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# NaCl Material for Winter Maintenance and Its Environmental Effect

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## Abstract

All over the world, winter maintenance is based on the application of the NaCl salt on roads, a product necessary for the elimination of slippery conditions. The quantities used for the salting operations are increasing with the development of the road network (in France, up to 2 million tons are applied each winter). This chapter will present the salt used as a deicer (its origin and chemical composition) and its chemical properties that are exploited for that purpose. Furthermore, an overview of the means of its transfer from the roads to the environment (soils and waters) as well as its impacts on these media will be presented, a special attention being devoted to the soil. The interactions of salt with other road pollutants and the treatment possibilities in the road pollution context will be discussed.

**Keywords:** NaCl, winter maintenance, road salt, pollution, environmental media, environmental impacts, road runoff

## 1. Introduction

In order to ensure the road safety and accessibility during winter in cold regions, winter road maintenance operations need to be performed. These operations are mainly based on the application of chemicals on roads with specialized vehicles. Large quantities of the so-called road salts, or deicing salts, are thus applied in order to clear the pavement and allow the normal traffic flow and economic activity [1].

Road salt was first introduced for snow melting operations in the 1930s [2], in order to improve vehicle traction [3] and thus reduce automobile collisions [4]. Sodium chloride (NaCl) has been the most commonly used deicing agent since the late 1940s [5, 6]. Application of road salts has been shown to reduce automobile accidents by 88% and human injuries due to icy conditions by 85% [7].

According to various climatic characteristics, urban environments, economy, and life requirements, people in different regions have different requirements for the consumptions of chlorine deicing salt [8, 9]. Improved management practices and regulations have resulted in reduced road salt application in some regions [4, 10]. However, the amount of deicing salt spread during cold periods increased since the 1940s [5, 11], but more particularly during the 1960s with the increasing road and highway network [12–14] and when its usage became widespread for highway maintenance [2]. For instance, the quantities applied in the USA increased from 149,000 tons in 1940 to over 18 million tons in 2005 [11]. Hence, this led the transportation

officials to yearly apply approximately 17 million tons in the United States, 6 million tons in Canada [7], up to 2 million tons of NaCl in France [15], and 600,000 tons in China [16]. The precise amounts of road salt applied are difficult to quantify [17], especially when it comes to road salts applied by individual land owners and other private entities. Kelly et al. [4] estimated that up to 40% of deicing salt application in some areas may be from private users [8].

Once spread on roads, due to several meteorological conditions and traffic, the road salt is transported out of the roads into the surrounding environment [10]. Another part remains on the road surface until the humidity coming from the precipitations or from the ice/snow melting is sufficient for flows of a road runoff [12]. In order to diminish the direct transfers of road runoffs to the environment, treatment systems, such as retention ponds, are constructed alongside roads [13, 18]. However, these ponds treating the pollutants only by sedimentation, dissolved pollutants, such as sodium chloride, will only pass through the pond and be rejected into the environment at its output [5, 18].

Severe impacts related to road salt applications have been reported on water and soil, as well as on their vegetation and population. Significant increases in chloride and sodium concentrations in surface water, groundwater, roadside soils, and organisms have been reported and were correlated to deicing salt application [19–21]. Indeed, salt stress can reduce the utilization rate of water in soil, cause water shortage, and even cause plant death in severe cases [22]. Different soil types and plants suffered different degrees of deicing salt damage [23, 24]. In some cases, concentrations have even reached toxicity thresholds beginning to threaten biodiversity [25, 26]. Moreover, salt has indirect environmental impacts, as  $\text{Na}^+$  and  $\text{Cl}^-$  ions are known to remobilize heavy metals adsorbed on the particle surface (soils and sludge) [27].

Despite the increasing use and concerns about the environmental impacts of road salt, only a few countries regulated the quantities spread on roads or developed a specific treatment for wastewaters contaminated by sodium chloride [28]. Canada, on the other hand, has much more drastic regulation declaring deicing salts as toxic products and limiting their use [29].

## **2. Salting operations**

During winter conditions, certain meteorological phenomena lead to slippery conditions that provoke a decrease of the friction between the vehicle tires and the road surface [30], thus representing a risk for traffic. Thus, the transportation officials have the responsibility to ensure the winter road maintenance, which encompasses all the actions and decisions aiming to fight the consequences of winter phenomena on the road network necessary in order to maintain the viability and safety of road users. Snow and ice control can be made with mechanical or chemical methods [31]. Mechanical methods for the removal of snow, ice, or frost from the road surface consist of scraping or pushing [1]. These methods are mainly used on the mountain roads, where the thickness of the accumulated snow on the roads is too large [32]. Chemical treatment, based on the use of road salts, is the method used in a large number of countries of Europe, Africa, Asia, and the USA. Numerous road salts exist: chlorides of sodium, magnesium, or calcium, alcohols (methanol, ethanol, and ethylene glycol), acetates of potassium or sodium, and formates of potassium or sodium [33]. The salt selection depends not only on the local climate and legislation [9] but also on the surface that needs to be treated. Hence, for more sensitive zones, less corrosive acetates and formates are employed [34].

