resilience against dilution and loss of brine into and run off from the road surface.

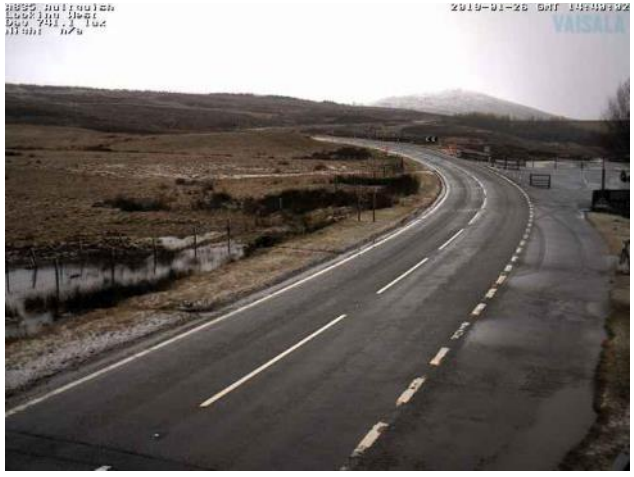
Table 3. Summary of brine only treatment events

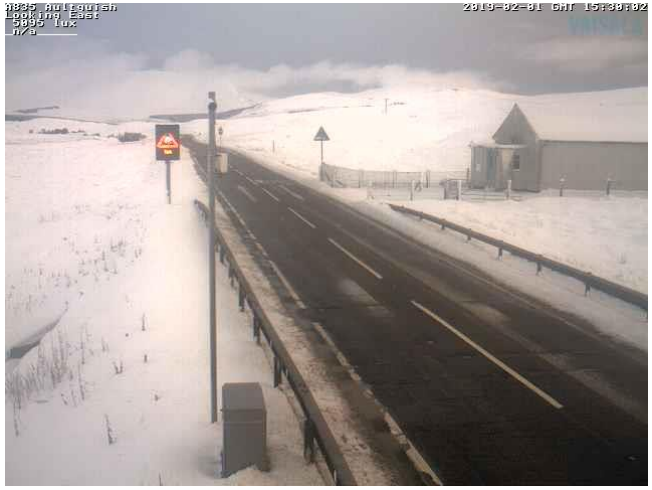
Date	Time and type of Treatment	Minimum surface temperature (°C)	Maximum layer thickness (mm)	Precipitation before event	Ice reports			FPT>RST (Active sensor)	General description
					Patrol, public, police	Embedded sensor	Non – invasive sensor		
26/01/19	10ml/m² Brine at 01:15	-0.5°C at 02:30	0.33mm at time of treatment 3mm at 03:00	0.2mm to 02:00 0.6mm to 04:00	-	-	-	FPT>RST from 02:00 to 04:00	Light snow during and after treatment.
26/01/19	30ml/m² brine at 14:00 20ml/m² brine at 02:00	-1.6°C at 19:30	0.52mm at time of 1st treatment 1.02mm at 18:50		Snow	Snow	Snow/slush	FPT>RST from 14:00 to 19:00	Light during treatment and throughout day and night. 11.6mm total precipitation High wind speeds up to 30mph during night
27/01/19	20ml/m² Brine at 15.00 (15.30 at Aultguish)	-3.5°C when ice reported by non-invasive	0.24mm at time of treatment	0.3mm to 19.30	-	-	Icy (19.30 to 21.30)	FPT>RST from 16.30 to 19.30	Light snow during and immediately after treatment

01/02/19	20ml/m² Brine at 15.00	-1.7°C at time of treatment. -3.3°C when ice reported by non-invasive at 18:10	0.43mm at time of treatment	0.1mm to 18:10	Ice	-	Icy (18:10 to 21:30)	FPT>RST from 14:00 to 22:00	Treatment immediately after period of snowfall resulting in very wet road surfaces and falling RST
04/02/19	20ml/m² Brine at 15.00 (15.30 at Aultguish)	-1.1°C when FPT>RST	0.05mm at time of treatment 0.12mm at 21:10 during precipitation	0.2mm before 22.00	Call out for ice at 21:25	-	-	FPT>RST from 22.00 to 23.00	Light snow at Aultguish from 19:50 to 21:20. Heavy localised rain in other areas - 2.3mm in 40 minutes at Brahan 0.2mm precipitation before FPT>RST Max wind speed at time of treatment 15.2mph from west
05/02/19	20ml/m² Brine at 21.00 10ml/m² Brine at 04.00	-1°C 04:20	0.18mm at time of treatment 0.54mm at 05:20	1.4mm to 04.30	-	-	-	FPT>RST on and off from 04.30 to 07.30 on 06/02/19	Light/medium snow on and off through night
07/02/19	20ml/m² Brine at 16.00	-0.5°C at 23:30 -1.1°C at 01:20	0.01mm at treatment 0.15mm at 20:40	0.5mm to 23.20	-	-	-	FPT>RST from 23.30 to 00.30	Light rain in evening after treatment

	10ml/m² Brine at 03.00		0.03mm at 23.30						0.5mm total precipitation
10/02/19	20ml/m² Brine at 19.00 20ml/m² Brine at 03.00	RST falling after precipitation: -1°C when FPT>RST -5°C at 08.30	0.05mm at time of both treatments 0.15mm at 01.50	0.7mm to 03:00	-	-	-	FPT>RST from 03.00 to 09.00	Light rain in evening during and after 1st treatment. 0.7mm total precipitation

Table 4. Observations of road conditions during brine only treatment events

26/01/19 Treatment at Aultguish at 02:00 FPT>RST from 02:00 to 04:00	Road conditions at time of treatment: 	Road conditions at time of treatment: 
26/01/19 FPT>RST from 14:00 to 20:00	Road conditions at time of treatment: 	Road conditions at 19:30 

27/01/19 Non-invasive sensor detects ice 4 hours after treatment (at temperature -3°C) Light snow during and immediately after treatment	Road conditions at time of treatment: 	
01/02/2019	Road conditions at time of treatment: 	Road conditions at 21:00: 

06/02/19 Active sensor: FPT>RST between 04.30 to 07.30 Light/medium snow on and off through night	Road conditions when FPT>RST: 	Road conditions when FPT>RST: 

Table 5. Summary of high brine share pre-wetted treatment events (30:70 dry salt:brine)

Date	Time and type of Treatment	Minimum surface temperature (°C)	Maximum layer thickness (mm)	Precipitation before event	Ice/snow reports (patrol, public, police)	Embedded sensor	Non - invasive	Active (FPT>RST)	General description
08/03/19	30g/m² at 20:00 20g/m² at 03:00 Front line patrol	-4.5°C at 06:20	0.32mm at 07:50		Snow	-	Snow/slush between 05:50 to 06:20	FPT>RST between 02:30 and 03:30 05:30 and 06:30	Light medium snow during treatment and throughout night Max wind speeds between 20-30mph after 19.30 3mm precipitation
09/03/19	30g/m² at 15:00 20g/m² at 03:00 Front line patrol	-5.3°C at 03:50	0.19mm at 18:00		-	-	-	FPT>RST between 20:30 and 03:30	Snow in evening after treatment 15:00 to 21:30 1.1mm total precipitation
10/03/19	30g/m² at 14:00	-3.1°C at 05:40	0.12mm at time of treatment		Snow	Snowy between 02:10 and 02:30	Snowy between 17:50 and 18:40	FPT>RST from 17:00 intermitten	Light medium snow during treatment and throughout night

	20g/m² at 02:00 Front line patrol		0.38mm at 17:00	1.7mm to 17:00			02:10 to 03:40	tly through night	
22/03/19	20g/m² at 20:00 10g/m² at 03:00	-1°C at 06:40	0.21mm at time of 1st treatment. 0.61mm at 05:40		-	-	-	FPT>RST between 00:00 and 06:30	Light snow during treatment and intermittently throughout night. Max wind speed 20 – 30mph

Table 6. Observations of road conditions during high brine share pre-wetted treatment events (30:70 dry salt:brine)

Morning of 09/03/19: FPT>RST between 02:30 and 03:30 05:30 and 06:30	Road conditions at 02:30: 	Road conditions at 06:00: 
09/03/19: FPT>RST between 20:30 and 03:30 (Road too dry for accurate reading – 0.01mm)	Road conditions at 22:30:	Road conditions at 00:10: Light frosting visible between 00:00 and 02:00 after light snow at 00:00. Some readings of 0.01mm snow from non-invasive sensor

		
22/03/19 FPT>RST between 00:00 and 06:30 morning of 23/03)	Road conditions at time of 1st treatment (20:50) 	Road conditions at 06:00 
22/03/19	Road conditions at time of 1st treatment (14:30)	Road conditions at 17:40

Table 7. Summary of pre-wetted treatment events (70:30 dry salt:brine)

Date	Time and type of Treatment	Minimum surface temperature (°C)	Maximum layer thickness (mm)	Ice/snow reports (patrol, public, police)	Embedded sensor	Non - invasive	Active (FPT>RST)	General description
16/12/18	10g/m² at 14:00 10g/m² at 02:00	-2.5°C at 20:00 after 1st treatment -3.6°C at 06:30 after 2nd treatment	0.05mm at time of 1st treatment	-	-	-	FPT>RST between 19:00 and 23:30	Freezing of damp/wet road after light rain
22/12/18	10g/m² at 16:00 20g/m² at 03:00	-3.2°C at 04:00	0.05mm at time of 1st treatment 0.27mm at 23:00	-	-	Icy between 02:10 and 03:50	FPT>RST between 00:30 and 04:00	Precipitation after 1st afternoon treatment. 1.8mm precipitation after 1st treatment before non-invasive report of ice.
14/01/19	20g/m² at 01:00	-4.8°C at 09:00	0.04mm at time of treatment	-	-	-	FPT>RST between 04:45 to 06:45	Freezing of damp/wet road after light rain – spreading in early hours with no traffic
16/01/19	30g/m² at 14:00	-4.6°C at 22:30	0.17mm at 19:30	Snow	Snow	Icy (21:00 to 22:30)	FPT>RST between	Light snow throughout period.

	20g/m² at 03:00 Front line patrol						19:30 and 23:30 01:00 and 09:00	
29/01/2019	20g/m² at 12:50 20g/m² at 02:00 Front line patrol	-7.7°C at 21:00 after 1st treatment -9°C at 08:30 after 2nd treatment	0.33mm at time of 1st treatment 1.26mm at 05:30	Snow	Snow (02:10 to 03:40)	Icy (17:50 to 19:00) Snowy (01:20 to 04:40)	FPT>RST between 13.00 and 19:30 01:00 and 22:00	Light snow between 23:30 and 02:30
02/02/19	20g/m² at 15:00 20g/m² at 03:00 Front line patrol from 07:00	-10°C at 22:00	0.1mm at time of 1st treatment 0.29mm at 07:00	Snow	Icy (01:40 to 02:30) -	Slush/snow (02:40 to 04:10)	FPT>RST between 02:30 and 03:30	Light snow from 01:20 to 03:30 0.2mm total precipitation

Table 8. Observations of road conditions during pre-wetted treatment events (70:30 dry salt:brine)

22/12/19 FPT>RST between 00:30 and 04:00 Non-invasive report of ice between 02:10 and 03:50	Road conditions at 18:20: 	Road conditions at 21:20: 
16/01/19 FPT>RST between 13.00 and 19:30 01:00 and 22:00 Non-invasive report of ice (17:50 to 19:00)	Road conditions at 18:20: 	Road conditions at 02:00: 

29/01/19 FPT>RST between 13.00 and 19:30	Road conditions at time of 1st treatment 	Road conditions at 02:30: 
02/02/19 FPT>RST between 02:30 and 03:30 (morning of 03/02/19)	Road conditions at 01:30: 	Road conditions at 02:30: 

8 Treatment type and spread rate recommendations

Guidelines are provided in this section for suitable treatment options, spread rates and some important notes regarding road conditions.

8.1 Precautionary treatments

Based on the spread rates and weather conditions under which the brine only and pre-wetted spreading have been trialled over all of the trial phases, recommendations for spread rates for brine only and high brine share precautionary pre-wetted treatments are provided in Table 10 and Table 11.

Spread rates before precipitation are included in Table 10 and Table 11. However, it should be recognised that definitive and/or precise recommendations in this regard are not possible because of the large variations that can occur in the road conditions at time of spreading, amount of precipitation, its water content, road surface temperature variation with time after spreading and the effects of traffic.

Key varying factors that will influence treatment effectiveness during precipitation include:

- Precipitation type, intensity and amount
- Snow wetness
- Cycle time
- Temperature – low point and variation with time

Guidelines are provided in Table 9 (to be used in conjunction with Table 10 and Table 11) on the suitability of brine only or high brine share (FS70) treatments before precipitation.

