DE-ICING SALT AND ROADSIDE ENVIRONMENT – STRATEGIES FOR IMPACT ANALYSES

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1. Abstract

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 de-icing medium can lead to several impacts on human health and nature, as for instance damage to ground water resources and vegetation. The question of whether the political goals of accessibility, transport quality and safety can be fulfilled at the same time as the goal of a good environment is fulfilled, must be seen as a delicate matter of conflicting interests.

In order to be able to evaluate countermeasures taken against the undesired impacts, the system needs to be monitored with indicators at several levels within the system. An integrated environmental assessment framework that is suitable for such evaluations is the DPSIR-approach. It is for instance used by the Swedish Environmental Protection Agency for the follow-up of the national environmental quality objectives in Sweden. According to this framework there is a chain of causal links, from the societal need for transportation as driving force (D) of the system, over the pressure (P) of roadside exposure to salt, to an altered state (S) of the roadside environment leading to different kinds of impact (I), which may require some kind of societal response (R).

In most cases it is important to find useful indicators as early in the system as possible, especially when the environmental effect is delayed in time, as for instance regarding contamination of ground water resources. In that case an early warning could be reached.

By assigning adequate indicators to the different levels of the DPSIR model, the road keeper will not only strengthen his scientific understanding of the ecological effects, but also increase his possibilities to take appropriate measures to improve the sustainability of the system and finally increase the knowledge of the environmental utility of the strategic actions taken.

2. Introduction

In June 1998, the Swedish Parliament adopted a new transport policy on the basis of the Government Bill "Transport policy for sustainable development" (1997). The overall goal of the transport policy is defined to be a transport system that is environmentally, economically, culturally, and socially sustainable. The overall goal was divided into five sub-goals: an accessible transport system, a high transport quality, a safe traffic, a good environment, and a positive regional development. In addition to that, the Swedish Roads Act (1971, section 23) states that roads shall be held in a satisfactory state by maintenance and other measures. Therefore, in order to maintain road safety and accessibility of the road network at acceptable levels also during the winter season, the roads are kept free from ice and snow by ploughing and by the use of chemical de-icing. The winter road maintenance regulations of Sweden (Drift 96…, 1996) prescribe sodium chloride as the only allowed chemical de-icing agent to be used. Unfortunately the salt solution does not stay on the road surface where it has its desired effects, but will by different mechanisms be dispersed into the roadside where it may lead to undesired environmental impacts (Blomqvist, 1999; Thunqvist, 2000). The question of whether the goals of accessibility, transport quality and safety can be fulfilled at the same time as the goal of a good environment is fulfilled, must therefore be seen as a delicate matter of conflicting interests.

The Swedish National Road Administration (SNRA) is responsible for the winter road maintenance of about 98 000 km of state roads in Sweden (Ölander, 2000). Twenty-five per cent of the SNRA appropriation for road maintenance and operations is spent on winter road maintenance works, such as snow ploughing and de-icing (Ölander, 2000). The de-icing salt use on the national road network has approximately doubled since the 1970’s and has for the last six seasons varied in the size between 200 000 and 300 000 metric tonnes (figure 1).

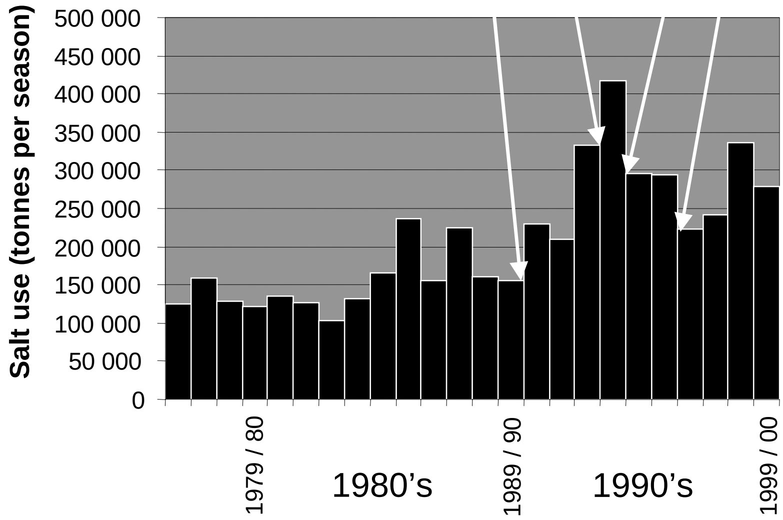

Figure 1 The Seasonal Salt Use On The Swedish National Road Network (Metric Tonnes Per Season). The Arrows Depict The Changes In The Winter Road Maintenance Regulations During The Last Decade. Before That The Winter Maintenance Was Regulated In Five-year Plans.