For the road treatment, on the other hand, sodium chloride is the most preferred anti-icing compound, and is thus used in the largest quantities. It has been widely selected because of its low cost, high availability, easy use and storage, and high efficiency up to a temperature of approximately  $-8^{\circ}\text{C}$  [2, 5, 31].

## 2.1 Origin and composition of sodium chloride as a road salt

Sodium chloride used as road salt can come from different sources. The main types are sea salt (produced by natural evaporation of sea water) and rock salt (salt mechanically extracted from underground deposits) (**Figure 1**), but the new European standard includes other possible origins: ignigenic salt (obtained by recrystallization of brine produced by injection of water into the salt layers), salt of second intention (coproduct or industrial waste revalued), and brine of natural sodium chloride or produced from the dissolution of salt in water [35].

Besides the origin, road salt has to fulfill requirements stated in the European standard also in terms of granularity, humidity, pH, and composition (proportion of chlorides, soluble sulfates, heavy metals, insolubles, and anti-caking agents).

Road salt is mainly composed of its so-called active compound (sodium chloride), but it also contains insolubles and impurities such as metallic trace elements, whose quantity and nature vary as a function of the salt origin [12, 36]. Furthermore, other substances may be added for better efficiencies, such as anti-caking agents [2].

As an example, the composition of the rock salt extracted from the Varangéville mine, the only mine extracting rock salt for winter maintenance in France, is presented in **Table 1**.

## 2.2 Principles of operation of road salt

Deicing salt is a product whose physical and chemical characteristics permit to move the equilibrium of water phases in order to lower the freezing point. Under atmospheric pressure, pure water will have a freezing point at  $0^{\circ}\text{C}$ , and beneath that temperature, it will be in its solid form and will form ice on the road surface. It is possible to decrease the freezing point by the addition and dissolution of a solute, such as salt, in water (**Figure 2**). Thus, the formed aqueous solution is called brine when the solute is sodium chloride.



**Figure 1.** Stocks of sea salt coming from the Aigues-Mortes in the Occitanie region of France (left) and of rock salt coming from the Varangéville mine in the Lorraine region of France (right).

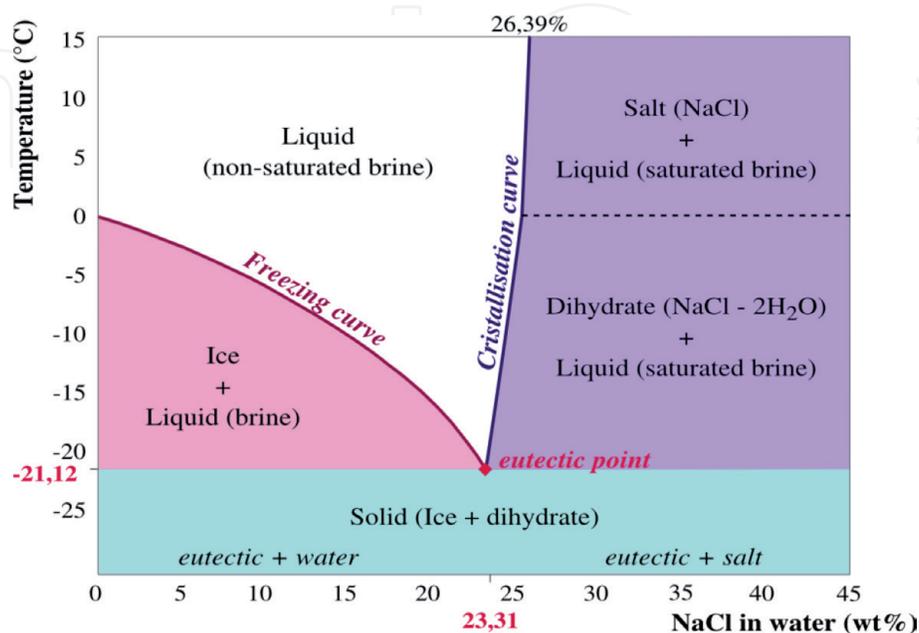
Solubles (mass % on dry)		Insolubles (mass %)	
Cl <sup>-</sup>	56.4	Silicates	90
SO <sub>4</sub> <sup>2-</sup>	0.86	Carbonates	5
Br <sup>-</sup>	0.01	Sulfates	5
Na <sup>+</sup>	36.6		
Ca <sup>2+</sup>	0.36		
Mg <sup>2+</sup>	0.02		
K <sup>+</sup>	0.09		
Fe(Cn <sub>6</sub> )Na <sub>4</sub> , 10H <sub>2</sub> O: 114 mg/kg			

