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*Göran Blomqvist, VTI and
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Airborne spreading and deposition of de-icing salt — a case study

Göran Blomqvist^{a,*}, Eva-Lotta Johansson^b

^a*Swedish National Road and Transport Research Institute, SE-581 95 Linköping, Sweden*

^b*Royal Institute of Technology, KTH Haninge, Marinens väg 30, SE-136 40 Haninge, Sweden*

Abstract

In this study it was concluded that between 20 and 63% of the de-icing salt applied on the road was transported by air and deposited on the ground 2–40 m from the road. The reason for the higher percentages is suggested to be intense snowfall, which leads to more splash generation and ploughing. Ninety percent or more of the total deposition occurs within 20 m at all transects. For all periods and both localities the deposition was greater on the east side of the road, which reflects the prevailing westerly winds in relation to the de-icing action occasions. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Snow and ice control can be made with mechanical or chemical methods. In Sweden the de-icing agent almost exclusively used is sodium chloride due to its low price. Sodium chloride is spread mechanically to the roads either as dry

salt, moistured salt or in solution, depending on the state of the road.

The de-icing salt applied on the road surface can be spread to the roadside environment through different transport mechanisms such as runoff, infiltration, airborne spreading (splash, spray, particulates) and ploughing (Fig. 1). Salt has been found to be transported by air several hundreds of metres from the road above open ground (Kelsey and Hootman, 1992), but at forested sites the vegetation is filtering the air leading to higher deposited amounts on the

* Corresponding author. Tel.: +46-13-20-41-71; fax: +46-13-20-40-30.

E-mail address: goran.blomqvist@vti.se (G. Blomqvist)

Fig. 1. Conceptual model of transport mechanisms and sampling method.

ground under the vegetation (Hautala et al., 1995). Under certain conditions the vegetation is likely to be damaged by such salt deposition. Deposition on the ground might also lead to effects such as alteration of soil structure and possible infiltration and percolation to groundwater (Bäckman and Folkeson, 1995).

The deposition of de-icing salt next to roads has been assessed by e.g. collecting the deposition in containers (Karlqvist, 1974; Kelsey and Hootman, 1992; Pedersen and Fostad, 1996), by snow-sampling (Simini and Leone, 1986; McBean and Al-Nassri 1987; Hautala et al., 1995; Eliasson, 1996) by soil sampling (Hofstra et al., 1979; Dragsted, 1980; Persson and Røyseland, 1981; Jones et al., 1986; Rutter and Thompson, 1986; Pilon and Howard, 1987; Bäckman and Folkeson, 1995; Pedersen and Fostad, 1996; Røhr, 1996; Bäckman, 1997) or by analysing salt concentration in vegetation (Hofstra and Hall, 1971; Bäckman and Folkeson, 1995; Pedersen and Fostad, 1996).

Budgets have been made for lead and PAHs based on vehicular emissions (Harrison et al., 1985; Hewitt and Rashed, 1990).

In studies of airborne de-icing salt migration McBean and Al-Nassri (1987) concluded that 90% of the deposited salt was found within 13 m. However, they assumed that the maximum possible distance to which the salt will migrate is 30 m from the edge of the road shoulder, and in their investigation the deposition is not related to the amount of salt applied on the road. Pedersen and Fostad (1996) showed that 10–25% of the applied salt was spread through the air and that most of this salt was deposited within 8 m of the roadway. The samples were taken 2–16 or 2–20 m from the

edge of the road and the budget is calculated from the total amount of road salt applied during that season.

The aims of the present study are to quantify the amount of de-icing salt transported by air (the remainder will be transported as runoff or infiltrate in the road construction) and deposited on the ground adjacent to the road and relate that to the total amount of salt applied on the road. During the deposition periods, meteorological parameters such as temperature, wind direction and speed, and precipitation amount and type were registered in order to investigate their importance for the deposition pattern.

2. Materials and methods

The Swedish National Road administration has developed a system for supervision of the local weather at some major Swedish roads. The Road Weather Information System (RWIS) measures, e.g. temperature in air and at road surface, wind velocity and direction and precipitation type and amount. In order to investigate the meteorological factors the two field investigations were located at RWIS stations.

