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Particle transport during snowmelt : Influence by road salt, temperature and surface slope

Transport de particules lors de la fonte des neiges : Influence du salage, de la température et de la pente de la route

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RESUME

Au début de mars 2006, de la neige polluée fut prélevée à Lulea, au nord de la Suède, sur le bord d'une route avec une densité de trafic d'environ 8000 véhicules/jour. La neige a été homogénéisée et divisée en échantillons de 30 litres. Les volumes et densités initiaux des échantillons ont été mesurés et calculés. Les échantillons de neige ont été fondus dans des salles chauffées, avec quatre configurations expérimentales différentes afin d'étudier l'influence du salage, de la température et de la pente de la route sur le transport de solides totaux en suspensions (STS) (3 reproduction pour chaque condition expérimentale). Le volume total de ruissellement de fonte de neige a été collecté et analysé (pH, conductivité, teneurs en STS et chlorures). Les résultats révèlent que les teneurs mesurées, les charges calculées et les t-tests statistiques effectués de STS pour la neige fondue des quatre configurations impliquaient que la charge transportée de STS était plus élevée lors du salage de route et à une température ambiante plus élevée. Toutefois, les résultats ont montré une plus faible charge de STS transportée pour les pentes plus faibles.

ABSTRACT

In the beginning of March 2006, polluted snow from a roadside in Luleå, in the north of Sweden, with a traffic intensity of approximately 8000 vehicles/day was collected. The snow was homogenously mixed, and divided into samples of 30 litres. The initial volumes and densities of the snow samples were measured and calculated. The snow samples were melted in climate rooms, with four different experimental configurations to investigate the influence of road salt, temperature and surface slope upon the transport of total suspended solids (TSS) (three replicates for each experimental configuration). The total volume of snowmelt runoff was collected and analysed for pH, conductivity, concentrations of TSS and chlorides. The results showed that measured concentrations, calculated loads and performed statistical t-tests of TSS for the snowmelt of the four different configurations implied that the transported load of TSS was higher at addition of road salt, and at a higher ambient temperature. However, the results showed a lower load of transported TSS for the lower slope.

KEYWORDS

Road salt, Snow, Snowmelt, Total suspended solids, Transport

1 INTRODUCTION

The rapid urbanisation of today create environmental problems such as large quantities of solid waste, loss of green space and pollution to receiving air and water bodies. The sources of these pollutants in the urban environment are numerous and in cold climates one source with detrimental environmental effects is NaCl, a de-icing chemical often used to keep ice-free conditions on roads and highways. NaCl is clearly harmful to the environment by destroying vegetation, disturbing ecosystems and polluting groundwater, etc. It was discovered by Viklander and Malmqvist (1993) that the runoff intensity was more dependent upon the ambient air temperature and the initial snow density than the shape of the lysimeter. It was also found by Viklander and Malmqvist (1994) that repeated freezing and thawing cycles had a delaying effect on pollutants attached to particles due to a detention within the snowpack. The same results were found earlier by Schöndorf and Herrman (1987). Westerström (1995) observed a low pH and high concentrations of chloride ions in the early phases of the snowmelt as comparison to the parent snow cover. However, it should be noted that the studied lysimeter was located away from roads, indicating low TSS concentrations. To mitigate environmental impact, it is of paramount importance to understand the affect of different parameters such as road salt, temperature and surface slope upon the transport of pollutants that are accumulated during the long winter period in cold climates.

2 OBJECTIVES

	+5 ° C		+20 ° C	
	No salt	Salt	No salt	Salt
Slope 2%	X			
Slope 15%	X	X	X	

Table 1. Experimental configuration

The objective of this article was to investigate the influence of road salt (NaCl), temperature, and surface slope upon the transport of total suspended solids from urban snow during snowmelt.

This was done through studying the snowmelt from four different experimental configurations; five degrees, fifteen percent slope and no added road salt (5°, 15%, NS), five degrees, fifteen percent slope and added road salt (5°, 15%, S) five degrees, two percent slope and no added road salt (5°, 2%, NS), and twenty degrees, fifteen percent slope and no added road salt (20°, 15%, NS), see Table 1.

3 EXPERIMENTAL SETUP, MEASUREMENTS AND ANALYSES

On the 9th of March 2006, polluted snow from a roadside in Luleå, in the north of Sweden, with a traffic intensity of approximately 8000 vehicles/day was collected. The collected snow was stored on, and covered by a tarpaulin from the 9th of March until the 9th of May. The snow was then homogenously mixed, and divided into twelve samples of 30 litres with cylindrical shape. The initial volumes, weight and densities of the twelve snow samples were measured and calculated, see Table 2.