The levels of precipitation are defined as:

- Light precipitation – Total precipitation from Snow or Rain up to 1mm between spreading and minimum forecast temperature
- Moderate/heavy precipitation - Total precipitation from Snow or Rain over 1mm between spreading and minimum forecast temperature

Table 9. Suitability of treatments methods before precipitation

		Brine only		High brine share (FS70)	
Road Surface Temperature (°C)	**Road surface state at time of treatment**	**Light precipitation**	**Moderate/Heavy precipitation**	**Light precipitation**	**Moderate/Heavy precipitation**
At or above -1.0°C	Dry/Damp/Wet (< 0.1mm)	✓*	✗	✓	✓*
	Wet > 0.1mm	✓*	✗	✓*	✓*
-1.1°C to -2.0°C	Dry/Damp/Wet	✓*	✗	✓	✓*
	Wet > 0.1mm	✓*	✗	✓*	✓*
-2.1°C to -5.0°C	Dry/Damp/Wet	✗	✗	✓*	✓*
	Wet > 0.1mm	✗	✗	✓*	✓*
< -5°C	Dry/Damp/Wet	✗	✗	✓*	✗
	Wet > 0.1mm	✗	✗	✓*	✗

* Requires close monitoring and, if required, retreatment or successive treatments

Brine only treatments

Note 1. The spread rates are dependent on spreading brine with a concentration in the range of 20 to 23%, with a recommended target concentration of 22-23%.

Note 2. When very wet road surfaces (>0.1mm) occur roads should be closely monitored and consideration given to increasing the spread rate, making additional treatments or both.

Note 3. When treatments are carried out during high wind conditions (>20mph), it is recommended to closely monitor residual salt levels and consider carrying out additional treatments if and where necessary.

Note 4. Where the table provides a range 10 to 20ml/m² (Frost susceptible for road surface conditions C and D), treatments at 10ml/m² can be considered for dry or lightly damp road surfaces and/or when there is confidence that residual salt will be present from previous treatments.

Table 10. Spreading rates for brine only precautionary treatments

Spreading rates for precautionary treatments with brine (ml/m²)		
Road surface condition	**Frost Susceptible/surface water run-off area**	**Road Surface Wet**
A. RST higher than plus 1°C	0	0
B. RST lower than or equal to plus 1°C but higher than minus 2°C	10	20
C. RST lower than or equal to minus 2°C but higher than minus 5°C	10 to 20	20
D. RST lower than or equal to minus 5°C	10 to 20	20
E. RST lower than or equal to plus 1°C but higher than minus 2°C following rain	20	30

F. RST lower than or equal to minus 2°C but higher than minus 5°C following rain	30	30
G. RST lower than or equal to minus 5°C following rain	30	30
H. Hoar Frost	20	20
I. Freezing Fog	10	20
J. Freezing Rain	30	30
K. Total precipitation from Snow or Rain up to 1mm See Table 9 for suitable temperature ranges and weather conditions	30	30
L. Total precipitation from Snow or Rain over 1mm	N/A Use pre-wetted salt	N/A Use pre-wetted salt
M. Hard Packed Snow/Ice	N/A See clearance matrix	N/A See clearance matrix

High brine share pre-wetted treatments (FS70)

Note 1. The spread rates in the tables below apply to pre-wetted treatments comprising a 30:70 ratio by weight of dry salt to sodium chloride brine (sometimes denoted as FS 70), with a recommended target concentration of 22-23%.

Note 2. When very wet road surfaces (>0.1mm) occur roads should be closely monitored and consideration given to increasing the spread rate, making additional treatments or both.

Note 3. When treatments are carried out during high wind conditions (>20mph), it is recommended to closely monitor residual salt levels and consider carrying out additional treatments if and where necessary.

Note 4. Where the table provides a range 10 to 20g/m² (Frost susceptible for road surface conditions C and D), treatments at 10g/m² can be considered for dry or lightly damp road surfaces and/or when there is confidence that residual salt will be present from previous treatments.

Table 11. Spreading rates for high brine share pre-wetted (FS70) precautionary treatments

Spreading rates for precautionary treatments with pre-wetted salt (FS70) (g/m²)		
Road surface condition	**Frost Susceptible/surface water run-off area**	**Road Surface Wet**
A. RST higher than plus 1°C	0	0
B. RST lower than or equal to plus 1°C but higher than minus 2°C	10	20
C. RST lower than or equal to minus 2°C but higher than minus 5°C	10 to 20	20
D. RST lower than or equal to minus 5°C	10 to 20	20
E. RST lower than or equal to plus 1°C but higher than minus 2°C following rain (see note 1)	20	30
F. RST lower than or equal to minus 2°C but higher than minus 5°C following rain (see note 1)	30	30
G. RST lower than or equal to minus 5°C following rain (see note 1)	30	30
H. Hoar Frost	20	20
I. Freezing Fog	10	20
J. Freezing Rain	30	30
K. Total precipitation from Snow or Rain up to 1mm	30	30

See Table 9 for suitable temperature ranges and weather conditions		
L. Total precipitation from Snow or Rain over 1mm See Table 9 for suitable temperature ranges and weather conditions	40	40
M. Hard Packed Snow/Ice	N/A See clearance matrix	N/A See clearance matrix

8.2 Snow and Ice clearance

Where ice has formed or snow has settled on surface, dry salt is the preferred treatment, to penetrate snow and keep in a soft and ploughable condition.

Refer to clearance matrix 8/3 in NW Winter Plan.

9 Conclusions

The following conclusions can be drawn from the trials:

- Brine spreading carried out using current treatment guidelines has provided effective precautionary treatments for frost/ice (no precipitation) hazards on dry, damp and wet roads (<0.1mm water)
- Except for the cases of very light precipitation (0.1 mm rainfall or less), all precipitation events that occurred during or after spreading on the trial site resulted in very wet roads (road wetness levels greater than 0.1mm).
- As road wetness increases above 0.1mm, all treatment types show reduced freezing points of the road surface moisture, with road surface temperatures often falling below the freezing point of the moisture for the wetter conditions.
- For treatments on very wet roads and during precipitation, the brine only treatments while initially providing comparable performance (for 1-2 hours after treatment) were not assessed to provide as long lasting treatments as standard or higher brine share pre-wetted spreading.
- The trial route provided a severe challenge for winter maintenance, with precipitation and very wet road surfaces occurring during many of the treatments carried out. Low levels of traffic also contributed to the road surface remaining very wet for significant periods after rainfall, with little traffic to disperse water, or to aid the break up and dispersal of snow.
- On low trafficked routes such as the A835 trial site, and in very wet and snow/slush conditions, the loss of the salt particles will be reduced compared to treatments on drier and/or more highly trafficked routes.
- Further trials of higher brine share pre-wetted spreading carried out using a 50:50 ratio of dry salt:brine will provide confirmation of the optimum treatment for the Transport Scotland network.
- The use of a spray bar is the preferred option for delivering brine treatments, in particular if spreading at higher speeds of 40-50mph, with the spray bar used for this trial assessed to provide a good distribution of brine and to be less affected by wind than the distribution from the spinning disc used in the 2017/18 trial.

10 Acknowledgements

The assistance of the following was much appreciated: Kevin Campbell and Willie MacDougall of BEAR Scotland; Donald Kerr of Aebi Schmidt UK Limited, Iain McDonald and Martin Thomson of Transport Scotland.

References

Evans M, Jordan R and Rasalingham S (2011). The feasibility of brine spreading on the Highways Agency's road network, *Published Project Report PPR512*, Wokingham, Berkshire: Transport Research Laboratory (TRL).

NWSRG (2019a). Spread rates for Precautionary Salting.

NWSRG (2019b). Treatments for Snow and Ice.

Appendix A Freezing Point temperature and residual salt measurement variation with time after spreading

For the case where very wet roads (water thickness >0.1mm) occur during or after spreading:

- Figures A1 to A3 show the variation in amount of salt with time after spreading
- Figures A4 to A6 show the variation in freezing point with time after spreading

For dry/damp/wet roads (water thickness <0.1mm):

- Figures A7 to A9 show the variation in amount of salt with time after spreading
- Figures A10 to A12 show the variation in freezing point with time after spreading

The plots are colour coded by treatment method as shown in Table A1.

Table A1. Colour key for treatment methods

Treatment	
Brine only	
Pre-wetted (70:30 dry salt:brine)	
High brine share pre-wetted (30:70 dry salt:brine)	

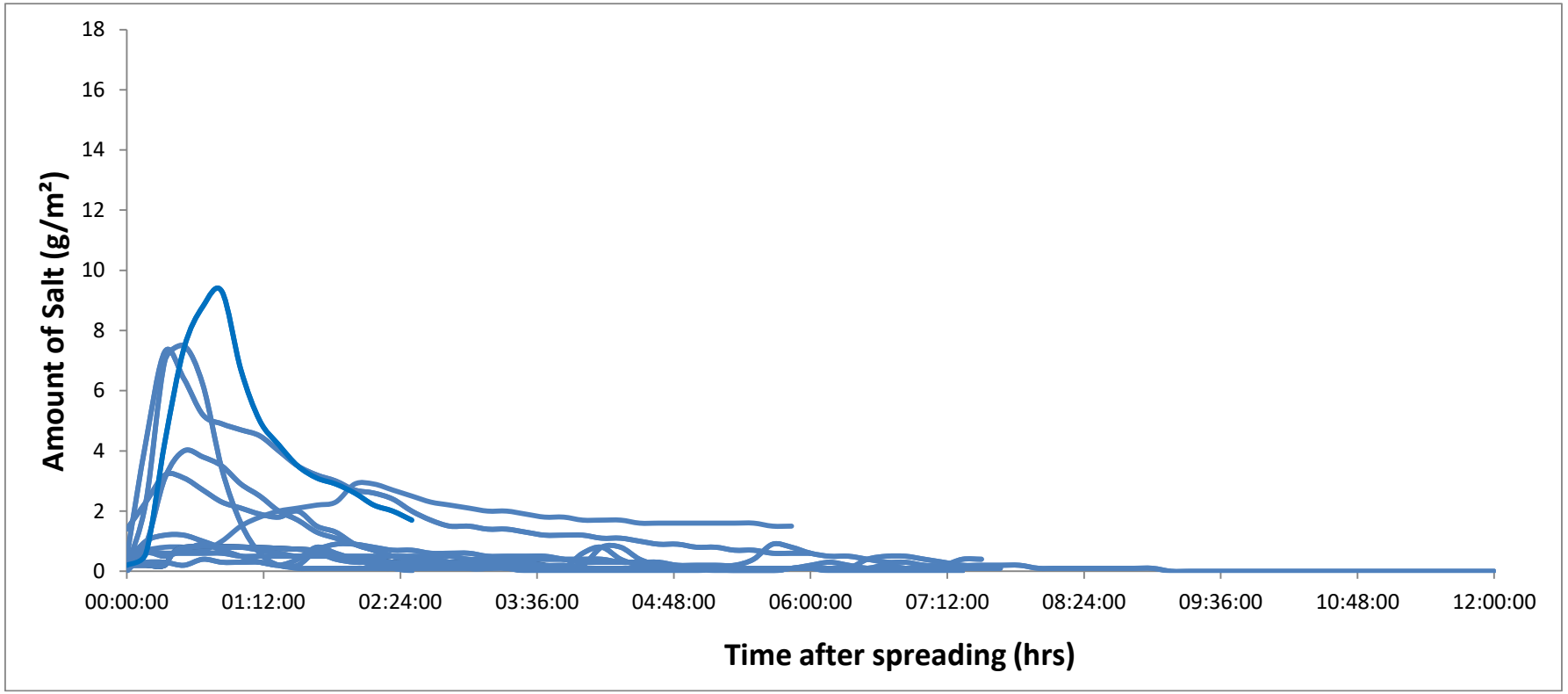


Figure A1. Variation in amount of salt (passive sensor) with time after spreading – brine only on very wet road (>0.1mm) during or after spreading

