

ENVIRONMENTAL IMPACT OF CHEMICAL DEICERS – A REVIEW

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(Received 1 December 2004; accepted 18 May 2005)

Abstract. Increased application of chemical deicers for winter maintenance has resulted in increased concentrations of deicer constituents in the environment. The runoffs from the deicing operation have a deteriorating effect on soil and water quality. But the degree of impact is localized and it depends on various climatic factors and can also be attributed to the type of salts used and their storage conditions. This paper presents a review of the environmental impact of deicing chemicals.

Keywords: road salts, chemical deicers, surface water, groundwater, soils, impacts

1. Introduction

In urban and semi-urbanised areas located in cold regions, safe driving conditions during winter months are of primary concern. Hence, large quantities of deicing chemicals are applied in order to clear the pavement and allow the normal traffic flow (Novotny, 1986; Field *et al.*, 1975; Butter and Labadia, 1999; Murray *et al.*, 1977). Road salt was first introduced for snow melting operations in 1930's. Its usage became widespread during 1960's for highway maintenance (Paschka *et al.*, 1999). Presently, a wide range of deicing chemicals is being used in order to enhance the melting process (Jones, 1986; Oberts, 1986). It was reported that approximately 9 to 10 million tons of sodium chloride, 0.3 million tons of calcium chloride and 11 million tons of abrasives are used annually. Highway salting rates range from 400 to 800 pounds of salts per mile of highway per application, and many roads annually receive more than 50 tons per mile (Field *et al.*, 1974).

Any salt spread into the environment eventually ends up being in some part of the environment at detectable levels. The salt spread on the snow or ice will enter into any one or combination of the following three possible alternative pathways:

- (a) Salt may dissolve in the melting snow and run off directly,
- (b) Moving traffic may splash salt or salt in solution into the adjacent roadside environment where 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 or

- (c) Salt-laden ice and snow may be picked up, hauled away, and eventually be discarded (Zinger and Delisle, 1988).

The runoff from snowmelt may also be accompanied with high concentrations of other pollutants, and the impact of other pollutant on the environment is not included in the scope of this review. The ultimate depository of all salts discharged into the environment would either be water and/or soil. Less permeable soils favour runoff and, therefore, there will be greater horizontal salt movement over the soils. Greater horizontal movement can also occur in winter because of the presence of frost in case of less permeable soils. The degree of percolation into the soil depends on the soil permeability and the season of the year. After reaching the water table, the salt-bearing water moves downwards with respect to the water table (Fritzsche, 1992; EPA, 1971; Ruth, 2003; Diment *et al.*, 1973).

Various kinds of deicers are used for snow melting operations. The deicers range from rock salt to urea (Schraufnagel, 1967). Among all salts, calcium chloride and sodium chloride are the most widely used. The term 'salt' is used in a generic sense meaning either calcium chloride or sodium chloride (Gutiw, 1998). Apart from snow removal operations, small quantities of road salts are also used as dust suppressants (Mayer *et al.*, 1999).

Special substances may be added such as prussian blue, sodium ferro-cyanide (Yellow prussiate of soda), chromates, and phosphates to sodium chloride and calcium chloride for better efficiencies (EPA, 1971). These substances are called anticaking agents. Other compounds, for example, ethylene glycol, urea, calcium magnesium acetate and tetra potassium pyrophosphate are being used, but in substantially smaller quantities and for specialized application (Gutiw, 1998).

2. Impacts of Deicers on Water and Soil Quality

2.1. SODIUM CHLORIDE (NaCl) OR ROCK SALT

Salt is the most preferred deicing compound. It is easy to store, less costly, easy to handle and it disperses easily on the surfaces. Rock salts are effective upto a temperature of approximately -9°C (16°F). When applied at colder temperatures, the added salts soften the ice and may melt approximately 10% of the total water content of the snow and ice layer of the treated surface.

2.1.1. *Impact on Surface Water*

Surface waters are complex ecosystems. Many physical and biochemical cycles co-exist and interact within the ecosystem. The ecosystem takes a longer time to adapt to any change occurred (Mayer *et al.*, 1999). The point of concern is the rapid change, such as pulse inputs of salts into surface waters, which have a deteriorating effect on the water quality.