The twelve samples were melted in climate rooms, with four different experimental configurations, to investigate the influence of road salt, temperature and surface slope upon the transport of TSS (three replicates for each experimental configuration). The configuration with road salt was simulated by addition and mixing of five dl of NaCl. For all twelve samples, the total volume of snowmelt runoff was collected and analysed for pH, conductivity, concentrations of total suspended solids (TSS) and chlorides. For the first five litres

of snowmelt, 500 ml samples were collected, the subsequent five litres of snowmelt, 1 litre samples were collected, and for the rest of the snowmelt, 2 litres samples were collected. After collection of the samples they were processed (within a few hours after completed sampling) in the laboratory at Luleå University of Technology. The pH was measured at 25° C, with a Radiometer PHM 95 and an electrode Schott Blue Line 13 pH. The conductivity was measured using a Radiometer CDM 210 with electrode CDC 741 T at 25° C. The chloride concentration was measured by using a QuAAtro Applications. The method used was Method no Q-006-04 (multitest MT9/MT10), Chloride in water and wastewater. The concentration of total suspended solids was measured according to the standard method SS-EN 872, which has the status of the

European Standard EN 872:1996 (EN 872, 1996 and SIS, 1996).

Configuration	Snow volume (m ³)	Density (kg/m ³)
5°, 15%, NS	0.032	606
	0.031	635
	0.035	565
5°, 15%, S	0.031	643
	0.032	638
	0.031	618
5°, 2%, NS	0.030	641
	0.032	637
	0.034	586
20°, 15%, NS	0.032	619
	0.031	677
	0.034	604

Table 2. Initial snow volume and density.

4 RESULTS AND DISCUSSION

4.1 Initial snow

The pH, conductivity and concentrations of chloride and TSS of the initial snow, before the start of the snowmelt can be seen in Table 3. The presented initial values for the configuration with mixed-in road salt (5°, 15%, S), is before/after the addition of road salt.

Configuration	pH	Cond (mS/m)	Chloride (mg/l)	TSS (mg/l)
5°, 15%, NS	7.6	13	18	6600
	7.5	13	16	7200
	7.5	13	18	5800
5°, 15%, S	7.7	10/	9/	6700
	7.8 / 6.3	9.0 / 5100	8 / 19500	7400
	7.9	10	11	6800
5°, 2%, NS	8.0	11	14	6100
	8.1	12	14	6900
	8.1	11	13	6400
20°, 15%, NS	8.2	9.0	8,7	7500
	8.1	9.8	11	6400
	8.1	11	13	6200

Table 3. Concentrations of TSS, pH, and conductivity of initial snow in lysimeter 1 to 12.

Generally, the values of the three replicates for each of the four configurations were relatively similar. The pH and concentration of TSS were high while as compared to rural snow. The conductivity and chloride concentration is rather low, apart from the samples with added road salt, causing an extensive increase in conductivity and chloride, and a slight decrease in pH.

4.2 Snowmelt

4.2.1 Concentrations

The total snowmelt volume of the three replicates for the four configurations could be seen in Table 4. The total snowmelt volume, approximately seventy percent of the initial snow volume, was rather well in accordance with the suggested initial snow density, see Table 2.

Configuration	Vol. (l)		
5°, 15%, NS	19.5	20.7	19.9
5°, 15%, S	20.2	18.4	19.6
5°, 2%, NS	19.2	19.9	19.4
20°, 15%, NS	21.9	21.0	20.5

Table 4. Total volume of snowmelt.

In Figure 1, the sequence of measurements and analyses of the pH, conductivity and concentrations of TSS and chlorides throughout the snowmelt could be seen. The average and standard deviation was presented in numbers within the figure for each parameter. The pH was high and relatively constant for all the configurations apart from the one with added road salt (5°, 15%, S), where the pH is initially lower and then successively increasing towards the end of the snowmelt. Acidification of a soil profile was found by Hindar *et al.*, (1993) due to a sea salt episode where the chloride concentrations increased by eight times the normal concentrations. The acidification was explained by cation exchange processes involving exchange of Na⁺ with H⁺ and Al and/or base cations. The acidification of the snowmelt could very well be explained by a competition of Na⁺-ions in favour of H⁺-ions for adsorption spaces on particles in the snowmelt. The NaCl was readily enriched in the first snowmelt for all configurations, which can be seen from the chloride measurements in Figure 1, and as the concentrations were decreasing through washout, the pH was increasing due to the declining number of competing Na⁺-ions. For all the configurations, it can be seen that conductivity and chloride had a very good, linear agreement. The same result has been found in many studies, and the conductivity could be measured as an indication of road salt influence (Foos, 2002). The concentrations of TSS for all four configurations were the highest in the beginning of the snowmelt. However, this was not likely to occur during snowmelt since particles usually stay behind until the snowpack is entirely depleted (Viklander, 1997), and the results were most likely due to high water content of the snow samples when collected and taken to the climate rooms. The high water content transported the particles earlier during the snowmelt as compared to if the snow samples would have had a lower liquid to solid ratio, i.e. a lower density. Because of that experimental outcome, additional snowmelt experiments were performed. The same initial snow was used, with the difference that these samples were frozen before the start of the snowmelt. The concentration factor, C_t (snowmelt concentration at time t / arithmetic mean concentration), was used to investigate when, during the snowmelt, the transportation of TSS occurred. The results from this study showed that the concentrations of TSS were the highest at the end of the snowmelt, which was more likely, see Figure 2.