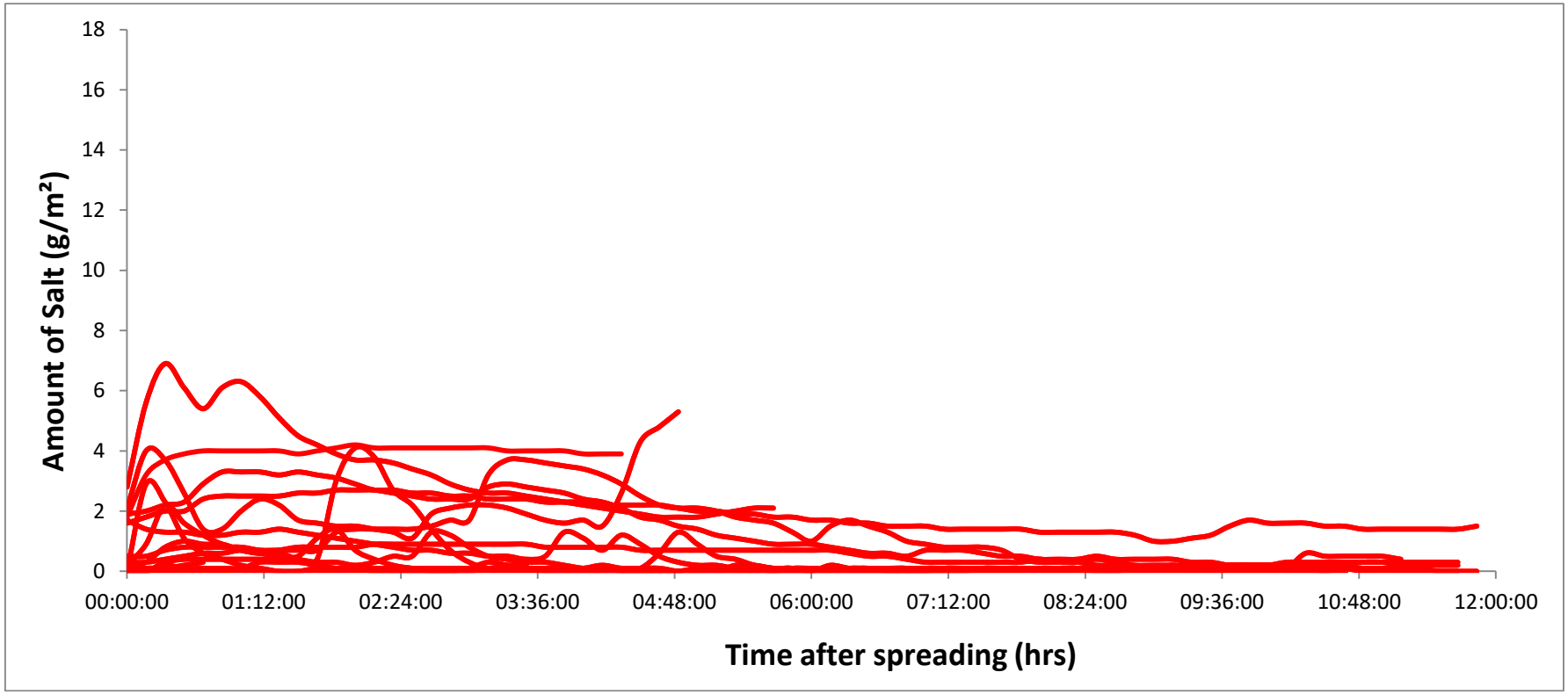


Figure A2. Variation in amount of salt (passive sensor) with time after spreading - pre-wetted treatment (70:30 dry salt:brine) on very wet road (>0.1mm) during or after spreading

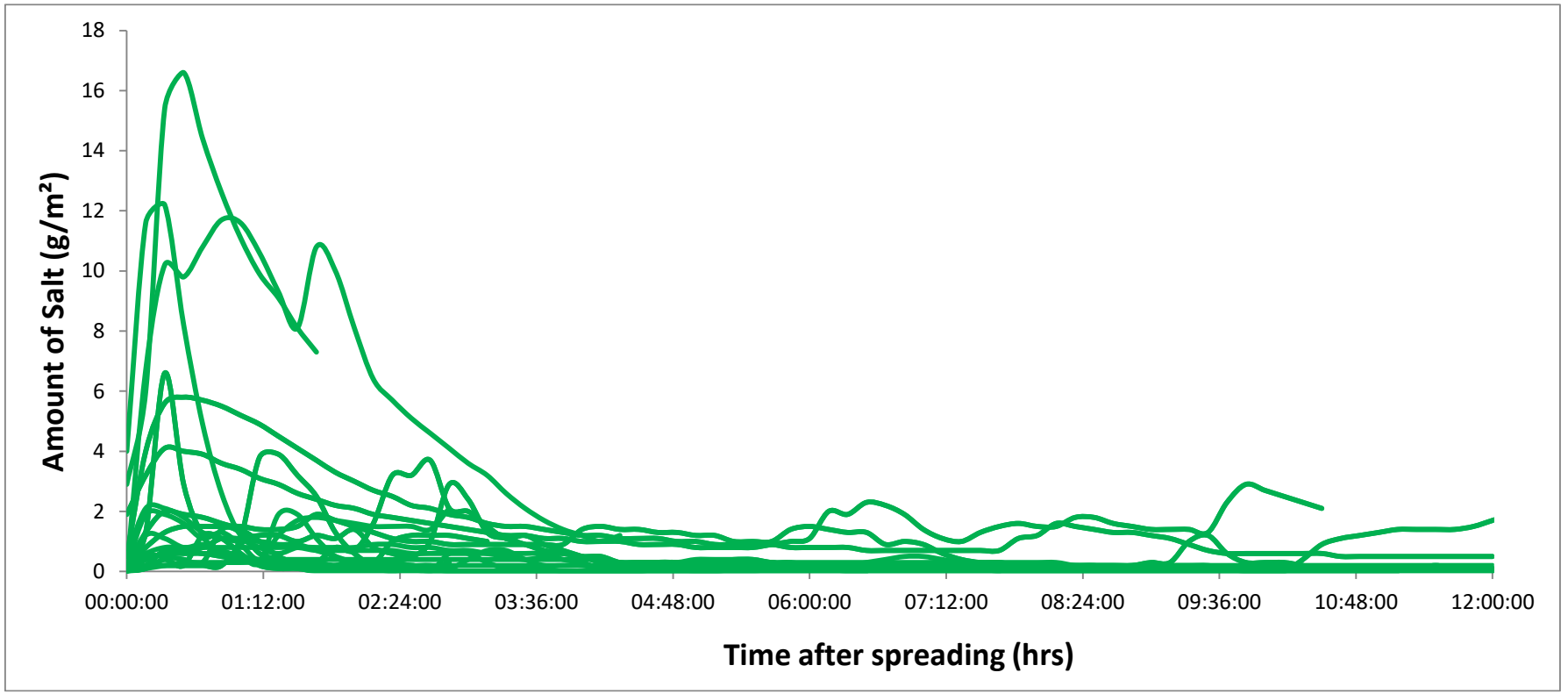


Figure A3. Variation in amount of salt (passive sensor) with time after spreading - high brine share pre-wetted treatment events (30:70 dry salt:brine) on very wet road (>0.1mm) during or after spreading

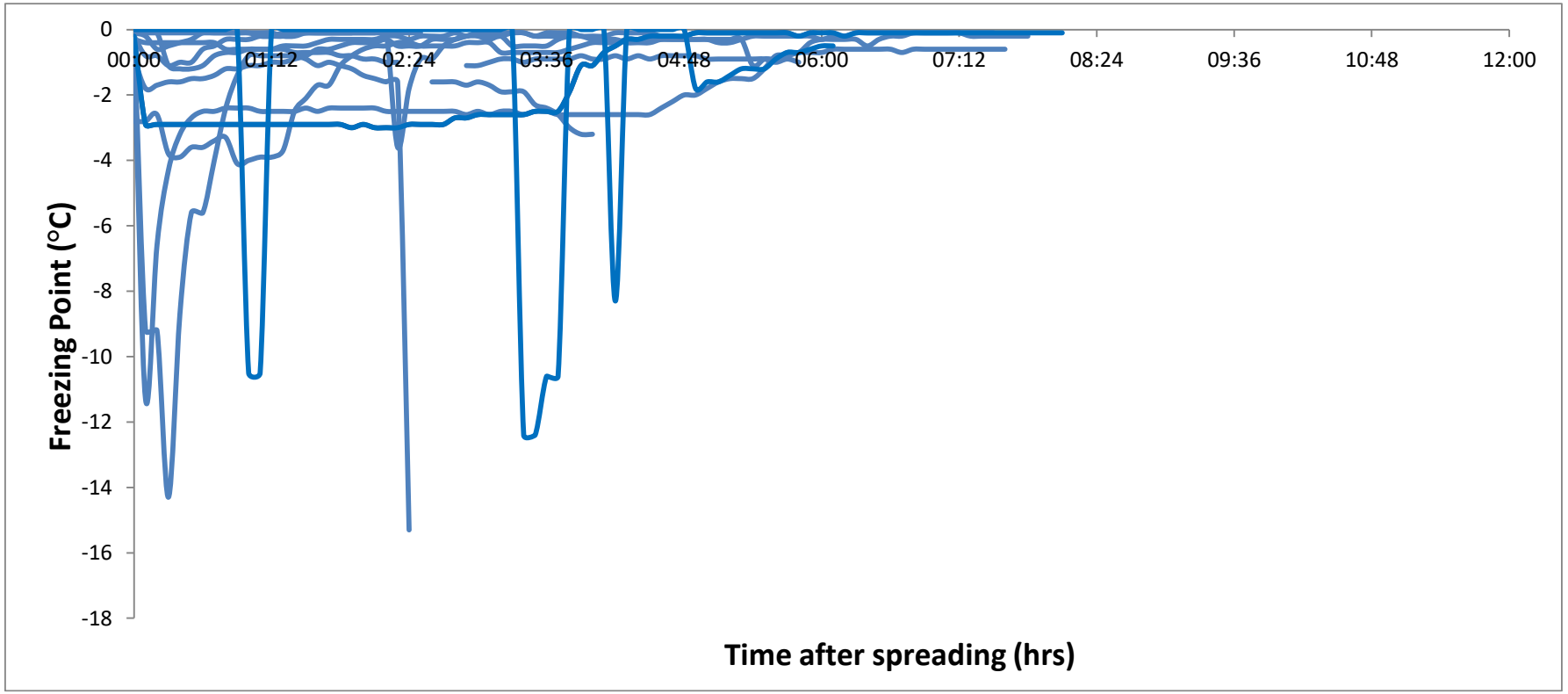


Figure A4. Freezing point variation (active sensor) with time after spreading - brine only on very wet road (>0.1mm) during or after spreading

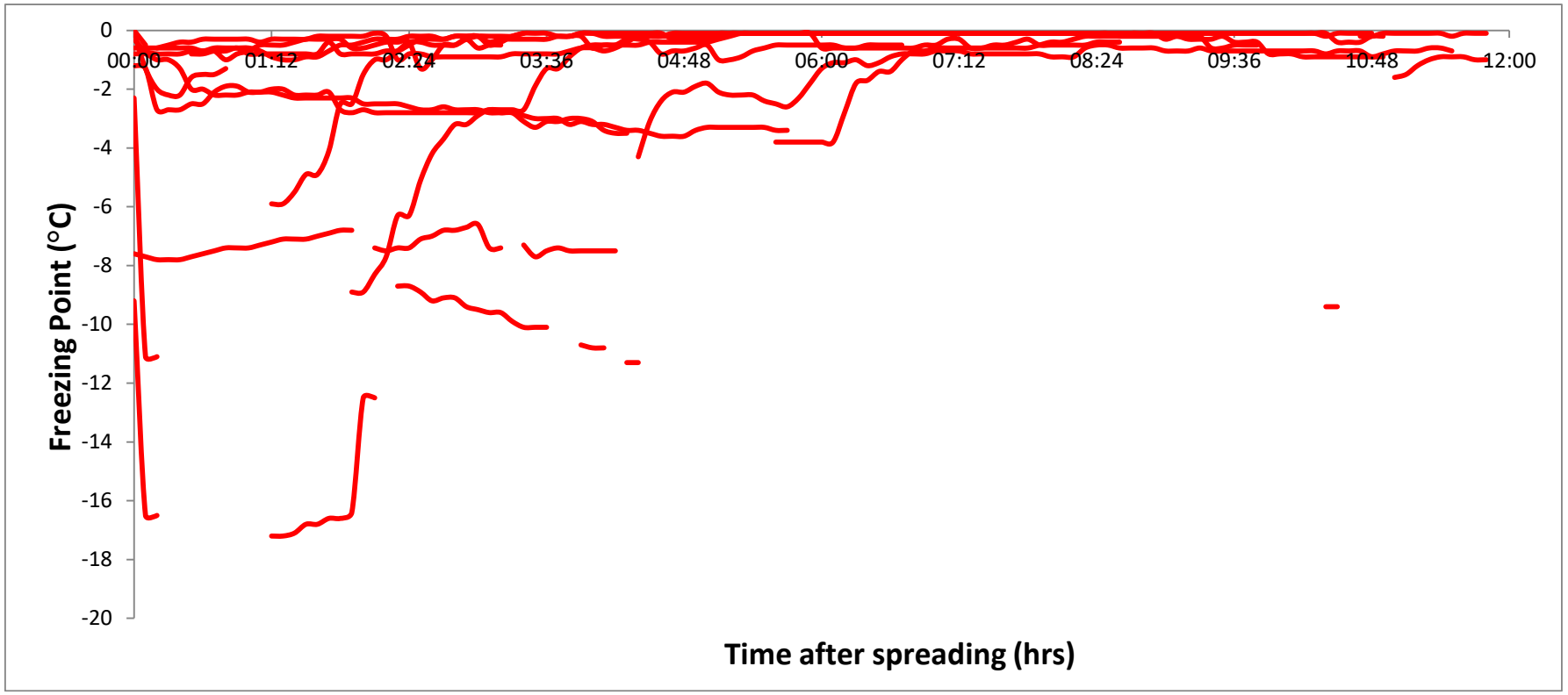


Figure A5. Freezing point variation (active sensor) with time after spreading - pre-wetted treatment (70:30 dry salt:brine) on very wet road (>0.1mm) during or after spreading

