THE ENVIRONMENTAL SUB-MODEL OF THE SWEDISH WINTER MODEL – UPDATED ALGORITHMS FOR THE DESCRIPTION OF SALT DAMAGE TO ROADSIDE ENVIRONMENT

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ABSTRACT

Modeling the impact of the use of chemical anti-/deicing on the roadside environment requires knowledge of the roadside exposure to salt, the vulnerability or dose-response relationship of the modeled environmental subjects and, preferably, the “cost” of the following impacts. The results presented in this paper are the first tentative test runs of the environmental sub-model of the Swedish Winter model. The environmental cost will in this case study be the cost for vegetation damage larger than a chosen accepted level of damage, and a cost for groundwater protection installations. The total environmental cost in this small case study will roughly be between 1.5 and 2.5 MSEK.

KEYWORDS

DEICING / ENVIRONMENT / MODELLING

1. INTRODUCTION

Society needs to maintain road safety and accessibility of the road network at acceptable levels during the winter season. The use of sodium chloride as anti- or deicing medium can lead to several impacts on human health and nature, as for instance damage to ground water resources and roadside vegetation [1, 2, 3].

Modeling the impact of the use of chemical anti-/deicing on the roadside environment requires knowledge of the roadside exposure to salt, the vulnerability or dose-response relationship of the modeled environmental subjects and, preferably, the “cost” of their following impacts. The Winter Model consists of sub models for assessing the state of the road, its effects and their appraisement [4]. One of the sub models is describing the environmental effects by modeling the roadside exposure to salt [5]. The road surface condition model is described in greater detail by Möller (in these proceedings) together with brief descriptions of the other sub-models. Working within the Swedish project Winter Model has given a unique opportunity to combine many different kinds of field measurements during the same time. This paper will illustrate how data is used between different sub-models and present the most recent algorithms for the description of environmental impacts, used in the model.

2. THE “SYSTEM”

2.1. An overview

Salt (mainly sodium chloride) is widely used in winter maintenance for deicing and anti icing purposes. Because of the well known environmental draw-backs of salt exposure to e.g. roadside vegetation and groundwater, the road keepers constantly strive to minimize the amount of salt used during the winters and improve the techniques used. However the salt will eventually leave the road where it has its beneficial effects and reach the surroundings where the effects may lead to unwanted impacts (figure 1).

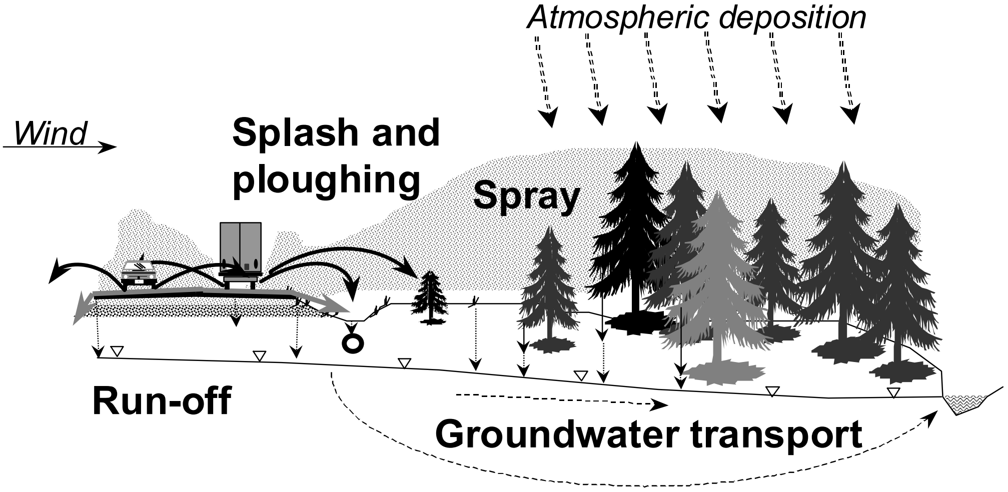

Figure 1. A conceptual model of the system of anti-/de-icing and its surroundings.