The SNRA has a constant ambition of improving the requirements of the winter road maintenance regulations. Therefore the regulations have changed several times during the last decade (figure 1). In 1996 a limit value of 200 000 tonnes salt per year was set up as a goal to be reached by the year 2000 (Kretsloppsanpassad väghållning… 1996). This goal was indeed reached as the salt-use in the calendar year of 2000 was 196 700 tonnes (Pettersson, personal communication). For the future, the strategy for decreasing the salt use is the development of a salt index that allows the actual salt use to be compared to the salt needed according to the weather conditions prevailing during the entire winter (Ölander, personal communication). In that way the actions of the contractors can be compared to the requirements of the regulations.

A key issue when taking management decisions in the road sector is to ensure that the limited funds are spent to greatest effect within the various constraints that pertain (Robinson et al., 1998). Knowledge of the different interrelationships within the system is therefore of great importance. Since 1999 the Swedish Environmental Code (1998, chapter 2, section 2) states that those who pursue an activity or take a measure, or intend to do so, must possess the knowledge that is necessary in view of the nature and scope of the activity or measure to protect human health and the environment against damage or detriment. After decades of investigations, however, we still have to deal with the problem of environmental effects of the use of de-icing salt in the winter road management. The regulations of the winter road management have changed four times during the 1990’s (figure 1) but, since we don’t have useful indicators of the environmental pressure, states and impacts, we still don’t know the environmental utility of these changes. The objective of this paper is to describe the system of de-icing practices and their environmental effects with special reference to the salt exposure of the roadside environment and damage to Norway spruce seedlings. The objective is also to describe a monitoring system and discuss the importance of indicators for the follow-up, which ultimately will increase the knowledge of the environmental utility of the strategic actions taken by the road administrator.

3. Describing the system

Full understanding of the total system is probably not possible, but by simplifying the system of the real world into a model to start with, a conceptual understanding of the total system could be reached.

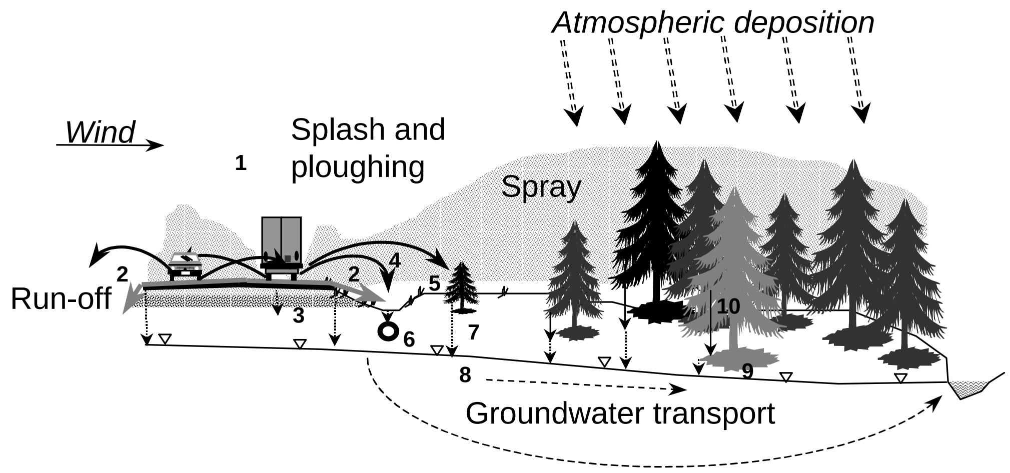

Figure 2 A Conceptual Model Of The Transport Mechanisms And Pathways From The Road.