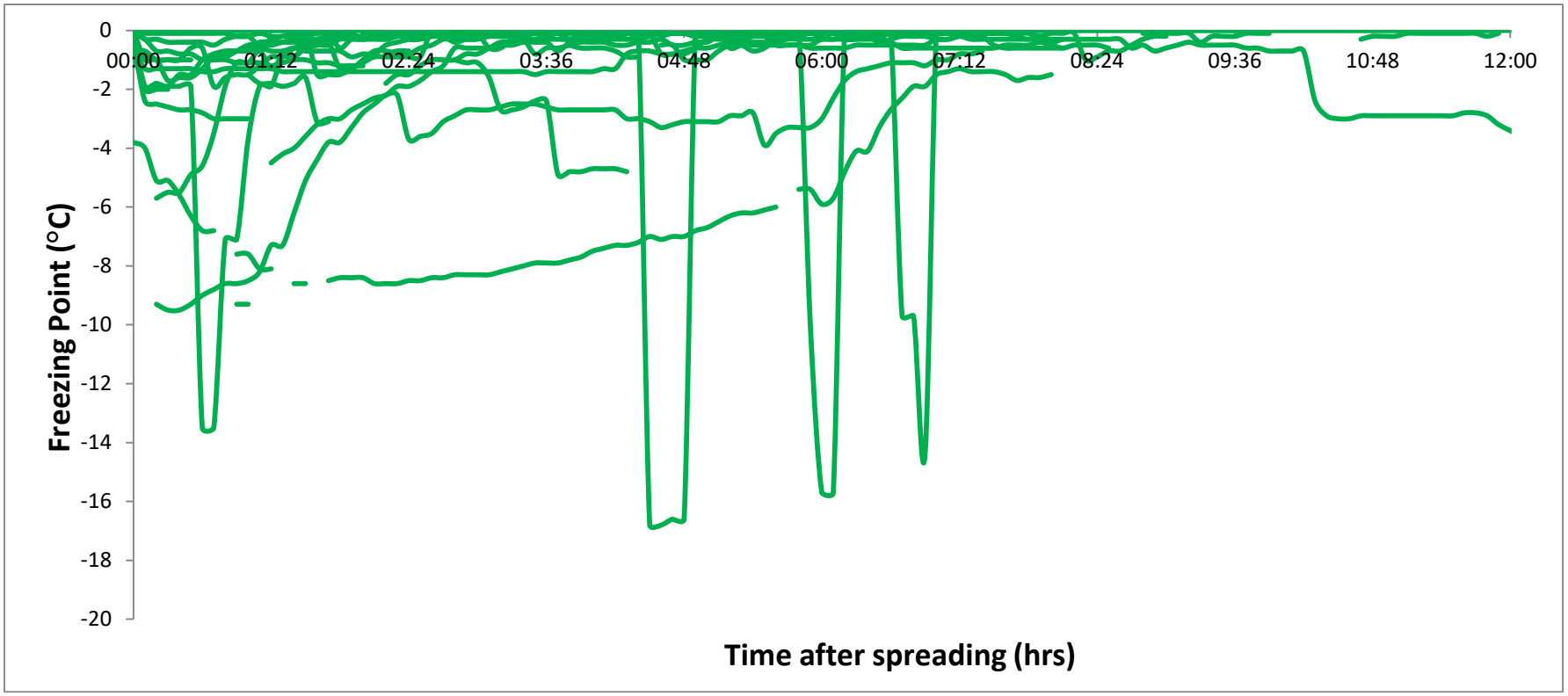


Figure A6. Freezing point variation (active sensor) with time after spreading - high brine share pre-wetted treatment events (30:70 dry salt:brine) on very wet road (>0.1mm) during or after spreading

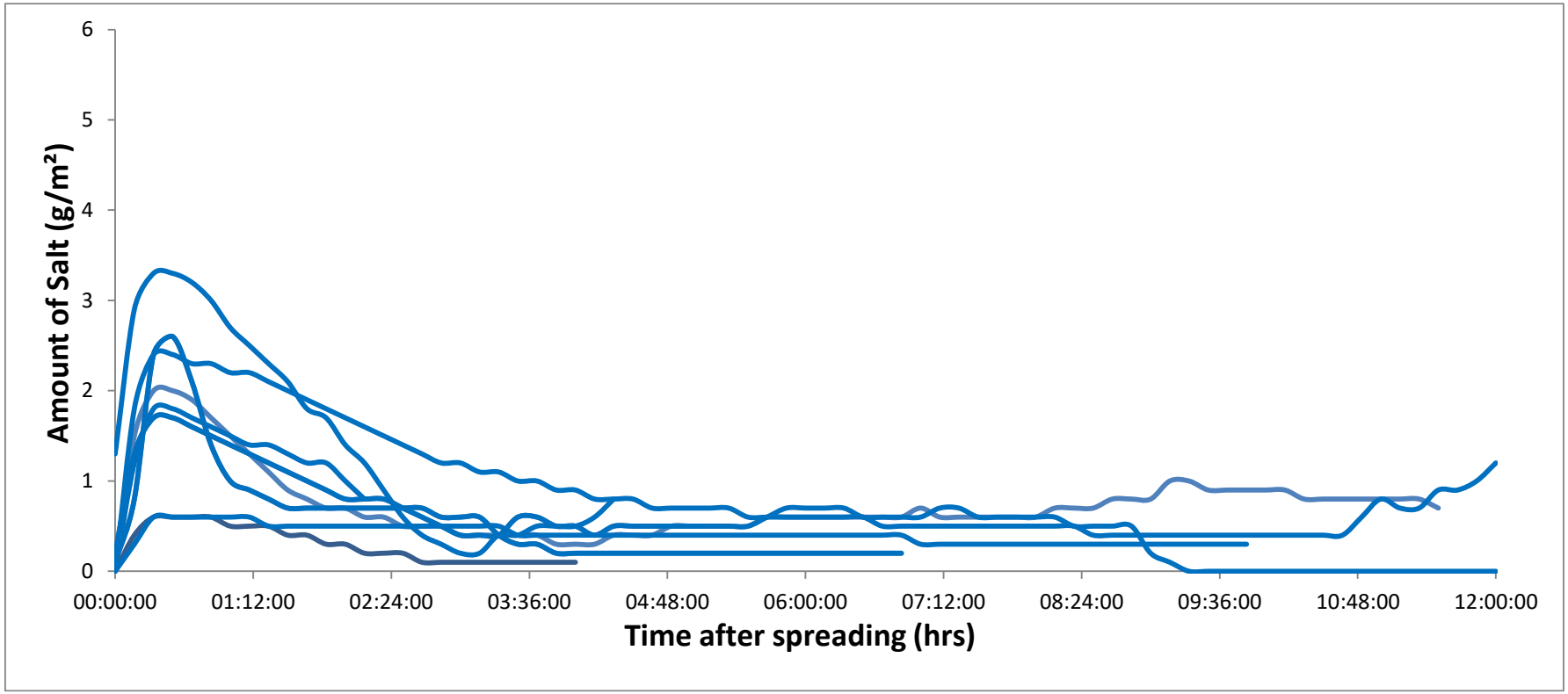


Figure A7. Variation in amount of salt (passive sensor) with time after spreading – brine only on dry/damp/wet road (<0.1mm) during or after spreading

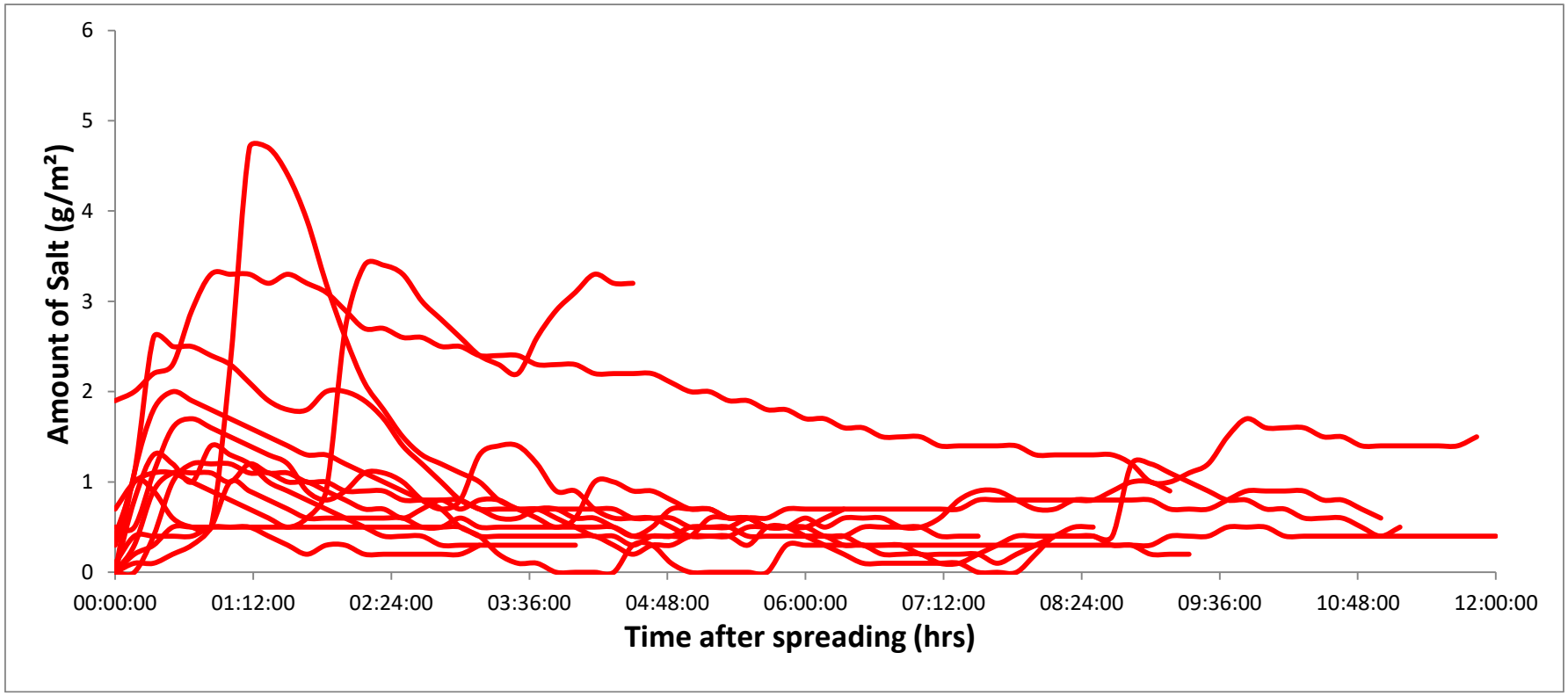


Figure A8. Variation in amount of salt (passive sensor) with time after spreading – pre-wetted treatment (70:30 dry salt:brine) on dry/damp/wet road (<0.1mm) during or after spreading