**Table 1.**  
Composition of a sample of rock salt from the Varangéville mine [37].

A brine can be characterized by its so-called weight percentage, that is, the ratio between the mass of the salt dissolved and the mass of the solution. As shown in the NaCl-H<sub>2</sub>O phase diagram presented in **Figure 2**, a brine's freezing point decreases with the concentration increase until the eutectic point, which corresponds to a weight percentage of 23.31 and a freezing point at -21°C. For temperatures lower than -21°C, a sodium chloride dihydrate, NaCl · 2H<sub>2</sub>O, is formed.

The NaCl-H<sub>2</sub>O phase diagram permits to identify the role of the salt diluted in water. Indeed, if we concentrate on what happens at -5°C, we can see that for low concentrations, the solution will be composed of ice and liquid. A part of the solution being frozen, there is danger of appearance of slippery conditions. However, for higher concentrations (weight percentage above 10%), the solution will be entirely liquid.

In winter maintenance context, rock salt applied on ice will captivate free water, forming a brine. When the thus formed brine's freezing point becomes lower than the surrounding temperature, the fusion of ice or snow will start, diminishing the presence of the solid phase. The efficiency of the deicing salt to melt ice will depend on its concentration, the quantity of water present (from



**Figure 2.**  
NaCl-H<sub>2</sub>O phase diagram [37].

precipitations, air humidity, or water on the road surface), as well as on the temperature [38].

Depending on the state of the road, deicing salt can be spread as [12, 31]:

- dry salt: method convenient for very wet periods,
- in solution as a brine: efficient at dry conditions as it adheres to the surface, even though the brine can be easily drained off,
- moistured/humidified salt (mixture of a 30 wt% brine and of rock salt): efficient in numerous situations, as the dry salt will be the salt stock and ensures a mechanical effect, whereas the brine will bring the humidity necessary for the fusion.

The application can be performed either before the appearance of slippery conditions (preventive salt spreading) or once they are present on the road surface (curative salt spreading). With its capacity to lower the freezing point of the liquid present at the road surface, road salt prevents the formation of ice or provokes its melting.

### 3. Transfers of salt to the environment and its environmental impacts

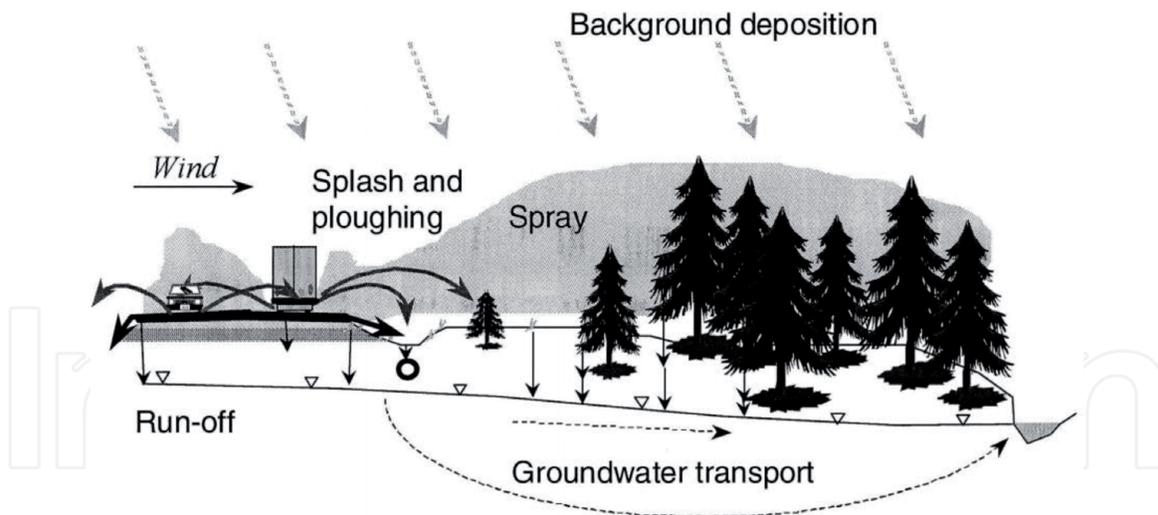
Numerous parameters and mechanisms lead the salt to be transported out of the roads into the environment. When deposited on soils, it can either be retained by the soil or infiltrate and percolate to groundwater [6, 31].