One of the localities chosen for field studies was Älgviken, 50 km south of Stockholm (Fig. 2) at National Road 73 which has an average daily traffic of 8000 vehicles and a speed limit of 90 km h⁻¹. At the locality the road runs in a north-south orientation with a ploughed field west of the road and a meadow east of the road. On the west side there is a ditch at about 4 m from the edge line, and on the east side the ditch is at a distance of

Fig. 2. Map of the two sampling localities (squares) and precipitation stations (circles).

about 6 m from the road. The Baltic Sea is about 2 km east of the road.

The other locality was Bankekind, 10 km south-east of Linköping (Fig. 2) at the National Road 35. The road has an average daily traffic of 5500 vehicles, a speed limit of 90 km h^{-1} and runs in a NW-SE orientation. West of the road there is a meadow and east of the road there is a harvested but not ploughed farmland. There are ditches on both sides of the road at 4 m from the edge line.

The deposition was collected in 2.7-l polyethy-

lene buckets (175 mm diameter). The containers were placed in double transects 2 m apart at the distances of 2, 4, 6, 10, 20, and 40 m from the edge line of the road on both sides of the road. At Älgviken the containers were collected and replaced once a week (i.e. 7–15 February, 15–22 February, and 22 February–1 March 1997, Fig. 3). At Bankekind the containers were collected every two weeks (i.e. 6–19 February, and 19 February–3 March 1997, Fig. 3) except from a 400 m profile with containers placed at 2, 4, 6, 10, 20, 40, 60, 100, 200 and 400 m, where the containers were collected after 4 weeks (i.e. 6 February–3 March 1997).

Both roads were de-iced with NaCl during the sampling period. Data about applied amount of salt were available at the local road maintenance stations. In this case the applied amount of salt was given in $\text{g} \cdot \text{m}^{-2}$ applied road surface or in tonnes per km road length. The amounts were recalculated to amounts of salt in $\text{g} \cdot \text{m}^{-1}$ in order to compare the amounts applied on the road to the amounts deposited at different distances. Furthermore, at each locality a road weather information device registered the amount and type of precipitation, speed and direction of wind and temperatures in the air and at the road surface every half-hour. According to Ericsson (1995) there is a rapid decrease in concentration of de-icing salt on the road within the first hours after a de-icing action has taken place. Hence, the wind direction and speed was considered only

Fig. 3. Sampling periods and de-icing action occasions at each locality.

Fig. 4. Deposition pattern in Älgviken, week 1 and 2. Estimated precipitation week 1, 15–20 mm, week 2, 15–20 mm. Amount of salt applied on the road week 1, $405 \text{ g} \cdot \text{m}^{-1}$; week 2, $370 \text{ g} \cdot \text{m}^{-1}$.

Fig. 5. Deposition pattern in Bankekind week 1–2 and 3–4. Estimated precipitation week 1–2, 25–30 mm; week 3–4, 7–10 mm. Amount of salt applied on the road week 1–2, $1290 \text{ g} \cdot \text{m}^{-1}$; week 3–4, $690 \text{ g} \cdot \text{m}^{-1}$.

Table 1
Percentages of depositions and winds

	Älgviken, Week 1		Älgviken, Week 2		Bankekind, Week 1–2		Bankekind, Week 3–4	
	W	E	W	E	W	E	W	E
Percentage of collected salt deposited on each side of the road	32	68	26	74	44	56	19	81
Percentage of collected salt deposited within 10 m from edge line	79	78	91	94	94	93	86	85
Winds from ^a	61	39	100	0	45	55	95	5
Winds from ^a , speed > 5 ms ⁻¹	78	22	100	0	98	2	100	0
Percentage of salt applied, deposited 2–40 m from edge line	20		63		36		26	

^aWinds that are parallel to the road orientation are not included.

for the first 6 h following each de-icing operation. Only the winds not parallel to the road were taken into account.

The samples were stored for 1–3 weeks prior to analysis. The water was filtered and samples of 100 ml were stored cool for further analyses. Subsequently, the concentration of Na was measured with an ICP (Induced Coupled Plasma Emission) of the brand Jobin-Yvon and the Cl-concentration was measured with a Dionex Dx-120 ion-chromatograph.

In order to calculate the total deposition the mean values were calculated from the double transects. Missing values (non-filled bars in Figs. 4 and 5) were interpolated by the geometric mean

between the surrounding two values (Fig. 4) and by extrapolating the second last value to the outmost position (Fig. 5). The total amounts of sodium chloride deposited on both sides of the road were then integrated and the sum related to the amount of de-icing salt applied on the road.

3. Results

For all periods and both localities, the deposition was greater on the east side (Table 1).