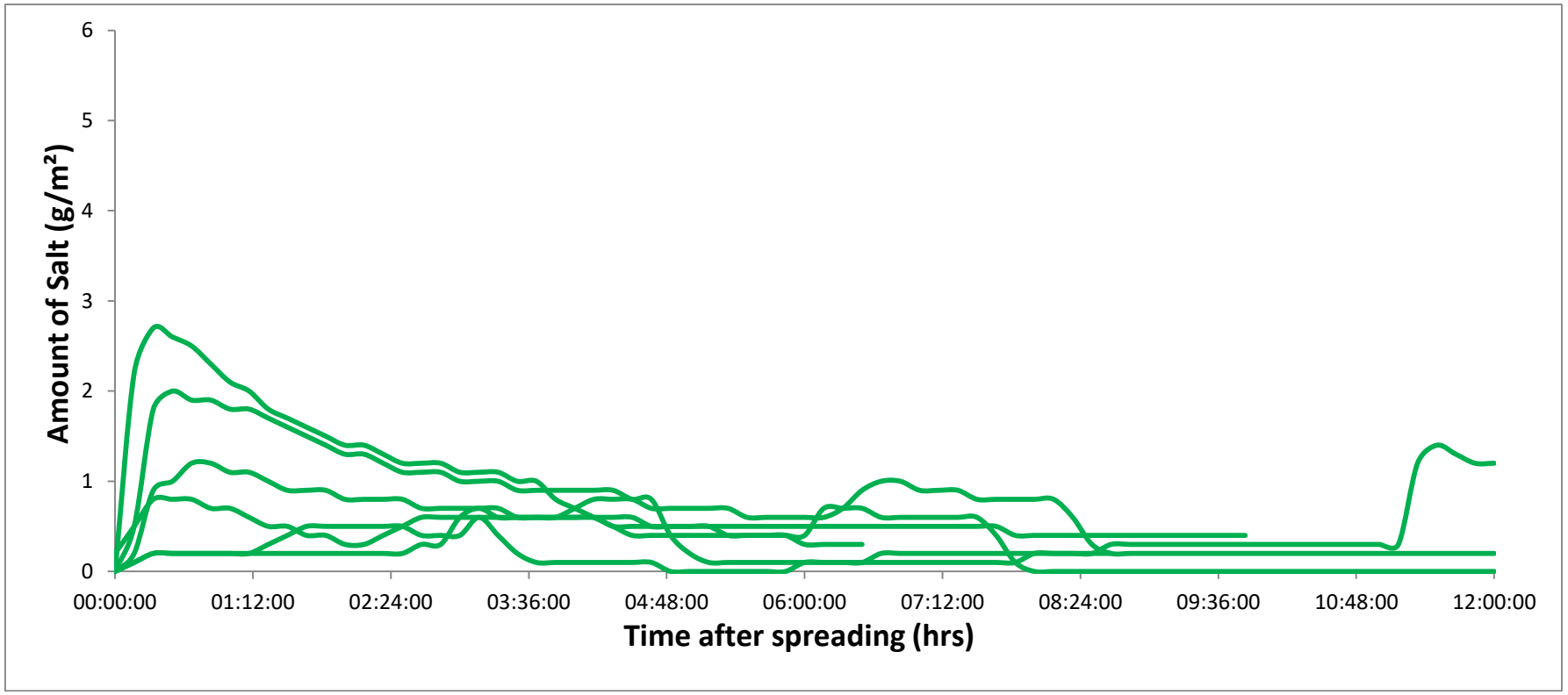


Figure A9. Variation in amount of salt (passive sensor) with time after spreading – high brine share pre-wetted treatment events (30:70 dry salt:brine) on dry/damp/wet road (<0.1mm) during or after spreading

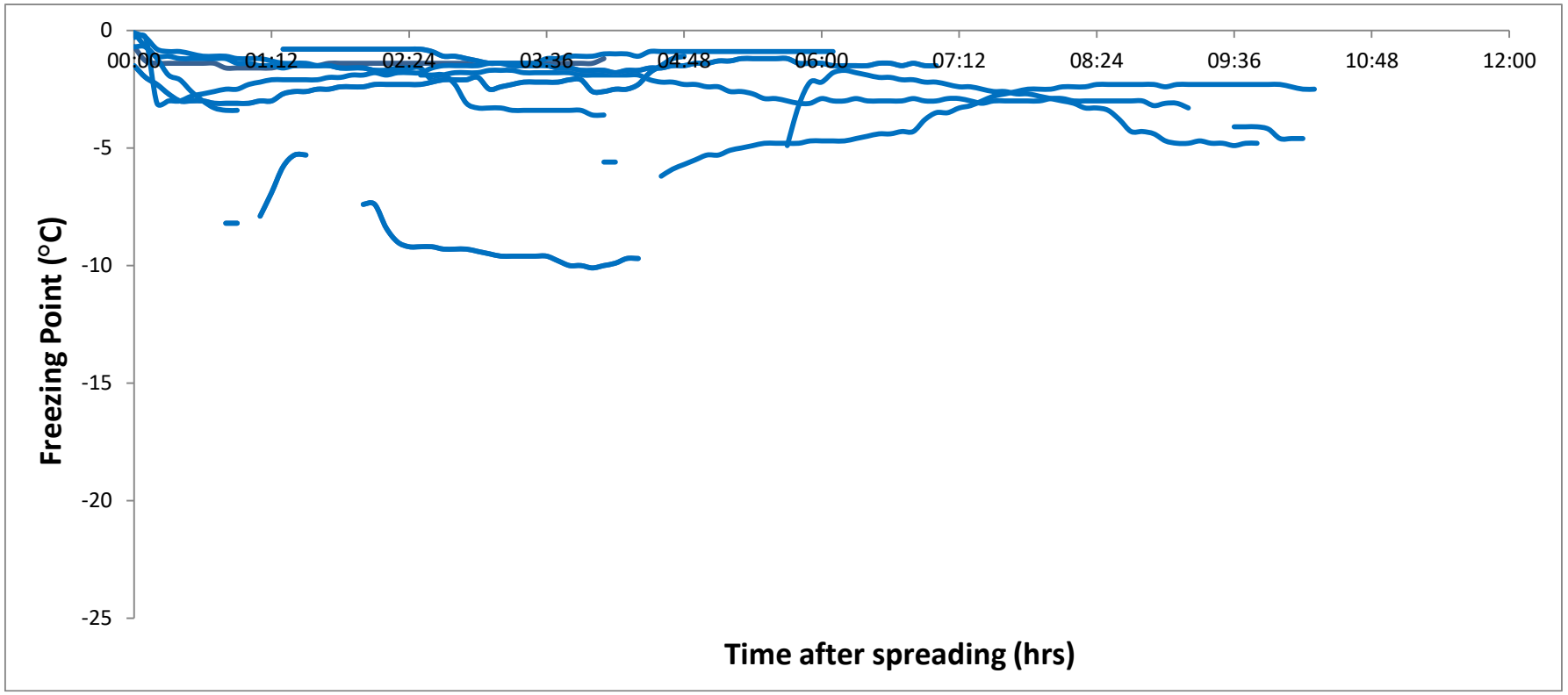


Figure A10. Freezing point variation (active sensor) with time after spreading – brine only on dry/damp/wet road (<0.1mm) during or after spreading

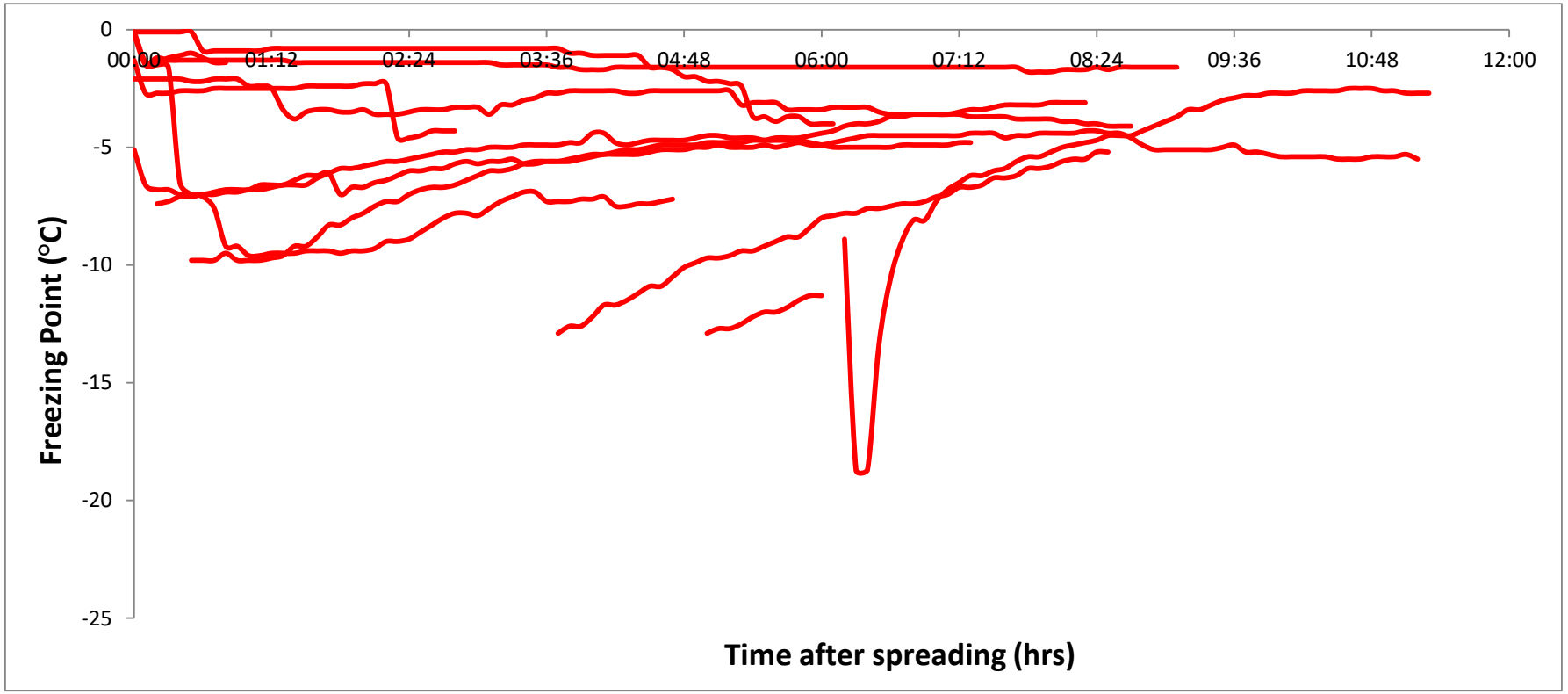


Figure A11. Freezing point variation (active sensor) with time after spreading – pre-wetted treatment (70:30 dry salt:brine) on dry/damp/wet road (<0.1mm) during or after spreading

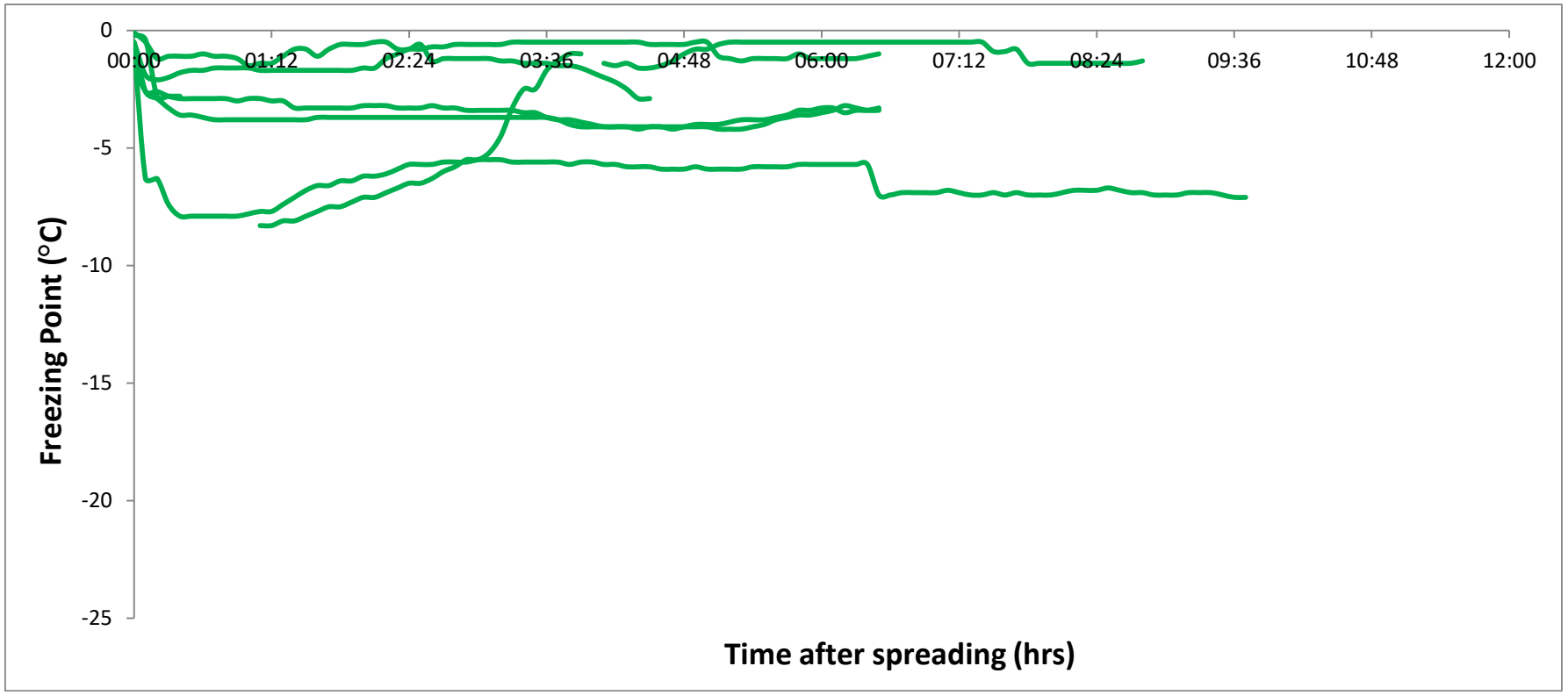


Figure A12. Freezing point variation (active sensor) with time after spreading – high brine share pre-wetted treatment events (30:70 dry salt:brine) on dry/damp/wet road (<0.1mm) during or after spreading

Appendix B Freezing Point temperature and residual salt measurement variation with road wetness

Figures B1 to B3 summarise the freezing points measured by the embedded active sensor at Aultguish following treatments carried out using each of the different treatment methods.