This represents a real environmental issue since NaCl is known to have adverse environmental impacts [5]. Indeed, besides increasing the salinity in soil and water, salt may induce a range of other effects [39]. First of all, it increases the hardness of water, provokes acidification of receiving waters [40], and strongly influences water geochemistry by the ion mobility, more specifically of metallic ions, *via* ionic exchanges and complexation with chlorides [20, 41–43]. Secondly, it can be retained onto soils and increase ionic strength and pH, thus modifying ion speciation [41, 44], but may also lead to alteration of the soil structure [31]. As a result, the disintegration of soil aggregates and increased mobilization of colloids can lead to a transport of heavy metals from soil to groundwater [27, 39]. And finally, in high concentrations, NaCl causes stress to ecosystems, decreasing biomass development and increasing mortality of species and therefore causing a modification of the biotope [45–48].

#### 3.1 Transfers

Any salt spread eventually ends up being in some part of the environment [2]. After their application on roads, road salt will be submitted to numerous parameters, such as meteorological conditions (precipitations and wind) and traffic [23, 49], which will influence its evolution. Most of this salt is removed through drainage (after precipitations or snow/ice melting) [3, 8] or traffic spray processes which will transfer it to the adjacent roadside environment [2]. The main transfer mechanisms, such as runoff, infiltration, airborne spreading, and plowing, are represented in **Figure 3**.

The transfers to the different environmental compartments will take place in the first hours following the salting operations [31]. First of all, it is estimated that 20–40% of the totality of rock salt spread is directly projected out of the roads during the salting operation [15]. Blomqvist and Johansson [31] stated that 20–63% of road salt is transported by air (projected by vehicles and wind).



**Figure 3.**  
A conceptual model of the transport mechanisms and pathways from the road [10].

The NaCl dissolved in storm water can be transferred in two ways. Firstly, it is projected out of the roads by nebulization. The distance to which road salt is transferred by nebulization can reach 400 m [50], even though more than 90% is found within 20 m from the road [31] and 98% within 50 m of the road edge [14]. Secondly, the runoff containing dissolved salt can be collected in retention ponds. These systems can collect between 40 and 80% of the totality of the road salt applied, depending on the meteorological conditions [12] and have the role of improving water quality and reducing flooding risks. Retention ponds allow the reduction of metallic pollution by decantation of suspended solids bearing trace elements, but in general, they are not designed to treat dissolved pollutants like NaCl [5]. Since sodium chloride is not removed by the retention ponds, after passing through those systems, road salt is rejected into the environment. There is thus a lack of appropriate storm water management practices [6].

It is found that up to 50% of the applied road salt reaches surface waters [6, 51, 52]. The remaining 50% enters the subsurface as aquifer recharge and migrates toward groundwater [6, 46, 53].

Further transfers will depend on the nature of the elements that are deposited, as the salt will be dissociated into sodium and chloride. On the one hand, chloride is considered to be a conservative element as it does not participate in chemical reactions. It will therefore follow the water and be transported down to the groundwater, from where it can be further transported to other groundwater aquifers or to various surface waters. Sodium, on the other hand, takes part in chemical processes, such as cation exchanges, with soil particles and is therefore retained in the soil [39, 54].

### 3.2 Impacts on waters

Concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  increase in superficial and underground waters during winter, following the salting operations [14, 20, 36, 42, 43, 55–61]. Due to long retention times of these ions by soils and waters, this increase can continue during the summer period [56] and high concentrations in lakes and underground waters can be observed during several years [36, 42, 57].

Increased chloride concentrations in groundwater or surface waters because of deicing salt application are the first observable change in water quality and indicate that there is a hydraulic connection between the road and the water [39].

### 3.2.1 Underground waters

Road runoff reaches underground waters by infiltration in soils [62]. Salt concentration of underground waters varies with the quality of soil or from 1 year to another. The increase of the salting operations leads to an increase in the salt concentration of shallow ground waters [53–55]. The concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  ions present in underground waters were also correlated with the permeable surface fraction which can receive road salt [46].

Aquifers play a role of reservoir wells for NaCl during winter [62], and become a source during summer, rejecting salted waters in the streams, thus contaminating surface waters [42, 54].