The system of de-icing salt can be described in several ways. This can be illustrated e.g. as in the picture above (figure 2) showing the transport mechanisms and pathways from the road, or as a box model divided into several compartments as shown below (figure 3). The de-icing salt is either transported through the compartments or accumulated within them.

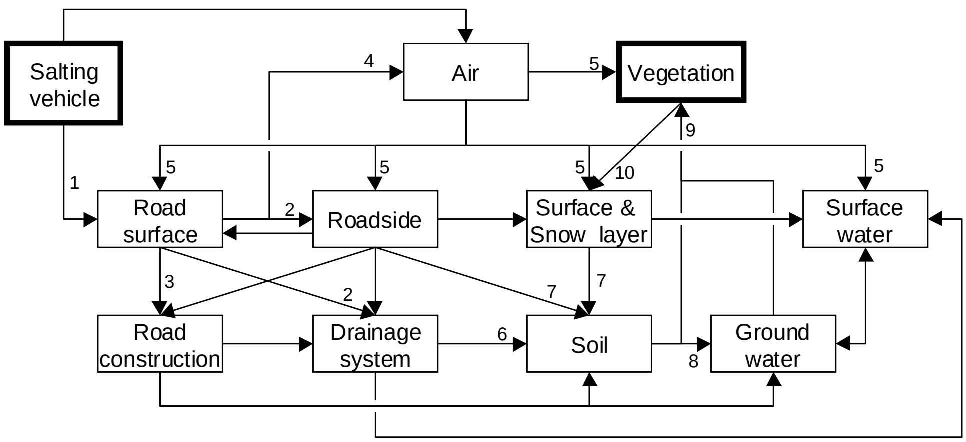

Figure 3 A Box Model Of The Physical System Of De-icing Salt Migration From The Vehicle That Carries On The De-icing Actions To The Compartments On, In Or Around The Road Which Are Involved In The Migration Or Accumulation Of De-icing Salt. The Boxes Depict The Compartments Where The De-icing Salt Either Is Passing Through Or – To Some Extent – Is Retained Or Accumulated. The Arrows Depict The Mechanisms That Govern The Migration Of The De-icing Salt, Such As: Deposition, Run-off, Infiltration, Percolation, and Root Uptake.

The de-icing vehicle applies the salt on to the road surface[1]. This is the action where the entire system origins. The salt will then leave the road surface by itself (by gravity) or by the action from traffic in the following ways. By run-off,[2] the salt will reach the roadside or the drainage systems. Some parts may infiltrate[3] the road surface and reach the interior of the road construction. By being forced into the air[4] by the vehicles or by ploughing, the salt leaves the road as splash, spray or dry crystals to be deposited[5] onto the road surface or roadside (roadside cover, ditch, etc.) of the technosphere or on the vegetation, soil surface, snow layer or surface waters in the surrounding ecosphere. By leaving the drainage system[6] or percolating[7] from the roadside or soil surface through the soil the salt solution may reach the groundwater[8]. Where the soil solution and groundwater are in contact with the root zone of vegetation, uptake[9] through the roots may occur. Some part of the salt deposited onto the foliage, stem and branches of the vegetation will enter the interior of the plant, but a large portion will be transported as throughfall[10] and stemflow[10] to the soil surface beneath the vegetation.

The pathways by which the de-icing salt may reach the different plant parts have been discussed extensively in the literature. There is no doubt that damage may occur either when the salt is deposited onto the foliage and when it reaches the root system. This has been shown both in field studies and in laboratory studies under controlled conditions (Dobson, 1991; Brod, 1993; Pedersen and Fostad, 1996). When the salt is deposited on to the foliage it may either stay on the exterior parts (needles, leaves, stem etc.) or be transported to the interior of the plants either through the leaf cuticle or through the bark on the branches or stem. Also the stomata have been suggested to be a pathway to the interior parts (Burkhardt and Eiden, 1994). Different kinds of particles deposited on the exterior parts of needles have been suggested to lead to additional damage (Flückiger et al. 1977).