2.2. Anti-icing, deicing and residual salt

Salt has been widely used for decades in order to maintain road safety and accessibility of the road network at acceptable levels also during the winter season. The use of sodium chloride for deicing and anti icing purposes started in the 1940's in the United States and has increased ever since, as the motoring has developed. In the Nordic countries the use of deicing salt started in the mid-1960. The concept "anti-icing" is in this paper used to describe the actions taken in preventing the formation of frost or ice on the road surface and is performed by putting brine (40 g/m^2) across the entire modeled road (7.5 m width). The concept "deicing", on the other hand, is used to describe the use of pre-wetted salt (10 g/m^2) on one lane of the modeled road (3.75 m width) while plowing.

2.3. Roadside exposure

Using salt for anti- and deicing has the purpose of preventing the occurrence of slippery conditions caused by frost, ice, snow or slush. By forming a brine layer preventing snow and ice from bonding to the road surface, the presence of salt will also facilitate plowing of snow and slush off the road. The salt is also supposed to facilitate the formation of slush from the snow by the mechanical action of the vehicles and tires on the road surface, and the salt-laden slush is then intended to be forced off the road by the vehicles and gravity. Hence, the exposure of the roadside environment to salt is built into the system already from the beginning as the salt will leave the road as plowed material, splash, spray, run-off and/or dry crystals (Figure 1). Blomqvist [6] suggested the air borne spreading of salt to be described by a function of the added transport mechanisms of splash and spray, each of which was described by an exponential function. The total deposition at a certain distance was then suggested to be described by the function:

$$\text{Deposition} = a_{\text{splash}} \cdot e^{(b_{\text{splash}} \cdot \text{Distance})} + a_{\text{spray}} \cdot e^{(b_{\text{spray}} \cdot \text{Distance})} + \text{background}$$

Equation 1 – Deposition of air borne salt in roadside environment (from: [6])

2.4. Salt damaged vegetation

Already at an early stage, it was recognized that the use of salt had not only the desired effect of improved traffic safety and accessibility but also several negative impacts. Numerous investigations of impacts on e.g. vegetation, soil and groundwater have been presented and the matter is still of great concern in North America, Europe and Japan [7, 8, 9, 10, 11, 12, 13, 14, 15, 16].

2.5. Ground water

The government approval document of the Swedish Road Administration for the year 2007 points out an important long-term goal regarding groundwater quality, namely that no later than 2010 are no major water-supplies along the main road system to exceed Swedish standards for drinking water of good quality regarding any pollutant caused by roads or traffic [17]. Such a target is not easily achieved and requires a focused action towards goal fulfillment. The main pollutant threatening the drinking water standards is the anti- and deicing salt used in the winter maintenance operations.

2.6. Environmental cost

Some attempts have been made to calculate the cost of salt damage to trees [1]. In [18] the cost was calculated as the cost of removing a dead tree and planting and maintaining a young tree in its place. On the other hand, Vitaliano [19] represented the cost as the lessened demand for viewing a scenery of less aesthetically pleasing trees in areas heavily impacted by road salting. The two cost assessments focus on different aspects of the same problem: whereas the first considers the cost for mitigating the problem of dead trees, the second considers the costs of degraded landscape scenery. Both assessments are concerned with the costs of damage that has already occurred. Randrup and Pedersen [20], however, focus on the cost of damage prevention, which they define as the estimated cost of replacing the soil of urban trees and of protecting trees using plastic-covered straw mats.

3. FIELD MEASUREMENTS

To understand the mechanisms responsible for the transport of the de-icing salt away from the road, the factors regulating the transport mechanisms should be studied separately. These factors can be divided into five main categories: traffic characteristics, road characteristics, maintenance and operation, meteorological factors and the physical factors of the surroundings (see a literature survey in [21]). Few investigations have related the roadside salt exposure to the deicing action itself, to the road-surface and traffic characteristics during the action or to the meteorological conditions. Knowledge of these relationships would aid the road administrator in managing the deicing action so as to minimize undesired environmental consequences.