### 3.2.2 Surface waters

Road runoff presents very high  $\text{Cl}^-$  concentrations during winter, leading to salinity increase and water quality degradation [20, 36, 40, 58, 63]. In suburban and urban streams of Maryland, chloride concentrations can achieve 5 g/L [20] and the lakes of Minneapolis receiving waters charged in road salt have  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations 10–25 times greater [36].

The impacts of road salt on surface water can be physical, chemical, or biological: change of lake density stratification, eutrophication, mobilization of metals, reduced diversity, and so on [58].

In France, the Luitel Lake (Isère) is a remarkable example of the road salt influence on surface waters. Indeed, the winter Olympic Games organized in 1968 at Grenoble led to the emergence of winter sport resorts and the development of the road network to access it. The Luitel bog, located upstream and below a department road leading to the Chamrousse resort, suffered the consequences of this development, with an important increase of  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations since 1968: chloride concentration measured in 1955 was 3.7 mg/L, 34 mg/L in 1982, and 49 mg/L in 1999 [15]. A change in the lake's aquatic population was later observed [64]. Another example is the Saint-Augustin Lake in Québec where an unexpected presence of some brackish water and marine samples appeared in the second half of the twentieth century. This was identified as a result of the increasingly saline conditions from road and highway saltings [21].

The residence time will determine the evolution of  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations. If the residence time is lower than a year, these concentrations will diminish before the next winter season, forming annual cycles [36, 65]. If the residence time is longer,  $\text{Na}^+$  and  $\text{Cl}^-$  will not be flushed completely between salting seasons and will still be present in waters next winter, leading to a gradual increase of these concentrations from 1 year to another [62]. Hence, Kelly et al. [42] observed the increase of  $\text{Cl}^-$  and  $\text{Na}^+$  concentration in rural streams of New York of 1.5 and 0.9 mg/L, respectively.

The salinity increase in waters was correlated to the increase of  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and  $\text{Ca}^{2+}$  cation concentrations coming from soil road runoff passed through [66, 67]. Judd et al. [68] attributed the  $\text{Ca}^{2+}$  and  $\text{K}^+$  concentration increase in the Third Sister lake (Michigan) between 1981 and 2004, to cationic exchanges between those ions and sodium, whereas concentrations of  $\text{Mg}^{2+}$  and  $\text{SO}_4^{2-}$  remained unchanged.

Lakes present stratification with a temperature and density gradient, the superficial layer being warmer. In autumn, as the air temperature decreases, it induces convection streams leading to a homogenization of the water column permitting the brewing of nutrients and dissolved oxygen. In winter, the presence of ice on the lake surface leads to a stratification reversal, the surface layer becoming colder than the lower layer. At spring, air warming inverses the process [69].

The income of dissolved NaCl induces a modification of the thermal stratification in favor of a chemical stratification. Waters charged in NaCl, denser, are located in depths [70]. This chemical stratification prevents the brewing of water masses, with eutrophication risks [36].

### **3.3 Impacts on soils**

After being deposited on the ground, road salt infiltrates the soil and is further transported down the soil profile to eventually reach the groundwater [39]. Despite the runoff and storm drains, one part of salt is accumulated in soil [23]. Hence, Howard and Haynes [51] estimated that only 45% of the chlorides were removed annually by surface runoff in Toronto (Canada), the rest of it remaining in soil water or ground water.

#### *3.3.1 Cation speciation*

It was observed that Ca and Mg are present in higher concentrations in soils in the vicinity of roads [23, 40, 41]. Indeed, after salting operations, Na<sup>+</sup> concentration increases in the soil solution. Sodium enters in competition with other cations at the sites of ionic exchanges leading to an increase in Mg<sup>2+</sup> and Ca<sup>2+</sup> concentrations in the soil solution [19, 41, 56, 61, 63, 66, 71–75]. Because of its stronger attraction to negatively charged soil particles, Mg<sup>2+</sup> may accelerate Na<sup>+</sup> leaching by displacing it in soils [23]. Thus, faster movement of Na<sup>+</sup> through soils make Na<sup>+</sup> less available to plants, but more available to aquatic systems [23].

Sodium can also enhance the release of metals from soils to groundwater [19, 23, 27, 76]. Hence, increased transport of heavy metals (Zn, Cd, Cu and Pb) coincident with road salt applications has been observed in roadside soils in Germany, Sweden, and the United States [36].