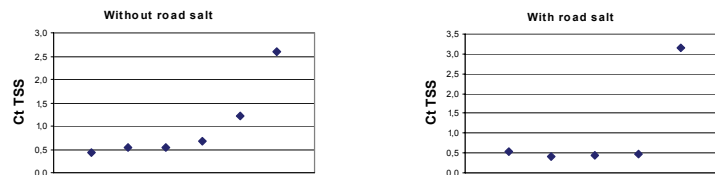


Figure 2. Conc. factor for TSS from additional snowmelt experiments with and without road salt.

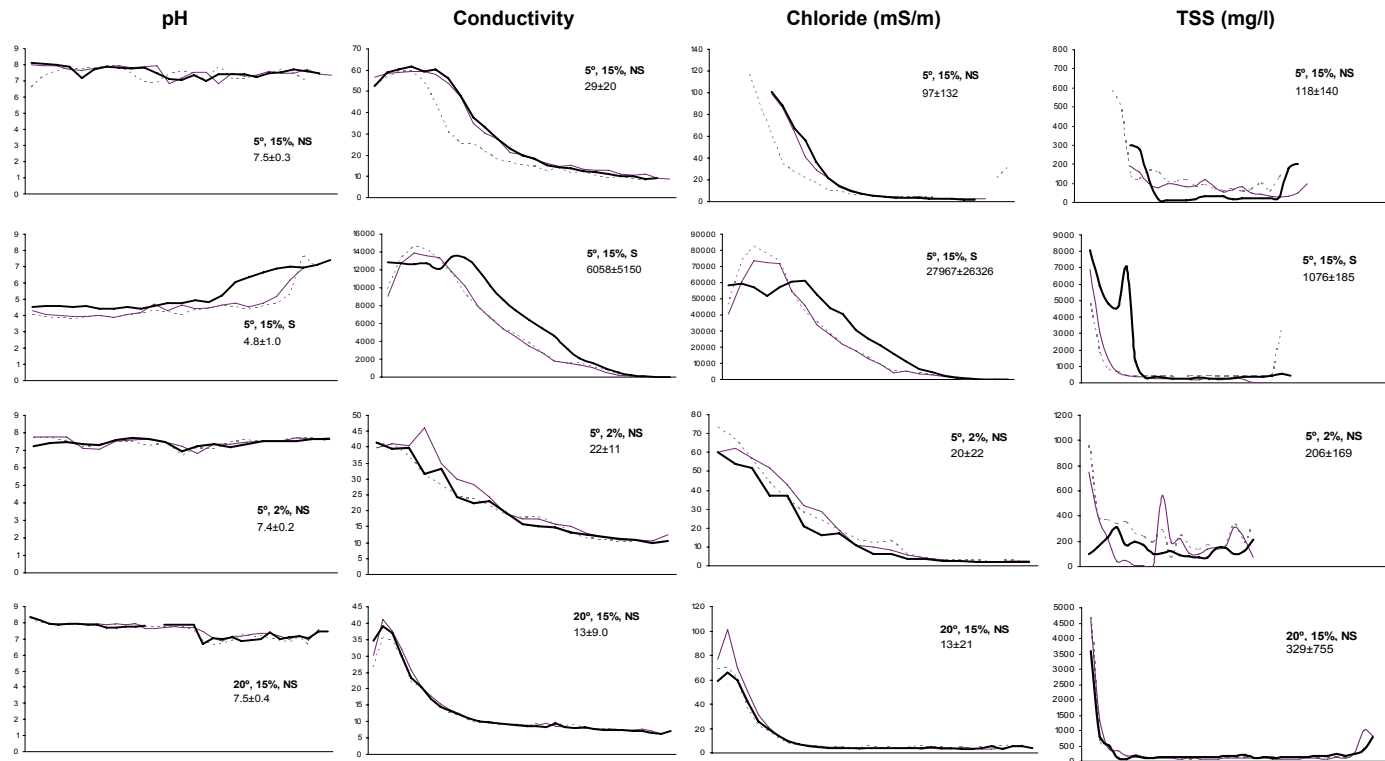


Figure 1. pH, conductivity, and concentrations of chloride (mS/m) and TSS (mg/l) throughout snowmelt.