Numerous studies (short term and long term) have been carried out in order to understand the pollution load from deicing operations and their effects on water bodies. One such study was carried on four tributaries to Rich Lake located in central Adirondack Mountains of New York by Demers and Sage (1990). Four streams, flat brook, no name brook, plantation brook and CCC brook, intersecting route 28 N were selected for chloride monitoring. Other than their association with 28 N there was no source of chloride contamination within the watersheds of these four streams. The total amount of salt applied in the study area was 44 ton in 1986–87 and 41 ton in 1987–1988. Table I shows the mean chloride concentration of water samples collected at four sampling stations for each study stream.

Results showed that, the application of road salt to route 28 N increased the chloride levels in the downstream section of the streams dramatically and there was no significant difference found between the downstream 50 m and downstream 100 m samples in any of the streams indicating that the elevated chloride levels were not just an immediate roadside phenomenon. This chloride was carried into the Rich Lake. The highest concentration of chloride found in Rich Lake was 3.69 mg/L, well below the average value for fresh waters of 8.3 mg/L. This relatively low concentration of chloride coupled with the overall size of the lake shows that the application of road salt to route 28 N has increased the chloride levels in the downstream section of the four streams. It was also observed that denser saline water entering into the lake was accumulating in the deeper portions of the lake below the lower density fresh water indicating that chlorides are more concentrated at the lower depths.

Similar results were observed in First Sister Lake (Judd and Stegall, 1982) resulting in an increased stability to stratification, to such an extent that complete mixing was prevented. It was reported that First Sister Lake did not undergo complete overturn following the winters of 1964–1965 and 1966–1967. Chlorides reached as high as 177 mg/L and conductivity 754 ohms in the lower meter of water during these periods. The lake was highly eutrophic with a deeper layer of organic matter

TABLE I
Mean chloride concentration (mg/L) of four Adirondack streams

Brook	Flow rate (m ³ /s)	Mean chloride concentration (mg/L)		
		Upstream 100 m	Downstream 50 m	Downstream 100 m
Flat brook	0.22	1.13	1.7	1.77
No name	0.01	0.53	17.05	17.03
Plantation	0.01	0.53	7.21	7.54
CCC	0.02	0.51	3.73	3.58
All brooks combined		1.35	7.4	7.18

Demers and Sage (1990).

on the bottom. It appeared as if the sediments rapidly took up the oxygen in the hypolimnion.

The long-term studies of Lake Erie have shown that average chloride content has increased three-fold in the last 50 years, from 7 mg/L in 1910 to about 23 mg/L in 1964. It is reported that the present use of water from the lake does not have any deleterious impact as the concentration is not much high, but a continued rate of chloride build up due to road salt application can cause serious impairment of water uses in the near future. Highway salts are estimated to contribute 11 percent of the total annual input of chlorides into Lake Erie waters. Similar reported estimates of road salt inputs for Lake Superior, Michigan, Huron and Ontario were 91,000 tons, 438,000 tons, 198,000 tons, and 525,000 tons respectively (EPA, 1971).

The study conducted by Godwin *et al.* (2003) on Mohawk River basin showed that the concentration of Na^+ and Cl^- had increased by 130% and 243%, respectively from 1950's to 1990's while other constituents have decreased or remained the same. The use of deicing salt on roads within the watersheds, an estimated 39 kg/km²-day addition, appeared to be the primary mechanism responsible for the increase in concentration.

Scott (1980) studied the road salt movement into Don River and Black Creek on the northern boundary of metropolitan Toronto. The variation in the chloride concentration and discharge at two sites in Black Creek and Don River for two different periods was also studied. It was observed that increased levels of deicing salts in the water courses generally coincided with thaw periods, but significantly higher levels than base values were observed during snow storms and on other occasions. During summer months the salts stored in the roadside soils leached into the stream and caused elevated salt levels. Although these levels are not as high as observed during the winter months, they persist for most of the spring and summer. But the highest levels of chloride were seen during summertime in case of Sleepers Rivers Basin, Vermont as a result of summertime base flows (EPA, 1971; McDonnell and Taylor, 1987; Howard and Livingstone, 2000; Runge *et al.*, 1989). Crowther and Hynes (1977) in their study on Laurel Creek reported that the winter peak concentration was associated with periods of low discharge, although there was a little direct correlation between salt levels and discharge. In the summer, however, when the water level falls more or less steadily because of evaporation, high temperatures and low rainfall, the correlation between salt level and discharge was strong, and fairly high salt levels were found many months after the last treatment of roads.