Therefore several field measurements of residual salt, traffic volume, weather, salt deposition, etc., were made between 2001 and 2005 [22].

4. MODELING

4.1. Residual salt

The salting occasions of both anti icing and deicing are in the model calculated as described in Möller (these proceedings). For the modeling purposes in this study the two inner wheel tracks (closest to the road centre) have been chosen to represent the amount of residual salt on the road surface available to roadside exposure. The reason for using the two inner wheel tracks is that this is the track that both private cars and larger heavy vehicles most often share, and that the other two wheel tracks are more scattered in space. The calculation of the residual salt on the road surface has been modeled by the approach in the equation below [5, 23].

$$RS = S \cdot \mathrm{e}^{-\mathrm{k} \cdot PC_{eq}}$$

Equation 2 – Residual salt on road surface (after: [5, 23])

In this model, the "RS" denotes the residual salt on road surface, the "S" denotes the amount of salt used at the salting occasions, the "k" is a coefficient influenced by the road surface condition, and finally, "PC_{eq}" denotes the number of accumulated private car equivalents for each hour. The private car equivalent is calculated by multiplying each truck and truck with trailer with a constant, which in this paper is 5, and 7, respectively.

4.2. Road surface condition

The road surface condition factor varies, depending mainly on the wetness or moisture of the road surface [23, 24] but is most probably also influenced by the road surface texture [7, 10, 13, 25]. The road surface conditions that occurred in the modeled case study and their relative occurrence and the k-values chosen for each one of them are given in table 1.

Table 1 – Road surface condition, model k-values and relative occurrence

Road surface conditions	Chosen k-value	Number of hours
Dry bare ground	0.2	226
Moist bare ground	0.8	25
Wet bare ground	1.2	74
Slush	0	1
Hard-packed snow	0	4
Loose snow	0	3
Thin ice	0	3

4.3. Road side exposure

The roadside exposure is in this version of the model described by a simplified version of equation 1. The function is for this modeling study simplified into only one transport mechanism

$$\mathrm{Exposure} = \mathrm{a} \cdot \mathrm{e}^{(\mathrm{b} \cdot \mathrm{Distance})} + \mathrm{background},$$

Equation 3 – Simplified model of the roadside deposition of air borne salt.

where the variable "a" is a function of the calculated residual salt loss (ΔRS) for each hour, and "b" is a function of the road perpendicular wind component (W), giving us the function:

$$\mathrm{Exposure} = K_1 \cdot \Delta RS^{K_2} \cdot \mathrm{e}^{(\mathrm{K}_3 \cdot \mathrm{W}^{\mathrm{K}_4} \cdot \mathrm{Distance})} + \mathrm{background}$$

Equation 4 – Model of roadside exposure

Based on the field studies described in [22] the model constants K_1, K_2, K_3, and K_4 is presented in table 2.

Table 2 – Model constants in the exposure model

Model constant	Value in the model
K_1	33.40
K_2	0.615
K_3	0.129
K_4	-0.188

4.4. Damage to vegetation

The salt damage to vegetation is suggested to follow a sigmoidal-shaped dose-response function as described in this function:

$$\text{Damage} = \frac{100}{\left(1 + a \cdot \exp\left(-100 \cdot b \cdot \text{exposure}\right)\right)}$$

Equation 5 – Salt damage to vegetation

This function originates from a study of salt exposure to 1.5 year old seedlings of Norway Spruce [1, 6]. The variable “exposure” in the function is measured as the chloride concentration (%, dry weight) of the exposed needles. This is however not the same as the exposure given by roadside exposure model, but is according to Blomqvist [26] following a linear relationship on the form:

$$\text{exposure}_{\text{needle}} = 3.73 \cdot \text{exposure}_{\text{roadside}} + 0.0017$$

Equation 6 – Modeled chloride concentration in needles (from:[24])

4.5. Damage to ground water

Damage to ground water will in the model be based upon a simple hydrological model that calculates the salt concentration in a simple ground water aquifer. Depending on whether the long-term concentration is either constantly rising by time or above a chosen limit-value, or not, a cost will fall out. This cost will then be the installation cost for a ground water protection system for the entire modeled basin. In this paper this part of the model is, however, not implemented.