4.2.2 Loads

For all replicates of the four configurations it was clear that most of the pollutant load in the snow stayed on the surface when melted and a miniscule part was transported with the snowmelt. In Figure 3, the percentage and weight (on top of each bar) of transported TSS in the snowmelt as compared to the TSS concentrations in the parent snow samples was shown.

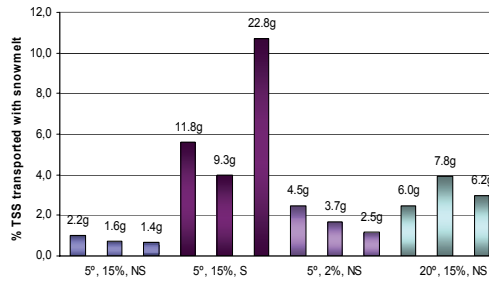


Figure 3. Percentage (%) and weight (g) transported load of TSS during the snowmelt.

The percentage of transported load (10.7%) of TSS for one replicate of the configuration with road salt (5°, 15%, S) was notably higher than the other two. This particular replicate was melting at a higher rate, likely to be explained by the shape of that snow sample, whereas the cylindrical shape was destroyed when putting the snow on the experimental setup. Generally, it can be said that the average of the three replicates from the configuration with salt (5°, 15%, S) is transporting the largest load of TSS as compared to the three other configurations. The second largest transport is for the configuration with the higher temperature (20°, 15%, NS). The explanation for the higher transport of these two configurations could be the higher melting rate due to the road salt and the warmer temperature, resulting in a higher flow and therefore increased transport capacity of TSS. Slightly lower transport capacity was found for the configuration with a low slope (5°, 2%, NS). This was expounded by a lower transport capacity due to the lack of road salt and the lower temperature. However, the transport of TSS was lower for the configuration with a higher slope (5°, 15%, NS) as compared to the lower slope (5°, 2%, NS). No good explanation could be found for this.

Configuration	Statistically significant difference	P-value
Salt vs no salt	YES	< 0.1
High slope 15% vs low slope 2%	YES	< 0.1
High temp. +20°C vs low temp. +5°C	YES	< 0.05

Table 5. Performed T-tests.

temperatures, surface slopes and addition of road salt, t-tests were performed, see Table 5. The t-test gave a p-value of less than 0.1 for the comparison of the configurations with (5°, 15%, S) and without road salt (5°, 15%, NS) and the comparison of different slopes, (5°, 2%, NS) and (5°, 15%, NS), implying a significant difference and a higher transport of TSS for the configuration with salt and with the lower surface slope, at a confidence level of 90%. The confidence level for the comparison of different temperatures, (20°, 15%, NS) implied a significant difference at 95% with a higher transport at the higher temperature.

To statistically test if the discerned differences in the transport capacity of TSS depending on different

In Figure 4, cumulative curves for TSS could be seen. As well as for the concentrations, the transported loads of TSS were the highest in the beginning of the snowmelt. However, if the first flush of TSS was disregarded due to the initial high water content, the TSS transport was somewhat linear, with a last flush of TSS load for some of the configuration replicates. Similar patterns with a last flush of TSS load

were found for of the additional snow samples, for both with and without the addition of road salt, see Figure 5. This was suggesting that an initially low liquid to solid ratio, i.e., low density snow, would transport the highest concentrations and loads at the end of the snowmelt, while a high density snow would transport the highest concentrations and loads in the beginning of the snowmelt.