Figures B4 to B6 summarise the amount of salt (g/m^2) measured by the embedded passive sensor.

The sensor measurements are plotted against the level of road wetness at the time of each measurement. Road wetness is differentiated based on the classification shown in Table B1..

Table B1. Road wetness classification

Surface state	Water thickness (mm)
Dry/damp	Less than 0.05
Wet	0.05 to 0.1
Very Wet	Greater than 0.1

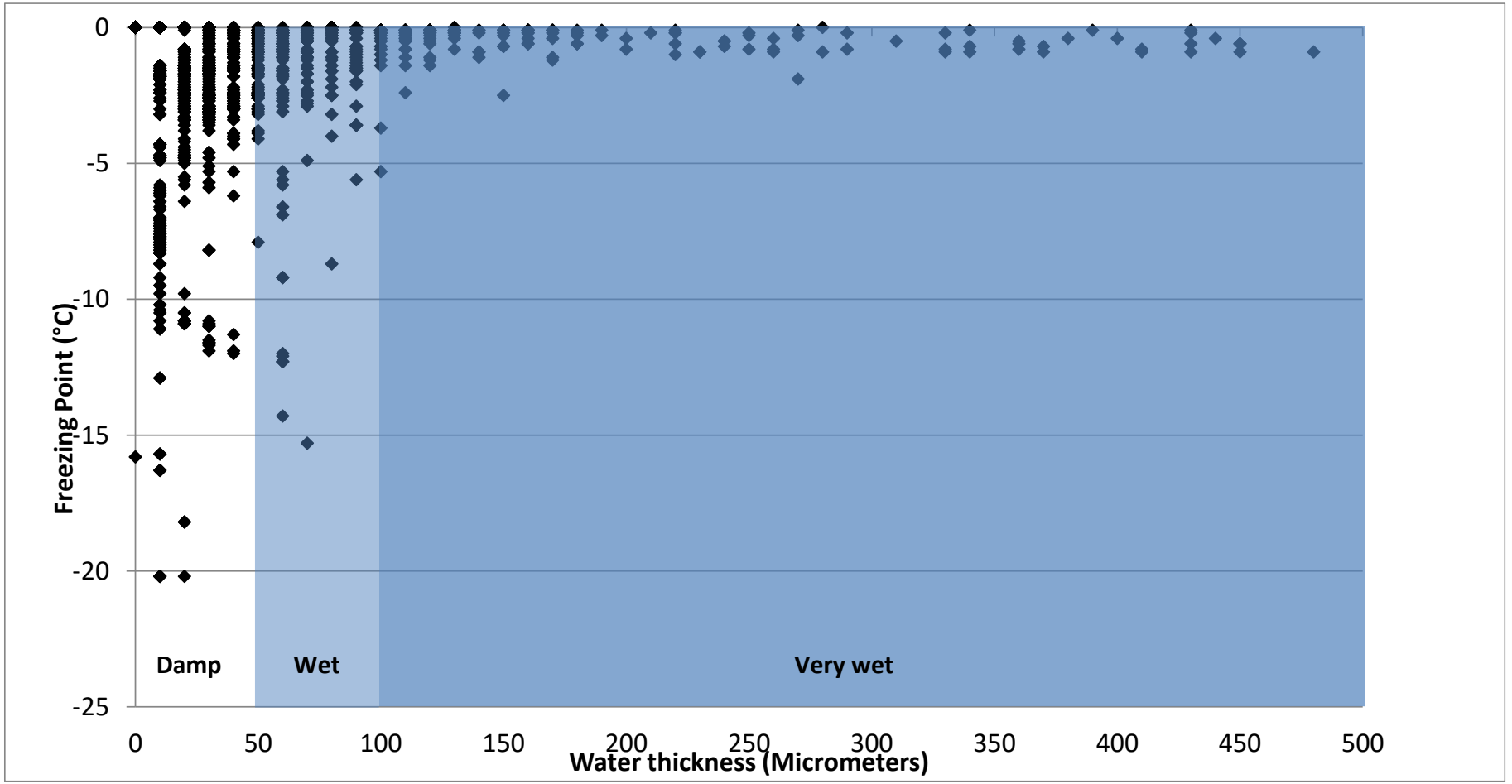


Figure B1. Freezing point from active sensor during brine only treatments

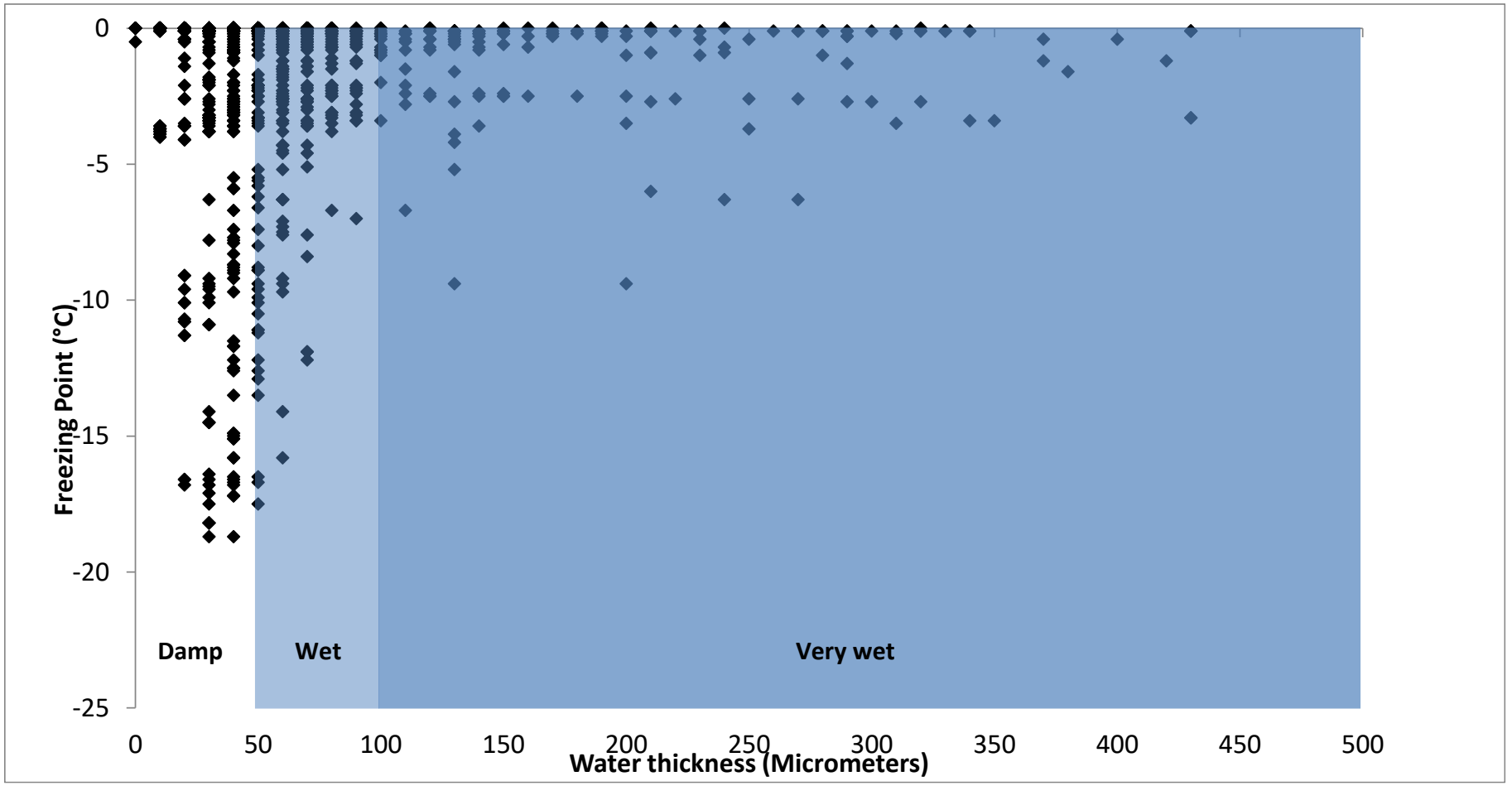


Figure B2. Freezing point from active sensor during pre-wetted salt treatments (70:30 salt:brine)

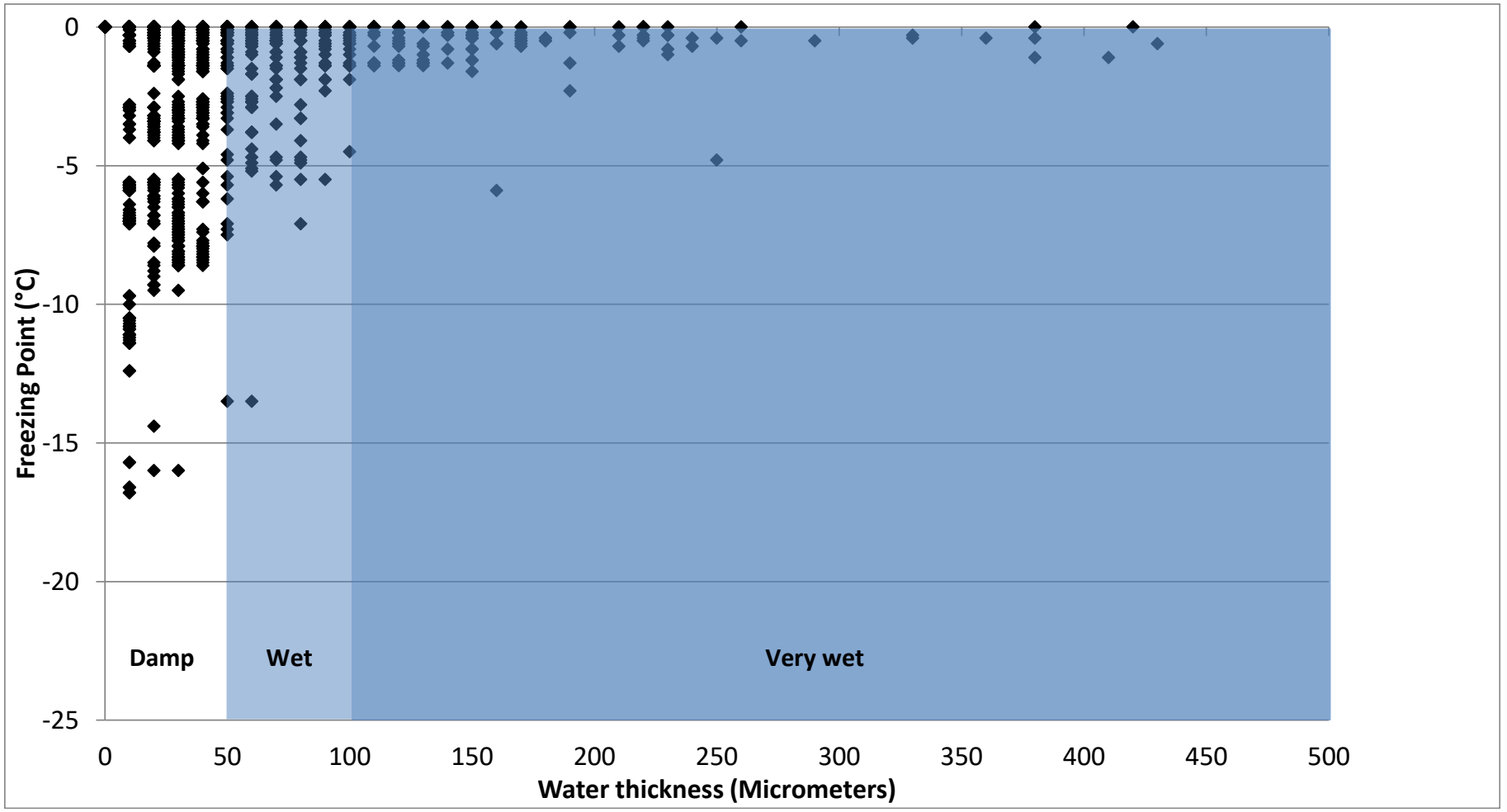


Figure B3. Freezing point from active sensor during high brine share pre-wetted treatments (30:70 salt:brine)