In most of the studies, a point noticed in common was a surge in winter peak concentrations and gradual stabilization of the pollutant over other periods. One of the main reasons for the existence of high chloride levels during summer is the base flow. It is because; cationic exchange traps the sodium with humus in the soil, leaving chloride to pass down to the ground water. A large proportion of the salt applied to the surface may move down into the ground water in the same way, so it remains as a reserve supply available for summer discharge. In some cases the

chloride concentrations have considerably increased while in others the increase in chloride concentrations falls below the guideline levels. Smaller lakes are at great risk compared to large water bodies due to dilution (Jones and Jeffrey, 1992; Gales and Vandermeulen, 1992). The following impacts on surface waters are grouped due to the influx of runoff from salt application,

1) **Change in density gradient**

The salt contaminated runoff alters the physical and ecological characteristics of the lake. If the runoff contains large amounts of salt, the density of the inflow water increases and this inflow appears at the bottom of the lake resulting in no spring overturn. In order to maintain a normal eco-system the mixing of layers of water is very essential as it distributes oxygen and nutrients within the lake (Jones and Jeffrey, 1992). Some researchers report that if the present use of deicing salts continues, a population shift towards less desirable, salt tolerant aquatic species may occur in some lakes (Gales and Vandermeulen, 1992).

2) **Increased chloride concentrations**

The chloride concentrations are less in large drainage basins when compared to smaller lakes as the greater volume of water flow in the basin usually dilutes chloride concentration to below guideline levels. Hence the surface waters in large drainage basins are generally considered to be at low risk in relation to road salt pollution when compared to smaller lakes. The temporal and spatial factors are the two factors influencing the degree and distribution of elevated chloride concentrations (Jones and Jeffrey, 1992).

3) **Salt-induced stratification**

Seasonal mixing of lake waters is essential to maintain the animal and plant life in a lake (Jones and Jeffrey, 1992). Incomplete mixing of salt ions entering lakes creates layers of different densities and can cause depletion of oxygen. The NaCl concentrated in water bodies get involved in ion exchange releasing toxic metal ions (e.g., mercury) that are present in the sediments (Gales and Vandermeulen, 1992). The salt-induced lake stratification was seen in First Sister Lake, Ann Arbor, Michigan (Judd and Stegall, 1982) and Irondequoit Bay, Rochester, New York (Diment *et al.*, 1973). Judd and Stegall (1982) reported low DO in the deeper waters of First Sister Lake for an extended period of time causing detrimental changes in animal and plant life in the lake. They indicated that deeper zones of the lake were without oxygen for some ten months, and the entire lake below the 10-foot depth was virtually devoid of DO for about eight months.

4) **Salt stimulation of algal growth**

Briggins and Walsh (1989) reported that sodium could increase the growth of blue-green algae, thereby stimulating nuisance algal bloom. Sodium concentrations greater than 40 mg/L may be necessary for triggering undue growth of blue-greens. However, 5 mg/L of sodium is required to provide an optimum growth of *Anabaena cylindria*, which is essential on the suspected relationship between eutrophication and sodium build up from deicing salts (EPA, 1971).

The route of the saline runoff from salted roadbeds to nearby surface waters may be direct (as during precipitation or a thaw, when much surface runoff will flow directly into nearby water courses) or indirect (as when runoff may be temporarily detained in roadside drainage ditches or may infiltrate the overburden and percolate down to the aquifer before being released into lakes and rivers) (Jones and Jeffrey, 1992). The study on the Northern Wisconsin and other lakes showed some links for the transport of chloride between road salting and lakes via groundwater systems indicating ground water as a potential pathway for the road salt contaminants into the surface waters (Bowser, 1992). All observed lakes demonstrated a lower Na/Cl ratio as a result of ion exchange processes in the transit of runoff to the lakes via groundwater. So far, little attention has been paid to the effects of exchanged ions such as calcium, magnesium, potassium and ammonium released by sodium uptake (Mason *et al.*, 1999; Shanley, 1994). If groundwaters are significant pathways to lake systems it means that all the other contaminants share the same pathway and equal concern should be given to other soluble contaminants released.