4.6. Cost

The environmental cost will in this case study be the cost for vegetation damage larger than a chosen accepted level of damage, and a cost for groundwater protection installations (modeling part of the latter is not implemented, why the model in this stage will result in a cost range, one with the groundwater cost, and one without). The cost for vegetation damage is based on two aspects, one is the cost of buying the area of the damaged tree plants from the land-owner, and the other is the cost of the aesthetical degradation of the damaged area.

5. CASE STUDY

5.1. Modeling assumptions

The case study of modeling environmental effects that is presented in this paper is built upon the same assumptions and data as is presented in the paper given by Möller (these proceedings). The modeled period is only two weeks (representing January 10th to 24th, 2007). The temperature (air and road surface) and precipitation (rain and snow – both measured as mm liquid) are from a real road weather information system station (figure 2). The road surface conditions used in the modeling (table 1) is the calculated road surface condition of the wheel tracks and is calculated within the road condition model, presented by Möller (these proceedings). For each of the seven possible road surface conditions a k-value is chosen that will be used in the algorithm describing the decrease of residual salt on the road surface (wheel tracks) as a function of traffic and road surface condition.

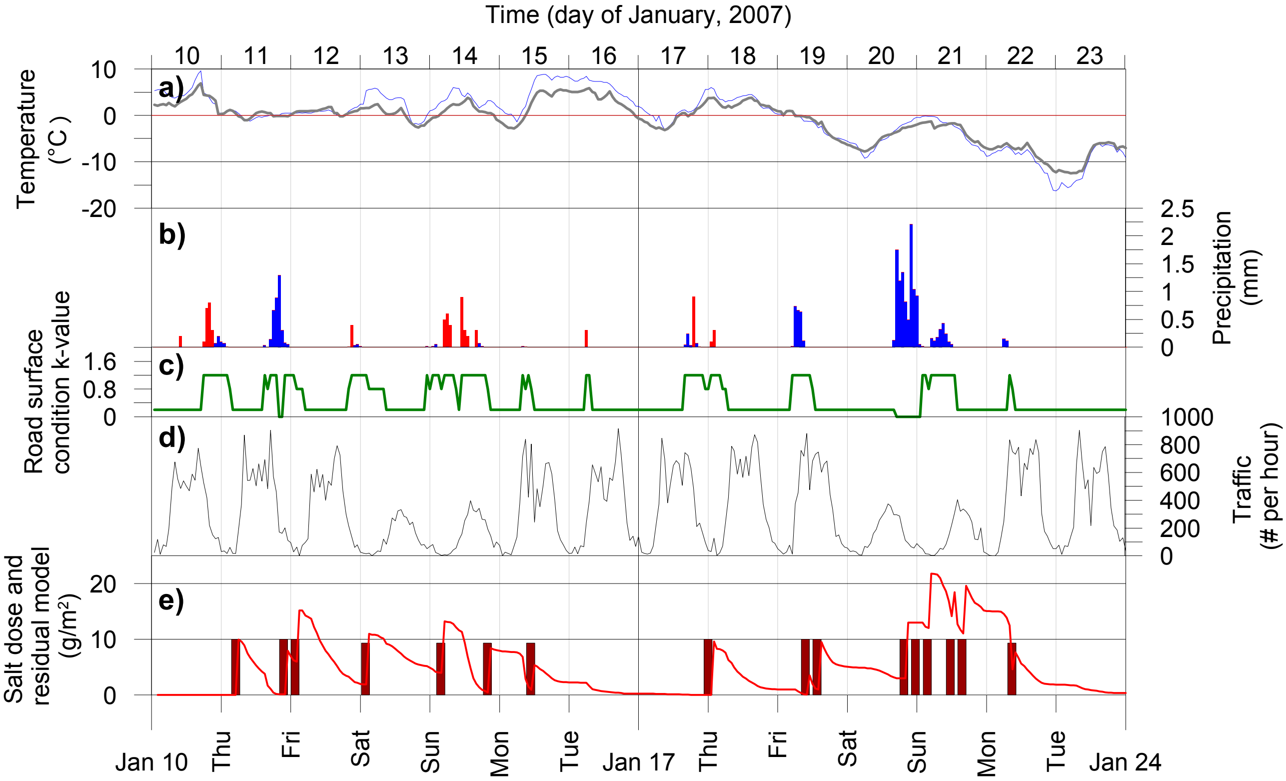

Figure 2 – Hourly weather, road condition, traffic, salt use and modeled residual salt for the modeled case study. In a) the air (blue) and road surface temperature (gray), b) the precipitation of rain (red) and snow (blue), both measured as mm liquid. In c) the chosen k-values for each of the calculated road surface conditions. In d) the traffic data used for modeling the residual salt, and, finally, in e) the salt use (g/m^2) and modeled residual salt (red line).

In figure 3, the modeling results of roadside exposure to salt are presented. At the top (a) the calculated hourly salt loss in the wheel tracks is presented for the two weeks of the case study. Then the road perpendicular wind component is presented as vectors (Figure 3, b). These two datasets will by the use of equation 4 end up in the hourly exposure as is presented in Figure 3 c) by interpolating hour by hour to the distance from the road on both sides.