During the first week at Älgviken (Fig. 4), 20% of the total amount of salt applied on the road was deposited on the ground, 2–40 m from the

Fig. 6. Amount of deposition (mm) at Älgviken.

Fig. 7. Deposition pattern in Älgviken, week 3. Estimated precipitation week 3, 6–8 mm. No de-icing action took place.

edge of the road (Table 1). During the second week a much larger amount of deposition was found in the collectors close to the road (Fig. 6) and the total deposition was much greater (63%). The deposition was also registered during a week when no de-icing action took place (Fig. 3). The amount of salt deposited on the ground was one order of magnitude lower (Fig. 7), but still considerable taking into account that no salt was applied on the road.

At Bankekind (Fig. 5) 36% of the salt applied on the road was transported by air and deposited 2–40 m from the road the first 2-week period. (Table 1). During the second period less salt was deposited; 26% of the amount applied was deposited. In the 400-m profile from Bankekind the deposition seems not to have levelled out at 40 m (Fig. 8).

When considering both localities and all periods, it is obvious that the major part of the

deposition occurs within the first few metres from the edge line of the road (Fig. 9).

4. Discussion

Pedersen and Fostad (1996) showed that 10–25% of the applied salt was spread through the air. But since their result is calculated from deposition 2–16 or 2–20 m, and the salt probably is transported to greater distances, their result might be an underestimation. In this investigation 20–63% of the applied salt was spread through air and deposited 2–40 m from the edge line (Table 1). One reason for the higher percentages in this study is the longer profiles.

The reason for the high variation between the periods is that the transport mechanisms (Fig. 1) have different influence depending on the meteorological conditions during each period. The high percentages in Älgviken week 2 (63%), and in Bankekind week 1–2 (36%) is suggested to be due to a period of intense snowfall occurring in these two periods which lead to more splash generation and ploughing. This can also be seen in the amount of liquid deposited within the first metres in Älgviken week 2 as compared to Älgviken week 1 (Fig. 6). The high percentage of deposited salt during week 2 in Älgviken is coherent with Dragsted (1980) who found that the salt was transported a shorter distance during a period with many snowfalls than during a period with just wet road surface.

For all periods and both localities, the deposition was greater on the east side. When compar-

Fig. 8. Deposition pattern in Bankekind, week 1–4, long profile. Estimated precipitation week 1–4, 33–37 mm. Amount of salt applied on the road week 1–4, 1980 g · m⁻¹.

Fig. 9. Distribution of the relative amount of deposited NaCl at each transect and time period.

ing the periods; the deposition on the east side was greater during the second week in Älgviken which coincided with strong solely westerly winds (Table 1). In Bankekind the deposition was notably higher on the east side weeks 3–4 when there was a high percentage strong westerly winds compared to the first 1–2 weeks when there were more easterly than westerly winds, although the westerly winds were stronger (Table 1).

McBean and Al-Nassri (1987) concluded that 90% of the total amount of deposited salt was found within 13 m. However, at roads with higher velocities (80 and 100 km h⁻¹) no samples were taken 1–6 m from the edge of the road where

most likely a large amount of deposition occurs. In our investigation 90% or more of the total deposition between 2 and 40 m has occurred within 20 m at all transects (Fig. 9).

Data from the nearest precipitation stations in the nationwide network, Aspvreten and Tyresta (Fig. 2), show that the depositions of Na and Cl vary considerably during February and March 1997 (Fig. 10). In the 400 m profile the deposition at 100 m seems to be in accordance with background values (Fig. 10), which means that some deposition has occurred between 40 and 100 m. However, since there is no consistent background value for NaCl-deposition, and since the con-

Fig. 10. NaCl-concentration in deposition 100–400 of the road at Bankekind as compared to regional background values for two precipitation stations (Aspvreten and Tyresta).

tribution from background deposition is very small compared to the deposition resulting from road salt, no reduction for background deposition has been made in the calculations. The deposition between 40 and 100 m has been left out of account for the same reasons.

The high amount of deposition the third week in Älgviken is suggested to be a result of resuspension of road salt, which is considered to be of importance for the increase of atmospheric concentrations of NaCl during winter (Nicholson and Branson, 1990).

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Adress
Postal address
SE-581 95 Linköping, Sweden

Telefon
Telephone
Nat 013-20 40 00
Int +46 13 20 40 00

Fax
Nat 013-14 14 36
Int +46 13 14 14 36

E-post
E-mail
vti@vti.se