The symptoms of salt damage in coniferous trees are often described as needle browning and needle loss (Pedersen and Fostad, 1996). Some trees are able to compensate for damage by producing new shoots, but when the damage is too great, this is not possible (Pyykkö, 1977; Blomqvist, 1999).

The consequences of this damage are many. One is the impact on biota in itself; another is the effect on the landscape. The impact of de-icing salt on conifers is a result of a complex interplay of many causal relationships (e.g. loss of needles: lower photosynthetic capacity; increased amount of salt in soil water: osmotic stress: inhibition of water uptake; stress avoidance of the plant: energy expenditure). Most of these effects will in the end result in diminished growth of the tree stand and can also predispose the tree to damage from fungi or insects. Such effects have been described by e.g. Pedersen and Fostad (1996). It is often difficult to separate between different stress factors since one factor may have predisposed the tree to damage, another factor can have triggered the damage, and a third factor may have contributed to the actual killing of the tree (Aronsson et al., 1995).

The extent of damage is governed by some kind of dose-response function. For some species, the function has been suggested to be S-shaped (Figure 4) (Dragsted, 1990). Many investigations of the amount of chloride in e.g. needle tissue compared to the extent of visible damage symptoms have been performed and comprehensive compilations have been published by e.g. Dobson (1991) and Brod (1993). The theoretical extent of damage can be calculated by combining the distance–exposure and exposure–damage functions (Figure 4). One should, however, keep in mind that the roadside environment is also exposed to many other stress factors (Viskari, 1999).

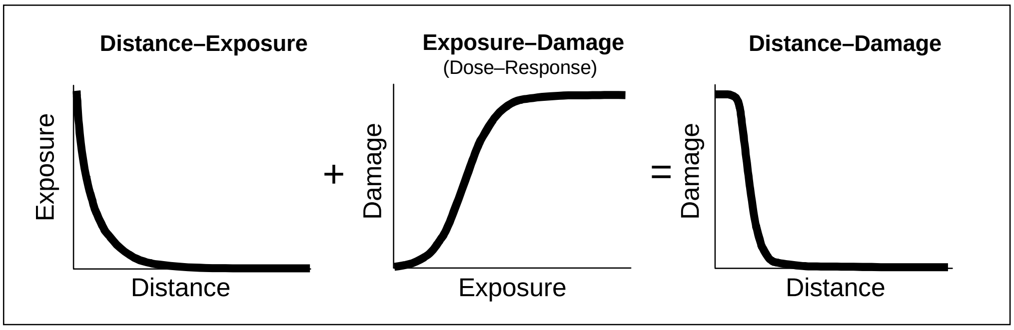

Figure 4 Theoretical Functions Of Exposure To Salt And Susceptibility To Salt Damage Give The Pattern Of Damage In The Roadside Environment

Forestry should be thought of as a process rather than a steady state. While one effect of the roadside exposure to de-icing salt is a lower yield from forestry, a possibly more important long-term consequence may manifest itself when reforestation is to take place. The seedlings and young plants are much more sensitive to salt exposure than are older trees. Reforestation may therefore be virtually impossible in a zone of up to several tens of metres from the road. This extends in many places beyond the road reserve area and, hence, may affect the land next to the road. If reforestation is made impossible the landowner is subjected to a forced change of land-use (Figure 5), which probably will lead to a different situation concerning the legislative possibilities to claim for damages, than do the impact of diminished growth in the roadside.