Now, the significant question of concern is the amount of salt pollution into the stream and the temporal and spatial factors influencing its degree and distribution (Jones and Jeffrey, 1992). Scott (1981) correlated the salt inputs into the streams to the length and type of road draining into the streams and the amount of salt applied prior to thaw periods. The level and duration of deicing salt concentration in the watercourse is affected by the following factors: road drainage system, topography, discharge of the receiving stream, degree of urbanization of the watershed, temperature and precipitation.

2.1.2. *Groundwaters*

Unlike surface waters, which have, almost unlimited power of dilution due to their flow rate and the volumes involved, a water table is characterized by a clearly defined volume. Saline solutions can percolate through roadside soils from the upper layers into the water table, but the extent of ions retained depends on the nature of the soil, its permeability, ion exchange capacity, the existing plant cover, the type of ion, the level of moisture in the soil, and the depth of the water table. Seasonal variations in the ionic composition of the water table are not very pronounced due to the time taken for solutions to percolate from the surface. Accumulation phenomena can be observed at some distance when saline solutions percolate laterally on impermeable layers before flowing through fractures (Defourny, 2000).

The most significant impact of road salting on groundwater is the contamination of water supplies which results mainly into an alteration of the organoleptic characteristics (salty taste) of water intended for drinking. Pollock and Toler (1973) studied the effect of highway deicing salts on groundwater and water supplies in Massachusetts. The samples were collected from 10 different sites from the wells installed at several depths. All the wells installed were on the downgrade side of the highway with respect to the water table. They found that in some localities, the concentration of chloride has increased beyond the 250 mg/L recommended

by the USEPA as an upper limit for drinking water supplies. Similar results were found in roadside wells of Manistee County in Michigan, Wisconsin, Illinois, New Hampshire, Maine, Ohio and Connecticut (EPA, 1971). Increase in hardness, alkalinity and total dissolved solids were also reported in the study conducted by O'Brien and Majewski (1975). No other significant impact on groundwater has been reported in the literature on the impact of groundwater by road salt application.

2.1.3. *Impact on Soil*

Sodium, calcium and chloride ions have a definite effect on soil properties. Voorde *et al.* (1973) studied the effect of road salt on streams and soil for a period of two years and reported that the disadvantages of salt pollution on roads were temporary and were not sufficient to warrant discontinuation of the use of salt, which was important in reducing the risks produced by ice on road traffic. The study carried along the US highway 41, near Marquette, Michigan reported that sodium levels were high along the highway immediately following the snowmelt and calcium levels did not increase sufficiently, but as the winter months progressed the calcium concentrations increased gradually in the soil (Bowers *et al.*, 1976). The study on the roadside salinity changes along Saskatchewan highway # 46 on two different types of soil showed that the majority of the deicer ions were accumulated within the shoulder and adjacent ditch bottom areas near to the surface. It was found that the soil with larger proportions of silt and clay was more effective in retaining the deicer residue (Gutiw and Jin, 1998a,b).

The soil particles and chloride ions are both negatively charged. Since sodium and chloride ions are quite soluble, they are readily transported by water over and through the roadside soil. The negative charge and small size make chloride ions very mobile through the soil column. The chloride anion is highly conserved and most of the chloride applied to the road will pass through the soil contributing salinity to the soil. But sodium ions are positively charged and are less mobile through the soil. Negatively charged soil particles adsorb cations, like sodium, from soil water by cation exchange sites. When sodium is present in high concentrations, it displaces naturally occurring calcium and magnesium cations. The soil's high sodium content disperses the organic and inorganic particles that are present in the pores of the soil and flushes them down the soil column. This results in decreased soil permeability, decreased aeration and increased overland flow, surface runoff and erosion. The increased erosion finally results in nutrient and heavy metal transport from the roadside to surface waters (Defourny, 2000; Fritzsche, 1992).