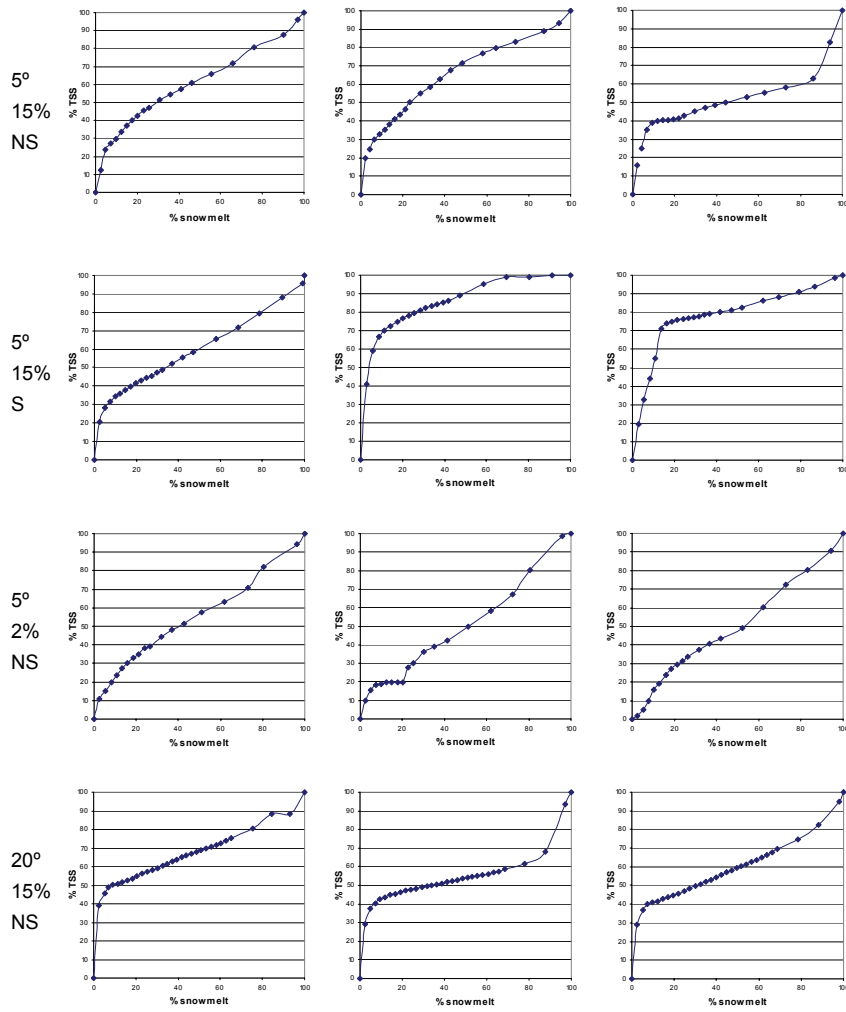


Figure 4. Cumulative curves of TSS (%) for the four configurations.

The results suggested that depending on climatic conditions and local attributes of the snow location, such as temperature and surface slope, as well as the choice of snow management strategies, e.g., the use of traction sand or de-icing chemicals would greatly affect the transport of solids from snow.

Figure 1. pH, conductivity, and concentrations of chloride (mS/m) and TSS (mg/l) throughout snowmelt.

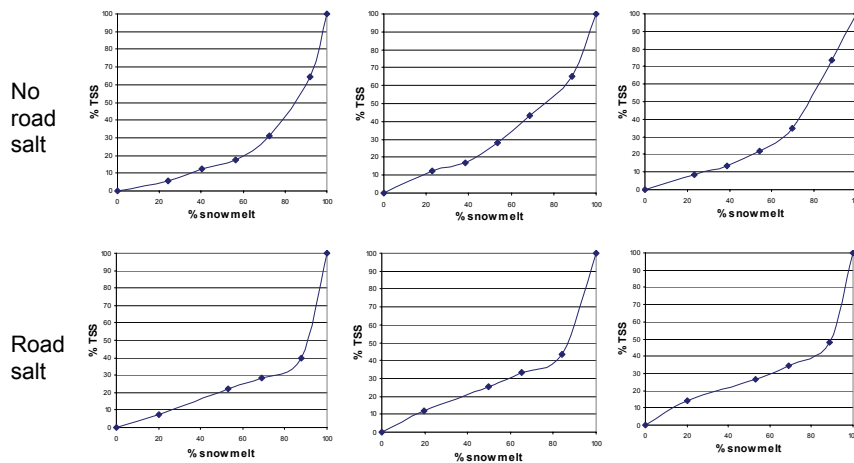


Figure 5. Cumulative curves of TSS (%) from additional snowmelt experiments with and without road salt.

5 CONCLUSIONS

Measured concentrations, calculated loads and performed statistical t-tests of TSS for the snowmelt of the four different configurations implied that the transported load of TSS was higher at addition of road salt, and at a higher ambient temperature. However, the results showed a lower load of transported TSS for the lower slope.

6 ACKNOWLEDGEMENTS

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