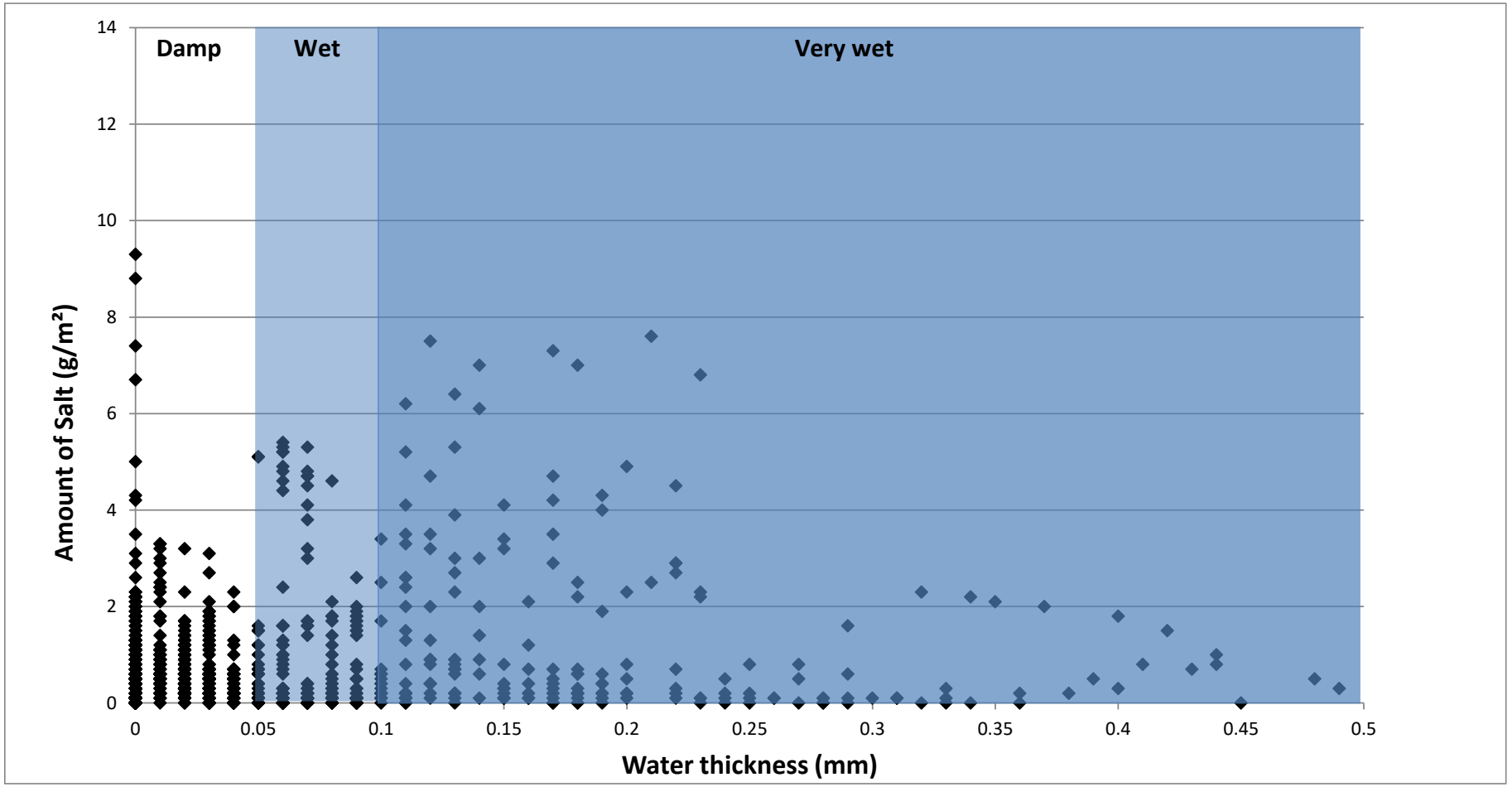


Figure B4. Amount of salt (g/m²) point from passive sensor during brine only treatments

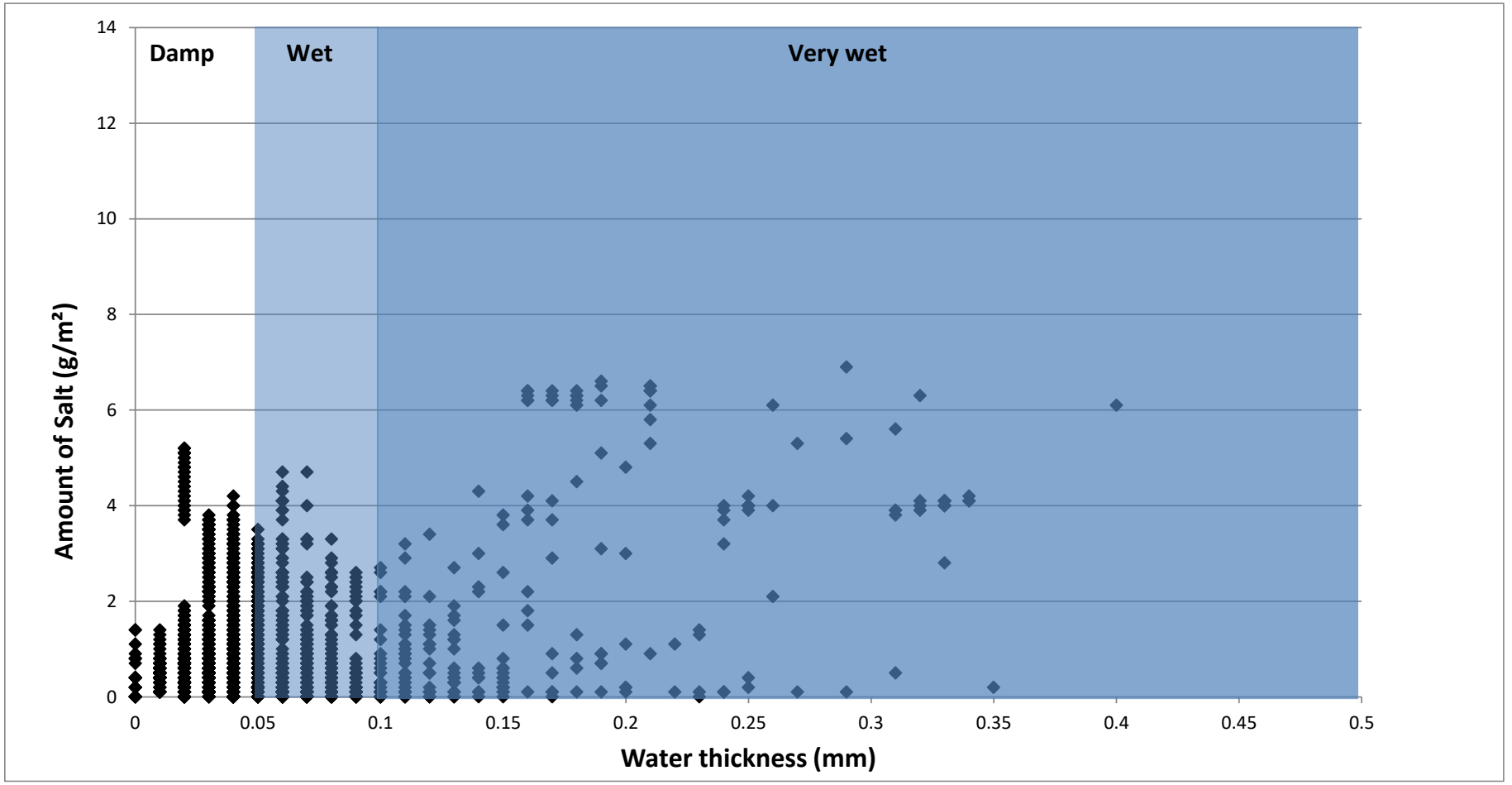


Figure B5. Amount of salt (g/m²) point from passive sensor during pre-wetted salt treatments (70:30 salt:brine)

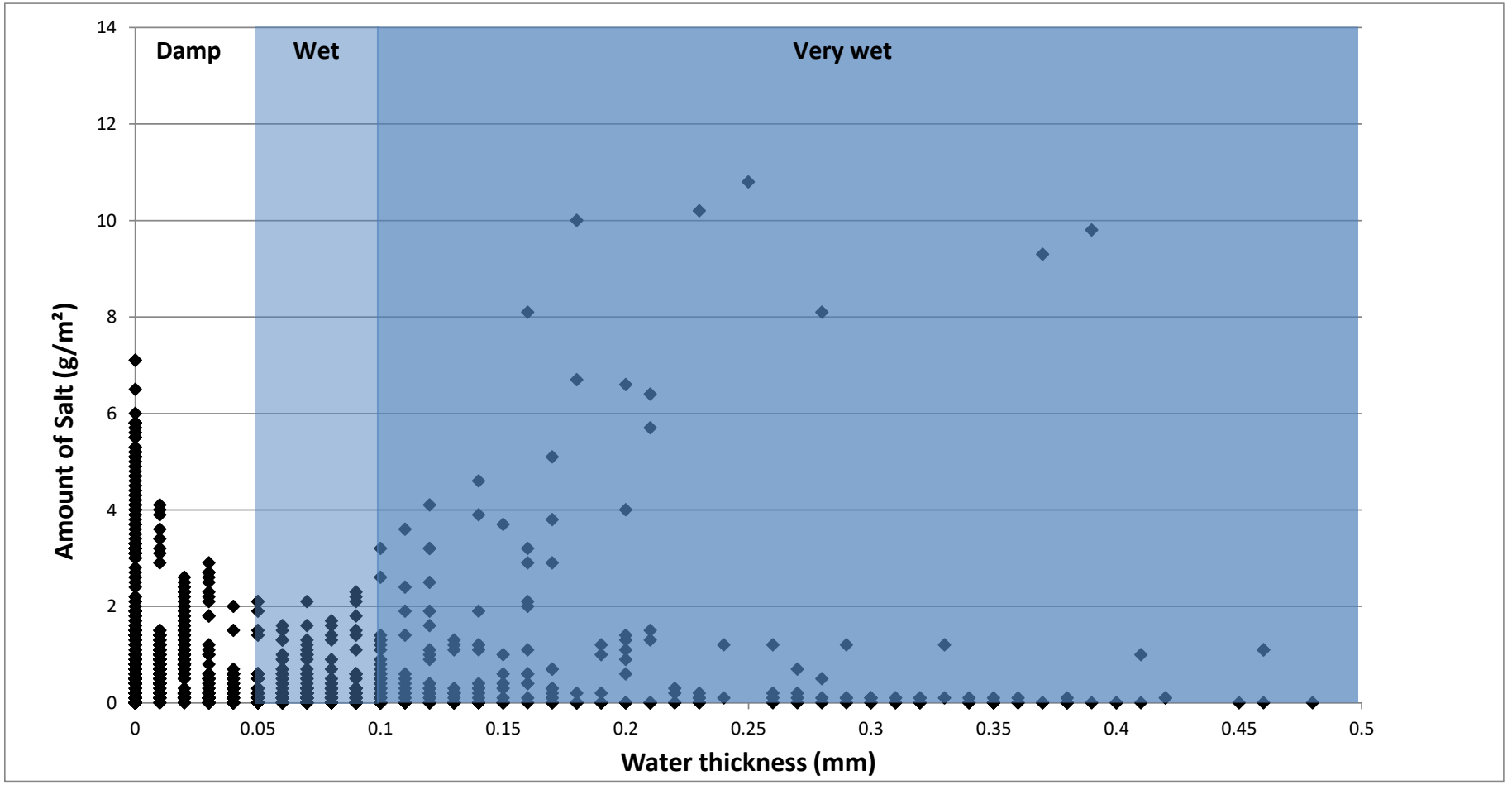


Figure B6. Amount of salt (g/m²) point from passive sensor during high brine share pre-wetted treatments (30:70 salt:brine)