2.2. ROAD SALTS WITH ANTICAKING AGENT

When road salts are exposed to air with a fluctuating humidity, it can cake, thereby making spreading very difficult. If the relative atmospheric humidity exceeds 70–75%, a brine solution is formed on the surface of salt crystals. As relative humidity drops below 75%, water evaporates and the brine solution recrystallizes between

salt crystals causing aggregation of crystals (caking). The large quantity of road salt used makes it impossible to keep salt dry during handling, shipping and storage. So anticaking agents are often used (Paschka *et al.*, 1999). Material storage sites are a frequent source of salt pollution to surface streams. Deicing salts are often stock piled in open areas without suitable protection against inclement weather (EPA, 1971).

Ohno (1996) monitored the concentration of Na, Cl and total cyanide (simple and complex) of surface waters in the proximity of sand-salt storage facilities of the Maine Department of Transportation. These sampling locations represented worse case scenarios due to the closeness to sand-salt mixes being stored in uncovered, outdoor facilities. Results showed that the ratio of Na and Cl (on a molar base) was close to unity indicating that there was no appreciable attenuation by soil and sediment adsorption. A general seasonal trend of high concentration of NaCl was seen during summer months. The concentration of total Cyanide ranged from below the detectable limit of 10 $\mu\text{g/L}$ to 200 $\mu\text{g/L}$. The total CN:Cl ratios were lower in the sampled water indicating that some of the complex iron-CN was being adsorbed onto the soil and/or sediment surfaces. The monitoring results showed an elevated concentration of Na, Cl and CN.

It is observed that photo degradation of complex CN takes place upon exposure to sunlight giving a free cyanide form that is more toxic (Novotny *et al.*, 1999; Paschka *et al.*, 1999; Ohno, 1990; Muehring, 1997). The rate of breakdown of complex cyanide is retarded during winter due to a decrease in the angle of incidence. Also, the decomposition is slow in soil and groundwater. However, the water-quality effects by iron cyanide contamination due to road salt runoff is minimized due to dilution and the likely volatilization of free cyanide (Novotny *et al.*, 1999). Till date no thorough field monitoring has been carried out to investigate cyanide levels in surface and ground water as a result of the application of deicing salt (Paschka *et al.*, 1999).

2.3. CALCIUM MAGNESIUM ACETATE

Calcium magnesium acetate (CMA) is a man-made powdered mixture of dolomite lime and acetic acid. Field studies show that the capability of CMA to melt ice is as good as salt at lower application rates. Calcium magnesium acetate works well when mixed with sand. Sand improves adhesion of the chemical to the road surface until melting action begins. Although CMA mixed with sand also adheres better to snow and ice than salt, it does not do so in the same manner or as effectively as salt. Compared to salt, CMA is slower acting and less effective in freezing rain, drier snowstorms, and light-traffic conditions.

2.3.1. *Impact on Surface Water*

Calcium magnesium acetate is an organic compound that is formed by reaction of acetic acid with dolomite limestone giving it a characteristic vinegar smell (Enick,

1995). CMA is currently thought to be the best alternative of all deicers in question (Goldman and Lubnow, 1992). However, the depletion of oxygen in receiving waters from the degradation of acetate appears to be a major potential impact related to the use of this deicing compound (Brenner and Horner, 1992; Novotny *et al.*, 1999).

Horner and Brenner (1992) investigated CMA biodegradation at several temperatures in water. At 20 °C and 10 °C, most of the ultimate BOD was exerted within 5 and 10 days, respectively in water. The same levels of decomposition required 100 days in water at 2 °C. CMA involves the bacterial degradation of the acetate ion, which incidentally is the most abundant organic acid metabolite in nature. If too much of CMA is applied, at greater levels than usual, the biodegradation of acetate could increase the BOD in the receiving waters and result in localized depletion of dissolved oxygen. Several factors mitigate the occurrence of significant localized DO depletion. For example, the effects of the acetate concentration are minimized by, dilution, absorption on to the soil, microbial degradation in soils, and the reduced rate of microbial action at the lower temperature prevailing during deicing (D'Itri, 1992).