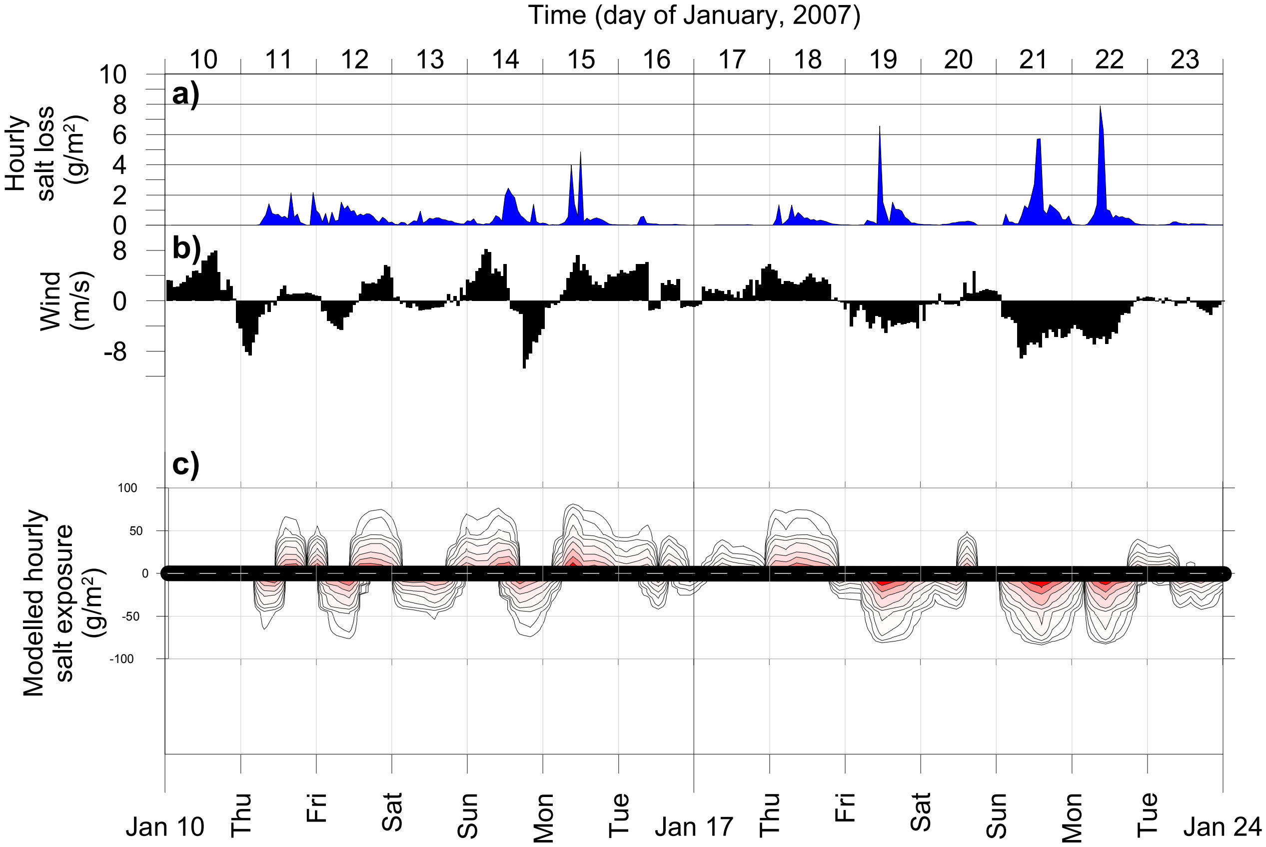

Figure 3 – Modeling results. In a) the calculated hourly residual salt loss, ΔRS, from the residual salt model, In b) the road perpendicular wind component (m/s), and finally, in c) the resulting modeled hourly roadside salt exposure.

5.2. A calculation example

In order to give some figures to the calculation example given by Möller (these proceedings), here are some assumptions and calculations described.

Given the equation 5 and 6 and dose-response relationships from the vegetation experiment in [1, 6], 50% damage to vegetation will occur when the roadside exposure reaches 3.8 g/m^2.

If we assume that the winter conditions of the two week case study in this paper will prevail for 10 weeks and that this describes the total winter well enough, the 3.8 g/m is reached at 15.8 m distance at the one side of the road and at 16.4 m at the other side.

If we assume that the right-of-way in this example extends to a distance of 5 m from the paved road edge, the total area outside the right-of-way in which the vegetation is affected is approximately 25 m^2 per m road length. Since the length of the road network in this case study calculation is 100 km (Möller, these proceedings), and if we assume that the damaged vegetation type is occurring in 25% of the total area, the affected area would sum up to 625 thousand m^2. Assuming a cost of 12 SEK (Swedish crowns) per m^2 [27], the total cost of buying this area of land would sum up to 7.5 MSEK in the test area.

Adding an aesthetical cost to the cost of buying the land, the assumption used here is that the concept used by Vitaliano [19] can be applied also in this test area. No consideration is taken regarding changes in currency rates or trends of the consumer price index since 1992 when the Vitaliano case was calculated. In Vitaliano [19] the cost is estimated to be