Appendix C Summary of minimum temperatures, maximum water layer thicknesses and total amounts of precipitation

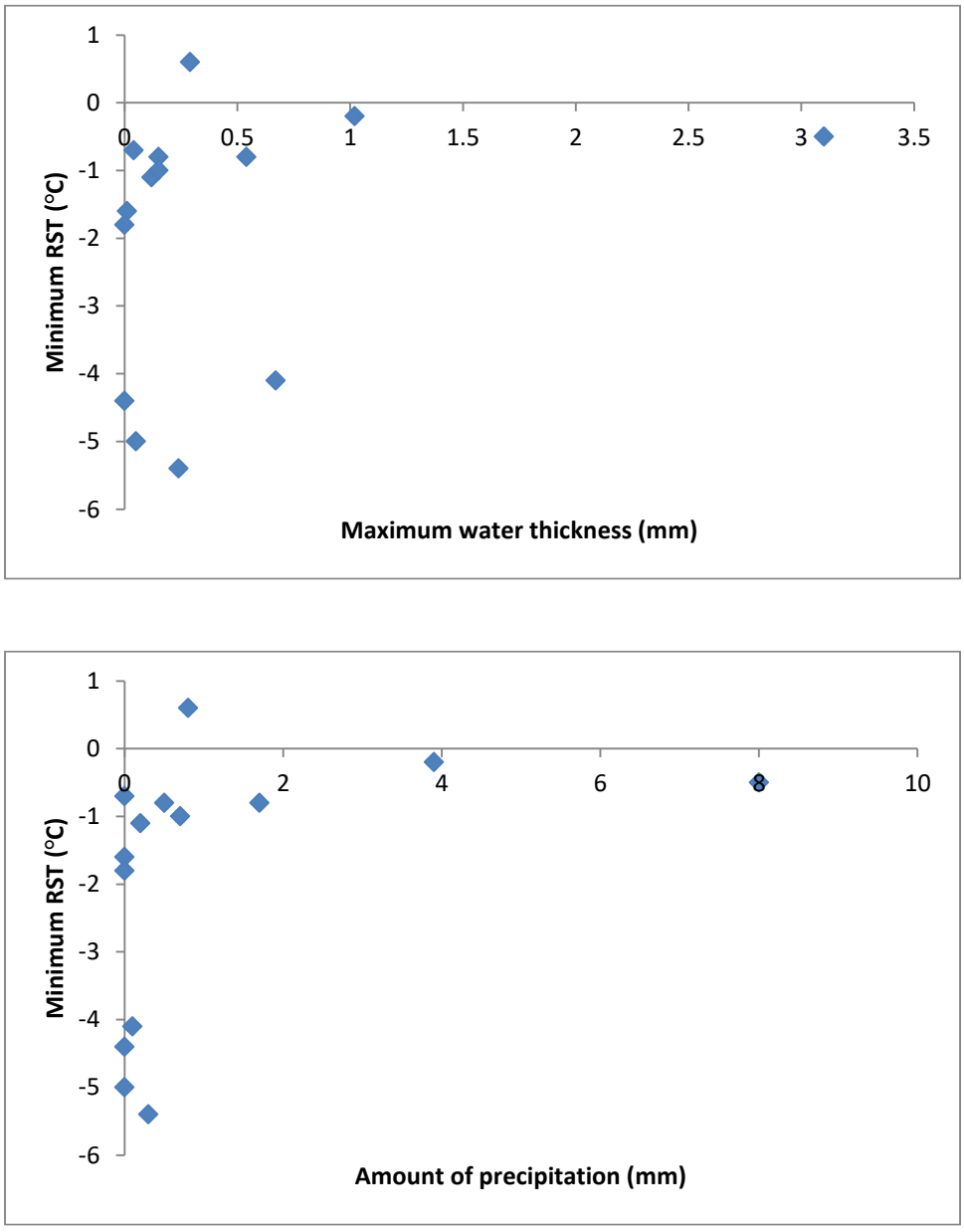
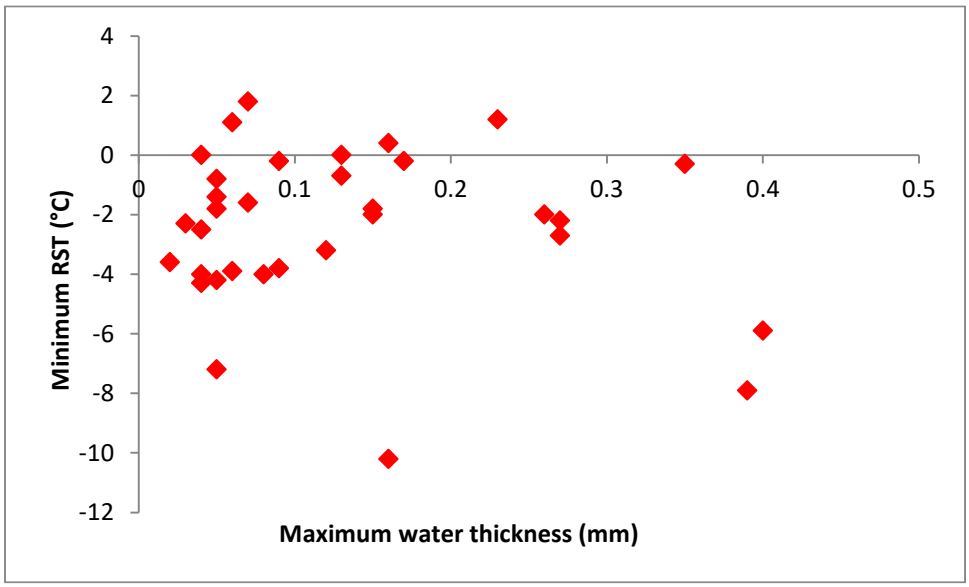


Figure C1. Conditions during brine only treatments at Aultguish weather station



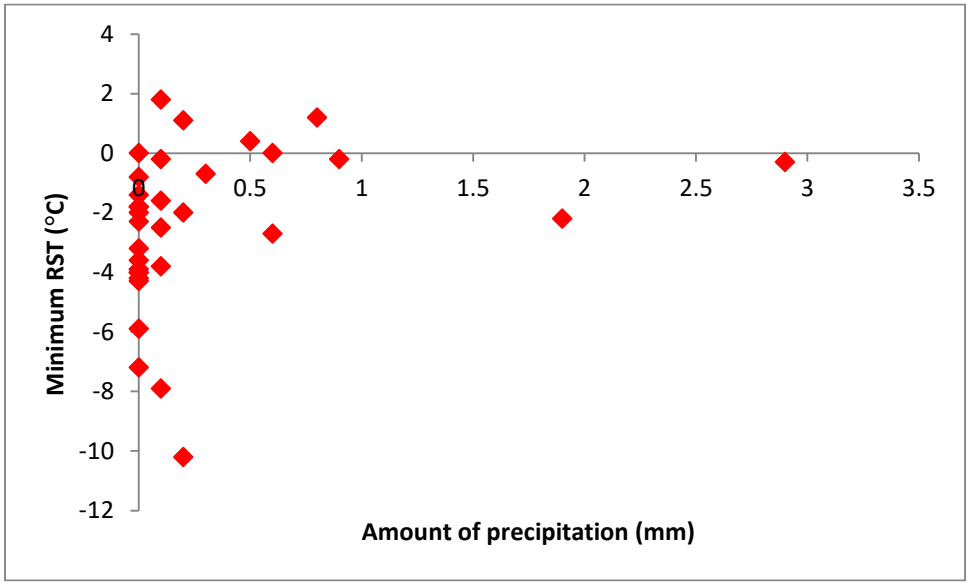
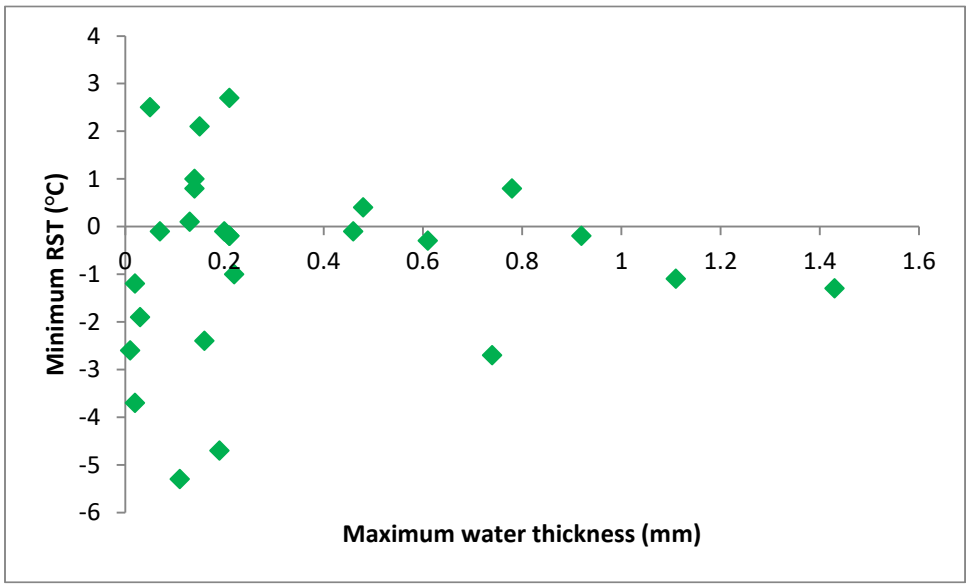


Figure C2. Conditions during pre-wetted salt treatments (70:30 salt:brine) at Aultguish weather station



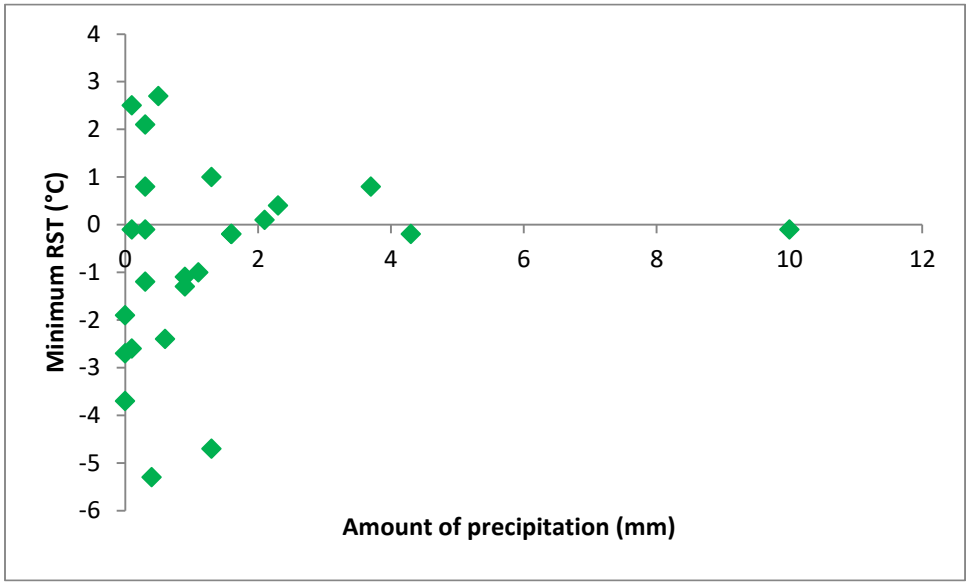


Figure C3. Conditions during high brine share pre-wetted salt treatments (30:70 salt:brine) at Aultguish weather station

Trials of Brine Spreading Performance on Scotland's Roads: 2018-19

A further phase of live trials was carried out on the Transport Scotland network, as part of routine winter treatments in the North West Trunk Road Unit. The trials encompassed both brine only and higher brine share pre-wetted treatments than the UK standard 70:30 dry salt:brine ratio.

Brine spreading carried out using current treatment guidelines has provided effective precautionary treatments on dry, damp and wet roads (<0.1mm water). Observations and sensor measurements, including operator feedback, indicated that standard and higher brine share pre-wetted treatments provided improved performance over brine only spreading on very wet roads and snow conditions. On low trafficked routes such as the trial site, and in very wet and snow/slush conditions, the loss of the salt particles in dry and pre-wetted salt caused by traffic will be reduced compared to treatments on drier and/or more highly trafficked routes.

Where ice has formed or snow has settled on the road surface, dry or pre-wetted salt (salt:brine ratio of 70:30 or 50:50) is the preferred treatment, to penetrate snow and keep it in a soft and ploughable condition. Brine-only spreading in snow should only be considered for marginal conditions (e.g. temperatures greater than -1°C) and where the road can be kept clear either from frequent ploughing passes (as a minimum every 1 to 2 hours) or where there is sufficient traffic to mix brine into snow or disperse and prevent a hard packed layer from forming.

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