However, modelling results suggest that CMA application, as a deicing chemical should have little impact on the DO concentration of ponds and lakes. Much of the CMA will be biodegraded in soil prior to ever reaching the receiving body of water. Even if CMA does not begin to biodegrade until a runoff event occurs, only about 10% of the material will remain after flowing over a length of 30 ft. Due to the low biodegradation rate relative to re-aeration rates at winter temperatures, the maximum oxygen deficit due to CMA loading should be less than 2.5 mg/L for most application scenarios (Fritzsche, 1992). Modelling efforts have so far indicated that for the vast majority of CMA applications, the use of CMA as a road deicer will have little impact on receiving waters (McFarland and O'Reilly, 1992).

Laboratory studies indicated the potential for acetate mobility in soils that receive CMA spray or runoff from highways and potential for mobilization of certain metals in the soils as a result of ion exchange involving the calcium and magnesium constituents of CMA. However, the field observations weakly confirmed the above investigation. It is also reported that CMA addition to soil may initially increase the mobility of the soil, but the sustained use of CMA increases pH which in turn decreases metal mobility (Novotny *et al.*, 1999). Hence, it was recommended that CMA should not be applied in the vicinity of roadside soils that are highly contaminated with metals, and where any mobilized metals could easily be released to a sensitive surface receiving water, until this question is researched thoroughly under actual highway conditions (Horner and Brenner, 1992).

2.3.2. *Impact on Soil*

Calcium magnesium acetate affects the soil differently than salt as its components are quite different than salt. The acetate ion is less mobile in soil than the chloride ion. Acetate is readily degraded by soil microorganisms and therefore it is

not conserved. The half-life of acetate is less than 2 days at 7 °C (45 °F). Acetate degradation produces carbon dioxide, water and bicarbonate, and results in metal carbonate precipitation. Carbonate and bicarbonate increases the soil pH and decrease the heavy metal solubility. It is reported that, calcium and magnesium ion mobility in soil is limited unless in case of road salts because calcium and magnesium cations have high affinities for the cation exchange sites on soil particles. However, laboratory studies confirm the potential of ion exchange of other metals with calcium and magnesium. In contrast to sodium cations, calcium and magnesium cation increases the soil permeability and aeration. This may be the result of organic and inorganic particle flocculation by calcium and magnesium creating more pore space. Literature recommends calcium magnesium acetate as an alternative deicer for sodium chloride based on laboratory results, however there are not enough field investigations done (Defourny, 2000).

2.4. AIRCRAFT DEICERS

All aircraft anti-icing and deicing chemicals used at airports are based on formulations of either ethylene or propylene glycol. These formulations are grouped into two classes. Type I deicers are unthickened fluids used for deicing or anti-icing to remove ice or snow and to provide some protection against refreezing. Type II deicers are thicker fluids that provide greater protection against refreezing even during precipitation.

Glycol mixtures contain between 10% and 20% of other additives. These additives consist of metal corrosion inhibitors, rust inhibitors, thickening agents, and surfactants. Propylene glycols can reduce the melting temperatures of ice to $-59\text{ }^{\circ}\text{C}$ ($-74\text{ }^{\circ}\text{F}$). Glycols themselves are not acutely toxic; however, deicing and anti-icing mixtures are known to exhibit significant chronic toxicity. Because of additives, both deicer and anti-icer solutions are more toxic than the reported values for pure glycol compounds.

2.4.1. Urea

Urea contains nitrogen and is considered as a nutrient. Urea is used for runways in airports in combination with glycols. Urea is used occasionally in highway deicing applications. Aircraft deicing operations are a necessary part of safe air travel, but release large quantities of aircraft deicing fluids to the environment (Cornell *et al.*, 1998). Propylene glycol, ethylene glycol and urea-based glycol are used as aircraft deicers (Corsi *et al.*, 2001). Contaminants and adhesives present in the ethylene glycol deicers include di-ethylene glycol, ethylene oxide, dioxane, urea, rust inhibitors and acetaldehyde. Ethylene glycol has a very low potential to be adsorbed by soil particles and therefore prone to rapid movement. Degradation occurs rapidly in aerobic conditions but would occur very slowly in anoxic conditions. It is found that ethylene glycol has low bioaccumulation potential and a high biodegradation rate and it gets rapidly degraded by light (Hartwell *et al.*, 1995).