72 USD (550 SEK) per ton salt used. Applying this in the case study, where 762 g salt per m road length is used during the two week period, this will end up in a cost of 210,000 SEK for a 10 week winter (as assumed above).

Assuming an installation cost for a groundwater protection system of 5 MSEK. The total environmental cost, with the assumptions made in this case study, sums up to between approximately 7.7 to 12.7 MSEK, depending on whether the groundwater protection is needed or not.

These calculations has been assuming an entire 10 week long winter. In order for the figures to be comparable to the figures of the other sub-models, presented in Möller (these proceedings), which only is calculated for a two-week period, the figures should be divided by 5. Hence, the total environmental cost in this small case study will roughly be between 1.5 and 2.5 MSEK. See further comparisons between the different sub-models in Möller (these proceedings).

6. DISCUSSION

It must be remembered that the modeling performed in this case study depends on a vast amount of assumptions. The winter model, at least the environmental part of it, is not supposed to be applied on true cases in the real world, but rather be seen as only one out of many possible versions of situations in the real world. A repeatable version under some given circumstances: a scenario machine. By changing the in-data to the model e.g. the regulation governing the salting occasions, new scenarios will be produced.

One very important issue that remains to be done in the model development is sensitivity analyses of the assumptions made, but also – and most important – of the constants used in the model equations.

A lot of model improvements are possible to make. The results presented in this paper are the first tentative test runs of the environmental sub-model, and should be regarded as such until further model development and validation is executed. So, please take the results with a “grain of salt” (*Cum grano salis*).

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