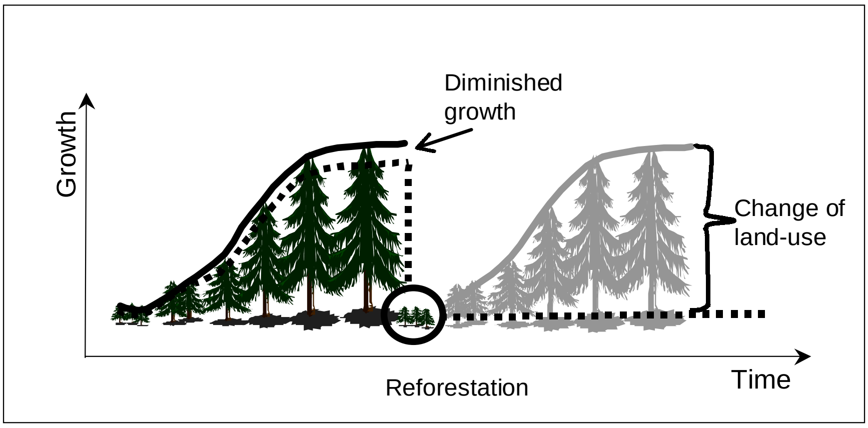

Figure 5 Implications for forestry, seen as a process

Sweden has a long tradition of monitoring salt concentrations in groundwater. Starting already in the late 1970's, Bäckman has been monitoring sodium and chloride concentrations in observation wells as influenced by de-icing salt. Long-term increases have been documented (Bäckman 1980, 1997). The same result has been obtained in long-term monitoring of chloride concentrations in municipal groundwater supplies (Knutsson et al. 1998; Rosén et al. 1998). Likewise, a long-term increase trend was documented by Thunqvist (2000) compiling data from up to 23 Swedish municipal groundwater plants for the period 1954–1999. By compiling data from 13 000 private drilled wells, Olofsson and Sandström (1998) found that wells located close to major roads had increased concentration of chloride.

The salt that has percolated through the road construction, or roadside and reached the soil or groundwater will to a large extent be transported with the groundwater to the surface waters and then follow the water cycle to the sea. In that sense this is – in a very long time-scale – a geochemical cycle of salt, extracted from the seas or rocks, placed on the roads and then returning to the seas again. On the road surface, most effects are desired and in the seas salt is at least not harmful. The important issue is what happens in between (Thunqvist, 2000).

4. Monitoring the system

Robinson et al. (1998) have stated that: "A key challenge for the road manager is to find ways in which to describe the problems and impacts of road maintenance that can be understood by the politicians and the general public". One could also state that a crucial challenge for the scientific community would be to find key parameters and indicators of the system's different compartments that can be understood and utilised by the road managers (Blomqvist, 2001b). A system that is used by the European Environmental Agency (EEA) as a generic tool to support understanding of complex environmental systems is the DPSIR model (Towards a transport and environment reporting mechanism 'TERM' for the EU, 1999). This system is used for facilitating communication and is based on indicators of the different compartments. Societal needs and activities can be viewed as driving forces (D) that lead to a pressure (P) on the environment. The pressure may change the state (S) of some compartments of the environment. This, in turn, can lead to impacts (I) on a system such as human health or nature. Finally, the society will respond (R) in some way to combat the problem in one or several of the earlier stages in the model (Figure 5).

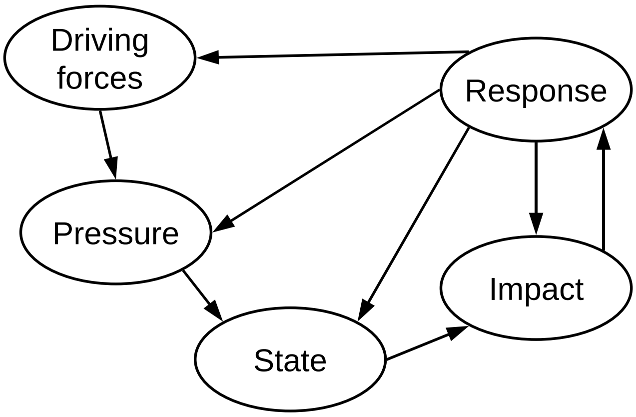

Figure 5 The DPSIR Framework For Reporting On Environmental Issues

Using the DPSIR-model (figure 5), the use of de-icing salt and damage to vegetation could be described as follows. The need for transportation (D) leads to a roadside exposure to salt (P), which alters the state of the vegetation (S), thereby leading to different impacts (I), which may require some kind of response (R) from society (Figure 6).