Due to their physicochemical properties, metallic trace elements have different speciations according to the pH and chemical environment. Metallic trace elements with weak solubilities fix on preferential phases that vary according to physicochemical conditions on the water-solid interface. Metals such as Cu and Cd have strong affinities for organic matter and are present in aqueous phases in the form of chloride complexes. Other metal, such as Pb, Cr, and Zn have a strong affinity for organic matter that influences their mobility in the presence of Na<sup>+</sup> and Cl<sup>-</sup>. Li et al. [77] showed that in a soil of a nontreated road, Pb and Zn were present mainly in the phases of carbonates and oxides of Fe and Mn, whereas Cu was mainly associated to organic fractions and to sulfides. Durand et al. [78] observed in sediments of retention ponds that Cd, Pb, and Zn were linked to fulvic acids and were mobile, while Ni and Cr were mainly present in the humic fraction and were thus little mobile. Pb and Zn can also precipitate as oxides [76], while Cd forms chloride complexes in the presence of dissolved NaCl [74].

#### *3.3.2 Impacts on the soil quality*

Several anthropogenic factors disturb the state of urban soil by changing its natural features and internal processes [79]. Geomechanical transformations are often accompanied by chemical changes. The accumulation of different pollutants and their subsequent synergetic and antagonistic reactions lead to an increasing level of toxicity in urban soil [80]. One of the observed changes is the salinification of urban soils, a side effect of salting the roads in winter, which will lead to a physicochemical modification of the soil and influence the mobility of metallic trace elements.

Soils in the vicinity of roads present higher concentration of metals and road salts. As an example, the first 20 cm of depth next to main roads in Opole (Poland), chloride concentration can go up to 1.5 g/kg [79].

Road salt accumulation in soils depends on several parameters: the soil permeability and its density, and its mechanical properties influence the salt transport and the physicochemical processes. The  $\text{Na}^+$  and  $\text{Cl}^-$  ions can be retained in soils next to rural and urban roads in Missouri for 2–3 months after the end of the salting period, namely in soils containing organic matter, such as sandy soils [61]. According to Lundmark and Olofsson [81], soils with coarse particle size, which are more permeable, will have greater salt leaching down the soil profile.

More conservative  $\text{Cl}^-$  is less retained by soils [2], leading to concentrations in water higher by 10–15% than the  $\text{Na}^+$  concentration [40]. However, several studies showed that chlorides can be retained in forest soils [82], as well as rural soils [83]. Indeed, the chloride ion can interact with the organic matter in order to form chlorinated organic complexes and be stocked in soil micropores [40, 56, 82, 84]. Besides acting like a well, soil is also a source by liberation mechanisms with  $\text{Cl}^-$  and  $\text{Na}^+$  ions interacting with the soil components [82, 84]. The ions are then leached toward underground waters or transported to surface waters.

Numerous lixiviation tests showed the capacity of NaCl to remobilize metallic trace elements. The alternation of leaching with rainwater charged in  $\text{Na}^+$  and  $\text{Cl}^-$  and water with weak ionic force promotes the release of colloids formed of carbonates, clay, and organic matter [27, 72, 74, 85]. Moreover, the presence of  $\text{Na}^+$  and  $\text{Cl}^-$  leads to a competition for the sorption sites [63]. Metallic trace elements are easily leached in the presence of NaCl [19, 27, 72, 74, 76, 85] and can be transported by the soil solution toward surface or underground water.

Salinization is a threat for soils, mainly in arid countries where irrigation is performed with salted waters [12]. Clays can contain in their structure  $\text{Ca}^{2+}$  ions that permit to obtain structures presenting little swelling or dispersion. Conversely, the presence of  $\text{Na}^+$  in clays induces the formation of a platelet structure, more mobile in interstitial water. The presence of  $\text{Na}^+$  in the soil provokes particle (clay and organic matter) dispersions [66] and a swelling decreasing hydraulic conductivity by obstruction of pores [86, 87]. Structural stability of a soil, apparent density, and soil permeability will then decrease in the presence of  $\text{Na}^+$  [86–89]. Colloids are evacuated during the leaching of soils by salty waters [72, 74]. The soils presenting high salinities induce a release of Ca, Mg, and K.

### 3.3.3 *Impacts on the vegetation*

Once in the roadside environment, salt may percolate downward into the soil and become available to plant roots or the underlying water table or be deposited directly on roadside vegetation [79]. Many authors have shown a direct correlation between the content of  $\text{Na}^+$  and  $\text{Cl}^-$  ions in the soil and the degree of plant damage [22, 90]. Indeed, increases in  $\text{Na}^+$  concentration tend to leach out K, Ca, and Mg cations, which can result in nutrient deficiencies in certain soil types [24, 72]. The higher the concentration of  $\text{Na}^+$  and  $\text{Cl}^-$  ions in the soil, the higher their accumulation in plants and, consequently, the greater the damage to plants [79].