Corsi *et al.* (2001) studied the water chemistry and dissolved oxygen at General Mitchell International Airport (GMIA) due to application of aircraft deicers. The deicing compounds used at GMIA were washed through storm drains to the Kinnickinnic River above the Milwaukee harbour. Largest measured concentrations and instantaneous loads of deicers were observed in receiving streams during wet freezing rain as opposed to those during snowfall or freezing rains that produced low runoff volumes. The measured high BOD concentrations in the river showed that the DO concentration could be depressed at times, however no correlation was apparent between DO concentration and the presence or absence of deicing compounds. Data collected at most downstream monitoring sites indicated that concentration of glycol deicer runoff from GMIA became sufficiently diluted and degraded that it falls below the laboratory detection limits.

Turnbull and Bevan (1995) studied the damaging effects of airport deicer (urea) from New Castle International Airport on one of the tributaries of the Ouseburn. In the winter of 91–92, 91 tonnes of granular urea and 3000 litres of liquid glycol were used in order to deice the runway, taxiways and aprons during winter months. Concentrations of total ammonia were measured during seven freezing and eight non-freezing periods at 17 locations throughout the catchment. High concentrations of ammonia were recorded during cold weather and these values peaked during runoff events. It was suggested that hydrolysis, facilitated by urea digesting bacteria, and surface runoff are the mechanisms by which ammonia enters the stream. The airport tributary had less diverse macroinvertebrate fauna than expected and also had larger numbers of bacteria, which were able to utilize urea. They concluded that urea application had an adverse impact on the mainstream water quality and ecology.

3. Discussion

Long term and short term studies due to influx of road salts into soil and water were reviewed. From the cases examined it was evident that there is a considerable increase in Na and Cl ions in the surface water as a result of road applications. However these relatively low concentrations coupled with the volume of water results in negligible impact on the surface water quality. It was presumed initially that the salt would have a temporary effect on the environment (Voorde *et al.*, 1973). But long-term studies confirmed the salts have pronounced effect on water and soil. A surge in concentration of these chemicals was found during winter but the concentration gradually decreased with dilution, but the chloride persisted throughout the year due to base flows and leachate from roadside soils. The salt in the runoff induces stratification, stimulates algal growth, increases the chloride concentration and changes the density gradient. The increased chloride concentration in the groundwater affects water supply. The sodium chloride in soil results in decreased soil permeability, decreases aeration and increases overland flow, surface runoff and erosion.

When anticaking agents are used along with road salts, it was found that the cyanide concentration was found likely to be low in the surface waters due to dilution and volatilization of free cyanide before entering into the water bodies. No impact has been recorded so far on the water quality due to cyanides, but different studies have reported that the free cyanides are toxic to aquatic organisms and detrimental if the source is used as a domestic supply.

Calcium magnesium acetate is thought to be an alternative chemical deicer for road salt, but it is not recommended for application in the vicinity of surface waters due to high potential for acetate mobility in the soil and the possibility of the mobilized toxic metal entry into the surface waters. The acetate in CMA exerts BOD and results in depletion of dissolved oxygen in surface water bodies. Acetate degradation in soil produces carbon dioxide, water and bicarbonate, resulting in increased soil pH and lowered heavy metal solubility.

The use of aircraft deicers such as urea was found to have adverse impact on the surface water quality. High BOD concentration was reported in case of Kinnickinnic River as a result of deicing operations in Mitchell international airport.

4. Conclusions

The degree of impact varies from area to area and within the area due to many factors such as length and type of road draining into the streams, the amount of salt applied prior to thaw periods, road drainage system, topography, discharge of the receiving stream, degree of urbanization of the watershed, temperature, precipitation, dilution, adsorption on to the soil, and microbial degradation in soils. Hence it can be concluded that the impact of deicing salts on soil and water quality is local and transient.

In order to gain insight on the possible impact of deicing chemicals on water quality, further research is recommended on long term monitoring of these chemicals, their fate during transportation, the impact of discharge on the concentration at the time of entry and the subsequent changes over a period of time due to exchanges with sediments and the contributions of base flows. Research is needed to develop eco-friendly alternative deicers and improved application technology for the deicers. Though CMA is considered to be an alternative deicer, more field investigations are necessary to examine ion exchange of other metals with calcium and magnesium in soil.

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