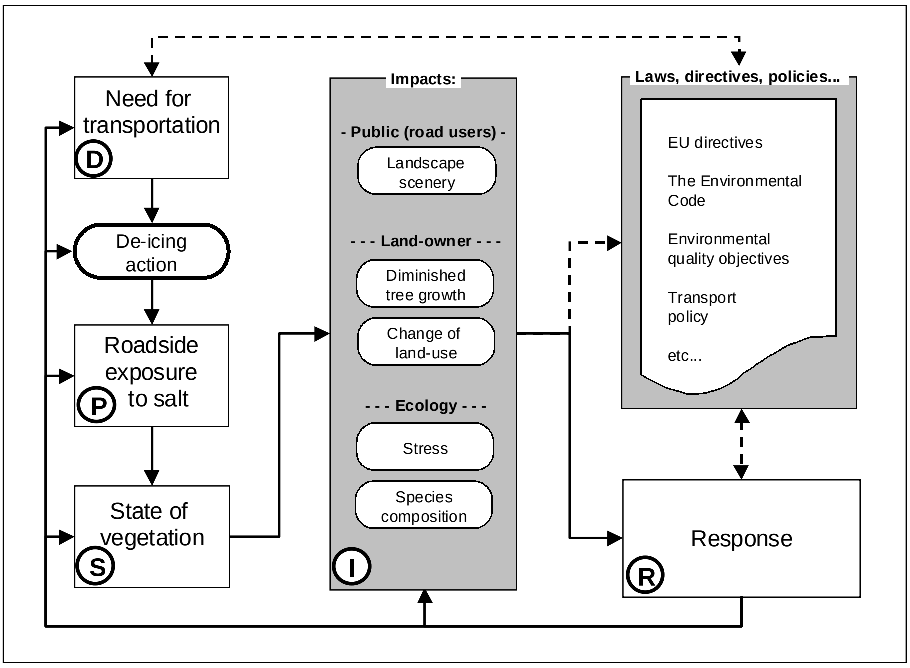

Figure 6 The System Of De-icing Action And Damage To Vegetation As Illustrated By The DPSIR model.

The impacts have been divided into different spheres of interest where the interest of the public as road users is threatened by the impaired landscape scenery. The interest of the rural landowners can be threatened by the diminished tree growth or the forced change of land-use that may occur if reforestation is made impossible in the salt exposed environment. The vegetation as part of the ecosystem can be influenced by being stressed and as a result there may be a change in the species composition of the roadsides.

By adding two new compartments to the original DPSIR model, the model is made suitable to be used for identifying the involved processes. The two new compartments are the first oval between the driving force and pressure (figure 6) which represents the activity that is induced by the driving force, causing the pressure. In this case it is the actual de-icing measure taken. The other new compartment in figure 6 is the box of laws, directives, policies, regulations, contract conditions, etc. These are partly a result of the needs within the society (e.g. need for transportation is manifested in some of the goals of the transport policy), but it can also be used as a toolbox of the society to respond to all of the stages in the DPSIR model.

In most cases it is important to find useful indicators as early in the system as possible, especially when the environmental effect is delayed in time, as for instance regarding contamination of ground water resources. In that case an early warning could be reached.

By assigning adequate indicators to the different levels of the DPSIR model, the road keeper will not only strengthen his scientific understanding of the ecological effects, but also increase his possibilities to take appropriate measures to improve the sustainability of the system. The road keeper needs also to know the environmental utility of the responses he has taken.

6. Ongoing research

Research at the Swedish National Road and Transport Research Institute (VTI) in Linköping, Sweden is currently addressing the issue of roadside exposure to salt and the development of indicators of different components within the system as described above, both regarding groundwater contamination and damage to vegetation.

7. Acknowledgement

This paper is based on the results of the licentiate thesis "Air-borne transport of de-icing salt and damage to pine and spruce trees in a roadside environment"(Blomqvist, 1999) and PhD thesis "De-icing salt and the roadside environment: Air-borne exposure, damage to Norway spruce and system monitoring" (Blomqvist, 2001). They are results from the project "Influence of De-icing salt on Roadside Vegetation" (VTI Project No 80131) performed at VTI during 1996–2001. The work has been financed by the Swedish National Road Administration through the Centre for Research and Education in Operation and Maintenance of Infrastructure (CDU) at the Royal Institute of Technology (KTH) in Stockholm and by the Swedish National Road and Transport Research Institute (VTI) in Linköping, Sweden.

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