The most significant symptoms of salts on roadside trees are growth limitation/reduction in biomass, necrosis, defoliation, and in extreme cases, the entire destruction of a plant [12, 49, 79]. These symptoms can be caused by several salt effects: photosynthesis reduction, decrease of soil moisture, decrease of water content in leaf tissues, alteration of nutrient availability, etc. [24]. It is estimated that the use of road salt is responsible for the death of 700,000 trees/year in Western Europe [91] (**Figure 4**).



**Figure 4.**  
*Roadside vegetation impacted by road salt [92].*

A good example of the impact of urban runoff on biota is the Frenchman's Bay lagoon, receiving direct runoff from Canada's busiest highway. Eyles et al. [53] underlined a marked reduction in the area of vegetation of a wetland corresponding to 30% since 1970 and 60% since 1939. Furthermore, reduced diversity and coverage of submergent plant species is reflected in changing fish populations in the lagoon. The authors showed that the largest contemporary impactor on environmental quality in Frenchman's Bay watershed derives from the salting operations.

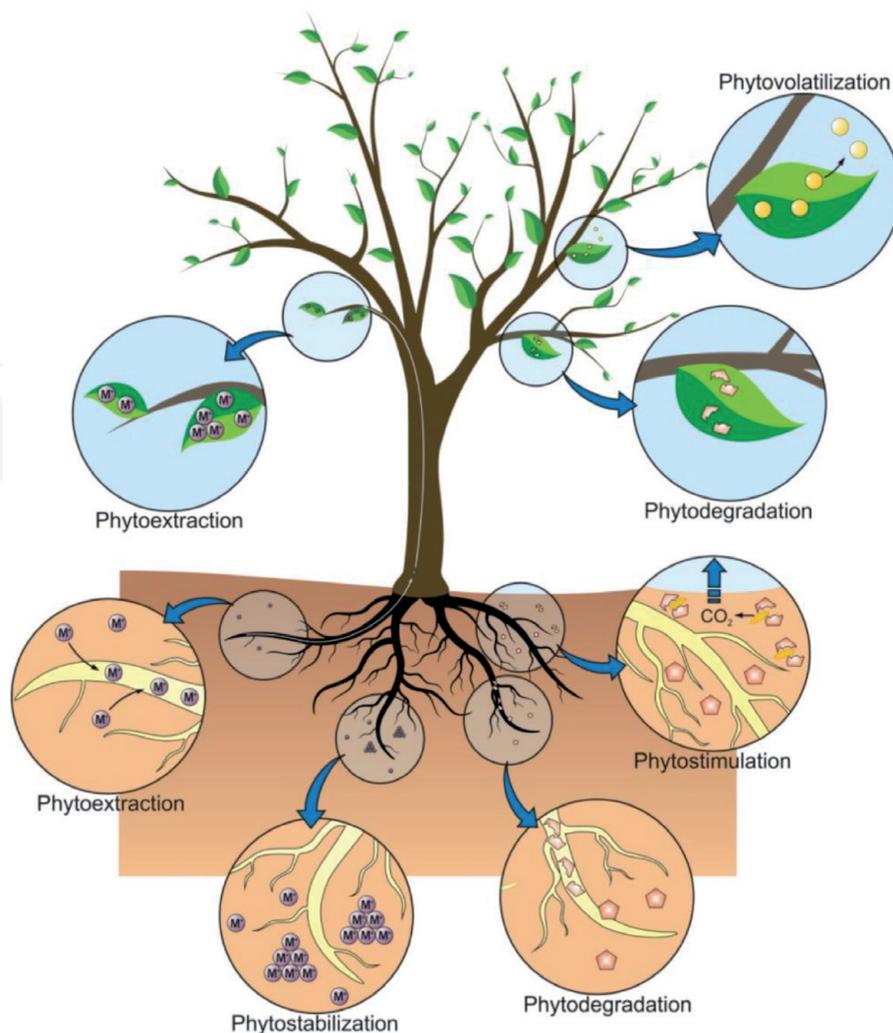
#### 4. Treatment possibilities

Contaminated soils and waters can be remediated by various methods which are not suitable for an *in situ* treatment. For the road runoff treatment, conventional desalination techniques (reverse osmosis and membrane processes) are too expensive.

Currently, preference is being given to *in situ* methods that are less environmentally disruptive and more economical. In this context, biotechnology offers phytoremediation techniques as a suitable alternative [93].

Phytoremediation is based on the use of plants and their associated microorganisms for the removal, degradation, or stabilization of toxic substances from the environment. Depending on the contaminant and on the plant characteristics, different phytoremediation techniques take place (**Figure 5**).

The first objective of the phytoremediation is to limit the impacts of some contaminants. This can be obtained by several ways. Firstly, by phytostabilization, that is, immobilization of the contaminant in the contaminated soils (after incorporation of contaminants into roots, metals are precipitated as insoluble forms and trapped in the soil matrix). This technique diminishes the mobility and bioavailability of contaminants by different mechanisms such as sorption, complexation, or precipitation [94]. Secondly, by phytodegradation of the contaminant (contaminants are degraded inside plant cells by specific enzymes) [93, 95]. And finally, by phytoextraction from the soil which involves the absorption of contaminants by roots and their accumulation in the aerial parts [96]. It is mainly applied to metals (Cd, Ni, Cu, Zn, and Pb) and preferentially uses hyperaccumulator plants that have the ability to store high concentrations of specific metals in their aerial parts (0.01–1% dry weight, depending on the metal). Phytoextraction is the most commonly used technique and probably the most economic and efficient one [94].



**Figure 5.**  
Schematic representation of phytoremediation strategies [93].

In order to develop such a technique for the remediation of a contaminated soil, it is important to choose appropriate plants. Indeed, the choice of the plant will depend on the environmental conditions it will be submitted to, mainly soil composition and pollutant that is aimed for phytoremediation. In order for a plant to be considered as a good phytoremediator, it has to have high tolerance to the pollutants and has to be able to accumulate or degrade pollutants. For a good efficiency, it is necessary that the plant has fast growth and high biomass production, as well as a well-developed root system. Finally, it has to be well adapted on the climatic and environmental conditions it will be submitted to [18].

Phytodesalination, in particular, is a modality of phytoextraction based on the use of halophytes for removal of salts from saline soils. Several studies investigate the possibility of using phytodesalination for road runoff treatment [97–102].

Morteau et al. [100] investigated a possibility for the treatment of road runoff in Québec by *Atriplex patula*, *Salicornia europaea*, and *Spergularia canadensis*. The authors showed that all species accumulated important masses of salt, but that the mass of accumulated salt depends on the plant morphology (size and weight), species, and concentration of the salt exposure. Their study shows that, taking into account the chloride accumulation and plant weight, *Atriplex patula* is the most suitable for the accumulation of chlorides and of sodium.

Suaire et al. [102] and Durickovic et al. [97] showed that two *Atriplex* species (*Atriplex hortensis* and *Atriplex halimus*) seem to be well adapted for the road runoff remediation. Indeed, these species showed they both have salt and metal

accumulation abilities, but also have capacities suited for the implementation in the road runoff treatment systems. Indeed, *Atriplex hortensis* is particularly interesting because of its fast growth rate, attaining 1 m of height in 1 year and *Atriplex halimus* because of its water stress tolerance and ability to accumulate metals, contaminants that are also present in road runoffs.

## 5. Conclusion

Significant increases in sodium and chloride concentrations in the different environmental compartments (water, soil, and biota) have been reported and correlated to deicing salt application. These increases lead to important environmental impacts such as the increase in soil pH and salinity, modification of the soil structure, reduction of the availability of nutrients for the vegetation, and loss of biodiversity. Hence, many European countries (Germany, Finland, Norway, Sweden, and Switzerland) and Canada are preoccupied with the environmental risks that the usage of deicing salt implies. They entered the usage of deicing salts in their code of the environment and prohibited their use in vulnerable areas. Canada also entered road salt in their list of toxic products of the Canadian law for the protection of the environment in 1999.

Despite of its well-known environmental impacts, it is not possible to overcome the need of usage of salt as road salt. Numerous studies are led in order to optimize its applications and diminish its rejections into the environment. However, even if the quantities applied on roads are diminished, the salt will nevertheless end in the environment.

The concentrations of sodium and chlorides rejected into the environment may only be regulated by controlling the water output flow of collection systems or retention ponds along roadside. Several studies investigate the possibility of using phytodesalination (i.e., extraction of salt from soil or water by plants which concentrate it in their biomass) for road runoff treatment. These studies show promising results, particularly with the *Atriplex* halophytes species, but are still in their research phase and are not yet operational. In the meantime, salt surveillance in environmental media is thus of great importance in order to identify the areas that are most vulnerable and where optimization of salting operations, as well as of retention systems are needed.

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